Rules and Guidelines

IV *Industrial Services*

2 Guideline for the Certification of Offshore Wind Turbines

Edition 2005

Germanischer Lloyd
WindEnergie

This Guideline was compiled by Germanischer Lloyd WindEnergie GmbH in cooperation with the Wind Energy Committee. The Wind Energy Committee consists of representatives from manufacturers, universities, insurance companies, associations, engineering offices, authorities and institutes. The current members of the Wind Energy Committee are named on our website: www.gl-group.com/glwind

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The latest edition of the General Terms and Conditions of Germanischer Lloyd WindEnergie GmbH is applicable.

Germanischer Lloyd WindEnergie GmbH
Steinhoeft 9, 20459 Hamburg / Germany

Phone: +49 40 31106-707 Fax: +49 40 31106-1720
E-mail: glwind@gl-group.com Internet: http://www.gl-group.com/glwind

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Table of Contents

Note:

This Chapter 2 contains amongst other things requirements on how the control system and safety system shall react on sensor signals. Requirements on Condition Monitoring Systems are given in Chapter 13.

Chapter 3 Requirements for Manufacturers, Quality Management, Materials, Production and Corrosion Protection

Appendix 3.A

Appendix 3.B

Chapter 4 Load Assumptions

Appendix 4.A

Appendix 4.B

Appendix 4.C

Appendix 4.D

Appendix 4.E

Appendix 4.F

Appendix 4.G

Appendix 4.H

Appendix 4.I

Appendix 4.J

Chapter 5 Strength Analyses

Chapter 7 Machinery Components

Chapter 8 Electrical Installations

Chapter 9 Manuals

Chapter 10 Testing of Offshore Wind Turbines

List of Abbreviations

Abbreviation	Meaning
A	Abnormal (for partial safety factors)
C	Condition of the serviceability
CD	Chart Datum
CMS	Condition Monitoring System
Coh	Coherence function
CQC	Complete Quadratic Combination
CRP	Carbon fibre Reinforced Plastic
DAF	Dynamic Amplification Factor
DLC	Design Load Case
ECD	Extreme Coherent gust with Direction change
ECG	Extreme Coherent Gust
EDC	Extreme Direction Change
EIS	Electrical Insulation System
EOG	Extreme Operating Gust
EWM	Extreme Wind speed Model
EWS	Extreme Wind Shear
F	Fatigue
FEM	Finite Element Method
FRP	Fibre Reinforced Plastic
GL	Germanischer Lloyd
GL Wind	Germanischer Lloyd WindEnergie GmbH
GRP	Glass fibre Reinforced Plastic
HAT	Highest Astronomical Tide
HSWL	Highest Still Water Level
JONSWAP	Joint North Sea Wave Atmosphere Program
LAT	Lowest Astronomical Tide
LDD	Load Duration Distribution
LSWL	Lowest Still Water Level
MSL	Mean Sea Level
N	Normal and extreme (for partial safety factors)
NTM	Normal Turbulence Model
NWP	Normal Wind Profile
S	Wind turbine class S (S for special)
T	Transport, erection and maintenance (for partial safety factors and for the wind speed)
U	Ultimate limit state

Symbols and Units

Symbols and Units Used in the Guideline

Note:

This list is not entirely complete. Symbols defined and only used in certain sections are not included.

Symbol	Meaning	Unit	Remarks
A	cross-section area (strength) reference surface (aerodynamics)	m² -	
A	category of turbulence intensity	-	(see Section 4.2.2)
A_S	stress cross-section	m²	(see Section 5.3.4.4.1)
a	slope parameter of the turbulence intensity	-	(see Section 4.2.2)
a	added mass coefficient	-	(see Section 4.3.2.7)
a	parameter for the calculation of breaking wave height	-	(see Section 4.2.3.1.5)
a_w	wave particle acceleration	m/s^2	(see Section 4.3.2.3.1)
B	category of turbulence intensity	-	(see Section 4.2.2)
b	parameter for the calculation of breaking wave height	-	(see Section 4.2.3.1.5)
C	scale parameter of the Weibull function	m/s	(see Section 4.2.2.3.1)
C	category of turbulence intensity	-	(see Section 4.2.2)
$C(\gamma)$	normalising factor used for the JONSWAP spectrum	-	(see Section 4.2.3.1.2)
C_A	coefficient of aerodynamic lift	-	
C_D	drag coefficient	-	(see Section 4.3.2.3.2)
C_{IFF}	reduction factor for inter-fibre failure	-	(cf. Section 5.5.3.3)
C_M	coefficient of aerodynamic moment	-	
C_W	coefficient of aerodynamic drag	-	
c	stiffness of the impacting part of the vessel	MN/m	(see Section 4.3.2.7)
c_{max}	maximum blade depth	m	(cf. Section 4.2.4.4)
c_{min}	parameter for calculating the ice formation on the blade	m	(see Section 4.2.4.4)
D	damage	-	
D, d	diameter	m	
D_F	damage contribution of the actions from the operating conditions	-	(see Section 6.6.6.9)
D_Q	damage contribution from vortex-induced transverse vibrations	-	(see Section 6.6.6.9)
d	nominal bolt diameter	m	(see Section 5.3.4.4.1)
d	water depth	m	
E	E-modulus (modulus of elasticity)	MPa, N/mm²	
F	force	N	
$F(H_S)$	marginal probability distribution function of wave heights	-	(see Section 4.2.3.1.4)
$F_{boatimpact}$	impact force due to boat impact	N	(see Section 4.3.2.7)
F_D	design sea current load	F	(see Section 4.3.2.3.2)
F_i	impact term of braking wave force	N	(see Chapter 4, Appendix 4.I)

Symbol	Meaning	Unit	Remarks
$F_{total,max}$	total force/moment	N	(see Section 4.3.3.3)
$F_{wave,max}$	maximal force/moment due to wave action	N	(see Section 4.3.3.3)
$F_{wind,max}$	maximal force/moment due to wind action	N	(see Section 4.3.3.3)
$F_{wind,mean}$	mean force/moment due to wind action	N	(see Section 4.3.3.3)
f	line force	N/m	
f	frequency	1/s	$f = \omega/(2\pi)$
$f_{0,n}$	n-th natural frequency	1/s	n = 1, 2, …
f_R	maximum rotating frequency of the rotor in the normal operating range	1/s	
$f_{R,m}$	transition frequency of the *m* rotor blades	1/s	
g	acceleration due to gravity (=9.81m/s²)	m/s²	
H	wave height	m	
H_0	height of the deep water wave	m	(see Section 4.2.3.1.5)
$H_{1/3}$	average of the 1/3 highest waves	m	(see Section 4.2.3.1.2)
H_B	breaking wave height	m	(see Section 4.2.3.1.5)
H_D	design wave height	m	(see Section 4.2.3.1.4)
H_{max}	maximum wave height	m	(see Section 4.3.2.3.1)
H_{max50}	height of the extreme wave with recurrence period of 50 years	m	(see Section 4.2.3.1.4)
H_{red}	reduced wave height	m	(see Section 4.3.2.3.1)
H_s	significant or modal wave height	m	(see Section 4.2.3.1.2)
H_{s50}	significant wave height with the recurrence period of 50 years	m	(see Section 4.2.3.1.4)
h	height	m	
h_1	opening height	m	(see Section 6.6.5.4.4)
I	moment of inertia	m^4	
I_{15}	characteristic value of the turbulence intensity for a wind speed of 15 m/s (10-minute average)	-	(see Section 4.2.2)
j	casting quality level	-	(see Section 5.3.4.4.3)
j_0	constant	-	(see Section 5.3.4.4.3)
K	modified Bessel function	-	
K_A	application factor	-	(see Section 7.4.4.3.1)
k	shape parameter of the Weibull function	-	(see Section 4.2.2.3.1)
k_s	reduction factor for the design S/N curve of large bolts	-	(see Section 5.3.4.4.1)
L	isotropic, integral turbulence scale parameter	m	
L_e	scale parameter of the coherence function	m	
L_k	integral length parameter of the speed component	m	
l	component length	m	
l	statically effective span	m	
M	moment	Nm	
M_{Bmin}	minimum required braking moment	kNm	(see Section 7.5.1)
$M_{BminAusl}$	minimum design braking moment	kNm	(see Section 7.5.1)
M_{Bmax}	maximum actual braking moment	kNm	(see Section 7.5.1)
M_k	tilting moment of the induction generator	Nm	(see Chapter 4, Appendix 4.C)
M_n	rated torque	Nm	(see Chapter 4, Appendix 4.C)
m	mass	kg	

Symbol	Meaning	Unit	Remarks
m	slope parameter of the S/N curve	-	
m	vessel displacement	kg	(see Section 4.3.2.7)
m_0	variance of the wave spectra	m^2	(see Section 4.2.3.1.2)
m_n	n-th order moments of the wave spectrum	-	(see Section 4.2.3.1.2)
N	permissible load cycle number	-	
N	perpendicular force (axial force)	N	
N	recurrence period for extreme conditions	a	
N_i	tolerable number of stress cycles	-	(see Section 5.3.4.2.3)
N_D	limiting stress cycle number – fatigue limit	-	(see Section 5.3.4.4)
N_{SS50}	number of sea states with a duration of 3 hours in 50 years	-	(see Section 4.2.3.1.4)
n	quantity (i.e. number of)	-	
n	rotational speed	1/min	
n_1	minimum operating rotational speed	1/min	(see Section 2.2.2.5)
n_2	set value of the speed controller	1/min	(see Section 2.2.2.5)
n_3	maximum operating rotational speed	1/min	(see Section 2.2.2.5)
n_4	cut-out speed	1/min	(see Section 2.2.2.5)
n_A	activation speed	1/min	(see Section 2.2.2.5)
n_i	number of existing stress cycles	-	(see Section 5.3.4.2.3)
n_{max}	maximum overspeed	1/min	(see Section 2.2.2.5)
n_r	rated speed	1/min	(see Section 2.2.2.5)
n_{ref}	reference load cycle number	-	(see Chapter 4, Appendix 4.B)
P	confidence level	-	
P	live load	N	
P	power	W	
P_0	minimum crushing strength of the impact-ing part of the vessel	MN	(see Section 4.3.2.7)
P_A	activation power	kW	(see Section 2.2.2.6)
P_r	rated power	kW	(see Section 2.2.2.6)
P_R (V_{hub})	Rayleigh probability distribution, i.e. the probability that $V < V_o$	-	(see Section 4.2.2.3.1)
P_T	over-power	kW	(see Section 2.2.2.6)
$P_{Ü}$	survival probability	-	(see Section 5.3.4.4.2)
P_W (V_{hub})	Weibull probability distribution	-	(see Section 4.2.2.3.1)
p	area live load	N/m²	
Q	total load	N	
q	area loading	N/m²	
q_D	design sea current pressure	N/m^2	(see Section 4.3.2.3.2)
R	resistance	N, Nm, MPa	generic term, referring e.g. to a tolerable bending moment
R	stress or strain ratio	-	$R = \sigma_{min}/\sigma_{max}$
R, r	radius	m	
S	action	N, Nm, MPa	generic term, referring e.g. to an acting bending moment
S (f)	power spectral density	m^2/s^2	(see Section 4.2.3.1.2)
S_d	reduction factor – casting quality	-	(see Section 5.3.4.4.3)
S_F	safety against tooth root fracture	-	
S_H	safety against pitting	-	

Symbol	Meaning	Unit	Remarks
$S_{Pü}$	reduction factor – survival probability	-	>2/3 (see Section 5.3.4.4)
S_S	safety against scuffing	-	
$S_\zeta(\omega)$	wave (energy) spectrum	m^2/s	(see Section 4.2.3.1.2)
s	sea floor slope	-	s = tanβ (see Section 4.2.3.1.5)
s_K	tilting slip of the induction generator	-	(see Chapter 4, Appendix 4.C)
T	temperature	°C, K	
T	time interval	s	
T	characteristic gust shape duration	s	
T	wave period	s	(see Section 4.2.3.1.5)
T_1	mean (characteristic) wave period of the sea state, represents the average time between successive wave crests in a record of stationary sea surface elevations.	s	(see Section 4.2.3.1.2)
T_1	time constant of the stator	s	(see Chapter 4, Appendix 4.C)
T_D	design wave period	s	(see Section 4.2.3.1.4)
T_p	peak period T_p of the sea state	s	$= 2\pi/\omega_p$ (see Section 4.2.3.1.2)
T_{ref}	reference period	s	(see Section 4.2.3.1.4)
T_z	zero crossing period defined as the average time between successive zero crossings in the same direction (upwards or downwards	s	(see Section 4.2.3.1.2)
t	component thickness	m	
t	time (as a variable)	s	
$U_c(z)$	total current velocity at level z	m/s	(see Section 4.2.3.2)
$U_{c,\ sub}$	sub surface current velocity at the still water level	m/s	(see Section 4.2.3.2)
$U_{c,\ surf}$	wave induced current velocity at the still water level	m/s	(see Section 4.2.3.2)
$U_{c,\ wind}$	wind-generated current velocity at the still water level	m/s	(see Section 4.2.3.2)
U_D	design sea current speed	m/s	(see Section 4.3.2.3.2)
U_i	i% fractile value of the normal distribution	-	
u	displacement in the x direction	m	
u(10 m, 1 hour)	hourly mean wind speed at 10m height	m/s	(see Section 4.2.3.2)
u_{max}	maximum particle velocity in top breaking waves	m/s	
u_w	wave particle velocity	m/s	(see Section 4.2.3.1)
V	thrust	N	
V	wind speed	m/s	
V (y, z, t)	longitudinal component of the wind speed, describing the horizontal wind shear	m/s	(EWS: see Section 4.2.2.4.6)
V (z)	magnitude of the wind speed at the height z	m/s	(see Section 4.2.2.3.2)
V (z, t)	longitudinal component of the wind speed in relation to height and time	m/s	(EWS: see Section 4.2.2.4.6)
V_A	short-term cut-out wind speed	m/s	(see Section 2.2.2.7)
V_{ave}	annual average wind speed at hub height	m/s	(see Section 4.2.2)
V_{cg}	extreme value of the wind speed amplitude for the coherent gust shape over the swept rotor area, applying the extreme coherent gust	m/s	(ECG: see Section 4.2.2.4.4)

Symbol	Meaning	Unit	Remarks
V_{eN}	expected extreme wind speed (averaged over 3 s), with a recurrence period of N years. V_{e1} and V_{e50} representing 1 and 50 years. The EWM is applied with a steady wind model.	m/s	(EWM: see Section 4.2.2.4.1)
$V_{gust\ N}$	maximum value of the wind speed for the extreme operating gust, with an expected recurrence period of N years	m/s	(EOG: see Section 4.2.2.4.2)
V_{hub}	10-min mean of the wind speed at hub height	m/s	
V_{in}	cut-in wind speed	m/s	(see Section 2.2.2.7)
V_N	expected extreme wind speed (averaged over 10 min), with a recurrence period of N years. V_1 and V_{50} for 1 or 50 years respectively, applying the turbulent extreme wind speed model	m/s	(EWM: see Section 4.2.2.4.1)
V_{Nred}	expected reduced extreme wind speed (averaged over 60 s), with a recurrence period of N years. V_{1red} and V_{50red} representing 1 and 50 years. The EWM is applied with a steady wind model.	m/s	(EWM: see Section 4.2.2.4.1)
V_{out}	cut-out wind speed	m/s	(see Section 2.2.2.7)
V_r	rated wind speed	m/s	(see Section 2.2.2.7)
V_{ref}	reference wind speed: corresponds to the 10-min mean of the extreme wind speed with a recurrence period of 50 years at hub height.	m/s	(see Section 4.2.2)
V_T	10-min mean of the wind speed at hub height, specified by the manufacturer for maintenance, erection and transport. V_T can consist of several quantities.	m/s	(cf. Section 4.3.3.12)
v	coefficient of variation	-	
v	displacement in the y direction	m	
v_{boat}	boat impact speed	m/s	(see Section 4.3.2.7)
W	section modulus of a plane	m^3	
w	displacement in the z direction	m	
X''_d	subtransient reactance	-	(see Chapter 4, Appendix 4.C)
x; x'	coordinates	m	
y	parameter for the extreme wind shear model: horizontal distance to the hub centreline	-	(EWS: see Section 4.2.2.4.6)
y; y'	coordinates	m	
z	distance from still water level, positive upwards	m	(see Section 4.2.3.2)
z	height above still water line	m	(see Section 4.2.2.3.2)
z_{hub}	hub height of the wind turbine above still water line	m	(see Section 4.2.2.3.2)
z; z'	coordinates	m	
α	power law exponent for the normal wind profile	-	(see Section 4.2.2.3.2)
α	generalized Phillips´ constant to be used with the JONSWAP spectrum	-	(see Section 4.2.3.1.2)
α_S	inclination of the outer flange surfaces	°	(see Section 6.5.1.4)

Symbol	Meaning	Unit	Remarks
β	parameter for the models of extreme operating gust, extreme direction change and extreme wind shear	-	(EOG: see Section 4.2.2.4.2), (EDC: see Section 4.2.2.4.3), (EWS: see Section 4.2.2.4.6)
β	sea floor inclination	°	(see Section 4.2.3.1.5)
Γ	gamma function	-	(see Section 4.2.3.1.1)
γ	slip	-	= τ/G
γ	peakedness parameter of the wave spectrum	-	(see Section 4.2.3.1.2)
γ_F	partial safety factor for the loads	-	(see Section 4.3.7)
γ_{Gr}	partial safety factor for the analysis of the safety against bearing capacity failure	-	(see Section 6.7.9.2)
γ_M	partial safety factor for the material	-	(see Sections 5.3.3.1, 5.3.4.2.2, 5.3.4.2.3, 5.4.1.4.2, 6.6.1 and 6.6.6.1.3)
γ_{M0}	material partial safety factor	-	= 1.35, see Section 5.5.2.4, para 1
γ_{Ma}	material partial safety factor for short-term strength	-	(see Section 5.5.2)
γ_{Mb}	material partial safety factor for fatigue strength	-	(see Section 5.5.2)
γ_{Mc}	material partial safety factor for stability	-	(see Section 5.5.3)
γ_{Md}	material partial safety factor for bonding, short-term strength	-	(see Section 5.5.6)
γ_{Me}	material partial safety factor for bonding, long-term strength	-	(see Section 5.5.6)
$\gamma_{M,3}$	material partial safety factor for the analysis of shear-loaded connections	-	(see Section 6.5.1.3)
γ_{iT}	load partial safety factor for the rotor blade test	-	i from 1 to 2
δ	opening angle	°	(see Section 6.6.7.2)
δ_B	logarithmic decrement	-	
ε	strain	-	= σ/E
ε	nonlinear notch strain	-	(see Section 5.A.1.5)
$\varepsilon(\omega)$	randomly distributed phase angle	-	(see Section 4.2.3.1.2)
ζ	instantaneous water elevation	m	(see Section 4.2.3.1.2)
Θ_{cg}	greatest angular deviation during a gust development from the direction of the average wind speed, applying the model for extreme coherent gust with direction change	°	(ECD: see Section 4.2.2.4.5)
$\Theta(t)$	time curve of the wind direction change	°	
Θ_{eN}	extreme direction change, with a recurrence period of N years, applying the model of the extreme direction change	°	(EDC: see Section 4.2.2.4.3)
$\Theta_{N(t)}$	time curve of the extreme direction change with a recurrence period of N years, applying the model of the extreme direction change	°	(EDC: see Section 4.2.2.4.3)
Θ	temperature	°C	
$\Theta_{\text{mean, year}}$	annual average temperature	°C	(see Section 4.3.4)
$\Theta_{\text{1year min/max}}$	extreme temperature with a recurrence period of 1 year	°C	(see Section 4.3.4)
$\Theta_{\text{min/max, operation}}$	extreme temperature for operation	°C	(see Section 4.3.4)

Symbol	Meaning	Unit	Remarks
Λ_1	turbulence scale parameter	m	(see Section 4.2.2.3.3)
λ	wave length	m	(see Section 4.2.3.1.5)
λ_0	length of the undisturbed wave	m	(see Section 4.2.3.1.5)
μ	friction coefficient / slip factor	-	
μ_E	parameter for calculating the ice formation on the rotor blade	kg/m,	(see Section 4.2.4.4)
ξ	relation between the sea floor slope and the square root of the wave steepness	-	(see Section 4.2.3.1.5)
ξ^*	highest wave elevation	m	(see Section 4.2.3.3)
δ	wave elevation coefficient	-	(see Section 4.2.3.3)
ρ	atmospheric density	kg/m^3	(see Section 4.2.2.2)
ρ_E	density of the ice	kg/m^3	(see Section 4.2.4.4)
σ	normal stress	MPa, N/mm^2	
σ	wave spectral width parameter	-	(see Section 4.2.3.1.2)
σ	nonlinear notch stress	MPa, N/mm^2	(see Appendix 5.A, Section 5.A.1.5)
$\Delta\sigma_A$	reference value of the S/N curve	MPa, N/mm^2	(see Section 5.3.4.4.2)
$\Delta\sigma^*_A$	reference value of the S/N curve	MPa, N/mm^2	(see Section 5.3.4.4.2)
σ_k	linear-elastic notch stress	MPa, N/mm^2	(see Appendix 5.A, Section 5.A.1.5)
σ_S	structural or hot spot stress	MPa, N/mm^2	(see Appendix 5.A, Section 5.A.1.5)
σ_1	standard deviation of the longitudinal wind speed at hub height	m/s	(see Section 4.2.2.3.3)
$\Delta\sigma_i$	stress range	MPa, N/mm^2	(see Section 5.3.4.2.3)
τ	shear stress	MPa, N/mm^2	
Φ	inclination of the plane	°	
Φ	angle for two-phase short circuit	°	(see Chapter 4, Appendix 4.C)
φ	yaw error	°	(see Section 2.2.2.8)
φ_A	cut-out yaw error	°	(see Section 2.2.2.8)
ω	angular velocity	1/s	$\omega = 2\pi f$
ω	$= 2\,\pi/T$ circular frequency of elementary waves with period T	1/s	(see Section 4.2.3.1.2)
ω_p	peak frequency of the wave spectrum	1/s	(see Section 4.2.3.1.2)
Ωg	grid angular frequency	1/s	(see Chapter 4, Appendix 4.C)
1P, 2P, 3P…	excitation of the wind turbine through the rotor speed multiplied by the factor 1, 2, 3…	1/s	

Subscripts

Symbol	Meaning	Remarks
A	amplitude	
c	pressure	separated by a comma ($\sigma_{Sd,c}$)
d	design value	
F	load, action	
F	tooth root	
i	enumeration	
k	characteristic quantity	

Symbol	Meaning	Remarks
M	material, mean value	e.g. γ_M, ε_M
max	maximum	
min	minimum	
p	prestress	separated by a comma ($\sigma_{Rd,p}$)
R	resisting	preceding in combination with the subscripts k and d, but without separation by a comma (e.g. σ_{Rd} or ε_{Rk})
res	resulting	
S	acting	preceding in combination with the subscripts k and d, but without separation by a comma (e.g. F_{Sd} or M_{Sk})
t	tension	separated by a comma ($\sigma_{Rd,t}$)
x; x’	coordinate designation	
y; y’	coordinate designation	
z; z’	coordinate designation	

Auxiliary symbols

Symbol	Meaning
$\bar{\ }$	mean value of the overlined quantity

Prefixes

Symbol	Meaning
Δ	difference or part of the subsequent quantities
Π	product of the subsequent quantities
Σ	sum of the subsequent quantities

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2 Guideline for the Certification of Offshore Wind Turbines

1 General Conditions for Approval

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Table of Contents

1.1 Scope

1.1.1 General

(1) This Guideline applies to the design, assessment and certification of offshore wind turbines and offshore wind farms. The Guideline can be applied for Type Certification and Project Certification.

(2) This Guideline represents a completely revised version of the "Regulations for the Certification of Offshore Wind Energy Conversion Systems" of Germanischer Lloyd (GL), Edition 1999. Knowledge gained through the certification of offshore wind farms, the participation in research projects and expert groups, the project management and operation of the FINO 1 research platform and comments from our Wind Energy Committee led to a substantial improvement of our Guideline.

(3) Topics, which are not specific to offshore conditions, but specific to the design of wind turbines, are treated as given in the "Guideline for the Certification of Wind Turbines" [1] and have been included in this Guideline.

(4) When carrying out Type Certification, the overall concept of the offshore wind turbine according to a wind turbine class is assessed. The certification covers all components and elements of the offshore wind turbine, i.e. safety as well as design, construction, workmanship and quality are checked, assessed and certified. Prototype Testing, examination of the Implementation of the design requirements in production and erection and check of quality management system are to be performed after the Design Assessment and build the final steps of Type Certification (see Section 1.2.2).

(5) When carrying out Project Certification, conformity is assessed and certified that type-certified offshore wind turbines and particular support structure designs meet requirements governed by site-specific external conditions, local codes and other requirements relevant to the site. Within Project Certification the individual offshore wind turbines / wind farms are monitored during manufacturing, transport, installation and commissioning. Periodic Monitoring is carried out in regular intervals (see Section 1.2.3).

(6) The actual operating life of an offshore wind turbine can deviate from the design lifetime, and will in general be longer. For wearing parts and for coolants, oils and lubricants that do not attain the design lifetime of the offshore wind turbine, the manufacturer of the offshore wind turbine shall prescribe regular replacement intervals.

(7) Certification of an offshore wind turbine or an offshore wind farm on the basis of this Guideline is carried out by Germanischer Lloyd WindEnergie GmbH (GL Wind) with regard to the points specified in Section 1.2.

Note 1:

When carrying out Project Certification it is common practice to rely on a turbine type (machinery including nacelle, rotor blades, safety and electrical system), which has already been type certified according to a wind turbine class, see Chapter 4. Other external conditions are to be chosen conservative, which allows that the type certified offshore wind turbine type will cover the external conditions of specific offshore sites during project certification. Alternatively a site specific certification of the machinery can be performed instead of Type Certification.

Note 2:

In the design of the offshore wind turbine, aspects of labour safety can be taken into account through compliance with the standard EN 50308 "Wind turbines – Labour safety" in addition to offshore related standards and guidelines. National labour-safety guidelines shall be observed in the case of project certification.

1.1.2 Transition periods

(1) For the application of this Guideline, the following transition periods shall apply after it comes into force, during which the GL "Regulations for the Certification of Offshore Wind Energy Conversion Systems", Edition 1999, may still be applied from publication date:

– 6 months for Type Certification of new offshore wind turbine types

– up to 2 years for modifications of the design of offshore wind turbine types that were already assessed or type certified by GL Wind according to the GL Regulations, Edition 1999, after consultation with GL Wind

– up to 2 years for re-certification on expiry of the validity of a Type Certificate issued by GL Wind

– 1 year for Project Certification of new offshore wind farms

(2) In the case of new turbine types or new offshore wind farms, the transition period shall only be applied if all documents needed for the requested extent of certification are submitted during the transition period.

(3) The application of editions of the GL Regulations that are older than the Edition 1999 is not admissible.

1.1.3 Deviations

(1) Deviations from this Guideline are, as a matter of principle, permitted only with the consent of GL Wind.

(2) The certification may in individual cases involve inclusion of locally applicable regulations and codes.

(3) The level of safety set by this Guideline shall be observed as a minimum requirement, even if national or regional laws or regulations require less.

(4) In the case of designs to which this Guideline or parts of it cannot be applied, GL Wind reserves the right to proceed in the spirit of the Guideline.

(5) If analysis concepts of different standards are to be applied, these shall generally not be mixed.

1.1.4 International standards and guidelines

An overview of the international standards, technical guidelines and specifications of the IEC, CENELEC, ISO and GL Wind with regard to offshore wind turbines is given in Appendix 1.A.

1.1.5 Assessment documents

Texts in assessment documents shall be worded in German or English. Relevant excerpts of referenced documents that are not generally known shall be appended to the assessment documents.

1.1.6 Additional Requirements

(1) This Guideline presents the state of the art of offshore wind technologies with respect to strength and safety of the offshore wind turbine.

(2) Additional requirements for the offshore wind turbine resulting from, e.g.

- local regulations
- manned/unmanned operation
- shipping and navigational requirements
- lighting and marking
- boat/helicopter service

shall be taken into account besides the requirements defined in this Regulation.

1.1.7 Definitions

A description of the terms and definitions for an offshore wind turbine can be found in Figure 1.1.1. The offshore wind turbine consists of the machinery or topsides structure (rotor and nacelle) and the support structure (tower, sub structure and foundation). These definitions will be used in the Guideline.

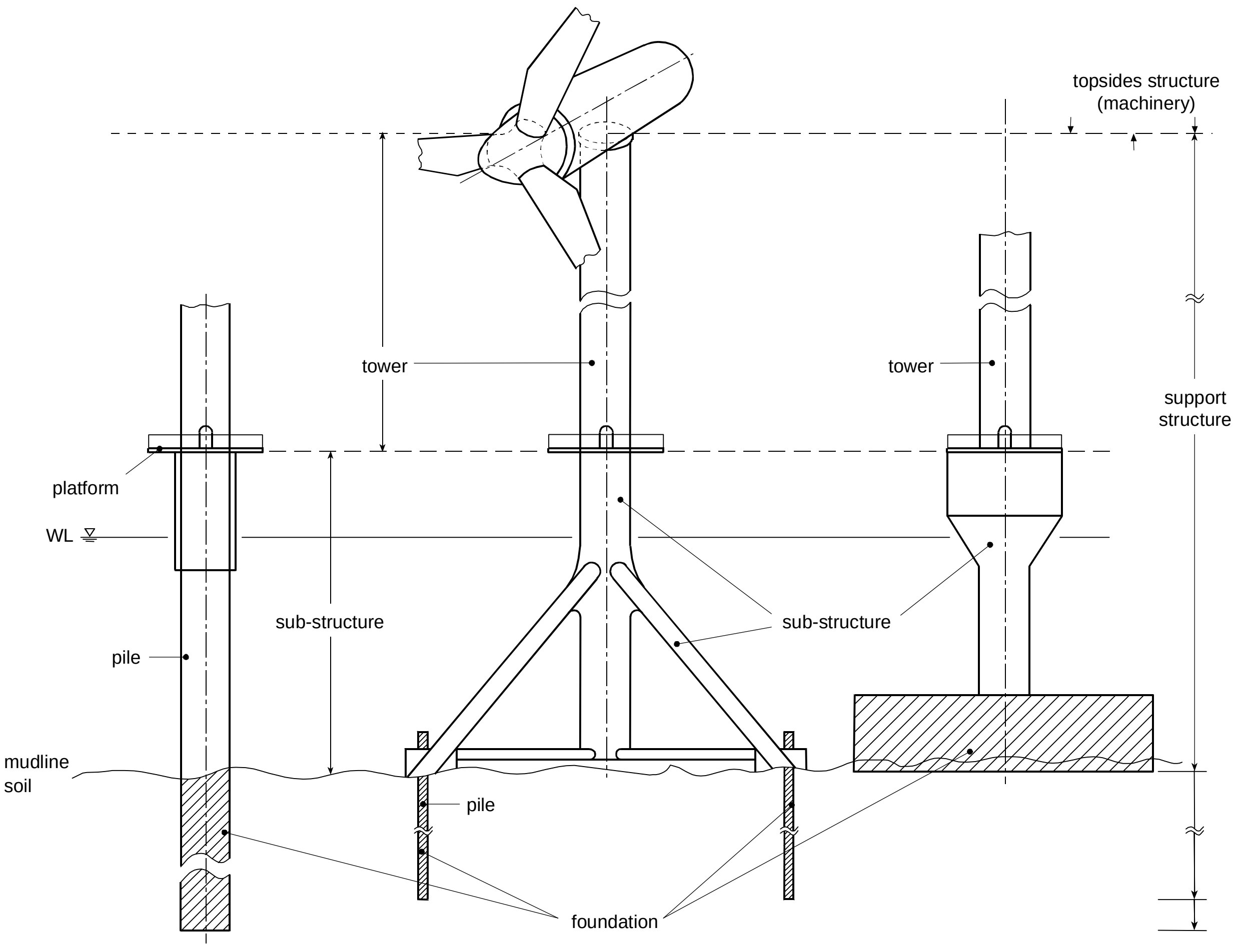


Fig. 1.1.1 Definition of offshore wind turbine sections

1.2 Extent of Certification

1.2.1 Scope and subdivision of the certification

The following sections define the scope for Certification of an offshore wind turbine or an offshore wind farm and the steps necessary for Certification.

1.2.2 Type Certification

1.2.2.1 General

(1) Type Certification shall confirm that the offshore wind turbine type is designed according to a wind turbine class in conformity with the design assumptions based on this Guideline and other technical requirements. It shall also confirm that the manufacturing process, component specifications, inspection and test procedures and corresponding documentation of the components covered by this Guideline are in conformity with the design documentation.

(2) Within Type Certification for a type of offshore wind turbine it is allowed to exclude the support structure (tower, substructure and foundation). Then the dynamic influence of a virtual support structure is to be considered in the load assumptions. Within a Project Certification the site specific support structure shall be assessed.

(3) To attain the Type Certificate, the following steps are necessary, see also Figure 1.2.1:

– A – Design Assessment (see Section 1.2.2.3)

– quality management system of the manufacturer (see Section 1.2.2.4)

– implementation of the design-related requirements in production and erection (see Section 1.2.2.5)

– witnessing of the test operation of a prototype (see Section 1.2.2.6 and Chapter 10)

(4) Following completion, GL Wind will issue Statements of Compliance on the A-Design Assessment, the implementation of the design-related requirements in production and erection and on the prototype test as well as the Type Certificate.

(5) The Type Certificate has a validity period of two years. During the validity period, all installed offshore wind turbines of this type shall be reported annually to GL Wind. The Type Certificate will already lapse before the two years have expired if the A – Design Assessment or the certificate for the quality system are no longer valid.

(6) Upon expiry of the validity period, re-certification will be performed on request of the manufacturer (see Section 1.2.2.7).

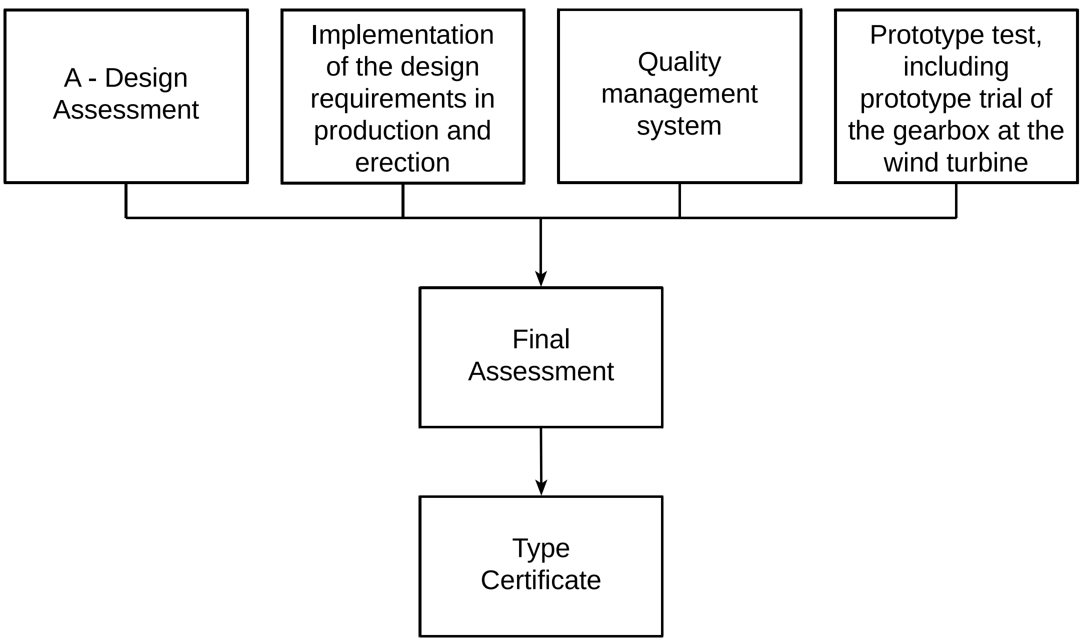


Fig. 1.2.1 Elements of the Type Certificate

1.2.2.2 C-Design Assessment

1.2.2.2.1 General

The C – Design Assessment (prototype assessment, in German: "Prototypengutachten") is used to erect the prototype of an offshore wind turbine. As a rule, power and load measurements shall be performed at the prototype, after which they shall be compared to the calculated values. Modifications to the control system are permissible, provided that the resulting loads do not change appreciably. The C – Design Assessment is usually based on a complete plausibility check of the loads, the rotor blades, the machinery components as well as of the tower and foundation. National or local regulations may require that the tower and foundation be subjected to a complete analysis.

1.2.2.2.2 Scope and validity

(1) For each type of offshore wind turbine, only one C – Design Assessment is produced. If a turbine type is modified with other rotor blades, a different operating mode or in other points strongly influencing the loads, then these are reasons which justify another prototype turbine and another C – Design Assessment.

(2) The C – Design Assessment is valid for test operation of one prototype wind turbine comprising a maximum of 2 years or 4000 equivalent hours at full load. The criterion met first shall apply. By this time at the latest, a B – Design Assessment shall be submitted for the offshore wind turbine.

1.2.2.2.3 Documents to be submitted

(1) For the C – Design Assessment, the following documents shall be submitted:

– general description of the offshore wind turbine

– description of the control and safety concepts

– description of the safety system and the braking systems

– complete calculation of the loads

– main drawings of the rotor blade, including structural design and blade connection

– general arrangement drawing of the nacelle

– drawing of the hub, main shaft and the main frame

– listing of the primary components to be used (e.g. main bearing, gearbox, brake, generator etc.)

– main drawings of support structure

– site conditions and soil investigation report (optional)

– description of the electrotechnical installations

– name and address of the owner

– planned location of the prototype

(2) In certain cases, further documents may be necessary:

– calculation documents for the support structure

(3) On conclusion of the measurements, the measurement reports and the comparisons of the measurement results with the design values shall be submitted to GL Wind for evaluation.

1.2.2.2.4 Scope of assessment

(1) With regard to the safety system of the offshore wind turbine, it is checked whether the safety-relevant operating values are sensed and made available to the safety system. Furthermore, the existence of two independent braking systems shall be checked.

(2) The blade root, hub and tower head loads to be submitted are checked for plausibility. This is possible if the extreme loads and fatigue loads can be compared with those of other offshore wind turbines of similar size. If an offshore wind turbine of a larger offshore wind turbine type is submitted for assessment, then the pertinent values shall be extrapolated with due consideration of the physical circumstances.

Note:

A complete examination of the loads can be waived, since modifications to the control system that influence the loads are permissible for a prototype.

(3) The rotor blades and the machinery components in the drive train are also checked for plausibility, if it is possible to apply the experience gained in the dimensioning of similar turbines. As already mentioned in Section 1.2.2.2.1, it may depend on local regulations or requirements as to whether a plausibility check of the tower and foundation is sufficient or whether a complete analysis is necessary.

1.2.2.3 A- and B- Design Assessment

1.2.2.3.1 Scope and validity

(1) To attain the A – or B – Design Assessment, the examinations, tests and witnessing set out in Section 1.2.2.3.2 and Section 1.2.2.3.3 are required; see Fig. 1.2.2.

(2) The B – Design Assessment may contain items that are still outstanding, providing these are not directly safety-relevant. The B – Design Assessment has a validity period of one year. During the validity period, all installed offshore wind turbines of this type shall be reported to GL Wind.

(3) The A – Design Assessment is only performed without outstanding items. The A – Design Assessment is valid indefinitely. It becomes invalid when modifications are made without the consent of GL Wind to the design of components which form part of the design assessment.

(4) The examination of a support structure is optional within the scope of the A – or B – Design Assessments.

1.2.2.3.2 Assessment of the design documentation

(1) For assessment of the design documentation, the manufacturer shall submit a full set of documents in the form of specifications, calculations, drawings, descriptions and parts lists. It is recommended that the documents for the implementation of design-related requirements in production and erection (see Section 1.2.2.5), which are to be submitted within the scope of type certification, also be submitted for examination within the design assessment.

(2) Initially, the documents which form the basis of the design are assessed; these are

– control and safety system concepts (Chapter 2)

– load case definitions / load assumptions (Chapter 4)

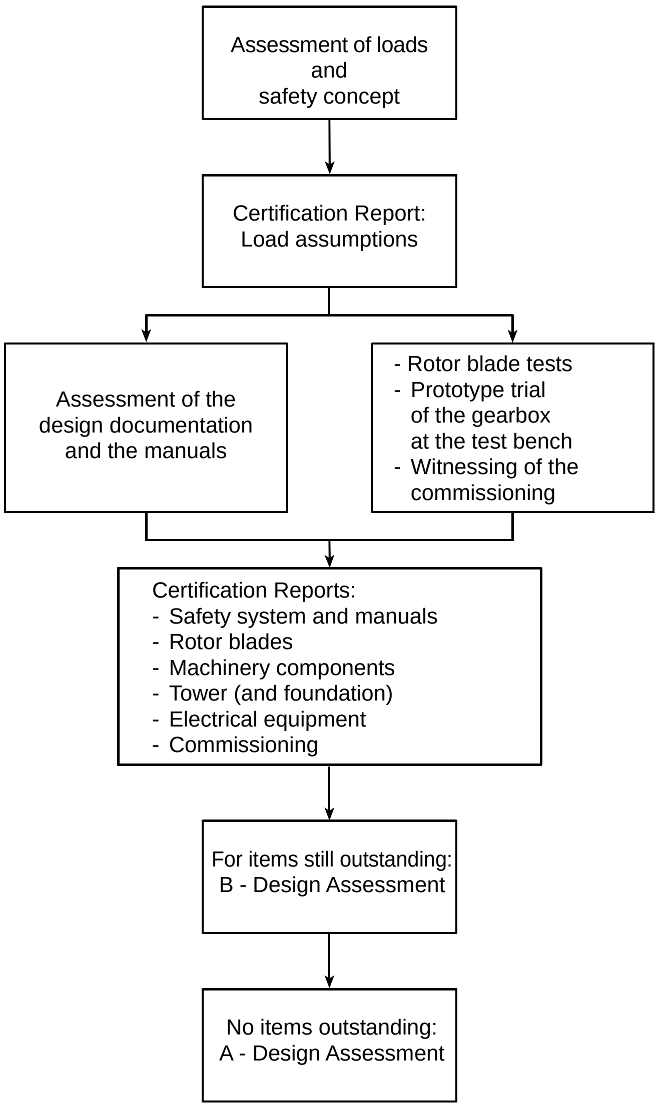


Fig. 1.2.2 Procedure for A – and B – Design Assessment

(3) Once these have been assessed, design assessment of the components and subassemblies listed below follows:

– safety system (Chapter 2)

– rotor blades (Section 6.2)

– mechanical structures (Sections 6.3, 6.5) including nacelle housing and spinner (Section 6.4)

– machinery components (Chapter 7)

– electrotechnical components, including lightning protection (Chapter 8)

– support structure (Section 6.6) , (optionally)

– manuals (Chapter 9): erection manual, commissioning manual, operating manual, maintenance manual

1.2.2.3.3 Witnessing and Tests

(1) The scope of the blade tests is defined in Section 6.2.5.

(2) The prototype test of the main gearbox at the test bench shall be completed before issuance of the A-Design Assessment (see Section 10.7).

(3) The commissioning procedure shall be witnessed at one of the first offshore wind turbines built in the version to be certified (see Section 10.8).

1.2.2.4 Quality management system

Within the scope of the quality management (QM) system, the manufacturer shall verify that he meets the requirements of ISO 9001 with regard to design and manufacture. As a rule, this is effected through the certification of the QM system by an accredited certification body (see Section 3.2).

1.2.2.5 Implementation of the design-related requirements in production and erection

(1) Objective: It shall be ensured that the requirements stipulated in the technical documentation with regard to the components are observed and implemented in production and erection. This is shown once only to GL Wind by the manufacturer of the components and the offshore wind turbine. Furthermore, this approach is generally intended to replace external surveillance during normal production.

(2) The extent of the surveillance during production and erection depends on the standard of the quality-management measures and shall be agreed with GL Wind.

(3) The descriptions of the quality management measures in production and in erection shall be presented in a summarizing document for the corresponding component or assembly. The quality management examinations can be supported by means of drawings, specifications and specimen documents.

(4) It is recommended that the descriptions of the quality management measures already be submitted within the scope of the design assessment.

(5) The documented implementation is examined by GL Wind once at the start of production within the scope of a personal inspection. It shall be decided in each individual case whether the conformity can be inspected in the component manufacturer’s works or as part of the incoming inspection of the turbine manufacturer.

(6) Changes in the procedure which influence the production quality or the component properties shall be reported to GL Wind. In the event of major changes, the descriptive documents shall be submitted for renewed examination and, if necessary, a repeated personal inspection shall be made.

(7) If information is obtained on deviations or malfunction in the operation of offshore wind turbines that must be ascribed to production flaws, GL Wind reserves the right to monitor the production surveillance also after the Type Certificate has been issued.

(8) The possibilities for rectifying faults are as follows:

– After revision of the descriptive documents, the defects that have occurred are remedied. A repeated personal inspection may be necessary.

– If the defects are not detected, GL Wind can impose external surveillance on the manufacturer for these components or assemblies.

1.2.2.6 Prototype test

(1) The measurements within the scope of test operation of a prototype generally comprise the following points:

– measurement of the power curve (see Section 10.2)

– measurement of the noise emission (see Section 10.3)

– measurement of the electrical characteristics (see Section 10.4)

– test of turbine behaviour (see Section 10.5)

– load measurements (see Section 10.6)

– prototype trial of the gearbox (see Section 10.7)

(2) Deviations from this measurement scope are only possible after agreement has been reached with GL Wind.

(3) Details on the measurements are given in Chapter 10. The measurement points, the planned scope of the measurements and their assessment shall be coordinated with GL Wind before installation commences (see also Chapter 10). If the results of the measurements are to be used as a basis for the strength analyses, additional requirements shall be coordinated with GL Wind before the measurements are started.

(4) On completion of the measurements, the following activities shall be performed:

– evaluation and documentation of the measurements

– plausibility check of the measurement results

– comparison of the measurement results with the assumptions in the design documentation

(5) The measurement reports on the various measurements and the comparisons shall be submitted to GL Wind for evaluation.

1.2.2.7 Re-certification

(1) Upon expiry of the validity period of the Type Certificate, re-certification will be performed on request of the manufacturer. After completion of the process, GL Wind issues a Type Certificate with a reference to the re-certification and a validity period of two years.

(2) For the re-certification, the following documents shall be submitted for evaluation by GL Wind:

– list of valid drawings

– list of all modifications to the design of components forming a part of the design assessment and, if applicable, documents for evaluation of the modifications

– list of alterations to the QM system since the last audit

– list of all installed offshore wind turbines of the type (at least statement of the type with precise designation of the variant, serial number, hub height, location)

– list of all major damages to the installed offshore wind turbines

(3) If modifications were made to the structure, these are examined and a revision of the Statement of Compliance for the A – Design Assessment is issued.

1.2.3 Project Certification

1.2.3.1 General

(1) Project Certification shall confirm for a specific site that type-certified offshore wind turbines and particular support structure designs meet requirements governed by site-specific external conditions and are in conformity with this Guideline, applicable local codes and other requirements relevant to the site. Within the Project Certification it will be assessed whether the metocean conditions, soil properties, other environmental and electrical network conditions at the site conform with those defined in the design documentation for the offshore wind turbine type and support structure(s).

(2) Project Certification shall also confirm that fabrication, transport, installation and commissioning are in conformity with GL rules and Guidelines or other accepted standards and other technical requirements, and that the offshore wind turbines are operated and maintained in conformity with the relevant manuals.

(3) The Project Certificate is valid until the end of the dedicated lifetime of the offshore wind farm on the basis that

– Periodic Monitoring is carried out according to the inspection plan

– maintenance and repair is carried out according to the maintenance plan

– major modifications, conversions or repairs are performed with GL Wind approval

– no unexpected malfunctions occur, based on the design or bad assumptions on the external conditions that have been made

If the conditions are not fulfilled GL Wind reserves the right to require recertification or to terminate the project certificate’s validity.

(4) To attain the Project Certificate for offshore wind turbines at a specific offshore site, the following steps are necessary, see also Figure 1.2.3:

– Type Certificate for the type of offshore wind turbine used (see Section 1.2.2)

- Site Assessment (see Section 1.2.3.2)
- Site-specific Design Assessment (see Section 1.2.3.3)
- Surveillance of Manufacturing (see Section 1.2.3.4)
- Surveillance of Transport and Installation (see Section 1.2.3.5)
- Surveillance of Commissioning (see Section 1.2.3.6)
- Periodical Inspection (periodic monitoring) to maintain the validity of the certificate (see Section 1.2.3.7)

(5) Following successful completion, GL Wind will issue the Project Certificate.

1.2.3.2 Site Assessment

(1) The site assessment includes the examination of the environment-related influences on the offshore wind turbine, and the mutual influence of the offshore wind farm configuration.

(2) For the site assessment, effects from the following influences are considered:

- wind conditions (Chapter 4)
- marine conditions (bathymetry, waves, tides, correlation of wind and waves, sea-ice, scour, marine growth, etc.) (Chapter 4)
- soil conditions (Section 6.7)
- site and wind farm configuration (Chapter 4)
- other environmental conditions, such as: salt content of the air, temperature, ice and snow, humidity, lightning strike, solar radiation, etc. (Chapter 4)
- electrical grid conditions (Chapter 4, 8)

These site conditions will be assessed for plausibility, quality and completeness of measurement reports and accreditation of measurement bodies or institutes establishing reports about the external conditions.

1.2.3.3 Site specific Design Assessment

Based on the external conditions at the site, the site specific Design Assessment will take place subdivided into the following assessment steps:

- site specific load assumptions (Chapter 4)
- comparison of site specific loads with those from Type Certification
- site specific support structure (tower, sub structure and foundation) (Chapter 3, 5, 6)
- modifications of the machinery part and rotor blades in relation to Type Certification, if modifications exist (Chapter 6, 7)
- stress reserve calculations for the machinery part and rotor blades, if load comparison indicates higher loads than for the type certified machinery components (Chapter 6, 7)

1.2.3.4 Surveillance of manufacturing

(1) Before surveillance of manufacturing begins, certain quality management (QM) requirements shall be met by the manufacturers. As a rule, the QM system shall be certified according to ISO 9001, otherwise the QM measures will be assessed by GL Wind. This will involve meeting the minimum requirements according to Section 3.2.3.

(2) The extent of the surveillance of manufacturing and the amount of samples to be surveyed depends on the standard of the quality management measures, and shall be agreed with GL Wind. In general, the following actions and approvals will be carried out by GL Wind:

- inspection and testing of materials and components (see Section 3.4)
- scrutiny of QM records such as test certificates, tracers, reports
- surveillance of manufacturing, including storage conditions and handling, by random sampling
- inspection of the corrosion protection
- dimensions and tolerances
- general appearance
- damages

1.2.3.5 Surveillance of transport and installation

(1) Before work begins, transport and installation manuals shall be submitted (see Section 9.1), which take account of the special circumstances of the site, if necessary. These will be checked for compatibility with the assessed design and with the transport and installation conditions (climate, job scheduling, etc.) prevailing at the site.

(2) The extent of GL Wind’s surveillance activities and the amount of samples to be surveyed depends on the quality management measures of the companies involved in transport and installation. As a rule, GL Wind will carry out the following activities:

- approval of transport and installation procedures
- identification and allocation of all components of the offshore wind turbine in question
- checking of the components for damage during transport
- inspection of the job schedules (e.g. for welding, installation, grouting, bolting up)
- inspection of prefabricated subassemblies, and of components to be installed, for adequate quality of manufacture, insofar as this has not been done at the manufacturers' works
- surveillance of important steps in the installation on a random-sampling basis (e.g. pile driving, grouting)
- inspection of grouted and bolted connections, surveillance of non-destructive tests (e.g. welded joints)
- inspection of the corrosion protection (see Section 3.5)
- inspection of scour protection system (see Section 6.7)
- inspection of the electrical installation (run of cables, equipment earths and earthing system) (see Chapter 8)
- inspection of sea fastening and marine operations (see Chapter 12)

1.2.3.6 Surveillance of commissioning

(1) Surveillance of commissioning is to be performed for all offshore wind turbines of the offshore wind farm and shall finally confirm that the offshore wind turbine is ready to operate and that the offshore wind turbine fulfils all standards and requirements to be applied.

(2) Before commissioning, the comissioning manual (see Section 9.2) and all tests planned shall be submitted for assessment. Before commissioning, the manufacturer shall provide proof that the offshore wind turbine has been erected properly and, as far as necessary, tested to ensure that operation is safe. In the absence of such proof, appropriate tests shall be carried out when putting the offshore wind turbine into operation. The commissioning is to be performed under surveillance of GL Wind.

(3) This surveillance covers witnessing by the surveyor of approximately 10 percent of offshore wind turbines during the actual commissioning. The other turbines shall be inspected after commissioning and the relevant records shall be scrutinized.

(4) Within the course of commissioning, all functions of the offshore wind turbine deriving from its operating and safety function modes shall be tested. This includes the following tests and activities (see also Section 9.2):

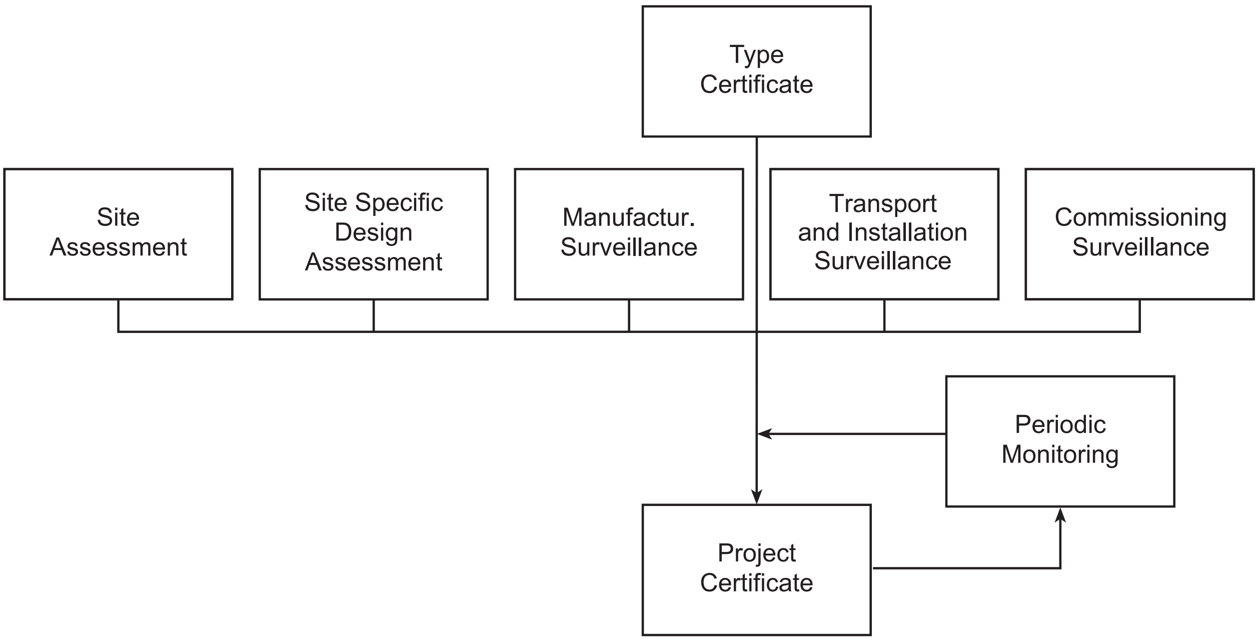


Fig. 1.2.3 Elements of Project Certificate

- functioning of the emergency push button
- triggering of the brakes by every operating condition possible in operation
- functioning of the yaw system
- behaviour at loss of load
- behaviour at overspeed
- functioning of automatic operation
- checking the logic of the control system’s indicators

In addition to the tests the following items shall be examined during commissioning surveillance by visual inspection of the entire offshore wind turbine (see also Section 9.2):

- general appearance
- corrosion protection
- damages
- conformity of the main components with the certified design and traceability / numeration of the same

1.2.3.7 Periodic Monitoring

(1) To maintain the validity of the certificate, maintenance of the offshore wind turbine shall be carried out in accordance with the approved maintenance manual (see Section 9.4), and the condition of the offshore wind turbine shall be monitored periodically by GL Wind in accordance with Chapter 11 “Periodic Monitoring”. Maintenance shall be carried out and documented by authorized persons. Periodic Monitoring intervals are to be defined in the inspection plan and to be agreed with GL Wind. These intervals may be varied depending on the condition of the offshore wind turbine.

(2) Major damages and repairs shall be reported to GL Wind. To maintain validity of the certificate, any alterations have to be approved by GL Wind. The extent to which this work is to be surveilled shall be agreed with GL Wind.

(3) The maintenance records will be perused by GL Wind. Periodic Monitoring by GL Wind comprises the following assemblies (see also Chapter 11):

- foundation and scour protection (if appropriate only perusal of relevant inspection records)
- substructure
- tower
- nacelle
- all parts of the drive train
- rotor blades
- hydraulic/pneumatic system
- safety and control systems
- electrical installation

(4) Details of the Periodic Monitoring are given in Chapter 11.

1.2.3.8 A and B Levels of Project Certification

The project certificate will be issued after successful accomplishment of the steps described in Section 1.2. Concerning the surveillance of manufacturing, transport, installation, commissioning and periodic monitoring it can be distinguished between two different levels of project certificates:

A - Project Certificate: Surveillance is to be undertaken covering 100 % of the offshore wind turbines, which means that all wind turbines of the offshore wind farm are to be monitored. Surveillance shall cover the support structure and essential parts of machinery, blades and electrical system.

B - Project Certificate: Surveillance is to be undertaken covering 25 % of the offshore wind turbines on a random sample basis, which means that a minimum of 25 percent of the offshore wind turbines are to be monitored. Surveillance shall cover the support structure and essential parts of machinery, blades and electrical system. In case the surveillance should reveal major failures, deviations from the certified design or deviations in the quality management the number of turbines to be monitored is to be doubled.

1.3 Basic Principles for Design and Construction

1.3.1 General

(1) The basis for this Guideline is provided by the general principles of reliability and durability of structures, as contained for example in ISO 2394 or the relevant Eurocodes.

(2) Offshore wind turbines intended to be certified shall be so designed, manufactured and maintained as to guarantee safe and economic operation during their envisaged operating life. This in particular requires proof that the offshore wind turbine / wind farm

– is capable of withstanding all loads (see Section 1.3.2.1) assumed to occur during manufacture and the envisaged operating life (ultimate limit states), and

– remains operable under the influence of each of the loads to be assumed in this connection (serviceability limit states).

(3) In general it is assumed that the offshore wind turbines are unmanned structures with a service life of at least 20 years.

(4) The offshore wind turbine should normally be designed so that minor causes cannot result in disproportionately heavy damage. This can for instance be achieved by

– designing the important components so that failure of a part does not result in destruction of the entire offshore wind turbine, or

– ensuring that all important components are capable of withstanding all foreseeable influences.

(5) Inspection and maintenance intervals shall be planned to provide adequate assurance that no significant deterioration in the condition of the turbine can arise in the interval. The design shall take into account the practicability of carrying out inspections of relevant components.

(6) Where inspection is not practicable, the component shall be so designed and made that adequate durability for the entire operating life of the offshore wind turbine is assured.

(7) The maintenance concept embraces all activities carried out by an authorized person during the operating life of an offshore wind turbine to ensure its durability. This includes:

– regular maintenance inspections

– extraordinary inspections (e.g. after damage, boat impact, major earthquakes or unpredictable extreme events)

– repairs

1.3.2 Definitions

1.3.2.1 Loads

Loads in the sense of this definition are all actions and interactions with the environment which cause a loading of the structure (action effects).

1.3.2.2 Limit states

The integrity of a structure or its components shall be proved by the investigation of limit states. The limit states are divided into two groups, the ultimate limit states and the serviceability limit states, which in turn may be subdivided further.

1.3.2.2.1 Ultimate limit state

(1) The ultimate limit state, which generally corresponds to the maximum load-bearing capacity, includes for example the following states:

(2) Rupture of critical parts of a structure comprising components, cross-sections and connections, for instance by:

– fracture / exceedance of ultimate strength

– loss of stability (buckling)

– fatigue

(3) Loss of the static equilibrium of a structure or its parts (e. g. overturning as a rigid body).

1.3.2.2.2 Serviceability limit state

Depending on design and function, the serviceability limit state is determined by various limiting values which are oriented towards the normally envisaged use of the offshore wind turbine. Limits to be observed are, amongst others:

– deformations

– vibration amplitudes and accelerations

– crack widths

– stresses and strains

– water tightness

1.3.2.3 Partial safety factors for loads

(1) The partial safety factors for the loads γ_F shall effect that, taking into account the probability of the load occurring, certain limiting values will not be exceeded with a given probability. These partial safety factors reflect the uncertainty of the loads and their probability of occurrence (e.g. normal and extreme loads), possible deviation of the loads from the representative/characteristic values, plus the accuracy of the load model (e.g. gravitational or aerodynamic forces).

(2) The partial safety factors for the loads are independent of the materials used and are stated for all load components in Section 4.3.7.

(3) To ensure reliable design values, the uncertainties and variances of the loads are covered by the partial safety factors for the loads as defined in Equation 1.3.1.

$$F_d = \gamma_F F_k \tag{1.3.1}$$

where:

F_d design values of the loads

γ_F partial safety factors for the loads

F_k characteristic values of the loads. In this Guideline, the alternative term "represen-tative value" is used in cases for which the characteristic value cannot easily be determined by statistical means.

(4) These varying uncertainties are in some cases considered by means of individual partial safety factors. In this Guideline, as in most other codes, the load-related factors are grouped together in a partial safety factor γ_F.

1.3.2.4 Partial safety factors for materials

(1) The partial safety factors for materials γ_M take into account the dependence on the type of material, the processing, component geometry and, if applicable, the influence of the manufacturing process on the strength.

(2) The design resistances R_d to be used for the strength analyses are derived by division of the characteristic strength R_k by the partial safety factor for materials as per Equation 1.3.2.

$$R_d = R_k / \gamma_M \tag{1.3.2}$$

(3) The partial safety factors for materials are stated, in dependence of the materials, in Sections 5.3, 5.4, 5.5 and Section 6.6.

1.3.3 Analysis procedure

(1) The stress S in a component is in this case determined using the design loads applicable for the respective limit state.

$$S = S\,(F_d) \tag{1.3.3}$$

(2) General proof is then required that the stresses resulting from the design loads remain below the design strengths.

$$S \le R_d \tag{1.3.4}$$

(3) The partial safety factor procedure aspired to in ISO 2394 and the Eurocodes cannot always be applied directly to offshore wind turbines, because the operating state of the offshore wind turbine in interaction with the environment results from the equilibrium of various load components. In such cases, the determination of section loads and stresses shall be carried out using the characteristic loads. The individual influences affected by uncertainty (e. g. rotational speed, aerodynamic forces) shall then be systematically varied so as to maintain the safety level implicitly defined by the partial safety factors. As a simplification, the section forces and stresses calculated on the basis of characteristic loads may be multiplied by the partial safety factor for loads most unfavourable for the particular load combination.

1.3.4 Mathematical model

(1) Stresses are usually determined by means of mathematical models, in which the behaviour of the offshore wind turbine or its components, and the types of loads acting on it, are idealized and approximated.

(2) The model and type of approximation chosen shall be appropriate for the limit state to be investigated.

(3) Dimensioning is possible on the basis of test results. However, these must be statistically well-founded.

Appendix 1.A IEC, CENELEC, ISO Standards and GL Guidelines

1.A.1 General

(1) The international standards for wind turbines have been compiled since 1988 by Technical Committee TC 88 of the International Electrotechnical Commission. TC 88 has a number of working groups, project teams and maintenance teams which have produced or are revising the standards, technical reports (TR) and technical specifications (TS).

(2) Each document produced by the IEC is distributed within the European Committee for Electrotechnical Standardization (CENELEC) for parallel harmonization. Documents which thereby attain the status of a European standard are also published as a German standard (DIN, VDE).

(3) In addition to the standards taken over from IEC, the TC 88 of the CENELEC also had own EN standards compiled by several European working groups. Documents listed in the following section are mentioned by title only, and not including the dates of issue and revision.

(4) The international ISO standards for offshore structures referenced in this Guideline are listed in Section 1.A.3.

(5) GL Rules and Guidelines to be applied in conjunction with the present Guideline are listed in 1.A.4.

1.A.2 List of normative documents in the area of wind energy

IEC WT01	System for Conformity Testing and Certification of Wind Turbines, Rules and Procedures
IEC 60050-415	International Electrotechnical Vocabulary - Part 415: Wind turbine generator systems
IEC 61400-1	Safety Requirements
IEC 61400-2	Safety Requirements of Small Wind Turbines
IEC 61400-3	(Committee Draft) Design Requirements for Offshore Wind Turbines
IEC 61400-11	Acoustic Noise Measurement Techniques
IEC 61400-12	Wind Turbine Power Performance Testing
IEC 61400-121	(Committee Draft) Power Performance Measurements of Grid Connected Wind Turbines
IEC TS 61400-13	Measurement of Mechanical Loads
IEC 61400-21	Measurement and Assessment of Power Quality Characteristics of Grid Connected Wind Turbines
IEC TS 61400-23	Full-Scale Structural Testing of Rotor Blades
IEC TR 61400-24	Lightning Protection
IEC 61400-25	(Committee Draft) Communication Standard for Control and Monitoring of Wind Power Plants
(DIN) EN 61400-1	Safety requirements
(DIN) EN 61400-2	Safety of small wind turbines
(DIN) EN 61400-11	Acoustic noise measurement techniques
(DIN) EN 61400-12	Wind turbines power performance testing
(DIN) EN 61400-21	Measurement and assessment of power quality characteristics of grid connected wind turbines
(DIN) EN 50308	Labour safety
(DIN) EN 50373	Electromagnetic compatibility
(DIN) EN 50376	Declaration of sound power level and tonality values of wind turbines

1.A.3 List of ISO standards for offshore structures

ISO 2394: 1998	General principles on reliability for structures

ISO 2533: 1975	Standard Atmosphere
ISO 4354: 1997	Wind actions on structures
ISO 9001: 2000	Quality management systems – Requirements
ISO 19900: 2002	General requirements for offshore structures
ISO 19901-1: 2003	DIS: Specific requirements for offshore structures – Part 1: Metocean design and operating conditions
ISO 19901-4: 2003	Specific requirements for offshore structures – Part 4: Geotechnical and foundation design considerations
ISO 19902: 2004	DIS: Fixed steel offshore structures
ISO 19903: 2004	DIS: Fixed concrete offshore structures

1.A.4 List of GL Rules and Guidelines

– Germanischer Lloyd Rules and Guidelines, IV – Industrial Services, Part 1 – Guideline for the Certification of Wind Turbines, Edition 2003 plus Supplement 2004, published by GL Wind

– Germanischer Lloyd Rules and Guidelines, IV – Industrial Services, Part 4 – Guideline for the Certification of Condition Monitoring Systems for Wind Turbines, published by GL Wind

– Germanischer Lloyd Rules and Guidelines, IV – Industrial Services, Part 6 – Offshore Installations

– Germanischer Lloyd Rules and Guidelines, IV – Industrial Services, Part 6 – Offshore Installations, Chapter 6 – Guidelines for the Construction and Classification/Certification of Floating Production, Storage and Off-Loading Units, Edition 2000

– Germanischer Lloyd Rules and Guidelines, IV – Industrial Services, Part 6 – Offshore Installations, Chapter 7 – Guideline for the Construction of Fixed Offshore Installations in Ice Infested Waters

– Germanischer Lloyd Rules and Guidelines, IV – Industrial Services, Part 8 – Pipelines, Chapter 1 – Rules for subsea pipelines and risers, Edition 2004

– Germanischer Lloyd Rules and Guidelines, I – Ship Technology, Part 5 – Underwater Technology, Edition 1998

– Germanischer Lloyd Rules and Guidelines, II – Materials and Welding, Part 3 – Welding, Edition 2000

1.A.5 Supply sources

IEC standards can be ordered via the Internet page “www.iec.ch”, EN standards via www.cenelec.org, DIN standards via www.din.de, ISO standards via www.iso.org, GL Wind Guidelines via www.gl-group.com/glwind and GL Rules and Guidelines via www.gl-group.com.

Rules and Guidelines

IV *Industrial Services*

2 Guideline for the Certification of Offshore Wind Turbines

2 Safety System, Protective and Monitoring Devices

Germanischer Lloyd
WindEnergie

Edition 2005

Table of Contents

Appendix 2.A

Note:

This Chapter 2 contains amongst other things requirements on how the control system and safety system shall react on sensor signals. Requirements on Condition Monitoring Systems are given in Chapter 13.

2.1 General

2.1.1 Assessment documents

(1) For the approval of the safety system and of the protective and monitoring devices, the following documents at least shall be submitted as a rule:

a description of the offshore wind turbine (type designation, general layout of the offshore wind turbine, functional principles, …)

b description of the control concept and the control system (structure of the control system, sequences of starting and stopping procedures, behaviour of the offshore wind turbine during normal operation, behaviour of the offshore wind turbine on detection of malfunctions, …)

c for the approval of the load assumptions, a description of the controller of the offshore wind turbine as per Section 2.1.3

d statement of other parameters in the operation management (numerical values that have been set) that influence the loads of the offshore wind turbine (cut-in and cut-out wind speeds, rotational speed values, power values, if applicable the control / regulation of the yaw movements, temperatures, …)

e description of the safety concept and the safety system (structure of the safety system, behaviour of the offshore wind turbine following activation of the safety system, statement of the criteria for which the safety system is triggered, …)

f statement of all parameters set in the safety system (numerical values)

g description of the sensors and, if applicable, measuring transducer of the safety system (type designation, setting values, time constants, …)

h description of the procedure for clearance of the offshore wind turbine after activation of the safety system

i description of the braking systems and their behaviour (structure of the braking systems, mode of operation, characteristic quantities, time constants, …)

j electrical and hydraulic (if applicable, also pneumatic) circuit diagrams, at least to the extent that the function of the safety system is shown. In the circuit diagrams, the connection between the electrical and hydraulic (and, if applicable, also pneumatic) system shall be clearly recognizable.

k systematic consideration of possible faults as per Section 2.1.2

l description of any inside and outside monitoring cameras and microphones if applicable

m description of measures to be taken, if the offshore wind turbine is out of operation for a longer period e.g. because of absence of the grid connection. This period has the duration of 3 months as a rule. The measures to be taken could be e.g. lockage of blade pitch system and/or rotor or installing a backup power supply. These measures influence the load assumptions and have to be considered accordingly (see Section 4.3.3.12 para 6).

Note:

The incident that the offshore wind turbine is parked without connection to the electrical grid for a period of up to e.g. 3 months shall be considered to happen once in the entire life of the offshore wind turbine.

n description of measures to be taken, if the offshore wind turbine is taken into operation after a longer period of standstill. The measures could be e.g. opening of locks and/or drying/heating of components, which need to be dry when repowered.

o description of measures to be taken, during the running in period of the offshore wind turbine (see also Section 7.4.9 para 1). These measures shall be at the minimum:

- limitation of the maximum power output depending on turbines age
- additional tests and measuring procedures during the running in period
- additional maintenance activities during and at the end of the running in period

p description of the supervisory wind farm control system and the remote control possibilities on individual turbines (e.g. alternation of electrical power output, pitch/yaw control parameters, …) if applicable

(2) The documents shall show that the requirements set out in Chapter 2 are met. The degree of detail shall be so selected that the behaviour of the installation is adequately defined with regard to the load assumptions.

2.1.2 Systematic consideration of possible faults

(1) A consideration of possible faults in the

– safety system,

– in the braking systems, and

– if a cut-out yaw error φA (see Section 2.2.2.8, para 2) was defined, in the yaw system

shall be submitted. In this consideration, all possible faults of these systems shall be specified and examined. The consideration shall be used for the definition of load cases of the groups DLC 2.x and DLC 7.x and for the evaluation of redundancies in the safety system.

(2) For each possible fault, the following information at least shall be given:

– designation and description of the possible fault

– affected component(s)

– possible cause(s)

– type of detection

– effect(s) of the fault

– measure(s) for limiting negative consequences

(3) The technique chosen for this examination (e.g. failure mode and effect analysis, fault tree, …) shall be selected as appropriate by the author of the documents.

2.1.3 Description of the controller for approval of the load assumptions

(1) For the simulation of the plant behaviour and the associated loads, a description shall be submitted for all relevant control circuits and monitoring devices that have an influence on the load response of the offshore wind turbine (e.g. power, rotational speed, yaw movement).

(2) The behaviour of the control of the offshore wind turbine shall be described by a block circuit diagram, if applicable with hierarchical subdivisions. For each block, formulae shall be given to describe unambiguously the input/output response and initial state.

(3) The block circuit diagram shall include the input and output signals of the controller and the interconnections of the blocks used. Signal paths shall be provided with arrows to indicate their direction of effect. Each signal in the block circuit diagram shall be named unambiguously.

(4) The functional relationship between inputs and outputs of the individual blocks of the controller shall be described in the form of discrete-time static or dynamic model equations (for linear blocks, Z-transfer functions are permissible) with statement of the time step.

Note:

The signals and parameters needed for the function of the controller can be given with their units in summarized form in a table.

2.2 Control and Safety System

2.2.1 General

The control concept and the safety concept are established in the design phase within the framework of the system concept of the offshore wind turbine, to optimize operation and keep the installation in a safe condition in the event of a malfunction. The safety concept shall take into account the relevant operating values such as admissible overspeed, decelerating moments, short-circuit moments, permissible vibrations etc. (see Section 2.2.3).

2.2.2 Definitions

2.2.2.1 Control concept and control system

(1) By control concept is meant a procedure aimed at operating the offshore wind turbine efficiently, as free from malfunctions as possible, lightly stressed and safely. The logic of the procedure is generally incorporated into a programmical unit, which forms part of the overall control system.

(2) With the aid of the control system, the offshore wind turbine shall be controlled, regulated and monitored. The control system shall keep the installation within the normal operating limits.

2.2.2.2 Safety concept and safety system

(1) By safety concept is meant a part of the system concept intended to ensure that in the event of a malfunction the offshore wind turbine remains in a safe condition. If malfunctions occur, it is the task of the safety system to ensure that the installation behaves in accordance with the safety concept.

(2) The safety system is a system logically superordinate to the control system, brought into action after safety-relevant limiting values have been exceeded or if the control system is incapable of keeping the installation within the normal operating limits. The safety system is intended to keep the installation in a safe condition.

2.2.2.3 Braking system

(1) The braking system is a system which by its nature is capable of reducing the rotor rotational speed and keeping it below a maximum value or braking it completely to a standstill. A braking system includes all components which on demand contribute towards braking the rotor.

(2) A braking system may e.g. be of aerodynamic, mechanical, electrical, hydraulic or pneumatic type. Such a system may also utilize more than one of the modes of operation mentioned, or consist of several subsystems.

2.2.2.4 Clearance

By clearance is meant a human intervention in the sense of the execution of a necessary repair or elimination of the cause of a malfunction, followed by release of the offshore wind turbine for operation. Clearance necessitates the presence and active involvement of a sufficiently qualified person on site at the offshore wind turbine.

2.2.2.5 Rotational speed of the rotor

(1) The operating range comprises the rotational speed range of the rotor from the “minimum operating speed” n_1 to the “maximum operating speed” n_3, within which the rotational speed lies under normal operating conditions. The operating range may include ranges acceptable only for a short time (e.g. exclusion of resonance speeds).

(2) The “rated speed” n_r is the rotational speed at the rated wind speed V_r (see Section 2.2.2.7, para 2).

(3) The “set value of the speed controller” n_2 is used for variable-speed plants in the operating state above the rated wind speed V_r (see Section 2.2.2.7, para 2). In this operating state, the rotational speed will deviate upwards or downwards from n_2 only by the standard tolerance.

(4) The “cut-out speed” n_4 is the rotational speed at which an immediate shutdown of the offshore wind turbine must be effected by the control system.

(5) The “activation speed” n_A is that rotational speed at which immediate triggering of the safety system must occur.

(6) The “maximum overspeed” n_{max} may never be exceeded, not even briefly.

(7) When defining the rotational speeds, the interaction of the individual components, in particular the vibratory behaviour (e.g. natural frequencies) of the rotor blades, the drive train and the tower shall be taken into account.

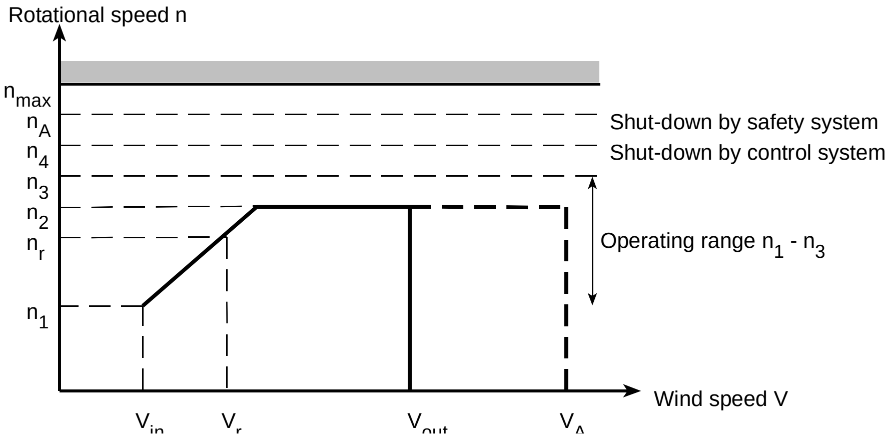


Fig. 2.2.1 Sketch of the rotational speed ranges, using the example of a variable-speed offshore wind turbine

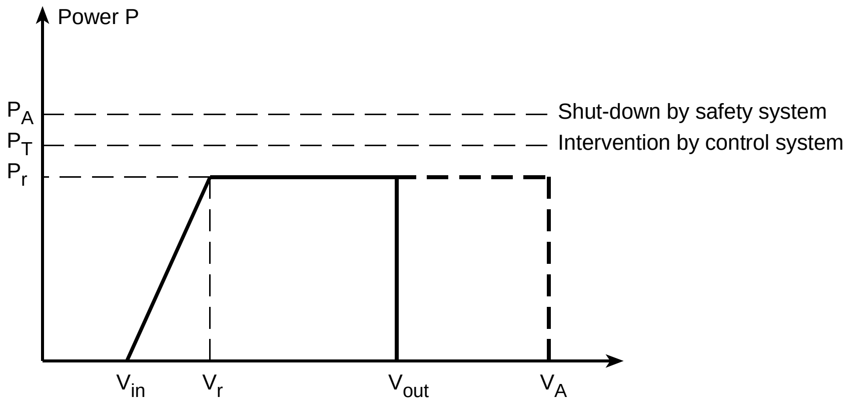


Fig. 2.2.2 Sketch of a power curve

2.2.2.6 Power

(1) The "rated power" P_r is the maximum continuous electrical power (effective power) at the output terminals of the offshore wind turbine (following a possible inverter system and before a possible transformer) resulting from the power curve under normal operating conditions. At this power, the generator or the generator/inverter system yields its rated electrical power on average as specified.

(2) The "over-power" P_T is the effective electrical power at the output terminals of the offshore wind turbine at which the control system must initiate a power reduction.

(3) The "activation power" P_A is the instantaneous effective electrical power at the output terminals of the offshore wind turbine at which immediate triggering of the safety system must occur.

2.2.2.7 Wind speed

(1) The "cut-in wind speed" V_{in} is the lowest mean wind speed at hub height (for the "normal wind profile model NWP", see Section 4.2.2.3.2) at which the offshore wind turbine starts to produce power.

(2) The "rated wind speed" V_r is the lowest mean wind speed at hub height (for the "normal wind profile model NWP", see Section 4.2.2.3.2) at which the offshore wind turbine produced the rated power according to Section 2.2.2.6, para 1).

(3) The "cut-out wind speed" V_{out} is defined as the maximum wind speed at hub height (averaging period to be defined by the manufacturer) at which the offshore wind turbine must be shut down.

(4) The "short-term cut-out wind speed" V_A is the instantaneous wind speed at hub height (averaging period to be defined by the manufacturer) above which the offshore wind turbine must be shut down immediately.

2.2.2.8 Wind direction and yaw error

(1) The yaw error φ is the angle between the wind direction (instantaneous direction of attack of the wind at hub height) and the rotor axis of the offshore wind turbine, measured in the horizontal plane.

(2) The “cut-out yaw error” φ_A is the largest admissible yaw error (averaging period to be defined by the manufacturer) above which the offshore wind turbine must be shut down immediately.

2.2.2.9 External power supply, mains failure

(1) By external power supply is meant the supply of any kind of primary or auxiliary power to automation, control or mechanical systems of the offshore wind turbine from outside. If energy is obtained by internal conversion of wind energy or kinetic energy of the rotor using the offshore wind turbine’s own devices and then utilized, this does not count as external power supply. Supply of electricity from batteries, mains or diesel generators is external power supply. Similarly, the external supply of auxiliary forms of power (such as control air, hydraulic system fluid etc.) belongs to the same class.

(2) Failure of the external power supply (mains failure) with a duration of up to one hour is regarded as a normal external condition. Furthermore, mains failure with a duration exceeding one hour up to a duration of 7 days shall be considered and regarded as a fault.

2.2.2.10 Locking devices

Locking devices are devices which secure the moving parts (rotor, yaw system, blade pitching system, …) already braked to a standstill.

2.2.3 Requirements and design concept

2.2.3.1 General safety concept

The safety system shall fulfil the following principal criteria:

2.2.3.1.1 Single failure

The failure of a single component which is relevant for the functioning of the safety system, e.g. a sensor or braking system, shall not lead to failure of the safety function. The simultaneous failure of two independent components is classed as an unlikely event and therefore need not be considered. Where components depend on one another, their simultaneous failure shall be classed as a single failure. The individual components of the safety system shall be of the highest specification as regards their availability and reliability.

2.2.3.1.2 Redundancy

(1) With regard to its design concept, the safety system shall be totally separate from the control system.

(2) The safety system shall have access to at least two mutually and totally independent braking systems.

Note:

By independence is meant that “faults with a common cause” shall rigorously be avoided in the system-engineering design stage. Accordingly, the failure of a single component shall not result in the failure of more than one braking system and thus the loss of the entire safety function.

2.2.3.2 Control and safety systems

2.2.3.2.1 Control system

The control system shall be so designed that it keeps the offshore wind turbine within the normal operating limits under all the external conditions specified in Section 4.2, or returns it to operation within these limits. Malfunctions (such as over-power, overspeed and overheating) shall be detected by the control system and followed by appropriate measures. The control system shall obtain its information from all of the sensors provided for the offshore wind turbine and shall be able to actuate at least two braking systems. Upon activation of the braking systems by the safety system, the control system shall subordinate itself.

2.2.3.2.2 Safety system

(1) The limiting values triggering the safety system shall be defined so that the limit values of the design basis are not exceeded and the offshore wind turbine is not endangered, but also so that the control system is not disturbed unnecessarily by the safety system.

(2) The functions of the control system shall be subordinated to the requirements of the safety system.

(3) The safety system shall have higher-priority access to at least two braking systems and to equipment for grid disconnection of the generator and, once triggered by deviations from the normal operating values, shall carry out its task without delay, keep the offshore wind turbine in a safe condition and in general initiate deceleration of the rotor with the aid of all the braking systems at its disposal.

Note:

The separation from the grid need not be carried out at the instant of activation of the safety system. Speeding-up of the offshore wind turbine and operation of the generator as a motor shall be avoided in any case.

(4) If the safety system has been activated, a clearance according to Section 2.2.2.4 is required in any case. This clearance of the safety system shall be independent of the control system and may in no case be activated automatically. If the safety system was triggered before grid loss, then clearance may not be activated automatically after the return of the grid.

2.2.3.3 Braking systems

2.2.3.3.1 Braking system requirements

(1) There shall be at least two mutually independent braking systems by means of which the rotor can be decelerated or brought to a standstill at any time.

(2) In the case of load shedding and a failure of one of the braking systems at the same time, the other braking system(s) must be able to keep the rotor below the maximum overspeed n_{max} (Section 2.2.2.5, para 6) (see Section 4.3.3.6).

(3) It shall be possible to bring the rotor to a standstill (see Section 2.3.2.14 and Sections 4.3.3.9 and 4.3.3.12).

2.2.3.3.2 Selection of the braking principle

At least one of the braking systems should operate on an aerodynamic principle, and as such act directly on the rotor. If this requirement is not met, at least one of the braking systems provided shall act on the parts (hub, shaft) of the offshore wind turbine that rotate at rotor speed.

2.2.3.3.3 External power supply

(1) The braking systems shall be so designed that they remain operable if the external power supply (see Section 2.2.2.9) fails. If this requirement cannot be met by all braking systems within the selected system concept, then additional measures that ensure the safety level of this Guideline in an equivalent manner shall be implemented and verified.

(2) If auxiliary power supply from accumulators (e.g. from the hydraulic unit or from batteries) is necessary for the functioning of the brakes, it shall be automatically monitored that a sufficient amount of energy is available for at least one emergency braking. If the function of the accumulator depends on its temperature, then the accumulator temperature shall also be monitored. If these monitoring tasks cannot be carried out continuously, then automatic tests shall be performed at least weekly. The offshore wind turbine shall be shut down immediately if the monitoring or a test reveals a negative result. Furthermore, Section 2.3.2.10 shall be taken into account.

2.2.3.4 Torque-limiting components

If components are provided to limit torque, any mechanical brake fitted shall be located between the torque-limiting device and the rotor hub.

2.2.4 Offshore applications

(1) If the safety system has been activated, a clearance according to Section 2.2.2.4 is required in any case. Section 2.2.3.2.2 para 4 is applicable. For offshore wind turbines sufficiently qualified personnel performing the clearance need not necessarily be on site at the turbine, but may make the clearance from the remote control centre, if the following prerequisites are met:

(2) The outside of the turbine shall be inspected from a distance before performing the clearance to make sure, that the main components are in place and look undamaged. This inspection may be made from a neighbouring turbine, a boat or helicopter and use of monitoring cameras is allowed.

(3) The inside of the nacelle shall be inspected after the clearance during the start up to make sure, that the main components are in place and undamaged. This inspection may be made by using monitoring camera(s) and microphones(s) or other suitable methods.

(4) The amount of allowable remote clearances of the safety system shall be limited. In the documentation shall be stated for each possible failure

– the amount of allowable remote clearances per 24 h and

– the amount of allowable remote clearances as a total for the same failure.

(5) It shall be possible to bring the rotor to a standstill by remote control prior to the possible arrival of personnel, if necessary in terms of personnel safety (e.g. heli-hoist operations, possible collision blade-tip / ship).

2.3 Protective and Monitoring Devices

2.3.1 General

(1) The safety system is activated when limiting values are exceeded. This initiates a braking process. The requirements on when a malfunction is to activate the safety system directly and/or how it is to be treated by the control system are given below.

(2) In Appendix 2.A of this chapter, the interaction of control system and safety system is represented graphically as a typical example.

2.3.2 Limiting values, control system

2.3.2.1 General

In the cases defined here in Section 2.3.2, the offshore wind turbine is permitted to start up again automatically without clearance following a turbine shut-down. This automatic start-up is limited to a few times every 24 hours for most transgressions of the limiting values. It is in keeping with this section that the transgressions counts for the different limiting values can be undertaken independently of each other.

2.3.2.2 Rotational speed

2.3.2.2.1 Measurement of rotational speed

The rotational speed shall be picked up at least twice by separate systems, and supplied at least twice to the control system and at least once to the safety system. At least one of the speed sensors shall be mounted on a component of the offshore wind turbine that runs at rotor speed.

Note:

Any automatic triggering of the blade tip brakes shall be reported to both the safety system and the control system. If that is not possible, it shall be ensured that the blade tips do not engage again and the rotor rotational speed then exceeds n_A again (see Section 2.2.2.5, para 5).

2.3.2.2.2 Operational reliability of the measurement system

(1) As a matter of principle, the speed measurement systems shall meet the same requirements as regards functioning and reliability as the braking equipment itself. In particular, the arrangement on the structure shall meet this requirement when considering fault sequences.

(2) The control system shall continuously monitor the plausibility of at least two of the measured speeds with regard to each other in all operating conditions of the offshore wind turbine.

2.3.2.2.3 Excessive speed and the reaction of the control system

(1) If the rotor speed exceeds the operating range (Section 2.2.2.5, para 1) ($n > n_3$), then the control system shall initiate a deceleration of the rotor.

(2) If the rotational speed n_4 (Section 2.2.2.5, para 4) is exceeded, then the control system shall shut down the offshore wind turbine.

(3) If the monitoring of the mutual speed plausibility detects an error, the offshore wind turbine shall be shut down.

(4) Following a shut-down in accordance with Section 2.3.2.2.3, an automatic re-start may take place without clearance if this is provided for in the system concept and there is no fault in the installation. The automatic start-up shall be limited to three times every 24 hours.

2.3.2.2.4 Rotational speed exceeding activation speed

If the activation speed n_A (Section 2.2.2.5, para 5) is exceeded, the safety system shall be activated immediately.

Note:

The maximum overspeed n_{max} (see Section 2.2.2.5, para 6) should not exceed 1.2 x n_2 (see Section 2.2.2.5, para 3), since this value covers the standard overspeed test according to international generator standards.

2.3.2.2.5 Behaviour following activation of the safety system

(1) If the safety system has responded after excessive speed according to Section 2.3.2.2.4, the maximum overspeed n_{max} (Section 2.2.2.5, para 6) shall not at any time be exceeded (not even briefly). This shall be taken into consideration particularly for aerodynamic brakes and for brakes whose action is staggered in time.

(2) The safety system shall shut down the offshore wind turbine immediately and bring it into a safe condition.

2.3.2.3 Power

2.3.2.3.1 Measurement of power

(1) Power measurement shall be regarded as an operational measurement and treated accordingly. In the case of plants with a rated power of 1 MW or more, an additional monitoring of the power for transgression of the activation power P_A as per Section 2.3.2.3.3 shall be provided. Recourse may be had to other physical parameters, as long as these have a clear and recognized relationship to the power. In this event, the relationship between the operationally sensed substitute parameter and power shall be established by measurement during the test phase and recorded in a suitable fashion (e.g. in the form of a performance graph).

(2) The measured power in combination with the rotational speed is regarded as a measure of the average loading of the whole plant.

2.3.2.3.2 Measurement of power for the control system

(1) Generally, the electrical power (effective power) shall be used as the measurement parameter. If the system concept includes the possibility of the over-power P_T according to Section 2.2.2.6, para 2, being exceeded, the power shall be picked up as a control parameter and supplied to the control system.

(2) The power measuring equipment shall be capable of picking up both average values (about 1–10 minute mean) and short-term power peaks (sampling rate at least once per second).

2.3.2.3.3 Monitoring the power for the safety system

(1) The power shall be monitored continuously for exceeding of the instantaneous activation power P_A. In the case of plants with a rated power of 1 MW or more, this monitoring and the measurement devices needed for the task shall be provided in redundancy to the power measurement of the control system and shall act directly on the safety system.

(2) An exception can be made from this provision if the exceeding of P_A is not possible according to the system concept or if the required redundancy in power measurement is given in some other manner.

2.3.2.3.4 Exceeding the over-power P_T or the rated power P_r

(1) If the power exceeds the over-power P_T (Section 2.2.2.6, para 2), then the corresponding measures shall be initiated automatically by the control system without delay. The long-term average of the power shall not exceed the rated power P_r (Section 2.2.2.6, para 1).

(2) The measures to be taken depend on the system concept. The power shall be reduced accordingly or the offshore wind turbine shall be shut down.

(3) The instantaneous value and the mean value for the over-power P_T shall be defined by the manufacturer together with the averaging periods, and taken into account appropriately in the load calculation (fatigue loads). During the prototype test, it shall be shown that the defined values are met.

Note:

As a rule, P_T should lie directly above the rated power P_r or be equal to it.

2.3.2.3.5 Exceeding the activation power P_A

(1) If the instantaneous power exceeds the activation power P_A (Section 2.2.2.6, para 3), protective measures shall be initiated automatically without delay by the safety system. The actual measures depend on the system concept. In all cases, the offshore wind turbine shall be shut down and brought into a safe condition.

(2) The value for the activation power P_A shall be defined by the manufacturer of the offshore wind turbine and taken into account correspondingly in the load calculation.

2.3.2.3.6 Automatic start-up

If the offshore wind turbine was shut down after exceeding the over-power P_T on the basis of Section 2.3.2.3.4, an automatic re-start may take place without clearance if this is provided for in the system concept and there is no fault in the installation. The automatic start-up shall be limited to three times every 24 hours.

2.3.2.4 Wind speed

2.3.2.4.1 Requirements

If safe operation of the offshore wind turbine depends on wind speed measurements, or if wind speed is one of the input parameters to the control system, a reliable and appropriate means of measuring wind speed shall be provided.

2.3.2.4.2 Measurement of wind speed

(1) If measurement of wind speed is necessary as described in Section 2.3.2.4.1, this requirement can be met by measuring the speed either directly or via another parameter with a clear and recognized relationship to it, which is then processed. As a matter of principle, suitable sensing points and measurement techniques shall be selected for operational measurements. The wind speed at hub height – with flow as undisturbed as possible – is to be considered as relevant measurement parameter.

(2) Selecting a measurement method which leads to a hazardous uncertainty in case of icing necessitates a continuous plausibility check of the measured values (e.g. by comparison with other measurands related to wind speed) and equipment of the sensor with a suitable heating which will be activated in case of the danger of icing.

2.3.2.4.3 Exceeding the cut-out wind speed

If a cut-out wind speed V_{out} according to Section 2.2.2.7, para 3, has been used as a basis for the offshore wind turbine design, the plant shall be shut down immediately and automatically by the control system if this limiting value is exceeded.

2.3.2.4.4 Exceeding the short-term cut-out wind speed

If a cut-out wind speed has been used as a basis for the offshore wind turbine design, the plant shall be shut down immediately and automatically by the control system if the short-term cut-out wind speed V_A according to Section 2.2.2.7, para 4, is exceeded.

2.3.2.4.5 Automatic start-up

If the offshore wind turbine was shut down after exceeding a cut-out wind speed, an automatic re-start may take place without clearance if the wind speed has fallen to a permissible value according to the system concept and there is no fault in the installation.

2.3.2.4.6 Control during faulty wind speed measurements

If the control system detects that the wind speed measurements reveal faulty results, the offshore wind turbine shall be shut down.

2.3.2.5 Shock

2.3.2.5.1 General

By shock is meant forced movements and accelerations of the offshore wind turbine, caused by damage, imbalance or other influences (e.g. earthquakes).

2.3.2.5.2 Measurement of shock

Monitoring for shock shall take place continuously, with the measurement being compared with the limiting value. The sensor shall be located at nacelle height, eccentric to the tower axis. As the shock to be sensed is generally noticeable as a movement of the whole nacelle, measurement techniques sensing the total movement shall be used. If the nacelle movement is not transmitted to the tower, a suitable relative movement may be sensed as a substitute.

2.3.2.5.3 Operational safety

The sensitivity of the sensor shall be matched to the conditions prevailing. It shall be protected effectively against all external influences, including interference by unauthorized persons. It is recommended that the sensitivity be set when the installation is running.

2.3.2.5.4 Exceeding the limiting value

If the shock actually measured exceeds the limiting value (to be determined beforehand), the safety system shall be activated and shall shut down the plant.

2.3.2.6 Operational vibration monitoring

2.3.2.6.1 General

(1) By vibration is meant forced movements of the offshore wind turbine, caused by imbalance and by operating the plant in the vicinity of a natural frequency of components. Imbalance may point to damage, malfunction (e.g. asymmetric pitching of the rotor blades) or other external influences (e.g. icing-up of the rotor blades).

(2) The continuous monitoring of vibrations in accordance with this Section (Operational vibration monitoring), is one of the prerequisites for operation of the offshore wind turbine in the resonance range close to the natural frequencies of the tower (see Section 6.6.4.2.1, para 4).

(3) In the case of offshore wind turbines for which aerodynamically related blade vibrations cannot be ruled out, a continuous monitoring of these vibrations according to this Section 2.3.2.6 may be necessary (in addition to the vibration monitoring of the tower, if applicable).

2.3.2.6.2 Measurement of vibrations

(1) The vibrations shall be measured constantly and their magnitude compared with the limiting values to be determined beforehand.

(2) The averaging periods in the signal processing and sensitivities, as well as the mounting points of the sensors, shall be so selected that all loading-relevant movements of the components to be monitored are measured reliably.

(3) The measurement and signal processing can be performed in the control system.

2.3.2.6.3 Determination of the limiting values

(1) The limiting values for the vibration monitoring shall be so determined that an alarm is triggered when the loads and/or movements defined in the design of the offshore wind turbine for the components to be monitored are exceeded. The vibration level determined during the design of the offshore wind turbine shall be taken as the basis.

(2) Criteria shall be defined for short-term monitoring (e.g. measurement period up to a few seconds) and for long-term monitoring (e.g. measurement period in the range of several minutes).

Note:

It is regarded as prudent to define these criteria in relation to the condition of the plant (e.g. wind speed, rotational speed, or power).

The effectiveness of these criteria shall be verified, e.g. through simulations.

Note:

For these simulations, malfunctions (e.g. mechanical and / or aerodynamic imbalance of the rotor, displacement of natural frequencies) can be defined, depending on the system concept and tower design. In the simulations, it shall then be shown that these malfunctions are detected by the vibration monitoring with the selected sensitivities, averaging periods and limiting values, without exceeding the loads defined for the design.

2.3.2.6.4 Exceeding the limiting value

If the currently measured vibrations exceed one of the defined limiting values, the offshore wind turbine shall be shut down by the control system.

2.3.2.6.5 Automatic start-up

Following a shut-down in accordance with Section 2.3.2.6.4, an automatic re-start may take place without clearance if this is provided for in the system concept and no fault can be detected in the installation. The automatic start-up shall be limited to three times every 24 hours.

2.3.2.7 Mains failure/load shedding

2.3.2.7.1 General

Should an offshore wind turbine lose its load (e.g. the mains load), the rotor may speed up very rapidly. This endangers individual components and the structural integrity of the entire plant.

2.3.2.7.2 Operation following mains failure

If there is a mains failure, or if an offshore wind turbine operating in stand-alone mode has lost its load, this shall be detected by the control system and the safety system, and the offshore wind turbine shall be shut down.

2.3.2.7.3 Operation after restoration of mains

Mains failure is considered an external event. For that reason, the offshore wind turbine may be started automatically by the control system once the mains grid is capable of taking power again.

2.3.2.8 Short circuit

2.3.2.8.1 Requirements

The offshore wind turbine shall be equipped with suitable short-circuit protection devices (see Section 8.7.2).

2.3.2.8.2 Operation following a short circuit

(1) If the protection devices detect a short circuit, they shall respond and simultaneously trigger the safety system.

(2) The safety system shall shut down the offshore wind turbine and bring it into a safe condition.

2.3.2.9 Monitoring the generator temperature

2.3.2.9.1 Requirements

The temperature in the windings of the generator shall be monitored to ensure that it is kept within the allowable operating limits. To achieve this aim, a self-monitoring measurement system that functions reliably and maintenance-free shall be selected.

2.3.2.9.2 Limiting values

The limiting value for the temperature in the windings is generally laid down according to information from the manufacturer based on the class of insulation used (see Section 8.2.6).

2.3.2.9.3 Operation after excess temperature

If the permissible winding temperature has been exceeded, the power output shall be reduced, to give the generator a chance to cool down. This is a task for the control system.

Note:

Even exceeding the permissible temperature limit only slightly reduces the life of the generator; exceeding it *substantially leads to its destruction in a short time. Excess current or power may result in mechanical as well as electrical overloading of components. Short-term excesses of rated operating values shall be reduced by the control devices. If the maximum permissible limiting values are exceeded, the offshore wind turbine shall be shut down.*

2.3.2.10 Condition monitoring of the braking systems

2.3.2.10.1 General

The braking systems of an offshore wind turbine are of particular relevance as regards safety. Mechanical braking systems are subject to a high degree of wear. For that reason, the service brake should as far as possible operate on a low-wear or no-wear principle (see Section 2.2.3.3.2). Should the design of the braking system of an offshore wind turbine permit the possibility of increased, unnoticed wear or a malfunction in the necessary accumulator (see Section 2.2.3.3.3) resulting in failure to respond when required, then monitoring of the condition of the braking equipment shall be provided.

2.3.2.10.2 Measurement parameters

The brake lining thickness and/or the brake slack in mechanical brakes, and also, depending on the design concept, the time to effect the braking or the power consumption, are all factors that can be used as relevant measurement parameters for condition monitoring. Accumulators shall be monitored in accordance with their design (see Section 2.2.3.3.3).

2.3.2.10.3 Safety requirement

If condition monitoring is provided, it shall meet the same safety standards as the braking system itself (i.e. the brake shall respond if the monitoring fails). The response of the condition monitoring equipment shall be such that possible progressive defects are detected early – at any rate before the required braking power can no longer be achieved – and countermeasures are initiated.

2.3.2.10.4 Operation after a fault is detected

If the condition monitoring detects that a braking system is not ready for operation, the offshore wind turbine shall be shut down by the control system. An unambiguous report of the failure detected shall be made. An automatic re-start of the plant is only permissible after clearance (see Section 2.2.2.4).

2.3.2.11 Cable twisting

2.3.2.11.1 Requirements

If operation of the offshore wind turbine may result in twisting of flexible cables, particularly the connecting cables between rotating parts (nacelle) and parts of the fixed structure (tower or foundation), technical measures shall be taken to prevent destruction of these cables by excessive twisting.

2.3.2.11.2 Measurement parameter

Direction-dependent counting or a similar procedure for identifying the total revolutions of the nacelle shall be regarded as an appropriate measurement parameter for the twisting of flexible cables.

2.3.2.11.3 Limiting value

The maximum acceptable degree of twisting for the flexible cables shall be defined by the manufacturer or supplier.

2.3.2.11.4 Operation after excessive twisting

(1) The monitoring equipment for twisting shall always respond before the maximum acceptable degree of twisting is reached.

(2) In the case of offshore wind turbines with active yaw systems, untwisting of the cables can be undertaken automatically by the control system through appropriate operation of the yaw drive. During the untwisting, the plant shall be shut down. If the flexible cables have been untwisted automatically, the offshore wind turbine can be re-started automatically without clearance.

(3) If the largest threshold value for automatic untwisting is exceeded without any response from the control system, the safety system shall shut down the offshore wind turbine and bring it to a safe condition.

Note:

To prevent possible danger to the offshore wind turbine structure, it may be advisable to suppress the automatic untwisting at extremely high wind speeds (e.g. $V \geq 0.8 * V_{ref}$) and to have the yaw system control the plant automatically until these wind speeds have dropped to an acceptable level.

(4) In the case of installations without active yaw systems, further rotation of the nacelle shall be prevented after the maximum acceptable degree of twisting (see Section 2.3.2.11.3) has been reached. The offshore wind turbine shall be brought into a safe condition.

2.3.2.12 Yaw system

2.3.2.12.1 Measurement of wind direction

If the measurement of wind direction is necessary for the control of the offshore wind turbine, the measurement equipment (e.g. windvane) shall be constantly monitored in a suitable way and equipped with a proper heating which shall be activated upon the danger of icing.

2.3.2.12.2 Operation for faulty wind direction measurements

If the control system detects that the wind direction measurements yield faulty results, the offshore wind turbine shall be shut down.

2.3.2.12.3 Active yaw system

(1) In the case of nacelles with active yaw systems, it shall be ensured that even straightforward manual maloperation cannot produce conditions which put the integrity of the offshore wind turbine at risk as a result of stresses not included in the calculations. The drive of nacelles with active yaw systems shall be provided with a braking system. Before starting, it shall be established unequivocally that the position of the nacelle conforms to the wind direction of the design.

Note:

This can be of particular importance for instance after a lengthy standstill, if since the time of shutting down the wind has veered something like 180° and the wind direction is not followed with the offshore wind turbine at standstill.

(2) If a cut-out yaw error φA (see Section 2.2.2.8, para 2) was defined in the system concept, the offshore wind turbine shall be shut down immediately when this value is exceeded. Once the yaw error is again within the permissible range, the offshore wind turbine can be re-started automatically without clearance.

2.3.2.12.4 Passive yaw system

In case of a passive yaw system, it shall be established unequivocally before start-up that the position of the nacelle conforms to the wind direction of the design.

2.3.2.13 Frequency and voltage

(1) In the case of offshore wind turbines operating in parallel with the mains, a fixed mains frequency is assumed. As a rule, the mains frequency is imposed on the offshore wind turbine. Specific monitoring and control is necessary to the extent required by the relevant grid operator to maintain satisfactory parallel operation. Apart from that, Section 4.2.4.8 shall apply.

(2) In offshore wind turbines operating in a stand-alone mode, on the other hand, the frequency is often determined by the offshore wind turbine itself. Whether and to what extent frequency variations can be tolerated should be determined by taking the individual service into consideration. In general, however, designs should not be based on deviations greater than ± 5 % or ± 10 % for short periods.

2.3.2.14 Emergency push button

2.3.2.14.1 General

As a means for manual intervention, at least one Emergency push button shall be provided each in the nacelle and at the control and regulating unit. The buttons shall be so arranged and constructed that they can be operated as their function requires and cannot be diverted to other purposes.

2.3.2.14.2 Requirements

Activation of Emergency Off is intended to divert danger from persons or the offshore wind turbine itself. This means the safety system must bring all movements of the offshore wind turbine to a standstill in the shortest possible time. The primary aim is not to effect the gentlest, but rather the most rapid, braking to a standstill that is compatible with the strength of the installation. Accordingly, any time delays that may be present shall be bypassed, provided this can be justified from the viewpoint of strength.

2.3.2.14.3 Operation after activation of Emergency push button

Operation for triggering of Emergency push button may be identical, for instance, with operation in the event of the safety system being triggered due to excessive vibration (see Section 2.3.2.5). Following engagement, the Emergency push button shall remain in the engaged position.

2.3.2.15 Faults in machinery components

(1) Machinery components shall be monitored according to the state of the art. Such monitoring equipment shall cover physical parameters which can be used as a measure of reliable operation (e.g. gear oil pressure, gear oil temperature, bearing temperatures etc.). The extent to which such equipment shall be provided depends essentially on the overall design concept.

(2) When limiting values are exceeded, the control system shall shut down the offshore wind turbine. Depending on the type of malfunction, the offshore wind turbine may then re-start automatically or be re-started by remote intervention from the control room. The automatic start-up shall be limited to three times every 24 hours.

(3) In the design of the control system concept, the structural integrity of the offshore wind turbine shall be given priority over its availability.

2.3.2.16 Operation of a cold plant

If a relationship between component temperature and the maximum admissible power transmission is specified by the manufacturer for certain components of the offshore wind turbine (e.g. gearing, generator, transformer), then a corresponding "warm-up phase" shall be provided in the control system of the plant. The power provided by the rotor shall at no time be permitted to be larger than the maximum specified for the momentary temperature by the manufacturer of the corresponding component.

2.3.2.17 Operativeness of the control system and data storage

(1) The control concept is defined as the procedure for operating the offshore wind turbine under the specified conditions (see Section 2.2.2.1). If the control is carried out by a programmable control system, this takes over control and regulation of the offshore wind turbine.

(2) If the control system detects that it has lost control of the offshore wind turbine (e. g. a demanded blade pitch is not executed), the control system shall trigger the safety system.

(3) The control system shall be monitored by a suitable arrangement (e.g. watch-dog). If this is triggered, the plant shall be shut down immediately. If this monitoring arrangement responds more than once in 24 hours, the safety system shall also be triggered.

(4) If the safety system is triggered in the case of plants with a rated power of 1 MW or more, the control system shall store the data of the final operating conditions.

2.3.2.18 Automatic detection of icing-up

2.3.2.18.1 Ice sensor

A device which automatically detects the formation of ice at a component of the offshore wind turbine can be certified.

2.3.2.18.2 Operation on detection of icing-up

If icing-up is detected, the control system shall shut down the offshore wind turbine to prevent pieces of ice from being hurled off the rotating parts. An automatic re-start of the plant is only permissible if it is possible to ensure that all rotating parts are free of ice. Otherwise clearance according to Section 2.2.2.4 is required before re-starting.

2.3.3 Safety equipment (locking devices) for maintenance

2.3.3.1 Requirements

An offshore wind turbine shall be equipped with at least one lock or equivalent device each for rotor, yaw system and blade-pitch system (see Section 2.2.2.10), with the function of locking these against movement. Automatic activation (automatic engagement on reaching standstill) is not necessary in general.

Note:

Braking equipment may not, as a rule, be regarded as constituting the required locking device at the same time. Deviation from this rule is possible in exceptional cases, provided the system design ensures that work on each part of the braking system can be carried out safely. Work on a braking system can be carried out safely only if all rotation of the parts of the offshore wind turbine which the system is intended to brake can be reliably prevented.

2.3.3.2 Design of the locking devices

(1) The locking devices shall be so designed that even with a brake removed they can reliably prevent any rotation of the rotor, nacelle or the rotor blade.

(2) The rotor lock shall be arranged to act on the drive train near the hub, and shall have form-fit. The design of the rotor lock shall be based on Section 7.5.3 para 4.

2.3.3.3 Safety requirements

The design of the locking device shall be based on the assumption that people deliberately enter, remain in and work in a hazardous area with confidence in the functioning of the device. Particularly high requirements shall thus be imposed as regards the operational safety, quality and accessibility of the device, as well as its engagement with the parts of the offshore wind turbine being locked (e.g. rotor blades, hub, shaft).

2.3.3.4 Activation of the locking device

If work is to be carried out on those parts of the offshore wind turbine which rotate during operation, the locking device shall always be activated. It shall also be activated even if the installation is held stopped by the brake capable of slowing the rotor to a standstill, or any azimuth brakes that may be provided. The operator shall be explicitly alerted to this safety measure. An appropriate note shall be inserted in the operating manual.

Appendix 2.A Interaction of the Control and Safety Systems

This sketch visualizes schematically the interaction of the control and safety systems and is intended to be helpful for understanding the wording in Chapter 2. However, the wording of Chapter 2 is binding.

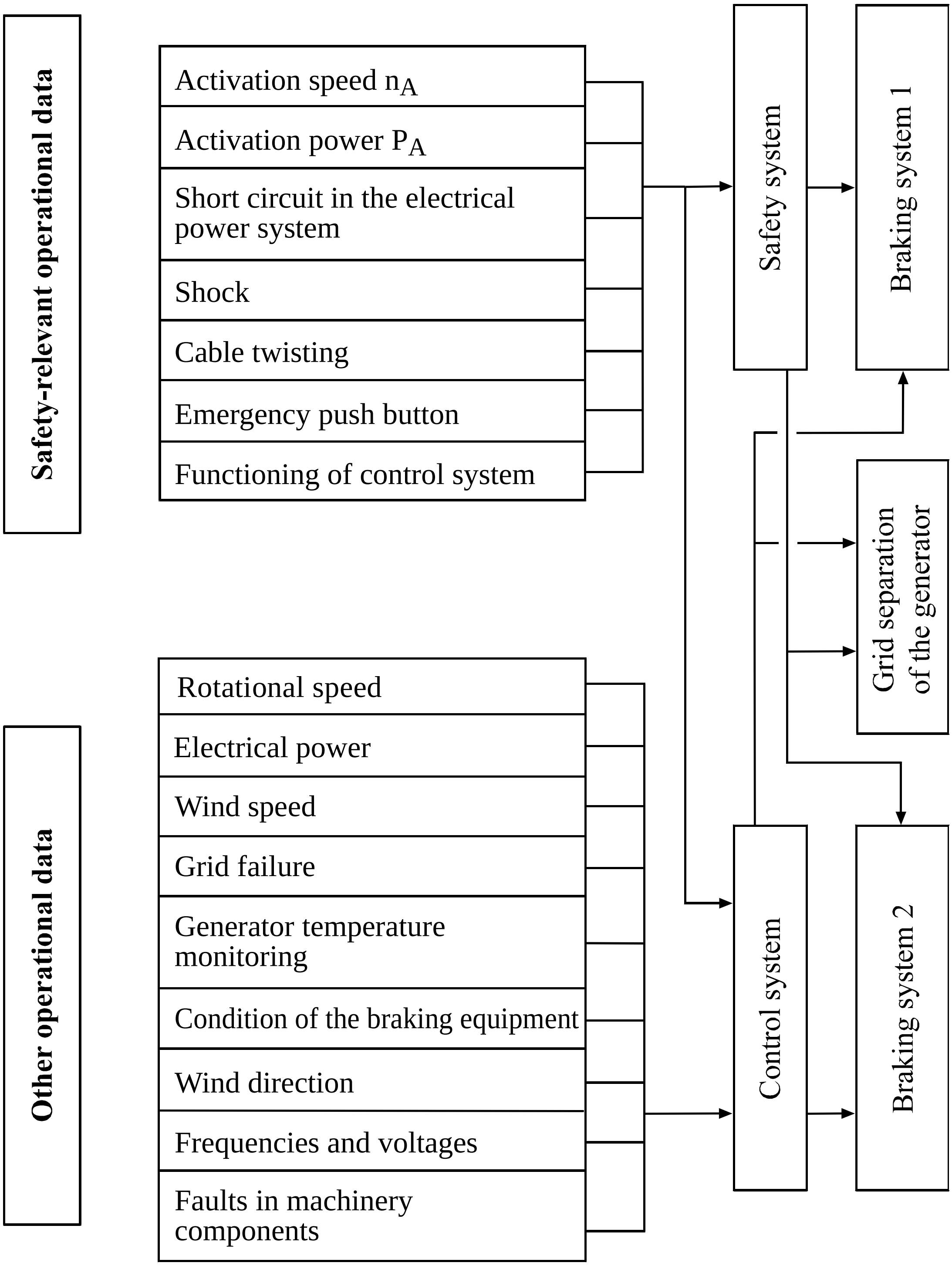


Fig. 2.A.1 Interaction of the control and safety systems

Rules and Guidelines

IV *Industrial Services*

2 Guideline for the Certification of Offshore Wind Turbines

3 Requirements for Manufacturers, Quality Management, Materials, Production and Corrosion Protection

Edition 2005

Germanischer Lloyd
WindEnergie

Table of Contents

3.1 Requirements for Manufacturers

3.1.1 General

(1) Manufacturers shall be suitable for the work to be carried out as regards their workshop facilities, manufacturing processes as well as training and capabilities of the personnel. Proof of this may be provided by means of a documented and certified quality management system (see Section 3.2). If required, GL Wind will issue a shop approval on request of a manufacturer, provided the approval conditions are fulfilled.

(2) It is the responsibility of the manufacturer to observe and conform to this Guideline, the pertinent laws and ordinances, technical regulations, standards and data sheets, such as those from the chemicals industry etc. (see also Section 3.2.1, para 2).

(3) Insofar as the requirements for the manufacturers set out below (especially as regards quality control) are not further defined, these shall be defined in accordance with the quality management requirements (see Section 3.2). Details shall be agreed with GL Wind for each individual case.

3.1.2 Works equipment

(1) The manufacturers shall have at their disposal suitable facilities and equipment for faultless execution of the work. External facilities may be included for consideration only if these meet the prerequisites for competent execution and are available without restriction.

(2) Equipment and facilities include, on the scale necessary for the manufacture in question, for instance the following:

- workshops, roofed-over working areas as required, equipment for assembly sites
- store-rooms for materials
- drying facilities (e.g. for wood, welding fillers etc.)
- lifting gear for assembly and transport
- processing machinery and tools
- tools and equipment for welding and cutting
- appliances for joining-up, and for welding, laminating, bonding and gluing
- air-condition monitoring instruments
- facilities for preheating and heat treatment
- test equipment and materials plus means for their calibration

3.1.3 Personnel

(1) The personnel employed by the company shall be such as to ensure that the components can be competently prepared, manufactured and tested to the extent necessary. GL Wind may require proof of the technical qualifications of the staff.

(2) The respective areas of responsibility shall be laid down and arrangements made for deputies for those responsible.

3.1.4 Shop approval

3.1.4.1 General

Shop approval is required for welding, laminating and bonding. Shop approvals by other organizations can be recognized after consultation with GL Wind. GL Wind reserves the right to demand approval for other manufacturing methods or working techniques.

3.1.4.2 Application for approval

(1) Application for approval shall be made on a form provided. Any additional information, documents and explanations demanded or necessary (see Sections 3.2, 3.3, 3.4 and 3.5) shall be enclosed with the application.

(2) The application shall describe the organization and technical facilities of the company, as well as provide information about personnel qualifications, scope of production and production processes plus quality control.

(3) GL Wind shall be notified of the individuals responsible for observation of the approval conditions and for the quality of the products manufactured, and of their deputies.

(4) The tests which are in the manufacturer's responsibility shall be documented. This may be acknowledged within the context of a certification of the quality management system (see Section 3.2).

3.1.4.3 Approval procedure, period of validity

(1) After GL Wind has checked the application for compliance with the requirements of Sections 3.3, 3.4 and 3.5 and has inspected the works, the shop approval may be granted for a period of three years. If in all sections of the workshop work under the surveillance of GL Wind is carried out continuously during the period of validity, this is extended by a year at a time without further checks. Renewed confirmation of the approval is then given as a notice in writing, but may be given formally at the request of the company.

(2) If no work under the surveillance of GL Wind has been carried out for more than one year, prolongation shall be applied for no later than the expiry of the three-year period of validity. Updated documentation shall be enclosed with the application. In this event, the approval may be renewed and extended for a further three years.

3.1.4.4 Change in approval conditions

GL Wind shall be informed immediately in writing of any changes in the approval conditions that have a significant influence, such as changes of the production facilities, the production processes, quality control, composition and qualification of the personnel etc. GL Wind shall be notified of any new production procedures in good time before their introduction. GL Wind reserves the right to demand validation tests of such procedures.

3.2 Quality Management

3.2.1 General

(1) Provided the manufacturer operates and applies a quality management (QM) system in accordance with a recognized standard, and this has been evaluated by GL Wind, a portion of the proofs required in this Guideline may be provided within the context of the QM system. A certification of the QM system by an accredited certification body is recognized through the assessment by GL Wind.

(2) Recognition of the QM system obliges the manufacturer to observe the requirements laid down in this Guideline. The obligation for proof of this rests on the company. GL Wind verifies the effectiveness of the system and the work-specific requirements on the basis of the documentation submitted by the company, e.g. within the context of shop approval, and checks it, at its discretion, by random inspections or by witnessing tests within the QM system.

(3) The manufacturer is responsible for ensuring that all tests and inspections laid down in accordance with this Guideline, as well as with any standards, specifications and other regulations that are also applicable, are carried out.

(4) GL Wind shall be notified without request prior to the introduction of any alterations to the QM system or to production processes which can be expected to have a significant effect on product quality. GL Wind reserves the right to check these issues (extraordinary inspection) and to review the approval of the QM system.

(5) Insofar as the certification of the QM system of a certification body was recognized by GL Wind, the manufacturer is under an obligation to inform GL Wind without delay about the loss of the certificate's validity.

3.2.2 Definitions

(1) The definitions of ISO 9000 apply.

(2) Manufacturer is the organizational unit which manufactures a product or independent component of the product, or which assembles and sells a product consisting of subcontracted components.

(3) Quality is the totality of features and characteristics of a product or a service that bear on its ability to satisfy stated or implied needs.

(4) Quality management (QM) comprises all planned and systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality.

(5) The QM system comprises the organizational structure, responsibilities, procedures, processes and resources for implementing quality management.

(6) The quality audit is a systematic and independent examination to determine whether quality activities and related results comply with planned actions, and whether these actions are implemented efficiently and are suitable to achieve the objectives.

(7) The QM system documentation comprises all the documents describing the functions of the QM system. It consists of:

– QM manual

– QM procedures

– QM work instructions

3.2.3 Requirements for the quality management system

(1) As a minimum, the QM system shall meet the requirements of the QM model according to ISO 9001. ISO 9000 and ISO 9004 contain basic principles and recommendations for the implementation of a QM system.

(2) The QM system shall be worked out in detail in writing (see also Section 3.2.2, para 7).

(3) For the manufacturers of products who do not pursue their own development activities, the exclusion of Subsection 7.3 ("Design and Development") within ISO 9001 is permissible.

3.2.4 Certification of the QM system

(1) A certification of the QM system by a certification body accredited according to EN 45012 is, as a rule, regarded as a prerequisite. The general procedure for the certification is described below.

(2) Certification of the QM system follows completion of the following assessments:

– checking of the QM system documentation in relation to the requirements of ISO 9001

– successful completion of the initial audit by the certification body. This includes a check on whether the QM activities set out in the QM system documentation are being implemented.

(3) The validity of the certificate is maintained by means of regular audits. These audits are carried out at set intervals in time (once a year and, if necessary, more often).

(4) The certification is generally valid for three years. It commences with the date of the certificate. On completion of the re-certification (usually comprising the execution of a renewal audit), a certificate may be issued which again is valid for three years. The validity of the certificate necessitates that all the conditions under which it was granted are still being met and no serious shortcomings have arisen in the QM system.

3.3 Materials

3.3.1 General requirements

3.3.1.1 General

(1) Only suitable materials with guaranteed properties (e.g. strength, toughness – at low temperatures if appropriate, cold deformability, suitability for welding, resistance to rot etc.) may be used for the force- and moment-transmitting components of an offshore wind turbine.

(2) Materials chosen shall be matched to the demands to be made on the component, particularly the type of load (shock load, oscillating load) as well as the external conditions (see Section 4.2) and to the design. The materials chosen shall be named clearly and comprehensively in the documents (drawings, parts lists) to be submitted for approval.

(3) All materials not listed in this Section shall be treated in accordance with the relevant standards as regards quality requirements and test conditions. The special environmental and operational conditions of the offshore wind turbine shall be taken into account.

(4) The temperature range and the design temperature TD for the materials to be used is laid down in Section 4.2.4.1. The use of materials outside this temperature range necessitates special consultation with GL Wind, cf. Section 4.2.4.2.

(5) For components which will be employed for the support structure of offshore wind turbines, only materials approved by GL Wind may be used in the case of offshore wind turbines for which an application for project certification has been submitted. Any other structural component may be included into the project certification process optionally.

3.3.1.2 Material tests

(1) The type and extent of material testing depends on the importance of and stress on a component, and on the type and extent of the possible or required post-manufacture tests. Depending on the type of certification, design analyses with all the required material and component tests according to Section 1.2.2.3.3 (A- and B-Design Assessment), an implementation of the design requirements in construction and erection according to Section 1.2.2.3 (Type Certificate) or surveillance during production according to Section 1.2.3.4 (Project Certificate) are required. If nothing else has been determined in detail, the following requirements apply.

(2) Material test documents (statements of compliance) shall correspond to EN 10204. They shall contain the results of the tests laid down in the standards or additionally agreed or demanded on the basis of the requirements. They shall furthermore contain data on the marking of the materials, so as to permit reliable tracing to components.

(3) Material test documents (statements of compliance) for components of an offshore wind turbine within the scope of the project certificate form a part of the surveillance during production by GL Wind.

(4) Within the scope of the A- and B-Design Assessment, inspection certificates in accordance with EN 10204 3.1 shall generally be submitted for the materials of those components that are subject to high static or dynamic loads and that are important for the integrity of the offshore wind turbine (e.g. special and primary structural members according to Section 3.3.2.2). Test certificates of redundant or damage-tolerant components of the same requirement class can, by way of exception, be certified by test reports according to EN 10204 2.2 (e.g. secondary structural members according to Section 3.3.2.2).

(5) For materials of other components or assemblies that are less highly stressed but of particular importance for the functioning of the offshore wind turbine, test reports in accordance with EN 10204 2.2 shall be submitted.

(6) In cases of doubt, the classification of the materials for components or assemblies shall be agreed with GL Wind. In the case of components not obtained with inspection certificates, the scope of the substitute requirements shall be discussed with GL Wind.

(7) For the components listed below, such as (insofar applicable)

– rotor blades
– blade bearings
– rotor hub
– main bearing
– brake
– generator
– rotor shaft and axle journal
– main frame

– blade-pitch, rotor and yaw locks

– yaw bearing

– tower and (optionally) foundation

that are important for the integrity of the offshore wind turbine and also present a high danger potential for human health and life, an implementation of the design requirements in production and erection according to Section 1.2.2.5 (Type Certificate) or surveillance during production according to Section 1.2.3.4 (Project Certificate) is required. For the bolted connections playing a significant role in the transmission of power, the standard of the quality-management measures shall be shown by a description of the QM measures.

(8) GL Wind reserves the right to extend the scope of surveillance during production accordingly for special materials, production processes or components.

(9) In the case of components not obtained with inspection certificates, the scope of the substitute requirements shall be discussed with GL Wind.

3.3.2 Metallic materials

3.3.2.1 General

(1) The materials to be employed for the steel structure of offshore wind turbines are to fulfil the minimum requirements detailed below. Beyond this, other codes and standards shall be observed as far as applicable.

(2) Only suitable materials with guaranteed properties (e.g. strength, toughness – at low temperatures if appropriate, cold deformability, suitability for welding etc.), as mentioned in the next section, may be used for the force- and moment-transmitting components of a offshore wind turbine made of metallic materials. The use of materials according to other regulations or standards requires the consent of GL Wind.

(3) The material tests shall be performed in accordance with Section 3.3.1.2.

(4) For the machinery components such as gearing, bearings, brakes, couplings etc., materials suitable for these components shall be used. Quality requirements and test conditions shall be taken from the relevant standards, taking into account the environmental operational conditions (see Section 4.2). Further special requirements are listed in Chapter 6.

(5) In special cases, limited continued operation of the offshore wind turbine may be accepted by GL Wind in the event of an incipient crack that is growing steadily. The material data to be applied for determining the remaining lifetime of a component shall be agreed with GL Wind before use.

3.3.2.2 Categories of structural members

(1) In the choice of materials for the different members of the steel structure the criteria explained below are to be observed:

– importance of the member within the structure (consequence of failure, redundancy)

– character of load and stress level (static or dynamic loads, residual stresses, stress concentrations, direction of stresses in relation to the rolling direction of the material, etc.)

– design temperature

– chemical composition (suitability for welding)

– yield and tensile strength of the material (dimensioning criteria)

– ductility of the material (resistance to brittle fracture at given design temperature)

– through-thickness properties (resistance to lamellar tearing)

Additional properties, such as corrosion resistance, have to be considered.

(2) Depending on the importance of the structural member and on the type of load and the stress level a structure can be subdivided into the following component categories:

– **Special structural members**
These are members essential to the overall integrity of the structure and which, apart from a high calculated stress level, are exposed to particularly arduous conditions (e.g., stress concentrations or multi-axial stresses due to the geometrical shape of the structural member and/or weld connections, or stresses acting in the through-thickness direction due to large-volume weld connections on the plate surface).

Note:

This applies e.g. to the cans of tubular nodes, ring flanges of tubular towers, thick-walled deck-to-leg and column connections, thick-walled points of introduction or reversal of forces.

– **Primary structural members**
These are members participating in the overall integrity of the structure or which are important for operational safety and exposed to calculated load stresses comparable to the special structural

members, but not to additional straining as mentioned above.

Note:

These are e.g. tower shells of offshore wind turbines, all other tubes of tubular truss-work structures (jacket legs, bracings, piles), girders and beams in the deck, self-supporting platings, etc.

– **Secondary structural members**
These are all structural members of minor significance, exposed to minor stresses only, and not coming under the above categories of "special" and "primary".

Note:

These are e.g. non-structural walls, stairs, pedestals, mountings for cables, etc.

(3) The categories of structural members as per Section 3.3.2.2 para 2 are to be fixed in the design stage and indicated in the construction documentation.

3.3.2.3 Selection criteria of steels

(1) Structural steels are defined depending on their minimum yield strength in the following strength classes:

– **normal strength (mild)** steels with minimum yield strength up to 285 N/mm^2

– **higher strength** steels with minimum yield strength over 285 N/mm^2 up to 380 N/mm^2

– **high strength** steels with minimum yield strength or 0.2 % proof stress over 380 N/mm^2

Note:

In particular for reasons of resistance to fatigue, for special and primary structures, fine grained structural steels suitable for welding with nominal yield strengths not exceeding 355 N/mm^2 are recommended. High-strength steels having nominal yield strengths (or 0.2 % proof stresses) exceeding 460 N/mm^2 may be employed in technically motivated exceptional cases only, with GL Wind's consent.

(2) The strength class chosen for the respective structural member and/or the kind of material corresponding to it are to be indicated in the construction documentation. The same applies to the special requirements possibly having to be met by the material.

(3) Steels with improved through-thickness properties shall be employed where structural members are rigid and/or particularly thick and where high residual welding stresses are to be expected, e.g. due to large-volume single-bevel butt joints or double-bevel butt joints with full root penetration, simultaneously implying high stresses acting in the through-thickness direction of the materials. This will normally be the case where special structural members are concerned.

(4) Depending on the structural member category, the design temperature and the material thickness, all steels to be employed for the structure have to meet the requirements listed in Section 3.3.2.4, in particular those for impact energy. Beyond this, for steels employed for special structural members and for steels employed for primary structural members, to which the criteria listed in Section 3.3.2.3 para 3 apply, proof is to be furnished of the prescribed through-thickness properties; cf. Section 3.3.2.4.6

3.3.2.4 Requirements for steels

3.3.2.4.1 Manufacturing procedures

(1) All steels are to be manufactured by the basic oxygen process, in the electric or open-hearth furnace, or by other methods approved by GL Wind.

(2) The following deoxidation practice has to be applied as a minimum:

– Steels with an impact test temperature of ≥ 0°C shall be semi-killed, i.e. equivalent to the deoxidation method FN according to EN 10025.

– Steels with an impact test temperature of < 0°C shall be fully killed, i.e. equivalent to the deoxidation method FF according to EN 10025.

– Steels with requirements to the through-thickness properties (cf. Section 3.3.2.3 para 3) shall be fully killed and fine grained.

3.3.2.4.2 Supply condition and heat treatment

(1) Steels intended for special and primary structural members shall be supplied normalized / normalized rolled (N), thermomechanically rolled (M) or quenched and tempered (Q) as defined in EN 10225.

(2) The steels have to fulfil the requirements for the general thickness limits prescribed in the standards. Beyond this, the following general thickness limits shall apply:

Table 3.3.1 Carbon equivalent CEV

Steel strength class	Material quality N		Material quality M + Q	
	t ≤ 40 mm	t > 40 mm	t ≤ 40 mm	t > 40 mm
High strength	0.42	0.45	0.42	0.45
Higher strength	0.45		0.43	
Normal strength	0.42		0.38	

Table 3.3.2 Yield strength ratio

Steel strength class	Material quality N		Material quality M + Q	
	t ≤ 16 mm	t > 16 mm	t ≤ 16 mm	t > 16 mm
Normal strength	0.80	0.80	0.80	0.80
Higher strength	0.87	0.85	0.93	0.90
High strength				

– normalized / normalized rolled (N):
up to 150 mm

– thermomechanically rolled (M):
up to 150 mm
for normal and higher strength steels
up to 100 mm
for high strength steels

– quenched and tempered (Q):
up to 150 mm
for normal and higher strength steels
up to 100 mm
for high strength steels

The thickness limits specified in Appendix B have to be observed if required by the construction detail only (see note).

(3) The smallest value shall be applied.

Note:

The thickness limits specified in Appendix B have to be observed e.g. in cases where high local stresses especially in connection with negative influences due to the heat affected zone of a welding may lead to initial cracks, e.g. high residual stresses due to thick butt welds or weldings at tubular nodes, or the surface of gas cuts without subsequent dressing and non destructive testing due to cracks.

For unaffected ground material the general thickness limits as specified above apply, e.g. for the flange body of ring flanges with neck.

Steel structures exceeding the general thickness limits may be employed in technically motivated exceptional cases with additional requirements on material testing, with GL Wind's consent.

3.3.2.4.3 Chemical composition and suitability for welding

(1) The steels shall fulfil the requirements for chemical composition, as determined by heat analysis, prescribed in the standards stated in Appendix 3.A or equal.

(2) The carbon equivalent CEV

$$CEV = C + \frac{Mn}{6} + \frac{Cr+Mo+V}{5} + \frac{Cu+Ni}{15} \qquad (3.3.1)$$

shall not exceed the values prescribed in the relevant standard or the values of Table 3.3.1 (the smaller value shall be applied).

(3) The carbon equivalent

$$P_{cm} = C + \frac{Si}{30} + \frac{Mn+Cu+Cr}{20} + \frac{Ni}{60} + \frac{Mo}{15} + \frac{V}{10} + 5B \qquad (3.3.2)$$

has to be calculated if required by the relevant steel standard, the project specification or if the requirements of Section 3.3.2.4.3 para 5 have to be fulfilled. The prescribed values shall not be exceeded.

Table 3.3.3 Impact energy [1]

Minimum nominal yield strength [2] [N/mm²]		235	275	355	420	460 [3]
Minimum impact energy [J] (Charpy-V-notch test specimen)	Longitudinal: Primary and Secondary Category	27	30 (27) [4]	40 (27) [4]	47	50
	Transversal: Special Category	27	30	40	47	50

1 Average values from 3 specimens; one of the values may be below the average value, but not less than 70 % of the average value.
2 Intermediate values may be interpolated.
3 Steels with nominal yield strengths exceeding 460 N/mm^2 are subject to the requirements of the approved specification.
4 Steels with impact energy values of 27 J may be used as 30 J at 10°C higher test temperature or 40 J at 20°C higher test temperature.

(4) Steels with requirements to the through-thickness properties (cf. Section 3.3.2.3 para 3) shall not exceed the limit value of 0.010 % for sulphur, as determined by heat analysis.

(5) Steels where high residual welding stresses are to be expected (cf. Section 3.3.2.3 para 3) shall not exceed the limit values for the carbon equivalent P_{cm} as follows:

– higher strength steels: 0.24

– high strength steels: 0.22

Note:

High residual welding stresses are normally to be expected at butt joints of thick plates, e.g. monopiles of offshore wind turbines.

3.3.2.4.4 Mechanical properties

(1) The requirements for tensile strength f_{uk}, yield strength f_{yk} or 0.2 % proof stress $R_{p0,2}$ and for elongation at break, as stated in the relevant standards and/or approved materials specifications, are to be observed; see also Section 3.3.2.3 para 1.

(2) Beyond this, for steels with required impact test temperatures ≤ -20 °C, the yield strength ratio f_{yk} / f_{uk} respectively $R_{p0,2} / f_{uk}$ as defined in Table 3.3.2 shall not be exceeded.

3.3.2.4.5 Impact energy

The minimum values listed in Table 3.3.3 apply, proof of which is to be furnished at the test temperature T_T indicated in Appendix 3.B.

3.3.2.4.6 Through-thickness properties

If properties are to be proved in the through-thickness direction (cf. Section 3.3.2.3 para 3) the testing shall be carried out in the final heat treatment condition. Testing is not required for a product thickness below 25 mm. The test shall be in accordance with EN 10164 and the test results shall meet the requirements as follows:

– The through-thickness tensile strength shall be not less than 80 % of the minimum prescribed tensile strength.

– minimum reduction of area Z = 35 %

3.3.2.4.7 Freedom from defects

Regarding their internal defects (flaws), plates and wide flats, for which through-thickness property requirements exist, have to at least meet the requirements as listed in the relevant standards, e.g. EN 10160 quality class S_2 or equivalent.

3.3.2.4.8 Inspections

(1) Unless otherwise fixed or agreed, the requirements as stated in Section 3.3.1.2 shall apply.

(2) Inspections of materials for special and primary structural members of offshore wind turbines for which an application for project certification has been submitted (cf. Section 3.3.1.1 para 5) are to be carried out by GL Wind Surveyors or GL Wind authorized personnel. For materials for secondary structural members delivery with works acceptance test certificate according to EN 10204 3.1 or equivalent may be agreed.

3.3.2.4.9 Identification and marking

(1) All products are to be marked such as to enable their clear identification and correlation to the inspection documentation. The minimum components for marking are to be the manufacturer's symbol, heat No. and steel grade.

(2) Products which cannot be clearly identified will be rejected, unless the properties stipulated can be determined by re-inspection.

3.3.2.5 Cast steels

3.3.2.5.1 General

Where cast steels are intended to be employed for special and primary structural members, relevant materials specifications containing all details required for assessment are to be submitted to GL Wind. For secondary structural members appropriate materials in accordance with the standards may be employed.

3.3.2.5.2 Approval test

Cast steels for special structural members are to be subjected to an approval test by GL Wind. The same applies to primary structural members, where no standardized materials are intended to be employed.

3.3.2.5.3 Supply conditions

All products are to be supplied in heat-treated condition. Heat treatment may comprise:

– normalizing

– normalizing and tempering

– quenching and tempering

3.3.2.5.4 Chemical conditions

The composition of forged and cast carbon and carbon manganese steel grades suitable for welding is to meet the requirements according to Section 3.3.2.4.3. Alloyed steels have to comply with the requirements listed in the approved specification.

3.3.2.5.5 Strength properties

The tensile and yield strength values of forgings and castings are to be adapted to those of the rolled steels employed for the remaining structure. In general, steel forgings and castings with yield strength exceeding 355 N/mm^2 are not to be employed.

3.3.2.5.6 Toughness requirements

Steel forgings and castings are to show adequate resistance to brittle fracture at design temperature. Unless otherwise stipulated, the minimum requirements for impact energy, as listed in Table 3.3.4, apply.

Table 3.3.4 Minimum impact energy requirements[1]

Kind of product	Minimum impact energy (Charpy-V-notch) [Joule] min.	Test temperature [2] [°C]	
		Special struct. members	Primary struct. members
Forgings	longitudinally: 40 transversely: 30	– 40	– 20
Steel casting	30	– 40	– 20

1 Products employed for secondary structural members are subject to the requirements listed in the standards.

2 If the design temperatures are below – 40 °C (special structural members) or – 20 °C (primary structural members), special requirements are to be agreed.

3.3.2.5.7 Scope of testing

(1) Unless otherwise stipulated in the approved specification, the products are to be combined into heats of up to 10 t each and subjected to tensile and notched bar impact tests.

(2) For cast components that are predominantly dynamically stressed, quality grade 3 in accordance with DIN 1690 T2:1985 in conjunction with EN 12681:2003 (Radiographic test), EN 12680-2:2003 (Ultrasonic test), EN 1371-1:1997 (Dye penetration test) and EN 1369:1997 (Magnetic crack detection test) is the least favourable permitted. The quality grades shall correspond to the assumptions of the computational analyses as per Section 5.3.4.4.3.

(3) The removal of faults through fabrication welding or repair welding is permissible only with specifications approved by GL Wind. The qualification of the welding workshop and the welder performing the work shall be verified in accordance with Section 3.4.2.

3.3.2.5.8 Material certificates

Products to be employed for special and primary structural members are to be tested in a GL Wind Surveyor's or GL Wind authorized personal's presence. For products intended for secondary structural members supply with inspection certificate according to EN 10204 3.1 or equivalent may be agreed.

3.3.2.6 Stainless steels

(1) Stainless steels shall be selected with respect to their resistance to corrosion, taking into account the processing conditions (e.g. welding). If nothing else has been agreed for individual cases, suitable steels, e.g. according to EN 10088 (Stainless steels) and EN 10213-4 (Steel castings for pressure vessels) may be selected in the case that no delivery is to take place on the basis of a specification approved by GL Wind.

(2) Only those grades suitable for welding with guaranteed resistance to intercrystalline corrosion may be used for welded structures. If it is intended to weld castings without post-weld heat treatment, only grades of cast steel that are corrosion-resistant in this condition as well shall be used, e.g. cast steels stabilized with Nb or containing not more than 0.03 % C.

(3) Other grades of cast steel conforming to other standards or material specifications may be used, provided that they are comparable to the grades of cast steel described in EN 10213-4 with regard to their delivery condition, heat treatment, chemical composition, mechanical properties and weldability, and provided that proof has been furnished of their suitability for the intended application. For this purpose, a first-time suitability test may be required.

(4) The limits for the lowest design temperatures according to Section 3.3.1.1 shall be observed.

3.3.2.7 Forging steels

Additional notes on selecting suitable materials can also be taken from the Guideline of GL (II, Part 1, Chapter 2, Section 3 [3.1]).

3.3.2.7.1 Standards

Forgings and bar stock for structures and components as per Chapters 6 and 7 shall be selected to EN 10083 in accordance with the requirements; in the case of larger cross-sections (i.e. greater than 100 mm / 250 mm; see EN 10083) according to Stahl-Eisen-Werkstoffblatt (Steel/Iron Materials Data Sheet) SEW 550. Further notes on selecting suitable materials can also be taken from the Guideline of GL (II, Part 1, Chapter 2, Section 3 [3.1]). For tempering and case-hardening steels, e.g. for the manufacture of gearwheels and pinions, the standards EN 10083 and 10084 apply; for stainless steels EN 10088 applies. Forgings and bar stock in accordance with other standards or manufacturers' material specifications may be used if properties equivalent to those in the standards listed above can be guaranteed, and if proof has been furnished of their suitability for the intended application. For this purpose, a first-time suitability test may be required.

3.3.2.7.2 Production processes

(1) Forging steel shall be produced by an oxygen steel-making process in an electric or Siemens-Martin furnace or by other processes approved by GL Wind, and shall be cast killed. On request, GL Wind shall be informed of the melting process.

(2) Enough shall be cut off at the top and bottom of the ingots to ensure that the forgings are free from any harmful segregations. These are all inhomogeneities which might impair the required quality characteristics.

(3) As far as possible, the pieces shall be forged to the dimensions of the finished part, taking into account an appropriate machining allowance. Excessive machining to produce the final shape, which might impair the quality characteristics by for example exposing the core area, is not allowed. In the case of stepped shafts, forged starting material shall be used for turned grooves larger than 1/10 of the outer diameter. The degree of deformation shall be so selected that the core zone of the forging is adequately forged through. The total degree of deformation shall not be less than 3.5 : 1.

(4) Collars and hollow pieces shall be made from ingot or cogged ingot sections competently punched, bored or pierced before the parts are reamed or rolled over a suitable mandrel.

3.3.2.7.3 Delivery condition, heat treatment

(1) All forgings shall be heat treated in a manner appropriate to the material. The treatment shall be carried out in suitable furnaces, maintained effectively and regularly. These shall be equipped with means for controlling and indicating the temperature. The dimensions of the furnace shall make it possible to bring the entire forging uniformly to the required annealing temperature. Where, in the case of very large forgings, the furnace dimensions do not permit total normalizing in one step, alternative heat treatment processes shall be agreed with GL Wind.

(2) All hot-forging work shall be completed before the final heat treatment. If a forging has for any reason to be reheated for further hot working, the final heat treatment shall be repeated.

(3) If a forging is hot- or cold-straightened after final heat treatment, subsequent stress-relieving to remove the residual stress may be demanded.

(4) Forgings which after forging undergo large changes in cross-section by machining may be hardened and tempered only after adequate pretreatment.

The weight at hardening and tempering shall not be more than 1.25 times the finished weight.

3.3.2.7.4 General forging quality

(1) All forgings shall be free from any faults which may impair use and processing to more than an insignificant extent, e.g. flakes, cracks, shrinkage holes, segregations, peripheral blowholes and major non-metallic inclusions. Forgings to be delivered unmachined shall have a smooth surface appropriate to the production process.

(2) Small surface faults may be removed by pointing and/or grinding. Complete removal of the fault shall be demonstrated by a magnetic crack detection test or a dye penetration test.

(3) Proof of the chemical composition:
The manufacturer shall determine the chemical composition of every melt and submit a corresponding certificate in accordance with Section 3.3.1.2. This certificate shall state the chemical composition of the melt which characterizes the steel grade. If there is any doubt as to the composition, or if the connection between certificate and forging cannot be proved, a product analysis shall be carried out.

3.3.2.7.5 Mechanical-technological testing

(1) Tensile test:
The mechanical properties shall be checked by means of the tensile test, in which the tensile strength, the yield point or 0.2 % elastic strain limit, the elongation at fracture and the reduction in area at fracture are to be determined.

(2) Notched-bar impact-bending test:
A notched-bar impact-bending test shall be carried out if this is stated in the standards. Unless otherwise specified, the notched-bar impact work shall be verified on every forging or test piece by notched-bar impact-bending tests.

(3) Sampling:
As a rule, the taking of samples from forgings shall be arranged by forging-on sample sections outside the forging dimensions. The sample section may generally be separated from the forging only after the final heat treatment. Subsequent stress relieving need not be taken into account in this connection. Premature separation is permitted only if unavoidable for production reasons. In this event, the forging and the sample section shall be heat treated together.

(4) In deviation from this provision, in the case of series-production drop forgings, the samples may be taken from items surplus to requirements or separately forged sample sections; these shall belong to the same melt and be heat treated together with the associated items under test. The test batch sizes laid down in the standards apply as regards sample selection.

(5) All sample cut-offs shall be forged with the same degree of deformation to that cross-section which is also representative of the forging's typical cross-section. The sample cut-offs shall be large enough to provide specimens for any test which might be necessary as well as those required for any repeated tests.

(6) All sample cut-offs and test specimens shall be so marked that they can be clearly assigned to the forgings or test units they represent. As a rule, the samples shall be taken from a point of the sample cut-off or test specimen lying one-third of the diameter or thickness below the surface.

3.3.2.7.6 Non-destructive testing

(1) If surface crack testing is required, it shall preferably be effected by means of the magnetic crack detection method, except in the case of austenitic steels. The tests shall generally be carried out on forgings which have undergone final heat treatment, if possible after machining. If current flow is being used, care shall be taken that no penetration points are caused by the contact electrodes. The effective tangential field intensity shall be at least 2 kA/m (25 Oe) at the workpiece surface, but shall not exceed 5 kA/m (62.5 Oe).

(2) Surface crack tests using the dye penetration method are possible in exceptional cases (and for austenitic steels). The tests shall be carried out with a testing-medium combination comprising penetrant, intermediate cleanser and developer in accordance with the testing-medium manufacturer's instructions.

(3) Ultrasonic testing shall preferably be carried out while the piece still has a simple geometric shape, the pieces to be tested having been at least normalized. Provided shape and size of the piece permit, ultrasound shall be passed through it radially and axially. Technical data relating to the test, such as method, type of appliance, testing head, appliance adjustment, recording threshold and error margins shall be laid down and made known by the manufacturer. The qualification of the tester shall be demonstrated. The company shall prepare a report on the ultrasonic testing, containing the details of the process listed above and an assessment of the readings.

3.3.2.8 Cast iron

(1) For structures and components in accordance with Chapters 6 and 7, cast iron with either spheroidal graphite (EN-GJS) according to EN 1563:2003 or lamellar graphite (EN-GJL) according to EN 1561:1997 may be used, depending on the mechanical properties required. Furthermore, the provisions set out in EN 1559-1:1997 and EN 1559-3:1997 shall be observed.

(2) Without additional verification, cast iron with a tendency for brittle fracture (EN-GJS with a high percentage of pearlite; EN-GJL) shall not be selected for components that play a significant role in the transmission of power and are under high dynamic stress, e.g. rotor hubs, gearbox housings with integrated rotor bearings, castings of rotor bearing and machine foundations.

(3) For cast iron with spheroidal graphite, the manufacturing processes shall ensure that 90 % of the graphite in the spheroidal form V and VI (according to ISO 945:1994) has been segregated. For the determination of the microstructure, ISO 945 may be applied. For the ferritic types, the pearlite proportion within the grain structure of the metallic base material shall not exceed 10 %.

(4) The use of other types of cast iron according to other standards or material specifications shall be agreed with GL Wind.

(5) For the assessment of the casting quality of components with consideration of internal flaws, non-destructive testing methods such as ultrasound (according to EN 12680-3:2003) and/or radiographic tests (according to EN 12681:2003) shall be applied. For radiographic tests, the radiation source shall be selected in relation to the maximum wall thicknesses in accordance with EN 444. If no satisfactory rear-panel or error echo is obtained for the ultrasonic test, a combination with the radiographic test shall be performed.

(6) For components that are predominantly dynamically stressed and made of cast iron with spheroidal graphite, a quality level requirement shall be set according to EN 12680-3:2003 (Ultrasonic test) and VDG instruction sheet P-541 (Verein Deutscher Gießereifachleute) in conjunction with EN 12681:2003 (Radiographic test), EN 1369:1997 (Magnetic crack detection test) and EN 1371-1:1997 (Dye penetration test). These shall correspond to the assumptions of the computational analyses as per Section 5.3.4.4.3.

(7) The flaw types blowholes (flaw class A), non-metallic inclusions (B) and enclosed shrinkage holes (C) shall be classified according to their quality after the radiographic test (see also Table 3.3.5). Here the worst acceptable is quality level 3 according to VDG instruction sheet P-541. Dross (Z) or shrinkage holes (C) cut by mechanical processing are fundamentally inadmissible in highly stressed areas and shall be removed by mechanical means, taking into account the permissible reduction in wall thickness. All other types of flaws shall, if applicable, be assessed separately and possible countermeasures shall be coordinated with GL Wind.

Table 3.3.5 Allocation of the flaw class to wall thicknesses and quality levels for radiographic testing of EN-GJS on the basis of VDG instruction sheet P-541

Quality level	Flaw classes		
	Wall thickness up to 100 mm	Wall thickness > 100 – 250 mm	Wall thickness > 250 – 400 mm
1	A1, B1, C1	A1, B1, C2	A1, B1, C3
2	A2, B2, C2	A2, B2, C3	A2, B2, C4
3	A3, B3, C4	A3, B3, C5	A3, B3, C6

(8) For components that are predominantly dynamically stressed and made of cast iron with spheroidal graphite, a quality level requirement shall be set according to EN 12680-3:2003 for indications to be reported. Here the worst acceptable is quality level 3.

(9) The removal of sample cut-offs or test specimens for determining the mechanico-technological properties and the grain and graphite structures, and for determining the casting quality, shall be so executed that the typical characteristics of the component are registered properly. In many cases, it is necessary to prescribe varying sampling points on the component.

(10) All sample cut-offs and test specimens shall be so marked that they can be clearly assigned. The corresponding specifications shall be submitted to GL Wind.

(11) The test results shall be documented in accordance with Section 3.3.1.2.

(12) The removal of faults through fabrication welding or repair welding is permissible only with approved procedure testing. With regard to the qualification of the welding workshop and the welder performing the work, Section 3.4.2 shall be observed. Prior to the start of welding work of this type, the welding process, the heat treatment and the scope of the tests shall be agreed with GL Wind. Mixed welding of dynamically stressed components is inadmissible.

(13) The limits for the lowest design temperatures according to Section 3.3.1.1 shall be observed.

3.3.2.9 Aluminium alloys

(1) Only aluminium alloys that are suited to the intended purpose and have been approved by GL Wind shall be used. If applicable, proof of suitability for welding shall be furnished for the alloys.

(2) As regards fatigue strength and sensitivity to notches, aluminium is comparable to high tensile steels, and therefore demands careful design and manufacturing.

(3) Proper processing and suitable corrosion protection shall be applied in order to prevent contact corrosion and particularly corrosion in a marine atmosphere.

3.3.2.9.1 Wrought alloys

(1) For the chemical composition of the aluminium alloys, the Euronorm EN 573 shall be observed, for the mechanical properties EN 755-2, and for the definition of the material conditions of semifinished products EN 515.

(2) Compliance with the tolerances and the requirements for the general condition lies within the responsibility of the manufacturer.

3.3.2.9.2 Cast alloys

(1) The chemical composition and mechanical properties of castings made of aluminium and aluminium alloys shall comply with the values given in Euronorm EN 1706.

(2) All castings shall be free from any internal or external faults which may impair use and competent processing to more than an insignificant extent.

(3) If defects are to be removed by welding, the manufacturer shall compile a welding specification and obtain the consent of GL Wind. Furthermore, in the case of doubts concerning the freedom from defects of the castings, non-destructive tests shall be initiated by the casting manufacturer and performed at the relevant points. Repaired defects as well as areas that are critical from the viewpoint of casting technology shall be included in the tests.

(4) The results of the tests shall be documented in accordance with Section 3.3.1.2.

3.3.3 Fibre-reinforced plastics (FRP)

3.3.3.1 Definitions

(1) Fibre-reinforced plastics are heterogeneous materials, consisting of a cured reaction resin compound as matrix with fibrous reinforcing materials embedded in it.

(2) The reaction resin compound is a multiple-component mix, consisting of reaction resin and hardener, plus possibly additives.

(3) Reinforcing materials are fibres of various materials processed to form various reinforcement products, depending on the intended use. A distinction is made between:

– homogeneous:
  The reinforcement product contains fibres of one single material.

– inhomogeneous:
  The reinforcement product contains fibres of diverse materials, though individual layers or directions in one layer may be homogeneous.

(4) Laminate is produced by layerwise arrangement of reinforcement products with reaction resin compounds.

(5) Sandwich laminate comprises layers of laminate bonded together by an intermediate core of lightweight material.

(6) Prepreg is a reinforcing material pre-impregnated with reaction resin compound, and can be worked without having any more resin compound added. A distinction can be made between wet and dry prepregs, where the wet prepregs are often known as “indoor prepreg”, since they are produced at the workshop of the component manufacturer.

3.3.3.2 General

(1) The properties of fibre-reinforced plastics are strongly influenced by their processing. For this reason, the requirements for manufacturers set out in Section 3.4.4 shall be observed.

(2) Notwithstanding the availability of approvals or confirmations of the quality of individual components (resin compound, reinforcing material, adhesive etc.), it shall be checked that the properties of the corresponding composite material comply with the design values.

3.3.3.3 Reaction resin compounds

(1) Depending on the purpose and thus on the requirements, a distinction shall be made between laminating resins and gelcoat resins. For the combination of gelcoat and laminating resins, compatibility shall be demonstrated unless the basic resins are the same.

(2) Gelcoat resins are intended to protect the laminate against external damage and influences. In cured condition, they are therefore required to have good resistance to moisture, chemical attack, UV radiation, marine and industrial environments, and to exhibit a high degree of resistance to abrasion and a low water absorption capacity as well as a high elasticity. The only additives permitted are, to a limited extent, thixotropic agents and pigments.

(3) Laminating resins shall have good impregnation properties in the working state, whereas in the cured state they shall be moisture-resistant and highly resistant to ageing. These properties shall also be provided with the permitted additives and fillers.

(4) In the case of reaction resin compounds, all additives to resins (catalysts, accelerators, inhibitors, fillers and pigments) shall be harmonized with the reaction resin and be compatible amongst themselves and with it, whereby total curing of the resin shall be guaranteed. The additives shall be dispersed in the resin compound with care and in accordance with the manufacturer's instructions. Catalysts which initiate the hardening process and accelerators or inhibitors which control the working time (pot life) and curing time shall be used in accordance with the manufacturer's processing guidelines.

(5) In the case of epoxy resins, the resin and hardener constituents shall, as far as possible, be mixed exactly to the manufacturer's regulations. As a rule, only the resin/hardener combinations prescribed by the manufacturer are permissible.

(6) All systems which are cured at room temperature (cold-curing systems) shall be matched in such a way that satisfactory curing is guaranteed at temperatures from 16 °C to 25 °C. Cold-curing systems intended to cure at other temperatures and hot-curing systems may only be used in accordance with a production specification approved by GL Wind.

(7) Fillers shall not significantly impair the properties of the resins. The type and amount of filler may not lead to the resin properties seriously dropping below the nominal properties. In general, the proportion of fillers in the laminating resins shall not exceed 12 % by weight (including a maximum of 1.5 % by weight of thixotropic agent). If the manufacturer has laid down a lower figure, however, this shall apply. The proportion of thixotropic agent in the gelcoat resin may not exceed 3 % by weight.

(8) Pigments shall be weatherproof and consist of inorganic or light-resistant organic colouring substances. Their maximum permitted proportion shall not exceed the figure laid down by the manufacturer, or else 5 % by weight.

3.3.3.4 Reinforcing materials

(1) Commonly used reinforcing materials with continuous filaments of glass, carbon fibre and aramide are available in various forms:

– Rovings:
  A large number of roughly parallel fibres bundled together, twisted or untwisted. In spray moulding processes, they can be used as cut rovings.

– Mat:
  Random layering of continuous filaments or strands of fibres at least 50 mm long, bonded together by means of a binder.

– Fabric:
  Fibre strands woven together, the conventional weave types for textiles such as linen, satin, twill or sateen being employed. Warp and weft may differ as regards material and/or thread count.

– Complex of fibres:
  Unidirectional layers of fibres randomly arranged one above the other, and either glued or tacked to one another or to mats by thin fibre strands. There may be differing materials and/or thread counts in the individual layers.

(2) The fibres shall be given protective and/or adhesion-improving coatings (in the case of glass fibres "size", in the case of carbon fibres "finish", in that of aramide fibres "avivage"), matched to the intended laminate resin. This is necessary to ensure an adequate ageing- and moisture-resistant bond between the fibres and laminating resin.

(3) For glass fibres, aluminium-boron-silicate glass (alkaline-oxide content < 1 %) shall preferably be used, for instance E-glass in accordance with VDE 0334/Part 1 – Section 4. Other types of glass, such as R- or S-glass, may also be permitted by GL Wind if suitable.

(4) For load-bearing structures, the average filament diameter of the glass fibres shall not exceed 20 µm without further proof (see Section 5.5.4, para 4).

(5) In the case of carbon fibres, pitch-based and “heavy tow” products are not permissible without further proof.

Note:

Heavy tow fibres are carbon fibres with a filament count of 48 K to 320 K, exhibiting a carbonization grade less than 99 %.

3.3.3.5 Core materials

(1) Core materials shall be proved to be suitable for the intended purpose and shall not impair the curing of the laminating resin compound. Especially for rigid plastic foam, the permissible material temperature may not be exceeded when curing the laminating resin.

(2) Core materials other than those listed below may be used with the consent of GL Wind, provided they are suitable for the intended purpose.

(3) Rigid plastic foam used as core material for sandwich laminates or as reinforcing webs shall have a closed-cell structure and shall be highly resistant to the laminating resin and the adhesive, as well as to ageing, and marine and industrial environments. Other requirements are a low water absorption capacity and a sufficient raw density.

(4) End-grain balsa intended for use as core material for sandwich laminates shall meet the requirements below. It shall

– be treated with fungicide and insecticide immediately after felling

– be sterilised and homogenized

– be kiln-dried within ten days of felling

– have an average moisture content of 12 %.

Due to the possible water absorption of the end-grain balsa, it shall be completely sealed in the component.

3.3.3.6 Prepregs

(1) Fibre reinforcement pre-impregnated with laminating resin compound (prepregs) shall meet the demands on its constituent parts. Furthermore, the resin content shall not be less than 35 % by volume, and there shall be adequate adhesiveness at working temperature.

(2) For dry prepregs, the storage conditions and the shelf life shall be specified on the packaging. Prepregs shall no longer be used once the expiry date set by the manufacturer has passed, unless their suitability for further use has been verified by appropriate tests.

(3) For reinforcement materials with intermediate layers of reaction resin, similar requirements apply.

3.3.3.7 Adhesives

(1) Two-component reaction adhesives shall preferably be used, if possible based on the laminate resin compound.

(2) Where hot-curing adhesives are used, the maximum permissible thermal stress on the materials to be bonded may not be exceeded. The same applies for single-component hot-melting adhesives.

(3) The adhesives shall be used in accordance with the manufacturer’s instructions. They shall not affect the materials to be bonded and shall have a good resistance to moisture and ageing. The effect of temperature on the strength of the adhesive bond should be as low as possible.

(4) The adhesives shall remain servicable up to at least 60 °C (see Section 5.5.2.2, para 4).

3.3.3.8 Approval of materials

(1) If FRP components are manufactured for mounting on or installation in offshore wind turbines and if an application for project certification has been submitted, then prior approval by GL is required for all materials. The approval conditions are specified in [3.2]. Approval by other authorities may be accepted in certain cases after consultation with GL Wind, provided the scope of the tests on which the approval is based meets the requirements.

(2) Before manufacture of the components, the necessary material approvals shall be submitted in the above case. If none or not all of the necessary approvals are available, proof of the properties of the base materials may in exceptional cases, and with the agreement of GL Wind, be obtained in the context of the material tests required for the laminates of the component.

3.3.4 Wood

3.3.4.1 Types of wood

Quality grade I pine wood of class S 13 according to DIN 4074 and quality grade I according to DIN 1052 or wood with equivalent strength properties shall be used, with a laminar thickness after planing which does not exceed 33 mm. For solid wood rotor blades, the board width shall not exceed 22 cm.

3.3.4.2 Material testing and approval

(1) All glue and coating components and all wood preservatives used in the manufacture of wooden rotor blades shall be approved in advance by GL. Approval shall be applied for from GL by the material manufacturer or supplier.

(2) Approval will be granted if testing under the surveillance of GL or a report from an independent testing body recognized by GL proves that the material meets all the requirements of GL.

(3) The proofs shall be submitted before production commences.

3.3.4.3 Glues and adhesives

(1) Glues and adhesives used in the manufacture of wooden rotor blades shall be compatible with the wood constituents, wood preservatives and coating materials. They shall be resistant to ageing and fatigue in the face of sharp climatic variations.

(2) Only resorcinol resin glues or epoxy resins shall be used. These shall have passed the test in accordance with DIN 68141.

(3) Synthetic resin glues and adhesives, their constituents plus coating materials shall no longer be used once the expiry date set by the manufacturer has passed, except with the consent of the manufacturer and GL Wind.

3.3.4.4 Surface protection

(1) The surface protection shall ensure effective protection against moisture. The materials used shall exhibit high elasticity, shall be impermeable to water and shall have little tendency to absorb steam. They shall have good resistance to UV radiation and ageing and to marine, tropical and industrial environments. Furthermore, adequate resistance to abrasion shall be guaranteed. Compatibility with the wood constituents and preservatives shall be ensured. Fabric inserts may be used to prevent cracking.

(2) For submerged structures made of FRP or structures in the splash zone, additional requirements have to be considered in consultation with GL Wind.

3.3.4.5 Wood preservatives

Wood preservatives used shall have been proved to be compatible with glues and adhesives in accordance with DIN 52179. In addition, compatibility with the surface-protection materials shall be ensured.

3.3.4.6 Mechanical fasteners

Fasteners securing the wooden blades to the rotor hub shall be made from materials which guarantee long-term operation. If metal components are used, the design shall be such that it takes into account the great differences in stress and strain behaviour between these components and wood.

3.3.5 Concrete – plain, reinforced or prestressed

3.3.5.1 General

(1) The sub-sections below apply to site-mixed concrete, ready-mixed concrete or factory-made concrete.

(2) They refer to the load-bearing and bracing components of non-reinforced, reinforced and prestressed concrete with a close-grained texture.

3.3.5.2 Standards

(1) Recognized international or national standards relating to concrete structures shall be used as a basis for design, calculations and construction.

(2) A design concept based on partial safety factors for the assessment (e.g. Eurocode 2, Part 1 [3.3] or DIN 1045-1:2001-07) is favourized. Other concepts can be chosen as well, but it has to be ensured that only one uniform safety concept is to be used throughout.

(3) For example the following acknowledged standards and regulations may be used:

– ACI Standard 318-02, Building Code Requirements for Structural Concrete

– ACI Report 357 R-84 (97), Guide for the Design and Construction of Fixed Offshore Concrete Structures

– British Standard 8110, The Structural Use of Concrete

– FIP Recommendations, Design and Construction of Concrete Sea Structures

(4) The standards intended to be used for design, analysis and construction are to be indicated to GL Wind in good time and their application shall be approved by GL Wind in each individual case.

Table 3.3.6 Strength classes for concrete according to DIN 1045-1: 2001-07

Strength class	C 12/15	C 16/20	C 20/25	C 25/30	C 30/37	C 35/45	C 40/50	C 45/55	C 50/60	C 55/67	C 60/75	C 70/85	C 80/95	C 90/105	C 100/115
$f_{ck,cyl}$ [1] N/mm^2	12	16	20	25	30	35	40	45	50	55	60	70	80	90	100
$f_{ck,cube}$ N/mm^2	15	20	25	30	37	45	50	55	60	67	75	85	95	105	115

[1] $f_{ck,cyl}$ is identical to the strength class f_{ck} used in the Eurocodes.

Table 3.3.7 Conformity criteria for the compression strength according to EN 206-1

Production	Number "n" of test results for the compression strength of each series	Criterion 1	Criterion 2
		Mean Value of "n" results (f_{cm}) [N/mm^2]	Each test result (f_{ci}) [N/mm^2]
Primary production	3	$\geq f_{ck} + 4$	$\geq f_{ck} - 4$
Continuous production	15	$\geq f_{ck} + 1.48\ \sigma$	$\geq f_{ck} - 4$

(5) If the acknowledged standards do not cover all the areas of design, analysis and construction, additional appropriate standards shall be incorporated. This applies in particular to manufacture, testing and quality control of materials. Exceptions can be agreed with GL Wind.

(6) Principles of construction and design, material qualities or methods of stress analysis differing from those in the acknowledged standards may be adopted if their practicability is proven by tests, experiments or theoretical investigations, and if it is shown that they satisfy the safety requirements of this Guideline.

3.3.5.3 Raw materials for concrete

3.3.5.3.1 Cement types

The types of cement shall comply with EN 197 or DIN 1164 or the respective national standards or regulations applying where the concrete is being used.

3.3.5.3.2 Concrete aggregate

(1) Aggregates shall comply with the requirements of the national standards or the regulations applying where the concrete is being used (e.g. DIN 4226-1). They shall not contain harmful constituents in such quantities that the durability of the concrete is adversely affected or corrosion of the reinforcing material is initiated.

(2) Aggregate with alkali-sensitive constituents may not be used as a rule.

(3) Maximum grain size and grading curve of the aggregate shall be selected in accordance with EN 206.

(4) The combined aggregate should be as coarse-grained and dense-graded as practicable. The maximum particle size is to be selected as a function of the spacing between the reinforcing bars and of the concrete cover so that placing and compaction of the concrete is possible.

(5) Aggregates with continuous and discontinuous grading curves (gap gradings) may be used.

3.3.5.3.3 Added water

(1) The added water shall not contain harmful constituents in such quantities as to impair setting, hardening and durability of the concrete or to initiate corrosion of the reinforcing material. In Europe, drinking water from public supplies is in general suitable for making concrete.

(2) Where there is any doubt about the suitability of the water, investigation will be necessary.
Sea water may be used only in special cases for plain concrete, agreement on this is required.

3.3.5.3.4 Admixtures

(1) Concrete admixtures may be used for concrete and cement mortar only if tests have shown that they do not produce adverse changes in important properties of the concrete nor impair the corrosion protection of the reinforcement. Special suitability tests for the concrete to be made may in individual cases be required by GL Wind.

(2) Chlorides, chloride-bearing or other steel-corrosion-promoting materials may not be added to reinforced or prestressed concrete.

3.3.5.3.5 Additives

Additives may only be applied to the concrete mix in such quantities that they do not impair the durability of the concrete or result in corrosion of the reinforcement.

3.3.5.4 Building materials

3.3.5.4.1 Concrete

(1) The composition of concrete shall be so chosen that all requirements regarding the properties of the green and the set concrete are met, including consistency, bulk density, strength and durability plus protection of steel reinforcement against corrosion. The composition shall be adjusted to the workability necessary for the construction method adopted.

(2) The concrete is classified according to its compressive strength at the age of 28 days into strength classes in accordance with e.g. DIN 1045-1 (see Table 3.3.6). The compressive strength is determined with the aid of standard test procedures (e.g. in accordance with EN 206) applied to either concrete cylinders or cubes with an edge length of 15 cm.

(3) This Guideline is based on the characteristic cylinder compressive strength (28-day-strength) fck, i.e. fck is identical to fck,cyl as in Table 3.3.6. It is defined as the strength figure above which 95 % of the population of all possible strength measurements of the concrete in question may be expected to lie (95 % fractile). This shall be verified with a confidence level of 95 %.

(4) Conformity criteria for samples as stated in EN 206-1 are given in Table 3.3.7. Conformity is proven if both criteria are fulfilled. Further requirements can be obtained from EN 206-1 [3.1].

(5) Concrete exposed to sea water should be of strength class C 35/45 as a minimum.

(6) It shall be considered that additional requirements are given for high strength concrete in the relevant codes (e.g. EN 206-1). In EN 206-1, high strength concrete is defined as concrete of a strength class of more than C 50/60 in case of normal or heavy weight concrete, respectively more than LC 50/55 in case of light weight concrete.

(7) The ultrafines content of concrete consisting of cement and particles up to 0.25 mm is to be so selected that the concrete is properly workable and achieves a closed texture.

(8) The concrete should contain so much cement that the required compressive strength, and in reinforced and prestressed concrete an adequate degree of protection of the steel against corrosion can be achieved.

(9) The water/cement ratio shall not exceed 0.45.

(10) Concrete having a low temperature of hydration should be used in massive sections.

(11) Consistency of fresh concrete is to be specified before the start of work, having regard to the conditions for placing and working the concrete.

3.3.5.4.2 Concrete with special properties

(1) Concrete which is exposed to frequent and abrupt alternations of freezing and thawing in a moisture-saturated condition should have high frost resistance. This requires frost-resistant aggregate and waterproof concrete. If the concrete frequently comes into contact with de-icing salts or similar chemicals, sufficient quantity of an air-entraining additive shall be added so that the mean air content in the fresh concrete makes up approximately 4 % of the volume.

(2) The resistance of concrete to chemical attack depends to a great extent on its density and its water/cement ratio. If there is a strong likelihood of chemical attack the concrete should be dense enough to ensure that the maximum depth of water penetration under test (e.g. to DIN 1048) is not larger than 3 cm.

(3) For concrete which is exposed to attack by water containing more than 400 mg of SO_4 per litre, cement with high sulphate resistance shall be used.

(4) Concrete for placing under water (underwater concrete) should flow as a coherent mass so as to obtain a closed even texture without compaction. It is preferable to use continuous gradings and a sufficiently high content of ultrafine particles (see also Section 3.4.8.5).

3.3.5.4.3 Concrete-reinforcing steel

(1) This sub-section applies to concrete-reinforcing steel, from coil and mats, used as reinforcement in concrete structures.

(2) Diameter, surface characteristics, strength properties and marking of concrete reinforcing steels shall correspond to the standards (e.g. ENV 10080, DIN 488). If welding is to be carried out on concrete-reinforcing steels, only grades suitable for this may be used (e.g. according to DIN 488, Part 1).

3.3.5.4.4 Prestressing steel and prestressing procedure

(1) This sub-section applies to wires, rods and braids that are used as prestressing elements in concrete structures.

(2) The properties of the prestressing steel shall correspond to the standards (e.g. EN 10138) and shall be proved by certificates from the manufacturer. In particular, data and test results concerning the composition of the steel, mode of production, stress-strain characteristic, elastic limit, yield point, tensile strength, fatigue strength and creep limit shall be submitted. This documentation may be replaced by a type approval of the relevant authorities.

(3) For the prestressing procedure (anchors, couplings, grout pipes, etc.), a type approval according to the applicable standards is generally required.

3.3.5.4.5 Grouting mortar

(1) The grouting mortar is made from cement, water and admixtures/additions, its function being to ensure a good bond between prestressing elements and enclosing body and to protect the enclosed steel against corrosion, by enveloping the elements and filling up all the spaces inside the sheath.

(2) As a rule, only Portland cement shall be used. Drinking water from public supplies is in the great majority of cases suitable for making grouting cement. Admixtures and additives shall comply with the standards.

(3) Sea water shall not be used. The additives shall be tested for suitability.

3.3.5.4.6 Steel for fixtures and prestressed high-tensile bolts

(1) Fixtures are normally made from S 235 or S 355 (see Section 3.3.2) in compliance with standards (e.g. EN 10025).

(2) Prestressed high-tensile bolts shall be used in accordance with the standards. Only bolts in strength classes 8.8 or 10.9 shall be used.

3.3.5.5 Durability of the concrete

(1) In order to produce a concrete of adequate durability, which protects the reinforcing steel against corrosion and adequately withstands the external and operating conditions to which it is exposed during the anticipated working life of the structure, the following factors shall be taken into consideration:

- selection of suitable raw materials that do not contain any harmful constituents which may impair the concrete’s durability and cause corrosion of the reinforcing material
- selection of a suitable composition for the concrete so that it
  - meets all the criteria laid down for the properties of green and set concrete
  - can be so poured and compacted that a dense concrete covering layer is formed
  - withstands internal influences
  - withstands external influences, e.g. environmental ones
- attacks of a mechanical nature
- mixing, pouring and compacting of the green concrete so that the raw materials are distributed evenly throughout the mixture and do not bleed, and a close-grained texture for the concrete is achieved
- curing of the concrete so that in particular the portion near the surface (covering layer) attains the properties to be expected from its composition

(2) Information on defining the environmental conditions for the design can be obtained from e.g. DIN EN 206.

(3) All these factors shall be controlled and verified by the constructor, subcontractor or supplier within their respective zones of responsibility, in an overall context of their respective internal surveillance (production control).

3.4 Production and Testing

3.4.1 Fabrication and construction of steel structures

3.4.1.1 General

(1) Fabrication, other than welding, shall be in accordance with a national or regional fabrication specification that complements the design code used. Fabrication tolerances shall be compatible with design assumptions, except where specific service requirements dictate the use of more severe control over the deviations assumed in the design.

(2) This sub-section defines the minimum requirements for the fabrication and construction of steel structures. These requirements analogously apply to work carried out at the steel structure prior to or during transport, installation and operation and for repairs. For welding, see Section 3.4.2; for inspection and testing, see Section 3.4.3.

3.4.1.2 Standards, specifications

The application of relevant standards, codes, guidelines, specifications, etc. may be agreed to by GL Wind. Should such standards, codes, guidelines, specifications etc. contradict the present Guideline, the latter shall take precedence over all others.

3.4.1.3 Fabrication specification, schedule

A specification containing the main aspects of fabrication and construction is to be submitted to GL Wind for approval. A time schedule is to be submitted for information. For welding procedure and NDT specifications, see Section 3.4.2.3.1 and Section 3.4.3.1.6 para 4 respectively.

3.4.1.4 Quality assurance and quality control

(1) Manufacturers are to introduce a quality control system which ensures that the materials, fabrication and construction are in accordance with this Guideline, the approved drawings and specifications or any other conditions stated in the approvals.

(2) The quality control shall be performed by competent personnel with defined responsibilities covering all aspects of quality control including welding and NDT. The quality control department shall be independent from the manufacturing departments. An organization chart, including proof of qualification of the personnel in charge of control, is to be submitted to GL Wind.

(3) During fabrication and construction controls are to be carried out, inter alia, as to

– the storage and marking of materials

– the preparation and assembly of components

– the accuracy to size of the components and the overall structure.

For checking of weldings, see Section 3.4.3.1.6 and for the final inspections including NDT, see Section 3.4.3.1.

(4) The control is to also cover all work, which may affect the integrity and strength of the structure including the fitting of auxiliary structures and equipment to the structure, fairing and repair work, as well as corrosion protection measures.

(5) All quality control measures are to be recorded, thus proving the kind, scope and results of the checks. A summary analysis of results is to offer a clear picture of the progress of work, including possible rework and controls. The records and analysis are to be submitted to GL Wind for approval at reasonable intervals.

(6) Manufacturers will be responsible for compliance with this Guideline, the approved drawings and specifications as well as with any other conditions which may be agreed or stated in the approvals. The inspections performed by GL Wind do not relieve manufacturers of this responsibility.

3.4.1.5 Deviations, defects and repair work

Any deviations from the Guideline, approved drawings and specifications or conditions agreed or stated in the approvals require prior approval by GL Wind. The same applies analogously to major repairs. Proposal for intended repair work is to be prepared by manufacturers and to be presented to GL Wind for approval, together with a report on defects. Repair work shall be started only following approval of the repair procedure by GL Wind. For admissible tolerances, see Section 3.4.1.14.

3.4.1.6 Identification and storage of materials

(1) All materials (plates, tubes, etc.) for main (special and primary) structural parts are to be clearly marked as to enable them to be definitely identified on the basis of the pertinent certificates.

(2) Non-identified materials are to be rejected, unless compliance with this Guideline and/or the approved specifications has been verified by renewed testing. The number and type of tests shall be in accordance with Section 3.3.1.

(3) Manufacturers shall introduce a system enabling to trace the material within the structure. During each stage of manufacture correlation of the pertinent materials certificates to each individual component shall be possible.

(4) All materials and structural members are to be stored and handled such as to exclude their surface finish and properties being unduly affected. For the storage of welding consumables and auxiliary materials, see Section 3.4.2.2.3.

3.4.1.7 Surface and edge preparation of materials and structural members

(1) When applying thermal (cutting) procedures, the possibility of hardening of the basic material and - depending on the materials employed - variation of the strength and/or toughness values shall be taken into account. For flame straightening, see Section 3.4.1.12.

(2) Excessive flame cutting drag lines, (e.g. due to burner failure) are to be ground notch-free with smooth transitions. Where possible, weld repairs are to be avoided and require approval by the GL Surveyor.

(3) Plates or tubes shall be prepared by machining or by thermal cutting (flame, arc gouging, plasma cutting, etc.) followed by mechanical cleaning where appropriate in accordance with an internationally accepted standard. The same applies analogously to shear cuts, the fins of which are to be rough-planed in all cases.

(4) Surfaces to be welded shall be visually examined to ensure freedom from lamination, carbon deposits, cracks, slag inclusions and cutting notches. Any such defect shall be dressed out by mechanical cleaning. If the depth of excavation exceeds 5 mm, a weld repair shall be made using an approved welding procedure. The surface of the steel within 25 mm of the proposed weld shall be dry, clean and free from scale or paint, except that the use of a protective primer may be qualified by use in a welding procedure qualification test. The clean area shall be increased to 75 mm where required for ultrasonic testing or to avoid noxious fumes.

(5) Flame cut edges that are not subsequently welded shall be ground to remove nicks and burrs. The use of flame gouging or “washing” is not permitted.

(6) Where practicable, penetrations through main members (e.g. for piping or cables) are to be drilled. Flame-cut penetrations shall under all circumstances be completely ground notch-free. The edges are to be chamfered or rounded off.

3.4.1.8 Cold and hot forming

(1) Cold forming resulting in permanent deformation (elongation) by more than 3 % should be avoided and normally requires performance of a strain ageing test of the base material with retesting of mechanical properties. For welding in cold formed areas, see Section 3.4.2.5.5.

(2) The forming of T-sections into flanged ring stiffeners of any diameter may require mechanical tests to demonstrate that the properties required by the application are maintained after forming and welding.

(3) Acceptance of wedges or other techniques to assist rolling will be subject to the visual acceptability of the product and to acceptable mechanical test results from regions of maximum strain

(4) Hot forming should normally be performed at a temperature not exceeding 700 °C unless subsequent heat treatment is carried out and mechanical properties as specified are proved by retests in the final condition. Hot forming is not allowed for TMCP steels.

3.4.1.9 Fitting and assembly

(1) Excessive jamming is to be avoided during fitting and assembly. Major deformations of individual members are to be faired prior to further assembly. The welding-on of assembly aids is to be restricted to a minimum. For weld preparation, assembly and tack welding, see Section 3.4.2.6.3.

(2) Components which are to be spliced, shall be aligned as accurately as possible. Special attention shall be paid to the alignment of (butting) members, which are interrupted by transverse members. If necessary, such alignment shall be facilitated by drilling check holes in the transverse members which are later seal-welded. The fit-up is to be checked before welding. For allowable tolerances, see Section 3.4.1.14.

3.4.1.10 Weather protection

Prefabrication is to be performed as far as possible in weather-protected workshops. For assembly the components and in particular the areas, in which weldings are performed, are to be protected by provisional coverings against the effects of weather (e.g. rain and wind). For welding under low ambient temperatures and pre-heating, see Section 3.4.2.6.4.

3.4.1.11 Removal of auxiliary material

(1) Clamping plates, aligning ties and other auxiliary materials, temporarily welded on structural members, shall be limited as much as practicable.

(2) Where attachments are necessary, the following requirements apply:

– Temporary attachments shall not be removed by hammering or arc-air gouging. Attachments to leg joint cans, skirt sleeve joint cans, brace joint can, brace stub ends and joint stiffening rings shall be flame cut to 3 mm above parent metal and mechanically ground to a smooth flush finish with the parent metal.

– Attachments on all areas that will be painted shall be removed as above, prior to any painting.

– Attachments to all other areas, not defined above, shall be removed by flame cutting just above the attachment weld (maximum 6 mm above weld); the remaining attachment steel shall be completely seal welded.

– Attachments to aid in the splicing of legs, braces, sleeves, piling, conductors, etc, shall be removed to a smooth, flush finish.

(3) If during rough-planing the surface of the structural members is damaged, the areas concerned are to be gorged flat and ground notch-free and subsequently checked for cracks. Where possible, repair by welding is to be avoided; otherwise, approval by the GL Wind Surveyor is required.

3.4.1.12 Flame straightening

Flame straightening shall not impair the properties of the materials and of the welded joints and shall be avoided completely, where practicable. In cases of doubt, proof of satisfactory performance of thermal treatment may be demanded.

Note:

Standard flame straightening carried out on higher-strength (normalized) steels may generally be regarded as acceptable provided that the straigthening temperature does not exceed 700 °C and that localized overheating and abrupt cooling (e.g. with water) are avoided. Prior to flame straightening of high-strength (quenched and tempered) structural steel, special agreement based on steel manufacturers recommendations is required.

3.4.1.13 Heat treatment

(1) If heat treatment is required, it is to be performed in accordance with a procedure specification, listing in detail:

– structural member, dimensions and material

– heating facilities and insulation

– control devices and recording equipment

– heating and cooling rates (temperature gradients)

– holding range and time

(2) The specification is to be submitted to GL Wind for approval. For post-weld heat treatment, see Section 3.4.2.6.8. Regarding TMCP steels, see Section 3.4.1.8 para 4 (heat treatment not allowed).

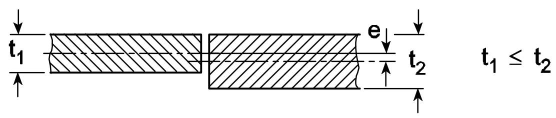
3.4.1.14 Fabrication tolerances

3.4.1.14.1 General

Allowable fabrication and construction tolerances shall be specified depending on the significance of the structural members and the loads acting on them. The specification is to be submitted to GL Wind for approval. A general guidance for allowable tolerances is given in Section 3.4.1.14.2 to Section 3.4.1.14.12, for weld imperfections see Section 3.4.2.6.6 and Section 3.4.3.1.6.

3.4.1.14.2 Misalignment of butt (weld) joints

The misalignment e shall be as follows:



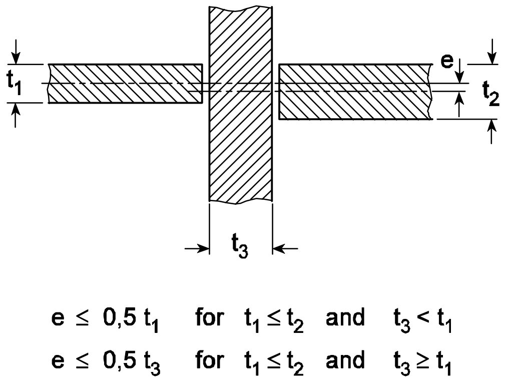
$e \leq 0{,}15\, t_1$; max. 3 mm

$e \leq 1$ mm for $t_1 \leq 6{,}5$ mm

The misalignment e may have to be reduced in case of high cyclic (fatigue) stresses. See also Section 6.6.6.

3.4.1.14.3 Misalignment of cruciform (weld) joints

The misalignment e shall be as follows:



The misalignment e may have to be reduced in case of high cyclic (fatigue) stresses across the plate t_3. See also Section 6.6.6.

3.4.1.14.4 Roundness of tubular members

(1) The external circumference shall not differ from the designed or calculated circumference by more than ± 0.3 % of the specified external diameter.

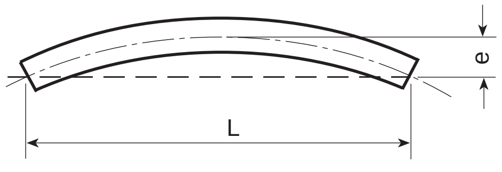
(2) The difference between the measured maximum and minimum diameters shall not exceed 1 % of the specified diameter or 6 mm, whichever is less.

(3) Lower values and/or additional limitations may be required for towers, masts, crane pillars and similar components of lifting appliances.

(4) The global and local tolerances for circular cylindrical shells (e.g. of flotation tanks, buoyancy structures etc.) exposed to outer pressure are to be calculated and specified in each single case depending on maximum pressure, diameter to wall thickness ratio and stiffener distance to diameter ratio.

(5) For limitations regarding buckling, see Section 6.6.5.4.

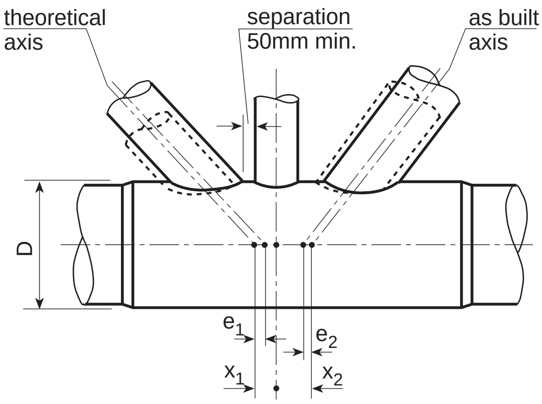
3.4.1.14.5 Straightness of (prefabricated) tubular members and girders or beams



(1) The deviation of straightness e shall be e ≤ 0.001 L or 3 mm, whichever is greater, for compression members (e.g. columns), primary truss members and girders or beams with non-hollow cross sections.

(2) The deviation of straightness e shall be e ≤ 0.002 L or 5 mm, whichever is greater, for girders or beams with hollow cross sections and for all other applications (but not greater than 25 mm).

3.4.1.14.6 Deviation from the theoretical axis in tubular nodes



(1) If the specified (designed) eccentricity x is less than D/4, the deviations are defined as follows:

– x as built < x designed (x_1 in Fig. above): $e_1 \leq x_1$, but separation requirement 50 mm min. (see Fig. above) to be observed

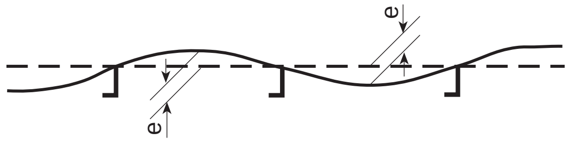
– x as built > x designed (x_2 in Fig. above): $e_2 \leq 0.1\ x_2$, max. 50 mm

(2) If the specified (designed) eccentricity x is greater or equal to D/4, which has to be considered in the strength calculations, the deviations are:

– $e_{1,2} \leq 0.1\ x_{1,2}$, max. 50 mm

– separation requirement of 50 mm minimum (see Fig. above) to be observed

3.4.1.14.7 Bulges in plating (deviation from straight line)



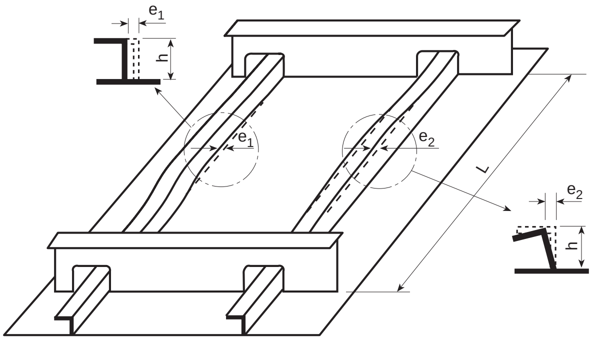
– e ≤ 4 mm in 95% of all cases

– e ≤ 6 mm in the remaining 5% of all cases

Lower values may be required for reasons of buckling strength.

3.4.1.14.8 Stiffeners between two supporting members

The permissible deviation e of deformations in plane, stiffened platings from straight line is defined as follows:



$$e_1 \le 1 + 0.001\,\mathrm{L},\ \max.10\ mm,$$
$$e_2 \le 1 + 0.01\,h,\ \max.10\ mm. \qquad (3.4.1)$$
$$(\text{all dimensions in mm})$$

Lower values may be required for reasons of buckling strength.

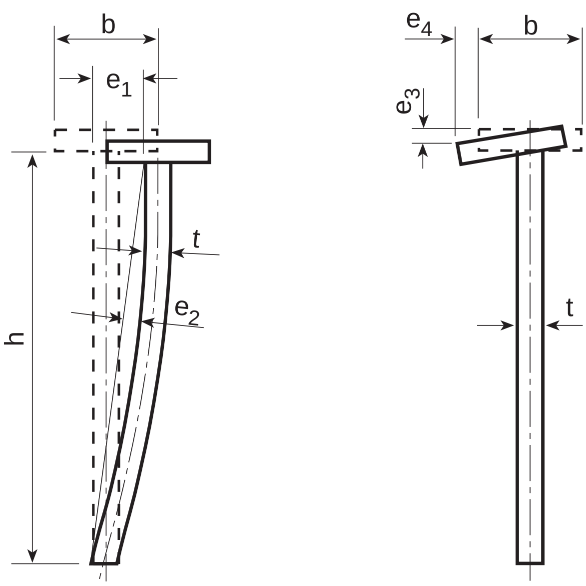
3.4.1.14.9 Deformation of plane, stiffened platings (deviation from straight line)

$$e \le 0.2\,\sqrt{L}\ (\text{"}e\text{" and "}L\text{" in mm}). \qquad (3.4.2)$$

Lower values may be required for reasons of buckling strength or sufficient water drainage.

3.4.1.14.10 Deviation and/or distortion of girders

The permissible deviation and/or distortion of girders is defined as follows:



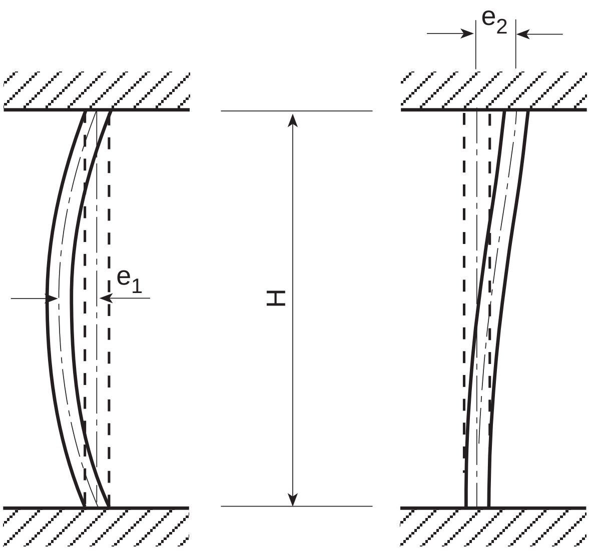
$$e_1 \le 1 + 0.01\,h,\quad max.10\ mm \qquad (3.4.3)$$
$$e_1 \le 0.01\,h,\quad max.0.5\ t$$

$$e_3 \le 1 + 0.01\,b,\quad max.6\ mm \qquad (3.4.4)$$
$$e_4 \le 0.02\,b,\quad max.t$$

(all dimensions in mm)

Lower values may be required for reasons of buckling strength.

3.4.1.14.11 Lateral deflection and inclination of (as built) columns



(1) Lateral deflection e_1 shall be in accordance with the requirements given in Section 3.4.1.15.5 (L = H in mm).

(2) Deviation $e_2 \le 0.0015$ H or 4 mm, whichever is greater, but not greater than 25 mm.

3.4.1.14.12 Tolerances for trusses

Tolerances for trusses are to be specified analogously to those given in Section 3.4.1.14.6 (deviation from the theoretical axis in tubular nodes), Section 3.4.1.14.10 (deviation and/or distortion of girders) and Section 3.4.1.14.11 (lateral deflection and inclination of (as built) columns). Special consideration is to be given to areas of introduction or deviation of forces, e.g. at stabbing points or connections of crane pedestals.

3.4.2 Welding

3.4.2.1 General requirements

3.4.2.1.1 Scope, welding rules

This section defines the general conditions for the preparation and performance of all welding work including quality assurance measures. It is taken for granted that all further details of welding (not listed here) will be laid down in the welding specifications in accordance with standards, codes, guidelines etc. recognized by GL Wind.

3.4.2.1.2 Standards, codes

(1) The standards, codes etc. mentioned in the Guideline constitute an integral part of it and require no special consent. The version current at the time when this Guideline is issued shall be applied. New editions of the standards, codes etc. may be used in agreement with GL Wind.

(2) The application of other standards, codes etc. may be agreed by GL Wind. They shall be listed in the construction particulars, e.g. in the welding specifications, and presented to GL Wind on request.

(3) If any of these standards, codes etc. contradict this Guideline, the latter shall automatically take precedence over all the others. Any deviations require approval by GL Wind from case to case.

3.4.2.1.3 Terms and definitions

The terms and definitions as contained in recognized standards, codes etc. shall be employed. The standard or code used is to be indicated in the design and/or construction documentation and presented to GL Wind on request. Any other deviating terms and definitions are to be separately explained in the welding specifications.

3.4.2.1.4 Welding works equipment

The manufacturers (welding works) shall have suitable equipment and plant for the satisfactory performance of welding work. Apart from perfectly functioning cutting and welding machines and tools, this equipment shall include dry, heatable storage facilities, redrying ovens and heated holding boxes for the welding consumables, and equipment for preheating and temperature control.

3.4.2.1.5 Welding supervision

The preparation and performance of welding operations shall be supervised by specially trained and experienced welding supervisors. Proof of the latters' professional qualifications is to be furnished to GL Wind; their tasks and responsibilities are to be defined and made known to GL Wind.

3.4.2.1.6 Performance of qualification tests

Qualification tests are to be performed under the supervision of GL Wind on the manufacturers' premises. Fabrication conditions shall be simulated as far as possible. Non-destructive and destructive tests may - in agreement with GL Wind - be performed on the premises of another independent, neutral testing body. Unless otherwise stated, sampling, specimens and performance of tests shall be in accordance with the requirements of this guideline.

3.4.2.1.7 Documentation

(1) The manufacturer shall produce and submit to GL Wind prior to production a documentation, covering the main aspects of welding work as follows:

- drawings showing all weld details
- welding procedure specifications
- procedure qualification records
- welding supervisors' qualification
- welders' qualification certificates
- welders' identification system

(2) For documentation on materials, see Section 3.3.2.4.9 and Section 3.4.1.6 for weld inspection and NDT, see Section 3.4.3.1.1 para 7.

3.4.2.2 Welding consumables

3.4.2.2.1 Approval of welding consumables

(1) All welding consumables and auxiliary materials (rod electrodes, wire electrodes, wire-gas-combinations or wire-flux-combinations) intended to be used on offshore steel structures shall be approved by GL Wind or an acknowledged body for the respective range of application (base materials, welding positions, heat treatment condition, etc.).

(2) Welding consumables and auxiliary materials not approved by GL Wind or an acknowledged body may be qualified with special agreement by GL Wind - in the course of the welding procedure qualification tests. In this case, one round tensile test specimen is to be additionally taken lengthwise, mainly from the weld metal of the butt welds.

(3) Such qualifications are, however, limited to the users' work in the range of application according to the approved welding procedure specifications and remain valid for not longer than one year, unless repeat tests are carried out.

3.4.2.2.2 Selection of welding consumables

(1) The welding consumables and auxiliary materials are to be chosen such that in the weld connection, including the areas of transition to the base material, at least the same mechanical properties as those specified for the base materials are achieved.

(2) Welding consumables and auxiliary materials with a controlled low hydrogen content in the weld metal (symbols H15, H10 or H5 according to the relevant EN standard or equivalent) shall be used for welding of higher and high strength steels (yield strength > 285 N/mm^2), for all steels having a carbon equivalent ≥ 0.42 % and are recommended for all highly stressed and thick-walled components exposed to low temperatures as well as for steel forgings and castings.

(3) Welding consumables and auxiliary materials other than low hydrogen types may only be used with special agreement by GL Wind, except for secondary structures.

3.4.2.2.3 Storage and redrying of welding consumables

(1) All welding consumables and auxiliary materials (except shielding gases) are to be stored as far as possible in the original packages - in a dry storage room, where a minimum temperature of 20 °C is maintained. The manufacturer's recommendations are to be observed. The welding consumables and auxiliary materials shall be properly identifiable up to their final use.

(2) Prior to use low hydrogen rod electrodes, folded flux core wire electrodes and fluxes are to be redried (baked) in accordance with the manufacturer's instructions (observing the maximum baking time specified). Unless otherwise specified, the baking temperature should be 250 to 350 °C, the baking time ≥ 2 hours, but not longer than 12 hours in total. Repeated baking is permissible, as long as the maximum drying period of 12 hours is not exceeded.

(3) At the place of work, the welding consumables and auxiliary materials are to be protected against the effects of weather (moisture) and contamination. Low hydrogen rod electrodes and fluxes are to be kept in heated holding boxes at temperatures between 100 and 150 °C. All unidentifiable, damaged, wet, rusty or otherwise contaminated welding consumables and auxiliary materials are to be discarded.

3.4.2.3 Welding procedure specification and approval

In general, the specification and approval of welding procedures for metallic materials shall be in accordance with EN 288. Other equivalent codes, standards, rules or recommendations may be used with GL Wind's consent.

3.4.2.3.1 Welding procedure specifications

(1) Welding procedure specifications (WPS) are to be prepared and submitted to GL Wind for review. The WPS shall contain all essential data on the preparation and performance of weldings as given in EN 288-2.

(2) WPS are to be submitted for new, as well as for repair welds. For specifications to be submitted concerning inspections procedures, see Section 3.4.3.1.6.

3.4.2.3.2 Welding procedure approval

(1) The manufacturers (welding works) shall prove their ability to apply the specified welding procedures in a sufficient manner and with satisfactory results, in conjunction with the actual materials and welding consumables. Such proof is to be provided prior to fabrication.

(2) Unless otherwise agreed, welding procedures shall be approved in accordance with EN 288. Welding procedure tests shall be witnessed by GL Wind.

(3) At the discretion of GL Wind, common proved welding procedures such as

– manual metal arc welding
– semi-mechanized gas shielded arc welding
– one wire submerged arc welding

of normal strength (mild) steels according to Section 3.3.2.3 para 1 may be accepted as being prequalified without any further welding procedure qualification tests.

(4) In exceptional cases, GL Wind may recognize in part or in whole existing welding procedure approval records based on tests witnessed and approved by another competent and independent authority. Therefore, adequate documentation, including complete test reports, is to be submitted to GL Wind.

(5) The approval for a welding procedure is restricted to the manufacturer and to the welding works or working unit, where the test welds were performed. The approval is valid within the limitations of the essential variables according to Section 3.4.2.3.4.

(6) The approval for the use of the welding procedure is normally valid for the fabrication period of the structure. Where this period exceeds 3 years, or where the fabrication has been interrupted for more than 3 months, GL Wind may require production tests or repeated welding procedure qualification tests.

(7) Production tests or repeated welding procedure tests may also be required if the conditions under which the approval was granted (e.g. personnel, premises) do not longer apply, or in the event of doubts as to satisfactory execution of the weldings.

3.4.2.3.3 Welding procedure tests

(1) Welding procedure tests are to be carried out in accordance with EN 288-3.

(2) For the welding procedure tests a programme is to be prepared and submitted to GL Wind for approval. The different base materials and welding consumables, prematerials (e.g. plates or tubes), plate and/or wall thicknesses, seam forms and weld positions, as well as the effects of seam preparation and possibly back-gouging at the workshop are to be taken into account.

(3) The base materials for the test assemblies shall be of the same type as those used for the steel construction and shall be selected such that the carbon content and the carbon equivalent value are in the upper range of the specified values. The rolling direction shall be parallel to the weld seam.

(4) Non-destructive testing of the test assemblies is to be performed in the same manner as specified in Section 3.4.3. Sampling of test specimen and mechanical testing shall comply with the specifications given in EN 288-3.

(5) GL Wind may require additional tests (e.g. fracture mechanic tests for higher and high tensile steels and/or heavy welded joints) as well as other test conditions (e.g. test temperatures for the charpy impact tests) or may specify other (more stringent) acceptance requirements.

(6) Protocols are to be prepared on the test weldings and testing and submitted to GL Wind for recognition. These protocols shall contain all welding data, including seam preparation, back-gouging, preheating, interpass temperatures, a possible post-weld treatment and all results of the non-destructive and mechanical and technological testing.

3.4.2.3.4 Limits of application of approved welding procedures

(1) Approved welding procedures may be used within the limitations as specified in EN 288-3. for welding above water. For welding under water see Section 3.4.2.3.6 para 5. GL Wind may specify other limits if the peculiarities of a welding procedure, the material, the joint configuration and thicknesses or other parameters have a considerable effect on the properties of a weld.

(2) Changes of the variables as specified in EN 288-3 are to be considered as being essential and in general require performance of a new or additional welding procedure test unless otherwise agreed. When a combination of welding processes is used, the variables applicable to each process shall apply.

3.4.2.3.5 Qualification for tubular node connections

(1) For full penetration groove welds between tubes and/or plates or girders (T-, Y- or K-joints) forming node connections welding procedure tests are to be performed analogously to the requirements stated above and following the indications given in the following paragraphs. A detailed test programme is to be prepared by the manufacturers in agreement with GL Wind from case to case.

(2) The test programme shall cover the different joint configurations, tube diameters and wall thickness, angles included between the axes of the tubes as well as the different welding positions for each in-dividual proove type. If not otherwise required, the test pieces may be formed as a brace to can connection according to Fig. 3.4.1.

(3) When the diameter "D" (of the can) exceeds 600 mm, this tube may be replaced by a plate of same or equivalent steel grade and of relevant size and similar thickness, but not less than 25 mm. When other types of welding (double side, partial penetration groove or fillet weldings) are intended and approved for fabrication, these types are to be approved separately. Double side welding may be covered by single side welding approval with GL Wind's consent in each individual case.

(4) The joint is to be tested by ultrasonic and magnetic particle method. From each position marked with a circle (A, B, C) in Fig. 3.4.1 one set of test specimens as required in EN 288-3 is to be prepared and tested. Charpy impact test specimen are to be taken from positions "A" and "C" only and those from fusion line and heat affected zone shall be placed on the bracing side, if not otherwise required.

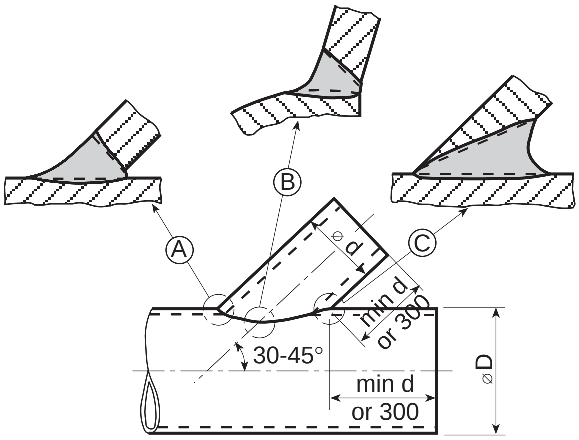


Fig. 3.4.1 Tubular node test piece

(5) In addition to the limitations and essential variables given in Section 3.4.2.3.4, for tubular node connections the following limitation shall apply: change of more than 5° from the included angle between the axes of the tubes or girders to smaller angles requires requalification when the included angle is 45° or less.

3.4.2.3.6 Qualification for underwater welding

(1) Underwater welding, to be used for construction or repair, is to be approved by a test, following the scheme given for welding above water, conducted under actual welding conditions at the welding site or simulated at a test facility. The test is to be carried out at the same water depth or at similar conditions as for the actual welding operation.

(2) For underwater welding generally a low hydrogen process shall be used, carried out in a dry chamber under pressure equivalent to the water depth or under one atmosphere pressure (habitat welding). Underwater wet welding, where the arc is working in the water or in a small gas-filled cavern, is normally restricted to minor or temporary repair work in shallow waters and requires GL Wind's consent in each individual case.

(3) Prior to the welding procedure test, a detailed welding procedure specification (WPS) is to be prepared by the manufacturer and submitted to GL Wind for review. In addition to the particulars mentioned in Section 3.4.2.3.1, the following data are to be specified:

– maximum and minimum water depth
– chamber (habitat) atmosphere (gas composition and pressure)
– maximum humidity in the chamber (habitat)
– temperature fluctuations inside the chamber
– electrode transport and monitoring system
– inspection schedule and methods

(4) Based on the welding procedure specification according to Section 3.4.2.3.6 para 3 a welding procedure test programme is to be established by the manufacturer (welding works) and submitted to GL Wind for approval. The manufacturer shall also document his previous experience with similar welding work; otherwise an extended testing may be required by GL Wind. Testing requirements given in Section 3.4.2.3.3 apply analogously.

(5) In addition to the limitations and essential variables given in Section 3.4.2.3.4, for underwater welding the following variations are considered to be essential:

– change from habitat welding to wet welding and vice versa
– change in water depth (working pressure) beyond the agreed range
– change in habitat atmosphere (gas composition)
– change in welding consumables
– change in welding current/polarity
– change in welding parameters (amperage, voltage, travel speed) of more than 10 % (mean value)

Regarding production tests to be performed prior to actual welding see Section 3.4.2.6.9 and Section 3.4.2.6.10.

3.4.2.4 Welders' qualification

In general, the approval testing of welders shall be in accordance with EN 287. Other equivalent codes, standards, rules or recommendations may be used with GL Wind's consent.

3.4.2.4.1 Qualification rest requirements

(1) Manual or semi-mechanized (hand guided) welding shall be performed by qualified welders. The welders' qualification tests are to be witnessed by GL Wind. GL Wind may accept qualification tests witnessed by another independent authority.

(2) The manufacturers (welding works) are required to maintain a list, card index or the like furnishing complete information about the number, names, identification marks, welders' qualification levels and dates of the initial and repeat tests passed by the welders. Copies are to be submitted to GL Wind, the relevant original documentation (test reports) is to be retained at the welding works, for examination by GL Wind on demand.

Table 3.4.1 Test piece dimensions and range of applicability

	Test piece dimensions	Range of applicability
Plate/wall thickness “t”	up to 20 mm	0,5 t – 2 t
	more than 20 mm	all thickness greater than 10 mm
Tube diameter “D”	up to 600 mm	tested diameter – 100 / + 200 mm
	more than 600 mm	all diameters greater than 500 mm

(3) Welding operators applying fully mechanized welding processes such as the submerged arc welding process generally need not pass a welder’s performance test. They shall have been instructed and trained for work at the plant and shall mark their welds for later identification. As far as possible, the operators shall be involved in the welding procedure tests. GL Wind may require production tests to prove their capability.

3.4.2.4.2 Scope of tests and limitations

(1) Welders who are to perform welding work on offshore wind turbine steel structures should be properly trained and shall be tested as comprehensively as possible.

(2) Welders’ qualification tests are to be performed with the respective welding process for those kinds of materials (plates, tubes), joint types (butts, fillets, T-, K- and Y-connections) and welding positions which will be employed during later manufacture, in accordance with EN 287. The details and further data are to comply with those stated in the welding procedure specifications.

(3) Plate thickness, tube diameters and wall thicknesses of the test pieces shall be in accordance with the requirements given in EN 287-1, Table 1 and 2 as well as Table 3.4.1 (the more restrictive requirement applies).

(4) Additionally to the limitations mentioned before, the following variations are considered essential and shall require requalification by a new or additional performance test:

– material: change from normal strength (mild) steel to higher strength steel or change from higher strength steel to high strength steel

– joint type: change from double side welding to single side welding

– welding process: any change

3.4.2.4.3 Qualification of underwater welders

(1) For underwater welding only those welders may be qualified, who are well trained, experienced and qualified for relevant welding above water. Prior to the welding tests under water, the welders are to be given sufficient training to get familiar with the underwater welding conditions such as pressure, atmosphere, temperatures etc.

(2) The test welds are to be performed using materials comparable in chemical composition (weldability) and strength to the actual welding job, and with the welding process in question under actual or simulated diving conditions.

(3) Type and scope of testing are to be based on the actual welding job analogously to those given above and will be decided from case to case. Limitations given above apply analogously, the limitation of applicable (greater) water depth for welding will be decided in each single case.

3.4.2.4.4 Validity of qualification certificates

(1) The validity of a welder’s qualification certificate is two years, provided that during this period the welder’s work is monitored by visual and/or non-destructive testing. GL Wind may demand annual repeat tests if monitoring mainly takes the form of visual inspections or if the results of NDT cannot be correlated to the welder.

(2) A repeat test is required where a welder who has been tested in more than one welding process has not used the process in question for a period exceeding six months but has meanwhile used another process. A repeat test is required if a welder has not performed any welding work as defined in Section 3.4.2.4.1 para1 for a period exceeding three months. GL Wind may demand a repeat test at any time if reasonable doubts should arise as to a welder’s performance.

3.4.2.5 Design of weld connections

3.4.2.5.1 General requirements

(1) The drawings, specifications etc. shall provide clear and complete information regarding location, type, size and extent of all welds. The drawings shall also clearly distinguish between shop and field welds. Symbols and signs used to specify welding joints shall be in accordance with recognized standards or codes (to be mentioned in the drawings, specifications etc.), e.g. EN 22553, or shall be explained in these documents. Special weld (groove) details shall be shown by sketches and/or relevant remarks.

(2) It is recommended that standard welding details, symbols etc. including any workmanship or inspection requirements are to be laid down in standard drawings submitted to GL Wind for general approval. Dimensions of welding should not form a part of those standard drawings, but shall be designated in the contract or shop drawings for each individual structural part or welding respectively.

(3) All welds shall be planned and designed in such a way that they are readily accessible during fabrication and can be executed in an adequate welding position and welding sequence, see also Section 3.4.2.6.5. Welded joints, which are subject to NDT-inspection shall be placed and designed to facilitate application of the required inspection procedure, so that tests offering reliable results may be carried out.

3.4.2.5.2 Weld shapes and dimensions

(1) Weld shapes (groove configurations) shall be in accordance with recognized standards and codes, such as EN ISO 9692 or equivalent. As far as possible, full penetration butt or T-joints shall be designed as double side weldings with the possibility of sufficient root treatment (gouging) instead of single side weldings. Fillet welds shall be made on both sides of the abutting plate or web. Typical single side bevelled groove weld shapes are shown in Fig. 3.4.2.

(2) Weld shapes shall be designed to ensure, that the proposed weld type and quality (e.g. full penetration) can be satisfactorily achieved under the given fabrication conditions. Failing this, provisions shall be made for welds, which are easier to execute. The (possibly lower) load-bearing capacity of these welds shall be taken into consideration in the dimensional design. According to Fig. 3.4.7, the effective throat thickness of a partial penetration groove weld shall be the depth of bevel less 3 mm if not otherwise proved in way of welding procedure tests and agreed by GL Wind.

(3) Special weld shapes, differing from those laid down in the a. m. rules and standards (e.g. single side, full penetration groove welds in tubular T-, Y- or K-connections) or weld shapes for special welding processes shall have been proved in connection with the welding procedure tests according to Section 3.4.2.3.3 and Section 3.4.2.3.5 and are to be approved by GL Wind. Typical welds of tubular T-, Y- and K-connections with and without back welding are shown in Fig. 3.4.3 and 3.4.4.

(4) The weld contour is to be designed with smooth transitions tangent to the parent material in order to achieve the actual calculated fatigue life. The requirements regarding the weld contour including additional treatment, such as grinding of weld toes to a smooth profile depending on the actual detail category (see Section 6.6.6) are to be laid down in the drawings and/or specifications. A typical improved weld contour of a T-joint is shown in Fig. 3.4.5. The cap layer should be made with single passes (no excessive weave technique), starting at base material and making the last passes in temper bead technique on top of the weld to avoid excessive hardness in the heat effected zone.

(5) Dimensions (effective throat thicknesses and lengths) of welds are to be determined in context with the static and fatigue strength calculations and are to be specified in the drawings submitted to GL Wind for approval. The effective throat thickness of a complete penetration groove weld shall be the thickness of the thinner part to be joined. For partial penetration groove welds, the drawings shall specify the groove depth applicable to the effective throat thickness required for the welding procedure to be used (see Section 3.4.2.5.2 para 2 and Fig. 3.4.7), as well as the calculated effective throat thickness.

(6) The throat thickness of fillet welds is the size “a” in Fig. 3.4.6. In the drawings, fillet weld dimensions may be specified by the size “a” or by the leg length “ℓ” which is "$a \cdot \sqrt{2}$".

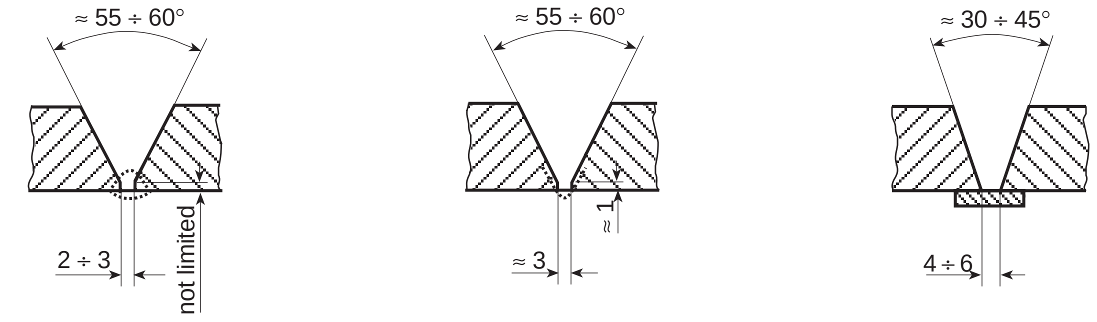
(7) The throat thickness of fillet welds shall not exceed 0.7 times the lesser thickness of the parts to be welded (generally the web thickness). The minimum throat thickness is defined by the expression:

$$a_{min} = \sqrt{\frac{t_1 + t_2}{3}} \; [\text{mm}], \text{ but not less than 3 mm} \qquad (3.4.5)$$

where:

t_1 = lesser (e.g. the web) plate thickness [mm]

t_2 = greater (e.g. the flange) plate thickness [mm]



Groove weld with back welding, root gouged (double side welding)

Groove weld without back welding (single side welding)

Groove weld with backing flat bar, for minor purposes only

Fig. 3.4.2 Typical single side bevelled groove weld shapes

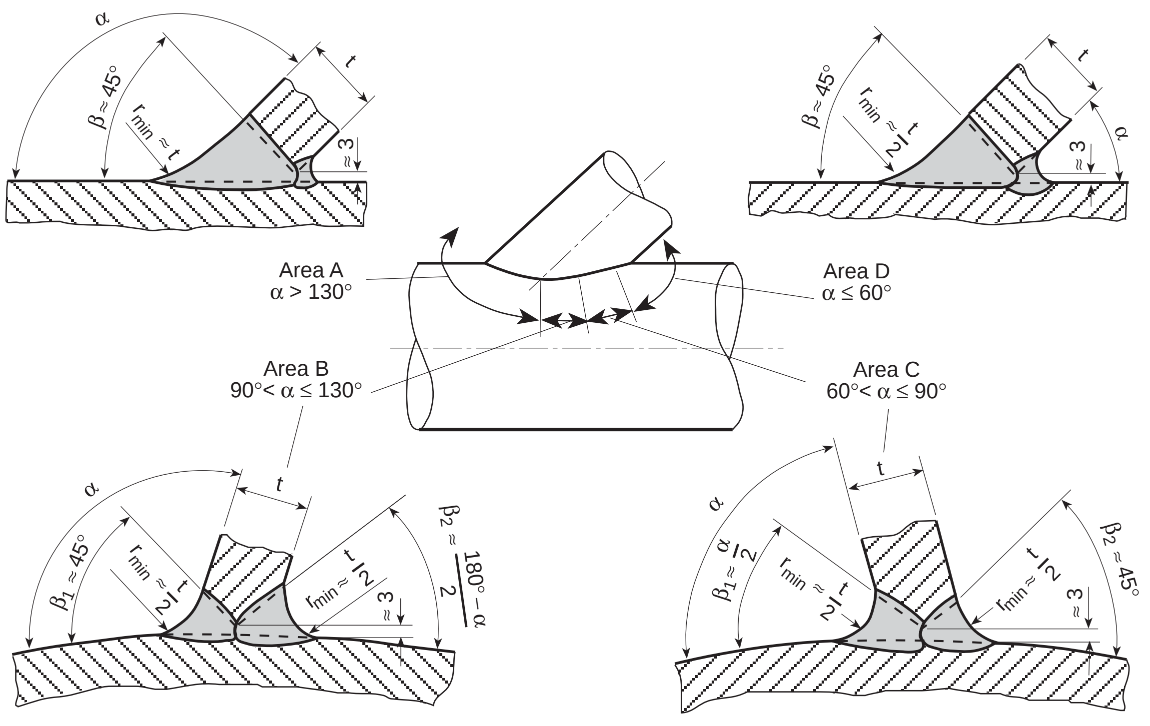


Fig. 3.4.3 Typical tubular weld connections with back welding

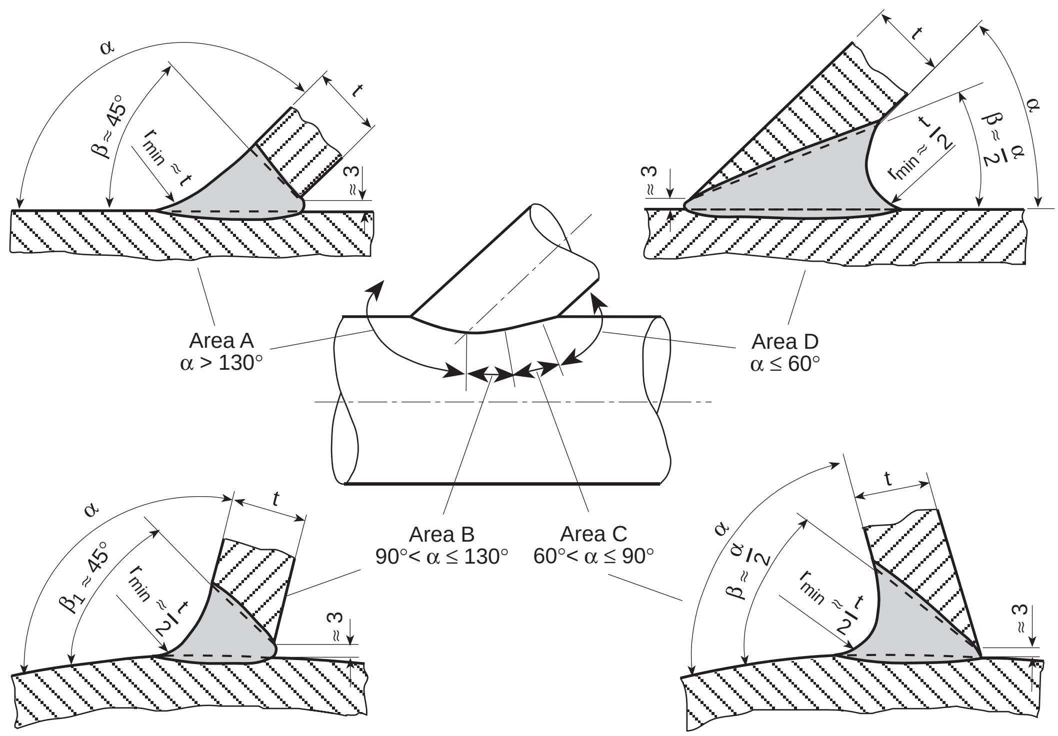


Fig. 3.4.4 Typical tubular weld connections without back welding

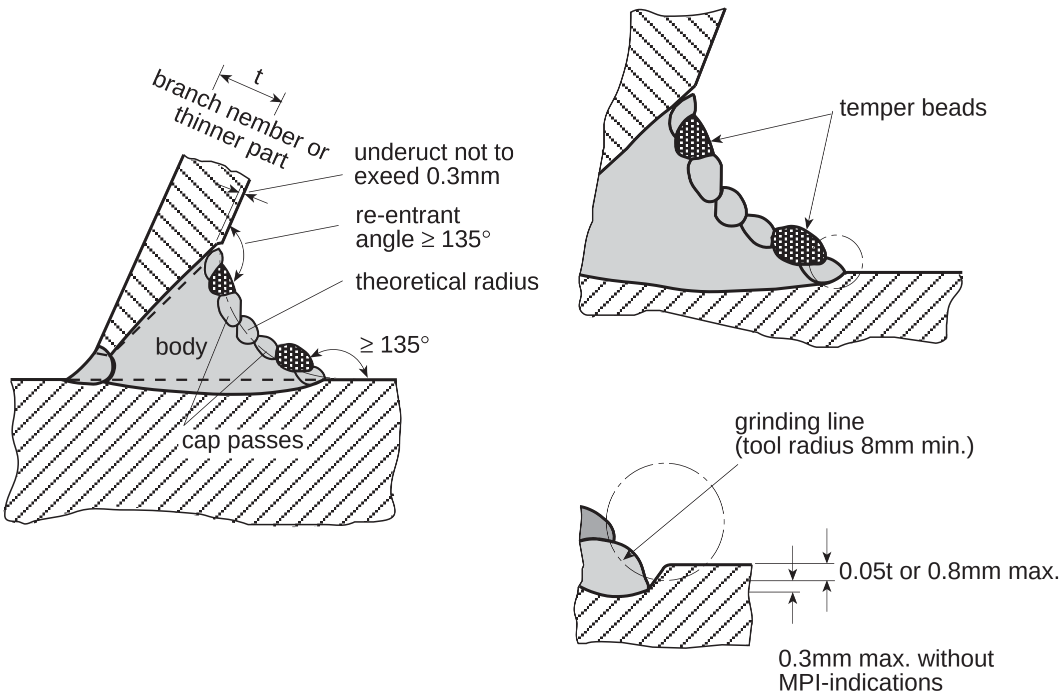


Fig. 3.4.5 Typical improved weld contour

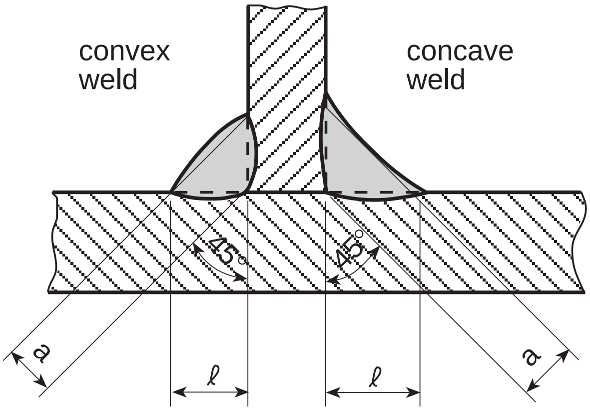


Fig. 3.4.6 Effective throat thickness "a" and leg length "ℓ" of filled welds

3.4.2.5.3 Details of welded joints

(1) All welded joints on primary members shall be designed to provide a stress flow as smooth as possible without major internal or external notches, discontinuities in rigidity and obstructions to strains. The transition between differing component dimensions e.g. of girders or stiffeners shall be smooth and gradual. The length of the transition should be at least 3 times the difference in depth, see Fig. 3.4.8.

(2) The requirements given in Section 3.4.2.5.3 para 1 apply in analogous manner to the welding of secondary mem bers to primary (or special) supporting members. The ends should have smooth transitions to the main structure, see Fig. 3.4.9.

(3) Where the plate or wall thicknesses differ more than 3 mm at joints mainly stressed perpendicularly to the (butt) weld direction, the difference shall be smoothened by bevelling and/or buttering according to Fig. 3.4.10 prior to butt welding. Differences in surface levels up to 3 mm may be equalized within the weld.

(4) If a misalignment due to component or plate respective wall thickness tolerances cannot be eliminated by adjusting (e.g. in case of circumferential butt welds in tubes) and the difference "X" is not greater than one quarter of the thinner plate or wall thickness, the misalignment may be equalized by chamfering or built up welding according to Fig. 3.4.11. Where the difference is greater and/or highly fatigue stressed joints are involved, equalization is to be decided and agreed upon by GL Wind in each individual case.

(5) Where platings (including girder web and flange plates) or tube walls are subjected locally to increased stresses, thicker plates are to be inserted in preference to doubler platings. This applies analogously to flanges, stuffing-boxes, hubs, bearing bushes or similar components to be welded into platings. The minimum size of those reinforcement plates shall be

D_{min} = 170 + 3·(t - 10), but not less than 170 mm

where

D = the diameter of round inserts or the length/breadth of angular inserts [mm],

t = plating thickness [mm].

The corner radii of angular reinforcing plates shall be at least 50 mm. The weldings between those reinforcement plates or inserts and the plating shall be full penetration butt welds and the transitions shall be in accordance with Section 3.4.2.5.3 para 3.

(6) Doubler plates (cover plates) may be used to reinforce girder flanges or similar components in the area of maximum bending moments. Doubler plates shall be limited to one per flange and their thickness "t" shall not exceed 1.5 times the thickness of the flange, their width "w" should not exceed 20 times their thickness. The ends of doubler plates shall be extended beyond the calculated, theoretical start or end conforming to Fig. 3.4.12. The fillet welds connecting the doubler plate to the flange shall be continuous welds. The welds at the ends of the doubler plates shall confirm to Fig. 3.4.12.

(7) Local clustering of welds and short distances between welds are to be avoided. Adjacent butt welds should be separated from each other by a distance of at least

50 mm + 4 t

where t = plate thickness. Fillet welds should be separated from each other and from butt welds by a distance of at least

30 mm + 2 t

(8) Where tubular joints (node sections) without overlapping require increased wall thicknesses and/or special steel in the main member (chord, can) and/or in the branch members (bracing stubs), the separation of the welds shall be in accordance with Fig. 3.4.13. The larger measures apply.

(9) In overlapping tubular joints (node sections), in which part of the load is transferred directly from one branch member (bracing) to another through their common weld, the overlapping of the welds shall be at least in accordance with Fig. 3.4.14. The greater measure applies. The actual length of the overlapping weld is to be determined by calculation. The heavier brace shall preferably be the through brace with its full circumference welded to the chord.

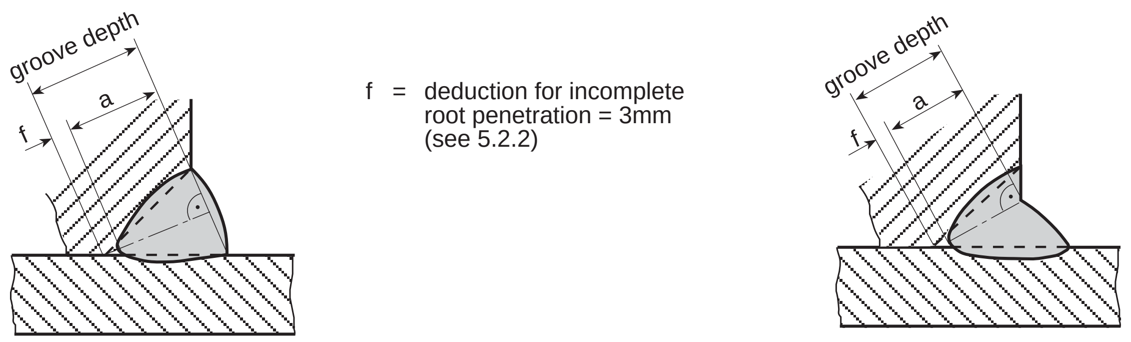


Fig. 3.4.7 Effective throat thickness “a” of partial penetration groove welds

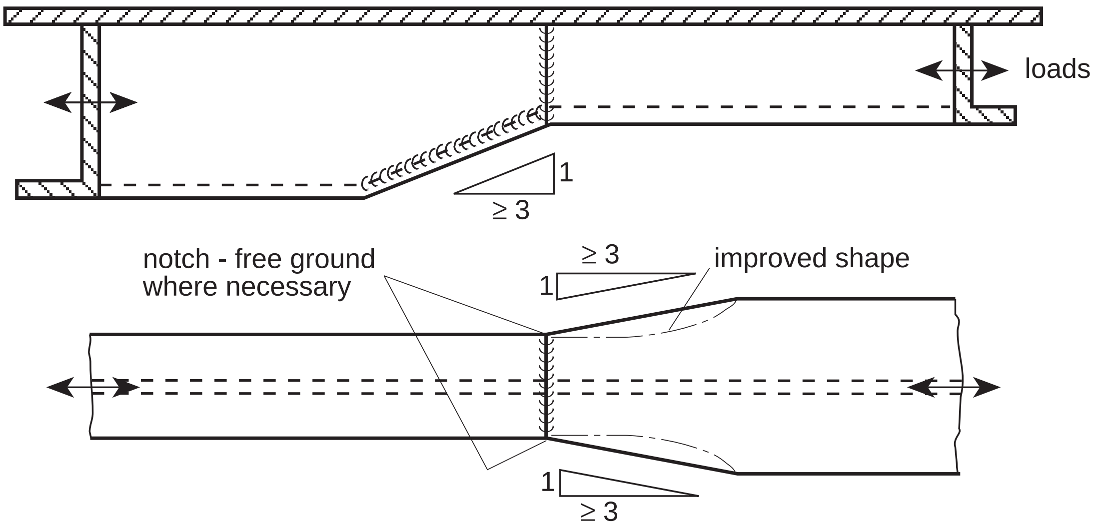


Fig. 3.4.8 Transitions between components with differing dimensions

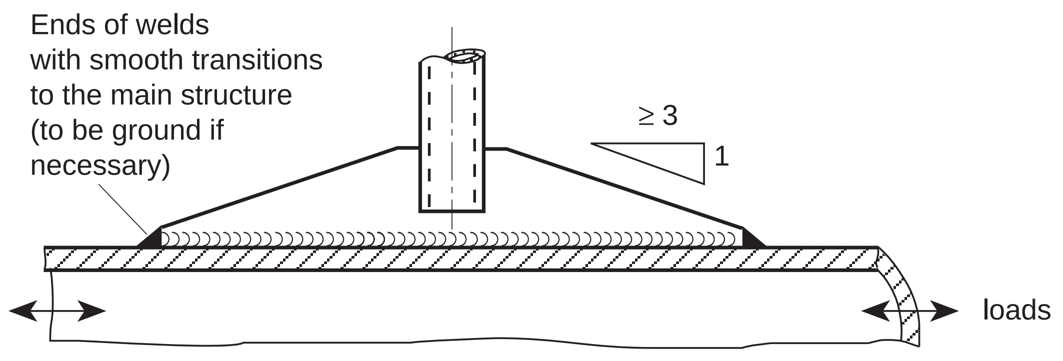


Fig. 3.4.9 Ends of secondary members welded on to main structures

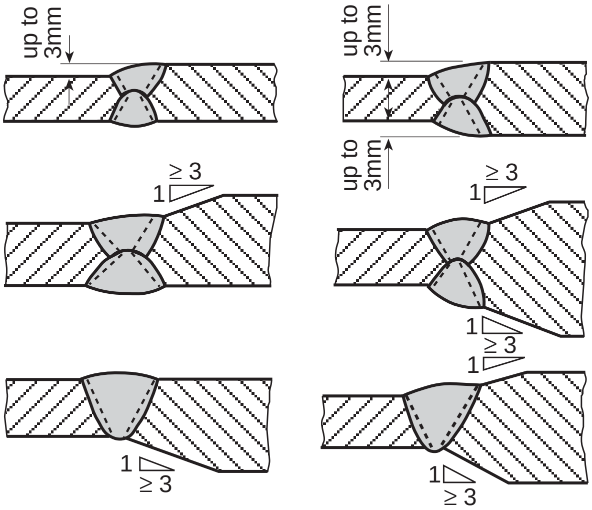


Fig. 3.4.10 Transition in butt welds of unequal thickness

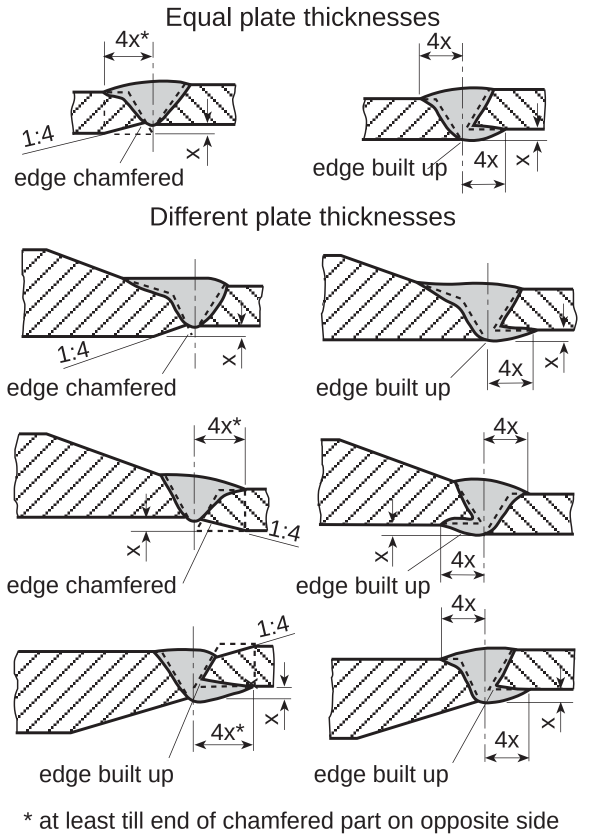


Fig. 3.4.11 Equalization of misalignment in butt welds

3.4.2.5.4 Calculation of welded joints

(1) Any calculation relating to welded joints which is stipulated in this Guideline or prescribed as an alternative to this Guideline governing dimensions shall be performed in accordance with the codes, standards, rules or recommendations acknowledged by GL Wind.

(2) Proof by calculation of adequate dimensioning (a general stress analysis) is required where, with mainly static loading, the thickness of butt welds are not equivalent to the plate thickness, and in the case of throat thicknesses of fillet welds.

(3) For welded joints subjected to mainly dynamic loads, the permissible loading shall be determined by reference to the range of stress variations, the global loading conditions, the limit stress ratio and the detail category (proof of fatigue strength). The detail category is a function of the geometrical configuration of the welded joint. It also depends on the proof of the absence of serious internal notches (welding defects).

(4) Tubular joints shall be designed using proven procedures. For non-standard or complex joints, e.g. ring stiffened or cast steel joints, appropriate analytical and/or experimental investigations may be required. For all tubular joints which are subject to dynamic loading, a fatigue analysis shall be performed, see Section 6.6.6.

3.4.2.5.5 Welding in cold formed (bended) areas, bending radii

(1) Wherever possible, welding should be avoided at the cold formed sections with more than 3 % permanent elongation and in the adjacent areas where structural steels with a tendency towards strain ageing are used.

Elongation ε in the outer tensile-stressed zone:

$$\varepsilon = \frac{100}{1+2\frac{r}{t}}[\%] \qquad (3.4.6)$$

r = inner bending radius [mm]

t = plate thickness [mm]

Table 3.4.2 Minimum bending radii

Plate thickness t	Minimum inner bending radius r
4 mm or less	1 × plate thickness
8 mm or less	1.5 × plate thickness
12 mm or less	2 × plate thickness
24 mm or less	3 × plate thickness
over 24 mm	5 × plate thickness
Note: *The bending capacity of the material may necessitate a larger bending radius.*	

(2) For other steels and other materials, where applicable, the necessary minimum bending radius shall, in case of doubt, be established by test. Proof of adequate toughness after welding may be stipulated for steels with minimum yield strengths of more than 355 N/mm^2 and plate thicknesses of 30 mm and above which have undergone cold forming resulting in 2 % or more permanent elongation.

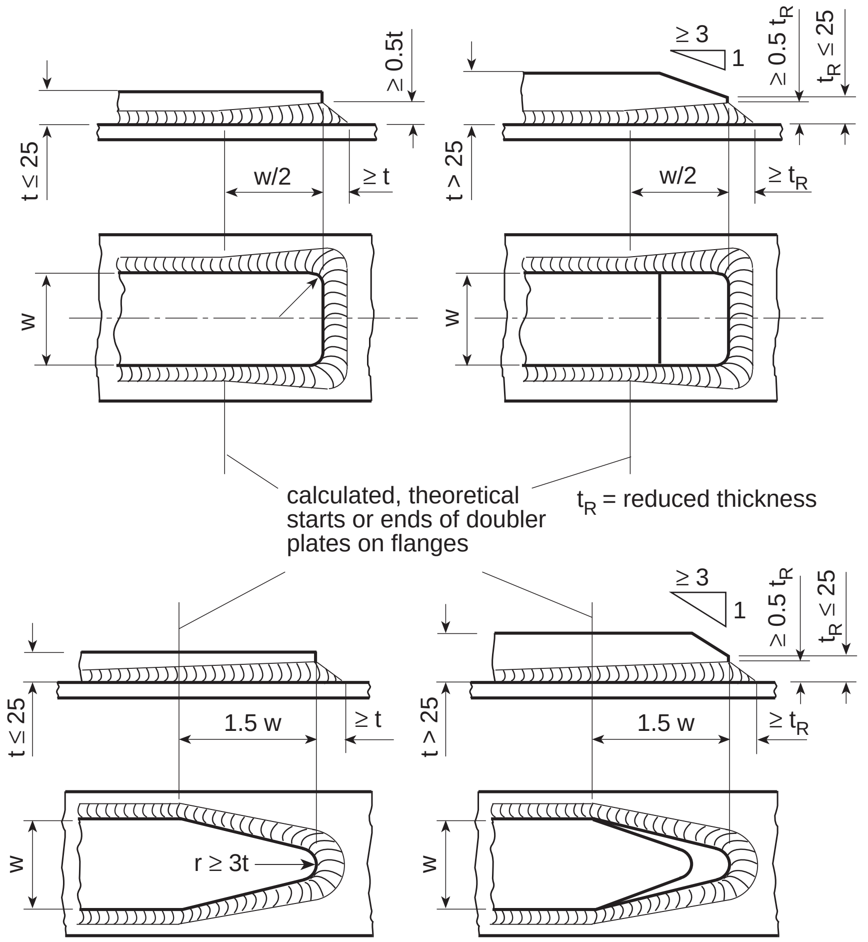


Fig. 3.4.12 Configuration and welding of the ends of doubler plates on flanges

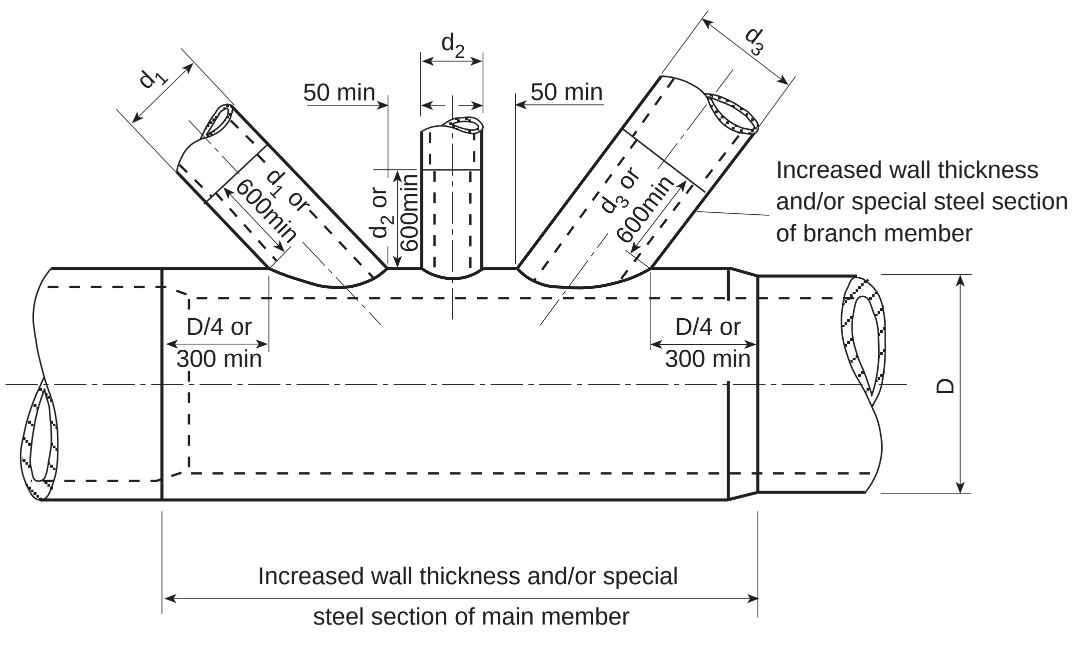


Fig. 3.4.13 Separation of welds in tubular joints

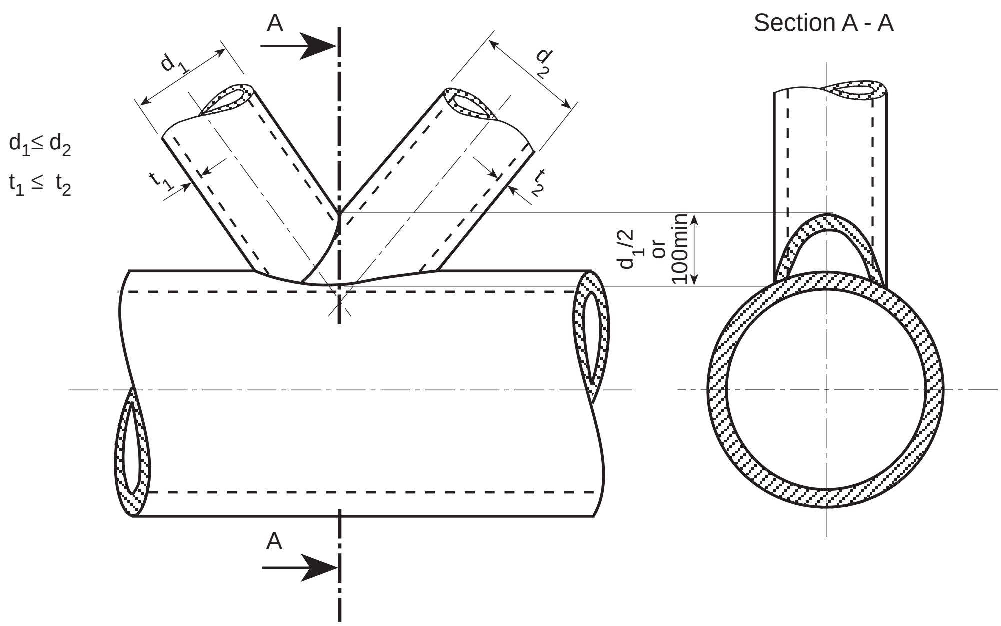


Fig. 3.4.14 Separation of welds in overlapping tubular joints

3.4.2.6 Performance of welding, workmanship

3.4.2.6.1 General requirements

(1) All welding is to be performed observing the applicable paragraphs of this Section as well as the common state of the art of welding technology to achieve the required quality. Compliance with this Guideline and with any other conditions which may be agreed or stated in the drawings and specifications or imposed in connection with approvals as well as with good workmanship is the responsibility of the manufacturers. Inspections performed by GL Wind do not relieve the manufacturers of this responsibility.

(2) The preparation and performance of all welding operations shall be supervised by manufacturer's welding supervisors (see Section 3.4.2.1.5). Regarding the qualification and the functions of the welding supervising personnel see EN 719. In the event of any deviations from the above stated operating conditions, the welding supervisory personnel shall, in agreement with GL Wind, take steps to ensure the constant and adequate quality of the welds. For inspection personnel see Section 3.4.3.1.5.

3.4.2.6.2 Overweldable shop primers

Overweldable shop primers which are applied to plates, sections etc. prior to welding and are not removed shall be tested in agreement with GL Wind.

3.4.2.6.3 Weld preparation, assembly, tack welding

(1) Machining, oxygen cutting, air carbon arc gouging, oxygen gouging, chipping or grinding may be used for joint preparation, back gouging, or the removal of unacceptable work or metal, except that oxygen gouging shall not be used on normalized or quenched and tempered steels.

(2) When preparing and assembling components care shall be taken to ensure compliance with the weld shapes and root openings (air gaps) specified in the drawing and specifications. With single and double-bevel T joints, especially, attention shall be paid to an adequate root opening in order to achieve sufficient root penetration.

(3) The root opening shall not exceed twice the specified gap. If the gap exceeds this value locally over a limited area, the gap may be reduced by buildup welding of the groove edges subject to the prior consent of the Surveyor. With fillet welds, the "a" dimension shall be increased accordingly, or a single or double-bevel weld shall be made if the air gap is large. Inserts and wires may not be used as fillers.

(4) With the Surveyor's agreement, large gaps except in highly stressed areas of special structural members - may be closed by means of a strip of plate with a width of at least 10 times the plate thickness or 300 mm, whichever is the larger.

(5) Members to be welded shall be brought into correct alignment (see also Section 3.4.1.9) and held in position by bolts, clamps, wedges, guy lines, struts, and other suitable devices, or by tack welds until welding has been completed. The use of jigs and fixtures is recommended where practicable. Suitable allowances shall be made for warpage and shrinkage.

(6) Clamping plates, temporary ties, aligning pins etc. shall be made of structural steel of good weldability and should not be used more than necessary. They are to be carefully removed to prevent damage to the surfaces of members when the components have been permanently welded.

(7) Clamping plates, temporary ties, aligning pins etc. shall not be welded to components or areas subject to particularly high stresses, nor shall they be welded to the edges of flange plates of girders or similar members. The same applies to the welding of handling lugs and other auxiliary fixtures.

(8) Tack welds should be used as sparingly as possible and should be made by trained operators using qualified welding procedures and consumables. Where their quality does not meet the requirements applicable to the subsequent welded joint, they are to be carfully removed before the permanent weld is made. All tack welds which will form part of the permanent weld shall be cleaned, ground down to a feather edge at both ends and visually inspected prior to welding of the root pass.

Note:

To avoid damages of the root preparation (bevelling), the use of round bars, to be tacked to the groove faces in accordance with the Fig. 3.4.15 and to be removed stepwise prior to root welding, is recommended where practicable.

(9) Particulary with mechanized welding processes - and invariably when end craters and defects at the start and end of the weld have to be avoided - run-in and run-off plates of adequate section shall be attached to components and cleanly removed on completion of the weld.

(10) Surfaces to be welded shall be clean and dry. Any scale, rust, cutting slag, grease, paint or dirt is to be carefully removed before welding (for overweldable shop primers, see Section 3.4.2.6.2). Moisture is to be removed by preheating. Edges (groove and root faces) are to have a smooth and uniform surface.

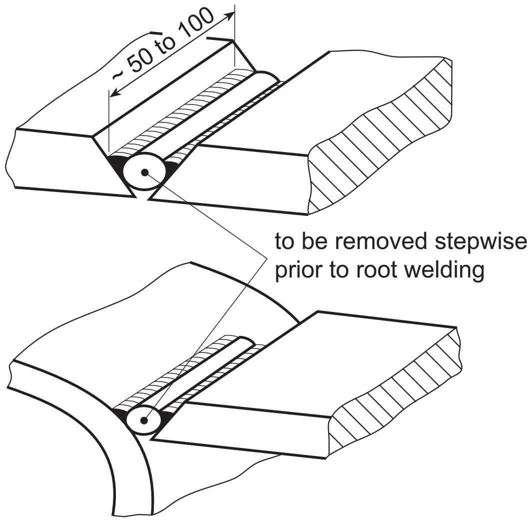


Fig. 3.4.15 Tack welding in one-side V-grooves

3.4.2.6.4 Weather protection, preheating

(1) The area in which welding is performed particularly outdoors - shall be sheltered from wind, moisture and cold. Where gas shielded arc welding is carried out, special attention is to be paid to ensuring adequate protection against draught. When working in the open under unfavourable weather conditions it is advisable to dry welding edges by preheating.

(2) At low (subzero) temperatures, suitable measures shall be taken to ensure the satisfactory quality of the welds. Such measures include the shielding of components, extensive preliminary heating and preheating - especially when welding with a relatively low heat input, e.g. when laying down thin fillet welds or welding thick-walled components. Wherever possible, no welding should be performed at temperatures below – 10 °C.

(3) The need for and the degree of preheating are governed by the following factors:

– the chemical composition and hence the hardening properties of the base material

– the thickness of the plate or component

– the rigidity, i.e. the internal shrinking stresses

– the ambient temperature and the temperature of the workpiece

– the heat input (energy applied per unit length of weld) when welding

– the mono- or multiaxial nature of the heat dissipation

Preheating may be as necessary for tack and auxiliary welds as for fabrication welds except for single pass tack welds, which are remelted and incorporated into final, continuous submerged arc welds.

(4) Apart from the measures prescribed in the paragraphs above mild steels do not normally require preheating. The following points may serve as a guide to the preheating of higher-strength steels: preheating is necessary where the temperature of the workpiece is below +5 °C. Where the workpiece temperature is above this level, preheating shall be applied to wall thicknesses of approximately 30 mm and over. The preheating temperature shall be between approximately 80 and 120 °C depending on the factors listed in Section 3.4.2.6.4 para 3. When welding, the interpass temperature should not exceed 250 °C.

Note:

In case of doubt, the need for and the degree of preheating shall be assessed by determining the likely temperature-time curve during welding (the cooling rate t 8/5) in accordance with [3.4] Annex 1, and by reference to the manufacturer's instructions concerning the most suitable cooling time t 8/5 for the base material in question. For the limit thicknesses for the preheating of high-strength (quenched and tempered) fine-grained structural steels with minimum yield points over 355 N/mm^2, see [3.4].

(5) Preheating shall be applied uniformly throughout the thickness of the plate or component and to a distance of 4 times the plate thickness, though not more than 100 mm, on both sides of the weld. Local overheating ist to be avoided. Preheating with gas burners should be performed with a gentle, though not sooty, flame. The preheating temperature shall be kept constant throughout the duration of the welding work.

3.4.2.6.5 Welding positions, welding sequence

(1) Welding should be performed in the optimum welding position, and welding in unfavourable positions shall be limited to the indispensable minimum. For similar and repetitive welding operations it is advisable to use a (rotary) jig enabling all welds, as far as practicable, to be made in the downhand position. Vertical-downward welding may not be used to join special and primary structural members.

(2) The welding sequence shall be chosen to allow shrinkage to take place as freely as possible and to minimize shrinking stresses. In special cases, GL Wind may require to set down the assembly procedure and welding sequence in an appropriate schedule.

3.4.2.6.6 Weld quality requirements

(1) The requirements to be met by the weld e.g. seam geometry, surface quality, admissible external and internal flaws depend on the significance of the respective welds for the overall integrity of the structure. The operability of individual components as well as the kind of loading (static-dynamic) and the stress level shall also be considered.

(2) The requirements to be met by the welds are to be laid down in the plans for production, inspection and testing e.g. drawings, specifications, etc. (see also Section 3.4.3.1.6 para 4) on the basis of relevant standards e.g. EN ISO 5817, quality level B and taking into account the criteria as stated in Section 3.4.2.6.6 para 1. These particulars are to be presented to GL Wind for review and approval. For inspection and testing of welds, see Section 3.4.3.

3.4.2.6.7 Repair welding

(1) For repair welds generally the requirements are identical to those applicable to the original weld. Prior to carrying out extensive repair welds or to repetition of repair welds, e.g. owing to inadequate results of non-destructive inspections, consultation with the GL Wind Surveyor shall be sought. The kind and scope of envisaged repair measures have to be agreed with him. For examination of repair welds, see Section 3.4.3.1.6 para 7.

(2) Where possible, minor surface defects have to be repaired by grinding only, ensuring smooth transitions from the ground area to the workpiece or welding seam surface. Extensive defects have to be gouged carefully, examined and welded. Due consideration of welding procedure specifications shall be made. If in one seam section several flaws requiring repair are located close to each other, the whole seam section has to be gouged and welded anew.

(3) In general, major repair welds at parts which have already undergone post-weld heat treatment, necessitate another heat treatment of the whole part. GL Wind may agree to local post-weld heat treatment or - in the case of minor repair welds - dispense with it completely; this has to be decided in each individual case.

3.4.2.6.8 Post-weld heat treatment

(1) Stress-relief annealing will be dealt with in the following under the heading of "post-weld heat treatment". Should other kinds of post-weld heat treatment be intended, then agreement shall be sought from GL Wind, who will consider the conditions on a case to case basis.

(2) Post-weld heat treatment should generally be performed at structural welds of joint exceeding the thickness limitations given in Appendix B, unless adequate fracture toughness can be proved in the as welded condition by evaluation based on fracture mechanics testing and analysis, e.g. in accordance with BS 7910. For restrained joints of complicated design, postweld heat treatment may be required for thicknesses less than given in Appendix B.

(3) Any heat treatment is to be performed in accordance with a procedure specification, to be prepared by the manufacturers and submitted to GL Wind for approval. This specification shall detail heating facilities, insulation, control devices and recording equipment as well as rated heating and cooling, temperature gradients, holding temperature ranges and times.

(4) Wherever possible, post-weld heat treatment shall be carried out in an enclosing furnace. Where this is impractical, local heat treatment may be performed with the consent of GL Wind. When local heat treatment is performed, an area extending over at least 3 times the material thickness on both sides of the weld is to be kept at the specified temperature.

(5) Any heat treatment cycle is to be recorded using thermocouples equally spaced externally and whenever possible - internally throughout the heated area. The heat treatment records are to be submitted to the GL Wind Surveyor. Regarding inspections and testing after heat treatment see Section 3.4.3.1.6 para 5.

3.4.2.6.9 Production tests

(1) Production tests, i.e. test pieces welded simultaneously at specified intervals during fabrication may be called for where the base material, the welding process or the loading conditions require that proof be provided of the sufficient mechanical characteristics of the welded joints produced under fabrication conditions.

(2) Production test pieces shall be welded and tested in a manner analogous to that prescribed in Section 3.4.2.3.3 in connection with welding procedure qualification tests. The scope of the tests and the requirements to be met shall be determined on a case to case basis.

3.4.2.6.10 Underwater welding

(1) Underwater welding - it may be used for construction and repairs - is generally to be carried out in a large chamber from which the water has been evacuated (habitat welding). Underwater wet welding, characterized by the arc working in the water or in a small gas-filled confinement, is normally restricted to minor repair work at secondary structures only in shallow water and requires the special consent of GL Wind from case to case.

(2) Underwater welding is to be performed in accordance with a detailed procedure specification to be prepared by the manufacturers and submitted to GL Wind for approval. It is to be carried out using especially qualified welding procedures (see Section 3.4.2.3.6) and by special qualified welders (see Section 3.4.2.4.2). The transfer and handling of welding consumables as well as redrying (baking) and storage in the welding habitat shall be considered in the welding procedure specification.

(3) Production test welds are to be carried out prior to commencing the underwater welding at the site in a manner which, as far as possible, reproduces the actual welding conditions thus checking that all systems are properly functioning and results in sound welds. The production test welds are to be visually inspected and non-destructively tested prior to production welding. Subsequently they are to be subjected to mechanical and technological testing. Type and number of test pieces and tests are to be specified and agreed to by GL Wind from case to case.

(4) Visual inspections and non-destructive testing are to be carried out on the actual production welds by competent operators, applying qualified and approved procedures (see also Section 3.4.3). The methods and extent of inspections and testing are to be specified and agreed by GL Wind from case to case. The finished welds are to fulfil the requirements specified for the individual structural parts or welds respectively.

(5) All underwater welding work, including qualifications, production tests, actual welding data and inspection and test results are to be recorded. The records are to be submitted to GL Wind for review and shall be kept for 5 years (see Section 3.4.3.1.1 para 7).

3.4.3 Inspection and testing of steel structures

3.4.3.1 General

3.4.3.1.1 General requirements

(1) Inspection and testing shall be performed by the manufacturers after finishing the steel structures or parts of it. These inspections and tests shall ensure that the structure and welds meet the requirements of this Guideline, the approved drawings and specifications or any other requirements stated or agreed upon.

(2) Inspection and testing are to be carried out in the fabrication, construction, and erection phases. For the quality control required during fabrication and construction, see Section 3.4.1.3.

(3) Manufacturers will be responsible for the due performance of the inspections and testing as required, as well as for compliance with the requirements laid down in the documents. Inspections performed by GL Wind do not relieve manufacturers of this responsibility.

(4) The GL Wind Surveyor shall have the opportunity of witnessing and observing the inspections and tests conducted. To this effect the Surveyor shall have permission to enter production areas and building sites and be assisted, wherever possible.

(5) Following inspection and testing by the manufacturers the structures or parts thereof are to be presented to the GL Wind Surveyor for final checking. Parts are to be presented in suitable sections enabling proper access for inspection, normally before painting. The Surveyor may reject components that have not been adequately inspected and tested by the manufacturers and may demand their resubmission upon successful completion of such inspections and corrections by the manufacturers.

(6) Assessment of defects (e.g. weld defects), which are identified by their nature, location, size and distribution shall take due account of the requirements applicable to the welded joints (see Section 3.4.3.1.6 para 4). Inspection or testing results respectively shall be evaluated by the testing department and/or the welding supervisory staff and submitted to GL Wind for recognition. The final assessment, together with the right of decision as to the accept or repair of defects in the material or weld shall rest with the GL Wind Surveyor.

(7) Reports shall be prepared on all (initial and repeat) inspections and tests, and these shall be submitted to the GL Wind Surveyor together with other documentation (e.g. radiographs) for review. The reports shall contain all the necessary details relating to the particular test method used (see Section 3.4.3.2.5 para 5, Section 3.4.3.3.7, and Section 3.4.3.4.4), the position at which the test was performed and the results obtained. The reports should at any time, during fabrication and construction, as well as during erection and installation, permit of unequivocal tracing of tested areas and test results. Test reports and documentation shall be kept for 5 years.

3.4.3.1.2 Standards, codes

(1) The standards, codes etc. mentioned constitute an integral part of this Guideline and require no special consent. The version in force on the date of publication of this Guideline shall be applied. New editions of the standards, codes etc. may be used in agreement with GL Wind.

(2) The application of other equivalent standards, codes etc. may be agreed to by GL Wind. They are to be listed in the construction particulars, e.g. in the inspection and testing plans and specifications, and presented to GL Wind on request.

(3) Where the standards, codes etc. are contradictory to this Guideline, the latter shall automatically take precedence. Any deviations from this Guideline require approval by GL Wind on a case to case basis.

3.4.3.1.3 Terms and definitions

The terms and definitions as contained in recognized standards, codes etc. are to be employed. The standard or code used is to be indicated in the inspection and testing documentation and presented to GL Wind on request. Any other deviating terms and definitions are to be explained separately in the inspection and testing specifications.

3.4.3.1.4 Testing equipment

(1) The testing facilities and equipment employed have to meet the latest technical standards and have to be in perfect condition. If manufacturers do not possess equipment of their own, they may use test equipment of third parties, e.g. testing institutes. GL Wind has to be informed accordingly, see also Section 3.4.3.1.5 para 3.

(2) The equipment has to be calibrated and/or gauged and the respective certificates have to be on hand.

(3) GL Wind may check the equipment or insist on having the equipment checked in the presence of their representative. Ultrasonic testing equipment and accessories may be checked within the scope of examining the testing personnel as per Section 3.4.3.1.5 para 4.

3.4.3.1.5 Inspection and testing personnel

(1) Inspection and testing personnel have to be qualified for and experienced in the respective testing method. Qualification has to be proved accordingly.

(2) Preparation and performance of testing have to be supervised by higher qualified supervisory personnel, whose qualifications have to be submitted to GL Wind.

(3) The testing personnel shall be independent of the production organization, see also Section 3.4.1.4 para

2. An organization chart is to be submitted to GL Wind. If manufacturers do not have their own testing personnel, they may use personnel of other companies or testing institutes. GL Wind has to be informed accordingly, see also Section 3.4.3.1.4 para 1.

(4) GL Wind reserve the right to examine the personnel for ultrasonic testing under actual working conditions at the construction site, see also Section 3.4.3.1.4 para 3.

3.4.3.1.6 Methods and extent of inspection and testing, schedule

(1) The methods of inspection and testing to be applied in each instance shall be selected with due consideration for the test conditions (shape and size of the weld, nature and location of possible defects, accessibility) so that any defects may be reliably detected. The methods of inspection and testing shall be agreed to by GL Wind. GL Wind may stipulate that two or more inspection and testing techniques respectively be used in conjunction.

(2) A complete visual inspection shall be performed after finishing the steel structure or parts of it. The inspection shall ensure completeness, correct dimensions and satisfactory workmanship meeting the requirements and the standards of good practice. For quality control during fabrication and construction work, see Section 3.4.1.4. A written report shall be prepared, confirming the visual inspection and indicating major corrections. The report is to be submitted to the GL Wind Surveyor prior to the final checking according to Section 3.4.3.1.1 para 5.

(3) Non-destructive inspections and testing (NDT) are to be performed at the weld connections according to their importance when considering overall integrity of the structure, type of load, stress level and their later (in-service) accessibility. A minimum scope of non-destructive inspections and testing is given in Table 3.4.3 for the categorization of structural members (cf. Section 3.3.2.2); the relevant weld connections are to be subdivided accordingly.

(4) The respective inspection and testing plans as well as relevant specifications shall be compiled by the manufacturers for each structure taking into consideration their individual design and stress conditions. These plans and specifications shall contain the scope and methods of inspection and testing as well as the acceptance limits for surface and internal weld defects. These limits are intended to be used for the assessment of the welds in accordance with common standards, e.g. EN ISO 5817, quality level B (see Section 3.4.2.6.6). Particularities depending on materials and processes (possibilities for faults) have to be considered besides the stresses. Plans and specifications are to be submitted to GL Wind for approval.

(5) All non-destructive testing of complicated and heavy structures (e.g. tubular node joints and other, thickwalled F-, Y- and K-connections) shall be performed not earlier than 48 hours after weld completion in order to be able to detect delayed cracking. Where components are subjected to postweld heat treatment, the non-destructive testing shall be performed after this heat treatment.

(6) Should the inspections and tests reveal defects of any considerable extent, the scope of the tests shall be increased. Unless otherwise agreed, tests shall then be performed on two further sections of weld of the same length for every weld section tested and found to be in need of repair. Where it is not certain that a defect is confined to the section of weld under test, the adjoining weld sections shall be additionally tested. GL Wind may stipulate further inspections and tests, especially in the event of doubts as to the professionally competent and satisfactory execution of the welds.

(7) Repaired welds shall be re-inspected. Where welds have been completely remade, retesting at least equal in scope to the initial inspections shall be performed in accordance with the Surveyor's instructions. Re-inspections are to be identified as such in test reports and on radiographs, e.g. by a letter "R" (= repair) placed next to reference of the radiograph.

3.4.3.2 Radiographic testing

3.4.3.2.1 Radiation sources, appliances

(1) Wherever possible, X-ray units shall be used as radiation sources for radiographic testing. The radiation energy (tube voltage) should lie within the limits specified in EN 1435 (consistent with EN 444). Allowing for the differences in thickness of the component, the radiation energy (tube voltage) should be kept as low as possible within the permissible working range so as to obtain a high-contrast image.

(2) Where justified in exceptional cases (e.g. by lack of accessibility), gamma ray sources - preferably Ir 192 - may be used, subject to the consent of GL Wind in each instance.

Table 3.4.3 Minimum scope of non-destructive inspections and testing [1]

Type of connection \ Category	Special structural members (welding)			Primary structural members (welding)			Secondary structural members (welding)		
	RT	**UT**	**MT**	**RT**	**UT**	**MT**	**RT**	**UT**	**MT**
Butt welds	10 % [2]	100 % [2]	10 %	10 % [2]	100 % [2]	10 %	spot	spot	spot
T-joints (full penetration)	—	100 %	100 %	—	100 %	100 %	—	spot	5 %
T-joints	—	[3]	100 %	—	[3]	100 %	—	—	spot
Fillet welds	—	—	10 %	—	—	10 %	—	—	spot

[1] All welds which will become inaccessible or very difficult to inspect in service are to be non-destructive tested over their full length

[2] Up to weld thickness of 30 mm ultrasonic testing (UT) may be replaced by radiographic testing (RT) up to an amount of 100 %

[3] Where partial penetration T-joints are admissible in highly stressed areas, an ultrasonic testing to determine the size of incompletion and the soundness of the welds may be required.

3.4.3.2.2 Films, intensifying screens

(1) The selection of film classes (cf. EN 584-1) used for radiographic testing shall be in accordance with EN 1435, Table 2.

(2) Front and rear 0.02 mm lead screens shall normally be used when radiographing steel. During radiography, the film and the screens shall be kept in intimate contact in suitable cassettes, packs, etc.

(3) The use of salt intensifying screens and fluorometal screens is not allowed.

3.4.3.2.3 Radiographic parameters

(1) The radiographic parameters prescribed in EN 1435 for test category A (General inspection procedure) are to be applied. For radiographic inspection using X-rays and a film length of 480 mm, the distance between the film and the focal point should normally be 700 mm and in any case not less than the length of the film. In special cases GL Wind may stipulate test category B (Higher-sensitivity inspection procedure).

(2) Any impurities on the surface of the work piece liable to impair the interpretation of the image are to be removed prior to the radiographic inspection together with any visible welding defects and damage. Traces of auxiliary welds are also to be removed. In special cases (e.g. where the surface of the weld is very rough or where the image quality is subject to special requirements), grinding of the weld faces may be required.

(3) In order to determine the image quality, at least one image quality indicator to EN 462-1 (wire type) shall, for each radiograph, be laid on the side of the weld away from the film and facing the radiation source and shall be radiographed together with the weld. Should this be impossible, the image quality indicator may, with the consent of GL Wind and after the preparation of comparative radiographs designed to determine the changed index of image quality, be fixed to the workpiece on the side close to the film (i.e. between the film and the weld). The film image shall be marked to indicate that this arrangement was used.

(4) Each film image shall be clearly and unmistakably marked by lead figures or letters simultaneously irradiated and depicted on the film. This identification shall be the same as that given in the test plan and shall enable any defects found to be readily located. The marking is to be located outside the weld area being inspected (weld width plus at least 10 mm on each side).

3.4.3.2.4 Film processing, density, image quality

(1) The films shall be processed in properly equipped darkrooms in such a way as to avoid any blemishes which interfere with their evaluation (e.g. fog density, scratches, dark crescent-shaped marks due to kinks in the film, etc.). The instructions and recommendations issued by the film and chemical manufacturers are to be followed. Premature interruption of the developing process and the reduction with chemicals of overexposed films is not allowed.

(2) The density “S” of radiographic images shall be at least 1.5 over the entire area for evaluation. The upper limit value depends on the brightness of the film viewers available for the evaluation, but should not exceed 2.5 with 3.0 as the maximum figure. Wider density differences within a single radiograph are to be avoided.

(3) The image quality shall be determined with an image quality indicator prescribed in Section 3.4.3.2.3 para 3 and in accordance with EN 462-3. For category A inspection (see Section 3.4.3.2.3 para 1), image quality B is desirable for steel, with image quality A as the minimum requirement. In the case of aluminium alloys and test category B, image quality B shall be attained. The criterion in each case is the smallest wire of the image quality indicator which is still visible in the area of the weld.

3.4.3.2.5 Viewing conditions, evaluation

(1) Viewers with a luminous density to EN 25580 sufficient for the required film density shall be used for the examination and evaluation of radiographs. Stops shall be fitted to enable the field of view to be adapted to the film size for, or capable of, evaluation. The brightness shall be adjustable.

(2) The viewing and evaluation of radiographs should take place in a dimly lit though not completely darkened room. Evaluation should only be performed after a sufficient period has been allowed for adaptation. Bright, dazzling areas within the field of view are to be screened. The use of magnifying glasses for the detection of fine details may be beneficial.

(3) The reference numbers given in EN ISO 6520-1 are to be used to identify weld defects in the test report.

(4) Initial evaluation shall be performed by the testing department and/or the welding supervisory of the manufacturers. Thereafter the films (the initial and the follow-up radiographs) shall be submitted to the GL Wind Surveyor for assessment together with the test reports. The assessment shall be made with due regard for the details provided above by the instructions “acceptable” or “not acceptable”.

(5) The following information is to be given in the test report, together with explanatory sketches where necessary:

– works number, component, test schedule number, inspection positions
– radiation source and size of tube focus or of emitter
– tube voltage or activity at time of inspection
– radiographic arrangement of EN 1435, position of wire penetrameter
– thickness of workpiece or weld, as appropriate
– type of film and nature and thickness of intensifying screens
– test category, image quality index and image quality class
– symbols denoting defects and assessment

The test report shall also indicate whether the information relates to an initial radiograph or to a follow-up inspection after repair work has been carried out (cf. Section 3.4.3.1.6 para 6).

3.4.3.3 Ultrasonic testing

3.4.3.3.1 Testing staff

(1) The staff performing ultrasonic tests shall be trained in the special field concerned and shall possess adequate practical experience. Their professional competence shall be documented by certificates relating to courses and tests which they have undergone and/or by a statement of the practical testing work in which they have hitherto been engaged.

(2) The competence of the testers, together with the test units, inspection method etc., will be verified by GL Wind or another competent and independent authority recognized by GL Wind (see also Section 3.4.3.1.4 para 3 and Section 3.4.3.1.5 para 4). Application for such verification, together with the following information and documents, shall be made to GL Head Office:

– documentary proof of the professional training of testing staff and, where appropriate, of test supervisors
– description of testing equipment (test units, probes, etc.)
– description of the test method (instrument setting, angles and direction of incidence, instrument sensitivity, etc.)
– method of determining size of defects
– form of test report

After successful verification, recognition and authorization may be granted for the independent performance of certain tests under the responsibility of the works’ staff.

(3) GL Wind reserves the right to carry out random monitoring inspections to verify the test reports compiled by the works’ testers or to require that such monitoring inspections be performed by a second testing body independent of the works. If the results of these inspections deviate substantially from those of the initial tests performed by the works, the scope of the monitoring inspections may be extended so far as to equal that of the prescribed initial tests.

3.4.3.3.2 Test appliances and accessories

(1) The test appliances, probes and other accessories (calibration and reference blocks for adjusting the sensitivity, reference scales, etc.) shall conform to the state of the art and to the relevant standards (e.g. EN 12223, EN 27963, EN 1714 or EN 583).

(2) All possible echo heights within the range of instrument sensitivity used shall be capable of being determined with the aid of an amplification control calibrated in dB and a suitable scale marking on the display. The interval between the switching stages shall not exceed 2 dB. Instruments not equipped with a calibrated amplification control may not be used.

(3) Stepless controls shall enable the ranges of adjustment available on the instrument to be juxtaposed, as far as possible without any intervening gap. Within each individual range the time sweep shall be continuously adjustable.

(4) With regard to the geometrical characteristics of the sound field, especially the incidence and squint angles, the test frequency and the resolution, the probes shall lie within the tolerances specified in the standards mentioned above. The incidence and squint angles shall not in either case deviate by more than 2° from the nominal value or from the centre line of the probe. The angle of incidence and the probe index (of angle beam probes) shall be verified.

3.4.3.3.3 Calibration, sensitivity setting

(1) The distance signal (time sweep) may be optionally calibrated in projection distances “a”, shortened projection distances “a'”, sonic distances “s” or, if possible, depth positions “b”. Unless otherwise agreed, calibration in shortened projection distances “a'” shall be preferred for weld inspections, or in sonic distances “s” for parts of complex shape (e.g. tubular joints acc. to Fig. 3.4.18).

(2) For calibrations in accordance with (1) a calibration block according to EN 12223 or EN 27963 shall be used for testing structural steels. Appropriate calibration or reference blocks shall be used for materials having other sound velocities (e.g. high alloy steels). Bore holes used for calibration shall not be larger than 2 mm and shall lie parallel to the testing surface. Where possible, calibration should not be performed at edges.

(3) Depending on the intended method of echo height definition, the sensitivity setting shall be performed using calibration reflectors of known shape, position and size (e.g. large flat reflectors, sidedrilled holes) in accordance with the provisions of EN 1714. Unless otherwise agreed, the DGS (Distance Gain Size) method of inspection shall be used. With the DGS method, the sensitivity setting is to be carried out in accordance with the instrument manufacturer’s instructions using calibration blocks to EN 12223 and EN 27963. Flat bottom holes and grooves should not be used as calibration reflectors.

(4) If necessary (e.g. for defects close to the surface), the sensitivity setting is to be corrected in accordance with EN 1714. In testing unalloyed and low alloy structural steels and where the sonic distances are not too large (cf. EN 1714), the sound attenuation may normally be disregarded. A transfer correction to determine the coupling differences between the surface of the reference block and that of the test piece shall, however, be performed in every case. The value of the transfer correction shall be stated in the test report.

(5) For more efficient detection of defects it is recommended that the work should be performed with a test sensitivity (search sensitivity) increased by approximately 6 dB over the chosen registration level (see Section 3.4.3.3.6). However, the registration level setting is generally to be used when evaluating defect indications. All echo indications to be registered shall attain at least 20 % of the display height even at the maximum sonic distance (cf. EN 1714). In the case of electrogas-welded seams, the inspection shall normally be performed with a sensitivity increased by 12 dB, and this fact shall be expressly stated in the test report with a reference to the welding process (e.g. EG + 12 dB).

3.4.3.3.4 Surface preparation, coupling

(1) On both sides of the welded seam (cf. Section 3.4.3.3.5 para 1) the testing surfaces shall be smooth and free from impurities liable to interfere with coupling. Rust, scale and weld spatter are to be removed so that the probes lie snugly against the surfaces, which should if necessary be ground. Firmly adhering paint need not be removed provided that it does not interfere with the inspection and quantitative allowance can be made for the resulting loss of sensitivity when evaluating the echo heights.

(2) Where angle beam probes have to be applied to the surface of the weld for the inspection of transverse defects (see Section 3.4.3.3.5 para 3), this shall also be prepared in the manner of the testing surfaces described above. Notches, grooves and the like lying across the beam axis which produce false indications and may impair the test are to be removed.

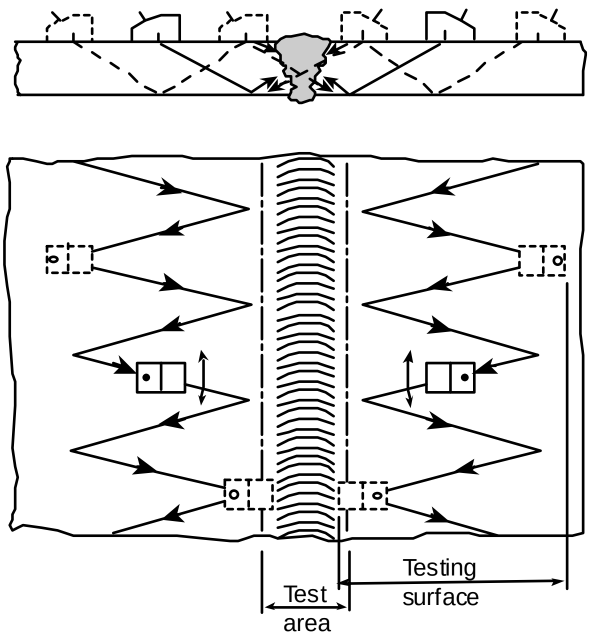


Fig. 3.4.16 Testing for longitudinal defects in butt welds

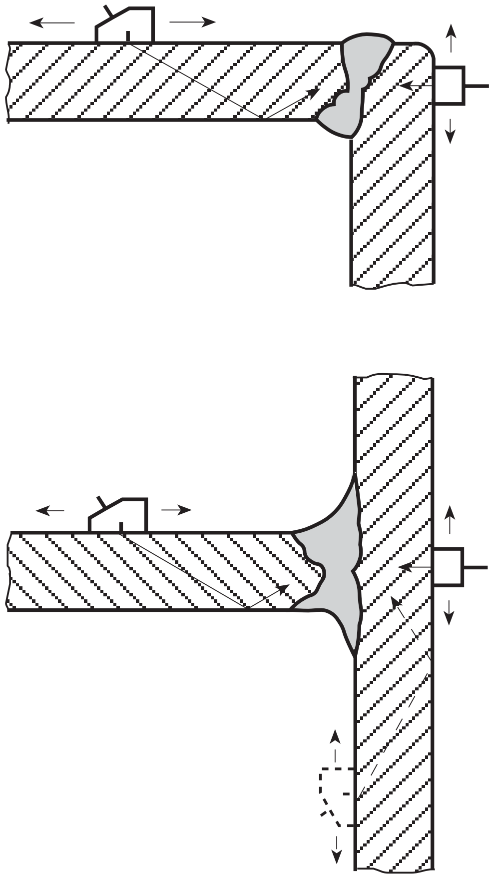


Fig. 3.4.17 Testing for longitudinal defects in corner and T-joint

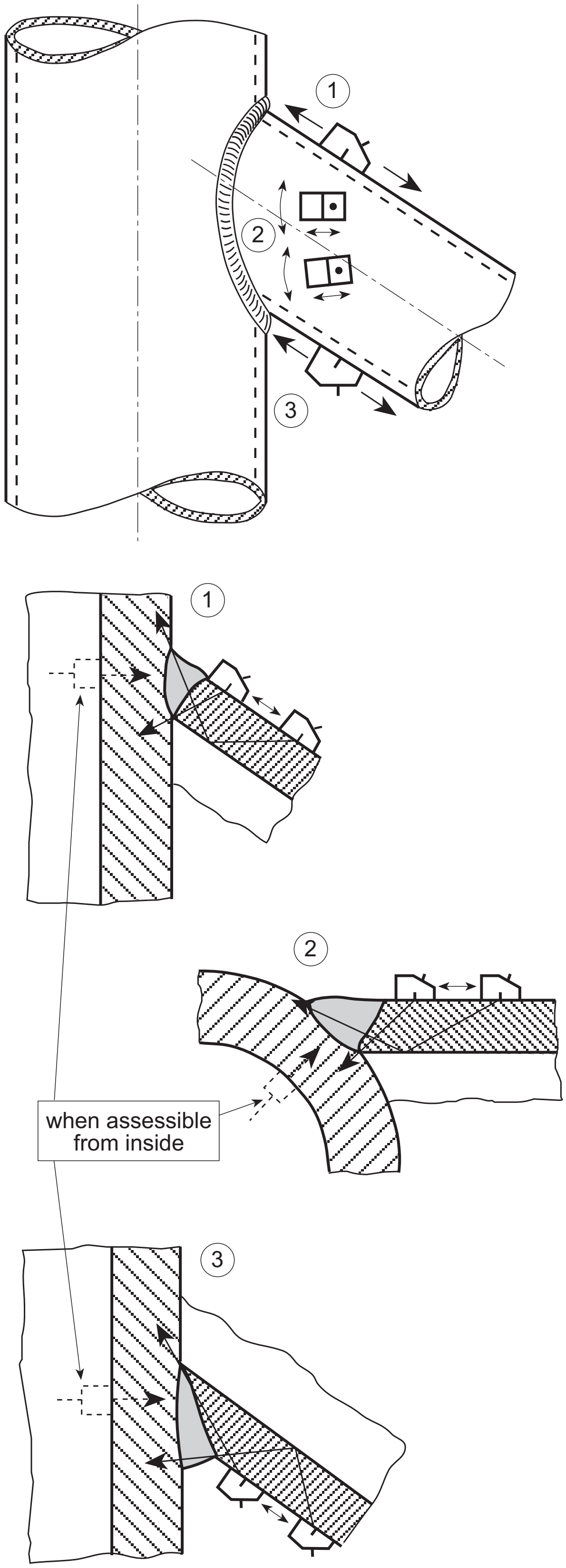


Fig. 3.4.18 Testing for longitudinal defects in tubular joints

(3) Coupling to the testing surfaces prepared in accordance with Section 3.4.3.3.4 para 1 should be as uniform as possible and shall not vary by more than ± 4 dB. If greater variations are found, the state of the surface shall be improved. Where greater variations cannot be avoided, this fact shall be stated in the test report. Flowing water, cellulose glue, oils, fats or glycerine may be used as coupling media.

3.4.3.3.5 Test directions, angle of incidence

(1) Unless otherwise agreed or stipulated, testing for longitudinal defects shall be performed from one surface and from both sides of the weld, as shown in Fig. 3.4.16. The testing area shall embrace the weld metal itself and an area on both sides of the seam equal to about 1/3 of the wall thickness, subject to a minimum of 10 mm and a maximum of 20 mm. The testing area shall encompass a width equal at least to the full skip distance plus twice the length of the probe.

(2) Depending on the weld geometry and the possible orientation of defects it may be expedient to perform the test from both surfaces or (e.g. in the case of bevels) from only one side of the seam. With corner and T-joints, the test shall normally be performed both from the side of the web using an angle probe and from that of the continuous (flange) plate using a standard probe, as shown in Fig. 3.4.17. Such probe arrangements differing from Section 3.4.3.3.5 para 1 shall be especially noted in the test report. The same applies in analogous manner to curved surfaces such as shown in Fig. 3.4.18 in case of tubular connections.

(3) Testing for transverse defects is to be performed from both sides of the weld in two directions along the seam as shown in Fig. 3.4.19 or where the test requirements are more stringent - on the ground surface of the weld. GL Wind may require that testing for transverse defects be performed with two probes connected in parallel. Where welds are made with a large weld pool (as in electroslag welding), testing for oblique defects shall also be performed at an angle of approximately 45° (cf. EN 1714).

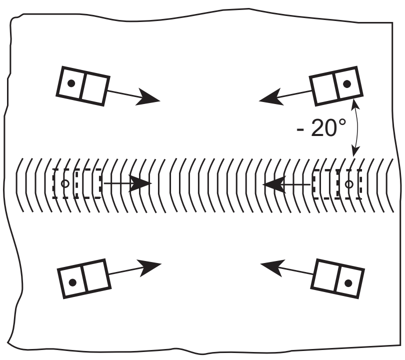


Fig. 3.4.19 Testing for transverse defects

(4) With plate thicknesses (weld thicknesses) of less than 30 mm, testing may be performed with an angle of incidence of 70°. With thicknesses of 30 mm and over, two angles of incidence (70° and 45° or 60°) shall be used. Where the surface is curved, the necessary angle of incidence shall be determined in accordance with EN 1714. With very large wall thicknesses (above about 100 mm) the inspection shall be performed using a tandem technique (with fixed, mechanical coupling of two similar probes) for different depth zones.

3.4.3.3.6 Registration level, evaluation of echo indications, acceptance limits

(1) For tests carried out by the DGS method, the registration level (reference reflector size) for longitudinal and transverse defects is given by the diameters of the disc shaped reflectors specified in Table 3.4.4 in relation to the wall thickness (weld thickness). Where the thickness is greater than 60 mm the registration level will be determined on a case to case basis. For tandem testing the registration level shall be determined by a 6 mm diameter disc shaped reflector. For other methods of echo height definition (e.g. the reference block method) the registration level shall be determined in accordance with EN 1714.

(2) The registration of non-form-related echo indications which are observed when inspecting welded joints and whose echo heights attain or exceed the registration level (reference reflector size) specified in Section 3.4.3.3.6 para 1 is required only where expressly stipulated by GL Wind or where subsequent repeat tests have to be performed. Otherwise only those echo indications shall be registered which exceed the repair limit value specified in Section 3.4.3.3.6 para 4.

(3) For the classification of echo indications it shall be stated by how many dB the maximum echo height of the reflections found differs from the registration level defined in Section 3.4.3.3.6 para 1. In the case of the DGS method, the size of the (substitute) disc shaped reflector may also be stated. Further characteristics to be stated are the registration lengths and half-value depths in accordance with EN 1714. The location of reflexions shall be defined by coordinates indicating the ‘longitudinal and transverse distances from a reference point’ and the ‘depth position’.

(4) Echo indications produced by longitudinal defects which exceed the acceptance limit values shown in Table 3.4.5 (Excess of registration lengths and/or echo heights above the registration level shown in Table 3.4.4) shall be regarded as weld defects which shall be repaired. Continuous echo indications which point to systematic weld defects (such as root defects due to incomplete penetration or rows of pores) call for repairs even if the repair limit values are not attained. Echo indications which point to the presence of cracks necessitate repairs in every case.

(5) Echo indications produced by transverse defects shall in every case count as weld defects requiring repair unless they can be unequivocally associated with the indications produced by longitudinal defects.

(6) Where the evaluation of echo indications gives rise to doubt regarding the need for repair, recourse may be had to radiographic inspection to help in the assessment (cf. Section 3.4.3.1.6). However, echo indications obtained with welded seams 30 mm or more in thickness which exceed the repair limit values specified in Table 3.4.5 invariably necessitate repair even if radiographic inspection fails to reveal any defects or fails to reveal them clearly.

Table 3.4.4 Registration levels

Wall thickness (weld thickness)	Diameter of dise 4 MHz	Shaped reflectors 2 MHz
≥ 10 up to 15 mm	1.0 mm	1.5 mm
> 15 up to 20 mm	1.5 mm	2.0 mm
> 20 up to 40 mm	2.0 mm	3.0 mm
> 40 up to 60 mm	3.0 mm	4.0 mm

(7) During testing of one side welded tubular intersection seams as per Fig. 3.4.18 the root area has to be specially assessed. Here, the acceptance limits as per Table 3.4.5 are not applicable. Depending on the envisaged seam shape, the details of analysis of indications from the root area have to be agreed with GL Wind from case to case.

3.4.3.3.7 Test reports

(1) Complete test reports as prescribed in EN 1714 and containing the information listed below shall be prepared for all ultrasonic tests in accordance with the test schedule (cf. Section 3.4.3.1.6 para 4). The test reports shall enable the inspections to be repeated identically. They shall be signed by the person performing the test and countesigned by the supervisor.

(2) The test reports shall contain the following details:

– clear identification of the test piece, the material, the welded joint inspected together with its dimensions and location (sketch to be provided for complex weld shapes and testing arrangements) and the welding process

– indication of any other regulations (e.g. specifications, standards or special agreements) applicable to the inspection

– place and time of the inspection, testing body and identification of the person performing the test

(3) Test reports shall contain at least the following specific details relating to the inspection:

– make and type of test equipment

– make, type, nominal frequency and angle of incidence of probes

– distance calibration (testing range)

– sensitivity setting (calibration reflector used, instrument sensitivity, registration level)

– correction values (for defects close to surface, transfer correction)

– test sensitivity

– surface preparation, coupling media

– testing surfaces, test directions, angles of incidence

(4) The test results - where these are to be stated in the report (cf. Section 3.4.3.3.6 para 2) - shall, wherever possible, be tabulated or shown on sketches with the following details:

– coordinates of defects with stated reference point

– maximum excess echo height (+...dB) above the given registration level (reference reflector size) or, where applicable, the diameter of the corresponding (substitute) disc shaped reflector

– defect characteristics (registration length, half-value depth)

Where echo indications below the acceptance limit values shown in Table 3.4.5 are also registered, each defect thus identified is to be allocated on assessment (e.g. acceptable or not acceptable).

3.4.3.4 Magnetic particle and dye penetrant testing

3.4.3.4.1 Test methods, test equipment, test media

(1) Wherever possible, the magnetic particle method as specified e.g. in EN 1290 should be used for testing magnetic materials for surface cracks. The use of the dye penetrant method as specified e.g. in EN 571-1 for magnetic materials is to be restricted to unavoidable, exceptional cases and requires GL Wind’s consent on each occasion. Non-magnetic materials (e.g. austenitic stainless steels and non-ferrous metals) are to be tested by the dye penetrant method.

(2) The test equipment and test media used shall conform to the state of the art and to the relevant standards (e.g. DIN 54130, EN ISO 9934 and EN ISO 3452). The magnetizing equipment shall be provided with markings or measuring devices which indicate the magnetizing current and field strength at any time. GL Wind may stipulate that measurements be performed to verify these data. On request, proof shall be furnished to GL Wind of the suitability of the test media employed.

(3) The acceptance levels shall conform to the state of the art and to the relevant standards (e.g. EN 1289 and EN 1291).

3.4.3.4.2 Magnetic particle inspection

(1) Wherever possible, magnetization shall be effected by passing a current through the work-piece or, in the case of minor localized inspections, by yoke magnetization using electromagnets or, if necessary, permanent magnets. In special cases (e.g. where burn marks have to be avoided at all costs or for circumferential welds), it may be expedient to effect magnetization with a live conductor (a cable or coil). A combination of different methods of magnetization for the detection of variously orientated defects is allowed.

(2) Where the current is passed through the work-piece, alternating, direct, impulse or surge current can be used. AC or DC magnets may be used for yoke magnetization. Where the magnetizing current is passed through the workpiece, fusible supply electrodes should be used to prevent burn marks. Where AC is used, fusible electrodes are obligatory.

(3) The effective magnetizing (tangential) field strength shall be at least 20 A/cm (25 Oe), but shall not exceed 50 A/cm (62.5 Oe). The adequacy of the magnetization shall be checked at the time of the test by suitable means (e.g. test indicator or with a tangential field strength meter).

(4) Magnetic particles suspended in suitable, readily volatile vehicle liquids shall be used as test media for revealing the leakage flux due to discontinuities in the material. These magnetic particles may be black or fluorescent. Where black magnetic particles are used, the surface to be tested shall be coated with a permanent white paint, applied as thinly as possible, to provide a contrast. The proportion of magnetic particles in the vehicle liquid shall conform to the manufacturer’s instructions and shall be verified (e.g. by means of a test indicator). Dry test media may only be used for tests at elevated temperatures (e.g. on root passes).

(5) The testing surfaces shall be free from loose scale, rust, weld spatter and other impurities. Notches, grooves, scratches, edges, etc., which can produce false indications, are to be removed prior to the test.

(6) Magnetization shall be effected, as shown in Fig. 3.4.20, in two different directions including an angle of not less than 60° and not more than 90° so as to enable variously orientated defects to be located.

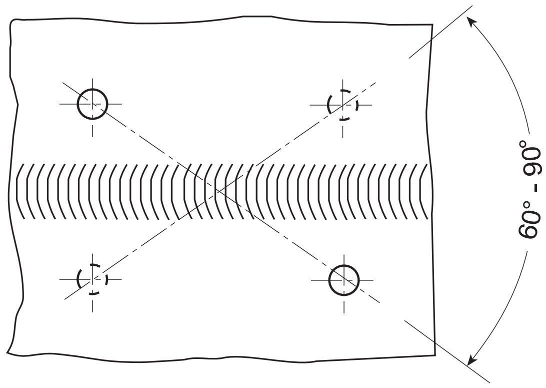


Fig. 3.4.20 Directions in which magnetization is to be effected

(7) Magnetization shall be continued at least as long as the testing surface is being sprayed with magnetic particle suspension and for as long thereafter as any movement of the vehicle liquid can be detected, subject to a minimum of 5 seconds. Testing under conditions of remanent magnetization is not permitted.

(8) Every accumulation of magnetic particles, not due to a false indication, indicates a discontinuity or crack in the material which is to be registered in the test report and repaired. In the case of small cracks (e.g. end crater cracks) this can be done by grinding. Larger cracks are to be worked out and repair welded.

3.4.3.4.3 Dye penetrant inspections

(1) Where possible, coloured dyes should be used as penetrant media, although fluorescent penetrants may also be used. The penetrant remover and the developer shall be compatible with the penetrant used. On request, proof shall be furnished to GL Wind of the suitability of the inspection system.

(2) To allow the penetrant to enter any defects present, the testing surfaces shall be completely freed from scale, rust, greases, oils, paints or electrodeposits before the penetrant is applied. During this operation care shall be taken to ensure that defects are not mechanically sealed by preliminary cleaning. The testing surfaces shall be dry. The temperature of the workpiece shall be between 5 °C and 50 °C.

Table 3.4.5 Acceptance limits for the ultrasonic testing

Quality level acc. to EN ISO 5817 [1]	Wall thickness [2] [mm]	Longitudinally orientated indication			Transversely orientated indications [4]		
		Number of indications per m seam length	Registration length [3] [mm]	Permissible excess echo height [dB]	Number of indications per m seam length	Registration lengt [3] [mm]	Permissible excess echo height [dB]
B	10...15	10 and 3 and 1	10 20 10	6 6 12	3	10	6
	> 15...20	10 and 3 and 1	10 20 10	6 6 12	3	10	6
	> 20...40	10 and 3 and 1	10 25 10	6 6 12	3	10	6
	> 40	10 and 3 and 1	10 30 10	6 6 12	3	10	6
C	10...20	10 and 3 and 1	15 30 10	6 6 12	3	10	6
	> 20...40	10 and 3 and 1	15 40 10	6 6 12	3	10	6
	> 40	10 and 3 and 1	15 50 10	6 6 12	3	10	6
D	10...20	10 and 3 and 1	15 50 10	6 6 12	5	10	6
	> 20...40	10 and 3 and 1	15 50 10	6 6 12	5	10	6
	> 40	10 and 3 and 1	20 50 10	6 6 12	5	10	6

1 See Section 3.4.2.6.5, 3.4.3.1.6.

2 Where the wall thickness differ, the lesser wall thickness (weld thickness excluding the weld reinforcement) is meant.

3 Where the wall thickness exceeds 60 mm, it is to be divided into test zones, each 60 mm thick, and is to be inspected from both faces. Each test zone is to be assessed separately. Test zones may overlap.
Continuous echo indications, which point to systematic weld defects (e.g. root defects due to incomplete penetration or rows of pores) call for repairs even if the repair limit values are not attained.

4 Echo indications of transverse defects are in any case to be regarded as indicating welding defects requiring repair. This does not apply, where echo indications can be unequivocally correlated to longitudinal defects.

(3) Any method of applying the penetrant may be used. Care shall be taken to ensure that the testing surface is completely wetted throughout the entire penetration time. The penetration time shall be chosen in accordance with the manufacturer's instructions but shall not be less than 15 minutes for workpiece temperatures of 15 °C and over or less than 30 minutes where the temperature is below 15 °C. The penetrant shall not become dry during the penetration period.

(4) Following penetration, the surplus penetrant shall be completely removed from the testing surface in such a way as to leave behind the portion lodged in possible defects. It is advisable first of all to wipe off the surplus penetrant with a cloth and only thereafter quickly to remove the remains with sparing use of the penetrant remover. The testing surface should then be dried as quickly as possible (max. 50 °C).

(5) The developer is to be applied evenly and as thinly as possible immediately after removal of the surplus penetrant and drying. The testing surface should be just covered. The developing time should be about the same as the time allowed for penetration. Visual inspection for defects shall begin as the developer is applied, but the final inspection can only take place after the expiry of the developing time. Paragraph Section 3.4.3.4.2 para 8 applies in analogous manner to the assessment.

(6) Should an unequivocal assessment of the indications be impossible, the entire inspection procedure, starting with preliminary cleaning, shall be repeated. Where necessary, the surface quality shall also be improved. The repeat inspection shall be performed using the same system as on the first occasion.

3.4.3.4.4 Test reports

(1) Complete test reports with full details of the performance of the test and the defects found shall be prepared for all surface crack inspections in accordance with the test schedule (cf. Section 3.4.3.1.6). These test reports shall be signed by the person performing the test and by the test supervisor.

(2) Test reports relating to magnetic particle inspections shall include the following details:

– details of the structural component and weld concerned
– method of magnetization
– type of current, and where appropriate the amperage, used for magnetization
– test arrangement (magnetizing equipment, distance between electrodes or poles)
– test media
– test results
– place and time of the inspection, testing body and identification of the person performing the test

(3) Test reports relating to penetrant medium inspections shall include the following details:

– details of the structural component and weld concerned
– test media (type, brand name)
– description of the test procedure (temperature of the workpiece, penetrant acting time, etc.)
– test results
– place and time of the inspection, testing body and identification of the person performing the test

Test reports shall conform to the form provided in Appendix B of EN 571-1.

3.4.4 Laminating fibre-reinforced plastics

3.4.4.1 Requirements for manufacturers

(1) All workshops, store-rooms and their operational equipment shall meet the requirements of the relevant safety authorities and employers' liability insurance associations. The responsibility for compliance with these requirements is solely the company's.

(2) The danger of contamination of materials for laminating shall as a rule be kept to a minimum by rigorous separation of production areas and other workshops as well as store-rooms. Only the quantity of materials required for production within the next two days shall be stored in the laminating workshops.

(3) Whilst laminating and gluing is progressing, dust-generating machinery may be operated in the laminating workshop only to a limited extent and only if fitted with a dust collection unit. Painting or spraying work is only permissible within the laminating workshop if the company can ensure that such activities will not affect the laminating quality.

3.4.4.2 Laminating workshops

(1) Laminating workshops shall be totally enclosed spaces capable of being heated as well as having ventilation supply and exhaust equipment. An ambient temperature of between 16 °C and 25 °C with a maximum relative humidity of between 20 % RH and 75 % RH shall be maintained as a rule during laminating work and curing. If the manufacturers of the laminating resins or adhesives have specified other processing temperatures, these shall apply.

(2) Thermographs and hygrographs shall be provided for monitoring the climatic conditions, whereby it shall be possible to read off the climatic conditions directly at any time. The location of the instruments shall be agreed with GL Wind, their number and arrangement depending on the operational conditions. The instruments shall bear valid calibration marks; the records on the climatic conditions shall be kept for a period of at least 10 years and submitted to GL Wind on demand.

(3) The provision of ventilation supply and exhaust equipment shall be such that an impairment of the materials is excluded and e.g. no unacceptable amounts of solvent are extracted from the laminate.

(4) The work places shall be illuminated in a suitable manner, precautionary measures being taken to prevent the controlled curing of the laminating resin from being impaired by the light from either the sun or the light fitting.

(5) The laminating workshops shall be of adequate size (floor area and ceiling height), in order that the components are easily accessible and the intended production processes can take place without hindrance.

3.4.4.3 Store-rooms

(1) Laminating resin compounds and adhesives shall be stored according to the manufacturer's instructions. The temperature in the store-rooms shall be recorded continuously.

(2) Prepregs shall be stored in special refrigerated compartments in accordance with the manufacturer's instructions. The temperature shall be recorded continuously.

(3) Reinforcing materials, core materials, fillers and additives shall be stored within closed containers in dust-free, dry conditions. The humidity in these spaces shall be recorded continuously and should not exceed 70 % RH or 80 % RH for short periods.

(4) Storage shall be arranged in such a way that the designation of the materials, and the storage conditions and maximum storage periods (expiration dates) prescribed by the manufacturer, are easily visible. Materials whose storage period has been exceeded shall be marked as being prohibited for use and then removed from the store as soon as possible.

(5) Quantities of materials due to be processed shall be brought to the processing rooms in good time to allow them to adjust properly ($\Delta T \leq 2$ °C) to the processing temperature with the packaging remaining sealed.

Note:

This temperature adjustment is necessary to ensure that the dewpoint is not reached.

(6) Packages removed from store and opened may be returned to store only in defined cases (e.g. hot-curing prepregs).

3.4.4.4 Processing requirements

(1) If rotor blades, shafts or other components are manufactured from FRP for mounting on or installation in offshore wind turbines and if an application for project certification has been submitted for the offshore wind turbine, then as a matter of principle only materials approved by GL shall be used for production. As well as suitable and approved materials being selected, their processing shall be treated with special care because of its significant influence on the properties of the product.

(2) Prior to the commencement of production, the manufacturer shall convince himself that the materials can be combined and are suitable for the intended process.

(3) For the preparation and processing of the resin compounds, the instructions of the material manufacturer plus any other applicable regulations, such as those of the relevant safety authorities and employers' liability insurance associations, shall be observed in addition to this Guideline.

(4) Resin and reaction agent shall be mixed in such a way that they are evenly distributed, care being taken to beat in as little air as possible. There may be cases where de-gassing of the resin compound under vacuum is necessary.

(5) If rigid plastic foam is used as the core material, this shall be de-gassed beforehand and if necessary tempered. In particular for slotted core materials, it shall be ensured that the material properties which were established as a basis within the scope of verification are achieved during the processing activities.

(6) During production, the processing time for the mixed resin compound specified by the manufacturer shall not be exceeded. In the absence of such information, the pot time shall be established in a preliminary test and the processing time then laid down in consultation with GL Wind.

(7) It is not possible for this Guideline to cover all the details of every production process. Deviation from this part of the Guideline is therefore possible after consultation with GL Wind.

(8) Prior to the start of laminating work, the mould surfaces shall be treated with an adequate quantity of a suitable release agent and brought up to the planned processing temperature. The surfaces shall be dry and dust-free. Release agents containing silicone are inadmissible.

3.4.4.5 Building-up the laminate

(1) If surface protection is to be achieved by means of a gelcoat, the resin shall be applied in a uniform layer of thickness in accordance with the approved production specification, using a suitable process.

(2) The first layer of laminate shall be applied as soon as possible after application of the gelcoat. For this, a reinforcement layer of low weight per unit surface and high resin content (e.g. in the case of glass fibre, max. 300 g/m² and 35 % glass by weight) shall be used.

(3) The laminate shall be built up in accordance with the approved production specification. The reinforcement layers shall be adequately deaerated and compressed so that the required fibre content is attained. Resin enrichment shall be avoided.

(4) The maximum thickness of the material that can be cured in one step is determined by the maximum permissible heat generation. In the case of vacuum bagging, the decisive factor as a rule is the maximum number of layers from which air can still be totally removed.

(5) If the laminating process is interrupted for more than three days in the case of cold-curing resins, the surface of the cured laminate shall be roughened and cleaned to obtain a surface providing adequate bonding. Deviating manufacturer's instructions (e.g. in the case of polyester resins with skin-forming additives) shall be followed.

(6) Transitions between different thicknesses of laminate shall be made gradually. The minimum value of the step length L [mm] for a laminate layer with a thickness d [mm] and fracture stress S [N/mm²] can be determined as follows:

$$L = (S/10\ \text{N/mm}^2) \cdot d \qquad (3.4.7)$$

If the attachment or cutting of reinforcement layers is unavoidable, e.g. in the case of complicated mouldings, then cut edges shall overlap or reinforcement strips shall be provided. In the butt or seam region of laminates, any reinforcement layer shall overlap by at least the value specified above for the step length.

(7) In the transition region from a sandwich construction to solid laminate, the core material shall be tapered with a gradient of at least 1 : 3.

(8) Parallel or insert linings shall be free from moisture and impurities. Their surfaces to be bonded to the laminate shall be prepared suitably (see Section 3.4.5.2, para 1).

3.4.4.6 Curing and tempering

(1) Components may only be removed from the moulds after adequate curing of the resin and the adhesive. The required curing time depends on the forces that may occur due to the separation of the component from the mould, the curing temperature and the resin systems used. The curing time shall be determined by experiment.

(2) Resin systems which cure under pressure, UV radiation and/or increased temperature shall be treated in accordance with the manufacturer's instructions or the results of suitable previous investigations.

(3) Immediately following curing, the components shall receive post-curing (tempering) at elevated temperature. The tempering time depends on the particular resin system and the temperature attainable within the component during tempering. This shall remain below the heat deflection temperature or glass transition temperature. Cold-curing systems which are not subsequently tempered shall be stored for 30 days under curing conditions. This period may be reduced with the consent of GL Wind, provided the relevant manufacturer's instructions for post-curing are available or confirmed experimental post-curing values can be presented.

3.4.4.7 Sealing

(1) Laminate surfaces without surface protection shall be sealed after curing/tempering, using suitable agents. In particular, the cut edges of cut-outs and glued joints shall be carefully protected against penetration by extraneous media (e.g. moisture).

(2) The sealing materials used shall not impair the properties of the laminate. They shall also suit the intended purpose of the component.

3.4.5 Adhesive bonding

3.4.5.1 Adhesive joints

(1) Adhesive joints for load-bearing parts shall generally be verified by tests to be agreed on for each individual case, unless comparable experience is available.

Note:

Particularly in the case of highly thixotropic adhesives, prior proof of their suitability shall be given with due consideration of the production process.

(2) A specification for production and testing shall be compiled for the adhesive joints of load-bearing structures. In particular, the nominal values and tolerances of adhesive-layer thicknesses as well as the maximum size and extent of permissible flaws shall be defined. The adhesive layer thicknesses, tolerances and the maximum size and extent of permissible flaws shall be considered during the computational verification of the adhesive joint (see Section 5.5.6).

(3) Only adhesives with confirmed properties may be used for bonding. If adhesives are used for structural bonding and these components are part of a project certification, the adhesive shall have GL approval in addition. The adhesives may not have any negative effects on the materials to be joined.

(4) The possibility of contact corrosion (bond-line corrosion) shall be countered by suitable means.

(5) If FRP components are to be bonded and a resin system differing from the laminating system is used, the components shall be totally cured before bonding.

3.4.5.2 Assembly process

(1) The various surface pretreatments for synthetic materials and metals are for example compiled in VDI 2229 and VDI 3821.

(2) The surfaces of the materials to be bonded together shall be dry and free of release agents (wax, grease, oil etc.), impurities (dust, rust etc.) and solvents. Especially when using solvents for cleaning purposes, compatibility with the material and sufficient ventilation time shall be ensured.

(3) Smooth surfaces shall be roughened either mechanically (rough-grinding, sand-blasting etc.) or chemically by etching. It is absolutely necessary that layers on the surface of the materials to be bonded that exert a negative effect on the bonding process (e.g. skin-forming additives in polyester resins or residues of peel ply in the case of FRP, or oxide layers in the case of aluminium) be removed.

(4) In many cases, an increase in the strength of the bonded connection can be achieved by the use of specially matched primers. The use of primers is particularly recommended for bonded joints which later in service are relatively heavily stressed by environmental influences.

(5) The adhesive shall be processed in accordance with the manufacturer’s instructions; the proportion of fillers may not exceed the permitted limit. When mixing the adhesive, its constituents shall be mixed in such a way that they are evenly distributed, care being taken to beat in as little air as possible.

(6) The adhesive shall be applied evenly and as bubble-free as possible to the materials to be joined. If highly thixotropic adhesives are used, it is advisable to apply a thin undercoat of the corresponding pure resin to the surfaces to be joined.

(7) Following application of the adhesive, the materials to be joined shall be brought together without delay and fixed in place.

(8) A loading of the adhesive joint before the adhesive has cured sufficiently is inadmissible (see Section 3.4.4.6, para 1). For all adhesive joints with thermosetting adhesives, subsequent tempering of the joint is recommended; in the case of cold-curing adhesives, tempering is necessary as a rule.

(9) After curing, the adhesive joint shall be protected by suitable means against penetration by extraneous media (e.g. moisture).

3.4.6 Manufacturing surveillance for FRP

3.4.6.1 General

(1) The following sections apply for the production surveillance of FRP components by GL Wind, as is the case in project certification for example.

(2) Manufacturing surveillance of FRP components comprises quality control of the raw material, surveillance during production, and checking the quality of the completed components.

(3) A distinction is made in manufacturing surveillance between internal and external surveillance. External surveillance in the sense of this Guideline means regular random-sampling checks of the internal surveillance and of the component quality by GL Wind or a body recognized by GL Wind.

(4) GL Wind reserves the right to make unannounced inspections of the works. The manufacturer shall allow the representative of GL Wind access to all spaces serving the purposes of manufacture, storage and testing and shall permit him to examine the available production and testing documentation.

(5) In the case of companies manufacturing components in series with a certified quality management system, external surveillance is usually limited to routine checks at set intervals to be prescribed (audits).

(6) For companies which have production and witnessing documentation assessed by GL Wind that exceeds the requirements as per Section 3.4.6.1, para 5, and have concluded an agreement with GL Wind on the reporting of production changes, production deviations and claims, a works expert can be appointed and notified by GL Wind to be responsible towards GL Wind for the surveillance during production.

3.4.6.2 Incoming inspection

(1) The characteristic values and properties of the materials shall be verified by the manufacturer by means of inspection documents. The following inspection documents according to EN 10204 (ISO 10474) are required as a minimum:

EN 10204-2.2	Fibre products, gelcoat resins, paints
EN 10204-3.1	Laminating resins, prepregs, core materials, adhesives

(2) During the incoming inspection, the goods shall at least be checked for any damage and for compliance of the details in the certificates with the requirements. Material values should be checked by random sampling.

(3) The goods shall be stored in accordance with the requirements of the manufacturer and this Guideline.

3.4.6.3 Production surveillance

(1) Details of the production process shall be laid down by specifications which also contain specimen documents for production and testing of the components. The tasks and responsibility of the production and quality control departments shall be defined clearly.

(2) As the work progresses, the individual production steps shall be signed by the employees responsible for each stage on the basis of the prescribed documentation.

(3) The individuals entrusted with production shall be trained in accordance with their task, and shall work under professionally qualified supervision. In the case of adhesive joints, the responsible supervisors shall have an appropriate qualification in adhesives, and the individuals performing the work shall have undergone suitable training.

Note:

Training as adhesive bonding worker / adhesive bonding specialist according to DVS / EWF 3305 is desirable.

(4) The batch numbers of the materials used in the component shall be given in the production documentation, in order that they can be traced back to the manufacturer if need be. Reinforcing layers introduced into the laminate shall be checked off immediately during the production process, with indication of the fibre direction.

(5) From every batch of reaction resin compound, a sample shall be taken and tested. If mixing is performed continuously, one sample per batch and production step is sufficient. These samples shall be randomly checked for their degree of curing. The results shall be recorded.

(6) On request by GL Wind, reference laminates of about 50 x 50 cm shall be produced in parallel. This shall result in confirmation of the material values used as a basis for the strength calculations.

3.4.6.4 Component checks

(1) The scope of the component checks shall be laid down in consultation with GL Wind before production commences.

(2) During and on completion of the production process, the component shall be visually checked, and critical areas shall be tested by tapping or by another suitable method. Attention shall be paid to air- and particle-inclusions, delamination, distortion, whitening, discoloration, damage etc. In addition, the general quality (e.g. surface finish) shall be visually checked.

(3) In justified cases and on request by GL Wind, the fibre content of the component shall be determined in a representative number of spots, to permit conclusions to be drawn regarding the quality of the laminating work. Similarly, the build-up of layers should be checked by suitable tests.

(4) Single or random-sampling tests of completed components regarding natural frequencies, static and/or dynamic loads plus their geometry shall be carried out on request of GL Wind.

(5) The repair of any defects that are detected in the component shall be documented. The repair procedures will be assessed beforehand within the scope of the production specifications to be submitted.

3.4.7 Wood processing

3.4.7.1 Manufacture of wooden rotor blades

3.4.7.1.1 General

(1) Apart from the selection of suitable and approved materials, their processing is of particular importance because of its significant influence on the properties of the product.

(2) In the preparation and processing of the components, the directions of the manufacturers of the raw material and the requirements of the relevant safety authorities and employers' liability insurance associations shall be taken into account together with this Guideline.

(3) It is not possible for this Guideline to cover all the details of every mould and production process. Deviations from this Guideline are therefore possible with the consent of GL Wind.

(4) Details of the production process shall be laid down in the form of checksheets or work progress slips, samples of which are to be enclosed with the quality manual. These shall be signed off by the employees responsible for each stage as the work progresses.

3.4.7.1.2 Mould requirements

The moulds for laminated-wood rotor blades shall, in addition to a high degree of dimensional accuracy, have sufficient rigidity to eliminate the risk of unacceptable deformation during the manufacturing process. Equipment shall be provided to ensure perfect joining when sub-structures are glued together.

3.4.7.1.3 Preparing the wood

(1) Pre-sorting shall be used to ensure that the sawn timber meets class S 13 according to DIN 4074-1 or a comparable quality standard according to other regulations.

(2) Prior to further processing, the mean moisture content shall be determined. It should be 10 % ± 2 % as the mean of 10 typical random samples. Under no circumstances may the variation in moisture content between individual samples exceed 4 %.

(3) When boards are processed into solid-wood rotor blades, this moisture content is generally achieved by chamber drying. Veneers used for the manufacture of moulded laminates shall, if supplied in dried condition, be stored in such a way that their moisture content does not exceed the stated tolerances.

(4) For good conformability, boards shall be planed on all sides. Rough-sawn boards shall not be permitted to reach the bonding stage.

(5) Secondary sorting shall be undertaken once the boards have been planed. Individual fault areas may be cut out.

3.4.7.1.4 Layer build-up and bonding

(1) Glueing of the wood shall be carried out as soon as possible after planing to prevent fouling of the surfaces to be glued and deformation as a result of subsequent shrinking or swelling.

(2) All components used for processing should be at room temperature. The ambient humidity of the room shall be adjusted so that the required moisture content tolerances are observed.

(3) The boards shall be oriented with their layers in such a way that the risk of the glued joints cracking open is kept to a minimum. Longitudinal butt-joints of individual boards shall be made as dovetail joints of load group I according to DIN 68140. It shall be ensured in the layering that there is sufficient offset of the longitudinal joints.

(4) If cross-sections with a width greater than 22 cm are being produced, each layer shall have several boards in parallel so arranged that there is sufficient overlap between the longitudinal joints within the layer.

(5) When processing veneers, either butt- or scarf-joints are permitted, provided care is taken to ensure an adequate overlap of the joints in the layers. The glue shall be applied evenly and in accordance with the manufacturer's instructions. To achieve a glue coating of constant high quality, automation of the glue application process is required.

(6) The boards to be glued shall be kept under pressure while the glue cures. The manufacturer's instructions shall be observed.

(7) When processing veneers into moulded wood laminate, vacuum processes should preferably be used.

The glueing of such part-skins shall be carried out following the pattern for gluing boards. Part- and half-skins shall be held in the desired position by suitable aids so that adequate dimensional accuracy is achieved.

(8) The temperature for glueing shall be at least 20 °C. Glueing temperatures up to 50 °C may be used to reduce the curing time.

3.4.7.1.5 Wood preservation

When boards have been glued together or half-skins have been produced, any hollow spaces shall be treated with wood preservative. This also applies to subsequently mechanically machined areas, such as drillings and millings for connection elements where the blade is joined to the hub.

3.4.7.1.6 Surface protection

(1) The wood surface to be treated shall be even and free from cracks. Small surface defects in the wood shall be eliminated in a competent manner.

(2) Materials for providing protection against moisture shall be processed and applied according to the manufacturer's instructions. Effective protection of the surface usually requires application of several coats.

(3) Textile inserts shall be incorporated in the surface coating in accordance with the processing rules for FRP rotor blades (see Section 3.4.5).

3.4.7.1.7 Blade connections

(1) Connections between the rotor blades and the hub shall be so designed that reliable load transfer is guaranteed. It is particularly important to ensure that the differences in elastic properties between wood, the connection elements and if applicable synthetic resins, are compensated for in the design. In addition, joints between the wooden blade, the connection element and the hub shall be protected effectively against the penetration of moisture into the wood.

(2) Because of the multiplicity of design possibilities, no generally applicable requirements for the protection of the joints are stated in this Guideline.

3.4.7.2 Manufacturing surveillance of wooden rotor blades

3.4.7.2.1 General

(1) The component properties of wooden rotor blades depend not only on the quality of the raw materials but also on their processing. Furthermore, the possibilities of checking the properties and discovering possible defects are more restricted at a later stage. It is therefore not sufficient just to test the raw material or the finished product; continuous surveillance during production is required.

(2) In manufacturing surveillance, a distinction is made between internal and external surveillance. External surveillance in the sense of this Guideline means regular checks (see Section 3.1.4 / Shop approval) of the internal surveillance and quality control.

3.4.7.2.2 Incoming inspection

(1) Proof of the characteristic values and mechanical properties laid down in the material approval procedure shall be provided by the manufacturer in a test report. In the case of wood, sorting class S 13 shall be verified in writing by the supplier.

(2) As part of the incoming inspection, the accompanying documentation shall be checked for conformity with the requirements, and the materials shall be stored in accordance with this Guideline and entered into the inventory file.

3.4.7.2.3 Visual checks

During and on completion of the production process, the component shall be visually checked. Attention shall be paid to completeness of glueing, flaws in the surface of the wood etc.

3.4.8 Making and working the concrete

The making and working of concrete can be carried out according to ENV 1992 (Eurocode 2) [3.3] and EN 206. The essential steps are listed in the following.

3.4.8.1 Proportioning and mixing the raw materials

(1) Mixing instructions, containing precise details of the type and quantity of the raw materials for the concrete mix to be produced, shall be available in writing.

(2) The raw materials shall be proportioned by weight.

(3) They shall be mixed in a mechanical mixer until a uniform mixture has been produced.

3.4.8.2 Transport, pouring and compacting

(1) The type of delivery and composition of the concrete shall be matched to prevent segregation.

(2) In pedestal- and wall-shuttering, down pipes ending just above the working point shall be used.

(3) Discharge pipes for pumped concrete shall be run in such a way that there is no break in the concrete flow within the pipes.

(4) The reinforcement rods shall be tightly encased in concrete.

(5) The concrete shall be completely compacted.

(6) The individual sections for concreting shall be determined before concreting starts. Construction joints shall be designed in such a way that all the stresses occurring can be withstood. The surface of the construction joints should be rough.

(7) In waterproof concrete the joints shall also be waterproof.

3.4.8.3 Curing

(1) In order to attain the properties expected of the concrete, especially in the surface region, careful curing and protective measures are required for a significant period.

(2) Curing and protection shall be started as soon as possible after the concrete has been compacted.

(3) Curing prevents premature drying-out, particularly due to sunshine and wind.

(4) In order to slow down the shrinkage of the young concrete and to ensure that it will harden properly at the surface also, it shall be kept moist. In general 7 days is adequate for this.

(5) Sea water shall not be used for curing.

(6) Further measures may comprise keeping the structural member in the formwork, covering surfaces with plastic foils or using approved curing agents.

3.4.8.4 Concreting in cool or hot weather

(1) In cool weather and in frost conditions, the concrete shall be poured at a specified minimum temperature and protected for a certain length of time against heat loss and drying-out.

(2) Green concrete shall not be added to frozen concrete. Aggregate may not be used in the frozen condition.

(3) In hot weather, account shall be taken of the effect of the sun on the green concrete (e.g. covering it over).

(4) The temperature of green concrete can be lowered by chilling the aggregate and the water to be added.

3.4.8.5 Concreting under water

(1) Underwater concrete is to be placed uninterruptedly by means of fixed hoppers in such a manner that it does not come into contact with the water on the delivery path. The water in the foundation pit shall be still.

(2) At water depths of up to 1 m the concrete may be placed by careful forward feeding along a natural slope.

(3) Underwater concrete is, alternatively, allowed to be made by injecting grout with low segregating tendency from below into a mass of aggregate.

3.4.8.6 Formwork and its supports

3.4.8.6.1 Forms

(1) Forms and boxing shall be made as dimensionally accurate as possible and tight enough to prevent the fine mortar of the concrete flowing out through the gaps during pouring and compacting.

(2) Forms and their supporting structure shall be so dimensioned that they can safely absorb all forces that may arise until hardening has occurred, account being taken also of the effect of the pouring speed and the type of compaction of the concrete.

(3) If slip forms are used the basic principles of this process are to be observed, as described for example in the data sheet “Gleitbauverfahren” (“Slip form building”; Deutscher Beton-Verein e.V.).

3.4.8.6.2 Dismantling the falsework

(1) Dismantling may only start if the contractor’s supervisor has confirmed that the concrete is sufficiently strong and has ordered removal. It may only be carried out after the concrete has attained sufficient strength as regards the load-carrying capacity and resistance to deformation of the component and the form is no longer needed for curing purposes.

(2) Special care is requested in the case of components that have been exposed to low temperatures after placing of the concrete.

(3) Auxiliary supports should be left or be erected immediately after dismantling the falsework in order to minimise displacements due to creep or shrinkage of the concrete.

3.4.8.7 Reinforcement

3.4.8.7.1 Installing of reinforcement

(1) Substances that may affect bonding, such as dirt, grease, ice, loose rust, are to be removed from the steel before it is used.

(2) The steel bars are to be joined in a rigid framework and kept in their proposed positions by means of spacers not affecting the corrosion protection, so that they are not displaced when the concrete is placed or compacted.

(3) Welding of reinforcement exposed to dynamic loads should be avoided in general and shall be agreed upon by GL Wind.

3.4.8.7.2 Concrete cover to reinforcement

(1) The concrete cover of each reinforcing bar or stirrup shall not be less than the following values on all sides, see Table 3.4.6.

(2) In the case of secondary loadbearing members of precast concrete components lower values may be selected for the concrete cover on the basis of the standards and with the agreement of GL Wind.

(3) For mobile units capable of being drydocked, a reduction of the concrete cover may be agreed upon.

3.4.8.7.3 Bar spacing

(1) The clear distance between parallel reinforcing bars shall be at least 2 cm and may not be less than the bar diameter. In the region of splices reinforcing bars shall be interlaced.

(2) The minimum value for the mutual spacing of the sheaths in the case of prestressed concrete is to be taken from the authorisation for the particular prestressing process.

Table 3.4.6 Concrete cover (nominal values)

	Reinforcing steel [mm]	Posttensioning ducts [mm]
In the splash zone and in the atmospheric zone subject to salt water spray	65	90
In the submerged zone and in the atmospheric zone without salt water spray	50	75

3.4.8.7.4 Anchorage

(1) The anchoring of reinforcing steel shall be carried out in accordance with the standards. The usual anchoring elements are: straight anchorages, U-hooks, L-hooks, loops, anchorage attachments and welded-on transverse bars.

(2) The anchoring of prestressed members shall comply with the official approval for the prestressing process or be verified by calculation for the stresses specified in the standards.

3.4.8.7.5 Splices in reinforcement

(1) Tensile splices in the reinforcement can be formed by laps with or without hooks at the bar ends, by loops, by welded-on transverse bars, by welding or by screwed connections.

(2) Tensile splices in cross-sections subject to bending stresses are, as far as practicable, to be disposed outside the areas of fully exposed steel cross-sections. The splices are to be distributed as uniformly as possible over the entire reinforcement area and should not to be laid next to each other in the longitudinal direction. Attention shall be paid to achieving adequate transverse reinforcement in the vicinity of splices.

(3) Compressive splices in reinforcing bars can be formed by laps, welding, screwed connections, contact splices.

(4) The specific requirements of the standards are applicable to the design of the splices. In the case of welded splices special standards are to be used (e.g. DIN 4099).

3.4.8.7.6 Arrangement of reinforcement in flexural components

(1) The arrangement of the reinforcement depends on the line of tensile force, on the magnitude of the shear loading, and on the type of shear reinforcement. Reinforcing bars no longer needed to cope with tensile force may be bent up and may be used for shear reinforcement.

(2) Freely rotatable or only freely restrained end supports shall have at least one quarter of the largest field reinforcement anchored behind the theoretical support line.

(3) Intermediate supports of continuous slabs and beams, end supports with attached brackets, clamped supports and frame corners shall have at least one quarter for beams, respectively 50% for slabs, of the largest field reinforcement led behind the support forward edge. In order to absorb unanticipated loads (e.g. effect of fire, setting of supports), as far as practicable a portion of the field reinforcement is to be laid interlaced through or spliced positively (forcelocking).

(4) The shear reinforcement shall be distributed approximately in accordance with the course of the shear force. Stirrups acting as shear reinforcement, shall go round the tensile reinforcement and, where appropriate, also the compressive reinforcement, and extend over the entire height of the cross-section.

3.4.8.7.7 Components loaded in compression

In so far as reinforcing bars are used for compressive reinforcement, they shall be made safe against buckling by means of stirrups in accordance with the relevant requirements of the standards. The maximum values given in the standards for compressive reinforcement shall not be exceeded.

3.4.8.7.8 Prestressing reinforcement

(1) Prestressing steels should be clean and free of rust when installed. Prestressing steels with a slight film of rust may be used. (The term "slight film of rust" refers to a coating of rust that can be removed by wiping with a dry rag. However, removal of the rust in this manner need not be carried out).

(2) Prestressing steel is to be cut to length and assembled in the dry. Until installation is finished prestressing members are to be stored clear of the floor in a dry place, and are to be protected against contact with harmful chemicals and moisture. Kinks or damage by machinery shall be avoided when laying out and installing prestressing members. Particular care shall be taken that prestressing steel is also protected against corrosion in the period between laying down and manufacture of the bond. In the case of short periods it may be sufficient to seal off the ends of the sheathing and to avoid local accumulations of moisture.

(3) Before the concrete is placed, sheathing or ducts are to be checked for kinks, dents or other damage; if there is any risk of impairing the tensioning process or if there are any leaks, remedial measures shall be taken.

(4) Special attention shall be paid to the sealing of splices. It is to be ensured, during placement of the concrete, that the pipes are not damaged.

(5) Welding at prestressing steel is not allowed. Prestressing steel shall be protected from welding heat and falling weld metal (e.g. by means of resistant jackets).

3.4.8.7.9 Application of the prestress

(1) Concrete may only be prestressed when it is strong enough to be able to absorb the resultant stresses, including the loads at the anchorage points. This prerequisite is regarded as fulfilled if the hardness test shows that the strength of the test specimen has reached 90 % of the characteristic strength given in Table 3.3.6.

(2) It may be expedient, in order to avoid shrinkage cracks or for early stripping of individual components, to apply a portion of the prestress as soon as practicable. This is only admissible if a hardness test shows that the strength of the test specimen has reached 50 % of the characteristic strength given in Table 3.3.6. In this case the partial prestressing forces and the concrete stresses in the rest of the component may not be more than 30 % of the admissible prestressing force or the admissible stresses for anchoring, respectively.

(3) Equipment used for prestressing is to be tested before first use and then generally every six months in order to ascertain what deviations from the desired value are occurring during use. Account is to be taken of the extent to which these deviations depend on external factors (e.g. on temperature during oil pressing).

(4) A precise tensioning programme is to be prepared and to be attached to the strength calculations. The tensioning programme shall contain, in addition to the time sequence for tensioning each member, data on the stressing force and tendon elongation with regard to compression of the concrete, friction and slip.

(5) The prestressing sequence is to be so selected that no inadmissible loads occur. All the measurements carried out during jacking are to be recorded in the tensioning report.

3.4.8.8 Quality control

3.4.8.8.1 General

(1) The contractor's supervisor is responsible for the execution and interpretation of the tests, specified below, for taking due account of the results of such tests in the execution of the job and for submitting the results to GL Wind in case of a Project Certification.

(2) The application of a quality management system in accordance with ISO 9001 is described in Section 3.2.

(3) This section contains a minimum of necessary control measures for the planning and construction of concrete structures. They comprise the important measures and decisions plus the necessary tests in connection with the construction regulations, standards and the generally accepted state of the art which together are important for the adherence to the prescribed requirements.

(4) Surveillance of manufacturing and construction comprises all measures for compliance with and control of the required quality of the building materialsand the workmanship. It consists of checks by visual inspection and testing, and also includes evaluation of the test results.

Table 3.4.1 Items to be checked during manufacturing and construction (taken from EC 2 [3.3], Section 7)

Item	Control of building materials and material production	Control during construction
Concrete	Raw materials Composition Production Green concrete Cured concrete	Transport, pouring Compacting Curing Surface treatment
Forms and supports	Material properties	Solidness Assembly, dismantling Camber Deflections Foundations Tightness Surface finish on concrete (inner) side
Reinforcement	Laid-down raw-material properties Surface finish	Treatment and storage Cutting to length Assembly, reinforcement Overlapping- and other end joints Welds Laying Concrete cover
Prestressing steel and prestressing gear	Laid-down raw-material properties Surface finish Prestressing gear Straightness of prestressing elements Grouting mortar	Treatment and storage Cutting to length Laying Prestressing gear Prestressing Grouting
Components, prefabricated parts	—	Dimensional deviations Camber and deflections Deviations from order specification

(5) Surveillance of manufacturing and construction comprises:

- suitability tests and methods of control
- tests and checks during construction
- final inspections and final checks

If necessary, suitability tests shall precede the start of construction, in order to ensure that the planned structure can be erected satisfactorily using the prescribed building materials, equipment and manufacturing procedures.

(6) The quality and compatibility of the materials with the raw materials of concrete, mortar etc. should be ensured either on the basis of previous experience or by tests carried out.

(7) Only standardized building materials should be used.

(8) Prestressing steel may only be used if the certificates from the steelworks as to its properties are available or if an official approval is obtained. The requirements contained therein, e.g. as to additional tests or special procedures during installation, shall be followed when verifying quality.

Note:

Methods of production, testing and conformity for prestressing tendons will in near futur be topic of a European standard which is at the moment only avaivable as a pre-standard prEN 10138.

(9) An approval for the prestressing procedure shall be available at the site.

(10) The checks required are summarized in Table 3.4.1.

3.4.8.8.2 Tests during construction

(1) General requirements:

- Dimensions, properties and suitability of the building materials, fixtures in the structure and the appliances fitted shall be surveiled continuously.
- The building materials and components delivered to the building site shall be checked against the order specification.
- Important findings shall be entered into written records (e.g. the construction logbook) and made accessible to all concerned.
- Depending on the required reliability level, special checks may be agreed additionally.
- For the quality control of concrete, EN 206 applies.
- For all other building materials or other materials, reference shall be made to currently valid technical documentation.

(2) Acceptance checks for site deliveries:

- For the delivery note of ready-mixed concrete, EN 206 applies.
- Aggregate should be regularly checked visually with regard to its granulometric composition and other significant properties. In doubtful cases the aggregate should be examined more thoroughly.
- Sieve tests for aggregates are necessary when the first delivery is affected and whenever there is a change-over to a different supplier. In addition, they are necessary at suitable intervals depending on local conditions. Alternatively, a certified production control of the aggregates can be referred to.
- For each delivery of reinforcing steel it shall be checked that the steel bears the distinctive mark - as laid down in the standard (e.g. EN ISO 15630-1 or DIN 488) - for the steel group and also the steelworks mark. If it does not, a yield point of only 220 N/mm^2 shall be assumed for the steel. Exceptions may be approved if the properties of the steel are confirmed by an independent institution.
- For prefabricated parts, the delivery note shall certify that they were made, marked and treated in accordance with the order specification.
- The delivery notes for reinforcing steel shall contain the following information:
  - steel in bundles, in coils or under the usual conditions of structural steel engineering
  - bars or welded-up reinforcing-steel mats
  - steel cut to length and bent
  - prefabricated reinforcement
- Origin and characteristics of the delivered steel shall be known for the entire reinforcement.
- For prestressing steel and prestressing equipment, ENV 1992 (Eurocode 2) [3.3] applies.

(3) Checks:

- The purpose of the preliminary test is to establish, before the concrete is used, what composition it should have in order to attain the required properties. It shall always be carried out for new concrete compositions. Regarding checks prior to concreting, see EN 206.

- Welding on reinforcing steel may only be carried out by firms possessing the required specialists and welding supervisors. Only welders who are especially qualified to weld reinforcing steel may be employed. Before welding begins, preliminary tests (procedure tests) are to be carried out under local manufacturing conditions, and during welding monitoring checks are to be undertaken. The individual requirements of the standard (e.g. DIN 4099-1) are to be followed.
- Before inserting the prestressing elements, a check shall be made to see whether any damage has occurred in the works or after arrival on the site.
- It is recommended that a general check be made before starting the prestressing to see whether the entire prestressing process can be carried out without hindrance.
- Preliminary tests of the compressive strength of the injection grout shall be carried out for each section of the construction before commencement of the injection work on specimens at least 7 days old.
- A suitable number of conformity checks shall be made during injection work (e.g. according to EN 446).
- The flowability, change of volume, compressive strength and the resistance to premature setting of the grout shall be verified for each section of the construction.
- A prestressing report shall be compiled on the measurements made during the individual prestressing steps (jack force, extensions, anchor slippage etc.).
- The interval between prestressing and completion of the protective measures for the reinforcing steel (grouting) shall be checked and recorded.
- During grouting, it is necessary to check the injection pressure, the unimpeded flow of the grouting mortar from the vents, the amount of mortar coming out of any leakage points and the amount of mortar injected, as well as to take samples for checking the consistency and water loss. If necessary, the strength of the mortar should be checked.

3.4.8.8.3 Supervision of the work

(1) The contractor's supervisor shall ensure that the work is properly carried out in accordance with the examined documents, particularly in respect of:

- accuracy of dimensions of the components
- safe construction of form- and falsework
- adequate quality of the materials used
- conformity of reinforcing and prestressing steels with the examined drawings

(2) In case of a project certification, GL Wind is to be notified, as far as is practicable 48 hours in advance of commencement of the work, of the planned initial concreting, recommencement of concreting work after any extensive interruption, and of any major welding work on the site.

(3) Depending on the nature and extent of the work to be carried out, reports are to be continuously prepared by the contractor's supervisor on the site for all processes incidental to quality and stability. These reports shall be available during the construction period on the site and are to be submitted to the supervising surveyor on request.

3.4.8.8.4 Conformity checks

(1) By conformity checks are meant all measures and decisions whose observation ensures that all prescribed requirements, criteria and conditions are entirely complied with. This includes the completion of the relevant documentation.

(2) For conformity checks for concrete, see EN 206.

(3) The purpose of the conformity check is to establish that the concrete made for use on the job attains the required properties. The compressive strength, the water/cement ratio and the consistency of the concrete shall be confirmed.

(4) For the conformity check of the compressive strength, a series of three test specimens is to be made for each 500 m^3 of concrete and at least on every seventh day of concreting (see also Section 3.3.5.4.1).

(5) Conformity checks for other building materials shall be based on international standards or, if these do not exist, on national standards or approvals.

3.4.8.8.5 Inspection and maintenance of the completed structure

(1) Special checks (inspections) to be carried out during service shall be laid down in an inspection programme.

(2) All information required for utilisation and maintenance should be at the disposal of whoever has responsibility for the entire structure.

3.5 Corrosion Protection

3.5.1 General

(1) Offshore wind turbines are exposed to a marine climate. Corrosion protection is thus to be taken into account by the selection of suitable materials and appropriate coatings and protective films, plus regular inspection. The assessment of mechanical and electrical components shall take into account not only the integrity but also the influence of corrosion on functioning, e.g. jamming of rusted joints or failure of sensors. In particular, freedom from corrosion is assumed for fatigue calculations. Analogous considerations are to be applied as regards the possibility of erosion, particularly for the rotor blades.

(2) Offshore wind turbine components are exposed to aggressive environmental conditions and not easily accessible. Because of the operational conditions, in many cases repeated protective coating is not possible. Special importance therefore attaches to the design, choice of material and corrosion protection measures.

(3) Offshore wind turbines are to be classed under “marine atmosphere” as regards corrosion attack.

3.5.2 Scope, application

(1) This chapter covers corrosion protection of steel and concrete offshore structures. Design, fabrication and installation of the corrosion protection system are subject to approval by GL Wind in connection with the overall certification procedure.

(2) Additional requirements regarding machinery components are given in Chapter 7.

(3) Recognized codes and standards from institutions such as NACE, DIN, BSI, NORSOK, ISO may be used for the design, if the classification of risk potential is applied in a correct manner.

3.5.3 Terms, definitions

3.5.3.1 Anode

An anode is an electrode in a galvanic cell or the part within a corrosion cell which emits a direct current in the form of positively charged ions, mostly with anode substance dissipation.

3.5.3.2 Coating

Coating is a collective term for one or several coherent layers on a base material, which are made from non-preformed materials and the binding agents of which mostly are of an organic nature.

3.5.3.3 Reference electrode

The reference electrode is a half cell characterized by a time-constant potential. In connection with potential values the reference electrode is always to be indicated.

3.5.3.4 Electrolytic solution

Electrolytic solution is an ion conducting medium in a corrosion element, such as sea water.

3.5.3.5 Cathode

The cathode is the electrode in a galvanic cell or the part within a corrosion cell at which reduction processes occur. Here, electrons leave the metal and/or are consumed by discharging of the positive ions in the electrolyte.

3.5.3.6 Cathodic protection (CP)

The cathodic protection is a protective method by which the material to be protected is made a cathode, by sacrificial anodes or impressed current systems.

3.5.3.7 Corrosion

Corrosion is the reaction of metallic material with its environment, which causes a measurable change of the material and may entail a corrosion damage.

3.5.3.8 Corrosion protection

Corrosion damages may be prevented by the following corrosion protection measures:

– by designing the systems and components through the application of suitable structural measures according to EN ISO 12944 part 3, see Section 3.5.5

– by influencing the characteristics of the reaction partners and/or modification of the reaction conditions

– by separating the metallic material from the electrolyte by protective layers applied

– by electrochemical action, e.g. cathodic protection, see Section 3.5.9

3.5.3.9 Splash zone

The splash zone is defined as the part of the structure being intermittently wetted by tide and wave action. The definition of the splash zone is specified in Section 4.2.4.11.

3.5.3.10 Current density

The current density is the current per unit of area.

3.5.3.11 Atmospheric zone

The atmospheric zone is the area above the splash zone, which is normally dry.

3.5.3.12 Metallic coating

Metallic coating is a collective term for one or several layers of metals applied on a base material.

3.5.3.13 Submerged zone

The submerge zone is the area permanently located under water.

3.5.4 Choice and suitability of corrosion protection systems

(1) Corrosion allowance instead of effective corrosion protection may be granted only for components of minor significance, for structures having a short service life or in cases in which regular checking and repairs are possible (see Section 6.2.1). For all other structures and components in the splash zone a corrosion allowance is to be considered together with a corrosion protection system. The value of the corrosion allowance depends on the used protection system, the choice of the quality of the steel and the environmental conditions. The applied corrosion allowance is to be considered in accordance with GL Wind. If such special measures are not be taken a corrosion allowance of 0.3 mm/a is to be considered in the splash zone.

(2) For the accessible area within the atmospheric and splash zone, an appropriate coating or a metallic coating according to EN ISO 12944 or an equivalent standard is to be taken.

(3) For all metal parts located in the splash zone, an appropriate corrosion protection system shall be provided, which shall be adapted to the service conditions of the respective structure and capable of being checked for its effectiveness.

(4) Corrosion protection in the submerged zone and in the area underneath the sea bottom shall be designed with a view to the service life of the installation, or else renewal or repair shall be possible. However, the duration of its efficiency at least shall correspond to the survey intervals envisaged for the components.

(5) The submerged zone of offshore steel installations not capable of being docked shall always be provided with cathodic protection. Where unfavourable current distribution shall be reckoned, additional coatings can be recommended.

(6) Gaps and areas in which cathodic protection is ineffective shall be avoided and/or be protected by special methods agreed with GL Wind.

(7) Void spaces, such as box girders, tube sockets, etc. for which proof can be furnished of permanent hermetic sealing, do not require internal protection. During assembly the voids should be clean and dry.

(8) In permanently flooded spaces in which water is either not exchanged, or to a limited extent only, corrosion protection requirements may be reduced in agreement with GL Wind.

(9) For novel corrosion protection systems not yet proven the envisaged application, proof of suitability, e.g. by experiments, will be demanded.

3.5.5 Design for corrosion protection

(1) A structural design which takes into account corrosion protection and -reduction has a significant effect on the ease of implementing, effectiveness and repairability of the corrosion protection. Basic rules are addressed in e.g. EN ISO 12944 Parts 3 and 5.

(2) Surfaces at risk from corrosion should be designed to be as smooth as possible. Any necessary stiffenings, fittings, pipes, etc. are wherever possible to be located in low-corrosion regions. Inaccessible hollow components are to be welded tight.

(3) Areas in which water or aggressive media can accumulate (water pockets) shall be avoided by means of suitable measures such as slopes, passages or run-offs. Condensation shall be reduced by means of design measures such as ventilation.

(4) Residues from welding, such as slag, loosely attached splashes and beads, shall be removed. Splashes or beads melted onto the surface shall be removed if the corrosion stress or the coating system makes this necessary.

(5) If the coating system, the stress in the structure or accident prevention requires it, burrs are to be removed and sharp edges rounded off.

3.5.6 Material selection

For areas which cannot be protected by coatings and protective coverings, suitable materials shall be used. The corrodibility of various materials is described in DIN 50930.

3.5.7 Coatings

(1) Coatings can be selected in accordance with EN ISO 12944 Part 5 which lists the stressing and the coating system to be used. Additional information can be taken from the GL Rules for Classification and Construction, Offshore Technology, Edition 1999 Chapter 2 Section 6, and the Shipbuilding Association Guideline (Schiffbautechnische Gesellschaft) STG Guideline No. 2215.

(2) For systems different Guidelines and Standards may have to be applied after consultation with GL Wind.

(3) Surfaces to be protected by coating shall be designed to be accessible for the necessary activities such as surface preparation, application, inspection and maintenance. Surface preparation shall be effected in accordance with EN ISO 12944 or an equivalent standard.

(4) For all coating systems that are not conform to any admitted standard it is possible to apply to GL Wind for an approval. It is necessary to provide sufficient evidence to GL Wind that the coating material is suitable for the intended purpose. A written application shall be submitted to GL Wind. After successful examination of the product datasheet, coating specifications and suitability documentation appended to the application, e.g. references and relevant test results etc., a certificate is issued by GL.

(5) Proof of efficiency of coating materials shall be furnished either by many years' proven practical use under the expected conditions or by well-founded experimental results.

(6) The choice of materials, coating thicknesses, workmanship, testing, etc. shall comply with EN ISO 12944 or an equivalent standard.

(7) Coatings shall be sufficiently resistant to the respective corrosion medium under the given service conditions.

(8) Coatings, including the production coating and primings employed, shall be compatible with the cathodic protection, i.e., they shall be resistant to blistering up to a potential of

$$U_{Cu/CuSO_4} = -1.1 Volt \qquad (3.5.1)$$

(see Section 3.5.9.2). They shall not be susceptible to hydrolysis or saponification.

(9) Coatings shall be as resistant as possible to damages due to fouling.

(10) The coatings in the atmospheric zone shall be inspected on the occasion of the usual periodical surveys of the structure, according to an agreed inspection plan and damage is to be repaired.

(11) The coating systems for the splash zone are to be chosen such as to render possible repairs by coating substances which harden under water, directly after application. Damages to coatings in the splash zone shall be repaired as soon as possible.

(12) Coatings of cathodically protected underwater structures are visually checked during the surveys. Repair of damages is, however, only required in exceptional cases in agreement with GL Wind.

3.5.8 Metallic coatings and platings

(1) Metallic coatings may have a more positive or a more negative free corrosion potential than the base material, in general unalloyed or low alloyed steel. They should be free from cracks and pores.

(2) With coatings using materials having a more positive potential (e.g., nickel and copper based alloys, stainless steel), there is a risk of contact corrosion at pores in the coatings and at the transition to the base material. Therefore, the coatings shall be free from cracks and pores. The transitions to the base material shall be coated. The risk of contact corrosion of the base metal does not exist in the case of cathodic protection.

(3) Coatings made of materials with a more negative potential, e.g. zinc or aluminium alloys, are well suited for temporary protection of equipment in the atmospheric zone. Depending on their thickness and composition, and on their working environment, coatings undergo uniform wear and have a limited life in the splash zone.

(4) In the surface preparation and application and testing of the metallic coatings, EN ISO 12944 or equivalent standards shall be observed.

(5) The plating of steels shall show perfect bonding with the base material, proof of which may be furnished by ultrasonic testing.

(6) In the case of metallic coatings or platings - in particular in the splash-zone - attention shall be paid to damages due to mechanical effects or contact corrosion. Damage shall be repaired in agreement with GL Wind.

3.5.9 Cathodic protection

3.5.9.1 General

(1) Cathodic protection is intended to prevent corrosion in the submerged zone electrochemically. This may be done by sacrificial anodes, impressed current systems or a combination of both.

(2) Cathodic protection shall be applied to external surfaces of offshore wind turbines in the submerged zone and below the sea bottom. Interior surfaces are to be protected in accordance with the corrosion attack to be expected.

(3) Cathodic protection may be combined with a coating for reducing the required current density and above all, in order to ensure a more favourable current distribution on the structure.

(4) Secondary structural parts, made of a material with the same electrochemical properties of the support structure, are to be attached conductively. If the materials of the support structure and the appurtenant structures have different electrochemical properties, it is not allowed to connect them conductively. In this case they have to be insulated.

3.5.9.2 Calculation principles

(1) The following parameters and conditions shall be observed in choosing and designing cathodic protection:

– size and form of the surface to be protected

– neighbouring structures

– possibility of repair and maintenance facilities

– intended service life of the structure

– coating of the structure

Table 3.5.1 Potentials for cathodic corrosion protection of unalloyed and low alloyed steels (yield point ≤ 800 N/mm^2)

	Reference electrode [V]		
	$Cu/CuSO_4$	Ag/AgCI	Zn
Minimum value	– 0.85	– 0.80	+ 0.25
Maximum value	– 1.10	– 1.05	+ 0.00

(2) The ambient conditions in the submerged zone have a bearing upon the required protective current density and current discharge of the anodes. Therefore, the following parameters shall be known:

– temperature range

– oxygen content

– conductivity

– velocity of flow (current, waves)

– chemical composition

– biological activity

– sand erosion

If these parameters are not known for the sea area concerned and if no experience has been gained there with offshore structures, measurements shall be carried out.

(3) Cathodic protection has to be designed and handled such that in all areas to be protected the potential values measured are within the limits given in Table 3.5.1 For cathodic protection of high tensile steels having yield points ≥ 800 N/mm^2, the potential range is to be agreed with GL Wind. For uncoated steel and for thick coatings exceeding 1 mm, values smaller than the maximum value can be applied.

(4) High alloy stainless steels may be protected against pitting and crevice corrosion by cathodic protection, through an adequate arrangement of the anodes which has to be agreed with GL Wind.

(5) When determining the current required for designing cathodic protection, the surfaces in the water and below the sea bottom, as well as foreign structures having an electrically conductive connection with the object to be protected, are to be taken into account.

(6) The current density varies with time. In the case of uncoated steel the current density decreases, while with coated steel it may increase as a result of coating damage. Table 3.5.2 shows examples for the minimum current density values for cathodic protection of uncoated steel.

Table 3.5.2 Minimum current density values for different sea areas, uncoated steel

	Current density [mA/m²]	
	Initial value	Final value
North Sea (South) till 55° N latitude	150	100
North Sea (North) 55° N till 62° N latitude	180	120
Mexican Gulf	150 [1]	75 [1]
US West Coast	150 [1]	100 [1]
Cook Inlet	430 [1]	380 [1]
Arabian Gulf	130 [1]	90 [1]
Indonesia	110 [1]	75 [1]
[1] NACE-RP-01-76-2003 [3.5]		

(7) For the uncoated steel surfaces located below the sea bottom - e.g. pile foundations - a protective current density of 20 mA/m^2 shall be provided.

(8) For the steel surfaces located in the splash zone the current densities stated in Table 3.5.2 shall be multiplied by the factor 1.2 according to EN 12495. In the splash zone the combination of cathodic protection and coating system shall be used. It has to be observed, that the coating breakdown factor for a life time of 20 years is approximately 50 %. This value depends on the execution of the coating system.

(9) When using an effective coating approx. 50 % of the current densities stated in Table 3.5.2 are required for a projected service life of 30 years. The necessary initial current density is approx. 10 % of the initial value in Table 3.5.2.

(10) If steel structures are in contact with the reinforcement of concrete structures, an electrically conductive through-connection of the reinforcement shall be established. For the external reinforcement - corresponding approximately to the concrete surface - a current density of 5 mA/m^2 shall be taken.

3.5.9.3 Protection by sacrificial anodes

3.5.9.3.1 Anode materials

(1) Possible anode materials are alloys on aluminium, zinc and magnesium basis. In sea water environment, magnesium anodes shall not be used.

(2) In general only materials from manufacturers approved by GL may be used. GL may accept approvals granted by other testing institutes or grant an approval on the basis of continuous quality control on the products.

(3) For works' approvals a description of the workshop shall be submitted to GL. The workshop shall have available appropriate manufacturing and quality control facilities, as well as laboratories for testing of the anodes. Where, in exceptional cases, anodes have to be tested by institutions outside the workshop, these have to dispose of the facilities required. Prior to approval of the workshop the manufacturing and testing facilities will be inspected.

(4) The anodes shall be provided with certificates which shall contain the following details:

– manufacturing workshop
– type of anode
– chemical analysis
– method of analysis
– current capacity [Ah/kg]
– current output [A]

(5) In special cases, or upon orderer's expressed wish, the tests are to be carried out under supervision by GL Wind. GL Wind reserve the right of carrying out checks at the consignments furnished with a manufacturer's certificate.

(6) All anodes shall be marked such as to enable perfect identification of the manufacturer, and type of anode.

(7) Where special requirements exist for the anodes, proof of suitability for the envisaged purpose shall be furnished.

(8) Where novel, not yet proven anode materials are used, their properties shall be determined by experiments the results of which are to be submitted to GL Wind.

(9) The metallic connection between the anode material and the mounting shall be safeguarded, and proof thereof is to be presented to GL Wind on request.

3.5.9.3.2 Dimensioning of anodes

(1) The calculation of the number and size of anodes required depends on the parameters mentioned in Section 3.5.9.2 (calculation principles). All relevant documents on the data related to the place of use, the structure and the anode material are to be submitted to GL Wind.

(2) The required anode weight can be calculated in accordance with the following formula:

$$m = \frac{A \cdot I \cdot t}{Q} \cdot j \; [kg] \qquad (3.5.2)$$

m = required total mass of anodes [kg]

A = total surface to be protected [m^2]

I = required protective current density [A/m^2]

t = duration of protection [h]

Q = practical current capacity [A·h/kg]

j = safety factor = 1.1

(3) The anodes shall be shaped geometrically such as to ensure the current delivery required.

3.5.9.3.3 Installation of anodes

(1) The anodes shall be connected to the object to be protected, such as to be permanently conductive. Where this is done by welding, the Section 3.4.2 Welding shall be applied.

(2) Where the anodes are not intended to be welded, proof shall be presented of a safe electric contact.

(3) In order to achieve a current distribution as uniform as possible, sacrificial anodes should have a minimum distance of approx. 30 cm from the structure.

(4) The anodes shall be distributed in such a way that, throughout, the potential is more negative than the protective potential according to Table 3.5.1, i.e. that no so-called shadow effects are caused by other components.

(5) The anodes and their mountings shall be dimensioned such as to be capable of resisting the loads due to currents and waves.

(6) With a view to the construction regulation to be applied to the respective structure and to possible damages to structural elements, fastening shall be agreed on with GL Wind.

(7) The anode surface shall be free from dirt and coating materials, so that the current output will not be impaired.

3.5.9.3.4 Control of cathodic protection

(1) Potential measurements are to be carried out after an appropriate period following commissioning of the structure for establishing whether the steel is provided with the required protection. Potentials are, as a rule, to be controlled once a year. In case of impressed current systems, the off-potentials are to be determined.

(2) For the control measurements Ag/AgCl/ KCl reference electrodes shall be used.

(3) The reference electrodes shall be carried as close to the structure as possible by a diver and/or manned or unmanned diving device in accordance with a defined schedule.

(4) The state of the sacrificial anodes shall be checked during the survey of the structure with regard to passivation and intercrystalline corrosion. At a selected number of anodes the potential and dimensions shall be established.

3.5.9.4 Cathodic protection by impressed current

3.5.9.4.1 Anode materials

(1) The anodes of impressed current installations may consist of lead-silver alloys, platinized tantalum, niobium or titanium, or of layers of metal oxides applied on well-conducting base metal.

(2) Anodes made of lead-silver alloys may only be used for water depths of up to 30 m.

(3) The platinum layer on tantalum, niobium or titanium shall show satisfactory adhesion to the carrier material.

(4) Platinum coated titanium anodes may be exposed to loads of up to 8 V, niobium anodes up to 60 V and tantalum anodes up to 150 V. Proof of suitability for higher direct voltages shall be presented to GL Wind. When determining the voltage, the applicable diving regulations shall be observed.

(5) Documents on the manufacturing workshop, manufacturing procedure, composition of alloys and thickness of the platinum coat and its determination shall be submitted to GL Wind.

3.5.9.4.2 Design of an impressed current system

(1) For calculation of the required current density the conditions outlined in Section 3.5.9.2 (calculation principles) apply.

(2) Owing to the normally small number of anodes and the concentrated current discharge the current distribution is not an optimum. Usually the surfaces neighbouring the anode are overprotected. Therefore, in designing the impressed current protection installation, the calculated total current density in dependence of the distance between anodes and steel structure shall be multiplied by a factor 1.2 to 1.5 (cf. Section 3.5.9.11).

(3) It has to be ensured that no areas without sufficient protection exist. Where owing to the shadow effect of other components surfaces are protected unsatisfactorily and where installation of additional external current anodes is not possible, in agreement with GL Wind a combination of protection by impressed current and sacrificial anodes may be provided.

3.5.9.4.3 Set-up of an impressed current system

(1) In the design and construction of electrical apparatus and installations, such as rectifiers, control and recording units, cable installation etc., regulations for offshore installations are to be observed.

(2) The cables shall be arranged such as to be relieved of tension and protected against mechanical damage (e.g. in steel tubes). It is to be considered that repairs or renewals of cables should be possible.

(3) The anodes shall be arranged at a distance of not less than 1,5 m from the steel structure, or else plastic shields are to be used which safeguard a corresponding distance between anode surface and steel surface to be protected.

(4) The anodes shall be designed such as to enable replacement under water. Therefore, free contacts shall be resistant to seawater and protected against fouling.

(5) The use of anodes not firmly attached to the structure - e.g. laid on the sea bottom - shall be agreed with GL Wind.

(6) For supervision of the installation, at appropriate points reference electrodes have to be fitted, the values of which can be read and/or record on board.

(7) The potential of the installation should be automatically controlled. In that case change-over to manual control shall be provided.

(8) For fastening of the anodes to the structure see Section 3.5.9.6.

3.5.9.4.4 Control of impressed current systems

(1) With impressed current installations, at least once a week, the functioning of the rectifier instruments and control devices, the voltage, the current delivery of the anodes and the potential values shall be checked by means of the installed reference electrodes.

(2) The condition of the impressed current anodes and cables shall be checked once a year on the occasion of the general annual survey of the structure.

3.5.10 Reinforced concrete

(1) The cover of the concrete above the reinforcement that will be applied should have the minimum value according to DIN 1045-1:2001-07. For offshore structures the exposition class of minimum cover is XS3. The corrosion protection system of prestressing, tendon and their fixing has to be designed by an arrangement with GL Wind.

(2) Bonded tendons for prestressing concrete have to be protected against corrosion according EN 445 – 447, EN 523 and EN 524. The grout is discussed in EN 445 – 447 and the behaviour and the quality control of the steel strip sheaths for prestressing tendons are discussed in EN 523 and 524.

Appendix 3.A Steels Suitable for Welded Offshore Structures

3.A.1 Preliminary remarks:

(1) Table 3.A.1 contains a selection of appropriate steels for plates and sections, while Table 3.A.2 lists materials suitable for tubes. It will have to be checked from case to case, whether the envisaged material complies with the impact energy requirements as laid down in the present Regulation and in the construction specification.

(2) Steels produced in accordance with other standards may be employed, provided they have equivalent properties. In that case, they will have to be correlated to the steel grades listed in Tables 3.A.1 and 3.A.2 in accordance with their properties.

Table 3.A.1 Appropriate steel for plates and sections

Structural member category	Steel strength class	Standard and/or Rules	Designation of material
Special	High strength	EN 10225 EN 10025-3 /-4 [2]	S 460 + S 420 of Group 2 + 3 S 460 NL [1] , S 460 ML [1] S 420 NL [1] , S 420 ML [1]
	Higher strength	EN 10225 EN 10025-3 /-4 [2]	S 355 of Group 2 + 3 S 355 NL [1] , S 355 ML [1]
	Normal strength	EN 10025-3 /-4 [2]	S 275 NL [1], S 275 ML [1]
Primary	As for category “special” and additionally:		
	High strength	EN 10025-3 /-4 [2]	S 460 N + NL , S 460 M + ML S 420 N + NL , S 420 M + ML
	Higher strength	EN 10225 EN 10025-3 /-4 [2] EN 10025-2 [3]	S 355 of Group 1 S 355 N + NL , S355 M + ML S 355 J2 + K2
	Normal strength	EN 10025-3 /-4 [2] EN 10025-2 [3]	S 275 N + NL , S 275 M + ML S 275 J2 + K2 S 235 J2 + K2
Secondary	As for category “special” and “primary” and additionally:		
	Higher strength	EN 10025-2 [3]	S 355 J0
	Normal strength	EN 10025-2 [3]	S 275 JR , S 275 J0 S 235 JR , S 235 J0

[1] max. P = 0.025 % , max. S = 0.010 %

[2] in connection with EN 10025-1. EN 10025-3 /-4 supersede EN 10113-2 /-3:1993

[3] in connection with EN 10025-1. EN 10025-2 supersedes EN 10025:1990

Table 3.A.2 Appropriate steels for tubes

Structural member category	**Steel strength class**	**Standard and/or Rules**	**Designation of material**
Special	High strength	EN 10225 EN 10219 EN 10210	S 460 + S 420 of Group 2 + 3 S 460 NLH [1] , S 460 MLH [1] S 420 MLH [1] S 460 NLH [1]
	Higher strength	EN 10225 EN 10219 EN 10210	S 355 of Group 2 + 3 S 355 NLH [1] , S 355 MLH [1] S 355 NLH [1]
	Normal strength	EN 10219 EN 10210	S 275 NLH [1] , S 275 MLH [1] S 275 NLH [1]
Primary	As for category “special” and additionally:		
	High strength	EN 10219 EN 10210	S 460 NH + NLH , S 460 MH + MLH S 420 M + ML S 460 NH + NLH
	Higher strength	EN 10225 EN 10219 EN 10210	S 355 of Group 1 S 355 NH + NLH , S355 MH + MLH S 355 J2H S 355 NH + NLH , S 355 J2H
	Normal strength	EN 10219 EN 10210	S 275 NH + NLH , S 275 MH + MLH S 275 J2H S 275 NH + NLH , S 275 J2H
Secondary	As for category “special” and “primary” and additionally:		
	Higher strength	EN 10219 EN 10210	S 355 J0H S 355 J0H
	Normal strength	EN 10219 EN 10210	S 275 J0H , S 235 JRH S 275 J0H , S 235 JRH

[1] max. P = 0.025 % , max. S = 0.010 %

Appendix 3.B Thickness Limitations of Structural Steels

3.B.1 Preliminary remarks:

Table 3.B.1 contains thickness limitations of structural steels for different structural categories and design temperatures. The grade of steel to be used shall in general be selected according to the design temperature and the thickness for the applicable structural category. Welded structural steels exceeding the prescribed thickness limits have to fulfil the requirements specified in Section 3.4.2.6.8 para 2.

Table 3.B.1 Thickness limitations (mm) of structural steels for different structural categories and design temperatures (°C)

Structural member category	Steel strength class	Charpy V-notch test temperature T_T	Design temperature T_D			
			≥ 10	0	-10	-20
Special	High strength	0	15	15	10	N.A.
		-20	30	30	25	20
		-40	60	60	50	40
		-60	150	150	100	80
	Higher strength	0	10	10	N.A.	N.A.
		-20	25	25	20	15
		-40	50	50	40	30
		-60	100	100	80	60
	Normal strength	-20	35	30	25	20
		-40	60	60	50	40
Primary	High strength	0	30	30	25	20
		-20	60	60	50	40
		-40	150	150	100	80
		-60	150	150	150	150
	Higher strength	0	25	25	20	15
		-20	55	55	45	35
		-40	100	100	80	60
		-60	150	150	150	150
	Normal strength	0	40	30	25	20
		-20	60	60	50	40
		-40	150	150	100	80
Secondary	High strength	0	60	60	50	40
		-20	150	150	100	80
		-40	150	150	150	150
		-60	150	150	150	150
	Higher strength	0	50	50	40	30
		-20	100	100	80	60
		-40	150	150	150	150
		-60	150	150	150	150
	Normal strength	not tested	30	30	25	20
		0	60	60	50	40
		-20	150	150	100	80
		-40	150	150	150	150

N.A. = no application

Rules and Guidelines

IV *Industrial Services*

2 Guideline for the Certification of Offshore Wind Turbines

4 Load Assumptions

Edition 2005

Germanischer Lloyd
WindEnergie

Table of Contents

4.1 Fundamentals

4.1.1 General

(1) The following sections define the requirements for the determination of the loads resulting from the environmental conditions in conjunction with the operational behaviour of an offshore wind turbine.

(2) A description of the terms and definitions can be found in Appendix 4.A and Section 1.1.7.

(3) The external conditions are classified according to intensity and shall be selected to match the desired requirements of the installation site as a design basis for the calculation of the loads.

(4) The design of the support structure (tower, sub structure and foundation) is usually site specific, for the machinery design (topsides structure) a generic approach according the wind classes defined in the following is possible.

(5) Special, requirements for loads during transport and installation of the offshore wind turbine are given in Chapter 12.

(6) For particular elements, components or procedures not specifically covered by the present Guidelines, and for floating units, other GL rules and guidelines may be applied where appropriate and agreed upon (see Appendix 1.A), e.g.:

– Guideline for the Certification of Wind Turbines
– Guideline for the Construction of Fixed Offshore Installations in Ice Infested Waters
– Rules for the Classification and Construction of Offshore Installations
– Guidelines for the Design, Construction and Certification of Floating Production, Storage and Offloading Installations
– Rules for Subsea Pipelines and Risers
– Rules for Underwater Technology

(7) In the application of the present guidelines it is assumed that the offshore wind turbine is unmanned. The turbine may include shelters but not permanent quarters.

(8) Consideration may be given to changed design requirements for the design of structures that are manned and have a different design life than the typical 20 years, or where the loss of or severe damage of the structure would result in a high consequence of failure.

4.1.2 Assessment documents

For the assessment of the load assumptions documents containing the following information shall be submitted:

a) Wind farm configuration charts with the position of turbines and bathymetry, as well as the natural frequencies of the turbines depending on their position.

b) Site Data, such as environmental conditions, information on the characteristics of the sea floor, geotechnical data, electrical conditions etc, shall be defined for the site or taken according to the requirements defined by the manufacturer and or the generic classes. The design documentation of the specific data shall at least contain the information listed in Appendix 4.D.

c) Description of the models used to derive environmental conditions and the values of essential design parameters, where the models in Section 4.2 are adopted, statement of the values of the parameters are sufficient.

d) Description of marine conditions influencing the structure's loading and its behaviour as well as the methods taken into account to reduce or exclude them, i.e. scour and scour protection, marine growth, corrosion protection and corrosion allowance.

e) Physical environmental parameters (e.g. air density, dynamic viscosity, water density, salinity etc.) at the intended installation site. At locations with extreme temperatures, the remarks in Section 4.3.4 shall be observed.

f) General specifications with an indication of the design life, environment, place(s) and period of construction, and the main stages of construction up to final assembly and/or installation at sea.

g) Documents on transport, installation and erection procedures: Details on special turbine states, and specification of the corresponding maximum permissible mean wind speeds and significant wave heights for transport, installation and erection and maintenance. Here the dimensioning loads for locking devices of moving components (e.g. blade, rotor and yaw bearing lock) shall be specified.

h) Marine operations may impose additional loads on the structure or structural members. The size and displacement of the maintenance boat shall be specified.

i) General arrangement and design details of mooring system, if applicable.

j) Drawings with principal dimensions and a compilation of the masses, mass moments of inertia, and centres of gravity. For the geometry of the rotor blade, this includes in particular the twist, chord length, profile thickness and profile type.

k) For all main structural components (e.g. rotor blade, drive train, support structure etc.), the mass distribution, stiffness, natural frequencies and damping used for the calculation shall be specified in the case of stresses determined by computational means.

l) The characteristic parameters of those electrical components (e.g. positioning drives, generator etc.) which have an influence on the dynamic behaviour of the turbine (see also Chapter 7 and Chapter 8).

m) A power curve as the result of the calculations in normal operation between V_{in} and V_{out} steady wind conditions.

n) Aerodynamic data for the profile types used (lift, drag and moment coefficients) in relation to the angle of incidence over 360° for the Reynolds' numbers and profile thicknesses in question. A 3D-correction of the data shall be performed.

o) Description of the soil conditions assumed for design and derived values used for load analysis, e.g. p-y-curves.

p) Methods to derive the hydrodynamic behaviour of the support structure and the derived (hydrodynamic coefficients) values. The influence of the appurtenances has to be considered.

q) A resonance diagram (e.g. Campbell diagram) shall be given, containing the natural frequencies to be considered (e.g. rotor blade, drive train, support structure) and the relevant excitations (e.g. rotor speed 1P, 3P, 6P etc.).

r) For operation within the resonance range of the support structure, see Section 4.3.6: Description of the functional principle and criteria for the application of vibration monitoring as well as the prescribed triggering values (see also Sections 2.3.2.6 and 4.3.6 para 3).

s) Detailed description of the controller to permit emulation (see Section 2.1.3).

t) The braking torque curve of the mechanical brake.

u) Description and, if applicable, a sketch of the coordinate systems used, showing the position of coordinate origins and their orientation (examples see Appendix 4.A).

v) Detailed description of the calculated load cases and the evaluation of extreme and fatigue loads.

w) The assessment documents shall be accompanied by a description of the functional principle of the offshore wind turbine and of all parts of the control and safety systems which exert an influence on the load response of the offshore wind turbine. The scope and content of the documents to be submitted in this regard are given in Section 2.1.1.

4.1.3 Design methods

(1) This Guideline is based – explicitly or implicitly – on nominal or design load values (design loads) to be used in structural analysis.

(2) If the design loads are determined by computation, a structural dynamics model shall be used. Calculations may generally be based on linear elastic theory. However, non-linear relations between loads and load effects shall be properly accounted for, where they are found to be important.

(3) A structure may become unsafe or unfit for use by damage or other changes of state according to different criteria. They may be defined by "Limit States". The limit states are classified in Section 1.3.2.2.

(4) The load cases are drawn up for general strength and fatigue strength analysis. If appropriate, the dynamic behaviour of the system (e. g. resonances, dynamic instabilities) is to be taken into account in both cases. The fatigue load analysis shall include the effect of the distribution of wind speed over the rotor swept area in an appropriate manner. This distribution is the result of deterministic (vertical wind-speed gradient, tower shadow) and stochastic influences (partial gusts, turbulence).

(5) Verification of the adequacy of the design shall be made by calculation and/or by measurements. If measured results are used in this verification, the environmental conditions prevailing during the test shall be shown to reflect the design situations defined in this Guideline. The selection of measurement conditions, including the test loads, shall take account of the relevant partial safety factors to be applied, and shall be agreed upon with GL Wind.

(6) For the definition of the loads, the meteorological and oceanographic data relevant for the installation site shall apply. If the actual external conditions are not sufficiently known, then the offshore wind turbine can be designed according to one of the wind turbine classes specified in Section 4.2.2.1 and hydrodynamic data described. Before erection of the turbine, however, it shall be ensured that the design conditions adequately cover the prevailing external conditions at the site. For turbines erected within a wind farm, the mutual influence shall be taken into account. This manifests itself in increased turbulence and non-uniform inflow.

(7) Semi-probabilistic design methods, usually in association with limit state and partial safety factor design, may be applied using adequate codes. The relevant data and safety factors shall be agreed upon with GL Wind.

(8) Probabilistic methods may be used in special cases, after consultation with GL Wind.

4.1.4 Safety classes

(1) An offshore wind turbine shall be designed according to one of the following two safety classes:

– the normal safety class which applies when a failure results in risk of personal injury or economic, environmental and social consequences;

– the special safety class which applies when the safety requirements are determined by local regulations and/or the safety requirements are agreed between the designer and the customer.

(2) Partial safety factors for the loads for a wind turbine of the normal safety class are specified in Section 4.3.7 of this Guideline. Partial safety factors for wind turbines of the special safety class require prior agreement. A wind turbine designed according to the special safety class is a “class S” turbine.

4.2 External Conditions

4.2.1 General

(1) Offshore wind turbines are subjected to oceanographic, meteorological and electrical conditions which may affect their loading, durability and operation. To ensure the appropriate level of safety and reliability, the environmental, electrical and soil parameters as well as other relevant parameters shall be taken into account in the design, and shall be explicitly stated in the design documentation.

(2) Within the scope of the offshore wind turbine certification, the conditions prevailing at the installation site shall be registered. This includes the features listed in the following sections. Other conditions which are not listed and may influence the design of the offshore wind turbine shall also be stated.

(3) For the definition of loads, the meteorological and oceanographical data and other marine climate conditions relevant for the installation site shall apply. Special attention shall be paid to extreme locations, such as polar regions and areas in which tropical cyclones may occur.

(4) Environmental conditions may be determined by wind, sea currents, sea waves, sea level, climatic conditions, temperature and marine growth, sea ice, sea bed, other influences, as applicable.

(5) Environmental design conditions are to be specified in a way that they cause the most adverse effect on the relevant probability level on the structure.

(6) For the purpose of combination with the operating conditions, the external conditions are subdivided into normal and extreme. Normal external conditions are in general those events which have a probability of being exceeded once a year or more often. Extreme external conditions on the other hand are events with a probability of being exceeded once in 50 years.

(7) Simplifying assumptions in this Guideline are made in accordance with the specification of related safety factors for structural design. If estimates of environmental design parameters are based on assumptions that are more appropriate for the design case than those specified in the Guideline, a reduction of the safety factor may be approved by GL Wind.

(8) For sites in regions of particular risks or if the environmental conditions are not determined according to the requirements of the Guideline, the safety factors can be adjusted to uphold the safety level of this Guideline.

(9) Limiting environmental design conditions may be specified on the basis of statistical observations, if available. Probabilistic estimations, if not specified in the Guideline, may be applied in consultation with GL Wind.

(10) Superposition of different environmental design parameters shall be based on physical relations or on statistical correlations between these parameters or between the environmental phenomena to which they belong.

(11) Estimation of design parameters on the basis of environmental design conditions (e. g. estimation of wave particle velocity or acceleration on the basis of wave height and period) may be used in consultation with GL Wind, if these are not carried out as specified in the Guideline.

(12) Corrosion protection is to be taken into account by the selection of suitable materials and appropriate coatings and protective films, plus regular inspection, see Section 3.5. The assessment of mechanical and electrical components shall take into account not only the integrity but also the influence of corrosion on functioning, e. g. jamming of rusted joints or failure of sensors. Analogous considerations are to be applied with regard to the possibility of erosion, particular for the rotor blades.

(13) It is to be borne in mind that offshore wind turbines are exposed structures and therefore at risk of being struck by lightning.

(14) The normal and extreme conditions which are to be considered in design are prescribed in the following sections.

4.2.2 Meteorological data

4.2.2.1 Wind turbine classes

(1) For an offshore wind turbine the definition of wind turbine classes in terms of wind speed and turbulence parameters remains appropriate as the basis for design of the topsides structure (turbine machinery). The values of wind speed and turbulence intensity parameters are intended to represent the characteristic values of many different sites and do not give a precise representation of any specific site. The goal is to achieve wind turbine classification with clearly varying degrees of robustness governed by the wind speed and turbulence intensity parameters. Table 4.2.1 specifies the basic parameters which define wind turbine classes.

(2) The design of support structures of offshore wind turbines shall be based on environmental conditions, including the marine conditions, which are representative of the specific site at which the offshore wind turbine will be installed.

(3) A turbine designed according to the wind turbine class with a reference wind speed V_{ref} is so designed that it can withstand the environmental conditions in which the 10-min mean of the extreme wind speed with a recurrence period of 50 years at hub height is equal to or less than V_{ref} .

(4) The mean wind speed V_{ave} is a statistical mean of the instantaneous value of the wind speed, averaged over a certain period ranging from a few seconds to many years. In this Guideline, the annual average of the wind speed over many years is meant. This value is used in the Weibull or Rayleigh functions which represent the wind speed distribution (see Section 4.2.2.3.1).

(5) The values as per Table 4.2.1 apply at hub height, where:

V_{ref} = reference wind speed

V_{ave} = annual average wind speed over many years at hub height

A = category for higher turbulence intensity values

B = category for medium turbulence intensity values

C = category for lower turbulence intensity values

I_{15} = characteristic value of the turbulence intensity at 15 m/s

a = slope parameter for turbulence characteristics

(6) In addition to these basic parameters, several other parameters are required to completely specify the external conditions used in the design of an offshore wind turbine. The values of these additional parameters are specified in Sections 4.2.2.2 to 4.2.2.5.

(7) The design lifetime shall be at least 20 years.

(8) The abbreviations added in parentheses within the headings in the remainder of this section are used for describing the external wind conditions for the design load cases defined in Section 4.3.3.4.

Table 4.2.1 Basic parameters for wind turbine classes

Wind turbine class	I	II	III	S
– V_{ref} [m/s]	50	42.5	37.5	Site Specific
– V_{ave} [m/s]	10	8.5	7.5	
– A I_{15} (-)	0.18			
– a (-)	2			
– B I_{15} (-)	0.16			
– a (-)	3			
– C I_{15} (-)	0.145			
– a (-)	3			

4.2.2.2 Determination of wind conditions

(1) Offshore wind turbines shall be designed to withstand safely the wind conditions defined for the site or the selected wind turbine class.

(2) In the design and at the specific site the basic parameters for the wind listed below shall be determined at least (see also Appendix 4.D):

- reference wind speed V_{ref}
- annual average wind speed V_{ave}
- wind speed distribution
- wind direction distribution (wind rose)
- turbulence intensity I_{15} at V_{hub} = 15 m/s
- wind shear

(3) The averaging time for the mean wind speed used in this Guideline is 10 minutes.

(4) Here I_{15} is the characteristic value of the turbulence intensity at hub height for a 10-min mean wind speed of 15 m/s. The characteristic value is determined through addition of the measured standard deviation of turbulence intensity to the measured mean value of the turbulence intensity.

(5) The wind conditions may be determined at the intended site by measurements. The site conditions shall be correlated with long-term records of local meteorological stations.

(6) The measurement period shall be sufficiently long to obtain reliable data for at least 6 months. If seasonal variations contribute significantly to the wind conditions, the measurement period shall take account of this influence. The measurement height shall be sufficient to eliminate disturbances from the wave surface.

(7) The value I_{15} should be determined from the measured data at wind speeds exceeding 10 m/s, by means of suitable statistical methods. If other local conditions influence the turbulence intensity, as low frequency trends in wind speed, these effects shall be included in the data. The frequency of measurements shall be high enough to produce a realistic representation of the wind power spectral density (PSD).

(8) Alternatively, the relevant characteristic values of the wind may be determined by numerical methods in consultation with GL Wind. Standard linkages of external parameters, such as effective fetch of the wind, roughness length, mean wind speed etc., to power spectra and coherence functions of the wind speed are regarded as fundamentally permissible as the starting point for a description of the turbulence.

(9) If the standard deviation of the turbulence intensity was not determined by measurement, the characteristic turbulence intensity at 15 m/s can be found by multiplying the calculated or measured mean turbulence intensity by the factor 1.2.

(10) The interval of each wind speed bin may be at most 2 m/s, and that of the wind direction sector at most 30°. All parameters, except the air density, shall be submitted as a function of the wind direction averaged over 10 minutes.

(11) The properties of the anemometer, the sampling rate and the averaging period for the recording of the measured values can influence the determination of the turbulence intensity. These influences shall be taken into account in forecasting the turbulence intensity from measurements.

(12) The models and parameter values for the wind conditions which could be assumed for the design of an offshore wind turbine are defined in following Sections.

4.2.2.3 Normal wind conditions

4.2.2.3.1 Wind speed distribution

(1) The wind speed distribution at the site is significant for the offshore wind turbine design, because it determines the frequency of occurrence of the individual load components. In the following, the Weibull distribution (equation 4.2.1) and the Rayleigh distribution (equation 4.2.2) are given.

(2) The wind speed distribution given in a Weibull distribution shall be based on site measurements which shall be verified with close-by long term measurements.

(3) For design in the standard wind turbine classes, the Rayleigh distribution (equation 4.2.2) shall be taken for the load calculations.

$$P_W(V_{hub}) = 1 - \exp[-(V_{hub}/C)^k] \tag{4.2.1}$$

$$P_R(V_{hub}) = 1 - \exp[-\pi(V_{hub}/2V_{ave})^2] \tag{4.2.2}$$

$$\text{with } V_{ave} = \left\{ \begin{array}{l} C\dfrac{\sqrt{\pi}}{2}, \; if \; k = 2 \\ C\,\Gamma\left(1+\dfrac{1}{k}\right) \end{array} \right\} \tag{4.2.3}$$

where:

$P_W(V_{hub})$ = Weibull probability distribution: cumulative probability function, i.e. the probability that $V < V_{\text{hub}}$ [-]

$P_R(V_{hub})$ = Rayleigh probability function: cumulative probability function, i.e. the probability that $V < V_{hub}$ [-]

V_{hub} = 10-min mean of the wind speed at hub height [m/s]

V_{ave} = annual average wind speed at hub height [m/s]

C = scale parameter of the Weibull function [m/s]

k = shape parameter of the Weibull function. For design in the standard wind turbine class, the value k = 2 shall be taken [-]

Γ = gamma function [-]

(4) *C* and *k* can be derived from real data. The Rayleigh function is identical to the Weibull function if $k = 2$ is selected and C and V_{ave} satisfy the condition given in equation 4.2.3 for $k = 2$.

(5) The distribution functions indicate the cumulative probability that the wind speed is less than V_{hub} . From this, it obtains that $(P\{V_1\} - P\{V_2\})$ specifies the proportion of the time in which the wind speed varies within the limits V_1 and V_2 . On derivation of the distribution functions, the corresponding probability density functions are obtained.

4.2.2.3.2 Normal wind profile model (NWP)

(1) The wind profile *V(z)* denotes the average wind speed as a function of height *z* above the still water line and shall be assumed to be given by the power law:

$$V(z) = V_{hub}\,(z / z_{hub})^{\alpha} \tag{4.2.4}$$

where:

$V(z)$ = wind speed at the height z [m/s]

z = height above still water line [m]

z_{hub} = hub height above still water line [m]

α = power law exponent [-]

(2) The assumed wind profile is used to define the average vertical wind shear across the rotor swept area.

(3) This model assumes neutral atmospheric stability and on the basis of a constant surface roughness length of 0.002 m, the power law exponent α is given with $\alpha = 0.14$ for all wind speeds.

4.2.2.3.3 Normal turbulence model (NTM)

(1) The turbulence of the wind is represented by energy carried along by the turbulence eddies. Its distribution over frequencies – represented by power spectra and coherence functions – can generally be regarded as an adequate representation of the turbulence over a period of approx. 10 minutes that is in the spirit of this Guideline. The characterization of the natural turbulence of the wind by statistic parameters for the relatively short period in which the spectrum remains unchanged, leads among other to the following parameters:

– mean value of the wind speed

– turbulence intensity

– integral length scales

(2) Standard combinations of external parameters, such as the fetch of the wind, roughness length, mean wind speed etc., with power spectra and coherence functions of the wind speed are considered as basically acceptable starting points for a description of the turbulence.

(3) The values of the turbulence intensity shall be taken at hub height. For other heights, it may be assumed that the standard deviation of the wind speed remains constant, whilst the wind speed varies with height according to Section 4.2.2.3.2, with the turbulence intensity thus also changing. Particular attention shall be paid to the random change in wind speed over the rotor swept area. This aspect, as well as deterministic wind speed changes, generates together with the rotation of the rotor the effect of "rotational sampling" (i.e. repeated passing through partial gusts). This effect can exert a considerable influence on the fatigue strength. In general, three-dimensional turbulence models, which consider not only the longitudinal but also the transversal and lateral wind speed components, shall be used.

(4) The site-specific influence on the turbulence intensity actually prevailing shall be taken into account. The change in the turbulence intensity, the mean value of the wind speed as well as the integral length scale for erection in a wind farm (mutual influence of the turbines) shall be considered.

(5) For the standard wind turbine classes, the power spectral densities of the random wind velocity vector field, whether used explicitly in the model or not, shall satisfy the following requirements:

a) The characteristic value for the standard deviation of the longitudinal wind velocity component at hub height shall be given by:

$$\sigma_1 = I_{15}(15\,m/s + aV_{hub})/(a+1) \qquad (4.2.5)$$

where:

σ_1 = standard deviation of the longitudinal wind speed at hub height [m/s]

This standard deviation shall be assumed to be invariant with height.

Note:

To perform the calculations of load cases in addition to those specified in Table 4.3.1, it may be appropriate to use different percentile values. Such percentile values shall be determined by adding the following value to equation 4.2.5:

$$\Delta\sigma_1 = (x-1)(2m/s)\,I_{15} \qquad (4.2.6)$$

where x *is determined from the normal probability distribution function. For example,* x *= 1.64 for a 95th percentile value.*

Values for I_{15} and a are given in Table 4.2.1. The standard deviation of the wind speed σ_1 and of the turbulence intensity σ_1/V_{hub} are shown in Fig. 4.2.1 as a function of wind speed for the specified values of I_{15} and a.

b) Towards the high frequency end of the inertial sub-range, the power spectral density of the longitudinal component of the turbulence $S_1(f)$ shall asymptotically approach the form:

$$S_1(f) = 0.05\,(\sigma_1)^2(\Lambda_1/V_{hub})^{-2/3} f^{-5/3} \qquad (4.2.7)$$

where:

$S_1(f)$ = power spectral density [m^2/s^2]

Λ_1 = turbulence scale parameter, defined as the wavelength at which the dimensionless longitudinal power spectral density $f\,S_1(f)/\sigma_1^2$ equals 0.05 [m]

f = frequency [s^{-1}]

The turbulence scale parameter Λ_1 shall be given by:

$$\Lambda_1 = \begin{cases} 0.7 z_{hub} & \text{for } z_{hub} < 60\text{m} \\ 42\text{m} & \text{for } z_{hub} \geq 60\text{m} \end{cases} \qquad (4.2.8)$$

(6) Specifications for stochastic turbulence models are given in [4.14] and [4.15].

(7) The following general requirements shall be observed for load calculations with turbulent wind:

– The simulation period of each simulation run with the normal turbulence model (NTM) shall be at least 10 minutes per simulation run (see also Section 4.3.3.4 para 9).

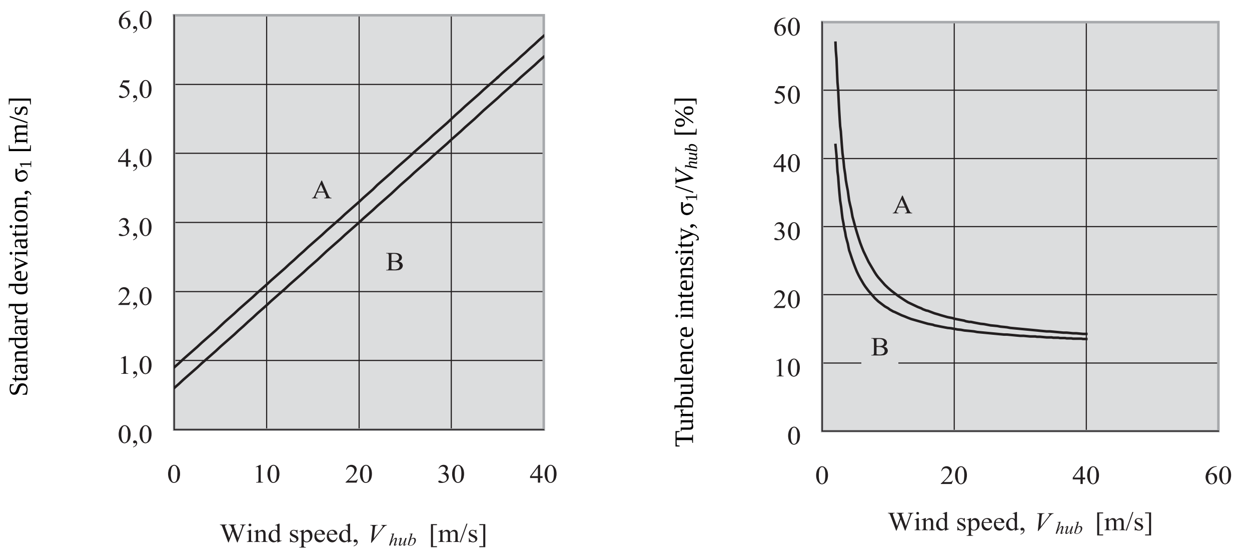


Fig. 4.2.1 Characteristic wind turbulence

– In the fatigue loading calculation, each simulation run shall be performed with a different initial value (“seed”) for producing the turbulent wind field.

– Three-dimensional turbulence fields shall be used.

– The resolution of the turbulent wind fields shall be adequate. A minimum of at least 10 x 10 points (depending on diameter) is recommended. However, the grid spacing should be less than 10 m.

– If tower section loads are evaluated, the wind field shall cover the entire plant (rotor and tower), or a substitute model may be used after consultation with GL Wind.

4.2.2.4 Extreme wind conditions

The extreme wind conditions are used to determine the extreme wind loads acting on offshore wind turbines. These conditions include peak wind speeds due to storms and rapid changes in wind speed and direction. These extreme conditions include the potential effects of wind turbulence, with the exception of the EWM (see Section 4.2.2.4.1), so that only the deterministic effects need to be considered in the design calculations.

4.2.2.4.1 Extreme wind speed model (EWM)

(1) The EWM shall be based on investigations at the installation site, or if no informations are available it can be obtained as described below.

(2) The EWM can be either a steady or a turbulent wind model. The wind models are based on the reference wind speed V_{ref} and a certain standard deviation σ_1.

(3) For the steady extreme wind model, the 50-year extreme wind speed V_{e50} , the one-year extreme wind speed V_{e1} and the reduced 50-years and one-year wind speed shall be based on the reference wind speed V_{ref} . The wind speed V_{e50}, V_{e1}, V_{50red} and V_{1red} can be computed as a function of the height z using the following equations:

$$V_{e50}(z) = 1.25\,V_{ref}(z/z_{hub})^{0.14} \qquad (4.2.9)$$

$$V_{e1}(z) = 0.8\,V_{e50}\,(z) \qquad (4.2.10)$$

$$V_{50red}(z) = 1.1\,V_{ref}(z/z_{hub})^{0.14} \qquad (4.2.11)$$

$$V_{1red}(z) = 0.8\,V_{e50red}\,(z) \qquad (4.2.12)$$

where:

$V_{eN}(z)$ = the expected extreme wind speed (averaged over 3 s), with a recurrence period of N years. V_{e1} and V_{e50} representing 1 and 50 years. The EWM is applied with a steady wind model.

V_{ref} = reference wind speed according to Section 4.2.2.1.

$V_{Nred}(z)$ = the expected reduced extreme wind speed (averaged over 60 s), with a recurrence period of N years. V_{1red} and V_{50red} representing 1 and 50 years. The EWM is applied with a steady wind model.

(4) For the turbulent extreme wind model, the 10-minute mean value of the wind speed is given as a function of the height z with a recurrence period of 50 years or 1 year by the following equations:

$$V_{50}\,(z) = V_{ref}\,\,(z/z_{hub})^{0.14} \qquad (4.2.13)$$

$$V_1(z) = 0.8\,V_{50}(z) \qquad (4.2.14)$$

where:

$V_N(z)$ = the expected extreme wind speed (averaged over 10 minutes), with a recurrence period of N years. V_1 and V_{50} representing 1 and 50 years.

(5) For the turbulent description of the extreme wind model (EWM), the mean wind speed at hub height V_{hub} shall be taken as V_{ref} or $0.8 \cdot V_{ref}$. In the turbulence model NTM (see Section 4.2.2.3.3), a standard deviation of at least $\sigma_1 = 0.12 \cdot V_{hub}$ shall be applied.

(6) Sometimes extreme wind speeds averaged over other periods or with other probabilities of being exceeded are available. In the absence of other confirmed data, the offshore wind with a probability of being exceeded once in 100 years may be converted to once in 50 years by reducing the speed by 3 %. The conversion of the wind speed to a different averaging time may be performed using Table 4.2.2.

Table 4.2.2 Conversion factors for averaging values of the wind speed (based on the 10 min value)

Averaging Time	**1 h**	**10 min**	**1 min**	**5 sec**	**3 sec**
Factor	0.91	1.00	1.10	1.21	1.25

(7) The following general requirements shall be observed for load calculations with the EWM:

– The simulation period of each simulation run with the EWM is stated in Section 4.3.3.4 para 9.

– For several simulations performed with turbulent wind for the entire load calculation, the wind fields used shall be based on different initial values (seeds) for generating the wind fields.

– If tower section loads are evaluated, the wind field shall cover the entire plant (rotor and tower), or a substitute model may be used after consultation with GL Wind.

– Further information is given in Appendix 4.B.1.

4.2.2.4.2 Extreme operating gust (EOG)

(1) The gust magnitude V_{gustN} at hub height for a recurrence period of *N* years shall be calculated for the standard wind turbine classes by the following relationship:

$$V_{gustN} = \beta \left(\frac{\sigma_1}{1 + 0.1(\frac{D}{\Lambda_1})} \right) \qquad (4.2.15)$$

where:

V_{gustN} = maximum value of the wind speed for the extreme operating gust, with an expected recurrence period of *N* years [m/s]

σ_1 = standard deviation, according to equation 4.2.5

Λ1 = turbulence scale parameter, given by:

$$\Lambda_1 = \begin{cases} 0.7 z_{hub} & \text{for } z_{hub} < 30\text{m} \\ 21\text{m} & \text{for } z_{hub} \geq 30\text{m} \end{cases} \qquad (4.2.16)$$

D = rotor diameter [m]

β = 4.8 for *N* = 1

β = 6.4 for *N* = 50

(2) The wind speed shall be defined for a recurrence period of *N* years by equation 4.2.17, where:

V(z) = see equation 4.2.4

T = 10.5 s for *N* = 1

T = 14.0 s for *N* = 50

(3) An example of an extreme operating gust for a recurrence period of 1 year is given in Fig. 4.2.2 for V_{hub} = 25 m/s and turbulence category A.

(4) The parameters were so determined for both recurrence periods that the maximum rise is the same.

4.2.2.4.3 Extreme direction change (EDC)

(1) The extreme direction change magnitude θ_{eN} for a recurrence period of *N* years shall be calculated using equation 4.2.18,

where:

θ_{eN} = extreme direction change, with a recurrence period of *N* years, limited to the range ± 180°

Λ_1 = turbulence scale parameter, according to equation 4.2.16

D = rotor diameter [m]

β = 4.8 for *N* = 1

β = 6.4 for *N* = 50

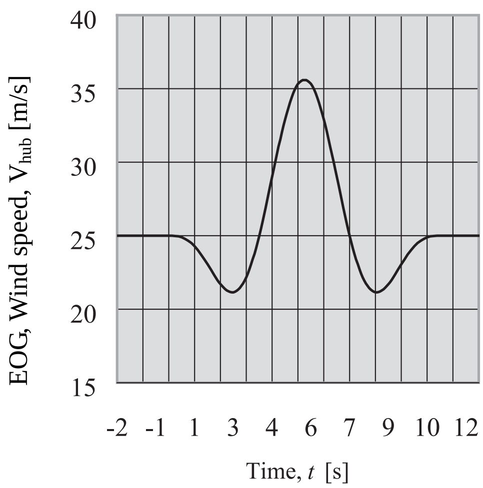


Fig. 4.2.2 Example of an extreme operating gust (N = 1, category A, D = 42m, z_{hub}= 30m, V_{hub} = 25m/s)

$$V(z,t) = \begin{cases} V(z) - 0.37 V_{gustN} \sin(3\pi t / T)(1 - \cos(2\pi t / T)) & \text{for } 0 \le t \le T \\ V(z) & \text{for } t < 0 \text{ and } t > T \end{cases} \qquad (4.2.17)$$

$$\theta_{eN} = \pm\beta \arctan\left(\frac{\sigma_1}{V_{hub}\left(1 + 0.1\left(\frac{D}{\Lambda_1}\right)\right)}\right) \qquad (4.2.18)$$

$$\theta_N(t) = \begin{cases} 0 & \textit{for } t < 0 \\ 0.5\, \theta_{eN} (1 - \cos(\pi t / T)) & \textit{for } 0 \le t \le T \\ \theta_{eN} & \textit{for } t > T \end{cases} \qquad (4.2.19)$$

$$V(z,t) = \begin{cases} V(z) & \textit{for } t < 0 \\ V(z) + 0.5 V_{cg} (1 - \cos(\pi t / T)) & \textit{for } 0 \le t \le T \\ V(z) + V_{cg} & \textit{for } t > T \end{cases} \qquad (4.2.20)$$

(2) The extreme direction change for a recurrence period of N years $\theta_N(t)$ shall be given by equation 4.2.19.

(3) Here T = 6 s is the duration of the extreme direction change transient. The sign shall be chosen so that the worst transient loading occurs. At the end of the direction change transient, the wind direction shall be assumed to remain unchanged. Furthermore, the wind speed shall be assumed to follow the normal wind profile model of Section 4.2.2.3.2.

(4) As an example, the extreme direction change with a recurrence period of 50 years, turbulence category A and V_{hub} = 25 m/s is shown in Figs. 4.2.3 and 4.2.4 as a function of V_{hub} and as a function of time for V_{hub} = 25 m/s.

4.2.2.4.4 Extreme coherent gust (ECG)

(1) For designs for the standard wind turbine classes, an extreme coherent gust with a magnitude of:

V_{cg} = 15 m/s

shall be assumed. The wind speed is defined by the relations given in equation 4.2.20.

(2) Here T = 10 s is the rise time and $V(z)$ the wind speed given in Section 4.2.2.3.2 “Normal wind profile model (NWP)”. The extreme coherent gust is illustrated in Fig. 4.2.5 for V_{hub} = 25 m/s.

4.2.2.4.5 Extreme coherent gust with direction change (ECD)

(1) In this case, the rise in wind speed (described by ECG, see Fig. 4.2.5) shall be assumed to occur simultaneously with the direction change θ_{cg}, where θ_{cg} is defined by the relations in the following equation:

$$\theta_{cg}(V_{hub}) = \begin{cases} 180° & \textit{for } V_{hub} < 4 m/s \\ \dfrac{720°\, m/s}{V_{hub}} & \textit{for } 4 m/s \le V_{hub} \le V_{ref} \end{cases} \qquad (4.2.21)$$

(2) The direction change θ_{cg} as a function of V_{hub} and as a function of time for V_{hub} = 25 m/s is shown in Figs. 4.2.6 and 4.2.7 respectively.

(3) The simultaneous direction change is given by equation 4.2.22.

(4) Here T = 10 s is the rise time. The normal wind profile model as specified in equation 4.2.4 shall be used.

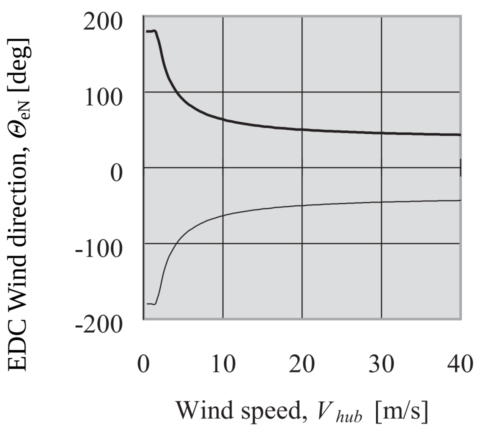


Fig. 4.2.3 Example of the magnitude of the extreme direction change (N = 50, category A, D = 42 m, z_{hub} = 30 m)

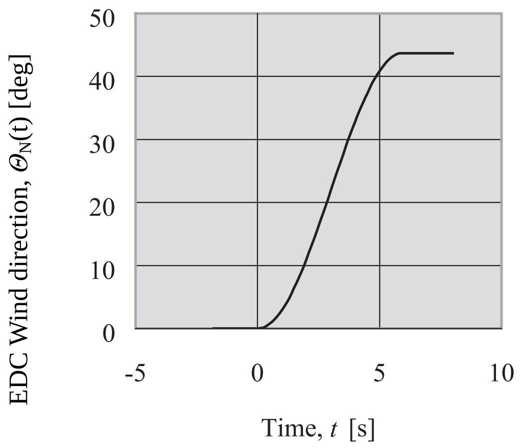


Fig. 4.2.4 Example of extreme direction change (N = 50, category A, V_{hub}=25 m/s)

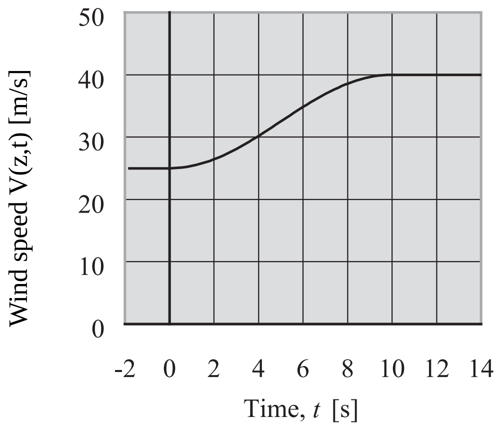


Fig. 4.2.5 Example of an extreme coherent gust (V_{hub} = 25 m/s) (ECG)

$$\theta(t) = \begin{cases} 0^0 & for\ \ t < 0 \\ \pm 0.5\,\theta_{cg}\,(1-\cos(\pi\, t/T)) & for\ \ 0 \le t \le T \\ \pm\,\theta_{cg} & for\ \ t > T \end{cases} \tag{4.2.22}$$

$$V(z,t) = \begin{cases} V_{hub}\left(\dfrac{z}{z_{hub}}\right)^{\alpha} + \left(\dfrac{z - z_{hub}}{D}\right)\left(2.5 + 0.2\beta\sigma_1\left(\dfrac{D}{\Lambda_1}\right)^{1/4}\right)\left(1-\cos\left(\dfrac{2\pi t}{T}\right)\right) & for\ 0 \le t \le T \\ V_{hub}\left(\dfrac{z}{z_{hub}}\right)^{\alpha} & for\ t < 0\ and\ t > T \end{cases} \tag{4.2.23}$$

$$V(y,z,t) = \begin{cases} V_{hub}\left(\dfrac{z}{z_{hub}}\right)^{\alpha} + \left(\dfrac{y}{D}\right)\left(2.5 + 0.2\beta\sigma_1\left(\dfrac{D}{\Lambda_1}\right)^{1/4}\right)\left(1-\cos\left(\dfrac{2\pi t}{T}\right)\right) & for\ 0 \le t \le T \\ V_{hub}\left(\dfrac{z}{z_{hub}}\right)^{\alpha} & for\ t < 0\ and\ t > T \end{cases} \tag{4.2.24}$$

4.2.2.4.6 Extreme wind shear (EWS)

(1) The extreme wind shear with a recurrence period of 50 years shall be considered by using the following two wind speed transients:

– for transient vertical shear, as defined in equation 4.2.23, and

– for transient horizontal shear, as defined in equation 4.2.24.

where:

α = 0.2

β = 6.4

T = 12 s

Λ_1 = turbulence scale parameter, according to equation 4.2.16

D = rotor diameter

(2) The sign for the horizontal wind shear transient shall be chosen so that the most unfavourable transient loading occurs. The two extreme wind shears are considered independently of each other and are therefore not applied simultaneously. As an example, the extreme vertical wind shear is illustrated in Fig. 4.2.8, which shows the wind profile before onset of the extreme event (t = 0 s). Fig 4.2.9 shows the wind speeds at the top and the bottom of the rotor swept area to illustrate the time development of the shear. In both figures, turbulence category A and V_{hub} = 25 m/s, z_{hub} = 30 m and rotor diameter D = 42 m are assumed.

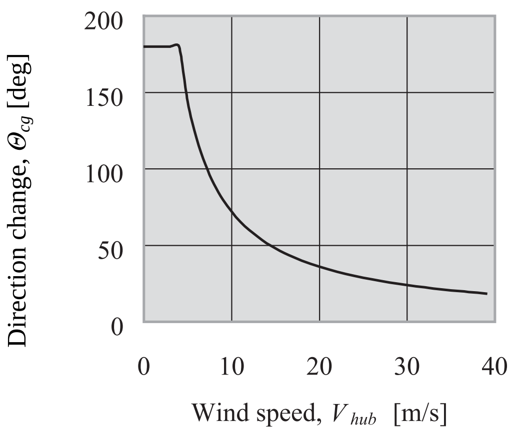


Fig. 4.2.6 Direction change for ECD

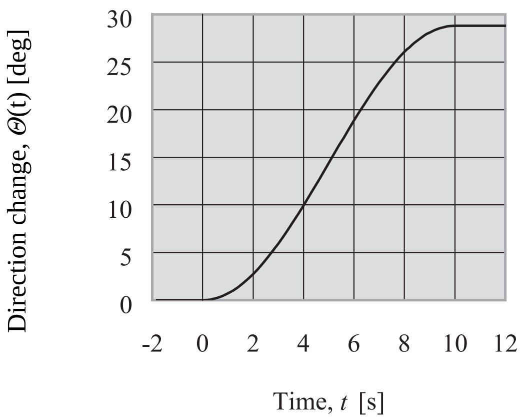


Fig. 4.2.7 Direction change for V_{hub} = 25 m/s

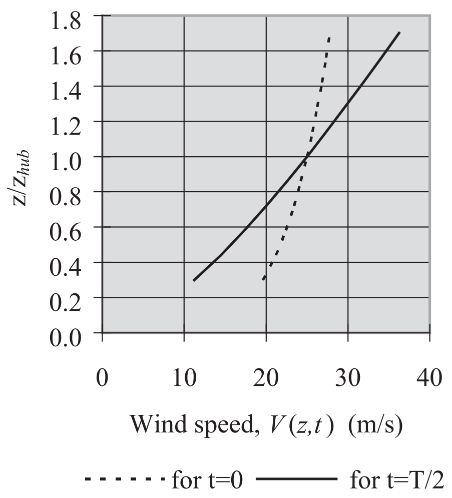


Fig. 4.2.8 Extreme vertical wind shear, wind profile before onset (t = 0, dashed line) and at maximum shear (t = 6 s, full line) (N = 50, turbulence category A, z_{hub} = 30 m, V_{hub} = 25 m/s, D = 42 m)

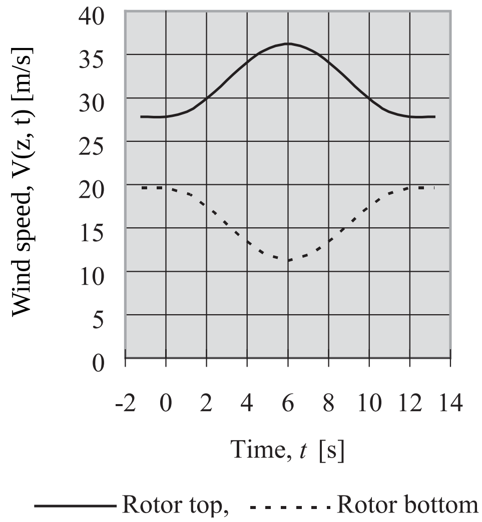


Fig. 4.2.9 Wind speeds at the top and bottom of the rotor swept area (assumptions as in Fig. 4.2.8)

4.2.2.5 Wind farm influence

(1) Offshore wind turbines are usually erected in wind farms, the extreme and fatigue influence exerted on the loads by wind field perturbations in the wake shall be considered. This shall be considered for both, a simple shadow effect and for superimposed wake interaction. For large wind farms, an increase in the environmental turbulence or terrain roughness shall be taken into account.

(2) Within a wind farm of operational offshore wind turbines, the turbulence intensity associated with wake flow may be considerably higher than the ambient turbulence intensity. In addition, wake flow is characterised by reduced mean wind speed and an increased shear profile. In the absence of a detailed analysis of the wind characteristics within a wind farm, an alternative is to base design calculations on an increased turbulence intensity

(3) The mutual influence of offshore wind turbines through the wake interaction behind the rotor shall be considered in a wind farm configuration up to a distance of the offshore wind turbines of 10 D.

(4) The wind farm influence can be determined with the aid of calculation models, for example by S. Frandsen “Turbulence and turbulence generated fatigue in wind turbine clusters”, (2003), [4.4], or “Dynamic Loads in Wind Farms II” (DLWF II), [4.5].

(5) Other validated calculation models may be used in consultation with GL Wind for the analysis of the wind farm induced loads.

4.2.3 Marine conditions

4.2.3.1 Waves

4.2.3.1.1 General

(1) The natural sea state is a stochastic process and can only be described using stochastic theory. To perform this description the simplifications of a sea state being stationary and ergodic (every sequence or sizeable sample is equally representative of the whole) are made. The sea state is assumed to be a Gaussian process and can be described by the superposition of an infinite number of harmonic waves with a different height, period and direction and random phase.

(2) The wave conditions to be applied for the design of an offshore wind turbine or wind farm, extreme conditions and conditions relevant for fatigue over the structures life span, have to be defined under consideration of the long term statistics. They shall be based on measurements performed at the site or on hindcast studies supported and validated by long term measurements near the site where the installation is planned.

(3) The basic quantity which characterises the severity of the sea state is the significant wave height H_s. A storm may be described through a sequence of several sea states, with varying significant wave heights. The storm, that shows a duration of several hours, is characterised by an initial phase of increasing severity and a final phase of decreasing severity. A sea state may refer to simple wave fields, typically wind waves in a generation area or swell in a decaying area, or complex wave fields, composed of several wind waves and swell systems.

(4) In the derivation of the sea state parameters the influence of shallow water effects depending on water depth shall be considered.

(5) Sea waves may be specified alternatively with

– natural sea state

– equivalent design wave

(6) The description of the natural sea state (wave conditions) is essential if load simulation considering stochastic effects has to be performed, while for quasi static analysis the equivalent design wave method may be used.

(7) The wave conditions to be considered during design of offshore wind turbines are described according to the type of analysis to be performed. For ultimate strength analysis the extreme wave influence (50-year storm event) and the extreme loading during operation have to be considered while for fatigue analysis the normal stochastic fluctuating wave series are used.

4.2.3.1.2 Short term wave conditions - natural sea states

(1) The sea state can be described in the frequency domain by a spectral density function. It may be given as a measured spectrum or in a parameterised form and determines the energy in different frequency and/or direction bands.

(2) Parameters required for defining a wave spectrum are the significant wave height and a representative frequency or period:

– The significant wave height H_s is defined by the modal wave height, derived by numerical analysis of the spectrum. Often $H_{1/3}$, defined as the average of the 1/3 highest wave heights in a record of stationary sea surface elevations is used as significant wave height. In deep water the modal wave height and $H_{1/3}$ have almost identical values.

– The wave spectrum is defined by the peak frequency ω_p or period T_p. Alternatively the spectra are often described by T_1, the characteristic wave period, defined as the average time between successive wave crests or T_z the zero crossing period defined as the average time between successive zero crossings in the same direction (upwards or downwards).

(3) A sea state may be described additionally by the mean wave direction μ and the wave spreading function

(4) In this Guideline it is assumed that the short term wave conditions remain stationary for a period of 3 hours. At some sites this assumption may have to be adjusted.

(5) For the calculation of the statistical properties of the sea state the n-th order moments of the wave spectra are used:

$$m_n = \int_0^\infty \omega^n \cdot S_\varsigma(\omega)\,d\omega \qquad (4.2.25)$$

where:

$S_\varsigma(\omega)$ = wave (energy) spectrum

m_n = n-th order moments of the spectrum

ω = circular frequency of elementary waves with period T, $\omega = 2\,\pi/T$

(6) Usually the conservative approach of the Rayleigh distribution of the maxima is used in deep water resulting in following relation for the significant wave height H_s:

$$H_s = 4\sqrt{m_0} \approx H_{1/3} \tag{4.2.26}$$

where:

H_s = significant or modal wave height

m_0 = variance of the wave spectra

$H_{1/3}$ = average of the 1/3 highest waves.

(7) In shallow water the modal wave height may be less than the average of the 1/3 highest wave heights.

(8) The mean (characteristic) wave period T_1 is defined as the average time between successive wave crests in a record of stationary sea surface elevations.

$$T_1 = 2\pi \cdot m_0 / m_1 \tag{4.2.27}$$

(9) The zero crossing period (water elevation $\zeta = 0$) in the same direction (upwards or downwards) is given by:

$$T_z = 2\pi \cdot \sqrt{m_0 / m_2} \tag{4.2.28}$$

(10) By superposition of elementary waves the natural sea state may be modelled if the phase angles are taken random with constant probability density between 0 and 2π. The water elevation may be derived from:

$$\zeta(t) = \int_0^\infty \sqrt{2 S_\zeta(\omega) d\omega} \cdot cos\left[\omega t + \varepsilon(\omega)\right] \tag{4.2.29}$$

where:

ζ = water elevation

S_ζ = wave frequency spectrum; $S_\zeta(\omega) = 2\,\pi S_\zeta(f)$

ω = circular wave frequency; $\omega = 2\,\pi f$

$\varepsilon(\omega)$ = randomly distributed phase angle

(11) The wave spectrum function may be given as a measured spectrum for the site of the wind farm. Visually estimated wave heights H_V and T_V may be considered to be approximately equal to $H_{1/3}$ and T_1, respectively.

(12) H_s and ω_p may be used to define a standard wave spectrum, e. g. the JONSWAP-spectrum, as follows:

$$S_{\zeta,JONSWAP}(\omega) = \frac{\alpha \cdot g^2}{\omega^5} \cdot \exp\left[-\frac{5}{4}\left(\frac{\omega_p}{\omega}\right)^4\right] \cdot \gamma^{\exp\left(-\frac{1}{2}\left(\frac{\omega-\omega_p}{\sigma\,\omega_p}\right)^2\right)} \tag{4.2.30}$$

where:

ω = circular wave frequency

ω_p = spectral peak frequency

g = acceleration of gravity

α = generalized Phillips' constant

σ = spectral width parameter ($\sigma_a \approx 0.07$ for $\omega < \omega_p$; $\sigma_b \approx 0.09$ for $\omega > \omega_p$)

γ = peakedness parameter (Pierson-Moskowitz spectrum for $\gamma = 1$)

The values for α and γ may be calculated from following formulas:

$$\alpha = \frac{5}{16}\frac{H_s^2\,\omega_p^4}{g^2} \cdot C(\gamma) \tag{4.2.31}$$

with:

$\gamma = 5$ for $T_p / \sqrt{H_s} \le 3.6$

$\gamma = \exp(5.75 - 1.15\,T_p / \sqrt{H_s})$ for $3.6 \le T_p / \sqrt{H_s} \le 5$

$\gamma = 1$ for $T_p / \sqrt{H_s} \ge 5$

(13) $C(\gamma)$ is a normalising factor to guarantee that the same significant wave height is used for the JONSWAP and the Pierson-Moskowitz-Spectrum.

$$C(\gamma) = (1 - 0.287 \ln \gamma) \tag{4.2.32}$$

(14) In the absence of site data in a preliminary planning stage or in the case the offshore wind turbine is designed according to the wind turbine classes in Section 4.2.2.1, the wave parameters may be taken according to the mean wind speed assuming infinite fetch and considering the water depth by applying correlation formulations. Some formulations applicable on many sites are shown in Appendix 4.E. The correlations to be used have to be used in consultation with GL Wind.

(15) In reality the water surface elevation in a sea state is three-dimensional (short-crested). A unidirectional random sea is a special case of the sea state (long-crested sea), where all frequency components propagate in the same direction. Normally directional information is difficult to measure and to validate, especially in shallow areas. In practical design of fixed offshore wind turbines with symmetrical substructures, unidirectional sea states should therefore be used.

(16) In the linear random wave model, the sea state is completely described by the directional wave spectrum $S_\zeta(\omega,\mu)$ of the water surface elevation. Guidance on possible use of directional wave spectra is given in Appendix 4.F.

(17) Application of other wave spectrum formulations, especially for a directional wave spectrum, may to be applied in consultation with GL Wind.

4.2.3.1.3 Long term statistics

(1) For the weighting of fatigue analysis and for the analysis of extreme events during the structures' lifetime the long term statistics of the sea conditions shall be established.

(2) For sites where adequate data are available the statistical distributions should consider the joint occurrence of the environmental parameters. Alternatively, the distributions can be marginal distributions for separate parameters. From these long-term distributions appropriate design parameters shall be derived.

(3) In the case where regular design waves are used for the design of offshore wind turbines the extreme (maximum) wave with an annual probability of exceedance of 0.02 is used (50 year wave).

4.2.3.1.4 Design wave

(1) From long term statistics (relative frequencies of occurrence) of wave heights and periods, a marginal probability distribution function $F(H_s)$, e. g. Weibull, shall be derived as at least square fit of the data. On this basis, the following two alternative procedures may be applied.

(2) A reference value H_{s50} is obtained from the inverse of $F(H_s)$ at $H_s = H_{s50}$.

$$F\left(H_{s50}\right) = 1 - 1/N_{SS50} \tag{4.2.33}$$

where:

H_{s50} = significant wave height with the recurrence period of 50 years

N_{SS50} = number of sea states with a duration of 3 hours in 50 years, $N_{SS50} = 50 \cdot 365 \cdot 8 = 146000$

e.g.

$$H_{s50} = F^{-1}\left(1 - 1/N_{SS50}\right) \tag{4.2.34}$$

(3) The value of the zero crossing period of a extreme sea state or the period of the extreme design wave is difficult to estimate directly by measurements. From experience and theoretical considerations the design wave period T_D may be estimated as

$$11.1\sqrt{H_{s50}/g} \le T_D \le 14.3\sqrt{H_{s50}/g} \tag{4.2.35}$$

where:

H_{s50} = significant wave height with the recurrence period of 50 years

g = acceleration of gravity

T_D = design wave period

(4) The design wave height H_D can thus be estimated as being the expected value of the highest wave during a 3 hours storm:

$$H_D = H_{s50} \cdot \sqrt{0.5 \cdot \ln\left(T_{ref}/T_D\right)} \tag{4.2.36}$$

where:

H_D = H_{max50}, design wave height

H_{s50} = significant wave height with the recurrence period of 50 years

T_{ref} = reference period, $T_{ref} = 10800\ s$

T_D = design wave period.

(5) The probability distribution function $F(H_s)$ as defined in para 2 can be used to solve (iteratively):

$$0.4 \cdot 10^{-8} = \sum_{i=1}^{I} \left[1 - F\left(H_{si}\right)\right] \cdot \exp\left\{-2\, H_D^2 / H_{si}^2\right\} \tag{4.2.37}$$

for $H_D = H_{max50}$, with I so large that no significant contribution to the sum is neglected. The class widths are limited by $\Delta H_s \le 1\ m$.

(6) The smaller value of the two alternative results of para 4 and para 5 may be used as the long term design value of the design wave height H_D. The design wave period T_D , as defined in para 3, shall not exceed 25 seconds.

(7) The significant wave height with a recurrence period of 1 year can be derived accordingly using

$N_{SS1} = 365 \cdot 8 = 2920$

and the probability of the maximum wave with the recurrence period of 1 year:

$$0.4 \cdot 10^{-8} \cdot 50 = \sum_{i=1}^{I} \left[1 - F\left(H_{si}\right)\right] \cdot \exp\left\{-2\, H_{\max 1}^{2} \big/ H_{si}^{2}\right\} \quad (4.2.38)$$

(8) The methods of para 2 and para 3 generally applies to deep water waves, i. e. waves with periods T that satisfy the condition $d/(gT^2) > 0.06$, where d is the water depth.

(9) Design wave parameters of wind induced transitional water waves, i. e. waves of periods T that satisfy the condition $0.002 < d/(gT^2) < 0.06$, may be defined from information on extreme wind speed and fetch using relevant theories, the methods can be applied in consultation with GL Wind.

4.2.3.1.5 Breaking waves

(1) The height of breaking waves is a function of the water depth and sea floor inclination. Generally no waves higher than the breaking wave height need to be assumed for design of offshore wind turbines.

(2) In depth limited waters, the kinematics of the waves may change considerably related to the deep water case. Following changes may occur:

– finite wave height
– Wave crests are considerably higher than troughs (up till approx. 3 times the height of the trough rather than having the same magnitude as troughs).
– The crest only appears down to 1/3 of the wavelength (rather than approximately half the wavelength).
– The wave profile becomes asymmetric lengthwise due to the fact that the steepness of the wave profile is greater towards the crest than behind the crest.
– Particle velocities in breaking waves become considerably higher, especially at the crest.
– The wave height distribution is changed (from the normally assumed Rayleigh distribution).

(3) In shallow water the empirical limit of the wave height is approximately 0.78 times the local water depth. In deep water, waves can also break with a theoretical limiting steepness of 1/7 (0.14 times wavelength λ).

(4) Simplified, for increasing sea floor, the breaking wave height H_B may be estimated from

$$H_B = \frac{b}{1/d + a/(g \cdot T^2)} \quad (4.2.39)$$

where:

H_B = breaking wave height

a = $44 \cdot [1 - \exp(-19 \cdot s)]$

b = $1.6 / [1 + \exp(-19 \cdot s)]$

s = sea floor slope, s= tanβ

d = water depth

T = wave period

(5) Three types of breaking waves may occur in shoaling waters, when the water depth decreases and the wave height increases (spilling, plunging or surging).

(6) The limits for breaking wave types are determined via the relation ξ between the sea floor slope s and the square root of the wave steepness. The steepness of the wave is calculated on the basis of the deep water wave H_0 or the breaking wave height H_B and the length of the undisturbed wave λ_0:

$$\xi_0 = \frac{s}{\sqrt{H_0/\lambda_0}} \quad (4.2.40)$$

$$\xi_B = \frac{s}{\sqrt{H_B/\lambda_0}} \quad (4.2.41)$$

The type of breaking may be specified if either ξ_0 or ξ_B are represented in the intervals as follows:

spilling	plunging	surging
$\xi_0 < 0.45$	$0.45 < \xi_0 < 3.3$	$3.3 < \xi_0$
$\xi_B < 0.4$	$0.4 < \xi_B < 2.0$	$2.0 < \xi_b$

(7) When breaking occurs the sea elevation process becomes somewhat “skewed” and will not be Gaussian, and the individual wave heights will not be Rayleigh distributed. The wave height distribution will be distorted and approach asymptotically the breaking wave height limit, see, “Wave height distributions on shallow foreshores” by J. Battjes and H. Groenendijk [4.6].

4.2.3.1.6 Swell

(1) Waves from a wind driven sea that travel out of the area can appear as swell in another area, far from where the waves were generated. For swells there is thus no direct connection with the local wind regime.

(2) Spectra for swells are much narrower than standard wave spectra. They are more or less symmetrical in shape around a dominant modal frequency. There are no standard parametric forms for swell spectra in common use.

4.2.3.2 Currents

(1) The sea current may be generated by different reasons. Main current categories are

– near surface current (current generated by the wind shear force)

– tide generated current

– barometrically generated current

– current caused by wind surge, locally or in connection with large water regions

– wave generated current (generated by the shear force of the breaking waves along the coast)

(2) The two main categories of current influencing fixed structure installed in shallow waters are wind induced currents and sub surface currents. Wave induced currents may locally reach significant values.

$$U_c(z) = U_{c,sub}(z) + U_{c,wind}(z) + U_{c,surf}(z) \qquad (4.2.42)$$

where:

$U_c(z)$ = total current velocity at level z

z = distance from still water level, positive upwards

$U_{c,sub}$ = sub surface current velocity at the still water level

$U_{c,wind}$ = wind-generated current velocity at the still water level

$U_{c,surf}$ = wave induced current velocity at the still water level

(3) Currents may be estimated using either statistical data combined with flow models or site specific measurements. If measurements are used tidal currents may be estimated on a basis of current and water level measurements of 1 month at least. For the extrapolation of the 50 year current from measurements at least 1 year of data shall be used. Current profiles different from those stated in the Guideline may be used if measurements at 3 levels at least exist.

4.2.3.2.1 Sub surface current

(1) Sub surface currents may be generated from the tidal motions, combined with the site specific topographical boundaries, from differences in water levels due to storm surge and barometric differences or by thermal and salinity differences of the water.

(2) The tidal currents are regular and predictable and the maximum tidal current precedes or follows the highest and lowest astronomical tides, HAT and LAT. Tidal currents can be strengthened by shoreline or sea floor configurations.

(3) The design velocity is based on the velocity at the surface and is site dependent. Sub surface currents in shallow waters are assumed to have an exponential profile:

$$U_{c,sub}(z) = U_{c,sub} \cdot \left(\frac{d+z}{d}\right)^{1/7} \qquad (4.2.43)$$

where:

$U_{c,sub}$ = sub surface current velocity at the still water level

d = water depth to still water level (taken positive)

z = distance from still water level, positive upwards

(4) In some cases (i.e. rivers) where mixing of different flow systems and/or waters of different salinity, the profile and form of the current may deviate considerable from the form given here. In deep water different current profiles, often a combination of linear and exponential profile may give a better description.

4.2.3.2.2 Wind generated current

(1) Wind generated currents are caused by the wind stress and atmospheric pressure gradient throughout a storm:

$$U_{c,wind}(z) = U_{c,wind}\left(\frac{d_0+z}{d_0}\right) \quad \text{and} \quad -d_0 \le z \le 0$$

$$U_{c,wind}(z) = 0 \quad \text{for} \quad z < -d_0 \qquad (4.2.44)$$

with d_0 equal to 20 meters. If the water depth is less than 20 meters the current should be cut of at the mud line.

$$U_{c,wind} = 0.015 \cdot u(10\,m, 1\,hour) \qquad (4.2.45)$$

where:

$U_{c,wind}$ = current speed at the water surface *u(10 m,1 hour)* = hourly mean wind speed at 10m height

4.2.3.2.3 Wave induced current

(1) In the case that the offshore wind turbine is to be sited near a breaking wave zone, consideration shall be given to the surf currents generated by the shear forces of the breaking waves along the coast.

(2) Water which is transported to the shore by the waves has to be compensated by a current bringing the water in opposite direction. Because of the mass transport of the water, a breaking wave becomes a wave of translation, an amount of water piles against the coast is established. This water can return directly to deeper water in opposite direction to the waves, but often it flows along the coast as an alongside current inside the breaking wave zone.

(3) The estimation of the surf currents can be performed using numerical method (e.g. using a Boussinesq model considering the fully coupled wave and current motions). As simplification for near shore currents, which have a direction parallel to the shore line, the design velocity U_{surf} at the location of breaking wave may be estimated from

$$U_{surf} = 2\,s \cdot \sqrt{g\,H_B} \qquad (4.2.46)$$

where:

H_B = breaking wave height

g = gravity acceleration

s = beach slope.

The vertical profile can be taken as equal to the sub surface current profile.

4.2.3.3 Sea level

(1) The highest still water level to be used for design is defined as the highest sea level with a recurrence period of 50 years, considering tidal and storm surge effects as well as seasonal variations. Conservative the highest still water level (HSWL) may be taken as the water depth d at the highest astronomical tide (HAT) plus water level elevations due to storm surge. A schematic description of the water level definitions is given in Appendix 4.A.

(2) Equivalent to the highest still water level, the lowest still water level (LSWL) shall be defined as the lowest sea level with a recurrence period of 50 years, considering tidal and storm surge effects as well as seasonal variation. Conservative the lowest still water level for design may be taken as the lowest value of either the water depth d due to the lowest astronomical tide minus water level decline due to storm surge, as applicable.

(3) The highest wave elevation ξ^* above still water level as indicated above is given as

$$\xi^* = \delta \cdot H_D \qquad (4.2.47)$$

where:

ξ^* = highest wave elevation

H_D = design wave height (Section 4.2.3.1.4)

δ = wave elevation coefficient, see Table 4.2.3

The wave elevation coefficient δ, as given in Table 4.2.3, is a function of the wave period T_D, as defined in 4.2.3.1.4 and the water depth *d*. Linear inter- or extrapolation is valid if $H_D < 0.7\,d$.

Table 4.2.3 Wave elevation coefficient δ

$d/(gT_D^2)$	$H_D/(gT_D^2)$					
	0.02	0.01	0.005	0.001	0.0005	0.0001
≥ 0.20	0.60	0.55	0.50	0.50	0.50	0.50
0.02	–	0.68	0.58	0.52	0.50	0.50
0.002	–	–	–	0.87	0.80	0.68

(4) Estimation of the water depths shall be based on measurements at the planed installation positions. The measurements shall be corrected for pressure, tidal, surge variations to achieve an accuracy of ≈ 0.1 m. The values of the tidal levels and storm surges may be derived from statistical data based on long term measurements and numerical models.

(5) Water depth and statistical wave data shall be provided by a competent authority. The application of the data is to be agreed upon with GL Wind.

4.2.3.4 Sea ice

(1) The probability of occurrence of sea ice in the operating area shall be established.

(2) If seasonal sea ice is probable in the operating area, the modes of occurrence and the mechanical properties of the ice shall be determined by a competent authority upon consultation with GL Wind.

(3) If permanent sea ice is probable in the operating area, thickness and extension as well as mechanical properties and drifting characteristics shall be determined by a competent authority upon agreement with GL Wind.

(4) A definition of the parameters to be considered in sea ice load analysis and methods to derive sea ice induced forces is given in the GL "Guideline for the Construction of Fixed Offshore Installations in Ice Infested Waters" [4.1]. Within the application range of this Guideline extreme sea ice loads should correspond to a recurrence period of fifty years.

4.2.3.5 Marine growth

(1) Marine growth may be considerable in some areas and should be taken into account, e.g. when investigating the wave and current loads acting on submerged parts of the structure or its weight. Relevant information shall be submitted to GL Wind for verification.

(2) Thickness of marine growth should be assessed according to local experience. If no relevant data are available, a thickness of 50 mm may be chosen for normal climatic conditions.

4.2.4 Determination of other environmental conditions

4.2.4.1 General

(1) Environmental (climatic) conditions other than wind and oceanograhphic can affect the integrity and safety of the offshore wind turbine, by thermal, photochemical, corrosive, mechanical, electrical or other physical action. Moreover, combinations of the climatic parameters given may increase their effect.

(2) At least the following other environmental conditions shall be taken into account and the action taken stated in the design documentation:

- normal and extreme temperature ranges
- humidity
- air density
- water density
- solar radiation
- rain, hail, snow and ice formation
- chemically active substances
- mechanically active particles
- lightning
- earthquakes
- salinity of water
- sand dune movements (sea bed variation)
- scour
- corrosion

(3) The climatic conditions for the design shall be defined in terms of representative values or by the limits of the variable conditions. The probability of simultaneous occurrence of the climatic conditions shall be taken into account when the design values are selected.

(4) Variations in the climatic conditions within the normal limits which correspond to a one-year recurrence period or higher shall be considered as normal external conditions.

(5) Normal environmental condition values should be taken into account as follows if no other data are available:

- offshore wind turbines shall be designed for an ambient air temperature range of –20 °C to +50 °C. As variations of the constant temperature components ± 35 K in relation to a mean temperature of + 15 °C shall be assumed. Operation shall be possible at ambient temperatures from –10 °C to +40 °C.
- relative humidity of up to 100 %
- atmospheric content equivalent to that of a non-polluted sea atmosphere
- solar radiation intensity of 1000 W/m^2
- air density of 1.225 kg/m^3
- water density of 1025 kg/m^3
- water salinity of 3.5%

(6) Other extreme environmental conditions which shall be considered are extreme temperature, lightning, ice formation and earthquakes.

(7) The design temperature T_D, for selection of material qualities shall be established as the lower value of the ambient temperature at the site.

(8) The lowest water temperature at sea level may be assumed to be 0°. Extra assumptions have to be made for sites with extreme temperature variations or where sea ice occurs.

(9) The atmospheric and water temperatures stated in this Guideline shall be 1 hour average values.

4.2.4.2 Extreme temperatures

(1) Estimates of design temperatures of air and water shall be based on relevant data that are provided by competent institutions.

(2) If the air temperature at the erection site is lower than –20 °C or greater than +50 °C on more than 9 days a year as a mean over many years, the lower or upper temperature limit shall be altered accordingly, and the following items shall be observed. It shall be verified that the offshore wind turbine is operative and structurally sound within the chosen temperature limits.

(3) If the mean value of the temperature over many years at the site deviates more than 15 K from the assumed mean temperature according to Section 4.2.4.1 para 5, this shall be taken into account.

(4) The air density shall be corrected in relation to the prevailing temperature of the site. The corrected air density shall be considered in the load calculation and in the determination of the power curve. In addition, the following items shall be observed in particular:

– The mechanical properties of the materials used shall be selected according to the ambient temperatures.

– Stresses caused by strongly differing thermal expansion coefficients shall be considered in the case of extreme temperatures.

– Coolers or heaters shall be dimensioned to account for the ambient temperatures and the required operating temperatures of the various components.

– Electronic devices shall also be protected against high or low temperatures. If proper operation of these components cannot be guaranteed, the plant shall be shut down.

– If there are components which can fail as a result of extreme temperatures, an appropriate monitoring facility shall be provided in the safety system to bring the offshore wind turbine into a safe condition in such an event.

(5) It shall be observed that ice formation can influence the aerodynamic coefficients.

4.2.4.3 Lightning

The provisions set out in Section 8.9 “Lighting protection” to safeguard against lightning strikes may be regarded as adequate for the standard wind turbine classes.

4.2.4.4 Ice formation

(1) For non-rotating parts of the offshore wind turbine, ice formation with a thickness of 30 mm on all sides shall be assumed for surfaces exposed to the weather. The density of the ice shall be taken as ρ_E = 900 kg/m^3. In the case of operating conditions in which the rotor is at standstill or idling, the rotor blades shall also be verified for this degree of ice formation on all sides.

(2) Where ice covering is due mainly to sea water spray, the ice thickness shall be adjusted accordingly. In absence of any data a thickness of 100 mm at sea level may be assumed. The ice thickness may be taken to decrease linearly to 30 mm from a level corresponding to the highest wave elevation to 60 m above that level.

(3) With the rotor rotating, the conditions “ice formation on all rotor blades” and “ice formation on all rotor blades except one” shall be investigated. The mass distribution (mass / unit length) shall be assumed at the leading edge. It increases linearly from zero in the rotor axis to the value μ_E at half the radius, and then remains constant up to the outermost radius. The value μ_E is calculated as follows:

$$\mu_E = \rho_E \cdot k \cdot c_{\min}(c_{\max} + c_{\min}) \qquad (4.2.48)$$

where:

μ_E	=	mass distribution on the leading edge of the rotor blade at half the rotor radius [kg/m]
ρ_E	=	density of the ice (900 kg/m^3)
k	=	0.00675 + 0.3 exp (-0.32 R/R$_1$)
R	=	rotor radius
R_1	=	1 m
c_{max}	=	maximum chord length
c_{min}	=	chord length at the blade tip, linearly extrapolated from the blade contour.

4.2.4.5 Earthquakes

(1) For locations where earthquakes may be expected, a so-called “Design Earthquake” shall be defined, using available statistical information. The characteristics of the earthquake (acceleration intensity, duration) shall be established by a competent authority and agreed upon with GL Wind.

(2) An earthquake analysis is not required for areas where the design horizontal ground acceleration (strength level) is less than 0.05 *g* (*g* being the gravitational acceleration), provided other significant environmental loads are to be accounted for, so that sufficient resistance against earthquake loading is ensured.

(3) Tsunami-type waves resulting from sub-sea earthquakes may have to be considered in particular cases; it will be decided from case to case, depending on the probability of occurrence, whether a Tsunami and the resulting loading have to be considered in connection with the design earthquake, or as an accidental load.

4.2.4.6 Foundation and soil properties

(1) The foundation (soil properties) at the intended site shall be analysed in accordance with the local situation (subsoil, building codes) by a geotechnical report as a rule. For this, Section 6.7 shall be taken into account.

(2) The geotechnical investigation for pile-supported structures shall provide, as a minimum, the soil engineering property data as defined in Section 6.7.

4.2.4.7 Sea bed and scour

(1) Offshore wind turbine structures founded on the sea floor may be affected by gradual or transient changes of the sea floor. These changes influence the validity of design parameters and the structural integrity and shall be accounted for.

(2) Sea floor stability: As outlined in Chapter 6 it will have to be determined whether, owing to topography and soil configuration, the possibility of slope failure or slides, cavity failure of erosion phenomena have to be considered. Settlement and soil liquefaction generally have to be taken into account where necessary.

(3) Scour is the removal of seabed soils by currents and waves. Such erosion can be due to a natural geological process or can be caused by structural elements interrupting the natural flow regime above the sea floor.

(4) From observations, sea floor variations can usually be characterised as some combination of the following.

a) Local scour. Steep sided scour pits around structure elements.

b) Global scour. Shallow scoured basins of large extent around a structure, possibly due to overall structure effects, multiple structure interaction, or wave-soil-structure inter-action.

c) Overall seabed movement of sand waves, ridges, and shoals that would also occur in the absence of a structure. The addition of manmade structures often changes the local sediment transport regime that can aggravate erosion, or cause accumulation.

(5) Scour can result in removal of vertical and lateral support for foundations, causing undesirable settlements of shallow foundations and overstressing of foundation elements. Where scour is a possibility it shall be taken into account in design and/or its mitigation shall be considered.

(6) Scour prediction remains an uncertain art. The uncertainty regarding design criteria should be accounted for by robust design and/or operating strategy of monitoring and remediation as needed. Guidance is given in Section 6.7.7.4.

4.2.4.8 Electrical power network conditions

(1) The electrical conditions shall be determined at the grid connection point between the offshore wind turbine and the existing electrical grid at the intended site, in order to ensure compatibility between the turbine and, where necessary, all electrical equipment located between the turbine and the grid. This shall include the following items at least:

– normal supply voltage and fluctuations
– normal supply frequency and fluctuations
– voltage symmetry
– symmetrical and asymmetrical faults
– number and type of the electrical grid outages and their average duration
– special features of the electrical grid at the site as well as requirements of the local grid operator shall be taken into account. These may be:
    – auto-reclosing cycles
    – short-circuit impedance at the connection points of the offshore wind turbine
    – harmonic voltage distortion from the turbine's power system

(2) The normal conditions to be considered at the offshore wind turbine terminals are listed in this section. Normal electrical power network conditions apply when the following parameters fall within the ranges stated below.

– voltage: nominal value ± 10 %
– frequency: nominal value ± 2 %

– voltage imbalance: The ratio of the negative-sequence component of voltage to the positive-sequence component shall not exceed 2 %.

(3) Grid failures: Electrical network outages shall be assumed to occur 20 times per year (see also Section 2.2.2.9).

(4) Further details for normal conditions can be found in DIN EN 50160:2000. When different than normal conditions occur, e.g. because of regulations by the local utility, they have to be stated clearly.

4.2.4.9 Risk analysis

Owing the location of certain sites, a risk analysis may be necessary. This analysis includes the risk estimation of particular damage events occurring at the offshore wind turbine with regard to the environment (e.g. transport routes, oil pipelines). The scope and type of investigation should be defined in consultation with GL Wind.

4.2.4.10 Corrosion and erosion

It shall be checked whether the intended corrosion protection is adequate for the site. Protection against corrosion and erosion shall therefore be taken into account by the selection of suitable materials, appropriate coatings and protective coverings, plus regular inspection. For more detailed guidance see Section 3.5. Special care has to be taken in the splash zone of the offshore support structure.

4.2.4.11 Splash zone

(1) The splash zone is defined as the part of the structure being intermittently wetted by tide and wave action. The extent of this zone is subject to large local variation. For special constructions (i.e. floating systems) the variation in draught and the motion of the structure is to be considered.

(2) The splash zone is defined by the highest and the lowest water levels as follows:

$$L_{\max} = L_{u\,SW} + \Delta s + L_{uWA} + L_{safety} \quad (4.2.49)$$

$$L_{\min} = L_{l\,SW} - L_{l\,WA} \quad (4.2.50)$$

Where:

$L_{u\,SW}$ = upper still water level acc. to para 3

$L_{l\,SW}$ = lower still water level acc. to para 3

Δs = expected settling of the foundation during life

$L_{u\,WA}$ = height of wave crest acc. to para 4

$L_{l\,WA}$ = height of wave trough acc. to para 4

L_{safety} = safety for run up etc. acc. to para 6

(3) The upper and lower still water levels for the definition of the splash zone shall be defined as the highest and lowest still water levels with a recurrence period of one year respectively ($HSWL_1$ and $LSWL_1$). If no data for the still water level considering tidal elevation and storm surge exist, the upper and lower still water levels can be derived from the highest and lowest astronomical tides and the storm surge with a recurrence period of one year:

$$L_{u\,SW} = HSWL_1 \;\text{ or }\; HAT + \text{storm surge}(1\,y) \quad (4.2.51)$$

$$L_{l\,SW} = LSWL_1 \;\text{ or }\; LAT - \text{storm surge}(1\,y) \quad (4.2.52)$$

(4) The height of the wave crest and trough to be considered for the splash zone definition can be derived from the height of the wave with a probability of exceedance equal to $P(H>H^*) = 0.01$. The wave height can be derived from the wave scatter diagram. If no scatter diagram is available the significant wave height with a recurrence period of 1 year may be choosen instead.

$$L_{u\;WA} = \delta \cdot H_{1\%} \quad (4.2.53)$$

$$L_{l\;WA} = (1-\delta) \cdot H_{1\%} \quad (4.2.54)$$

δ = wave elevation coefficient acc. to Section 4.2.3.3 para 3 (Table 4.2.3)

$H_{1\%}$ = Wave height with with a probability of exceedance equal to *0.01*.

(5) It has to be considered that in shallow waters the value for the maximum wave height and the wave elevation coefficient may vary with the actual water depth.

(6) The height of the additional safety level due to run up and wave distortion from the structure may be chosen as 20% of the wave height chosen in para 4.

(7) The highest and lowest water levels for the definition of the splash zone shall not be less than 2 m above or below the mean sea level (MSL) respectively.

***Note*:**

The wave height with the probability of exceedance equal to $P(H>H^*) = 0.01$ may be calculated using the scatter diagram (long term distribution) and the assumed short term distribution of the wave height if no direct statistics exist.

$$P\left(H > H^*\right) = \sum_{i}^{I} \sum_{j}^{J} P_s\left(H > H^*\right) f_L\left(H_{s\,i}, T_{p\,j}\right) \quad (4.2.55)$$

Where:

$P_s\left(H > H^*\right) = P_s\left(H > H^* \middle| H_{s\,i}, T_{p\,j}\right)$ = *Short term probability of the wave height conditioned on the significant wave height and the period of the sea state. Conservative a Rayleigh distribution may be assumed.*

$f_L\left(H_{s\,i}, T_{p\,j}\right)$ = *Long term probability of the i,j-th sea state from the wave scatter diagram.*

4.3 Calculation of Loads

4.3.1 General

(1) The structural design of offshore wind turbines shall be based on verification of the structural integrity of the load-carrying components. The ultimate and fatigue strength of structural members shall be verified by calculations and/or tests to demonstrate the structural integrity of the offshore wind turbine with the appropriate safety level.

(2) Calculations shall be performed using appropriate methods. Descriptions of the calculation methods shall be provided in the design documentation. These descriptions shall include evidence of the validity of the calculation methods or references to suitable verification studies. The load level in any test shall adequately reflect the partial safety factors in the corresponding calculation.

(3) The analysis method to be used will depend on the type of loading and the structural response. Time history analysis, e. g. by direct integration, will have to be used for dynamic problems with non-linear nature. Response spectral analysis will be used for structures with a linear elastic response to random loading, e. g. due to non-deterministic wave loads, provided a linearisation of the non-linear load effects is possible or to determine dynamic amplification effects.

(4) The calculation model (“idealization”) used has to take account of all main load bearing and stiffening components, and of the relevant supporting and constraining effects. The degree of subdivision (detailing) should take account of the geometry of the structure and its influence on the load distribution and introduction.

(5) Wind conditions are the primary external consideration for the structural integrity of the topsides structure, although the marine conditions may also have an influence in some cases depending on the dynamic properties of the support structure. During the design of the topsides structure, the structural integrity shall be demonstrated taking proper account of the marine conditions at each specific site at which the offshore wind turbine will be subsequently installed. The demonstration of the suitability of the topsides structure for a specific offshore site shall meet the requirements defined in Section 4.2.

(6) The design of the support structure of an offshore wind turbine shall be based on environmental conditions, including the marine conditions, which are representative of the specific site at which the offshore wind turbine will be installed.

(7) Account shall be taken of the soil properties at the site, including the time variation of such properties due to scour, sand waves etc. In the dynamic analysis of the loads the change in the stiffness properties for the soil condition at the site and the change in the masses during the design lifetime of the turbine shall be considered in the load case definitions, see also Chapter 6.

(8) Marine conditions as humidity, corrosion and marine fouling may vary during the turbine lifetime and influence the dynamic properties of the turbine. The load cases shall be defined in such a way that conservative loads are obtained for the entire lifetime of the offshore turbine.

(9) Usually a preliminary load analysis is based on a site assumption or a wind turbine class in combination with assumed marine conditions. Since the model dynamics and the soil behaviour depend on the loads, they may vary during design process. A final load evaluation or analysis shall be performed for critical load cases for all support structure configurations and the original assumptions have to be reconciled.

(10) For the definition of the load cases, the meteorological and oceanographic data relevant for the installation site shall apply.

4.3.2 Loads

(1) The loads described in Sections 4.3.2.1 to 4.3.2.9 shall be considered for the design calculations. Prototype tests and model investigations (tests) may also be used as a substitute for load calculation. Any test has to be supervised by an accredited institute and/or GL Wind. In special cases model tests may be required.

(2) In general a dynamic analysis of the offshore wind turbine, considering dynamic response for external and/or operating conditions is required.

(3) A quasi-static analysis shall only be carried out in the case of systems for which it is justified in consultation with GL Wind. The determination of dynamic amplification factors (DAF) shall also be agreed upon by GL Wind. For these cases, it can be carried out instead of a dynamic analysis for the sake of simplification.

(4) Response spectral analysis will be used for structures with a linear elastic response to random loading, e. g. due to non-deterministic wave loads, provided a linearisation of the non-linear load effects is possible. The method may be appropriate to determine dynamic amplification effects due to extreme wave loads on fixed jacket structures and also to perform fatigue damage accumulations.

4.3.2.1 Inertial and gravitational loads

(1) Inertial and gravitational loads are static and dynamic loads acting on the offshore wind turbine, resulting from vibration, rotation, gravity and seismic activity.

(2) In a dynamic analysis structural dynamics and the coupling of vibrational modes have to be considered. Following items shall be taken into account:

– the elasticity of the blades

– elasticity of the drive train and generator (drive train dynamics)

– bending of the support structure

– helideck dynamics (if relevant)

(3) The elastic mounting of the machinery, vibration dampers, the torsional stiffness of the support structure and the influence of the foundation shall also be included, if their influence cannot be neglected. In general, for structural components supporting rotating equipment, resonance shall be avoided.

(4) Interaction between the structure and soil should in general be modelled non-linearly. For piled foundations the non-linear behaviour of axial and lateral pile-soil support should be modelled explicitly to ensure load deflection compatibility between the structure and pile-soil system.

(5) For the rotor, the actual mass eccentricity according to the manufacturer's instructions shall be taken into account (see Section 4.3.3.5, DLC 1.1 to 1.15).

(6) Besides all effective structural and appurtenance masses, the hydrodynamic masses accounting for increased member thickness due to marine growth and water enclosed in submerged members are to be considered.

(7) In some load cases it is admitted and/or required to perform a quasi static analysis and consider structure dynamics by application of a dynamic amplification factor. The dynamic amplification factor to be applied should be defined in consultation with GL Wind (see Section 4.3.2.2 para 3).

4.3.2.2 Aerodynamic loads

(1) Aerodynamic loads are static and dynamic loads which are caused by the airflow and its interaction with the stationary and moving parts of offhsore wind turbines.

(2) The airflow is dependent upon the rotational speed of the rotor, the average wind speed across the rotor plane, the turbulence intensity, the density of the air, and the aerodynamic shapes of the offshore wind turbine components and their interactive effects, including the aeroelastic effects.

(3) Following influences shall be taken into account when wind loads on the offshore wind turbine are analysed:

– wind field perturbations due to the offshore wind turbine itself (wake-induced velocities, tower shadow, tower upwind effect etc.)

– the influence of three-dimensional flow on the blade aerodynamic characteristics (e.g. three-dimensional stall and aerodynamic tip loss)

– dynamic stall effects of the airflow for the profiles used

– unsteady aerodynamic effects

– aeroelastic effects

– Aerodynamic asymmetries, which can arise through production or assembly tolerances of the rotor blades. A verified tolerance shall be observed. If this is not (or not yet) known, a deviation of the blade angle of attack of ± 0.3° (i.e. for a three-blade plant: blade 1 at 0°, blade 2 at –0.3°, blade 3 at +0.3°) shall be assumed.

– dynamic response when parked (standstill or idling) and application of the EWM (see Section 4.3.3.10 and 4.3.3.11) with steady wind model by a gust reaction factor to the tower loads (see Section 6.1.3)

(4) The aerodynamic force coefficient c_f for structural parts, like towers, is to be determined in accordance with Eurocode 1 or with e. g. DIN 4131, Appendix A, for steel structures, and for prefabricated concrete masts in accordance with e. g. DIN 4228, Appendix A, or in accordance with equivalent international standards in consultation with GL Wind.

4.3.2.3 Hydrodynamic loads

(1) Hydrodynamic loads are stationary and instationary loads which are caused by the water flow and its interaction with the support structure of the offshore wind turbine.

(2) The hydrodynamic loads are dependent on the kinematics of the water flow, the density of the water, the water depth, the shape of the support structure and their interactive effects, including hydroelastic effects.

4.3.2.3.1 Wave loads

(1) Derived wave parameters are e. g. wave particle velocities and accelerations. Particle velocities u_w and accelerations a_w due to waves are related to wave height *H*, period *T* and water depth *d*.

(2) Based on acknowledged standards and text books, a relevant wave theory shall be used to define the design velocity and the design acceleration at the location of the structural element considered. Guidance on the application range of the different wave theories is given in Appendix 4.G.

(3) Linear (Airy) wave theory is applicable to define the wave kinematics parameters for deep water and transitional water waves. Linear wave theory is normally used for the generation of irregular sea states. Linear wave theory application is exemplified in Appendix 4.G.

(4) Higher order wave theories have to be applied to derive wave particle velocities and accelerations for very high waves or for waves in shallow water and breaking waves. The possibility of breaking waves has to be analysed in shallow water locations. The application of the specific higher order theory shall be applied in consultation with GL Wind.

(5) A structure is considered hydrodynamically transparent if wave scattering can be neglected, i.e. passing sea waves are not significantly changed in shape and direction. This condition is satisfied if $D/\lambda < 0.2$, with D being a characteristic dimension of the structure (e.g. diameter) in the direction of wave propagation and λ the wave length. Short description of the methods to analyse wave loads for hydrodynamic transparent and compact structures is given in Appendix 4.H.

(6) The present Guideline applies mainly for rigidly positioned offshore wind turbines. For flexibly positioned structures additional guidance is given in the GL "Rules for the Classification and Construction of Offshore Installations", [4.2] and the GL "Guidelines for the Design, Construction and Certification of Floating Production, Storage and Offloading Installations", [4.3].

(7) A structure is considered rigidly positioned if any possible deviation from its still water position due to waves is negligibly small when compared to the wave height.

(8) Methods for estimation of design wave loads depend on hydrodynamic characteristics of the structure and the way this structure is held on location.

(9) In the analysis of wave induced loads the influence of marine growth and of appurtenances, if not explicitly modelled, shall be considered.

(10) The extreme loads for the analysis of the offshore wind turbine shall be based on the extreme wave (H_{max50}) and wind load with a recurrence period of 50 years. In some load cases the extreme wave with a recurrence period of 1 year is used (H_{max1}).

(11) The extreme wave shall be analysed based on the assumption to occur once during a 3 hour storm condition.

(12) The extreme design wave during a 3 hour storm condition may be derived as stated in Section 4.2.3.1.4. As simplification the extreme wave height for design loads may be taken as

$$H_{\max} = 1.86 H_s \le H_B \qquad (4.3.1)$$

which is the probable maximum value for deep water based on 1000 waves and H_B is the breaking wave height.

(13) The reduced wave to be used to derive loading in combination with extreme wind speed (see Section 4.3.3.2 para 15) is associated with a wave height having a probability of 0.03 corresponding to

$$H_{red} = 1.32 H_s \le H_B \qquad (4.3.2)$$

for deep water.

(14) In shallow waters the wave height distribution may deviate from the Rayleigh distribution. In this case the factors shown in para 12 and para 13 may change. Different values may be used upon agreement with GL Wind.

4.3.2.3.2 Sea current loads

(1) A design value of sea current pressure on structural elements at depth z below still water level is defined as

$$q_D(z) = \rho_W / 2 \cdot U_D{}^2(z) \qquad (4.3.3)$$

where:

$q_D(z)$ = design sea current pressure at level z

ρ_W = density of water

$U_D(z)$ = design sea current speed at level z

z = distance from still water level, positive upwards, $0 \geq z \geq -d$

In this formula, the design sea current speed $U_D(z)$ is the component of the current speed $U_C(z)$ (see Section 4.2.3.2) directed perpendicular to the cylinder axis at height z.

(2) Using $q_D(z)$ as defined above, design sea current loads $F_D(z)$ may be estimated by :

$$F_D(z) = C_D \cdot q_D(z) \cdot D(z) \qquad (4.3.4)$$

where:

$F_D(z)$ = design sea current load at level z

C_D = drag coefficient

$q_D(z)$ = design sea current pressure at level z

$D(z)$ = projected width of the structure perpendicular to $u_D(z)$ at height z

The direction of $F_D(z)$ is equal to the direction of $U_D(z)$. For circular cylinders $D(z)$ is the diameter at height z.

(3) The drag coefficient C_D may be taken from textbooks or model tests and has to be corrected for effects of marine fouling and the influence of appurtenances.

4.3.2.3.3 Breaking wave loads

(1) If breaking waves can occur, the corresponding water level and wave height as well as the breaking wave kinematics have to be considered.

(2) The analysis of breaking wave loads is an uncertain art. In the following some guidance is given to estimate breaking wave loads. In general model tests are recommended for evaluation of global loads and confirmation of estimated support structure loading.

(3) For spilling (top) breaking waves the solitary waves can be simulated according to the stream function wave theory. Time series for shallow water waves (without plunging breaking) in the form of wave elevations and velocities can be simulated. The maximum particle velocity in a top breaking wave is given by the expression:

$$u_{\max} \leq 1.0 \cdot \sqrt{g\,d} \qquad (4.3.5)$$

where:

u_{max} = maximum particle velocity in top breaking wave

g = gravity acceleration

d = water depth

(4) For plunging breaking waves special conditions for structures during the exposure to plunging breaking shall be examined. The force of the breaking wave on a structure may be analysed in an impact force and a periodic force. The periodic force may be calculated using conventional wave theory i.e. stream function wave theory. In Appendix 4.I a method is given to calculate the impact force on cylinders.

(5) If the structure is considerably larger below the water surface than above the surface, this may cause plunging breaking, and a quantification of the effects hereof shall be given and considered in the design assumptions.

4.3.2.3.4 Wave slamming loads

(1) Structural members in the splash zone of waves may be subjected to impact loads (slamming). These loads are difficult to estimate accurately and should generally be avoided by structural design measures.

(2) Where structures are not or cannot be suitably designed to resist wave impact, the latter shall be avoided by providing sufficient distance between the probable highest wave elevation and the lower edge of the structure (e.g. lowest closed deck). A clearance – “air gap” - of 1.5 m is recommended. In case of structures not connected rigidly to the sea floor, their vertical motions shall be accounted for.

4.3.2.4 Hydrostatic loads

Hydrostatic loads, external or internal may occur if a member or compartment is wetted only from one side of its surface. Hydrostatic forces act in a direction normal to the surface. For large structures with empty spaces hydrostatic forces may have considerable influence.

4.3.2.5 Sea ice loads

(1) Static and dynamic sea ice loads acting on an offshore wind turbine are caused by current and wind induced motion of ice floes and their failure in contact with the support structure. The relevance of sea ice loads to the design of the support depends on the specific location and characteristics of the site at which the offshore wind turbine will be installed. Forces exerted on a structure by ice are to be evaluated for their effect on local structural elements and for global effects on the structure as a whole.

(2) Ice loads are to be evaluated for a range of ice - structure interactions. The range of interactions is determined by the ice environment of the area of operations, and may include:

– pressure from continuous first or multi-year level ice
– collision with first and/or multi-year ridges within the ice field
– impact by drifting ice floes (sea ice or glacial ice)
– impact by icebergs
– dynamic ice loading.

(3) Ice load evaluations are to include the forces exerted by ice on rubble ice or other ice pieces which are in firm contact with or held by the structure. This is of particular concern for multilegged structures and for structures designed to cause ice failure in modes other than crushing.

(4) The maximum compressive strength of the ice is to be considered as characteristic of the local loading of the structure by ice. In selection of the appropriate compressive strength the following factors shall be considered:

– temperature or temperature gradient in the ice
– orientation of the ice crystals
– salinity
– total porosity of the ice (brine volume, gas pockets and voids)
– strain rate
– loading rate
– scale effects (size of structure/ice thickness).

(5) The brittle nature of ice can lead to periodic dynamic loading even during ice-structure interactions where this is not initially apparent. Dynamic amplification of the structure's response in its natural vibratory modes shall be analysed.

(6) Model tests are recommended for evaluation of global loads and confirmation of expected ice failure modes.

(7) The methods to analyse sea ice loading on offshore wind turbine foundations are given in the GL "Guideline for the Construction of Fixed Offshore Installations in Ice Infested Waters", [4.1].

(8) Extra investigations and analysis shall be performed for dynamic ice loading upon agreement with GL Wind. In a simplified manner it may be assumed that the load oscillation period is equal to the support structure's natural period. The amplitude of the load oscillation may be assumed to be about 1/4 of the static horizontal ice load with a mean value equal to 3/4 of the sea ice load.

4.3.2.6 Earthquake loads

(1) The analysis of the dynamic response should be performed using recognized procedures such as:

– response spectrum analysis
– time history analysis

Generally a three-dimensional model of the structure shall be used for the analysis. The combination of earthquake loads with other loads is described in Section 4.3.5.

(2) When the response spectrum analysis is applied for the combination of the modal maxima, the use of the "Complete Quadratic Combination" (CQC) method [4.8] is recommended.

4.3.2.7 Boat impact loads

(1) The operational impact should be taken to be not less than that caused by the dedicated supply vessel coming into contact at a speed of 0.5 m/s. It should be assumed in this case that all the kinetic energy is absorbed by the turbine structure. The total kinetic energy involved can be expressed as:

$$E = \tfrac{1}{2}\, a \cdot m \cdot v_{boat}^2 \qquad (4.3.6)$$

where:

m = vessel displacement [kg]

a = added mass coefficient
= 1.6 for sideways collision
= 1.1 for bow or stern collision

v_{boat} = impact speed [m/s]

(2) The energy absorbed by the turbine structure may be less than the calculated value if the stiffness of the turbine structure is very large in comparison to that of the impacting part of the vessel. This may be the case for concrete structures. In such cases it is important to analyse the damage caused by the impact force.

(3) The impact force $F_{boat\ impact}$ may be taken as:

$$F_{boat\ impact} = P_0 \text{ or} \tag{4.3.7}$$

$$F_{boat\ impact} = v_{boat}\sqrt{c \cdot a \cdot m} \tag{4.3.8}$$

where:

P_0 = minimum crushing strength of the impacting part of the vessel [MN]

c = stiffness of the impacting part of the vessel [MN/m]

m = vessel displacement [kg]

a = added mass coefficient

= 1.6 for sideways collision

= 1.1 for bow or stern collision

v_{boat} = impact speed of the vessel [m/s]

(4) The vertical extent of the collision zone should be assessed on the basis of the vessel draft, maximum operational wave elevation and tidal elevation. In practice the vertical position will vary between +3 m to -5 m. For local pressure calculation a vertical extension of 2 m may be assumed.

(5) Special attention shall be paid to the strength of boat fender systems mounted at the turbine, which shall be suitable to carry gangway system as well.

4.3.2.8 Operational loads

Operational loads result from the operation and control of the offshore wind turbine. They shall be assigned to several categories. These are the control of rotor speed and the torque control by pitching of blades or other aerodynamic devices. Other operational loads are the mechanical braking and transient loads arising during the starting and stopping of the rotor, connection and disconnection of the generator, and yaw movements. The following influences shall be taken into account:

– static and load-dependent bearing friction moments (especially blade pitch bearing, yaw bearing)

– behaviour of the control and safety systems of the offshore wind turbine.

4.3.2.9 Other loads

(1) Other loads (such as maintenance loads, extreme temperature etc.) may occur and shall be included where appropriate. Special conditions of the installation site shall be considered.

(2) Loads resulting from installation and removal actions shall be considered in the structural design (see Chapter 12). These loads may result from:

– buoyancy aids, self floating

– lifting of parts or the of the whole structure

– piling

– launching

– submerging

4.3.3 Design situations and load cases

4.3.3.1 General

(1) For design purposes, the life of an offshore wind turbine can be represented by a set of design situations covering the most significant conditions which the offshore wind turbine may experience. In this section the construction of design load cases is described.

(2) The load cases shall be determined from the combination of specific erection, maintenance, and operational modes or design situations with the external conditions. All relevant load cases with a reasonable probability of occurrence shall be considered in conjunction with the behaviour of the control and safety systems.

(3) In general, the design load cases used to determine the structural integrity of the offshore wind turbine may be calculated from the following combinations:

– normal design situations and normal external conditions

– normal design situations and extreme external conditions

– fault design situations and appropriate external conditions

– design situations for transportation, installation and maintenance, and the appropriate external conditions.

Note:

Normal external conditions are assigned a recurrence period of 1 year, whereas extreme external conditions are assigned a recurrence period of 50 years as a rule.

(4) If any correlation exists between an extreme external condition and a fault situation, a realistic combination of the two shall be considered as a design load case.

4.3.3.2 Combination of external conditions

(1) The external design situations are built up by combination of wind, wave, ice, current and sea level conditions. Alternatively a combination of action effect on the structure with the specified return period may be used in consultation with GL Wind.

(2) For the load analysis scatter diagrams (long term statistics) including wave height, wave period and wind speed should be used to determine the wind wave combination to be considered. In some cases the evaluation of the directional distribution of wind and waves or their misalignment may be of importance and has to be included in the scatter diagrams considered.

(3) The combination of extreme external conditions (wind, wave, current, sea ice and water level) is performed in a way that results in the global extreme environmental action on the structure with the combined specified return period (50 year or 1 year).

(4) In absence of information on the long term probability distribution of combined extreme external conditions it can be assumed that the extreme external conditions occur during the same 3-hour storm event. i.e. the specified return period sea state is combined with the mean wind speed and the current velocity with the same specified return period, all determined by extrapolation of the individual parameters considered independently.

(5) It is assumed that there is a correlation of mean wind speed and significant wave height but no correlation of the extreme values during a short period. The extreme wave height and extreme gust wind speed are not assumed to occur simultaneously during one individual storm event but are randomly distributed during that time.

(6) In absence of information on combined wind and wave probability distribution or if wind turbine classes according to Section 4.2.2.1 are used, standard relations for the wind generated wave spectrum and thus for the significant wave height H_s may be used. The method described in Appendix 4.E for infinite fetch can be applied.

(7) In the case that the long term statistics of wind and waves are known, but not their combination, reasonable and conservative combinations may be built up in consultation with GL Wind. In Appendix 4.J one possible method is given allowing an approximation of the long term distributions of wind and waves by pairs of derived combinations.

(8) The combination of extreme wind and wave conditions may be performed using time series of stochastic wind fields and irregular sea states or by combining deterministic events of the wind speed and the regular waves. It is not recommended to combine stochastic time series of wind with regular deterministic waves and vice versa.

(9) It is recommended to consider both stochastic formulations and deterministic formulations of the extreme events to obtain the extreme loads on the offshore wind turbine. Stochastic simulations include all frequency components of the wind and wave conditions, but include in general only linear wave kinematics. In contrary deterministic regular waves consider non-linear kinematics.

(10) The combination of stochastic turbulent wind and irregular sea states shall be based on a sufficient number of different realisations to cover the statistical spread of combinations of single events within the time series.

(11) In the case that time series of irregular sea states are used in combination with stochastic wind field series the statistical properties of the time series have to be corrected for the same averaging time.

(12) For a combined analysis of wind and wave using the turbulent wind speed model, the 10 minute average wind speed can be converted to the 1 hour mean wind speed using Table 4.2.2. The standard deviation of the wind speed and the spectra can be assumed unchanged.

(13) For extreme load simulations using irregular sea states the significant wave height over 3 hours averaging time may transformed to a simulation time of 1 hour by multiplying with 1.1.

(14) When deterministic events (stationary wind and periodic regular wave) are combined the probability of simultaneous occurrence of wind speed and wave height is reached by combining reduced values of the gust wind with the maximum values of waves and vice versa.

(15) The combination of extreme deterministic events can be fulfilled if the extreme 1-minute averaged wind speed is combined with the maximum wave height during a 3 hour storm. Additionally the maximum 3-second gust wind speed shall be combined with a reduced wave height. See Section 4.3.2.3.1 and 4.2.2.4.1.

(16) For symmetric support structures it may be assumed that co-linear (mean direction) environmental actions are normally most critical. For other installations action combinations which involve a large difference in the mean action direction need to be addressed.

(17) Correlation between the wind directions where the wind load is largest, and the directions where the wave load is largest, does not necessarily exist. The wave load is normally dominated by the direction with the largest fetch.

(18) In case that no information on joint probability of wind, wave and currents exists, the sub surface currents shall be combined with wind, wave or sea ice events of the same recurrence period. For normal conditions a mean value may be used in agreement with GL Wind or the sub surface current with 1-year recurrence period.

(19) It has to be stated that the direction of the sub surface current is not correlated to the direction of wind and waves although it may be assumed that the highest loads occur when the sub surface current is in line with waves.

(20) It is generally assumed that sea ice actions need not to be combined with any wave actions. Sea ice shall be combined with wind and current. The ice load can be assumed to act in the direction of the largest current velocity.

(21) For most sites no correlation of sea ice conditions and wind speed and its direction can be established. The combination of wind and sea ice actions shall be based on worst conditions possible.

(22) The load analysis shall be performed with the water level resulting in the most adverse loading for the structure. The range of the water levels to be considered should take care of the recurrence period of the individual load case.

4.3.3.3 Combination of loads

(1) Load time series from combined external conditions include all components required. No further combination is needed.

(2) In some cases it is practical and may be permitted to analyse the aerodynamic loads using dynamic analysis and the wave loads using quasi-static calculation methods. The applicability of the method and the superposition of the loads depend on the design considered and have to be agreed with GL Wind for every case in advance.

(3) In the case that load time series are calculated independently it has to be shown by the designer that this does not lead to a significant loss of accuracy due to dynamic interaction and aeroelastic and hydroelastic effects or due to influence on the control system. In general it can be assumed that a load combination may be carried out for stiff systems.

(4) If separate analysis for extreme wind, wave and/or sea ice loading is performed the total force/moment may be assumed to be:

$$F_{total,\max} = F_{wind,mean} + \sqrt{(F_{wind,\max} - F_{wind,mean})^2 + F_{wave,\max}^2} \qquad (4.3.9)$$

where:

$F_{total,max}$ = total force/moment

$F_{wind,max}$ = maximal force/moment due to wind action

$F_{wind,mean}$ = mean force/moment due to wind action

$F_{wave,max}$ = maximal force/moment due to wave action

(5) The combination of the fatigue load may be performed in a similar manner assuming that all components have a stochastic nature with normal distributed amplitudes. The method has to be agreed in consultation with GL Wind.

4.3.3.4 Load cases

(1) For each design situation in the normal rotational speed range, several design load cases shall be considered to verify the structural integrity of offshore wind turbine components. As a minimum, the design load cases in Table 4.3.1 shall be considered. This table specifies the design load cases for each design situation through the description of the wind, marine, electrical and other external conditions. If other realistic combinations lead to more severe loading these shall be considered.

(2) Other design load cases relevant for safety shall be considered in consultation with GL Wind, if required by the specific offshore wind turbine design or by the control concept.

(3) For each design load case, the appropriate type of analysis is stated by “F” and “U” in Table 4.3.1. F refers to analysis of fatigue loads, to be used in the assessment of fatigue strength. U refers to the analysis of ultimate loads, such as analysis of exceeding the maximum material strength, analysis of tip deflection, and stability analysis.

(4) The design situations indicated with U are classified further as normal (N), extreme (E), abnormal (A), or transport and erection (T). Normal design situations are expected to occur frequently within the lifetime of an offshore wind turbine. The turbine is in a normal state or may have experienced minor malfunctions or abnormalities. For an extreme design situation a normal turbine state with extreme external conditions is considered. Abnormal design situations are less likely to occur. They usually correspond to design situations with more severe malfunctions, e.g. faults in the safety system. The type of design situation (N, E, A, or T) determines the partial safety factor γ_F to be applied to the ultimate loads. These factors are given in Table 4.3.4 in Section 4.3.7.

(5) In the definition of the design load cases, reference is made to the wind and marine conditions described in Section 4.2. When a wind speed range is indicated in Table 4.3.1, the wind speeds leading to the most adverse condition for the offshore wind turbine design shall be considered. For the analysis of ultimate strength (U), at least the wind speeds V_r and V_{out} shall be investigated in the wind range $V_{in} \le V_{hub} \le V_{out}$ (e.g. DLC 1.1), and at least V_r in the wind range $V_{in} \le V_{hub} \le V_r$ (e.g. DLC 1.3). For the analysis of the fatigue strength (F), the range may be divided into a number of sub-ranges; each sub-range shall be allocated the corresponding proportion of the turbine's operating life.

(6) If the use of a mechanical brake by the control or safety system is prescribed in a load case, both the minimum and the maximum braking torque shall be taken into account. The occurrence of each braking torque in the range between the minimum and the maximum braking torque is regarded as a normal condition and not as a fault condition. The suitability of the brakes (minimum braking torque) shall be verified for load case DLC 8.1. The definitions of the minimum and the maximum braking torques are given in Section 7.5.

(7) Where the assessment of site-specific external conditions determines wind and wave directional misalignment resulting in higher loads than those computed based on the preceding generic assumptions, the site-specific data shall be taken into account.

(8) The multi-directionality of the wind and waves may, in some cases, have an important influence on the loads acting on the support structure depending primarily on the extent to which the support structure is non-axisymmetric. For some design load cases the load calculations may be undertaken by assuming that the wind and waves are acting from a single, worst case direction. In these cases, however, the structural integrity shall be verified by application of the calculated worst case loads to relevant directional orientations of the support structure.

(9) For fatigue investigation simulation time length of 10 minutes is assumed to be adequate if the overall simulation time in every bin is not less than one hour. The simulations for estimation of extreme events using stochastic wind field and irregular sea states require a simulation time of 1 hour; the sum of different realisations shall at least 5 hours. Each simulation shall be carried out with a different seed.

Table 4.3.1 Design load cases

Design situation	**DLC**	**Wind conditions**[1]	**Marine conditions**	**Other conditions**	**Type of analysis**	**Partial safety factors**
1. Power production	1.1	NTM $V_{in} \le V_{hub} \le V_{out}$	Irregular sea state with $H_s(V)$ or acc. to scatter diagram		U	N
	1.2	NTM $V_{in} < V_{hub} < V_{out}$	Irregular sea state with $H_s(V)$ or acc. to scatter diagram		F	*
	1.3	ECD $V_{in} \le V_{hub} \le V_r$	$H{=}H_s(V)$		U	E
	1.4	NWP $V_{in} \le V_{hub} \le V_{out}$	$H{=}H_s(V)$	External electrical fault	U	N
	1.5	EOG_1 $V_{in} \le V_{hub} \le V_{out}$	$H{=}H_s(V)$	Grid loss	U	N
	1.6	EOG_{50} $V_{in} \le V_{hub} \le V_{out}$	$H{=}H_s(V)$		U	E
	1.7	EWS $V_{in} \le V_{hub} \le V_{out}$	$H{=}H_s(V)$		U	E
	1.8	EDC_{50} $V_{in} \le V_{hub} \le V_{out}$	$H{=}H_s(V)$		U	E
	1.9	ECG $V_{in} \le V_{hub} \le V_r$	$H{=}H_s(V)$		U	E
	1.10	NWP $V_{in} \le V_{hub} \le V_{out}$	$H{=}H_s(V)$	Ice formation on blades and structure	F / U	* / E
	1.11	Temperature effects, if applicable see Section 4.3.4			U	E
	1.12	Earthquakes, if applicable see Section 4.3.5			U	A
	1.13	NWP $V_{hub} = V_r$ or V_{out}	$H{=}H_s(V)$	Grid loss	F	*
	1.14	NWP $V_{hub} = V_r$ or V_{out}	-	Sea ice	F/U	*/E
	1.15	NWP $V_{hub} = V_r$ or V_{out}	$H{=}H_{max1}$ or $H_{max}(V)$		U	N
2. Power production plus occurrence of fault	2.1	NWP $V_{in} \le V_{hub} \le V_{out}$	$H{=}H_s(V)$	Fault in the control system	U	N
	2.2	NWP $V_{in} \le V_{hub} \le V_{out}$	$H{=}H_s(V)$	Fault in safety system or preceding internal electrical fault	U	A
	2.3	NTM $V_{in} < V_{hub} < V_{out}$	Irregular sea state with $H_s(V)$ or acc. to scatter diagram	Fault in the control system or safety system	F	*
3. Start-up	3.1	NWP $V_{in} < V_{hub} < V_{out}$	$H{=}H_s(V)$		F	*
	3.2	EOG_1 $V_{in} \le V_{hub} \le V_{out}$	$H{=}H_s(V)$		U	N
	3.3	EDC_1 $V_{in} \le V_{hub} \le V_{out}$	$H{=}H_s(V)$		U	N
4. Normal shut-down	4.1	NWP $V_{in} < V_{hub} < V_{out}$	$H{=}H_s(V)$		F	*
	4.2	EOG_1 $V_{in} \le V_{hub} \le V_{out}$	$H{=}H_s(V)$		U	N

Table 4.3.1 Design load cases (continued)

Design situation	DLC	Wind conditions[1]	Marine conditions	Other conditions	Type of analysis	Partial safety factors
5. Emergency shut-down	5.1	NWP $V_{in} \le V_{hub} \le V_{out}$	$H=H_s(V)$		U	N
6. Parked (standstill or idling)	6.1a	EWM $V_{hub}=V_{ref}$ Turbulent wind model	Irregular sea state with H_{s50}	Wind wave misalignment	U	E
	6.1b	EWM $V_{hub}=V_{e50}$ Steady wind model	$H=H_{red50}$	Wind wave misalignment	U	E
	6.1c	EWM $V_{hub}=V_{red50}$ Steady wind model	$H=H_{max50}$	Wind wave misalignment	U	E
	6.2a	EWM $V_{hub}=V_{ref}$ Turbulent wind model	Irregular sea state with H_{s50}	Grid loss	U	A
	6.2b	EWM $V_{hub}=V_{e50}$ Steady wind model	$H=H_{red50}$	Grid loss	U	A
	6.3a	EWM $V_{hub}=V_1$ Turbulent wind model	Irregular sea state with H_{s1}	Extreme oblique inflow	U	E
	6.3b	EWM $V_{hub}=V_{e1}$ Steady wind model	$H=H_{red50}$	Extreme oblique inflow	U	E
	6.4	NTM $V_{hub} < 0.7\ V_{ref}$	Irregular sea state with $H_s(V)$		F	*
	6.5	EDC_{50} $V_{hub} = V_{ref}$	$H=H_{red1}$	Ice formation on blades and structure	U	E
	6.6	Temperature effects, if applicable see Section 4.3.4			U	E
	6.7	EWM $V_{hub}=V_{50red}$ Steady wind model	-	50 year sea ice	U	E
7. Parked plus fault conditions	7.1a	EWM $V_{hub}=V_{e1}$ Steady wind model	$H=H_{red1}$		U	A
	7.1b	EWM $V_{hub}=V_{1red}$ Steady wind Model	$H=H_{max1}$		U	A
	7.2	NTM $V_{hub} < 0.7\ V_{ref}$	Irregular sea state with $H_s(V)$		F	*
8. Transport, erection, maintenance and repair	8.1	EOG_1 $V_{hub} = V_T$	$H=H_{sT}$	To be specified by the manufacturer	U	T
	8.2a	EWM $V_{hub}=V_{e1}$ Steady wind model	$H=H_{red}(V)$	Locked state	U	A
	8.2b	EWM $V_{hub}=V_{red1}$ Steady wind model	$H=H_{max}(V)$	Locked state	U	A
	8.3			Vortex-induced transverse vibrations	F	*

Table 4.3.1 Design load cases (continued)

Design situation	DLC	Wind conditions[1]	Marine conditions	Other conditions	Type of analysis	Partial safety factors
8. Transport, erection, maintenance and repair (continued)	8.4	NTM $V_{hub} < 0.7\ V_{ref}$	Irregular sea state with $H_s(V)$.	No grid during long period	F/U	*/A
	8.5	NWM $V_{hub} < V_T$	$H = H_{sT}$	Boat impact	U	A

* Partial safety factor for fatigue strength (see Section 4.3.7.3)
[1] If no cut-out wind speed V_{out} is defined, V_{ref} shall be used.

Meaning of the abbreviations in Table 4.3.1:

DLC Design load case

ECD Extreme coherent gust with direction change (see Section 4.2.2.4.5)

ECG Extreme coherent gust (see Section 4.2.2.4.4)

EDC Extreme direction change (see Section 4.2.2.4.3)

EOG Extreme operating gust (see Section 4.2.2.4.2)

EWM Extreme wind speed model (see Section 4.2.2.4.1)

EWS Extreme wind shear (see Section 4.2.2.4.6)

NTM Normal turbulence model (see Section 4.2.2.3.3)

NWP Normal wind profile model (see Section 4.2.2.3.2)

$H_s(V)$ Significant wave height corresponding to V_{hub} (see Section 4.3.3.2 para 6 and para 7)

$H_{red}(V)$ Reduced wave height corresponding to V_{hub} (see Section 4.3.2.3.1 and 4.3.3.2)

$H_{max}(V)$ Maximum wave height corresponding to V_{hub} (see Section 4.3.2.3.1 and 4.3.3.2)

H_{s1} Significant wave height with the recurrence period of 1 year (see Section 4.2.3.1.4)

H_{s50} Significant wave height with the recurrence period of 50 year (see Section 4.2.3.1.4)

H_{redN} Reduced wave height with the recurrence period of N years (see Section 4.3.2.3.1 and 4.2.3.1.4)

H_{max1} Maximum wave height with the recurrence period of 1 year (see Section 4.3.2.3.1)

H_{max50} Design wave height with the recurrence period of 50 years (see Section 4.3.2.3.1 and Section 4.2.3.1.4)

F Fatigue strength

U Ultimate strength

N Normal

E Extreme

A Abnormal

T Transport, erection, installation and maintenance

4.3.3.5 Power production (DLC 1.1 to 1.15)

(1) In this design situation, the offshore wind turbine is in operation and connected to the electrical grid. The assumed offshore wind turbine configuration shall take into account any rotor imbalance. The maximum mass and aerodynamic imbalances (e.g. blade pitch and twist deviations) specified for rotor manufacture shall be used in the design calculations (see Section 4.3.2.1 and 4.3.2.2, para 3).

(2) In addition, deviations from theoretical optimum operating situations, such as yaw misalignment and control system delays, shall be taken into account in the analyses of operational loads.

(3) Yaw misalignment and the hysteresis shall be considered for yaw movement. If smaller values cannot be verified, an average yaw misalignment of ± 8° shall be applied

(4) The deterministic wind and wave condition have to be combined in a conservative manner. The phase between wave and gust peak may be arbitrary and thus combined in the most adverse way.

(5) Design load cases DLC 1.1 and 1.2 embody the requirements for loads resulting from atmospheric turbulence. DLC 1.3, 1.6 – 1.10, 1.14 and 1.15 specify transient cases which have been selected as potentially critical events in the life of an offshore wind turbine. In DLC 1.4, 1.5 and 1.13 transitional events due to external faults and loss of electrical grid are considered.

(6) DLC 1.1, 1.2: For these design load cases, the discretisation of the wind speed intervals (bins) within the wind speed ranges to be investigated shall not be chosen to be larger than 2 m/s.

(7) DLC 1.3, 1.5 – 1.9: The rotor start positions which lead to the most unfavourable conditions for the offshore wind turbine shall be considered. The intervals between the rotor start positions shall be at most 30°.

(8) DLC 1.2: In the fatigue load calculation, 700 generator switching operations (high speed / low speed and vice versa) per year shall be included, if applicable. Additionally, in the case of horizontal-axis turbines with active yaw control, operation of the yaw system during the entire service life shall be considered if the yaw speed exceeds 15/R in °/s or the yaw acceleration exceeds $450/R^2$ in $°/s^2$ (where R is the rotor radius in m). Operation of the yaw system shall be considered during 10 % of the service life. Furthermore, 300 changes per year in the mean wind speeds from V_{in} to V_r and back to V_{in} shall be taken into account. 50 changes per year in the mean wind speeds from V_r to V_{out} and back to V_r shall be taken into account.

(9) DLC 1.4: In this load case, peculiarities arising from connection to an energy consumer (e.g. frequency, voltage and load fluctuations in a weak grid, operation of mechanically powered machinery, grid failure and special requirements of the grid operator) shall be taken into account as applicable. Examples of extreme influences on an offshore wind turbine are:

– major frequency, voltage and load fluctuations in an isolated grid
– interference voltages
– short-circuit in the grid
– sudden increase of resistance of a mechanical processing machine
– special requirements of a grid operator

(10) DLC 1.5: The grid loss can occur at any time during the course of the gust. The most unfavourable combinations shall be considered. At least the following three combinations of grid loss and gust shall be examined:

– The grid loss occurs at the time of the lowest wind speed.
– The grid loss occurs at the time of the highest gust acceleration.
– The grid loss occurs at the maximum wind speed.

(11) DLC 1.8: The most unfavourable combination of the conditions “wind direction change with characteristic yaw misalignment” shall be assumed in the calculation.

(12) DLC 1.10: The design load case DLC 1.10 considers humid weather conditions with ice formation. The conditions “ice formation on all rotor blades” and “ice formation on all rotor blades except one” shall be assumed. In the analysis of the fatigue loads, the manufacturer shall define assumptions regarding the duration of operation with ice formation. The ice formation shall be modelled according to Section 4.2.4.4.

(13) DLC 1.13: The transient switching operations of the offshore wind turbine triggered by grid failure shall be considered with regard to the analysis of the fatigue loads. The frequency of the grid failures per year may be dependent on the local grid stability; an appropriate value shall be assumed. If the number of grid failures is not verified in more detail, at least 20 grid outages per year shall be assumed.

(14) For DLC 1.1, 1.2 irregular sea state conditions shall be assumed. The significant wave height, peak spectral period and direction for each normal sea state shall be selected, together with the associated mean wind speed, based on the long term joint probability distribution of metocean parameters appropriate to the anticipated site. The designer shall ensure that number and resolution of the normal sea states considered are sufficient to account for the fatigue damage associated with the full long term distribution of metocean parameters.

(15) For DLC 1.3 **-** 1.13 a regular wave with the significant wave height corresponding to the mean wind speed ($H_s(V)$) according to Section 4.3.3.2 para 6 and 7 shall be assumed

(16) For DLC 1.15 a regular wave with the higher value of the maximum wave height (H_{max1}) with the reoccurrence period of 1 year or the maximum wave height ($H_{max}(V)$) corresponding to V_{hub} shall be assumed.

4.3.3.6 Power production plus occurrence of fault (DLC 2.1 to 2.3)

(1) Any fault in the control or safety systems or any internal fault in the electrical system that is significant for offshore wind turbine loading (such as generator short circuit) shall be assumed to occur during power production.

(2) It may be assumed that independent faults do not occur simultaneously.

(3) DLC 2.1: The occurrence of a fault in the control system which is considered a normal event shall be analysed in DLC 2.1. Exceedance of the limiting values of the control system, e.g. $n \geq n_{4,}$ (see Section 2.2.2.5), yaw error, pitch deviation of the blades to each other) shall be investigated.

(4) DLC 2.2: The occurrence of faults in the safety system or in the internal electrical system which are considered to be rare events shall be analysed in DLC 2.2. Exceedance of the limiting values for the safety system (e.g. $n \geq n_A$ (Section 2.2.2.5), $P \geq P_A$ (Section 2.2.2.6), vibrations, shock (Section 2.3.2.5), runaway of the blade pitch, failure of a braking system or runaway of yaw) shall be investigated. Furthermore, faults in the power system (see Appendix 4.C) shall be investigated. In the case of collective pitch control, Section 2.2.3.3.1 shall be observed.

(5) DLC 2.3: If a fault causes an immediate shut-down or the consequent loading can lead to significant fatigue damage, the probable number of shut-downs, or the duration of this extraordinary design situation, shall be considered in DLC 2.3. At least 10 shut-downs per year due to overspeed n_4 (see Section 2.2.2.5 para 4) and 24 hours of operation with extreme yaw error (value equal to the maximum permissible oblique inflow according to Sections 2.3.2.11 and 2.3.2.12) shall be considered.

(6) For DLC 2.1 and 2.2 a regular wave with the significant wave height corresponding to the mean wind speed ($H_s(V)$) shall be assumed.

(7) For DLC 2.3 irregular sea state conditions shall be assumed. The significant wave height, peak spectral period and direction for each normal sea state shall be selected, together with the associated mean wind speed, based on the long term joint probability distribution of metocean parameters appropriate to the anticipated site. The designer shall ensure that number and resolution of the normal sea states considered are sufficient to account for the fatigue damage associated with the full long term distribution of metocean parameters.

4.3.3.7 Start-up (DLC 3.1 to 3.3)

(1) This design situation includes all the events resulting in loads on the offshore wind turbine during the transitions from any standstill or idling situation to power production.

(2) DLC 3.1: Per year, at least 1000 start-up procedures at V_{in}, 50 start-up procedures at V_r and 50 start-up procedures at V_{out} shall be considered. If applicable, further start-up procedures shall be taken into account due to site-specific requirements, such as shadow criteria or conditions for installation within a wind farm (curtailment strategy).

(3) For DLC 3.1 - 3.3 a regular wave with the significant wave height corresponding to the mean wind speed ($H_s(V)$) shall be assumed.

4.3.3.8 Normal shut-down (DLC 4.1 to 4.2)

(1) This design situation includes all the events resulting in loads on the offshore wind turbine during normal transitions from power production to a stand-by condition (standstill or idling).

(2) DLC 4.1: Per year, at least 1000 shut-down procedures at V_{in}, 50 shut-down procedures at V_r and 50 shut-down procedures at V_{out} shall be considered. If applicable, further shut-down procedures shall be taken into account due to site-specific requirements, such as shadow criteria or conditions for installation within a wind farm (curtailment strategy), see also Section 4.2.2.5.

(3) For DLC 4.1 and DLC 4.2 a regular wave with the significant wave height corresponding to the mean wind speed ($H_s(V)$) shall be assumed.

4.3.3.9 Emergency shut-down (DLC 5.1)

(1) This load case covers manual actuation of the emergency stop pushbutton. For this load case, the rotor shall be brought to a standstill (Section 2.3.2.14).

(2) For DLC 5.1 a regular wave with the significant wave height corresponding to the mean wind speed ($H_s(V)$) shall be assumed.

4.3.3.10 Parked (standstill or idling) (DLC 6.1 to 6.7)

(1) For this design situation, the rotor of a parked offshore wind turbine in stand-by mode is standstill or idling.

(2) For design situations, either the steady wind model or the turbulent wind model shall be used as indicated in Table 4.3.1. If the turbulent wind model is used, this shall be combined with a stochastic wave model and the response shall be estimated using a full dynamic simulation. If the steady wind model is used, this shall be combined with a deterministic design wave and the response shall be estimated from a quasi-steady analysis with appropriate corrections for dynamic response.

(3) DLC 6.1: In this load case, transient oblique inflow of up to ± 15° for the steady extreme wind speed model, or an average oblique inflow of ± 8° for the turbulent extreme wind speed model, shall be assumed if it is ensured that the average yaw misalignment does not lead to larger values and that slippage of the yaw system can be excluded (in this case, an additional yaw error need not be considered). If this cannot be excluded, a yaw error of up to ± 180° shall be used.

(4) DLC 6.2: In this load case, a grid failure in an early stage of the storm with the extreme wind situation shall be assumed. A yaw error of up to ± 180° shall be assumed if no independent power supply is available for the control and yaw systems that ensures sufficient capacity for at least 6 h of operation and a power supply of the safety system of at least 48 h.

(5) DLC 6.3: In this load case, the extreme wind with a recurrence period of one year (annual wind) shall be assumed together with an extreme oblique inflow or average extreme oblique inflow. An extreme oblique inflow of up to ± 30° for the steady-state extreme wind speed model, and an average oblique inflow of up to ± 20° for the turbulent extreme wind speed model, shall be assumed. In this case, an additional yaw error need not be considered.

(6) In DLC 6.4, the expected number of hours of non-power production time at a fluctuating load appropriate for each wind speed where significant fatigue damage can occur to any components (e.g. from weight of idling blades) shall be considered.

(7) DLC 6.5: This design load case includes weather conditions with ice formation. The ice formation shall be modelled according to Section 4.2.4.4. An additional yaw error need not be considered here.

(8) DLC 6.7: In this load case 50 year sea ice conditions shall be investigated according Section 4.3.2.5.

(9) For DLC 6.1a and the DLC 6.2a the turbulent wind model shall be taken together with irregular sea state conditions. In this case the 50 year recurrence value of the significant wave height and the 50 year recurrence value of the mean wind speed shall be taken. The averaging values of the significant wave height and the mean wind have to be adjusted to the simulation time length (see Table 4.2.2 and Section 4.3.3.2).

(10) For DLC 6.1b and DLC 6.2b the steady extreme wind model shall be taken together with the reduced deterministic design wave. In this case the extreme wind speed (averaged over 3 seconds) with a recurrence period of 50 years and the reduced wave height H_{red50} with a recurrence period of 50 years shall be used.

(11) For DLC 6.1c the steady wind model with the reduced wind speed (see Section 4.2.2.4.1) shall be taken together with the extreme deterministic design wave. In this case the reduced wind speed (averaged over 1 minute) with a recurrence period of 50 years and the maximum wave height H_{max50} with a recurrence period of 50 years shall be used.

(12) For DLC 6.3a the turbulent wind model shall be taken together with irregular sea state conditions. In this case the 1 year recurrence value of the significant wave height and the 1 year recurrence value of mean wind speed shall be taken. The averaging values of the significant wave height and the mean wind have to be adjusted to the simulation time length (see Table 4.2.2 and Section 4.3.3.2).

(13) For DLC 6.3b the steady extreme wind model shall be taken together with the reduced deterministic design wave. In this case the extreme wind speed (averaged over 3 seconds) with a recurrence period of 1 year and the reduced wave height H_{red1} with a recurrence period of 1 year shall be used.

(14) In DLC 6.1, 6.2 and 6.3, a misalignment of up to ± 30 degrees shall be considered for the mean wind direction associated with the turbulent wind model relative to the mean wave direction. In the case of the steady wind model and with the exception of DLC 6.3b, an additional 7 degrees misalignment of the short term wind direction shall be considered relative to the wave direction. For DLC 6.3b the additional misalignment shall be taken as 10 degrees.

(15) For DLC 6.4 irregular sea state conditions shall be assumed. The significant wave height, peak spectral period and direction for each normal sea state shall be selected, together with the associated mean wind speed, based on the long term joint probability distribution of metocean parameters appropriate to the anticipated site. The designer shall ensure that number and resolution of the normal sea states considered are sufficient to account for the fatigue damage associated with the full long term distribution of metocean parameters.

(16) For DLC 6.5 the reduced deterministic design wave according to Section 4.3.2.3.1 shall be assumed.

4.3.3.11 Parked plus fault conditions (DLC 7.1 to 7.2)

(1) This load case considers the non-stand-by state (standstill or idling) resulting from the occurrence of a fault. Deviations from the normal behaviour of a parked offshore wind turbine, resulting from faults in the electrical network or within the offshore wind turbine, shall require analysis. If any fault other than a grid failure produces deviations from the normal behaviour of the offshore wind turbine in parked situations, the possible consequences shall be considered. Grid failure in this case shall be regarded as a fault condition (see Section 2.2.2.9) and therefore need not be considered together with any other fault of the offshore wind turbine.

(2) The fault condition shall be combined with the extreme wind speed model (EWM) and a recurrence period of one year. In this load case, transient oblique inflow of up to ± 15° for the steady extreme wind speed model shall be assumed. An additional yaw error need not be considered here, unless a failure of the yaw system itself is being investigated. In such a case, a yaw error of up to ± 180° shall be used. If slippage of the yaw system cannot be excluded, a yaw error of up to ± 180° shall be used.

(3) If a grid failure with a duration up to 1 week may occur and no backup energy system or redundant electricity supply is provided, the behaviour of the mechanical brake, the safety and yaw system shall be considered adequately in the load assumptions.

(4) For DLC 7.1a the extreme wind model shall be taken together with the reduced deterministic design wave. In this case the extreme wind speed (averaged over 3 seconds) with a recurrence period of 1 year and the reduced wave height H_{red1} with a recurrence period of 1 year shall be used.

(5) For DLC 7.1b the extreme wind model with the reduced wind speed (see Section 4.2.2.4.1) shall be taken together with the extreme deterministic design wave. In this case the reduced wind speed (averaged over 1 minute) with a recurrence period of 1 year and the maximum wave height H_{max1} with a recurrence period of 1 year shall be used.

(6) In DLC 7.1 a misalignment of up to ± 30 degrees shall be considered for the mean wind direction associated with the turbulent wind model relative to the mean wave direction. In the case of the steady wind model an additional 7 degrees misalignment of the short term wind direction shall be considered relative to the wave direction.

(7) In DLC 7.2, the expected number of hours of non-power production time due to faults on the electrical network or in the offshore wind turbine shall be considered for each wind speed where significant fatigue damage can occur in any component. The duration of non-power production time due to faults shall be determined as part of assessment of the site for the offshore wind turbine.

(8) For DLC 7.2 irregular sea state conditions shall be assumed. The significant wave height, peak spectral period and direction for each normal sea state shall be selected, together with the associated mean wind speed, based on the long term joint probability distribution of metocean parameters appropriate to the anticipated site. The designer shall ensure that number and resolution of the normal sea states considered are sufficient to account for the fatigue damage associated with the full long term distribution of metocean parameters.

4.3.3.12 Transport, erection, maintenance and repair (DLC 8.1 to 8.5)

(1) DLC 8.1: The manufacturer shall state all the wind conditions, marine conditions and design situations assumed for transport, erection, maintenance and repair of the offshore wind turbine, and especially up to which maximum average wind speed (10-min mean), for which significant wave height and for which oblique inflow the turbine may be erected and maintained. The maximum wind speed (V_T) and the significant wave height (H_{sT}) specified by the manufacturer applies for active work on the offshore wind turbine. If the wind and marine conditions exceed the specified limiting values, the work shall be halted.

(2) In the case of conditions for maintenance, particular consideration shall be given to the effect of the various locking devices (e.g. blade pitching, rotor and yaw drive) and the maintenance position which may have been adopted. Even with the rotor locked, the blade pitching system shall be able to move through its entire control range. Verification of standstill without the rotor lock activated shall be provided up to an oblique inflow of ± 10° (Section 2.2.3.3).

(3) For the verification of the mechanical brake (situation after actuation of the emergency stop pushbutton), a transient oblique inflow of up to ± 30° shall be assumed for this load case. The rotor positions which lead to the most unfavourable conditions for the offshore wind turbine shall be considered. The intervals between the rotor positions shall be at most 30°.

(4) DLC 8.2: In this design load case, the situation that the turbine has to be left behind in the locked condition is taken into account. In this load case, transient oblique inflow of up to ± 15° for the steady extreme wind speed model, or an average oblique inflow of ± 8° for the turbulent extreme wind speed model, shall be assumed if it is ensured that the yaw system is ready for operation during the entire period and that no slippage can be assured (in this case, an additional yaw error need not be considered). If a slippage cannot be excluded, a yaw error of up to ± 180° shall be used. The requirements for the locking devices according to Section 2.3.3 shall be met.

(5) DLC 8.3: Transverse oscillations due to vortex shedding shall be investigated in the verifications for the tower as per Section 6.1.3 para 7 and para 8 and Sections 6.6.4.2.2 and 6.6.6.9. Vortex shedding due to current and wave loading shall be considered, too.

(6) DLC 8.4: Long periods with a not fully erected or assembled offshore wind turbine, or without grid connection shall be considered in fatigue and ultimate load analysis. The period to be considered shall be defined in consultation with GL Wind. As a guideline a period of 3 month may be used, see Section 2.1.1 para 1 m.

(7) DLC 8.5: An operational boat impact may arise during operation of vessels in the vicinity. An impact with the dedicated maintenance/installation boat shall be considered. The size of the maintenance vessel (displacement) shall be stated by the manufacturer and/or operator of the offshore wind farm project, see Section 4.3.2.7.

(8) The maximum permissible significant wave height for vessel operations near the offshore wind turbine installation has to be stated in the operation manual. Any areas where vessels are not permitted to operate in close proximity should be specified in the operation manual.

(9) Functional loads occurring during installation and maintenance of the offshore wind turbine shall be considered, see Chapter 12. These may be:

– weight of tools and mobile equipment
– loads from operation of cranes and other conveyance equipment
– loads from transport operations, e.g. helicopter
– mooring/fendering loads from vessels serving the offshore wind turbine

(10) Loads, weight of tools and equipment shall be specified by the owner/designer. The specifications should also contain indications regarding permissible load combinations and limitations. Any such limitations shall be stated in the operation manual. The operating manual shall cover all relevant procedures and limiting conditions.

(11) The limiting operating conditions, i.e. environmental conditions tolerable during specified operations will generally be defined by the operator or designer. The regulations of the competent authorities/administrations have to be observed, particularly regarding collisions and helicopter operations.

(12) The environmental conditions, together with the turbine operating status and largest helicopter type expected have to be stated by the manufacturer. Safety aspects of helicopter operations regarding structural safety of landing platforms, clearance, fire protection, marking etc. will generally be treated according to relevant national and international regulations and codes.

(13) The helicopter load shall be combined with the loads from wind and wave conditions in accordance with the maximum helicopter operation conditions allowed.

4.3.4 Load assumptions for extreme temperatures

(1) The load calculation shall be matched to the selected temperature range. The wind loads are primarily affected by the change in air density. Here it shall be observed that the power curve and therefore the control behaviour will also change.

(2) In the cases where the elasticity or the control behaviour of the offshore turbine changes in such a way that the loads are influenced, this shall be taken into account.

(3) The calculation of the loads for the fatigue strength shall be performed at the mean temperature $\theta_{mean,year}$ determined for the site. If weather conditions can be expected at the site which leads to prolonged operation of the offshore wind turbine with ice formation, they shall be taken into account when determining the fatigue loads.

(4) For the determination of the extreme loads, the extreme temperature (1 year recurrence period) $\theta_{1year\ min/max}$ shall be combined with normal external conditions (NTM, NWP). For the load cases in which the turbine is in operation and the ambient temperature is monitored, the extreme temperature for operation of the plant $\theta_{min/max,\ operation}$ may be used as an alternative to the extreme temperature $\theta_{1year\ min/max}$.

(5) Extreme external conditions with a recurrence period of 50 years (EWS, EWM, EOG, EDC, ECD, ECG) shall be combined with the mean temperature

$\theta_{mean,year}$. If high wind speed and low temperature at the site are correlated, this correlation shall be taken into account.

(6) The condition after occurrence of a fault (DLC 7.1) shall be combined with the extreme temperature $\theta_{1year\ min/max}$ with a recurrence period of 1 year.

(7) The ice formation of the turbine shall be considered in the load assumptions (load cases DLC 1.10 and 6.5). It shall be checked whether this load case could become relevant for the site. At certain locations, the ice thickness shall be adjusted to suit the conditions.

(8) If a combination of turbine icing, sea ice occurrence and extreme temperatures can occur with a probability of 0.02 in one year or higher then this combination shall be considered.

(9) The temperature for which the load cases are to be analysed are shown in Table 4.3.2.

Table 4.3.2 Temperatures for which the load cases are to be analysed

Temperature	Load case (DLC)
$\theta_{mean,year}$	1.2; 1.3; 1.6; 1.7; 1.8; 1.9; 1.13; 2.3; 3.1; 4.1; 6.1: 6.2; 6.3; 6.4; 7.2, 8.2; 8.3
$\theta_{mean,year} \leq 0°C$	1.10; 1.14; 6.5; 6.7
$\theta_{1\ year\ min/max}$	7.1
$\theta_{1\ year\ min/max}$ or $\theta_{min/max,\ operation}$	1.1; 1.4; 1.5; 2.1; 2.2; 3.2; 3.3; 4.2; 5.1
To be specified by the manufacturer	8.1; 8.5

4.3.5 Influence of earthquakes

4.3.5.1 General

The loading caused by earthquake shall be taken into account in regions at risk of earthquakes. In the absence of any locally applicable regulation, a procedure based on Eurocode 8 [4.8] and/or API [4.9] may be applied in consultation with GL Wind.

4.3.5.2 Acceleration

The investigation of the earthquake-generated loads is based on the combination of the wind and wave loads and an earthquake acceleration with a recurrence period of 500 years.

4.3.5.3 Load case definition

The loading caused by earthquakes shall be combined with normal external conditions. All relevant load cases shall be taken into account. In the interests of simplification, it may be assumed that the earthquake load shall at least be combined with the load cases listed in Table 4.3.3. The partial safety factors to be considered for earthquake analysis are given in Section 4.3.7.2.3.

4.3.5.4 Analysis

(1) The loads resulting from earthquakes can be determined in either the frequency or the time domain. In all cases, it shall be ensured that an adequate number of natural modes (≥ 3) are considered and, for calculation in the time domain, an adequate number (≥ 6) of simulations are performed per load case.

(2) In general, an elastic load-bearing behaviour shall be assumed for the structure. For certain structures (e.g. lattice towers), a ductile behaviour may be assumed. The damping to be applied shall then be determined appropriately for the design in consultation with GL Wind. If ductile behaviour is assumed, it shall be possible to inspect the structure after earthquakes have occurred. The scope of such inspections shall be agreed with GL Wind and documented in the manuals.

4.3.6 Variation of support structure natural frequency and operation within the resonance range

(1) During the offshore wind turbine's lifetime the mass and stiffness of the structure and the soil may change considerably. Scour, corrosion, marine growth, soil settlings and sand movement may influence the turbine's natural frequencies.

(2) In the load analysis the change of the support structures natural frequencies shall be considered i.e. by applying the most adverse conditions for load analysis. Mean values may be applied for fatigue analysis if no resonant operation modes can appear.

(3) If the operation of an offshore wind turbine is desired within the resonance range of the support structure with a tolerance of ± 5 % of the structure's natural frequency (Section 6.6.4.2.1), suitable vibration monitoring systems shall be provided (Section 2.3.2.6). Within the load calculation, suitable threshold values for permissible vibrations shall be defined and taken into account.

Table 4.3.3 Load cases to be analysed in combination with earthquakes

DLC	Wind conditions	Marine conditions	Other conditions
E 1	NTM $V_{in} \le V_{hub} \le V_{out}$	Irregular Sea State with $H_s(V)$	Normal operation
E 2	NWP $V_{hub} = V_r$ or V_{out}	$H = H_s(V)$	1. Grid loss 2. Activation of the safety system by vibration sensor
E 3	NWP $V_{hub} = 0.8\ V_{ref}$	$H = H_{s1}$	Extreme yaw misalignment

Table 4.3.4 Partial safety factors for loads γ_F

Source of loading	Unfavourable loads				Favourable loads
	Type of design situation (see Table 4.3.1)				All design situations
	N Normal	E Extreme	A Abnormal	T Transport and erection	
Environmental	1.2	1.35	1.1	1.5	0.9
Operational	1.2	1.35	1.1	1.5	0.9
Gravity	1.1/1.35*	1.1/1.35*	1.1	1.25	0.9
Other inertial forces	1.2	1.25	1.1	1.3	0.9
Heat influence	–	1.35	–	–	0.9
* in the event of the masses not being determined by weighing.					

4.3.7 Partial safety factors for loads

4.3.7.1 Serviceability limit state

4.3.7.1.1 Partial safety factors for the loads in the analysis of serviceability limit states

For the analysis of the serviceability limit state, see Section 1.3.2.2.2, a partial safety factor for loads of $\gamma_F = 1.0$ shall be used for all load components.

4.3.7.1.2 Partial safety factor for the loads in deflection analysis

(1) It shall be verified that no deflections endangering the safety of the offhore wind turbine occur under the design conditions listed in Table 4.3.1. One of the most important considerations is that no contact can be permitted to occur between the blades and the tower. The maximum elastic deflection in the most unfavourable direction shall be determined for the load cases listed in Table 4.3.1.

(2) In consultation with GL Wind, methods of statistical extreme value analysis (e.g. the Gumbel method [4.7]) may also be used for the blade deflection. An extrapolation time of 50 years shall be applied.

(3) The partial safety factor for the loads shall be applied as $\gamma_F = 1.0$ in all cases. Observance of the permissible clearance between blade and tower shall be verified in accordance with Section 6.2.4.1 .

4.3.7.2 Ultimate limit state

4.3.7.2.1 Partial safety factors for the loads in the analysis of ultimate strength

(1) If the loads of different origins can be determined independently of each other, the partial safety factors for the loads shall have the values given in Table 4.3.4.

(2) In many cases, especially when unsteady loads lead to dynamic effects, the load components cannot be determined independently of each other. In these cases, the highest partial safety factor of the corresponding design situation in Table 4.3.4 shall be applied for the partial safety factors for the loads γ_F (see also Section 1.3.2.3).

4.3.7.2.2 Partial safety factor for the loads in the analysis of fatigue strength

The partial safety factor for the loads shall amount to $\gamma_F = 1.0$ for all normal and abnormal design situations.

4.3.7.2.3 Partial safety factor for earthquake loads

The safety factor for the loads resulting from earthquakes is $\gamma_F = 1.0$.

4.3.7.3 Special partial safety factors

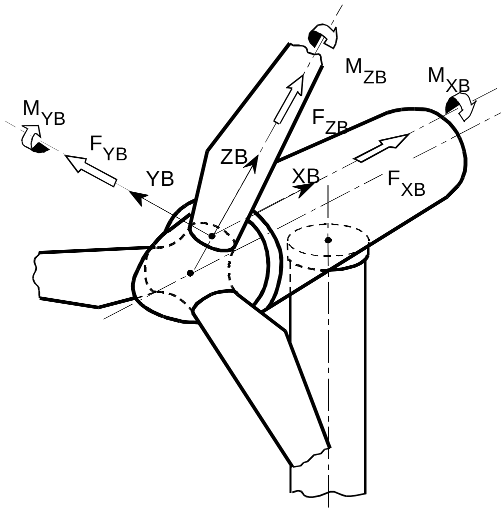
Smaller partial safety factors for loads may be used after consultation with GL Wind, if the loads were determined from measurements, or from analyses verified by measurements, with a higher level of confidence than is normally the case. The values of all partial safety factors shall be given in the design documentation.

Appendix 4.A Descriptions and Coordinate System

In general, the coordinate systems can be chosen freely. By way of suggestion, possible coordinate systems, together with their origin and orientation, are shown in the following diagrams. As a simplification, the representations of the rotor axis tilt angle and the cone angle were omitted.

4.A.1 Blade coordinate system

The blade coordinate system has its origin at the blade root and rotates with the rotor. Its orientation to the rotor hub is fixed.

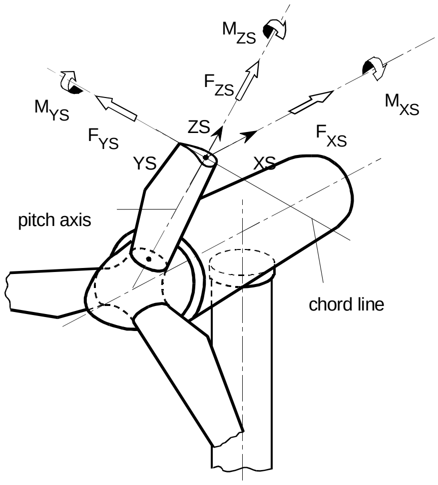


XB in direction of the rotor axis
ZB radially
YB so that XB, YB, ZB rotate clockwise

Fig. 4.A.1 Blade coordinate system

4.A.2 Chord coordinate system

The chord coordinate system has its origin at the intersection of the corresponding chord line and the blade pitch axis. It rotates with the rotor and the local pitch angle adjustment.

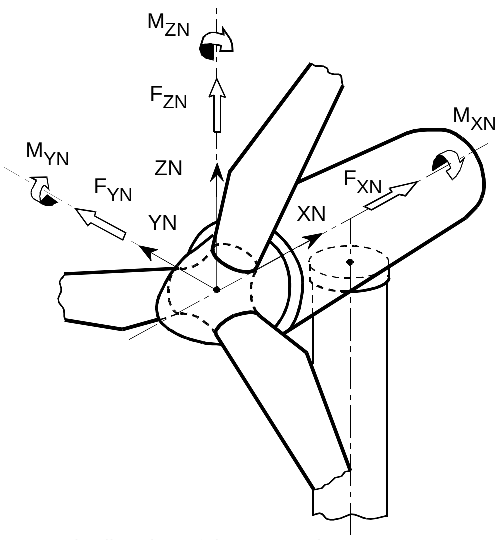


to
blade trailing edge
ZS in direction of the blade pitch axis
XS perpendicular to the chord, so that XS, YS, ZS rotate clockwise

Fig. 4.A.2 Chord coordinate system

4.A.3 Hub coordinate system

The hub coordinate system has its origin at the rotor centre (or any other position on the rotor axis, e.g. hub flange or main bearing) and does not rotate with the rotor.

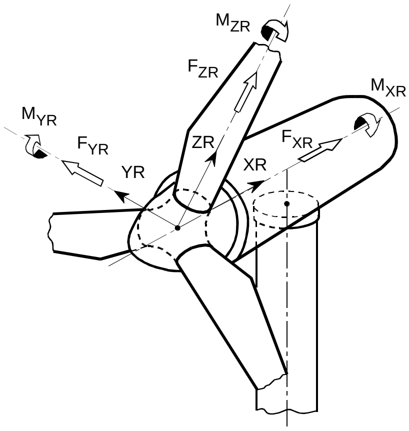


XN in direction of the rotor axis
ZN upwards perpendicular to XN
YN horizontally sideways, so that XN, YN, ZN rotate clockwise

Fig. 4.A.3 Hub coordinate system

4.A.4 Rotor coordinate system

The rotor coordinate system has its origin at the rotor centre (or any other position on the rotor axis, e.g. hub flange or main bearing) and rotates with the rotor.

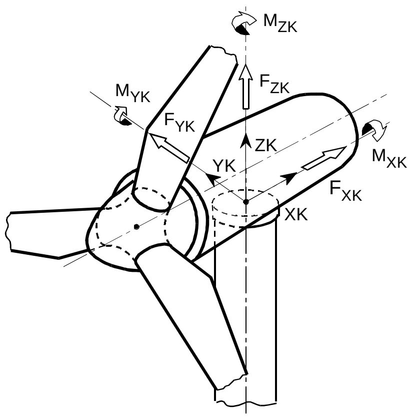


XR in direction of the rotor axis
ZR radially, orientated to rotor blade 1 and perpendicular to XR
YR perpendicular to XR, so that XR, YR, ZR rotate clockwise

Fig. 4.A.4 Rotor coordinate system

4.A.5 Tower top coordinate system

The tower top coordinate system has its origin at the intersection of the tower axis and the upper edge of the yaw bearing and does not rotate with the nacelle.

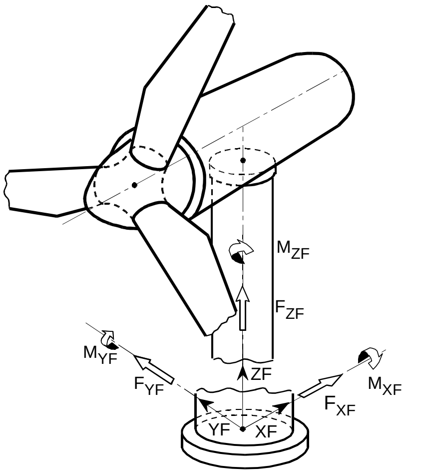


XK horizontal in direction of the rotor axis, fixed to the tower
ZK vertically upwards
YK horizontally sideways, so that XK, YK,ZK rotate clockwise

Fig. 4.A.5 Tower Top coordinate system

4.A.6 Support structure (tower) coordinate system

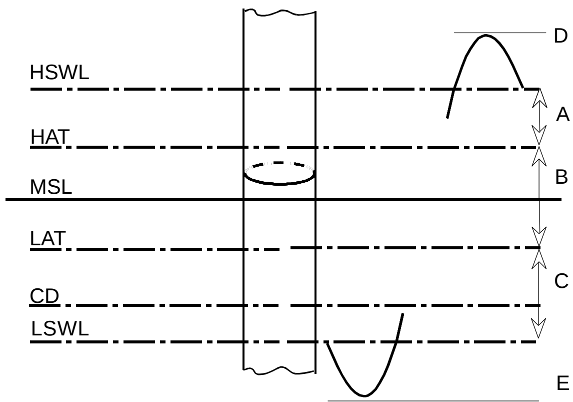
The support structure coordinate system has its origin between mudline and tower top at the intersection with the support system axis and does not rotate with the nacelle. The orientation corresponds to the tower top coordinate system (Section 4.A.5). In addition, other locations on the support system axis are also possible.



XF horizontal
ZF vertically upwards in direction of the tower axis
YF horizontally sideways, so that XF, YF, ZF rotate clockwise

Fig. 4.A.6 Support structure coordinate system

4.A.7 Water levels



HSWL	highest still water level
HAT	highest astronautical tide
MSL	mean sea level
LAT	lowest astronautical tide
CD	chart datum (often equal to LAT)
LSWL	lowest still water level
A	positive storm surge
B	tidal range
C	negative storm surge
D	maximum crest elevation
E	minimum trough elevation

Fig. 4.A.7 Water levels

Appendix 4.B Evaluation of the Loads

4.B.1 Presentation of load case definitions

(1) All calculated load cases shall be listed. For each load case, the principal simulation parameters (wind shear, wind model, possible ice loads, upflow, simulation duration etc.) as well as a description of the control and safety system parameters that are necessary for the load cases in question (braking procedures, shut-down procedures, yawing manoeuvres, delay times etc.) shall be specified.

(2) The variations of the load case in relation to the principal data of the load case definition shall be listed together with the filename of the time series with the associated parameters (e.g. wind speed, gust characteristics, oblique inflow, criteria for the activation of control or safety actions, etc.).

4.B.2 Presentation of the results

4.B.2.1 General

(1) In general, a distinction is made between extreme loads and fatigue loads when presenting the results. As a matter of principle, all loads used for the analyses of the component dimensioning shall be specified. The loads shall be presented in the same way as applied in the design process. In addition, the load evaluations shall be specified as described in Sections 4.B.2.2 and 4.B.2.3.

(2) All time series of the calculated extreme and fatigue load cases shall be supplied on computer storage media (e.g. DVD, CD-ROM).

4.B.2.2 Extreme loads

(1) The results of the extreme load evaluations, including the partial safety factors, shall be presented in tabular form for the positions investigated (e.g. blade sections, blade root, rotor shaft rotating, rotor shaft not rotating, etc.). This shall contain a brief description of the load case with statement of the partial safety factors used and the blade angle occurring at the extreme load situation. The following presentation format is recommended. The extreme values (maxima and minima) of the corresponding load component are located on the diagonal. The simultaneous loads of the other load components shall be given in the rows (see Table 4.B.1).

(2) For the extreme loads at the support structure, a column shall be added to the table for the wind speed and wind direction, as well as the wave direction belonging to the extreme load situation (the sign of the wind and wave direction shall be indicated in a sketch or stated in accordance with the coordinate systems listed in Appendix 4.A). A table of the loads including the partial safety factors and a table of the loads excluding them shall be given in each case.

Notes:

From the evaluation of the extreme loads with or without partial safety factors, differing load cases can be relevant.

With regard to the blade root, a table shall be compiled with all the corresponding loads from all the blade connections.

4.B.2.3 Fatigue loads

(1) In addition to the time series required in Section 4.B.2.1, all results of the evaluation shall be submitted in formats which can be edited by computer.

(2) For the evaluation of the fatigue loads, it is generally required that all design load cases of the fatigue strength shall be included (DLC 1.2, DLC 1.10, DLC 1.13, DLC 1.14, DLC 2.3, DLC 3.1, DLC 4.1, DLC 6.4, DLC 7.2, DLC 8.3, DLC 8.4).

(3) The assumptions made in the calculation of the fatigue loads shall be specified. These include e.g. the mean annual wind speed, the parameters of the wind speed and wave height distribution as well as their correlation, the operating life etc.

(4) For all load components, accumulated fatigue spectra within the simulated operating life shall be given in tabular, and if necessary graphic, form. In addition, equivalent constant-range spectra shall be computed from the accumulated fatigue spectra and also specified. Here the reference load cycle number n_{ref} shall be stated. Equivalent fatigue loads can be presented in tabular form for all material-relevant slope parameters of the S/N curves, in accordance with Table 4.B.2.

(5) For dynamically loaded components of fibre-reinforced plastic (GRP/CRP), such as the rotor blade, the Markov matrices (range-mean matrix) shall be given in addition at the sections investigated.

(6) In particular, for the evaluation of the fatigue loads at the blade root, the following procedure shall be observed:

(7) Apart from the evaluation for the bending moments in the flapwise and edgewise directions (Mx and My), the angular sector between these bending moments and the subsequent sector up to 90° shall be examined, so that a total sector of 180° is obtained. These bending moments shall be computed in angular intervals of at least 15°.

(8) Without further examination this examination can be dispensed with if the fatigue loads for the flapwise and edgewise directions are multiplied by a factor of 1.2.

(9) For the components of the blade pitching system, the drive train (main bearing, gearing, coupling etc.) and the yaw system, the average values from the fatigue loads as well as the distribution of the load duration distribution (LDD) shall be specified for the relevant load components (see also Chapter 7).

(10) For the support structure, the investigated load components shall be verified with a statement of the mean value and the amplitudes, e.g. through specification of the Markov matrices.

4.B.3 Further evaluations

– **Maximum blade deflection:** In the case of offshore wind turbines with a horizontal axis, the maximum blade deflection in the tower direction (determined for all load cases) shall be specified for the deformation analysis. Here the deformations of all blades shall be taken into account. The decisive load case shall be specified.

– **Maximum rotational speed:** Statement of the maximum rotational speed of the rotor and generator n_{max} occurring for the entire load case simulation, and naming of the corresponding load case.

– **Braking load cases:** Graphic presentation of the time series of a braking load case with application of the mechanical brake or of the braking system bringing the turbine to standstill, in which the maximum torque occurs (rotor torque versus simulation time).

– Statement of the maximum rotor braking time that is required when the mechanical brake is applied.

– **Operation within the support structure resonance range:** If the offshore wind turbine is operated within the support structure resonance range (see Section 6.6.5.1), the corresponding evaluation and definition of the limiting values shall be submitted and explained.

– **Design loads for locking devices:** For the dimensioning of the locking devices for the blade pitching, rotor and yaw systems, the relevant loads shall be specified with consideration of the partial safety factors. This concerns the load cases DLC 8.1 and DLC 8.2.

Table 4.B.1 Recommended presentation of the calculation results of extreme loads (Fres – resulting transverse force, Mres – resulting bending moment)

Results of the extreme load evaluation											
		Load case	γ_F	**Fx**	**Fy**	**Fz**	**Fres**	**Mx**	**My**	**Mz**	**Mres**
Fx	**Max**										
	Min										
Fy	**Max**										
	Min										
Fz	**Max**										
	Min										
Fres	**Max**										
	Min										
Mx	**Max**										
	Min										
My	**Max**										
	Min										
Mz	**Max**										
	Min										
Mres	**Max**										
	Min										

Table 4.B.2 Recommended presentation of the calculation results of equivalent fatigue loads for various slope parameters of the S/N curve

Results of the fatigue load evaluation							
n_{Ref}		Fx	Fy	Fz	Mx	My	Mz
Slope parameter of the S/N curve m	$\mathbf{m_a}$						
	$\mathbf{m_b}$						
	$\mathbf{m_c}$						
	$\mathbf{m_d}$						
	$\mathbf{m_e}$						
	$\mathbf{m_f}$						
	$\mathbf{m_g}$						
	$\mathbf{m_h}$						
	$\mathbf{m_i}$						
	$\mathbf{m_j}$						

Appendix 4.C Fault in the Power System

(1) In particular, the case of a short circuit in the generator shall be investigated, since this may result in very high transient loads. A two-phase short circuit generally leads to higher maximum torques than a three-phase short circuit, so that the two-phase case is decisive. In the absence of any proven values that are more precise, the equations given below shall be applied.

(2) In the case of a two-phase short circuit in a synchronous generator, the following electromagnetic torque (M) shall be analysed:

$$M = \frac{1.3 \cdot M_n}{X''_d} \quad (4.C.1)$$

where:

M_n = rated torque

X''_d = subtransient reactance of the synchronous generator, as stated by the generator manufacturer

If X''_d is unknown, the occurrence of 10.5 times the rated torque shall be taken into account.

(3) In the event of a two-phase short circuit in an induction generator, the following electromagnetic torque (M) shall be analysed:

$$\begin{aligned} M = & - \left[M_K/(1-\sigma)\right] \cdot \cos\alpha \\ & + \left[M_K/((1-\sigma)\right] \cdot \cos\left(2\,\omega_g t - \alpha\right) \\ & - 2\left[M_K/(1-\sigma)\right] \cdot \sin\left(\omega_g\, t\right) \cdot \exp\left(-t/T_1\right) \end{aligned}$$

where:

M_K = tilting moment of the induction generator

σ = leakage coefficient

α = angle for two-phase short circuit with $\alpha = \arctan(\omega_g T_1)$

ω_g = grid angular frequency

t = time

T_1 = time constant of the stator

The values M_K, σ and T_1 shall be applied in accordance with the information supplied by the generator manufacturer. If the required values are unknown, then 8 times the rated torque shall be taken into account.

(4) For induction generators, the case of a three-phase short circuit shall also be investigated. Here the following electromagnetic torque (M) shall be analysed:

$$M = 2\, M_K \cdot \sin\left(\omega_g\, t\right) \cdot \exp\left(-2\, s_K\, \omega_g\, t\right) \quad (4.C.2)$$

where:

ω_g = grid angular frequency

M_K = tilting moment

s_K = tilting slip of the induction generator, as stated by the generator manufacturer

The maximum torque is attained when the following applies:

$$\omega_g\, t = \arctan\left(\frac{1}{2\, s_K}\right) \quad (4.C.3)$$

Appendix 4.D Design Parameters for Describing an Offshore Wind Turbine

For offshore wind turbines, at least the following design parameters shall be given in a summary included in the design documentation:

4.D.1 Turbine parameters

Rated power		[kW]
Operating wind speed range at hub height	V_{in} to V_{out}	[m/s]
Rotational speed range		[rpm]
Hub height over MSL		[m]
Rotor diameter		[D]
Design lifetime		[a]
Installation weight		[kg]
Foundation description		
Natural frequencies of main components		[Hz]

4.D.2 Wind farm parameters

Number of Turbines	
Coordinates for each turbine location	
Water depth for each turbine location	[m]
Natural frequencies for each support structure	[Hz]

4.D.3 Wind conditions

Atmospheric density	[kg/m³]
Characteristic turbulence intensity as a function of the mean wind speed	
Annual average wind speed at hub height (10-minute average)	[m/s]
Wind direction distribution (wind rose)	
Distribution function for the wind speed (Weibull, Rayleigh, measured, other)	
Wind profile model and parameters	
Turbulence model and parameters	
Extreme wind speeds V_{e50} at hub height (10-minute average)	[m/s]
Extreme wind speed V_{e1} at hub height (10-minute average)	[m/s]
Model and parameters of the extreme gust for 1- and 50-year recurrence intervals	
Maximum wind speed for maintenance	[m/s]

4.D.4 Marine conditions

Mean sea level (MSL)	[m]
Tidal ranges (LAT and HAT)	[m]
Storm surge (50 years recurrence period)	[m]
Maximum still water level (HSWL)	[m]
Minimum still water level (LSWL)	[m]
Maximum water elevation	[m]
Water density	[kg/m³]
Salinity	[%]
Significant wave height (50 year and 1 year recurrence period)	[m]
Design wave height (50 year recurrence period)	[m]
Design wave period (50 year recurrence period)	[s]
Current speed (50 year and 1 year recurrence period)	[m/s]
Wind and wave joint distribution (*Hs*,*Tp*,*V*)	
Wind and wave joint directional distribution were appropriate	
Wave spectrum and parameters	
Deterministic wave model and parameters	
Breaking wave type model and parameters (height, period)	
Sea ice conditions	
Marine growth thickness	[mm]

4.D.5 Conditions of the electrical power network

Normal supply voltage and fluctuation	[V]
Normal supply frequency and fluctuation	[Hz]
Voltage imbalance	[V]
Maximum duration of grid outages	[d]
Number of grid outages	[1/a]
Auto-reclosing cycles (description)	
Behaviour during symmetrical and asymmetrical external faults (description)	
Location where electrical conditions applicable	

4.D.6 Other environmental conditions (where necessary)

Normal and extreme atmospheric temperature ranges	[°C]
Humidity	[%]
Intensity of the solar radiation	[W/m²]
Rain, hail, snow and ice	
Normal and extreme sea temperature ranges	[°C]
Scour allowance	[m]
Scour protection (description)	
Sea bed variations	
Description of soil conditions	
Description of the lightning protection system	
Earthquake model and parameters	
Corrosion allowance	
Corrosion protection (description)	
Size of supply vessel	

4.D.7 Limiting conditions for transport and errection

Maximum wind speed	
Maximum significant wave height	
Maximum water level variation	[m]
Permitted atmospheric temperature	[Hz]

4.D.8 Deviations to Guideline parameters and models

Any deviation to guideline parameters and models shall be stated

Appendix 4.E Wind Generated and Water Depth Limited Wave Spectra

(1) In the absence of any measured or hindcast data, or if the offshore wind turbine is designed according to a wind turbine class according to Section 4.2.2.1, the wave parameters may be derived by assuming a wind generated sea state. For not fully developed sea states the JONSWAP spectrum is used. The influence of duration and fetch of the wind may be considered with:

The dimensionless duration of wind:

$$\theta = g / u \cdot \mathrm{time} \tag{4.E.1}$$

The dimensionless fetch:

$$\xi = g / u^2 \cdot x \tag{4.E.2}$$

with

g	=	acceleration of gravity
u	=	hourly mean wind speed at 10m above the sea surface
x	=	fetch
time	=	duration the storm is blowing over the sea

The dimensionless peak frequency ν may be analysed by

$$\nu = \frac{\omega_p}{2\pi} \cdot \frac{u}{g} = \max\left(0.16;\ 2.84 \cdot \xi^{-0.3};\ 16.8 \cdot \theta^{-\frac{3}{7}}\right) \tag{4.E.3}$$

The peak period is then

$$T_p = \frac{u}{g} \cdot \frac{1}{\nu} \tag{4.E.4}$$

and the significant wave height is

$$H_{s,JONSWAP,wind} = 0.0094 \cdot \nu^{-\frac{5}{3}} \cdot \frac{u^2}{g} \tag{4.E.5}$$

(2) An extension of the JONSWAP spectrum is the water depth dependent TMA spectrum. For wind generated seas and finite water depth a self-similar spectral shape (TMA-Spectrum) may be used in conjunction with the formulations shown in Section 4.2.3.1.2 para 12.

$$S_{\zeta,TMA}(\omega) = S_{\zeta,JONSWAP} \cdot \Phi_k(\omega_d) \tag{4.E.6}$$

and

$$\omega_d = \omega \sqrt{\frac{d}{g}} \tag{4.E.7}$$

where:

Φ_k	=	transformation factor
ω_d	=	depth dependent frequency
d	=	water depth

The transformation factor may be approximated using:

$$\begin{aligned} &\Phi_k(\omega_d) = 0.5 \cdot \omega_d^2 && \text{for} \quad \omega_d \le 1 \\ &\Phi_k(\omega_d) = 1 - 0.5 \cdot (2 - \omega_d)^2 && \text{for} \quad 2 > \omega_d > 1 \\ &\Phi_k(\omega_d) = 1 && \text{for} \quad \omega_d \ge 2 \end{aligned} \tag{4.E.8}$$

Appendix 4.F Directional Distribution of Waves in a Sea State

(1) The directional characteristics are often assumed to be independent of frequency, allowing a separation of variables so that the directional wave spectrum can be expressed as the product of a wave directional spreading function, independent of frequency, and a wave frequency spectrum, which is independent of direction. The directional distribution of the waves in a given sea state is considered by:

$$S_{\zeta}(\omega,\mu_e) = S_{\zeta}(\omega)\cdot G(\mu_e) \qquad (4.F.1)$$

where:

$G(\mu_e)$ = directional distribution function

μ_e = wave direction in respect to mean

and

$$\int_{-\pi/2}^{\pi/2} G(\mu_e)\, d\mu_e = 1. \qquad (4.F.2)$$

(2) Parametric forms for the wave directional spreading function are given in the literature. Often the function has the form:

$$G_1(\mu_e) = k_n \cdot \cos^n(\mu_e) \qquad \text{for} \qquad -\frac{\pi}{2} \le \mu_e \le \frac{\pi}{2}$$

$$G_1(\mu_e) = 0 \qquad \text{else.} \qquad (4.F.3)$$

The factor k_n takes values to comply with the boundary condition i.e. $k_2 = 2/\pi$ *or* $k_4 = 8/(3\pi)$.

$$k_n = \frac{\Gamma(n/2+1)}{\sqrt{\pi\,\Gamma(n/2+1/2)}} \qquad (4.F.4)$$

The value for n to be used for wind seas is given with 2 or 4 while for swell seas a value of 6 should be used.

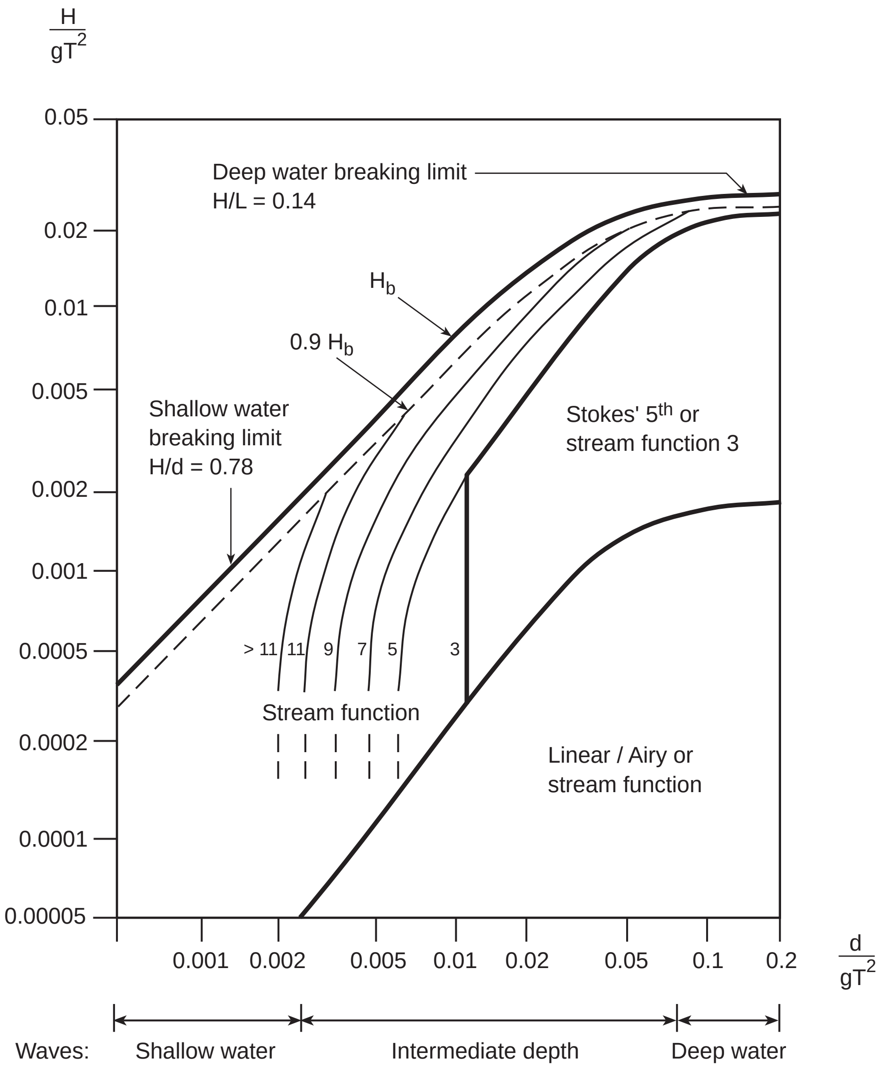
(3) Alternative methods may be used in consultation with GL Wind.

Appendix 4.G Computation of Wave Kinematics

4.G.1 General

(1) The prediction of the derived wave parameters are e. g. wave particle velocities and accelerations (wave particle kinematics) may be performed by the application of several theories. All of them consider two-dimensional wave kinematics for a wave which is symmetric about the crest, propagates with constant speed and its shape does not change in time. The theories differ in their functional formulation and in the degree to which they satisfy the non-linear kinematic and dynamic boundary conditions at the wave surface.

(2) Linear (Airy) wave theory is applicable to define these parameters for deep water and transitional water waves, if the limitations for $H/(gT^2)$ and $d/(gT^2)$ as shown in Figure 4.G.1 are observed. Higher order wave theories have to be applied to derive wave particle velocities and accelerations for high waves or for waves in shallow water and breaking waves.



The boundaries given are approximate and depend on the purpose of the analysis being performed. It is accepted that refraction and diffraction analysis will usually be based on linear theory.

Fig. 4.G.1 Wave selection diagram

(3) Linear (Airy) theory should be used only in the indicated range.

(4) In absence of non linear methods i.e. for hydrodynamically compact structures, the estimation of the incident wave potential may be based on linear (Airy) wave theory outside the area of application shown in Figure 4.E.1.

(5) The natural sea state is usually modelled by superposition of elementary waves with phase angles between 0 and 2π. The wave kinematics are calculated using linear wave theory by summing up the kinematics of the individual waves. Since linear theory is defined only up to still water line, the wave kinematics have to be stretched to consider the influence of the actual sea surface.

(6) For waves approaching the breaking wave limit Stream Function theory is recommended. A convergence check should be performed to ensure that the overall solution has converged. The shape of the wave should be checked, since multiple crest solutions may occur sometimes.

4.G.2 Linear wave theory

(1) A complex reference water particle velocity for deep water waves is defined at any time t as

$$u_R = 0.5 H_D \cdot \omega_D \cdot \exp\{i \cdot (\omega_D t - \kappa_D \xi)\} \qquad (4.G.1)$$

where:

ω_D = $2\pi/T_D$

κ_D = ω^2/g

ξ = $x \cdot \cos\mu + y \cdot \sin\mu$

i = $\sqrt{-1}$.

(Using a right hand co-ordinate system x-y-z with x-y-axes lying in the undisturbed sea surface and the z-axis directed vertically upwards.)

The waves propagate along the horizontal ξ-axis, μ being the angle between x- and and ξ-directions.

(2) The complex design velocity vector $\underline{u}_D$ at any point x,y,z under the sea surface for deep waters may thus be estimated from either the real or imaginary part of

$$\underline{u}_D = (u_{Dx}, u_{Dy}, u_{Dz}) = (i\cos\mu, i\sin\mu, -1) \cdot u_R \cdot \exp\{\kappa_D \cdot z\} \qquad (4.G.2)$$

In this way components $u_{Dx/y/z}$ are calculated in a phase correct manner, i. e. real (Re) and imaginary (Im) parts occur with a time lag (phase shift) of $T_D/4$, the real part leading the wave crest by t = T/4. Maximum velocities (amplitudes) during one wave cycle may be obtained from

$$u_{D\max} = \sqrt{[\mathrm{Re}(u_D)]^2 + [\mathrm{Im}(u_D)]^2} \qquad (4.G.3)$$

where u_D component refers to either x or y or z directions, respectively.

(3) The reference velocity u_R may be used to define a transitional water (intermediate depth) wave reference velocity u_{Rs} as follows

$$u_{Rs} = u_R(\kappa_{Ds}) / \sinh\{\kappa_{Ds} \cdot d\}, \qquad (4.G.4)$$

with water depth d, and κ_{Ds} being the solution of the dispersion equation

$$\kappa_{Ds} \cdot |\tanh\{\kappa_{Ds} \cdot d\}| = \omega^2 / g . \qquad (4.G.5)$$

The iterative solution of the wave number κ_{Ds} may need several iterations to converge. A first approximation may be derived by:

$$(\kappa_{Ds} \cdot d)^2 = x_k^4 + \frac{x_k^2}{1 + \sum_{i=1}^{6} f_i \cdot x_k^{2i}}; \qquad (4.G.6)$$

$$x_k = \omega \cdot d / \sqrt{g\,d} \qquad (4.G.7)$$

with:

$f_1 = 0.6$
$f_2 = 0.35$
$f_3 = 0.1608$
$f_4 = 0.0632098765$
$f_5 = 0.0217540484$
$f_6 = 0.0065407983$

(4) The design transitional water velocity vector u_{Ds} at any point (x, y, z) under sea surface may thus be estimated from

$$\underline{u}_{Ds} = (u_{Dsx}, u_{Dsy}, u_{Dsz}) = (i\cosh\xi \cdot \cos\mu, i\cosh\xi \cdot \sin\mu, -\sin\xi) \cdot u_{Rs} \qquad (4.G.8)$$

with $\xi = \kappa_{Ds} \cdot (z + d)$.

The maximum values (amplitudes) $u_{Dsx/y/z\,max}$ may be obtained analogously to $u_{D\,max}$.

(5) Water particle acceleration:

With the definitions given in the vector of water particle acceleration in deep or transitional water, $\underline{a}_D$ or $\underline{a}_{Ds}$, may be estimated from:

$$\underline{a}_D = i\omega_D \cdot \underline{u}_D, \underline{a}_{Ds} = i\omega_D \cdot \underline{u}_{Ds} \tag{4.G.9}$$

Components $a_{Dx/y/z\ max}$ or $a_{Dsx/y/z\ max}$ are calculated analogously to $u_{Dx/y/z\ max}$.

Appendix 4.H Estimation of Design Wave Loads for Rigidly Positioned Structures

4.H.1 Hydrodynamically transparent structures

(1) This method requires separate calculation of local wave loads on all structural elements subject to wave loading. Vectorial superposition of local wave loads in a phase correct manner defines global wave loads on the structure. Global design wave loads are defined *as* $F_D = (F_{D1}, F_{D2}, ..., F_{D6})$. Index i = 1, 2 and 3 is used for load components in direction of the x-y-z-coordinate system defined in Appendix 4.A, and index i = 4, 5 and 6 for the related moments (normally taken about the sea bed).

(2) A local component F_{Dk} of the design wave load on a structural element "k" of volume V_k, with area A_{ki} perpendicular to the considered "ith" wave particle velocity component and with the corresponding hydrodynamic drag coefficient C_D and a coefficient of inertia C_M, may be estimated from the Morison equation:

$$\underline{F}_{Dki} = C_D \cdot \rho_w / 2 \cdot |\underline{u}_D| \cdot \underline{u}_D \cdot A_{ki} + C_M \cdot \rho_w \cdot \underline{a}_D \cdot V_{ki} \qquad (4.H.1)$$

where index i and k for the parameters on the right hand side of this formula have been omitted only for convenience. It has to be stated that the six components of $\underline{F}_{Dki}$ are complex numbers (compare definition of the parameters $\underline{q}$ below). Thus vectorial superposition of all local wave loads in a phase correct manner to obtain $\underline{F}_D$ can be ascertained using either the real (Re) or imaginary (Im) part of its components $\underline{F}_{Dki}$.

(3) The first term on the right hand side of the formula for $\underline{F}_{DKi}$ is called drag term,

where:

ρ_w = water density

$\underline{u}_D$ = the design water particle velocity directed perpendicular to A

A = the projected (leeway) area of the structural element

and $\underline{u}_D$ as defined by its three components $u_{Dx/y/z}$ at the coordinates (x, y, z) of element "k", yielding a complex drag term of the design wave load, which may be linearised.

In the case the structure is moving the relative velocity $u_r = u_D - \dot{x}_k$ with $\dot{x}_k$ the member velocity perpendicular to A may be used.

(4) The second term on the right hand side of the formula for $\underline{F}_{Dki}$ is called inertia term with

$\underline{a}_D$ = the water particle acceleration at the coordinates (x, y, z) of element "k", yielding a complex inertia term of the design wave load

V = volume of the member

In the case of a moving structure the Morison equation has to be extended by the force of the added mass moving with the member under consideration:

$$\underline{F}_{Dki} = C_D \cdot \rho_w / 2 \cdot |\underline{u}_r| \cdot \underline{u}_r \cdot A_{ki} + C_M \cdot \rho_w \cdot \underline{a}_D \cdot V_{ki} - (C_M - 1) \cdot \rho_w \cdot \ddot{x}_k \cdot V_{ki} \qquad (4.H.2)$$

(5) A design wave load per unit length of a cylindrical element with circular cross section may be estimated from F_{Dki} as defined with

$$A = D$$
$$V = \pi D^2 / 4$$

where D is the diameter of the circular element at a location "k".

(6) For cylindrical elements of arbitrary cross sections the above formula may be used with D, the projected width of the cylindrical element perpendicular to $\underline{u}_D$ or $\underline{a}_D$ at a location "k".

(7) The values for the hydrodynamic coefficients C_D and C_M depend largely from the flow conditions around the structure, the structure shape and the surface roughness. The values to be used may be extracted from literature and/or model tests and have to be approved by GL Wind. The main parameters governing the coefficients (cylindrical members) are:

Reynolds number $$Re = u_{D\,max} \cdot \frac{D}{\nu} \qquad (4.H.3)$$

Relative surface roughness $$e = \frac{k}{D} \qquad (4.H.4)$$

Keulegan-Carpenter number $$K = u_{D\,max} \cdot \frac{T}{D} \qquad (4.H.5)$$

where:

Table 4.H.1 Indicative hydrodynamic coefficients for cylindrical members

Reynolds number	smooth cylinder		rough cylinder	
	C_D	C_M	C_D	C_M
$\leq 2 \cdot 10^5$	1.2	2.0	1.2	2.0
$> 2 \cdot 10^5$	0.7	1.6	1.1	2.0

$u_{D\max}$ = maximum velocity including current perpendicular to the member

D = cylinder diameter

ν = kinematic viscosity of water, depending on sea water temperature and salinity $\approx 1.2 \cdot 10^{-6}\ m^2/s$

k = average thickness of the "hard" marine growth

T = wave period

(8) For cylindrical members of length significantly larger than the diameter, some indicative values are given in the Table 4.H.1.

(9) Corrections due to marine fouling and current influence have to be made, as applicable. Specially for Keulegan-Carpenter numbers between 8 and 30 the C_D value may have to be multiplied with a factor up to 1.5 for rough cylinders. The inertia (added mass) coefficient C_M is mainly a function of the roughness and the Keulegan-Carpenter number. Additionally if attached appurtenances are not modelled their influence shall be included in the determination of the hydrodynamic coefficients and if appropriate a wake shielding factor applied. Some guidance is given in Draft ISO 19902 and API "Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms - Working Stress Design" API RP 2A-WSD, 2000 [4.9].

(10) C_D and C_M values for more complicated structural elements shall be provided by competent institutions. These values are to be agreed upon with GL Wind.

4.H.2 Hydrodynamically compact structures

(1) This method requires calculation of design wave pressures on the underwater surface of the structure, which may be estimated from the superposition of incident and diffraction wave potentials Φ_O and Φ_7 as

$$\Phi = \Phi_0 + \Phi_7 \tag{4.H.6}$$

$$p_{D,inst} = -\rho_w \frac{\partial \Phi}{\partial t} \tag{4.H.7}$$

where

ρ_w = water density,

Φ_0 = incident wave potential

Φ_7 = diffraction wave potential

(2) In cases including significant motion of the structure the potential of the flow due to the movement of the body (radiation) shall be added.

(3) Integration of pressures over the underwater surface of the entire structure yield the global wave loads $\underline{F}_D = (F_{D1}, F_{D2}, ..., F_{D6})$. Index i = 1, 2 and 3 is used for load components in direction of the x-y-z-coordinate system defined in Appendix 4.A, and index i = 4, 5 and 6 for the related moments (normally taken about the sea bed).

(4) Integration over underwater surfaces of specific elements "k" of the structure yields local wave loads $\underline{F}_{Dk}$. Thus, the six components F_{Di} of $\underline{F}_D$ or F_{Dki} of $\underline{F}_{Dk}$ are complex numbers.

(5) Estimation of the incident wave potential Φ_{OD} may be based on linear (Airy) wave theory, where only the structure's surface under the still water line is to be considered.

(6) Using a right hand co-ordinate system x-y-z with x-y-axes lying in the undisturbed sea surface and the z-axis directed vertically upward, the waves propagate along the horizontal ξ-axis, μ being the angle between x- and and ξ-directions the design incident wave potential for transitional water waves may be estimated from:

$$\Phi_O = -\frac{1}{2} H_D \cdot \frac{\omega_D}{\kappa_D} \cdot \frac{\cosh\{\kappa_{Ds}(z+d)\}}{\sinh(\kappa_{Ds}\, d)} \cdot \exp\{-\kappa_D\, z\} \cdot \exp\{i(\omega_D\, t - \kappa_D\, \xi)\} \tag{4.H.8}$$

where:

ω_D = $2\pi/T_D$

ξ = $x \cdot \cos\mu + y \cdot \sin\mu$

i = $\sqrt{-1}$.

d = water depth

and

$$\kappa_{Ds} \cdot \left| \tanh\left\{\kappa_{Ds} \cdot d\right\}\right| = \omega^2 / g . \quad (4.H.9)$$

(7) The design diffraction wave potential Φ_7 may be estimated satisfying the boundary condition

$$\partial\Phi_0 / \partial n = -\partial\Phi_7 / \partial n \quad (4.H.10)$$

at a sufficiently large number of points on the structure's underwater surface, where n indicates a direction into the fluid and normal to the structure's surface at these points. Details can be found in related text books. Computer programs based on this or a compatible procedure may be applied upon agreement with GL Wind.

(8) The force acting on the structure in direction i is then

$$\begin{aligned} F_{Di} &= -\iint_{S_0} p_{inst}\, n_i\, dS \\ &= -i\,\omega_D\,\rho_w \cdot \exp\left\{-i\,\omega_D\, t\right\} \\ &\quad \cdot \iint_{S_0} \left(\Phi_0 + \Phi_7\right) n_i\, dS \end{aligned} \quad (4.H.11)$$

Appendix 4.I Breaking Wave Loading on Piles

(1) Wave breaking, especially plunging breakers, may induce very high impact forces on a slender structure. A detailed analysis of the breaking wave forces is difficult, since the duration of these impact forces is extremely short.

(2) Due to the short duration, the impact force F_I must be included into the Morison equation as an additional part:

$$F_{wave\_break} = F_D + F_M + F_I \qquad (4.I.1)$$

where:

F_D = drag term of the wave force, see Appendix 4.H

F_M = inertia term of the wave force, see Appendix 4.H

F_I = impact term of the breaking wave force.

(3) The drag and inertia force varies in time in accordance to the water surface elevation associated with the wave cycle and may be analysed using a higher order wave theory.

(4) The impact force can be calculated according to J. Wienke, "Druckschlagbelastung auf schlanke zylindrische Bauwerke durch brechende Wellen – theoretische und großmaßstäbliche Laboruntersuchungen" Thesis, TU Braunschweig, http://www.biblio.tu-bs.de (in German) [4.10].

(5) The impact description is based on the following distinctive features:

– Velocity of hitting mass of water (breaker tongue) is equal to wave celerity (valid for plungers).

– Impact starts with first contact between cylinder and impinging mass of water and is completed when the front side of the cylinder is immersed and the immersed width is equal to the radius of the cylinder.

– Deformation of the free water surface during immersion process of a slender cylinder (pile-up effect) reduces duration of impact. Since the mass of water is deflected around the surface of the cylinder, the immersion process is accelerated and the maximum line force is enlarged.

– Impact takes place simultaneously at different levels of the cylinder due to deformation of free water surface.

– Maximum impact force ensues from wave breaking immediately in front of the cylinder.

– At the beginning of the impact very high pressures occur at the front line of the cylinder but only for a very short instant.

(6) Considering a cylinder in a breaking wave environment the impact area may be defined:

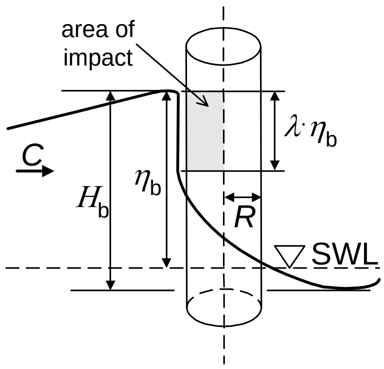


Fig. 4.I.1 Main breaking wave and cylinder parameters

where:

C = wave celerity

H_b = wave height at breaking location (see Section 4.2.3.1.5)

η_b = maximum elevation of the free water surface (see Section 4.2.3.3)

R = radius of the cylinder

λ = curling factor, maximum value is 0.5 for plunging breakers

The impact force may be calculated as:

$$F_I = \lambda \cdot \eta_b \cdot \rho_{water} \cdot R \cdot C^2 \cdot \cos^2\gamma \cdot \left(2 \cdot \pi - 2 \cdot \sqrt{\frac{C \cdot \cos\gamma}{R} \cdot t} \cdot \text{Artanh}\sqrt{1 - \frac{1}{4} \cdot \frac{C \cdot \cos\gamma}{R} \cdot t} \right)$$

$$\text{for } 0 \le t \le \frac{1}{8} \cdot \frac{R}{C \cdot \cos\gamma} \qquad (4.I.2)$$

and

$$F_I = \lambda \cdot \eta_b \cdot \rho_{water} \cdot R \cdot C^2 \cdot \cos^2$$
$$\cdot \left(\pi \cdot \sqrt{\frac{1}{6} \cdot \frac{1}{\frac{C \cdot \cos\gamma}{R} \cdot t'}} - \sqrt[4]{\frac{8}{3} \cdot \frac{C \cdot \cos\gamma}{R} \cdot t'} \right.$$
$$\left. \cdot \operatorname{Artanh} \sqrt{1 - \frac{C \cdot \cos\gamma}{R} \cdot t' \cdot \sqrt{6 \cdot \frac{C \cdot \cos\gamma}{R} \cdot t'}} \right)$$

for $\frac{3}{32} \cdot \frac{R}{C \cdot \cos\gamma} \le t' \le \frac{12}{32} \cdot \frac{R}{C \cdot \cos\gamma}$ (4.I.3)

with $t' = t - \frac{1}{32} \cdot \frac{R}{C \cdot \cos\gamma}$

The total duration T of the impact is given by:

$$T = \frac{13}{32} \cdot \frac{R}{C \cdot \cos\gamma} \qquad (4.I.4)$$

where:

γ = angle between direction of the motion of the mass of water and the perpendicular to the cylinder's axis

$\cos\gamma = 1$ for wave breaking at the vertical cylinder and

$\cos\gamma < 1$ for over curling breaker tongue hitting the vertical cylinder or wave breaking at an inclined cylinder

Note:

Curling factor λ increases with the cylinder's inclination against wave direction.

The maximum impact force occurs for a yaw angle of approximately 25° against wave direction.

(7) The above described time history of the impact force is plotted in the following figure:

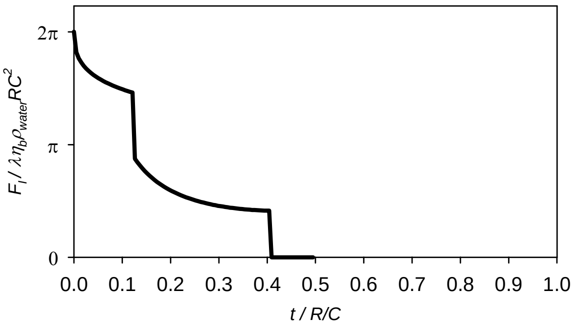


Fig. 4.I.2 **Time history of the impact force at the vertical cylinder (γ = 0°)**

(8) The maximum line force at the beginning of the impact is distributed along the height of the cylinder as shown in the following plot:

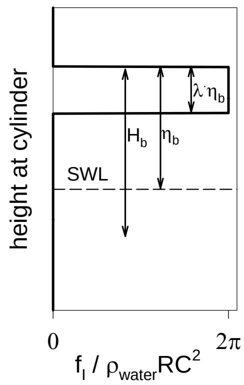


Fig. 4.I.3 **Distribution along the height of the maximum impact line force (γ = 0°)**

Appendix 4.J Combination of Wind and Wave Distributions

(1) In the following a method is given allowing an approximation of the long term distributions of wind and waves by pairs of derived combinations of u_{10}, Tp and H_S.

(2) A correlation between the sea state parameters and the wind speed can be given with the equations for the full developed JONSWAP spectrum according to the equations given in Appendix 4.E for the peak period,

$$T_p = \frac{u_{10}}{g} \cdot \frac{1}{0.16} \tag{4.J.1}$$

and the significant wave height

$$H_s = 0.0094 \cdot 0.16^{-\frac{5}{3}} \cdot \frac{u_{10}{}^2}{g} \tag{4.J.2}$$

with u_{10} the hourly mean wind speed at 10m above the sea surface.

(3) If the standard equations for wind driven seas according to the JONSWAP-spectrum are used on the wave scatter diagram data different wind speeds u_{Hs} and u_{Tp} can be obtained for most points of the matrix, since the equation for the significant wave height will result in a different wind speed u_{Hs} than the equation for zero crossing period will result in a wind speed u_{Tp}.

(4) A relation between wind speed distribution and wave distribution may be derived by using an artificial wind speed u_a defined in the following as

$$u_a = \alpha \cdot u_{Hs} + (1-\alpha) u_{Tp} \tag{4.J.3}$$

with the same assumption for the probability density function of

$$p_a(u_a) = \alpha \cdot p_{Hs}(u_{Hs}) + (1-\alpha)\, p_{Tp}(u_{Tp}) \tag{4.J.4}$$

(5) Minimising the error of this distribution for the given wind distribution at the offshore site

$$\int_0^\infty (p_a(u) - p(u))^2 \, du \longrightarrow Min \tag{4.J.5}$$

it will result in a solution for the parameter α and therefore in the information of the mean wind speed to be applied for the given set of sea state parameter.

Rules and Guidelines

IV *Industrial Services*

2 Guideline for the Certification of Offshore Wind Turbines

5 Strength Analyses

Germanischer Lloyd
WindEnergie

Edition 2005

Table of Contents

5.1 General

(1) Components of an offhsore wind turbine shall be subjected to verification of their Ultimate Limit State (ULS) and Serviceability Limit State (SLS) (as per Section 1.3.2.2). For this, the design loads (see Section 1.3.2.3) for the load cases determined according to Chapter 4 shall be applied.

(2) By strength is meant the resistance to loading of a component. It shall be verified in accordance with this section (see also the corresponding sections in Chapter 6). The strength depends on the material, on the shape of the loaded structure and on the type of loading (tension, compression, shear, bending, torsion).

(3) As a rule, analyses shall be performed by calculation. However, for fatigue analysis, component tests under simulated operating conditions are also permitted.

(4) Dynamic loading, such as resonance effects or impact forces, affecting the strain and stress levels of the offshore wind turbine to an extent which cannot be disregarded, shall be accounted for in a suitable manner (see also Sections 6.6 and 7.1).

(5) Local plastic deformation can adversely affect the functionality of a component. Both its function and that of the adjacent components shall be verified (e.g. bearings, gear box housings). The analyses to be made with regard to the limiting of deformation are described in detail in the relevant sections (e.g. Section 5.3.3 or 7.1).

(6) In addition to the guidelines listed below, further requirements for the analyses of the structures (rotor blades, forged, cast, welded structures, housings, tower and foundation, and bolted connections) and the special machinery components (e.g. gearbox, yaw systems, brakes, bearings, couplings and hydraulics), as given in Chapters 6 and 7, shall be observed.

5.2 Determination of the Stresses

5.2.1 General notes on the loading of the structure

(1) For the strength analyses, selected loading conditions which are decisive for the structural areas being analysed are considered as a rule. For assessments of fatigue strength, loading conditions which generate dynamic cyclic stresses at the critical regions shall be considered. The design situations (i.e. operating conditions) and design load cases are given in Section 4.3.3.

(2) Loads and loading conditions shall generally be treated in accordance with Chapter 4. More specific or especially adapted load criteria/values shall be well documented and agreed upon. The load cases and combinations to be considered in the design calculations shall cover the most unfavourable conditions likely to occur.

(3) Non-linearities in the load components shall, if relevant, be taken into account. For this, it shall be observed that the linear superposition principle does not apply here. In certain cases, forces which only arise for particular deformations (for example through the contact of structural areas) can be analysed in the form of additional load cases and superposed with consideration of the non-linear structural behaviour (e.g. radial compressive loads at the bearings).

(4) As an alternative to the approach using general strength analyses with selected load cases, special methods particularly suited to the complete consideration of the movements and loads (so-called time-series calculations) can be used.

(5) In calculations with time series, the loading or stressing process shall be generated from the characteristic data of the design load cases (cf. Section 4.3.3). The time series and the statistical frequencies for the structural analysis shall be chosen in accordance with Chapter 4. The validity of selected simplifications for the computational objective shall be documented in a plausible manner.

(6) Loading conditions occurring during construction, transport or sea installation have to be considered in the design, see also Section 6.1.5 and Sections 10.1 and 10.2.

5.2.2 Method of analysis

5.2.2.1 General

(1) Strength/stress analysis may be carried through according to recognized methods and standards (cf. Section 5.2.2.2). However, it shall be ascertained in every case that the design fundamentals and standards used are consistent and compatible for one structure or installation, regarding the considerations listed in Section 1.3.

(2) In general, the stress calculation may be carried out using conventional static theory. Where the decisive stresses cannot be established sufficiently accurately using these methods, calculations using numerical procedures (e.g. finite element method) shall be made.

(3) The calculation procedures shall ensure the state of equilibrium.

(4) The state of equilibrium can often be analyzed on the basis of the non-deformed structure (first order, linear theory).

(5) Non-linearities of the geometry (e. g. second order theory) and of the material (e. g. state II, i. e. cracked tension area in the case of concrete structures) shall be taken into account if they adversely influence the overall stability of the structure or the ultimate limit state. For that reason the inclination and deformations of the complete system (tower, foundation, ground) shall if applicable in general be taken into consideration when determining the section forces.

(6) For the strength analyses, the effects resulting from loads acting on the components are usually determined as the stresses. At the failure-critical region, the nominal stress or the structural stress shall be determined according to the currently accepted rules of technology, as reflected in the applicable standards and codes. The selection of the failure-critical regions shall be documented.

(7) Structural redundancy shall be considered at an early stage. As redundancy is not explicitly taken into account in the design methods currently in use, with the exception of the grouping of categories of structural elements (special, primary, secondary - see Section 3.3.2.2), the consequence of a failure will have to be specifically considered.

(8) Where structures are not or cannot be suitably designed to resist wave impact, the latter shall be avoided, see Section 4.3.2.3.4.

(9) The use of modifications to the analysis procedures listed in the following shall be agreed with GL Wind. Here it shall be ensured that a consistent analysis concept is applied.

(10) Further recommendations regarding the definition of objective, type and scope of a strength analysis as well as calculation and details on evaluation and documentation are also given in Appendix 5.A "Strength Analyses with the Finite Element Method".

5.2.2.2 Design methods and criteria

5.2.2.2.1 Choice of design concept/methods

(1) Structural strength calculations may generally be based on linear elastic theory. However, non-linear relations between loads and load effects shall be properly accounted for, where they are found to be important. Where plastic design is applied, the limitations described in Section 5.2.2.2.5 are to be observed.

(2) Influences that are based on the type of load, the geometry or the material shall be considered in the strength analyses. This also applies for non-linear influences of

– the loading (e.g. solely compressive loading for roller or sliding bearings), or
– the geometry (second order, linear theory; consideration of large deformations), or
– the material (plasticity theory and yield hinge theory).

5.2.2.2.2 Design criteria, limit states

(1) A structure may become unsafe or unfit for use by damages or other changes of state according to different criteria. They may be defined by "Limit States", i. e. states of loading, straining (deformation) or other impairment, at which a structure, or structural component, looses its planned operability or function (see Section 1.3.2.2).

(2) Corrosion may lead to exceeding either an ultimate or a serviceability limit state. Corrosion allowances (see Section 3.5.4) have to be considered in a conservative manner.

5.2.2.2.3 Nominal stress approach

(1) The nominal stress is the stress determined by means of the elementary theories of linear elastic mechanics. Stress components from the notch effect are not included. They shall be considered through stress concentration factors (SCFs) and fatigue notch factors referred to the nominal stresses.

(2) The nominal stress concept is limited to slender bars and beams and to such structures which can be idealized with a close approximation as component details having a strip, bar or beam shape.

(3) In the case of fatigue analysis of non-welded components, S/N curves containing the detail catetgories or geometrical discontinuities to be considered shall be used. If in welded components there is a geometric discontinuity not covered by the selected allocation of the detail category to the design details, the nominal stress shall be modified (see e.g. [5.1], [5.2], [5.5]).

(4) In the case of combined types of stresses, Sections 5.3.4.2.4 and 5.3.4.3 shall be observed.

5.2.2.2.4 Structural stress approach

(1) Structural stress is understood as the stress which completely describes a stress condition. It includes effects from complex component shapes (spatially curved structures) and from design-related notches (e.g. grooves, steps, drill-holes) and local influences at load introduction. In welded structures, the structural stress is known as the "hot-spot stress" (see also [5.5] and Appendix 5.A). The term indicates that this structural geometric stress includes the influence of the nominal stress and local effects, but not the notch effect of the weld seam itself. The determination of structural stresses usually necessitates calculation with numerical methods.

(2) In the case of fatigue analyses, material dependent S/N curves shall be used for non-welded components if the structural stress includes all local influences of the notch effect.

(3) Depending on the degree of discretization, it is necessary in the numerical calculations to consider a part of the notch effect which is not included in the structural stress, by reduction of the S/N curves.

(4) For welded joints, the hot-spot stresses (geometric stresses) are decisive in the fatigue analysis.

(5) In the case of combined types of stresses, Sections 5.3.4.2.4 and 5.3.4.3 shall be observed.

5.2.2.2.5 Plastic design

(1) A design utilising additional plastification resistance may be accepted provided the following conditions are met:

– It shall be possible to establish failure mechanisms with well-defined “hinges”. At plastic hinge locations, the cross-section of the members shall have sufficient rotational capacity to enable the required plastic hinge to develop without local buckling.

– The material employed at the points of possible plastic deformations shall be sufficiently ductile.

– The detail design and/or the nature of the loads shall be such that fatigue is prevented.

(2) Plastic design may be suitable e. g. for structures intended for collision protection, and earthquake design.

(3) In case plastification has been considered during seismic analysis, visual inspection of the structure shall be performed after major earthquake events.

(4) Plastic analysis of concrete structures should be limited to discontinuity regions and cases stated in para 2.

(5) When plastic design is applied, the safety factor γ_M has to be increased by a factor of 1.15.

5.2.2.2.6 Modelling of the structure

(1) The analysis model (“idealization”) used has to take account of all main load bearing and stiffening components, and of the relevant supporting and constraining effect. The degree of subdivision (detailing) shall take account of the geometry of the structure and its influence on the load distribution and introduction, of the distribution of external loads, and of the expected stress pattern. Elements or members considered as being of “secondary” importance may nevertheless have to be accounted for where they have an influence on stress distribution or dynamical properties of the structure.

(2) Where modelling is made by means of beam elements, the actual rigidities are to be accounted for as precisely as practicable, particularly in way of connections (joints). The effective width of associated plating should be chosen according to accepted standards (see also Section 6.2.2.).

5.2.2.2.7 Superposition of load effect components

Stresses or other load effects resulting from relevant global and local effects shall be added according to their degree of simultaneousness (see also Section 4.3.3.). Stresses of different type (e. g. tension, shear) and different direction shall be combined according to recognized criteria (e.g. equivalent stress, v. Mises).

5.3 Metallic Materials

5.3.1 Application

(1) The observations which follow refer to metal structures in general. Extended requirements are contained in Chapters 6 and 7 (e.g. requirements for verification of the ultimate and serviceability limit states of the support structure and foundation in Sections 6.6 and 6.7).

(2) The fatigue analysis of steel support structures shall comply with the requirements given in Section 6.6.6 while Section 5.3.4 refers to fatigue analysis of the machinery (topsides structure).

5.3.2 Material properties

(1) Requirements, analyses and certificates for the materials of machinery components are treated in Chapter 3. Additional information is given in the following sections of this chapter.

(2) The material parameters required for the computational analysis of steel structures can for instance be found in Eurocode 3, Part 1.9 [5.1], or in DIN 18800, Part 1.

5.3.3 General strength analysis

5.3.3.1 General

(1) The general strength analysis shall be carried out on the basis of German or equivalent international codes.

(2) Machinery components whose dimensioning is not covered by standard codes shall be designed and analysed according to the currently accepted rules of technology. For the dimensioning of bolted connections, the requirements set out in Section 6.5 shall be observed.

(3) The components shall be dimensioned with the design loads (see Section 1.3.2.3) with regard to the corresponding design strength (see Section 1.3.2.4).

(4) The partial material safety factor γ_M to be used as a basis for metallic components of all load case groups is

$$\gamma_M = 1.1$$

(5) The support structure and the foundation shall be treated according to the uniform concept of partial safety factors for design loads (see Sections 6.6.1 and 6.7).

5.3.3.2 Method of analysis

(1) When performing the analysis, the general points of Section 5.2.2 shall be observed.

(2) The dimensioning of a structure or component depends primarily on the type of possible failure. If two or more types of loading occur simultaneously, then combined stresses result. As a rule, the ultimate limit state verifications shall be carried out with regard to the material and loading, using the following equivalent stress hypotheses (see Section 5.3.4.3).

(3) For brittle materials, the behaviour of the material is described by the maximum principal stress hypothesis. In the case of semiductile materials, either the maximum principal stress hypothesis or the von Mises hypothesis (Maximum shear strain energy criterion; octahedral shear stress hypothesis) can be applied.

(4) For ductile materials, the von Mises or the maximum shear stress hypothesis describes the failure mechanism. Later hypotheses, such as the shear stress intensity hypothesis for ductile materials can be used as an alternative, if their usefulness is proven by convincing component tests.

(5) Minor local plastification is usually permissible for components made of ductile and semiductile materials. If, for structures consisting of such materials, the local stress values are lying above the elastic limit (start of yielding), it shall be observed that the local stress distribution and thus the local strains have to be considered for assessment of the static component strength. Here it must be taken into account that the local stress and strain distribution depends both on the component shape (e.g. notch) and on the type of load (tension/compression, bending, torsion). The permissible strain is dependent on the material. In addition, the permissible strain depends on the function of the structure, so that, in the case of permanent elongation, proof of operativeness shall be given for the component and its adjacent components. The procedure shall be defined in consultation with GL Wind.

5.3.4 Fatigue analysis

5.3.4.1 General

(1) For the predominantly dynamically loaded metallic components of offshore wind turbines, a fatigue analysis shall be carried out. As a rule, this applies to the drive-train components from the blade connection to the generator, the main frame including its connection to the tower, the support structure, the connecting elements plus other turbine-specific components (e.g. blade pitch mechanism).

(2) The fatigue analysis may be effected by component testing or by computational analyses. Component tests shall be carried out with loads relevant to operation and using Chapter 4 as a basis. Evaluation of the test results shall be such that the effects of those influences which cannot be taken into consideration directly (large number of load cycles > 10^9, scattering of the test results etc.) are reliably covered; cf. [5.2]).

(3) The analysis of adequate fatigue strength, i.e. the resistance against crack initiation under dynamic operational loads, serves the assessment and reduction of the crack initiation probability of components within the scope of the structural design. Owing to incalculabilities in the loading process, involving material- and production-related variances and ageing effects, crack initiation in later operation cannot completely be ruled out, necessitating measures such as periodical inspections.

(4) The technical initation of the crack shall be taken as a general failure criterion, i.e. a crack that is detectable on site with the usual non-destructive inspection methods [5.3].

(5) In special cases, the remaining lifetime of an initiated crack that is growing steadily may, in consultation with GL Wind, be used for limited continued operation of an offshore wind turbine. For this, the remaining lifetime shall be verified with suitable and recognized analysis methods. In addition, periodical inspections at appropriate intervals shall be laid down in consultation with GL Wind.

5.3.4.2 Methods for fatigue analysis

5.3.4.2.1 General

(1) Depending on the required computational accuracy, fatigue analysis by calculation may be performed with the aid of one of the following three procedures:

– by using stress-time series and damage accumulation to register the complex interaction between the external loadings and the structural responses as accurately as possible, or

– by using stress spectra and damage accumulation, whereby the superposition of the various load effects is included to adverse effect but with physical meaningfulness, or

– with equivalent constant-range spectra as a simplified form of the fatigue analysis. Here the equivalent constant-range spectra shall be used in accordance with Section 5.3.4.2.2 and documented accordingly.

(2) For the second and third methods, the influence of the mean stress shall be considered conservatively for materials which are sensitive to mean stress.

5.3.4.2.2 Simplified fatigue analysis

(1) For the simplified fatigue analysis, which is generally applied when considering safety margins (e.g. comparison of plant variants with different rotor diameters), equivalent constant-range spectra can be used. The elaboration of equivalent constant-range spectra on the basis of the Palmgren/Miner method will hereunder be assumed to be known. Explanations on this method can be taken from e.g. [5.2].

(2) When generating the equivalent constant-range spectrum, the slope parameter of the S/N curve corresponding to the structure shall be used. The decisive slope parameter of the design S/N curve is given in Section 5.3.4.4.

(3) In this and the other analysis approaches, the partial safety factor γ_M shall be applied in relation to the criteria given in Table 5.3.1.

(4) For the stress superposition in the case of multiaxial stress conditions, see Section 5.3.4.2.4.

(5) When using the simplified fatigue analysis for considering safety margins, it shall be observed that the assumed reference load cycle number does not correspond to the actual number.

(6) Reducing influences on the fatigue resistance (such as probability of survival $P_{ü}$, surface influence etc.) shall be taken into account analogously to the evaluation of the S/N curves according to Section 5.3.4.4.

Note:

By way of example, instances for the application of the partial safety factor γ_M are named in Table 5.3.2 for fatigue analyses which normally apply according to the criteria listed in Table 5.3.1 for the force- and moment-transmitting components of an offshore wind turbine to be considered here.

Table 5.3.1 Partial safety factor γ_M for fatigue verification

Inspection and accessibility	Component failure results in destruction of offshore wind turbine or endangers people	Component failure results in offshore wind turbine failure or consequential damage
Periodic monitoring and maintenance; good accessibility	1.15	1.0
Periodic monitoring and maintenance; poor accessibility	1.25	1.15

Table 5.3.2 Example for the partial safety factor γ_M

Penetrations for reinforcing steel in the foundation section	*Cannot be inspected*	γ_M*=1.25*
Bearing collar of the rotor shaft	*Cannot be inspected without removing the shaft*	γ_M *=1.25*
Locking bolt	*Can be inspected*	γ_M *=1.15*
Bolted connection of hub/rotor shaft	*Can be inspected*	γ_M *=1.15*

5.3.4.2.3 Damage calculation

(1) The execution of fatigue verifications via damage accumulation will hereunder be assumed to be known. Explanations of this method may for instance be taken from [5.1], [5.2], [5.3].

(2) When working out a damage accumulation, as a matter of principle all stress ranges $\Delta\sigma_i$ due to operational loads in accordance with Chapter 4 shall be used in conjunction with their associated stress cycle numbers n_i. The damage sum D from the fatigue strength calculation may not exceed the value of 1:

$$D \le 1 \qquad (5.3.1)$$

e.g. when using the Palmgren/Miner linear damage accumulation hypothesis:

$$D = \sum_i n_i / N_i \le 1 \qquad (5.3.2)$$

where:

n_i = number of stress cycles in one bin of stress ranges

N_i = number of tolerable stress cycles in one bin of stress ranges

(3) The number of tolerable stress cycles N_i is here the permissible number of stress cycles of the relevant S/N curve for the stress range $\Delta\sigma_i \cdot \gamma_M$.

(4) The partial safety factor γ_M is given in Table 5.3.1.

(5) For the damage accumulation, the design S/N curves given in the paragraphs that follow (see Section 5.3.4.4) and the equivalent stresses described in Section 5.3.4.3 shall be used.

(6) For stress superposition in the case of multi-axial stress conditions, see Section 5.3.4.2.4.

5.3.4.2.4 Notes on the superposition of multi-axial stress conditions

(1) For multi-axially stressed components (see Fig. 5.3.1), it is necessary to consider the complex stress conditions in a realistic manner and to prepare them for the damage accumulation calculation in a physically meaningful manner. For this, the relevant time series of the fatigue loads are applied in accordance with Chapter 4.

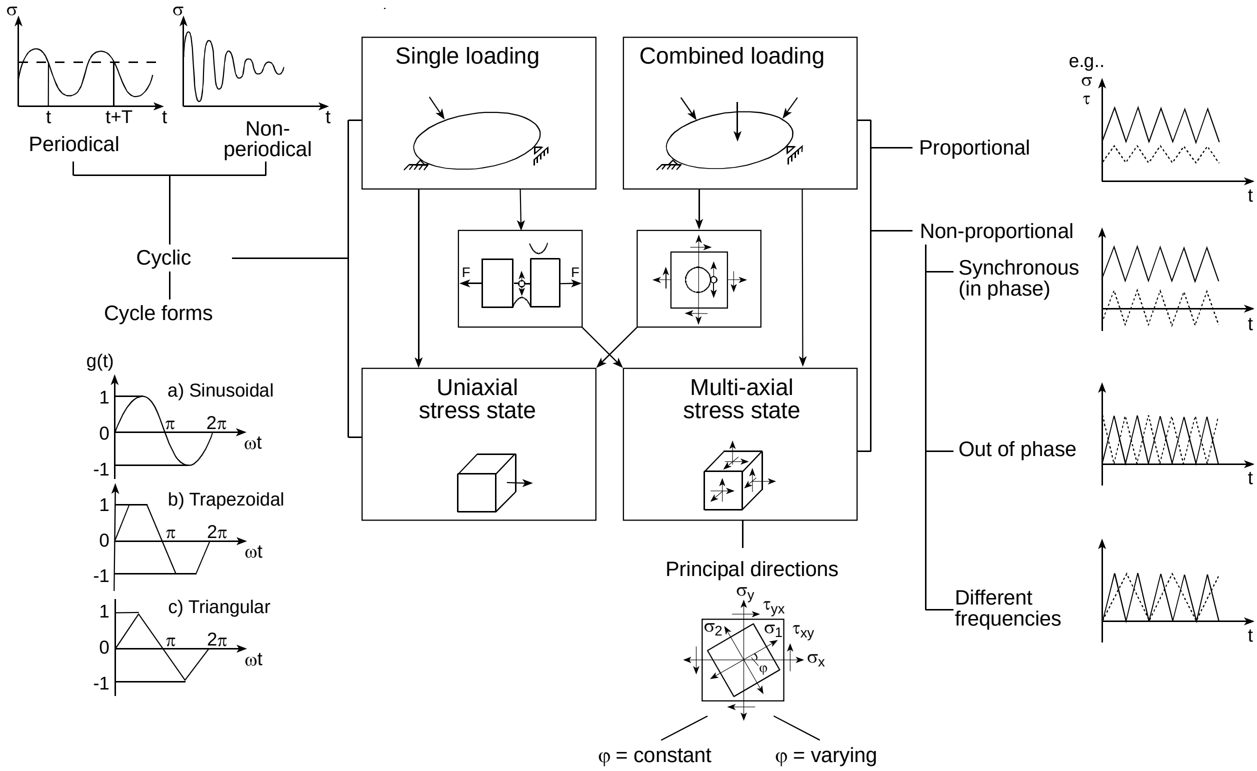


Fig. 5.3.1 Relationship of various terms in the field of multi-axialities according to Liu/Zenner

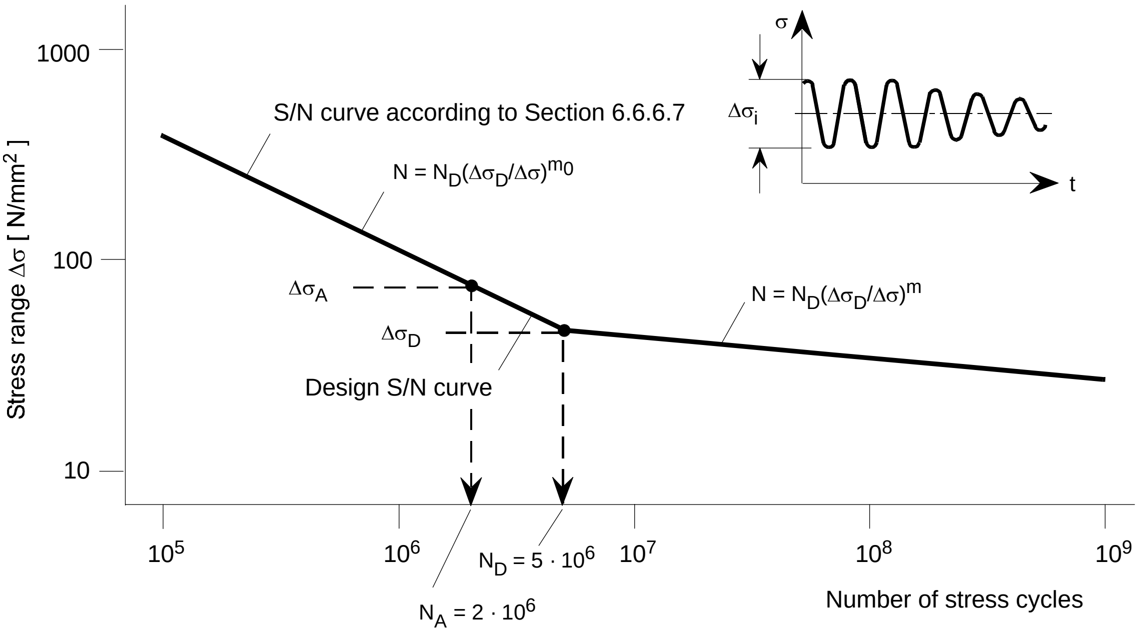


Fig. 5.3.2 S/N curve for structural steel, general shape

(2) When analysing multi-axial stresses, it is recommended that the dominating (damage-relevant) stress distribution or stress combination be established for the critical regions via consideration of the principal stresses and principal-stress directions. Occasionally, the presence of a dominating load component, or the combination of load components, may lead to a quasi-monoaxial stress condition. In such cases, this may allow a possible simplification that is appropriate for the problem.

(3) If normal and shear stresses occur simultaneously in welded joints, their combined effect shall be considered in accordance with [5.1] or [5.5].

(4) The procedure used shall be defined in consultation with GL Wind.

5.3.4.3 Equivalent stress hypotheses

(1) In cases of multi-axial stress conditions, the fatigue-relevant stress components (also as time series) shall be transformed to a mono-axial stress condition by means of the equivalent stress hypothesis. When applying the hypothesis of the maximum shear strain energy criterion (the “von Mises” hypothesis), there arise equivalent stress curves that are dependent on the mean stress and to some degree not conservative, so that their damage effect strongly underestimates the real damage accumulation behaviour of the material. Independently of the mean stress level, the normal stress hypothesis can be applied as a method of the critical plane without loss of relevance for the damage accumulation. It is valid for brittle and semiductile materials (e.g. EN-GJS-400-18U-LT belongs to the semiductile materials). Other hypotheses can be used if adequate proof of their usefulness is given.

(2) For welded joints, the decisive stresses are those transverse or parallel to the weld seam. If normal and shear stresses occur simultaneously in welded joints, their combined effect shall be considered in accordance with [5.1] or [5.5].

5.3.4.4 S/N curves for dimensioning

5.3.4.4.1 S/N curves for welded steel structures and bolted connections

(1) The selection of the S/N curves follows Section 6.6.6.7. Detail category shall be in accordance with Appendix 6.A for plate edges and welded steel structures and in accordance with ENV 1993-1-1 (Eurocode 3) for bolted connections not described in this Guideline. Application of equivalent codes (e.g. FKM Guideline [5.4] or GL Rules I – Ship Technology, Part 1 – Seagoing Ships, Chapter 1 – Hull Structures, Section 20) is permissible in consultation with GL Wind.

(2) Reducing influences, e.g. because of the material thickness or insufficient alignment of the two joints to be welded, shall be observed in accordance with Section 6.6.6.7.2 and para 10.

(3) For components stressed by predominantly variable stress ranges $\Delta\sigma_i$, fatigue verification is usually carried out using damage accumulation with the stress ranges in accordance with Chapter 4 as a basis.

(4) In the case of loading by normal stresses, the following agreement applies to the S/N curve as per Fig. 5.3.2:

– region I:
slope parameter of the S/N curve m_0, stress cycle numbers $Ni < 5 \cdot 10^6$

– region II:
slope parameter of the S/N curve m, stress cycle numbers $N_i \geq 5 \cdot 10^6$

(5) In deviation from EC 3, a threshold value of the fatigue strength (cut-off) is not permissible. Fig. 5.3.2 shows the general shape of the S/N curve to be used as a basis.

(6) For predominantly shear-stress loaded components, the S/N curves of EC 3 shall be used with a constant slope parameter m = 5:

– region I + II:
slope parameter of the S/N curve m = 5

(7) When establishing the tolerable number of stress cycles N_i (see Section 5.3.4.2.3), account shall be taken of the partial safety factors γ_M according to Table 5.3.1.

(8) When analysing the fatigue strength of bolted connections, whose stress levels are established under consideration of the tension and bending in the bolt, the following detail categories are permissible up to the size M30 (metric standard thread):

– hot-dip galvanized bolts rolled before heat treatment:
detail category 50

– bolts rolled before heat treatment:
detail category 71

– bolts rolled after heat treatment:

$$\text{detail category } 71 * \left(2 - \frac{F_{S\max}}{F_{0,2\min}}\right) \leq 85 \qquad (5.3.3)$$

where:

F_{Smax} = max. bolt force under extreme load

$F_{0,2min}$ = bolt force at the 0.2 % elastic strain limit

(9) Here the dimensioning-relevant cross-section A is the stress cross-section A_S in the thread. The influence of the reduction in cross-section can usually be neglected for hot-dip galvanized parts.

(10) For bolts larger than M30, a reduction of the S/N curve by the factor k_s with

$$k_s = (30mm/d)^{0,25} \quad (5.3.4)$$

shall be taken into account, where d is the nominal diameter. Further requirements on bolt dimensioning are given in Section 6.5.

5.3.4.4.2 S/N curves for the design of non-welded forged and rolled parts

(1) Selection

On principle, statistically assured S/N curves for the raw material should be used as a basis. If such S/N curves are not available for the steels to be used, synthetic S/N curves in accordance with [5.3] may be used for a comprehensive fatigue analysis (damage accumulation calculation in accordance with Section 5.3.4.2.3.

(2) Reducing influences

The following reducing influences on the fatigue resistance shall be considered (e.g. according to [5.3] or [5.6]):

- type of loading
- stress ratio
- stress concentration factor
- notch effect factor
- component size
- surface influence
- influence of technological parameters
- survival probability
- environmental conditions (corrosion etc.)

(3) Survival probability

Usually, S/N curves are assigned a survival probability of $P_Ü$ = 50 %, see e.g. [5.3] or [5.6]. The fatigue analysis shall be performed with a survival probability of $P_Ü$ > 97.7 %. Unless determined otherwise, the S/N curve reference value $\Delta\sigma_A$ shall be reduced to

$$\Delta\sigma^*_A = \Delta\sigma_A \cdot S_{Pü} \quad \text{where } S_{Pü} = 2/3 \qquad (5.3.5)$$

which corresponds to a survival probability of $P_Ü$ > 97.7 % (mean value – 2 · standard deviation). If S/N curves with a survival probability of $P_Ü$ > 50 % are used, a reduction factor $S_{Pü}$ > 2/3 may be assumed after consultation with GL Wind.

(4) Stress cycle numbers

For stress cycle numbers $N_i > N_D$, the S/N curves shall be extended from $\Delta\sigma^*_A$ with the slope parameters 2m-1, where m is the slope parameter of the fatigue strength line (see Fig. 5.3.3). Here the limiting stress cycle number N_D is that number at which, under optimum test conditions (no corrosion effect, etc.), the endurance limit is given. Where synthetic S/N curves are used, N_D results from its calculation.

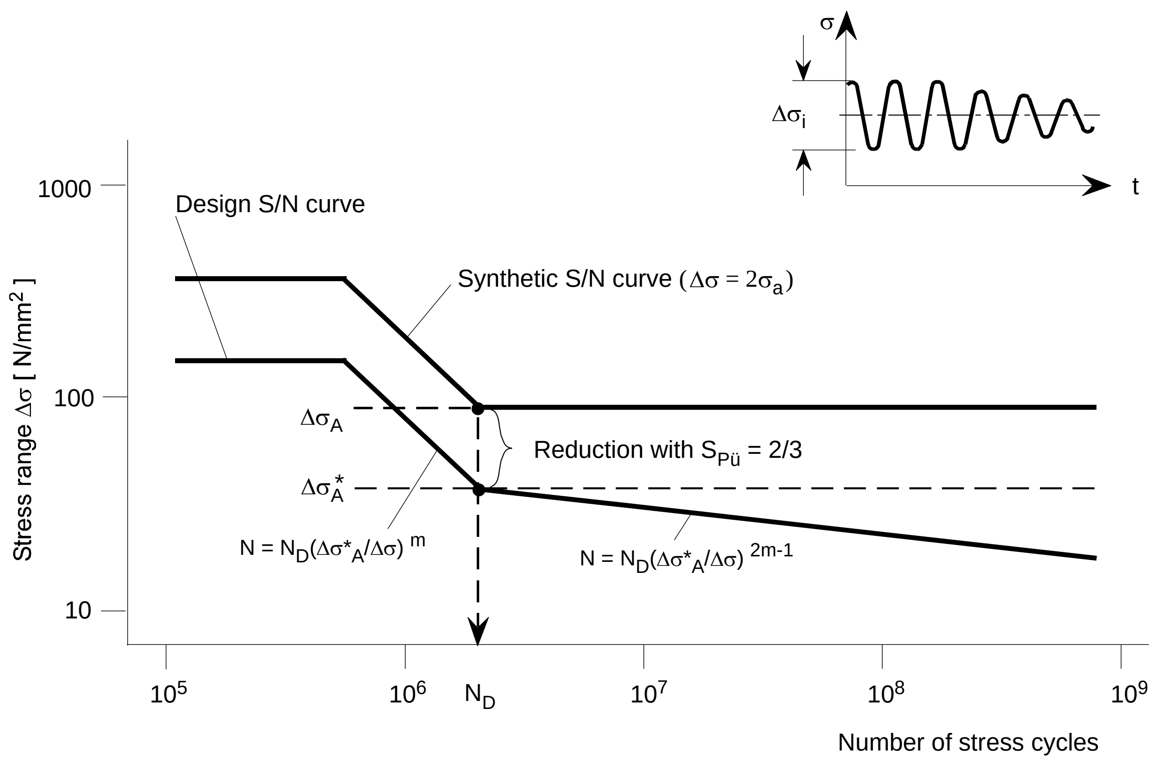


Fig. 5.3.3 S/N curve for non-welded forged and rolled parts, example "Synthetic S/N curve"; general shape

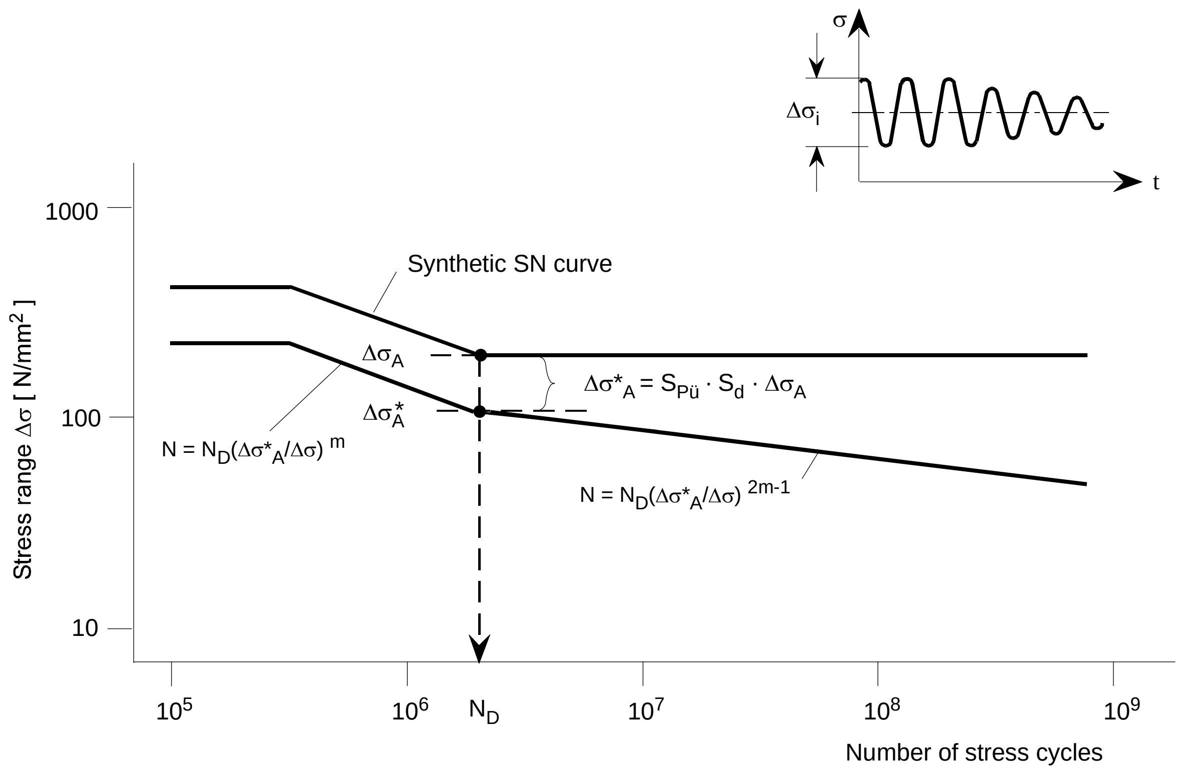


Fig. 5.3.4 S/N curve for cast steel and spheroidal graphite cast iron, example "Synthetic S/N curve"; general shape

5.3.4.4.3 S/N curves for the design of cast steel and spheroidal graphite cast iron

(1) Selection

On principle, statistically assured material S/N curves shall be used. If such S/N curves are not available for the cast material to be used, synthetic S/N curves in accordance with [5.3] may be used as a basis for a comprehensive fatigue analysis (damage accumulation calculation in accordance with Section 5.3.4.2.3).

(2) Influences

The following influences on the fatigue resistance shall be considered (see e.g. [5.3]):

– type of loading
– significant residual stresses (e.g. shot peening)
– stress ratio
– stress concentration factor
– notch effect factor
– component size
– surface influence
– influence of technological parameters
– survival probability
– environmental conditions (corrosion etc.)

(3) Survival probability

Usually, S/N curves are assigned a survival probability of $P_Ü$ = 50 %. For the fatigue analysis, the S/N curve reference value $\Delta\sigma_A$ shall be reduced to

$$\Delta\sigma^*_A = \Delta\sigma_A \cdot S_{Pü} \quad \text{where } S_{Pü} = 2/3 \qquad (5.3.6)$$

which corresponds to a survival probability of $P_Ü$ > 97.7 % (mean value – 2 · standard deviation). If S/N curves with a survival probability $P_Ü$ > 50 % are used, a reduction factor $S_{Pü}$ > 2/3 may be assumed after consultation with GL Wind.

(4) Reduction factors

The influence of large wall thicknesses and surface roughness shall be taken into account. In the case of S/N curves determined from specimens taken from equally thick component regions, this influence is included in the S/N curves. When determining synthetic S/N curves according to [5.3], both the thickness-dependent mechanical characteristic values (guaranteed minimum tensile strength and yield point) as well as the reduction through the existing surface roughness shall be observed.

(5) In using synthetic S/N curves, the influence of the flaws (e.g. blowholes, non-metallic inclusions, shrinkage holes; shrinkage holes cut by mechanical processing and dross are not permissible without posttreatment, cf. Section 3.3.2) shall be considered through the factor

$$S_d = 0.85^{(j-j_0)} \quad (5.3.7)$$

where:

j = the quality class for the component or component detail to be designed with adequate fatigue strength (1..3; cf. Sections 3.3.2.5 and 3.3.2.8)

j_0 = constant depending on the material and test method, with the following values:

Test method:	Cast steel:	Cast iron:
Ultrasonic or radiographic examination	j_0=1	j_0=0
Liquid penetrant or magnetic particle inspection	j_0=1	j_0=1

For the assessment of the casting quality and the testing techniques to be applied, the provisions set out in Sections 3.3.2.5 and 3.3.2.8 shall be observed.

(6) The classification into quality levels shall be documented consistently in the drawings, calculations and specifications and submitted to GL Wind for assessment within the scope of implementation of the design requirements in production and assembly or of surveillance during production (cf. Sections 1.2.5.3 and 1.2.6.2). The requirements of Section 3.3.2.5 (cast steel) and Section 3.3.2.8 (cast iron) shall be observed.

(7) Design S/N curve
The reference stress range to be used as a basis for the S/N curve is

$$\Delta\sigma^*_A = S_{Pü} \cdot S_d \cdot \Delta\sigma_A \quad (5.3.8)$$

as the ideal fatigue limit at the stress cycle number N_D (see Fig. 5.3.4). For stress cycle numbers $N_i > N_D$, the S/N curves shall be extended from $\Delta\sigma^*_A$ with the slope parameter 2m-1 (if corrosion can be excluded), where m is the slope parameter of the fatigue strength line (see Fig. 5.3.4).

5.3.4.4.4 S/N curves for the design of aluminium parts

(1) On principle, statistically assured S/N curves shall be used.

(2) For detail categories, the detail category selection shall be in accordance with [5.5]. In cases of doubt, the procedures shall be agreed with GL Wind.

5.3.5 Serviceability analysis

5.3.5.1 Partial safety factors

For verifications in the serviceability limit states, the partial safety factor shall be $\gamma_M = 1.0$.

5.3.5.2 Deformation analysis

If no special requirements arise from operation of the plant, a limitation of deformations is not necessary (see also Section 5.3.3.2, para 5).

5.4 Concrete and Grout Materials

5.4.1 General

5.4.1.1 Scope

This Section on concrete structures refers to load bearing and stiffening components of offshore wind turbines made from ordinary or heavyweight concrete with closed texture. It is applicable to plain, reinforced and prestressed concrete, normal and high strength concrete. It is applicable to prefabricated as well as insitu concrete.

5.4.1.2 Standards and safety concepts

(1) The following regulations are based on a safety concept using partial safety factors. They follow the German standard DIN 1045-1 (Concrete, reinforced and prestressed concrete structures) and take account of the special requirements for marine structures. Eurocode 2, Part 1 [3.3] can be used as well. A combined application of different standards shall be avoided.

(2) Design, analysis and construction may also be based on acknowledged international or national standards for concrete structures, using other safety concepts (probabilistic or global concepts) than those mentioned above in consultation with GL Wind. However, only one uniform safety concept is to be used throughout.

5.4.1.3 Assessment documents

(1) The documents to be examined include building specifications, drawings and structural design calculations (static and dynamic analysis).

(2) The building specifications shall contain the information necessary for understanding the drawings and calculations, and those for construction, transport, installation (especially when using precast concrete structures) and supervision of the construction. Design parameters and materials should be described in specifications. Construction, transport and installation procedures should also be described.

(3) The drawings shall show clearly and conveniently the dimensions of the components and their reinforcement. The strength class of the concrete is to be given. The reinforcement drawings shall also contain data on the concrete cover, the type of reinforcement steel and the number, diameter, shape and position of the reinforcing bars.

(4) The stability and adequate dimensioning of the structure and its components shall be analysed and presented in a convenient and readily checkable format. The origin of equations and calculation methods not in common use shall be stated.

5.4.1.4 Material properties

5.4.1.4.1 Characteristic values

The material parameters required for the computational analysis of concrete, reinforcing steel and prestressing steel can for instance be found in Eurocode 2, Section 3 or DIN 1045-1, Section 9.

5.4.1.4.2 Partial safety factors γ_M

(1) The design resistance shall be determined with due consideration of the partial safety factors γ_M according to Table 5.4.1. For calculations of deformations of towers made of reinforced concrete and prestressed concrete according to second order theory, $\gamma_M = 1.2$ may be assumed for concrete.

(2) The material properties of non-standardized products such as grout materials shall be determined by testing, see Section 3.3, too.

5.4.2 Principles of analysis

5.4.2.1 Necessary verifications

(1) The stability, load bearing capacity and durability of the load bearing structure shall be investigated for all load conditions occurring during erection and use. The following analyses are required for the ultimate limit states (ULS):

– strength of the load bearing system in accordance with Section 5.4.2.2.1

– stability of the load bearing system in accordance with Section 5.4.2.2.2

– safety of cross-sections against fracture in accordance with Section 5.4.2.2.3

– safety of materials against fatigue failure in accordance with Section 5.4.2.2.4

Table 5.4.1 Partial safety factors for the material γ_M

Material	Ultimate limit state		Serviceability limit state
	Fracture and stability failure	Fatigue	
Concrete	1.5 [1] (1.2) [2]	1.5	1.0
Spun concrete	1.4 [1] (1.2) [2]	1.4	1.0
Reinforcing and prestressing steel	1.15 [1]	1.15	1.0

[1] For unusual design situations, e.g. earthquake calculations, γ_M = 1.3 can be set for concrete and spun concrete and γ_M = 1.0 for reinforcing steel and prestressing steel.

[2] For the calculation of deformations when taking account of non-linearities of the geometry and/or the material, γ_M = 1.2 may be taken (value in brackets).

For the serviceability limit states (SLS) are required:

– crack width control in accordance with Section 5.4.2.3.2

– control of deflection in accordance with Section 5.4.2.3.3

– limitation of stresses in accordance with Section 5.4.2.3.4

(2) Zones of concentrated load introduction shall be investigated in detail.

(3) For prestressed concrete the checks according to Section 5.4.3 shall also be carried out.

5.4.2.2 Ultimate limit states

The analyses shall be performed with the least favourable of all combinations of actions of the groups N, E, A and T according to Section 4.3.3, Table 4.3.1.

5.4.2.2.1 Strength of the load bearing system

(1) The strength of the load bearing system and its components shall be verified by a recognized method. The cross-sectional values may be determined according to the theory of elasticity, disregarding the formation of cracks in the concrete and the effect of the reinforcement. Limit load analysis may be applied with the simplification of regrouping forces and moments in the cross-section relative to the distribution according to the theory of elasticity, provided equilibrium is ensured.

(2) Model tests can be used to verify the strength and distribution of cross-sectional values if they are carried out by acknowledged institutions with the relevant experience.

(3) Structures in which the failure or defect of one component can lead to the collapse of further components shall be avoided as far as it is possible.

5.4.2.2.2 Stability of the load bearing system

(1) The safety of the load bearing system and its components against instability shall be carefully investigated. If it is not already apparent that there is sufficient stiffness and stability, an analytical verification is necessary also incorporating stiffening by structural components. Account shall be taken here of geometrical inaccuracies in the system and undesired eccentricities of loads.

(2) Where the loadbearing or stiffening components are highly flexible, attention shall also be paid to the alterations in shape when determining the cross-sectional values (second order theory).

(3) Second order effects and imperfections shall be taken into account for slender members under compression in accordance with the standards, e.g. by using the model column method.

5.4.2.2.3 Safety of cross-sections against fracture

(1) The following dimensioning rules apply to cross-sections where the strains of the individual fibres are in proportion to their distance from the neutral axis.

This prerequisite is regarded as satisfied if the distance between points of zero bending moment is at least twice the girder height or the cantilever length is at least equal to the girder height.

(2) The relationship between stress and strain for concrete can be assumed to be as shown in Fig. 5.4.1 with ε_{c2} and ε_{c2u} according to the standards. For normal strength concrete up to C50/60, the values may be assumed as ε_{c2} = -0.2 % and ε_{c2u} = -0.35 %. For High Strength Concrete, the strain limits in Fig. 5.4.1 shall be adapted according to the standards, as e.g. DIN 1045-1, Table 9.

(3) For reinforcement steel the modulus of elasticity can be uniformly taken as 200 kN/mm^2 up to the yield point. Beyond that point the stress remains constant. Other approximations for the stress-strain behaviour of materials are admissible but shall be agreed with GL Wind.

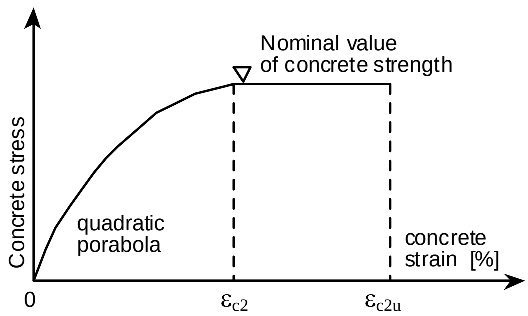


Fig. 5.4.1 Design values for stress and strain of concrete

(4) The maximum strain of the reinforcement steel in the cross-section shall not exceed a limiting value which may be selected at, for instance, 2.5 %.

(5) Tensile strength of the concrete may not be taken into account in any load case

(6) The safety factor for and the nominal value of the concrete strength in accordance with Fig. 5.4.1 shall be selected according to acknowledged standards. The corresponding load conditions of the standards shall agree with those of this Guideline.

(7) For ULS calculations, except for fatigue, the material safety factor for concrete γ_M =1.5 shall be increased by a factor γ_c` for high strength concrete of concrete class C 55/67, respectively LC 55/60 (*LC: light weight concrete according to EN 206-1*) or higher.

It may be determined by the following formula.

$$\gamma_C{}' = \frac{1}{1{,}1 - \frac{f_{CK}}{500}} \geq 1 \qquad (5.4.1)$$

where:

f_{ck} = characteristic compression strength according to Section 3.3.5.4.1

γ_M = material safety factor, γ_M =1.5 for concrete in general

γ_c` = factor for increasing γ_M for high strength concrete.

(8) Further investigations have to be done concerning

– shear forces
– torsion
– punching / concentrated loads (e.g. anchorage of prestressed tendons)

(9) In parts of the structure where the prerequisites given in para 1 are not fulfilled, the assessment shall be done using adequate modelling, e.g. strut-and-tie models or FE analyses.

5.4.2.2.4 Fatigue

(1) In the case of components of reinforced concrete or prestressed concrete, fatigue analysis shall be provided for the concrete, the reinforcing steel and the prestressing steel using the fatigue loads of Section 4.3.3.4 (group F in Table 4.3.1). These may be conducted as complete fatigue analyses or according to the simplified analysis procedure as per CEB-FIP Model Code 1990 [5.9] (DAfStb booklet 439 [5.7], Section 4.5 and 4.4). For offshore wind turbines with a nominal number of operational load cycles $N_{nom} = r \cdot n_R \cdot T \leq 2 \cdot 10^9$, a detailed analysis for concrete under compressive loading is not required, if the condition expressed in equation 5.4.2 is met:

$$S_{cd,max} \leq 0.40 + 0.46 \cdot S_{cd,min} \qquad (5.4.2)$$

with:

$S_{cd,min}$ = $\gamma_{Sd} \cdot \sigma_{c,min} \cdot \eta_c / f_{cd,fat}$

$S_{cd,max}$ = $\gamma_{Sd} \cdot \sigma_{c,max} \cdot \eta_c / f_{cd,fat}$

where:

γ_{Sd} = 1.1 – partial safety factor to consider the inaccuracies of the model for stress calculation

$\sigma_{c,max}$ = magnitude of the maximum concrete compressive stress, with the combinations of actions of group F according to Section 4.3.3.4, Table 4.3.1

$\sigma_{c,min}$ = magnitude of the minimum concrete compressive stress in the pressure zone at the same position at which $\sigma_{c,max}$ occurs, determined by the lower value of the action effect (for tensile stresses, $\sigma_{c,min}$ = 0 shall be set)

η_c = factor for considering the non-uniform distribution of the concrete compresssive stresses as per DAfStb booklet 439, equation (8); as a simplification, η_c = 1.0 may be set.

$f_{cd,fat}$ = $0.85 \cdot ß_{cc}(t) \cdot f_{ck} \cdot (1 - f_{ck}/250) / \gamma_c$; design value of the fatigue strength of the concrete under compressive loading

with:

f_{ck} = characteristic cylinder compressive strength in N/mm²

γ_c = partial safety factor for concrete (see Table 5.4.1)

$ß_{cc}(t)$ = coefficient for considering the time-dependent strength increase in the concrete. Here $ß_{cc}(t)$ shall not be set larger than 1.0, corresponding to a cyclic initial loading with a concrete age ≥ 28 days. In the case of cyclic initial loading at an earlier age of the concrete, $ß_{cc}(t)$ < 1.0 shall be determined and taken into account in the analysis.

(2) On principle, the following shall be investigated for the simplified analysis procedure:

– maximum load range
– load range with the largest concrete compressive stress $\sigma_{c,max}$
– load range with the smallest concrete compressive stress $\sigma_{c,min}$
– load range with the largest mean value for the concrete compressive stress

(3) The damage components of the load effects from erection conditions without the machine shall be considered in accordance with Section 6.6.6.9.

Note:

Model Code 1990 [5.9] gives a separate S/N curve for reinforcement steel in marine environment. This S/N curves applies for the splash zone only.

(4) Safety factors as given in Model Code 1990 for the fatigue calculation may be reduced in consideration with GL Wind, e.g. if the manufacturer can prove a lower variation of the material properties.

5.4.2.3 Serviceability limit states

5.4.2.3.1 Partial safety factors

For verifications in the serviceability limit states, the partial safety factor shall be γ_M = 1.0.

5.4.2.3.2 Limiting the crack width

(1) Crack widths in concrete structures at working loads are to be controlled, by suitable selection of the percentage of reinforcement, stress in the steel and bar diameter, that serviceability and durability are not affected.

(2) Additional requirements shall be laid down for water or oil tight structures such as tanks.

(3) Verification of crack width shall be provided for a theoretical crack width of 0.2 mm. Here, for components of reinforced concrete and prestressed concrete without bonding, the quasi-permanent combination of actions shall be used, and for components of prestressed concrete with bond the frequent combinations of actions DLC 1.2. For this, the heat influences as per Section 4.2.4.1 shall be applied.

(4) For offshore wind turbine support structures, the quasi-permanent combination of actions shall be chosen from the 1-hour mean value of the load cases DLC 1.1 and DLC 6.3a of Table 4.3.1.

(5) Parts of the structure that are permanently underwater or in the earth may be verified for a crack width of 0.3 mm.

5.4.2.3.3 Limiting the deflection

(1) The extent of shape alterations of components under the working load (for instance due to deflections or displacements) shall be limited that damage is prevented and serviceability is not affected.

(2) The analysis can be based on a constant modulus of elasticity of the concrete for compression and tension.

(3) The influence of creep and shrinkage of the concrete and temperature variations shall be taken into account when determining shape alterations if they have a substantial effect.

5.4.2.3.4 Limiting the stresses

For towers of reinforced concrete and prestressed concrete, the concrete compressive stresses shall be limited in consultation with GL Wind.

5.4.3 Prestressed concrete

5.4.3.1 Verifications

(1) The verifications required for reinforced concrete (see Section 5.4.2.1.) shall be carried out for prestressed concrete taking into account the prestressing of the steel.

(2) For towers of prestressed concrete, the concrete compressive stresses under constant loads the quasi-permanent combination of actions shall be limited to a maximum value to be agreed with GL Wind. For towers of prestressed concrete with bond, the verification of decompression shall be provided for the quasi-permanent combination of actions. This verification may be undertaken on the assumption that the relationship between stress and strain is linear.

(3) For offshore wind turbine support structures, the quasi-permanent combination of actions for this verification shall be chosen from the 1-hour mean value of the load cases DLC 1.1 and DLC 6.3.

(4) The frequent combination of actions shall be taken from load case DLC 1.2.

(5) Limitation of the steel stresses in the unstressed or prestressed reinforcement shall be verified as specified in acknowledged standards (see Section 3.3.5.2).

(6) The effects of prestressing, constant load, live load, temperature, creep, shrinkage, and constrainment due to settlement of the soil are also to be investigated separately as far as practicable and to be used to determine the most unfavourable loading.

(7) The condition directly after application of the prestress, the condition at the most unfavourable live load and with partial creep and shrinkage, and the condition with the most unfavourable live load after creep and shrinkage have ceased shall in general be verified separately.

(8) The tensile forces occurring in the concrete at the working load shall be absorbed by unstressed or by prestressed reinforcement, the stresses envisaged for this in the acknowledged standards being maintained. As an approximation the analysis may be based on the uncracked condition of the cross section instead of on the cracked condition.

(9) The stress-strain curve of the prestressing steel is to be derived from the official approval or the certificate from the manufacturer's works, it is being assumed, however, that the stress does not increase above the yield point or 0.2 % limit. Strain limitations have to be considered according to the standards or official approval.

5.4.3.2 Admissible stresses

The admissible stresses shall be obtained from recognized standards and are to be agreed before use with GL Wind.

5.4.4 Grouted connections

5.4.4.1 General

(1) Grouted connections can be used to connect prismatic steel members or to fix piles into bedrock.

(2) A distinction has to be made between grouted connections that are mainly exposed to axial forces and grouted connections that are mainly exposed to bending, because the load transfer mechanisms are different from each other.

(3) Grout material for grouted connections is generally characterised by high compression strength and a behaviour that is comparable to high strength concrete.

5.4.4.2 Ultimate limit state analysis

(1) Grouted connections mainly exposed to axial forces or axial forces in combination with torsion can be assessed according to acknowledged offshore standards, e.g. a procedure is given in draft ISO 19902, Chapter 15 [5.10]. The range of validity of parametric formulae has to be considered.

(2) Grouted connections mainly exposed to bending, e.g. connection between monopole and transition piece shall be verified on the basis of FE analyses or by testing, because no validated parametric formulae exist so far in the relevant codes.

A ratio of

$$L/D \approx 1.5 \qquad (5.4.3)$$

with

L = length of connection

D = diameter of connection

is recommended.

(3) Normal forces in such connections should be taken by shear keys that should be arranged in an area with low bending stresses, i.e. in general at the centre of the connection.

(4) If FE analyses are performed, special considerations shall be taken concerning the non-linear material behaviour, as well as the contact definition between steel surface and grout material. Detailed guidance on FE modelling and analysis is given in Appendix 5A "Strength Analyses with the Finite Element Method".

(5) The possibility of local buckling of the steel tubes shall be investigated.

(6) The grout material shall be verified against extreme loads using the maximum compression stress from the FE calculation if not by testing

(7) The resistance shall be calculated with the characteristic compression strength of the grout material reduced by a safety factor of $\gamma_M = 1.5$ and γ_C' according to Section 5.4.2.2.3 depending on the material strength.

(8) The fatigue analysis of the grout material shall be performed in accordance with CEB-FIP Model Code 1990 [5.9] under consideration of the mean value of the oscillation in the same way as for high strength concrete, using the maximum occurring stresses from the FE calculation or from testing.

5.5 Fibre Reinforced Plastics (FRP) and Bonded Joints

5.5.1 General

(1) The analyses are carried out with characteristic values which are determined from test results as described in Section 5.5.2.3. Verification shall be provided in such a way that the design values of the actions S_d are smaller than the design values of the component resistances R_d (characteristic value R_k divided by the partial safety factor for the material γ_{Mx}):

$$S_d \leq R_k / \gamma_{Mx} = R_d \tag{5.5.1}$$

(2) If there are no test results or other confirmed data for the analysis, the minimum characteristic values given in Sections 5.5.4 to 5.5.6 may be used. By start of production at the latest, it shall be verified that the material attains at least the characteristic values assumed in the analysis.

5.5.2 Materials

5.5.2.1 Requirements for manufacturers

(1) The production of FRP components which were assessed by GL Wind shall preferably take place at manufacturers approved by GL.

(2) The requirements for the manufacturers of rotor blades are set out in Section 3.1. Type and scope of the shop approval are also laid down there.

(3) The requirements for acknowledgement of a quality management system at the company, as well as the procedure for obtaining the acknowledgement and maintaining it, are given in Section 3.2.

(4) Special requirements as regards production are included in Sections 3.4.4 to 3.4.6.

5.5.2.2 Requirements for the materials

(1) Only materials with confirmed properties may be used. In some cases, GL approval is needed in addition; see Section 3.4.4.4, para 1 and Section 5.5.6, para 5.

(2) Requirements and quality verification (certificates, test reports, approvals) for the usual structural materials are listed in Sections 3.3.3.8 and 3.4.6.2, para 1.

(3) The strengths and stiffnesses of the materials used shall be sufficiently known in each case, i.e. modulus of elasticity (E-modulus), Poisson's number, failure strain and the failure stress of the typical laminate layers used, both for tensile and compressive loading parallel and transverse to the fibres and also for shear.

(4) The glass transition temperature (extrapolated onset temperature T_{eig} according to ISO 11357-2) of the matrix and of the structural bonding materials shall be higher than 65 °C and also higher than the temperature which is expected at the structural member.

5.5.2.3 Characteristic values

(1) The characteristic values R_k are generally calculated as follows:

$$R_k(\alpha, P, \upsilon, n) = \bar{x}\left[1 - \upsilon\left[U_\alpha + \frac{U_p}{\sqrt{n}}\right]\right] \tag{5.5.2}$$

where:

U_i = i% fractile (percentile) of the normal distribution

n = number of tests

$\bar{x}$ = the mean of the test values

υ = coefficient of variation for n test values

(2) For the equation, it is assumed that the standard deviation of the observed values corresponds to that of the normal distribution. The inaccuracies occurring thereby are covered by the reduction factors.

(3) The α = 5 % fractile for a probability P = 95 % (confidence level) assuming a normal distribution (DIN 55303, Part 1) shall be applied. This yields:

$$\mathrm{R}_k(5\%, 95\%, \upsilon, \mathrm{n}) = \bar{\mathrm{x}}\left[1 - \upsilon\left[1.645 + \frac{1.645}{\sqrt{\mathrm{n}}}\right]\right] \tag{5.5.3}$$

5.5.2.4 Partial safety factors for the material

(1) The partial safety factors for the material γ_{Mx} shall be determined separately for

– the short-term verification (x = a),

– the fatigue verification (x = b),

– the stability analysis (x = c), and

– the bonding analysis (x = d and x = e).

These factors are obtained by multiplying the partial safety factor γ_{M0} with the reduction factors C_{ix} :

$$\gamma_{Mx} = \gamma_{M0} \cdot \prod_i C_{ix} \qquad (5.5.4)$$

For all analyses, the partial safety factor γ_{M0} is:

$$\gamma_{M0} = 1.35 \qquad (5.5.5)$$

The reduction factors C_{ix} listed below apply without further verification. Reduction factors verified by experiment may be used as an alternative.

(2) In the short-term strength verification, γ_{Ma} shall be determined by multiplication of γ_{M0} as per Section 5.5.2.4, para 1, with the reduction factors C_{ia}. To take account of influences on the material properties, the following reduction factors shall be used:

C_{1a}	=	1.35	influence of ageing
C_{2a}	=	1.1	temperature effect
C_{3a}	=	1.1	laminate produced by prepregs, winding techniques, pultrusion or resin infusion method
	=	1.2	wet laminate with hand lay-up, pressing techniques
C_{4a}	=	1.0	post-cured laminate
	=	1.1	non post-cured laminate

(3) In the fatigue verification, γ_{Mb} shall be determined by multiplying γ_{M0} (see Section 5.5.2.4, para 1) with the following reduction factors C_{ib} :

C_{1b}	=	$N^{1/m}$	curve of high-cycle fatigue for the load cycle number N and slope parameter m. m is determined by an analysis (S/N curve) to be agreed with GL Wind. Regarding simplified assumptions for m, see Sections 5.5.4, para 4 and 5.5.5, para 6.
C_{2b}	=	1.1	temperature effect
C_{3b}	=	1.0	for unidirectional (UD) reinforcement products
	=	1.1	for non-woven fabrics and UD woven rovings
	=	1.2	for woven fabrics and mats
C_{4b}	=	1.0	for post-cured laminate
	=	1.1	for non post-cured laminate
C_{5b}	=	1.0 to 1.2	local partial safety factor for the blade trailing edge. The exact magnitude depends on the quality of the verification (1.0 for dynamic blade test in the edgewise direction, 1.1 for FE calculation, 1.2 for calculation according to Bernoulli theory).

5.5.3 Analyses

5.5.3.1 General

(1) The design values for the strains or the stresses are determined by the requirement to prevent laminate failure and stability failure with regard to the short-term strength, fatigue strength and stability in all load cases. The discontinuities in the laminate, the load introduction zones and the high load cycle numbers shall be taken into account.

(2) The actual safety shall be documented in the analysis for short-term strength and fatigue strength by a failure hypothesis for anisotropic materials that is acknowledged in the literature, e.g. as per VDI 2014 or Puck [5.8]. The use of other failure hypotheses is possible after consultation with GL Wind. For the strength analysis, a separate verification shall always be provided for fibre failure and inter-fibre failure.

(3) The verifications for fibre failure and inter-fibre failure and for stability regarding short-term and fatigue strength can be provided in the form of strain or stress analyses.

5.5.3.2 Analysis for fibre failure

(1) The analysis for fibre failure shall be carried out for areas under tensile, compressive and/or shear loading using the design values of the actions S_d.

(2) The fatigue analysis is based on the characteristic (see Section 5.5.2.3) S/N curve established for the laminate in question and the Goodman diagram constructed using this curve. If no S/N curve is available for the laminate, it shall be assumed to be as given in Section 5.5.2.4, para 3 (factor C_{1b}) and Sections 5.5.4, para 4 and 5.5.5, para 6.

(3) The Goodman diagram shows the relationship between the mean and the range components of the component resistances R and actions S (R and S as strains ε or stresses σ) and may be constructed as in Fig. 5.5.1.

For this, the number of tolerable load cycles N shall be determined as follows:

$$N = \left[\frac{R_{k,t} + |R_{k,c}| - |2 \cdot \gamma_{Ma} \cdot S_{k,M} - R_{k,t} + |R_{k,c}||}{2 \cdot (\gamma_{Mb}/C_{1b}) \cdot S_{k,A}} \right]^m \qquad (5.5.6)$$

where:

$S_{k,M}$ = mean value of the characteristic actions

$S_{k,A}$ = amplitude of the characteristic actions ($|S_{k,max} - S_{k,min}|/2$)

$R_{k,t}$ = characteristic short-term structural member resistance for tension

$R_{k,c}$ = characteristic short-term structural member resistance for compression

m = slope parameter m of the S/N curve

$R_{k,A}$ = amplitude of the characteristic structural member resistances for load cycle number N=1.

The auxiliary variables m and $R_{k,A}$ are laid down through an analysis (S/N curve) to be agreed with GL Wind. For simplified assumptions, see Sections 5.5.4 and 5.5.5.

N = permissible load cycle number

γ_{Ma} = partial safety factor for the material (as per Section 5.5.2.4, short-term strength)

γ_{Mb} = partial safety factor for the material (as per Section 5.5.2.4, fatigue strength)

C_{1b} = $N^{1/m}$, see Section 5.5.2.4, para 3 [i.e. (γ_{Mb}/C_{1b}) corresponds to γ_{Mb} without C_{1b}]

(4) For given actions, the Goodman diagram can be used to determine the permissible load cycle numbers N, which can be used to carry out a damage accumulation calculation. The damage D is defined as the sum of the quotients of existing load cycle numbers n_i to permissible load cycle numbers N_i. D must be less than unity:

$$D = \sum_i \frac{n_i}{N_i} \le 1 \qquad (5.5.7)$$

where:

D = damage

n_i = existing number of load cycles of a class i of actions

N_i = permissible number of load cycles of a class i of actions

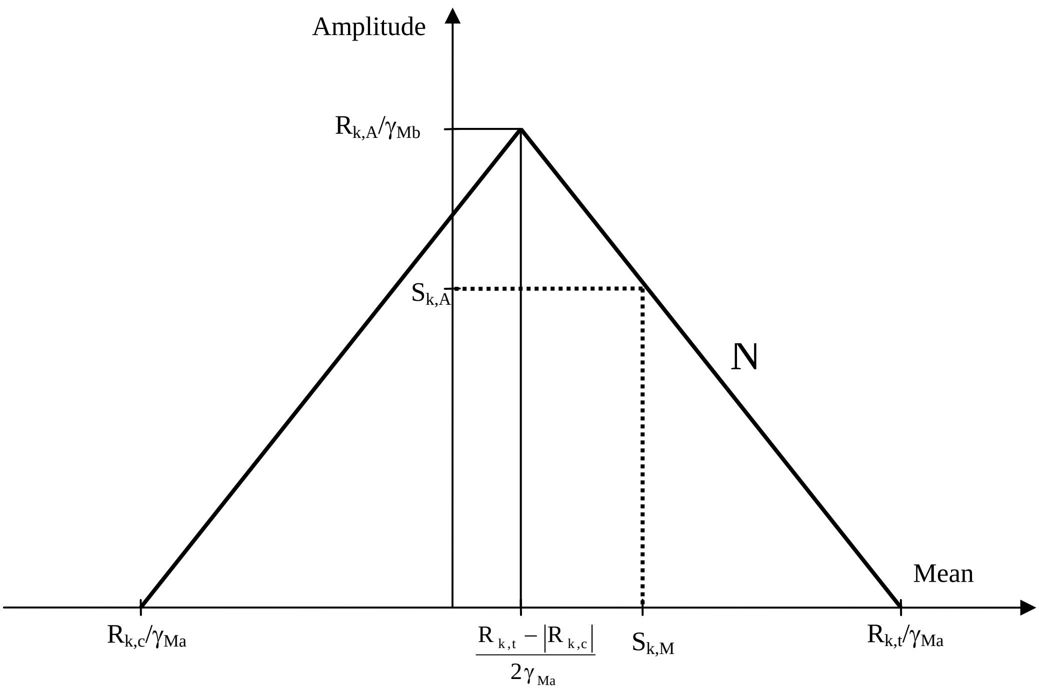


Fig. 5.5.1 Goodman diagram

5.5.3.3 Analysis for inter-fibre failure

(1) The cracking can be verified by computational means at the relevant critical positions as per Section 5.5.3.1, para 2, for the individual layers of laminate. To determine the permissible failure stresses and failure strains parallel and transverse to the fibres and for shear that are necessary for this verification, the characteristic parameters shall be reduced by a diminished factor ($\gamma_{Ma} \cdot C_{IFF}$). However, the factor resulting from ($\gamma_{Ma} \cdot C_{IFF}$) shall not be less than 1.35.

Note:

The transverse strains can be determined by computation or by experiment.

(2) If calculation shows that individual layers of laminate are not able to transfer the stresses assigned to them without cracking, the force component ΔF acting on the fractured layers shall be borne by other layers of the laminate. C_{IFF} is determined by the magnitude of the force component ΔF that has to be transfered, in accordance with Table 5.5.1.

(3) Precise tracing of the stress changes caused by the transfer in the individual layers of the partially cracked laminate is not necessary.

5.5.3.4 Stability analysis

(1) The stability (against buckling and wrinkling) of parts under tensile, compressive and/or shear loading shall be verified on the basis of the design values for the actions S_d.

(2) For the stability analysis, the partial safety factor for the material γ_{Mc} shall be applied to the mean values of the material stiffnesses in order to determine the design values of the component resistances R_d. γ_{Mc} shall be determined by multiplying the partial safety factor γ_{M0} (see Section 5.5.2.4, para 1) with the following reduction factors C_{ic}:

C_{1c}	=	1.1	for massive laminates and the skin layers of sandwich structures, to account for the scattering of the moduli
	=	1.3	for core materials, to account for the scattering of the moduli
	=	1.0	for the core materials, if verified minimum characteristics are used
C_{2c}	=	1.1	temperature effect (see Sections 5.5.4, para 7, and 5.5.5, para 8)

(3) Where verification is performed by computation and, as is generally the case, the actual structure cannot be analysed in detail, the assumptions and estimates made shall be of conservative nature.

(4) The stability analysis may be performed with a (geometric) non-linear FE computation. For each loading, a stress-free predeformation affine to the 1st linear buckling eigenform shall be applied to the structure. The global scaling of the 1st linear eigenform shall be performed in such a way that the maximum height of the critical buckle is 1/400 of its largest horizontal dimension (chord length). A smaller predeformation can be permitted if its height is verified. Under these circumstances, the permissible stresses shall not be exceeded with regard to the design values of the loads.

Table 5.5.1 C_{IFF} for analysis of the inter-fibre failure

Failure mode relative to fibre direction	Force component ΔF to be transposed in the case of inter-fibre failure	
	C_{IFF} for 0 % < ΔF < 5 %	C_{IFF} for ΔF > 5 %
Shear combined with transverse tension	0.60	0.80
Primarily shear, combined with transverse compression	0.60	0.80
Primarily transverse compression, combined with shear	0.80	1

(5) In the case of a stability analysis using a nonlinear FE computation, additional verification shall be provided according to a linear method, in order to determine the 1st bifurcation load. This must be larger than the characteristic load. In addition, it shall be shown that, as a result of the buckling after predeformation, no damage can occur at the adjacent structural members and structural details (e.g. at the bonded joints).

(6) If the stability analysis is performed with a linear FE computation, an additional safety factor of 1.25 shall be considered.

(7) As an alternative to the required stability analysis by means of an analytical approach, stability can be verified by testing. In this case, the design values for the loads and the reduction factors as per Section 5.5.3.4, para 2, shall be taken into account, whereby the reduction factor $C_{1c} = 1.0$ shall be applied. If the tests are to be performed on structural components or samples, the conditions for the acknowledgement of these tests shall be defined beforehand in consultation with GL Wind.

5.5.4 Glass Fibre Reinforced Plastics (GRP)

(1) To determine the strength and the stiffness of materials used for structural members at allowable ambient temperatures between -30 °C and +50 °C, at least the following tests shall be performed by a laboratory acknowledged by GL Wind or an accredited laboratory:

Note:

The properties of the fibres and size are more important than those of the non-woven fabric.

Matrix and bonding material:

– determination of temperature of deflection under load (according to DIN EN ISO 75-2, method A, with at least 3 specimens); minimum temperature for the glass transition temperature according to Section 5.5.2.2, para 4

Composite:

– tension test parallel to the fibre direction (DIN EN ISO 527-5, Type A) with a minimum of 6 specimens to determine tensile strength, failure strain, E-modulus and Poisson’s number

– tension test perpendicular to the fibre direction (DIN EN ISO 527-5, Type B) with a minimum of 6 specimens to determine tensile strength, failure strain and E-modulus

– compression test parallel to the fibre direction (DIN EN ISO 14126), test piece form B with a minimum of 6 specimens to determine compressive strength, failure strain and E-modulus

– tension test for ± 45° laminates (DIN EN ISO 14129) with a minimum of 6 specimens to determine the shear strength

– compression test perpendicular to the fibre direction (DIN 65375) with a minimum of 6 specimens to determine compressive strength and failure strain

(2) For allowable ambient temperatures lower than -30 °C, at least the following tests shall be additionally necessary:

Matrix and bonding material:

– determination of the dynamic mechanical properties (according to DIN EN ISO 6721-2) for the matrix and the bonding material with a starting temperature which is 10 °C beneath the lowest allowable ambient temperature; 3 specimens

– lap-shear test following the lines of DIN EN 1465 or equivalent tests at room temperature and at the lowest allowable ambient temperature; 6 specimens each. The test procedure and production of the specimens shall be agreed with GL Wind in advance.

Composite:

– tension test perpendicular to the fibre direction (DIN EN ISO 527-5, Type B) with a minimum of 6 specimens to determine tensile strength, failure strain and E-modulus for the lowest allowable ambient temperature

– tension test for ± 45° laminates (DIN EN ISO 14129) with a minimum of 6 specimens to determine the shear stress and the shear modulus for the lowest allowable ambient temperature

(3) Other quantities which may be needed can be derived from the test values or taken from the literature. Other standards can be chosen after prior consultation of GL Wind. The test results shall as a rule be verified every 4 years.

(4) The slope parameter m in factor C_{1b} for the fatigue verification as per Section 5.5.2.4, para 3, may be assumed as follows with consideration of Section 3.3.3.4, para 4:

– m = 9 for laminates with polyester resin matrix

– m = 10 for laminates with epoxy resin matrix

(5) This value of m applies without further verification for laminates with a fibre content of at least 30 % and at most 55 % by volume. For other fibre volume contents and matrix resins, an appropriate analysis (S/N curve) shall be performed.

(6) The amplitude of the characteristic structural member resistances for load cycle number N=1 may be assumed as

$$R_{k,A} = (R_{k,t}+|R_{k,c}|)/2 \tag{5.5.8}$$

(7) The factor C_{2x} applies for the influence of ambient temperatures between –30 °C and 50 °C, if the drop in the shear or flexural moduli of the laminates at 50 °C compared with that at 23 °C is not greater than 20 %.

(8) Structures whose load-bearing laminate is built up from unidirectional glass-fibre reinforcement layers may be qualified with regard to short-term and fatigue strength by a simplified strain verification. At design values of the actions, the strain along the fibre direction shall remain below the following design values:

– tensile strain $\varepsilon_{Rd,t} \leq 0.35\%$ (5.5.9)

– compressive strain $\varepsilon_{Rd,c} \leq |-0.25|\%$ (5.5.10)

(9) The mean bearing stress of load introduction zones shall not exceed the value of 100 N/mm² in the fibre direction without further verification.

5.5.5 Carbon Fibre Reinforced Plastics (CRP)

(1) The characteristic values prescribed in this section refer to high-tensile (HT) reinforcement fibres. For the verification of other fibre types (HM, HS, IM, pitch-based fibres, “heavy tows” etc.) the analysis shall be agreed with GL Wind (see Section 3.3.3.4, para 5).

(2) In the case of direct contact between CRP and metallic components, possible damages from contact corrosion shall be excluded by suitable measures.

(3) The mechanical properties on compression parallel to the fibre direction shall be proved by tests. The laminate quality of the test specimens shall be equivalent to that of the later production line. The quality of laminate (direction and waviness of fibres, porosity etc.) shall be specified in the production specification for the component.

(4) For the determination of the strength and stiffness of materials used for allowable ambient temperatures between −30 °C and +50 °C, refer to Section 5.5.4, para 1. In deviation from this, two tests shall be made according to the following standards for allowable ambient temperatures between −30 °C and +50 °C:

– tension test perpendicular to the fibre direction (DIN EN 2597) with a minimum of 6 specimens to determine tensile strength, failure strain and E-modulus

– compression test parallel to the fibre direction (DIN EN 2850, draft of April 1998), test piece form A1 (reduction of the free buckling length to 8 mm ± 0.25 mm is allowed) with a minimum of 6 specimens to determine compressive strength and failure strain

(5) For allowable ambient temperatures lower than −30 °C, Section 5.5.4, para 2 shall apply. In deviation from this, a test shall be made according to the following standards in the case of allowable ambient temperatures lower than −30 °C:

– tension test perpendicular to the fibre direction (DIN EN 2597) with a minimum of 6 specimens to determine tensile strength, failure strain and E-modulus

(6) The slope parameter m in factor C1b for the fatigue verification as per Section 5.5.2.4, para 3, may be assumed as m = 14 for CRP. This applies without further verification for laminates with a fibre content of at least 50 % and at most 60 % by volume and an epoxy resin matrix. For other fibre volume contents and matrix resins, an appropriate analysis (S/N curve) shall be performed.

(7) The amplitude of the characteristic structural member resistances for load cycle number N=1 may be assumed as

$$R_{k,A} = (R_{k,t}+|R_{k,c}|)/2 \tag{5.5.11}$$

(8) The factor C_{2x} applies for the influence of ambient temperatures between –30 °C and 50 °C, if the drop in the shear or flexural moduli of the laminates at 50 °C compared with that at 23 °C is no more than 20 %.

(9) Structures whose load-bearing laminate is built up from unidirectional glass-fibre reinforcement layers may be qualified with regard to short-term and fatigue strength by a simplified strain verification, provided a high laminate quality can be verified. At design values of the actions, the strain along the fibre direction shall remain below the following design values for the strains:

– tensile strain $\varepsilon_{Rd,t} \leq 0.24\%$ (5.5.12)

– compressive strain $\varepsilon_{Rd,c} \leq |-0.18|\%$ (5.5.13)

(10) The mean bearing stress of load introduction zones shall not exceed the value of 150 N/mm² in the fibre direction without further verification.

5.5.6 Bonded joints

(1) The strength analysis for bonding shall be performed according to Section 5.5.3, with the necessary changes. Stress concentrations within the bonding surfaces and flaws shall be taken into account (see Section 3.4.5.1, para 2).

(2) The application limits for the adhesive prescribed by the manufacturer shall be observed. Bonded joints shall be so designed that peeling moments or forces are avoided to the greatest possible extent.

(3) If the analyses are based on characteristic values obtained in tests, it shall in each case be checked that the findings concerning stress concentrations in the specimen can be transferred to the actual structural members. If necessary, the characteristic values shall be corrected in proportion to the various stress concentrations.

(4) To determine the allowable shear stress for steady stress curves, lap-shear tests or equivalent tests shall be performed at 23 °C and 50 °C for the adhesive used. The test procedure and production of the specimens shall be agreed with GL Wind in advance. The partial safety factor for the material γ_{Md} shall be applied to the characteristic value that is determined. γ_{Md} shall be obtained by multiplying the partial safety factor γ_{M0} (see Section 5.5.2.4, para 1) by the following reduction factors C_{id}:

C_{1d}	=	1.5	influence of ageing
C_{2d}	=	1.0	temperature effect
C_{3d}	=	1.1	bonding surface reproducibility
C_{4d}	=	1.0	post-cured bond
	=	1.1	non post-cured bond

(5) Without further verification, a characteristic shear stress of

$$\tau_{Rk} = 7 \text{ N/mm}^2 \qquad (5.5.14)$$

can be used for two-component thermosetting adhesives approved by GL. A stress concentration arising in the structural member is covered by this value up to a factor of 3.0.

(6) For the fatigue verification, a characteristic S/N curve shall be determined from tests at 23 °C. The test procedure and production of the specimens shall be agreed with GL Wind in advance. The partial safety factor for the material γ_{Me} shall be applied to the characteristic S/N curve that is determined. γ_{Me} shall be determined by multiplying the partial safety factor γ_{M0} (see Section 5.5.2.4, para 1) with the following reduction factors C_{ie} :

C_{1e}	=	1.0	(only a formal placeholder)
C_{2e}	=	1.1	temperature effect
C_{3e}	=	1.1	bonding surface reproducibility
C_{4e}	=	1.0	post-cured bond
	=	1.1	non post-cured bond

In the fatigue verification, the influence of the mean stress shall be taken into account analogously to Section 5.5.3.2, para 3 and para 4.

(7) The fatigue verification for joints that feature a steady shear stress curve without discontinuities (e.g. connection between web and chord or upper and lower shells for rotor blades) is provided for two-component thermosetting adhesives approved by GL if the stress range from the equivalent constant-range spectrum for 10^7 load cycles is less than

$$\tau_{Rd} = 1.0 \text{ N/mm}^2 \qquad (5.5.15)$$

A stress concentration arising in the structural member is covered by this value up to a factor of 3.0.

(8) For the fatigue verification of point loads (e.g. metallic inserts), a characteristic S/N curve shall be determined from tests at 23 °C. The influence of moisture on the joint shall be taken into account.

5.6 Wood

(1) The verification of the ultimate and serviceability limit states shall as a rule be carried out according to Eurocode 5.

(2) The analysis of dynamically loaded structural members, such as wooden rotor blades, shall be defined in consultation with GL Wind.

(3) Confirmed knowledge of fatigue behaviour of rotor blades constructed from various types of laminated wood currently exists only to a limited extent.

(4) In particular, the long-term effect of environmental influences is largely unknown. Effective moisture-proofing in accordance with the requirements of this Guideline is thus a basic prerequisite for dimensioning to ensure adequate fatigue strength for dynamically loaded structural members, such as rotor blades made of wood.

(5) Connecting elements between blade and hub shall be verified, as for the components of machinery and steel structure, in accordance with Section 5.3.

Appendix 5.A Strength Analyses with the Finite Element Method

5.A.1 General

Requirements and recommendations regarding the definition of objective, type and scope of a strength analysis as well as calculation and details on evaluation and documentation are given in the following. The necessary scope depends on the particular project in each case and can deviate from the requirements described here.

5.A.1.1 Introduction

(1) The goal of this appendix is to provide information and instructions on the strength analyses of the wind turbine with the finite element method (FEM), on the basis of the requirements specified in the Guidelines. Here the aim is to prevent errors in selecting the method, in the modelling and performing of the analysis and in the interpretation of the results, and to permit an assessment of the results that is both independent of the person and program in question and leads to useful structural conclusions. The appendix serves as an application-related supplement to the general guidelines and recommendations which contribute towards the quality assurance of finite element analyses. In this connection, reference is made to the more detailed specialist literature, which includes the publications of NAFEMS (International Association for the Engineering Analysis Community). The following refers primarily to metallic structures. For structures made of fibre reinforced plastics, the statements shall apply with the necessary changes.

(2) In general, strength analysis consists of the following steps, which are described in more detail in the sections below:

– modelling of the structure and the boundary conditions
– determination and modelling of the primary loads and load cases
– execution of the analysis
– verification of the model
– evaluation and assessment of the results

In conclusion, the working steps shall be documented (see Section 5.A.5).

(3) In modelling the structure as well as the boundary conditions and loading, certain simplifications are possible or even necessary, depending on the objective of the analysis and the type of structure. Since these aspects are determined by the possibilities offered by the available programs and computers, as well as by the envisaged extent of analysis, and can also change with the increasing state of knowledge, the following explanations are necessarily expressed in a generalized form, in order that they can remain applicable to a large number of cases. In addition to a short presentation of procedures currently in use, several notes are given on what should be observed during the modelling, analysis and assessment, especially for the various structures and components of wind turbines. Further instructions and information can be obtained from the more detailed specialist literature and from the descriptions of the software.

(4) The type and extent of the analysis depends primarily on the kind of structural response to be assessed. As a rule, the following structural responses are foremost in strength analyses:

– stresses and deformations for specified load conditions
– failure behaviour and magnitude of the failure limit loading (e.g. buckling load)
– eigenvalues for determining critical structural responses

The structural response is either assessed directly or in subsequent calculations.

(5) External loads as per Chapter 4 and possibly additional forces from the dead weight and accelerated masses shall be taken into account as the loading. In the case of time-variant loading, the dynamic behaviour of the structure shall, if applicable, be considered in the form of dynamically increased loads and/or structural responses (e.g. tower or drive train) or, as an alternative, dynamic analyses shall be performed (however, these are not discussed further here).

(6) It shall be noted that the structural response can depend on the loading magnitude in a linear or a nonlinear manner. Nonlinear effects can be of significance in the following cases:

– generally for an analysis of the failure behaviour of the structure
– geometric nonlinearity: for relatively flexible structures with large deformations

– structural nonlinearity: for contact problems or variable boundary conditions, e.g. load-depending opening of bolted connections

– material nonlinearity: nonlinear material behaviour through plastification of structural regions

(7) In the structural design of wind turbines, the deformations and stresses can usually be subdivided into the following categories, depending on the structural conditions:

– global deformations and stresses of the primary structural components (hub, main frame, tower etc.)

– local deformations and stresses of the primary structural components and their structural details (e.g. stiffeners)

– locally increased stresses at structural details

The objective of the strength analysis and the kind of modelling, loading and evaluation can refer to one of these categories, which are described in more detail in Sections 5.A.1.3 to 5.A.1.5.

5.A.1.2 Determining the objective, type and extent of the strength analysis

(1) The objective, type and extent of the strength analysis must be laid down clearly, since these aspects have a decisive effect on the modelling of the structure and the loading.

(2) The objective of the analysis results from the alternatives described in Section 5.A.1.1, para 4, whereby the category of the deformations and stresses to be considered in the analysis must be determined; see also Section 5.A.1.1, para 7 and Sections 5.A.1.3 to 5.A.1.5.

(3) The type of analysis comprises either a linear or a geometric-, structural- and/or material-related non-linear analysis; see Section 5.A.1.1, para 6.

(4) The extent of analysis is mainly oriented towards the selected extent of the model and the necessary mesh fineness; see also Sections 5.A.2.1 to 5.A.2.3.

5.A.1.3 Global deformations and stresses

(1) The structural response under tensile, shear, bending and torsional load consists of global (i.e. large-area) deformations and stresses. Particularly for complex geometries (e.g. main frame) or loads (e.g. hub), the structural responses to be expected cannot be modelled by the laws of the beam or plate theory.

(2) The resulting stresses are nominal stresses, i.e. stresses which would result from integral quantities of the section loads and cross-section values. Global nominal stresses contain no local stress increases; these must be superposed additionally (see Sections 5. A.1.4 and 5.A.1.5.

5.A.1.4 Local deformations and stresses

(1) In the structural details of components such as stiffeners and plates, additional local deformations and stresses can occur as a result of the local loading.

(2) The structural details of components include stiffeners, webs, flange plates and cut-outs, radii and transitions.

(3) The resulting local stresses are also nominal stresses (see Section 5.A.1.3, para 2) which have superposed themselves on the global stresses. This superposition can arise through eccentricities or other redirectionings in the force path which generate additional moments or forces locally. In addition, locally increased stresses can arise at structural details.

5.A.1.5 Locally increased stresses

(1) At structural details and discontinuities, locally increased stresses which must be assessed especially in respect of fatigue strength can occur. Here a distinction is made between two types of stresses:

– the maximum stress in the notch root; see para 2

– the structural or hot-spot stress defined specially for welded joints; see para 3

(2) The maximum stress at notched components can exceed the elastic limit of the material. Instead of the nonlinear notch stress σ and strain ε, the notch stress σ_k can be determined and assessed for normal cases under the assumption of linear-elastic material behaviour. In the case of very sharp notches, the local supporting effect of the (ductile) material can be considered.

(3) In complex welded structures, only the stress increase as a result of the structural geometry is generally calculated in the FE analysis, whilst that caused by the weld toe is (only) considered during the assessment. This leads to the structural or hot-spot stress σ_S at welds, and this is determined under the assumption of elastic material behaviour.

(4) Apart from a direct calculation of the locally increased stresses, it is possible to use catalogued stress concentration factors or detail categories. When using concentration factors and detail categories, the associated nominal stresses must be determined with sufficient accuracy in accordance with their definition. Moreover, the ranges of application and validity for the catalogued data shall be observed.

(5) Further notes on the definition and determination of locally increased stresses are given in the fatigue strength analyses in Chapter 5.

5.A.2 Modelling of the structure

5.A.2.1 Extent of the model

(1) FE models for wind turbines are usually produced for the individual components. For these models, it shall be ensured that meaningful boundary conditions are introduced, in order to represent the interaction with the neighbouring structural areas in a suitable way. If necessary, adjacent components shall also be considered in the model (see Fig. 5.A.1). Nonlinear effects shall be taken into account or linearized by means of suitable simplifications wherever applicable. If there is any risk that the results can be impaired by idealized boundary conditions, a correspondingly enlarged distance should be provided between the model boundary and the structural area under consideration.

(2) Partial models or submodels are used for local strength analyses of parts of the wind turbine components (see Fig. 5.A.2). Like 3D global models, partial models or submodels are generally used to analyse the complex, three-dimensional strength behaviour.

(3) Local models are used for the strength analysis of secondary or special components as well as structural details. The main focus of the investigations is usually on the analysis of the local structural behaviour and/or the locally increased stresses at structural details and discontinuities (detail from Fig. 5.A.3 or Fig. 5.A.4), which can be included in a coarse model (Fig. 5.A.3) but have no or only a minor influence on the current objective of the strength analysis (cf. Section 5.A.1.1, para 3). For this reason, the meshing of the half-model in Fig. 5.A.3 has been selected appropriately for the task at hand (sensitivity study), whereas it is not suitable for quantitative stress analyses of the supporting bracket.

Example:

The objective of the analysis for the supporting bracket in Fig. 5.A.4 (application of the submodel technique with the aim of analysing the influence of the weld seam of the supporting brackets with respect to the fatigue behaviour of the entire structure) is fundamental different to the objective of analysis using the half-model (sensitivity study on the arrangement of the tower shell at the tower top flange / detail 1 in Fig. 5.A.3).

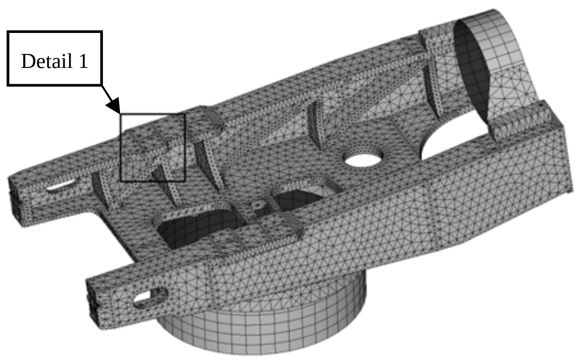


Fig. 5.A.1 Model of a main frame with adjacent components

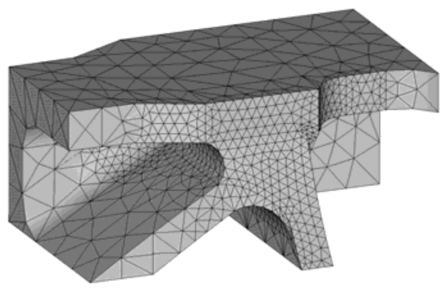


Fig. 5.A.2 Submodel of the main frame (detail 1 from Fig. 5.A.1)

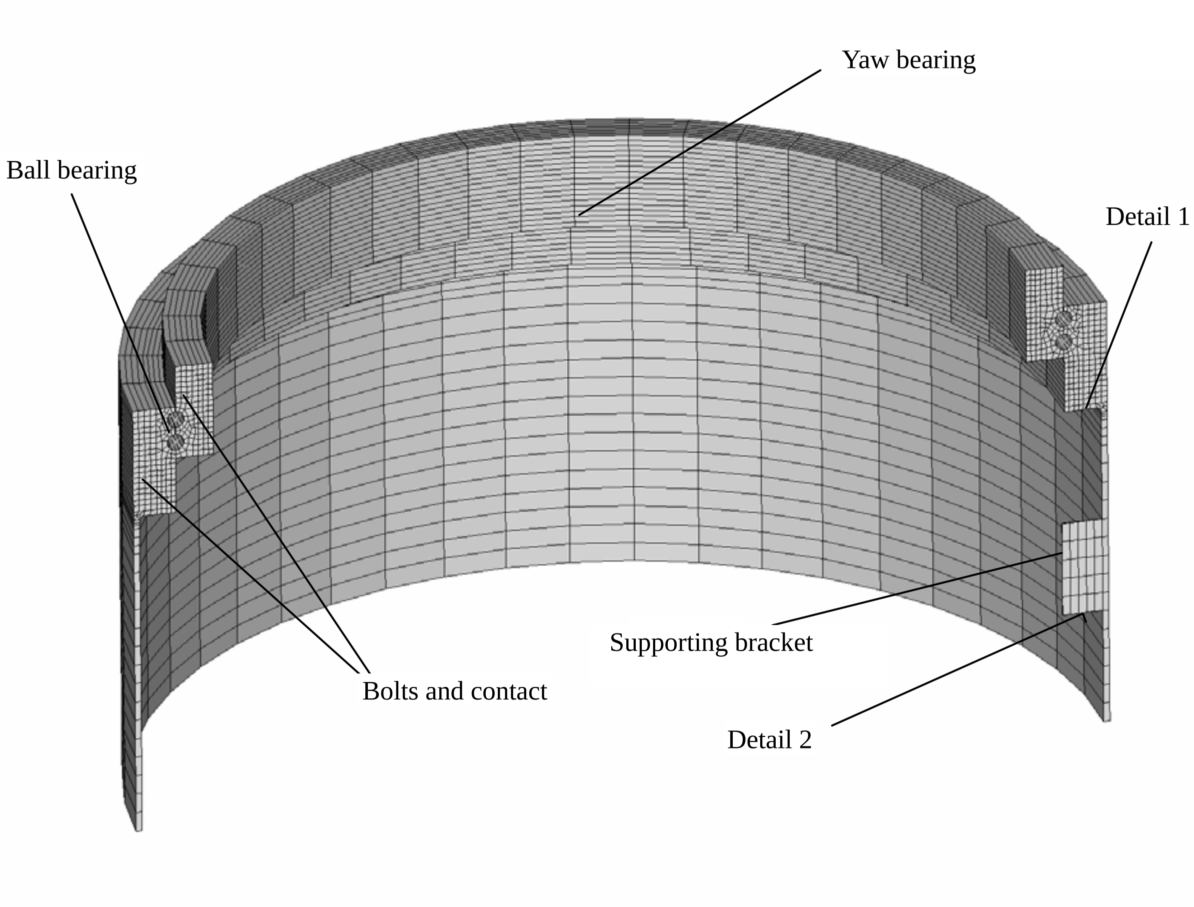


Fig. 5.A.3 Half-model for a sensitivity study on the arrangement of the yaw bearing at the tower top

5.A.2.2 Selecting the elements

(1) Selecting the type of element used primarily depends on the objective of the analysis. The characteristics of the selected element type must be able to reflect with sufficient accuracy the stiffness of the structure and the stresses to be analysed. When carrying out a strength analysis, adequate knowledge of the characteristics of the elements used is a prerequisite; the program documentation and applicable literature should be consulted.

(2) Usually, the following types of elements are used for strength calculations of wind turbine structures:

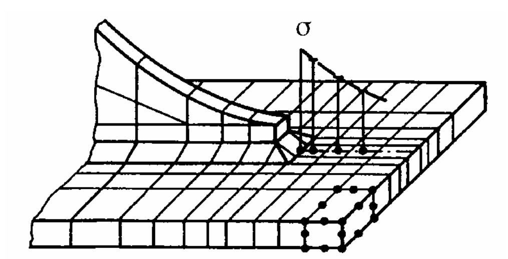


Fig. 5.A.4 Local model (detail 2 from Fig. 5.A.3)

– truss elements (1D elements with axial stiffness, but without bending stiffness)

– beam elements (1D elements with axial, shear, bending and torsional stiffness)

– plate and shell elements (2D elements with membrane, bending and torsional stiffness)

– solid elements (3D elements)

– boundary and spring elements

– contact elements (spring elements with nonlinear spring characteristic)

When using different element types, attention should be paid to the compatibility of the displacement functions as well as the transferability of the boundary loads and stresses, particularly for the coupling of elements with and without bending stiffness at the nodes.

(3) The selected element types must reflect the deformations and stresses for the load cases or the eigenvalues to be analysed, or reflect the failure behaviour when determining the magnitude of the failure limit loading. In some cases, certain effects of secondary importance can be excluded by suitable selection of the elements. A number of notes on the element types commonly used in the modelling of wind turbine structures are given below.

(4) In general, it must be determined how and to what extent the bending of components must be considered in the strength analysis. In cases of pure bending behaviour, the principles of the beam or shell theory can be applied with the corresponding element types. When using a solid element, a higher-order displacement function (e.g. with additional mid-side nodes) or a finer mesh may have to be chosen, if a corresponding bending behaviour is to be permitted.

(5) In local models, all stiffness components are generally of significance – even those of structural details – so that here plate, shell or solid elements are suitable. Further information on selecting elements in the calculation of locally increased stresses is given in Chapter 5 “Strength Analyses”.

(6) With a view to evaluating the results, the arrangement of shell elements at the model surface may be useful for indicating the surface stress, since here the stress condition is biaxial. Here it shall be observed that the shell elements may not be allowed to exert any influence on the local stiffness.

5.A.2.3 Element subdivision

(1) The mesh fineness shall be chosen by considering the element characteristics in such a way that the stiffness conditions of the structure, the types of stresses to be analysed, and possibly also the failure behaviour are modelled with sufficient accuracy. The selection of the element type and the mesh fineness exert a particularly great influence on the calculation of locally increased stresses and also of the failure limit loading. Insufficiently fine mesh subdivision frequently leads to a considerable underestimation of the local stress peaks and overestimation of the failure limit loading. A few notes on the mesh subdivision normally used in modelling wind turbine structures are given below.

(2) In subdividing the mesh, the structural geometry and the positions of load introductions or supports shall be taken into account.

(3) Whilst observing the element characteristics, the element proportions shall be selected so that the stiffnesses and the resulting deformations and stresses are not falsified. For simple displacement functions, the ratio of the edge lengths of the element should be not greater than 3 : 1.

(4) In calculating locally increased stresses, the mesh fineness shall be increased gradually in accordance with the stress gradient. Further notes on mesh fineness in the calculation of locally increased stresses are given in the relevant literature (e.g. NAFEMS).

5.A.2.4 Simplifications

(1) Owing to the complexity of the wind turbine structure, simplifications are generally necessary in modelling, especially for global strength analyses. Simplifications are permissible, provided that the results are only impaired to a negligible extent.

(2) Small secondary components or details that only affect the stiffness of the global model to a lesser extent can be neglected in the modelling. Examples of this are small cut-outs, drill-holes and radii; their local stress increasing effects shall, however, be considered in a suitable manner (e.g. through application of stress concentration factors).

(3) Large cut-outs influence the global structure and always exert an effect in local structure, and shall therefore be considered in all cases.

(4) Steps in the plate thickness or profile dimensions should lie on the element boundaries as far as possible. Insofar as they do not lie on the element boundaries, they shall be taken into account through correspondingly adapted element data or characteristics to obtain an equivalent stiffness.

(5) Plane elements should generally be positioned in the mid-plane of the corresponding components.

5.A.2.5 Boundary conditions and supports

(1) The provision of supports for the model by suppressing or prescribing of displacements or rotations serves several purposes:

– to suppress rigid body displacements and rotations of the model
– to model physically existing supporting points
– to model the interaction with the adjacent structural regions at the model edges

It shall be ensured that the supports do not cause any unrealistic constraints of the displacements or rotations.

(2) Physically existent supports that take up forces and moments should be modelled as realistically as possible with the actual supporting length and spring stiffness.

(3) For the strength analysis of the parts of the structures and components of wind turbines, the interaction with neighbouring structural regions at the model edges should also be modelled as realistically as possible. This can be done at planes of symmetry by means of symmetry or asymmetry conditions, insofar as the load and/or the structure is distributed symmetrically or asymmetrically. In certain cases, the interaction can also be portrayed by prescribed stresses, or forces and moments, at the boundary. These parameters can be obtained, for example, from the structural analyses of larger regions (submodel technique) or from beam forces and moments (e.g. tower segment). Nonlinear boundary conditions shall be taken into account, and if applicable can be linearized (e.g. opening in flange joints, load transfer for roller and sliding bearing only via compressive loads).

5.A.2.6 Checking the input data

(1) The input data used for modelling the structural geometry and for the material characteristics shall be checked thoroughly for errors. The effectiveness of the data check can be increased appreciably by visualization of the data.

(2) The geometry of the finite element mesh should generally be reviewed by visual inspection. Here the possibility that individual elements have been entered twice by mistake, or that adjacent elements are not connected with each other, should also be taken into account. Furthermore, geometry data which are not immediately visible, such as the thickness of 2D elements or the cross-sectional properties of 1D elements, should also be checked.

(3) In addition to the geometry data, the material data as well as the boundary conditions and supports that were introduced should be checked carefully. Note that these parameters generally exert a considerable influence on the results.

(4) The checks performed shall be documented.

(5) Further notes on the extent, the requirements and the documentation are given in Section 5.A.5.

5.A.3 Loading of the structure

5.A.3.1 General

The relevant loads for the strength analyses of structures and components of a wind turbine shall be applied in accordance with Section 5.2.1 “General notes on the loading of the structure”.

5.A.3.2 Modelling the loads

(1) The loads shall be modelled realistically. If necessary, the modelling of the structure must be adapted to the modelling of the loads; see Section 5.A.2.3, para 2.

(2) Distributed loads (e.g. line or area loads) shall be converted – if applicable – to the equivalent node forces and moments, considering the displacement function of the elements.

(3) If the boundary deformations derived from coarse models of large structural areas are applied to local models, the correspondingly interpolated values shall be specified for the intermediate nodes.

5.A.3.3 Checking the load input

(1) The input data for the loads shall be checked thoroughly for errors. As is the case for the structural geometry, here too the effectiveness of the check can be increased considerably with the aid of suitable checking programs and visualization of the data.

(2) It is particularly important to check the sums of the forces and moments. For balanced load cases, it must be ensured that the residual forces and moments are negligible and that the reaction forces and moments correspond to the applied loads.

(3) The checks performed shall be documented. Further notes on the extent, the requirements and the documentation are given in Section 5.A.5.

5.A.4 Calculation and evaluation of the results

5.A.4.1 Plausibility of the results

(1) During the evaluation, the results shall be checked for plausibility. This involves in particular the visual presentation and checking of the deformations to see whether their magnitudes lie within the expected range and whether their distributions are meaningful with respect to the loads and boundary conditions or supports.

(2) Furthermore, it shall be checked whether the forces and moments at the supports lie within the expected order of magnitude or are negligibly small.

(3) For local models with specified boundary deformations from the models of large structural regions, it is necessary to check whether the stresses near the boundaries correspond for the two models (verification of the submodel).

(4) Stress peaks shall be checked for plausibility of the location, distribution and magnitude of the stresses with regard to the loads and boundary conditions. Insofar as it is possible to define nominal stresses, concentration factors can be determined from the stress distribution and compared with tabulated concentration factors.

(5) For nonlinear computations, it is necessary to check whether the solution was determined with sufficient accuracy in the nonlinear zone.

5.A.4.2 Deformations

The deformations of the structure should generally be plotted so that other persons can perform a plausibility check of the results.

5.A.4.3 Stresses

(1) In strength analyses for specified load conditions (e.g. ultimate loads), the stresses of the entire component shall generally be represented pictorially. An exception is the analysis of locally increased stresses, for which it is possible that only the maximum value may be relevant.

(2) The stresses shall be checked with respect to the permissible values, as defined in Chapter 5. The corresponding stress category must be observed; cf. Section 5.A.1.1, para 7.

(3) For the stress evaluation, the changes in stress between the element centre and the element edge or corner must be taken into account. Simplifications in the model in relation to the real structure shall be included in the assessment. If cut-outs are considered in models with a coarse mesh in a simplified manner, the stresses shall be referred to the residual cross-section next to the cut-out.

(4) In models with relatively coarse meshes, local stress increases at existing structural details and discontinuities shall be included in the assessment, if their effect is not considered separately.

(5) To improve the clarity, it is recommended that the assessment be carried out with the aid of reserve factors which are obtained from the relationship between the permissible and the existing stress. In the case of extensive models, result tables should be set up.

(6) For analyses that are nonlinear with respect to materials, the local strain shall generally also be determined and assessed in addition to the local elastic-plastic stress.

(7) For the fatigue verification of bolted connections in accordance with Section 6.5.2 by means of FEM, the edge stresses resulting from the tensile and bending stresses shall be considered.

5.A.4.4 Fatigue strength

(1) Fatigue strength aspects should generally be taken into account in the assessment of wind turbine components, owing to the cyclic stresses that are usually present.

(2) In the assessment of the stresses with regard to fatigue strength, the stress type shall be considered, i.e. whether nominal stresses or locally increased notch or structural stresses are calculated with the chosen model; see also Section 5.A.1.1, para 7.

(3) For the assessment, it is recommended that utilisation ratio or reserve factors be applied.

(4) Further notes, particularly on special fatigue analyses, are given in Chapter 5.

5.A.4.5 Presentation of the results

(1) The results obtained and the conclusions made on the basis of these results shall be documented completely and clearly.

(2) The documentation can take the form of graphics and lists. In particular, lists are necessary when the graphic form is not able to represent the results with sufficient accuracy. Extensive lists should be sorted, for example according to utilisation ratio or reserve factors.

(3) All symbols and designations that are used should be explained, if possible in or before the plots and lists.

(4) Further notes on the extent, the requirements and the documentation are given in Section 5.A.5.4.

5.A.5 Documentation of FE analyses for the certification of wind turbines

5.A.5.1 General

The formal and content-related requirements for the documentation of computational analyses for the certification of wind turbine structures are set out in the following. The necessary scope may deviate from that described here.

5.A.5.2 General requirements for the documentation

(1) In this section, the requirements for the documentation are to a large extent presented independently of the analysis approach (analytical or FEM). They are oriented towards [5.9].

(2) From the technical and calculation viewpoint, the documentation of the computational analyses shall form a unified whole together with all other documents (drawings, specifications).

(3) The document shall have an unambiguous title designation with reference and revision number. The creation and release date shall be easily recognizable without doubt.

(4) The documentation shall be preceded by an overall table of contents reflecting the current state of revision in each case.

(5) The following shall be indicated:

– definition of the objective, type (methods used and theories applied) as well as extent of the calculation

– overall result, with statement of the primary load cases and indication of the utilisation ratio and/or reserve factors that may be of special use for future margin studies based on these results (cf. also Section 5.3.3.2.2)

(6) The terms, symbols and units shall be described and applied clearly in the documentation.

(7) The selected ordering systems shall be presented clearly. If several ordering systems are used, then the ordering systems shall be allocated unambiguously to each other. The ordering systems include:

– coordinate systems

– sign conventions (e.g. for section or displacement quantities, or for stresses and strains)

– allocations (e.g. item numbers, components, node-element numbering)

– load cases and combination of load cases, subsystems of an overall system

The allocation of the data used in the ordering systems (e.g. entries and results) shall be clearly recognizable.

(8) Citations of standards and guidelines applied and of references (also of special analysis methods or models) reflecting the state of the art shall be named and listed according to their order of appearance in the documentation.

(9) The reference of the certified loads is made through statement of the load documentation with naming of the title, reference number and revision number. The partial safety factors used for the loads shall be documented. Insofar as time series are applied in the fatigue analyses, the load spectra shall be appended in graphic form to the documentation, in order to show without doubt that the valid and approved loads were used.

(10) If mechanical models are used for individual conditioning/adaptation of the loads, their derivation shall be documented. This should preferably be done in pictorial form with the aid of sketches or (modified) assembly drawings. The results shall be presented as partial or interim results (see Section 5.A.5.4.2).

(11) As substantiation of the dimensions and eccentricities used in the computational analyses and of the mechanical boundary conditions and simplifications on which the calculations are based, the following shall be appended to the documentation:

– assembly drawings and sectional drawings which show the geometry clearly

– production and material specifications (for checking the design limits and the analysis hypothesis)

– individual parts drawings and/or type sheets of adjacent components, as well as the spring characteristics of connected elastomer bushings the data of which were used in the analyses

Note:

If the documents were submitted separately within the scope of certification for adjacent components or structures, it shall suffice to name the title, reference number and revision number of the relevant document.

5.A.5.3 Special requirements for the documentation

(1) The following requirements shall be applied especially for the documentation of FE analyses. This section is concerned with the input data, whilst Section 5.A.5.4 addresses the presentation of results. Insofar applicable, the documentation shall contain the following data:

– identification of the program used (name, variant and version designation; if applicable, designations of various software packages for preprocessing, post-processing and the solution phase)

– clear presentation of the inputs for the actions on the mechanical structure model. Apart from the loads named in Section 5.A.5.2, para 9, actions include in particular temperatures, prestresses and, if applicable, imperfections.

– description of the model through naming or presentation of the following:

  – the elements used (1D, 2D, 3D elements; naming of the element approach; contact and mass elements)

  – the additional element options (e.g. plane stress approach, axial symmetry)

  – the additional element constants (e.g. moment of inertia, definition of cross-section, element thickness)

  – the material values (e.g. elastic, plastic; friction coefficient)

  – the meshed FE model from all relevant perspectives, to demonstrate the level of detail and to clarify the support and boundary conditions. Here details shall be portrayed with a zoomed perspective and/or sections of the model (e.g. internal view).

  – all geometric simplifications. Neglected drill-holes, cut-outs, radii etc. shall be stated and justified with reference to the results.

  – the load introduction (as single, area or volume loads), according to position, size and direction of effect

  – the coupling conditions, mergings and the contact elements

  – the elements used for implementing bolt and spring prestressing

  – options used in the model but not listed until now, with justifications

(2) The inputs on which the calculations are based shall be prepared in one of the programs and documented in an appropriate number of overall and partial presentations. These inputs shall be shown in graphic form. They may only be printed out in tabular form if the overview and clarity of the data set cannot be improved considerably by a graphic presentation. It is important that any necessary supplements and explanations (even in handwriting) be appended.

5.A.5.4 Results

5.A.5.4.1 General

(1) The results can generally be divided into the partial and final results.

(2) If numerical results are to be processed further, it shall be observed that the accuracy of the overall result can depend strongly on the quality of the model.

5.A.5.4.2 Partial results

(1) Partial or interim results shall be used in the documentation for checking the plausibility of the input data (see Section 5.A.5.3).

(2) As and where applicable, the following partial results shall be documented:

– assessment of the mesh quality (in the highly-stressed regions)

  – through representation of the elements in the FE model with high distortions, warping and inadmissibly narrow or wide angles of the element edges

  – through error estimations of the elements (e.g. by means of energy hypotheses)

  – by stating the results of sensitivity studies with modified meshing of the entire FE model or of a partial model, especially for complex systems

– The influence

  – of the load introduction (e.g. transmission of individual loads using auxiliary structures, bolt prestressing, spoke wheel / St. Venant's principle)

  – of the symmetry conditions and coupling conditions used (St. Venant's principle)

  – of the deviations and simplifications (radii, drill-holes, averaged stiffnesses etc.)

  shall be assessed with regard to the results of the most highly stressed regions using deformation checks in relation to the unit loads applied. For this, the representation of the principal stresses and strains and their directions is useful. These results shall be used as a basis of argumentation for the selected boundary conditions and simplifications.

– When using nonlinearities, the connection between external load and the stress (i.e. structural response) shall be presented in graphic and tabular form (e.g. nonlinear curve of the bolt stress versus the load for partial openings in the joints). Any linearizations undertaken shall be described.

– the assessment on the selection of evaluation regions (e.g. geometric notches) for the component or the structure. Here figures shall be used to indicate clearly the position in the meshed global model. Insofar applicable, lists of the stresses (strains) shall be given for these evaluation regions, at least with unit loads as the transfer factor (or transfer function).

– It shall be shown that the stress concentration in the submodel to be investigated exerts no influence on the result at the submodel edge (St. Venant's principle).

– a check of the equilibrium through an analysis using reaction forces

– quality assessment through comparison of the calculated masses of the FE model with the drawing specifications

– statement of the assessment data from the FE model (e.g. averaged or non-averaged element/node results)

(3) The calculation results shall be prepared in one of the programs and documented in an appropriate number of overall and partial presentations. These results shall be shown in graphic form. They may only be printed out in tabular form if the overview and clarity of the data set cannot be improved considerably by a graphic presentation. It is important that any necessary supplements and explanations (even in handwriting) be appended.

(4) For margin studies, it is permissible to use certified models and the transfer factors calculated therein.

(5) In the case of frequent structural repetitions, reference examples can be applied.

(6) The FE results and the models shall be submitted with the documentation on appropriate data media in generally readable form (i.e. no machine or program code, unless expressly permitted/requested by GL Wind).

5.A.5.4.3 Final results

(1) The final result is the objective defined as per Section 5.A.5.2, para 5. Here this involves the results mentioned in Section 5.A.4.5. The results shall be documented separately from the viewpoint of the ultimate load and fatigue strength.

(2) Documentation of the ultimate strength analysis:

– The results of the ultimate loads shall be presented, with comments, preferably as a combination of the unit loads. It shall be ensured that there is perfect correspondence between the loads and their representation in the graphics/lists.

– A comparison between the calculated (equivalent) stresses and the design value shall be documented in accordance with the specifications in Chapter 5.

(3) Documentation of the fatigue strength analysis:

– The results shall be presented with consideration of the provisions described in Chapters 5 to 7 and with reference to the global FE model or previously selected regions (e.g. critical cross-sections, hot spots).

Rules and Guidelines

IV *Industrial Services*

2 Guideline for the Certification of Offshore Wind Turbines

6 Structures

Germanischer Lloyd
WindEnergie

Edition 2005

Table of Contents

6.1 General Requirements

6.1.1 Scope

(1) The term “structures of an offshore wind turbine” in this Guideline refers to the load-bearing components. These include the rotor blades, castings, forgings and welded structures, nacelle cover and spinner, tower and foundation as well as bolts for connecting these structures. Machinery components are treated separately; see Chapter 7.

(2) The following sections of this Chapter explain the scope and type of the assessment documents to be submitted as well as the analyses to be performed. Furthermore, the requirements for manufacturers, materials and final inspections are described, and reference is made to Chapter 3 where relevant.

(3) For the computational strength analysis, Chapter 5 shall be taken into account. The design loads (see Section 1.3.2.3, para 3) for the load cases determined according to Chapter 4 shall be applied.

6.1.2 General design considerations

(1) Structural integrity throughout the lifetime of an offshore installation depends on the thoroughness of design investigations, on the quality of materials and manufacture, and on the in-service inspection and maintenance. This Section deals with the necessary design investigations.

(2) Serviceability and functional considerations may have influence on the structural design. They will generally be specified by the owner/operator of the installation, but will be taken into account in the design review by GL Wind where relevant (see also Section 6.1.4).

(3) The soil stiffness is to be represented as precisely as practicable when designing structures resting on or penetrating into the sea floor (see also Section 6.7).

(4) For calculations analysing the dynamic behaviour of the complete structure (global behaviour), the mass distribution may generally be simulated in a simplified form, using equivalent or lumped masses. Details may have to be agreed upon (see also Section 6.6.4).

6.1.3 Loads on the structure

(1) In general, the determination of section forces of the support structure, by time domain computations considering simultaneous load effects and structure elasticity, is state-of-the-art and shall be favoured. Between the internal forces and moments determined in this way, it is permissible to interpolate linearly at arbitrary points.

(2) The loads on the support structure shall be calculated in accordance with Chapter 4.

(3) Full dynamic computations of the section forces for the complete system of the offshore wind turbine take into account the control behaviour of the turbine, the stiffnesses and the dynamic response of the support structure. After dimensioning, the stiffnesses and natural frequencies of the system “support structure” including the influence of the machinery (topsides structure) masses and inertia shall satisfy the relevant assumptions of the load analysis. If there is any deviation, review of the analysed load is necessary.

(4) If the section forces for fixed offshore wind turbines are determined with the aid of a quasi-static analysis, a dynamic amplification factor has to be considered. The loading is increased by the dynamic amplification factor to consider dynamic response of the offshore wind turbine on varying wind and wave loading. Different dynamic amplification factors may have to be applied for wind load on the turbine rotor, the support structure and wave load on the support structure. The selection of the dynamic amplification factor shall be agreed with GL Wind.

(5) If the section forces are determined with the aid of a quasi-static analysis, the horizontal thrust on the machinery part of the offshore wind turbines as well as the wind load on the tower in the load cases calculated with the extreme wind speed model (EWM) and with the turbine in the “out of service state” DLC 6.1, DLC 6.2, DLC 6.3, DLC 7.1 and DLC 8.2, is to be increased by the dynamic amplification factor. For aeroelastic computation of the section forces, the application of the dynamic amplification factor on the horizontal thrust on the machinery of the offshore wind turbines may be dispensed with, provided that the turbulence is taken into account appropriately (in consultation with GL Wind). The load on the support structure due to wind shall be enlarged by the gust reaction factor. The gust reaction factor can be determined in accordance with e.g. ENV 1991 (Eurocode 1) or DIN 1055-4.

(6) If wave induced forces are determined with the aid of a quasi-static analysis, the dynamic amplification factor on wave loading may be determined with the aid of the model of the single degree-of-freedom system upon agreement with GL Wind. The assumed total damping ratio depends on the turbine and support structure design. As a rough approximation the total damping ratio may be assumed to be $\beta \approx 0.01$. For vibrations in rotor axis direction the total damping ratio may be assumed to be $\beta_x \approx 0.07$ if the turbine is in power production operation.

Note:

For the stiffnesses and the dynamic response, possible bandwidths within the load calculations shall be assumed and documented.

(7) Wind-induced transverse vibrations
Lean structures like circular-, or near-circular-, section steel towers may be sensitive in view of vortex-induced vibrations transverse to the wind direction. The loading from these vibrations may be determined as given in Section 6.6.4.2.2 and 6.8.4 or in accordance with Eurocode 1, Chapter 9 and Annex C.

(8) Wave and/or current induced transverse vibrations
Vortex-induced vibrations on structures as mentioned in para 7 may also occur because of waves and/or sea currents. It shall be investigated if the structure is sensitive in view of these excitations. The analysis may be performed according to draft ISO 19902 [5.10], A.9.12.

(9) Global or local vortex induced vibrations due to wind and/or wave action shall be included in fatigue analysis if applicable.

(10) It shall be noticed that local forces of individual members of the structure may be influenced by vortex induced vibrations of the members themselves, even if they do not influence the global offshore wind turbine's behaviour.

6.1.4 Serviceability limit state

(1) For the analyses in the serviceability limit states, the design values of the actions shall be determined using the characteristic values (see Section 4.3.7.1).

(2) For steel structures, the statements made in Section 5.3.5 shall be taken into account.

(3) Structures of reinforced concrete and preloaded concrete shall be verified in accordance with Section 5.4.2.3.

(4) In supplement to Section 1.3.2, some examples of the limit states listed there are given below:

– The deformation limit state is for instance defined by the maintenance of a safety gap (distance rotor blade / tower or rotor blade / guy wire). It may also happen that thermal expansion becomes decisive.

– The vibration limit state is for instance defined by keeping vibration amplitudes or accelerations within acceptable limits. This limit state is usually enforced via the control system (see Section 2.3.2).

– The crack-formation limit state shall be observed in the case of concrete structures. Crack widths shall be kept within acceptable limits.

– The stress or strain limit state is for instance defined by the limitation of tensile and/or compressive stresses in concrete structures or the precondition that steel structures shall not undergo plastification under characteristic actions.

6.1.5 Durability

Particular attention shall be paid to durability, as long intervals of time elapse between periodical inspections of the offshore wind turbine structures. The basic principles for durable construction are set out e.g. in ENV 1992, Section 2.4 and DIN 1045 for reinforced and preloaded concrete structures; in DIN 18800, Part 1, Section 7.7, DIN 4131, DIN 4133 and DIN EN ISO 12944 for steel structures.

6.1.6 Model tests

Model investigations (tests) may be accepted as a supplement to structural analysis provided that a recognized institution is involved and the particulars have been agreed. In special cases model tests may be required.

6.2 Rotor Blades

6.2.1 General

6.2.1.1 Designs

(1) The strength and serviceability of rotor blades of most offshore wind turbines with horizontal axes can be analysed on the basis of the contents of this Chapter. Analysis of unusual designs shall be agreed with GL Wind.

(2) Typical materials for rotor blades and connection components are fibre reinforced plastics (FRP) and wood. Strength analysis of rotor blades and blade parts made from these materials shall be carried out as per Chapter 5.

(3) The rotor blades shall be equipped with a suitable lightning protection system in accordance with Section 8.9.3.9. Proof shall be provided for the connection of the conductor cross-sections specified there to the blade structure. The lightning conduction arrangements shall be such that the blade-hub transition or other attachments are able to conduct he lightning current safely from the rotor blade to the tower.

6.2.1.2 Requirements for manufacturers

See Section 5.5.2.1.

6.2.1.3 Requirements for materials

See Section 5.5.2.2.

6.2.2 Assessment documents

a documents for the material tests listed in Section 5.5.2.2. The tests shall be performed by a test laboratory acknowledged according to Section 6.2.5.1, para 2.

b written documents subject to assessment for the verifications set out in Section 6.2.4

c drawings for the blade in the delivery condition

d drawings and specifications describing the production sequence

e coordinates of the profile cross-sections, in ASCII or MS Excel format

f documents for the blade test (see Section 6.2.5)

6.2.3 Delivery checks

6.2.3.1 Final tests

(1) In addition to the quality controls during production, the manufacturer or someone appointed by him shall carry out final tests on a scale agreed with GL Wind. The quality documentation applicable to the rotor blade type shall be submitted to GL Wind for assessment before series production commences (see Section 1.2.2.5).

(2) At least the checks listed below are required as part of the final tests:

– plausibility and completeness check of the data and entries in test sheets, control sheets, work-progress slips and check sheets which accompany the rotor blade through the production process

– check of the geometry including accuracy of profile data (for at least one blade of a series, determination of the natural frequencies in flapwise and edgewise directions; in the event of large deviations in mass and center of gravity, this shall be carried out for a number of blades)

– determination of the mass and the centre of gravity

– check of the bonding through visual inspection of the exterior and, insofar possible, interior of the blade

– check for acceptability of the material characteristics on the basis of random samples (scope to be agreed with GL Wind)

– check of the balance quality for each set of blades; requirements as per Section 4.3.2.1

6.2.3.2 Documentation

(1) On completion of the final tests a delivery document containing at least the following data shall be issued for each rotor blade:

– rotor blade type

– serial number and year of manufacture

– dimensions

– mass and centre of gravity

– type of aerodynamic brake, if applicable

(2) Each rotor blade shall be permanently marked with its serial number in an easily accessible position. Furthermore, an identification plate shall be attached with the following information:

– manufacturer

– type designation

– serial number

6.2.3.3 Defects

Deviations from the manufacturing processes shall be documented. If safety-relevant defects are detected during manufacturing surveillance, corrective measures shall be defined in consultation with GL Wind.

6.2.4 Analyses

6.2.4.1 Analysis concept

(1) It shall be shown that the design values of the component resistances R_d are larger than the design values of the actions S_d . The strength of rotor blades shall as a rule be verified by an extreme strength analysis and a fatigue analysis. Areas under compressive and/or shear loading shall be examined for stability failure (buckling, crinkling, wrinkling) through analyses in the ultimate limit state.

(2) In the case of component whose strength cannot be verified by the usual methods, special investigations are necessary after consultation with GL Wind.

(3) For offshore wind turbines with a rated output of up to 100 kW, a reduced scope of analysis is possible in consultation with GL Wind.

(4) For rotor blades, the locations of greatest loading / damage resp. lowest safety (critical points) shall be shown for the decisive loads in each case, for both the extreme and fatigue strength analysis. If the location of these critical points and the type and magnitude of their decisive loading is not straight clear, calculations shall be performed to provide this information. Particular attention shall be given to points with non-linearities of the geometry and/or the material.

(5) In exceptional cases (e.g. for fatigue analysis), it is permissible by way of simplification to verify not the critical points but reference points with the applicable loads (e.g. points on the main axes or on axes of the chord coordinate system), from which conclusions can then be drawn on the safety of the critical points. The relationship of the minimum safety between the reference points and the critical points shall be verified adequately by means of fundamental investigations, sample calculations etc. For the fatigue analysis of the blade root, an extended examination is not necessary if a residual safety of 1.2 is given with regard to the flapwise and edgewise directions.

(6) Connections in the vicinity of local load introduction zones (e.g. tip shaft, metallic inserts at the blade root) shall be designed to be at least damage-tolerant. A construction is regarded to be damage-tolerant if an instance of damage does not lead to immediate failure of the structure.

(7) To ensure maintenance of a minimum clearance between the rotor blades and other parts of the plant, a deformation analysis shall be performed in the serviceability limit state. If the analysis is performed by static means, a minimum clearance of 50 % shall be verified for all load cases with the rotor turning, and 5 % for load cases with the rotor standing still, in relation to the clearance in the unloaded state.

(8) If the deformation analysis is performed by dynamic and aeroelastic means, at no time may the clearance be less than the minimum of 30 % for the rotor turning.

6.2.4.2 Actions

(1) The loads on which the strength analysis of the rotor blades shall be based are listed in Chapter 4. The load cases determined by superposition of the external conditions with the operating conditions (design situations) (see Section 4.3) shall be investigated and the dimensioning load cases shall be verified.

(2) It is generally sufficient to determine the envelopes of the extreme internal forces and moments as decisive actions.

6.2.4.3 Structural member resistances

The structural member resistances shall be determined according to Chapter 5.

6.2.5 Blade tests

6.2.5.1 General

(1) For the purpose of verifying the calculations, the rotor blades shall be subjected to tests of both the natural frequencies and the static loading within the scope of the assessment. The requirements for these tests are defined in the following. Owing to special features of the design, additional strength tests may be necessary for the rotor blades, rotor blade sections or reference samples. The requirements for this will be decided in each individual case.

(2) All tests shall either be performed by an acknowledged test laboratory (i.e. test laboratory accredited for the relevant tests or recognized by GL Wind) or performed under the surveillance of GL Wind. For all tests performed under the surveillance of GL Wind, an approved test specification is needed; this shall be submitted in good time before the start of the test.

6.2.5.2 Test requirements

(1) The rotor blade to be tested shall as a rule exhibit correspondence with the drawings and specifications submitted. If local reinforcements (e.g. in the area of the load introduction zones) become necessary because of the test, agreement shall be reached beforehand with GL Wind. As part of the test report, correspondence of the test blade with the drawings and specifications submitted shall be certified or, failing that, the modifications shall be listed. Before the start of the test, the mass and centre of gravity of the rotor blade shall be determined and documented.

(2) As a rule, the tests shall be performed in the flapwise and edgewise directions, both positive and negative, of the blade. After consultation with GL Wind, the scope of the test may be reduced in justified cases. Furthermore, at least the first natural frequency of the clamped rotor blade shall be determined in the flapwise and edgewise directions. For rotor blades with a length of more than 30 m, it shall be additionally necessary to determine the second natural frequency in the flapwise direction, together with the first torsional natural frequency for torsionally soft blades. In the case of rotor blades for stall-controlled turbines, the damping in the edgewise direction shall be measured.

(3) The test loading S_{Test} is determined as follows:

$$S_{Test} = S_d \bullet \gamma_{1T} \bullet \gamma_{2T}$$

where:

S_d = design values of the load

γ_{1T} = 1.1 for scattering of the rotor blade characteristics in series production

γ_{2T} = 1.0 for execution of the test with an ambient air temperature of at least 20 °C

= 1.1 for execution of the test with an ambient air temperature of -30 °C

The values between 20 °C and -30 °C may be interpolated linearly.

(4) With regard to the maximum load occurring in the test, at least the test load S_{Test} shall be obtained for each point in the range from at least 2.5 % to about 70 % of the blade length. In addition, the test for the sections with the lowest residual safety shall be performed. Here the influences on the loading from the deformation of the rotor blade shall be taken into account.

(5) In the following possibly critical areas, undisturbed loading is necessary:

– the part of the rotor blade from the blade root up to the profile section from which the cross-sectional properties only change slowly and continuously

– those parts of the rotor blade with the smallest calculated residual safeties against bulging or failure

– those parts of the rotor blade in which local reinforcements (e.g. for the blade tip brake) or other special design features are located

Without further analysis, it shall be assumed that there is no undisturbed loading over a length of 80 % of the local profile depth on both sides of a load introduction zone.

(6) Within the scope of the tests, at least the measurements listed below shall be performed. Here the results shall be determined for at least four load levels between 40 % and 100 % of the maximum test loading STest .

– The applied loads shall be measured at each load introduction point.

– The bending of the rotor blade shall be measured at least at half the rotor radius and at the blade tip.

– The strains of the girder in the upper and lower shell shall at least be measured at four cross-sections distributed over the test area as per Section 6.2.5.2, para 4.

– The strains of the leading and trailing edges shall at least be measured at the position of the maximum chord length and at half the blade length.

– The shear strains of the webs in the blade root area shall be measured, preferably at the point of greatest loading.

– The outside temperature shall be recorded during the test.

(7) Under certain circumstances, strain measurements may become necessary at other critical points. During the test, the corresponding load level shall be maintained for at least 10 seconds. Local failure or buckling during the test is not permissible without further analysis.

(8) It is recommended that rotor blades for offshore wind turbines be tested together with their adjacent structures and so instrumented that the stress conditions of the bolted connections can also be determined.

6.2.5.3 Documentation

(1) The loads and the loading set-up shall be described clearly in the test specification. In particular, the position and the magnitude of the load introduction as well as deviation between the actual and the required test load S_{Test} over the blade length shall be recorded. All measurements and measuring facilities shall be specified and the expected results shall be listed, whereby the maximum permissible deviations in the test shall be defined in relation to the precision of the calculations and measurements. Deviations of at most ± 7 % for the bending deflection, ± 5 % for the natural frequencies and ± 10 % for the strains are permissible as a rule. A test sequence plan and a specimen of the test records shall be appended.

(2) The test shall be documented in a report which describes clearly the test subject and the test procedure, lists the test results and asssesses them with regard to the calculations. The test report should contain the following points:

- date and time of the test
- person responsible for the test
- description and characteristic data of the rotor blade
- documentation of production (if necessary in an annex)
- determination of mass, centre of gravity and natural frequencies
- description and derivation of the test load STest from the load simulations
- description of the test set-up and method of load introduction
- description of the measuring facilities
- calibration of the measuring devices
- precision of the measurements
- measurement parameters (forces, deflections, strains, temperature etc.)
- comparison of actual to required value for the test load S_{Test}
- comparison of calculated and measured values
- assessment of the measurement results

6.3 Machinery Structures

6.3.1 General

The following guidelines apply especially to the force- and moment-transmitting machinery structures of an offshore wind turbine, or of offshore wind turbine components made of metallic materials as per Section 3.3.2.

6.3.2 Assessment documents

(1) For assessment of the strength and serviceability of machinery structures of wind turbines, the following documents are required:

(2) Data on the components with material properties, data from the manufacturer in the case of mass-produced parts, about the standard in the case of standardized parts, notes on the specifications used etc. In addition, parts lists may be necessary in the case of welded structures.

(3) Design documentation (assembly drawings, and if necessary working drawings and specifications), also of the primary adjacent components, executed in standard form and with clear identification (parts designation, drawing number, modification index), shall be submitted. These shall contain

– in the case of structures of casting and forging materials, all necessary data on the delivery condition, such as surface finish, heat treatment, corrosion protection etc.

– in the case of welded structures, data on material designations, type of welding seam, heat treatment, corrosion protection etc.

(4) For machinery structures which are contained in mass-produced parts and which have proved their suitability for use by successful service in comparable technical applications, type/data sheets are generally sufficient. Further documents or verifications are required for structures specially modified for the offshore wind turbine.

6.3.3 Analyses

(1) Strength calculations shall verify the ultimate strength and serviceability totally, clearly and confirmably for the machinery structures. They shall contain sufficient information on

– design loads

– static systems (analogous models) and general boundary conditions applied (also the influence of adjacent components)

– materials

– permissible stresses

– references used

(2) Requirements, verification and certificates for the materials are laid down in Chapter 3. Additional statements can be obtained from Section 5.3 and, if applicable, Chapter 7. The guidelines given in Chapter 4 with regard to the loads shall be observed.

(3) From the technical and calculation viewpoint, the documentation of the computational analyses shall form a unified whole together with all other documents (drawings, specifications). Here it shall be observed that the references of the adjacent components and structural areas which are mentioned in the computational analyses shall be included in the documentation.

(4) If the analysis concepts of different standards and guidelines are applied, these shall not be mixed.

6.4 Nacelle Covers and Spinners

6.4.1 General

6.4.1.1 Designs

(1) The strength and serviceability of the nacelle covers and spinners of offshore wind turbines with horizontal axes can be analysed on the basis of the contents of this Chapter. Analysis of unusual designs shall be agreed with GL Wind.

(2) With regard to the lightning protection system for nacelle covers and spinners, see Section 8.9.

6.4.1.2 Requirements for manufacturers

None.

6.4.1.3 Requirements for the materials

(1) For general requirements, see Chapter 3, and for fibre reinforced plastics (FRP), see Section 5.5.2.2.

(2) For fibre reinforced plastics (FRP), the following shall apply in deviation from Section 5.5.2.2: The strengths and stiffnesses of the materials used shall be sufficiently known in each case, i.e. modulus of elasticity (E-modulus), Poisson's number, failure strain and the failure stress of the typical laminates used, both for tensile and compressive loading parallel and transverse to the fibres and for shear. Material tests are not required; the moduli, strengths and stiffnesses can be taken from the material specifications of the manufacturer or from the literature. The manufacturer shall verify that the characteristic values on which the analyses were based (see Section 6.4.3) are fulfilled for running production.

6.4.2 Assessment documents

a written documents subject to assessment for the verifications set out in Section 6.4.3

b drawings and documents describing the design

6.4.3 Analyses

6.4.3.1 Analysis concept

(1) It shall be shown by calculation or testing that the design values of the resistances R_d are larger than the design values of the actions S_d. Global forces and load introductions from attachments shall be taken into account and traced to the primary structural members (e.g. main frame, hub). For fibre reinforced plastics (FRP), the following applies:

– In the case of verification by testing, the action S_d shall be increased by test factors analogously to Section 6.2.5.2, para 3.

– The analysis for inter-fibre failure may be omitted.

(2) As actions, only the extreme loads need to be applied as a rule.

(3) For the analysis of the serviceability limit state, a precise analysis may be dispensed with. It is recommended that the maximum bending deflection of a structural member under characteristic loads shall not be larger than 1/200 of its maximum free span (for frames or cantilevers: 1/150).

6.4.3.2 Actions

6.4.3.2.1 Dead weight

(1) In general, the values from Eurocode 1 shall be used. If the material used is not tabulated, 1.05 times the mean values (as an estimate of the characteristic values) of the manufacturer's figures shall be used for the case that the characteristic values are not expressly stated. In the event of contradictions or non-availability of individual values, the following priority shall apply:

– 1.05 times the mean values according to the manufacturer

– Eurocode 1

(2) For dead weight, the partial safety factor γ_F as per Chapter 4 shall be chosen.

6.4.3.2.2 Live loads

(1) Landings, floor plates, walkable cover parts inside, platforms etc.:

p_{Sk} = 3 kN/m²

F_{Sk} = 1.5 kN on 20 cm x 20 cm

(2) Roof loads, walkable cover parts outside:

p_{Sk} = 3.0 kN/m²
The total load on the roof can be reduced through appropriate labelling on site (e.g. notice at the exit hatch).

F_{Sk} = 1.5 kN on 20 cm x 20 cm

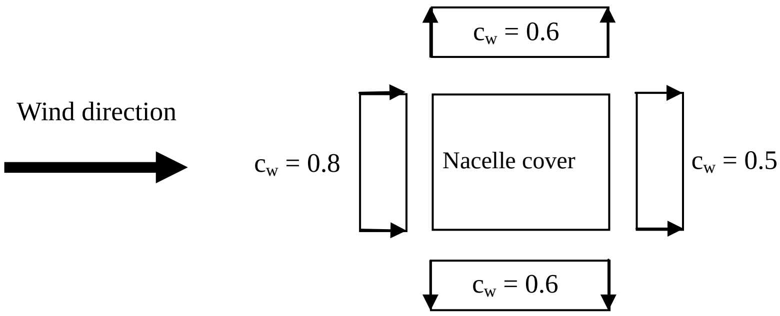


Fig. 6.4.1 Simplified c_W values assumed for a nacelle

Table 6.4.1 Simplified c_W values assumed for a nacelle

Aspect of surface A to the wind	Facing the wind	Facing away from the wind	Parallel to the wind direction
c_w	+0.8 (pressure)	-0.5 (suction)	-0.6 (suction)

(3) Horizontal loads on all structural elements which are intended to offer horizontal resistance (height H of the load application over the floor or standing level = 1.1 m, load distribution width 20 cm or 20 x 20 cm pressure area for large-area nacelle covers):

p_{Sk} = 1.0 kN/m

F_{Sk} = 1.5 kN in every direction

(4) The least favourable load in each case shall be decisive.

(5) Holding eyes as protection against falling (for personal safety, to be marked in a striking colour):

F_{Sk} = 20 kN in every direction

(6) The values given above are minimum values. If guidelines or regulations applying at the installation site of the offshore wind turbine (e.g. national labour safety regulations) demand higher values, these shall be authoritative.

(7) Partial safety factor for live loads: γ_F= 1,5

(8) Partial safety factor for holding eye load: γ_F = 1.0 (may be verified against the failure load)

6.4.3.2.3 Wind loads

$$w_{Sk} = \rho/2 \cdot v^2_{Wind} \cdot A \cdot c_W \qquad (6.4.1)$$

(Wind is an external event; gust reaction factors can be neglected.)

where:

ρ air density as per Chapter 4

v_{Wind} according to Chapter 4,

DLC 6.1 (50-year gust with an airflow within a sector of ± 15° from the front with γ_F = 1.35),

DLC 6.2 (50-year gust from all sides with γ_F = 1.1 for grid failure without energy buffer for the yaw drive) or

DLC 7.1 (annual gust from all sides with γ_F = 1.1 for grid failure with energy buffer for the yaw drive)

A Reference surface for w and c_W

c_W The provisions of Eurocode 1 may be applied. By way of simplification, the assumptions given in Fig. 6.4.1 and Table 6.4.1 are permissible.

(1) The c_W values are chosen in such a way that the vertical airflow represents the decisive case for each surface.

(2) The assumptions for c_W apply for nacelles with sharp edges. For rounded shapes, all c_W values can be reduced by 20 %. Rounded shapes are those for which the radius of curvature for the corner represents 10 % of the corresponding surface exposed to the wind (intermediate values can be interpolated linearly).

(3) Partial safety factor for wind loads: γ_F as per DLC 6.1, 6.2 and 7.1 from Chapter 4.

6.4.3.2.4 Snow and ice loads

Snow and ice loads are included in the live loads on the nacelle roof. The loads were thus determined in Section 6.4.3.2.2. If guidelines or regulations applying at the installation site of the offshore wind turbine (e.g. national labour safety regulations) demand higher values, these shall be authoritative.

6.4.3.2.5 Load combinations

The following load combinations shall be investigated:

– The dead weight shall be superposed with the live loads.

– The dead weight shall be superposed with the wind loads such that the least favourable cases are covered.

6.4.3.3 Component resistances

The component resistances Rd shall in general be determined in accordance with Chapter 5; plastic reserves and large displacements may be utilized.

6.5 Connections

6.5.1 Bolted connections

6.5.1.1 Assessment documents

For the assessment of bolted connections, at least the following documents shall be submitted:

a design calculations of the bolted connections according to the Sections 6.5.1.2 “Strength analyses of bolted connections”, 6.5.1.4 “Ring flange connections” and 6.5.1.3 “Shear-loaded bolted connections”

b work instruction for making the bolted connection (assembly instructions). These instructions shall contain at least the following:

- pretreatment or checks of the surfaces to be joined
- If additional activities at the flanges (e.g. underpinning) during the connecting work are already intended in the design, these shall be described together with the necessary materials. If these activities only become necessary if certain criteria are exceeded (e.g. maximum gap widths), the criteria and measurement procedures shall be stated.
- lubrication condition of thread and bolt/nut
- tightening procedure and all data needed for manufacture (e.g. preloading, torque required, tightening tool)
- tightening sequence

c work instruction for checking the bolted connection (maintenance instruction), with statement of at least the test intervals and test procedure; see Section 6.5.1.5.

d drawings and specifications providing the remaining parameters for the design of the bolted connection, such as:

- dimensions and tolerances
- data on possible coatings of the flange surfaces or parts thereof
- designation of the bolts, nuts and any washers
- corrosion protection

6.5.1.2 Strength analyses of bolted connections

(1) Bolt calculations shall be performed on the basis of VDI 2230 [6.1] (machinery components), DIN 18800 (construction) or other codes recognized by GL Wind.

(2) For dynamically loaded bolted connections, an adequate preloading is necessary. Influences from loading eccentricity, possible gaps in the joints and imperfections shall be taken into account. Here the finite element method may be used (see also Chapter 5, Appendix 5.A “Strength Analyses with the Finite Element Method”).

(3) The detail category to be used as a basis shall be applied in accordance with Section 5.3.4.4.1 para 9. For bolted connections subjected to cyclic loading, only the strength categories 8.8 and 10.9 are permissible for the connection of machinery structures.

(4) Due to increased danger of stress corrosion cracking for higher strength steels, only bolts of the strength category 10.9 (acc. to ISO 898-1:1999) or minor are permissible for bolted connections.

6.5.1.3 Shear-loaded bolted connections

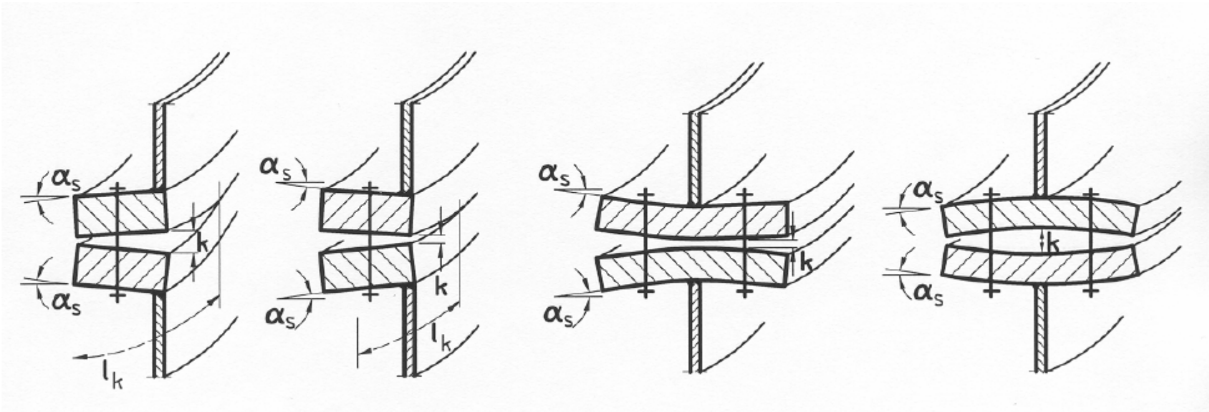
(1) Bolted connections at the joints and faces of components belonging to the primary supporting structure shall be executed as fitting shear connections (SLP, SLVP) or as slip-resistant preloaded connections (GV, GVP).

(2) In the case of SLP and SLVP connections, an analysis shall be performed for the perforated components and the bolts according to Section 6.6. In the case of fitting connections with hot-dip galvanized components, special corrosion protection measures shall be taken.

(3) For GV and GVP connections, it shall be verified that the maximum force acting in the ultimate limit state on a bolt in a shear joint does not exceed the design slip resistance according to equation 6.5.1:

$$F_{s,Rd} = 0.9 \cdot \frac{\mu}{\gamma_{M,3}} \cdot F_V \qquad (6.5.1)$$

where:



a) L-flange, b) T-flange

Fig. 6.5.1 Ring flange connections in steel towers

F_V regular preloading force according to DIN 18800-7. This preloading force shall be ensured by checking and if necessary retightening within the first half-year after erection, but not immediately following the commissioning.

$\mu \geq 0.5$ slip factor for the execution of the contact surfaces according to DIN 18800-7. For other versions, the slip factor shall be verified in accordance with Element 826 by a procedure test.

$\gamma_{M,3} = 1.25$ safety factor for combination of actions of group N and the operating conditions 1 to 4 according to Table 4.3.1

$\gamma_{M,3} = 1.1$ safety factor for combination of actions for all other design load cases according to Table 4.3.1

(4) In addition, the analyses of ultimate limit state for the perforated components shall be carried out as well as for shearing-off and face bearing pressure.

Note:

Through these analyses, the analysis of fatigue safety is also covered.

6.5.1.4 Ring flange connections for tubular towers

(1) Ring flange connections shall be controlled tightened, e.g. according to DIN 18800 Part 7.

(2) In the ultimate limit state analysis of the flange connections, the preloading force of the bolts need not be considered, i.e. the ultimate limit state analysis may be performed as for a non-preloaded bolted connection. Local plastifications (yield hinges in the flange and/or in the tower jacket) may be considered here.

(3) In the fatigue safety analysis of the flange connection, the fatigue loading of the bolts may be determined with consideration of the compressive preloading of the flanges, provided the following conditions are met.

(4) Adequate compressive preloading of the flange contact surfaces may be assumed if the gaps between the installed flanges meet the tolerance values prescribed by the manufacturer with at most 10 % of the design preload. These shall be stated in the working documents, especially in the drawing.

Notes:

All flange gaps k in the area of the tower wall are damage-relevant for the fatigue loading of the bolts (see Fig. 6.5.1), particularly when they extend only over part of the circumference. The damage influence grows with decreasing spanning length l_k over the circumference (Fig. 6.5.1).

Instead of stating prescribed tolerance values for the flange gaps k at a maximum of 10 % of the design preload, it is alternatively permissible to specify maximum values for the degree of preloading (referred to the design preload) in the working documents up to which all flange gaps k in the area of the tower wall shall have closed. These values shall be verified by computation.

(5) If the tolerance values specified in the working documents for the flange gaps are not complied with, suitable measures shall be taken. Suitable measures may e.g. include reworking, shimming or filling out the damage-relevant gap spaces before preloading takes place.

Note:

For the shimming of gap spaces, adapted shims shall be used for which the compressive strength (yield point under compression) at least complies with that of the *flange material. If the shimming is implemented by stacks of thin sheeting, the fitting inaccuracy of the individual shims shall not be greater than 0.5 mm. The lining shall be executed such that, either in the direct vicinity of each bolt or in the area between each individual bolt and the tower wall (including the area directly under the tower wall itself), perfect pressure contact is produced already at the start of the preloading process, but at the latest after applying 10 % of the preload. For filling up the spaces, a filler material shall be used with an E-modulus complying with that of the flange material.*

(6) If, after the preloading, the remaining inclination αS of the outer flange surfaces (see Fig. 6.5.1) exceeds the limiting value of 2 % according to DIN 18800-7, Element 814, suitable taper washers with sufficient hardness shall be used instead of the normal washers.

Notes:

If the bolt force function is determined without imperfections with the aid of an ideal calculation method (e.g. FEM using contact or spring elements), the flange gaps tolerated in the execution of the work may be taken into account by a suitable increase in the initial gradient of the bolt force function (see Fig. 6.5.2).

As a substitute, a simplified calculation method (e.g. according to Petersen) may be used if it covers flange gaps of the magnitude tolerated in execution of the work.

Assured findings on the magnitude of the flange gaps covered by a simplified calculation method were not available on publication of this Guideline. Accordingly, the simplified calculation methods according to Petersen and Schmidt-Neuper may be used for the calculation of the ring flange connections until a revised version is published. When using calculation methods which do not consider the influence of the bending moment on the bolt, the fatigue safety of the bolt shall be determined using detail category 36.*

Calculations with the aid of the finite element method (FEM) which do not consider flange gaps, as well as other calculation methods leading to comparable results, are not permissible.

6.5.1.5 Inspection of bolted connections

(1) During the operating life of the offshore wind turbine, the bolted connections shall be tested as part of maintenance. These tests shall be specified in the maintenance manual. Here the following shall be observed:

(2) All bolted connections that were tightened using a torque-controlled or tensioning-force-controlled method shall be retightened at least once after the commissioning. The interval required for this shall be specified. After this, these bolted connections shall be subjected to regular visual inspections and looseness checks.

(3) Instructions and times for the retightening and the regular checks shall be specified in the maintenance manual (see Section 9.4).

(4) In the case of bolted connections which were tightened by other methods or which were brought into the plastic zone when tensioned, special inspection procedures shall be defined for each individual case.

(5) In the case of bolted connections for which GRP, CRP or concrete is included in the tensioned material, special inspection procedures shall be defined for each individual case.

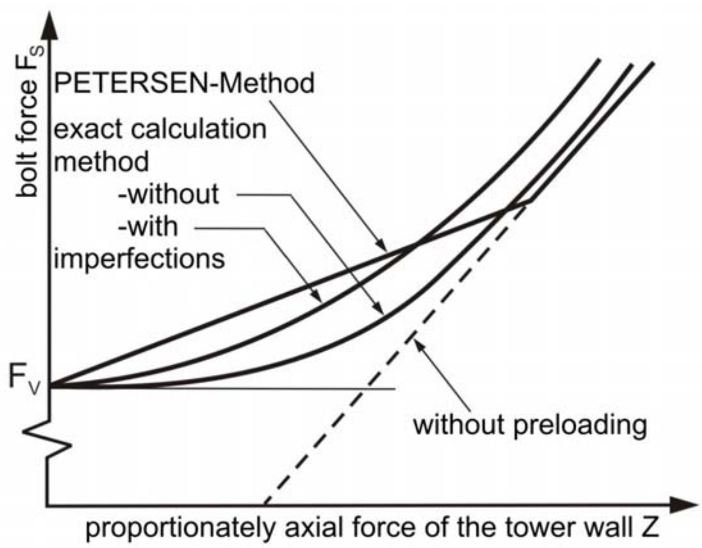


Fig. 6.5.2 Bolt force functions of preloaded ring flange connections

6.5.2 Grouted pile to structure connection

(1) Platform loads may be transferred to leg and sleeve piles by grouting the annulus. Shear keys may be added in order to improve the capacity of the steel grout bond.

(2) Grouted pile to structure connections under axial loading may be designed using parametric formulae, e. g. as provided by API [6.2] or the Department of Energy (U.K.). Due regard shall be given to the suitability of the formula for the geometric configuration investigated.

(3) For geometries not covered by the existing formulae the strength of the grouted connection shall be proven by suitable analysis methods or by tests.

(4) Grouted pile to structure connections that experience bending moments shall be assessed by suitable calculation methods, too, e.g. FEM, or by tests, see Section 5.4.

(5) Prior to the installation the suitability of the grout mix shall be proven. The compressive strength shall be confirmed by laboratory tests on grout samples which were mixed and cured under field conditions.

(6) The design grout strength shall be verified by a representative number of specimens taken during grouting operations. It shall be ensured that the specimens will be cured simulating in situ conditions.

6.5.3 Tubular joint design

6.5.3.1 General

(1) Tubular Joints shall be designed using the procedures given in the following. The formulas were mainly derived from the API RP 2A LRFD provisions and formatted for a semi-probabilistic design concept using partial safety factors. The intention is to derive design capacities which are comparable with those derived on basis of the API RP 2A LRFD [6.2] provisions.

(2) Alternative procedures given in other recognized standards might be acceptable but have to be agreed with GL Wind.

(3) If for non-standard or complex joints analytical and/or experimental investigations are required these also have to be agreed with GL Wind.

(4) In every case care shall be taken to achieve at least the same safety level as intended by these GL Wind Guidelines.

(5) In order to avoid stress concentrations and fabrication induced defects the general requirements given for steel structures (see Section 3.4) are to be observed.

(6) Connections in the splash zone should generally be avoided.

(7) For all tubular joints which are subject to cyclic loading, a fatigue analysis shall be performed (see Sections 6.5.3.4 and 6.6.6).

6.5.3.2 Simple tubular joints

(1) The static strength of simple tubular joints without overlap of principal braces and having no gussets, diaphragms, or stiffeners may be investigated as shown in the following.

The validity range for the formulae given is as follows, see Fig.6.5.3:

$0.2 \le \beta \le 1.0$ $\quad$ $10 \le \gamma \le 50$

$30° \le \Theta \le 90°$ $\quad$ $f_{yk} \le 500$ N/mm²

$g \ge 7{,}5$ mm or 2 T (whichever is the greater)

(2) Design capacity
The design capacity is restricted by the shear resistance $\tau_{Rd,a}$ of the weld connection (see para 3) as well as by the joint capacity (see para 4) – whichever leads to the smaller design capacity.

(3) Weld connection
The design punching shear stress τ_{Sd} shall not exceed the shear resistance $\tau_{Rd,a}$ of the weld connection:

$$\tau_{Sd} \le \tau_{Rd,a} = \frac{f_{yk}}{\sqrt{3} \cdot \gamma_m} \qquad (6.5.2)$$

f_{yk} = minimum specified yield strength (of the chord member); f_{yk} is not to be taken greater than 0.75 f_{uk}

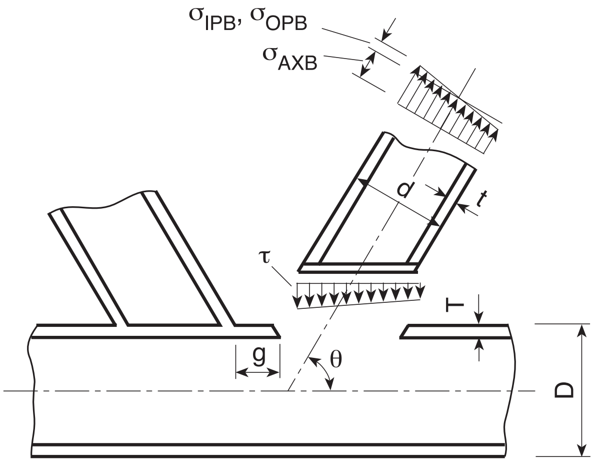
f_{uk} = minimum tensile strength

γ_m = 1.1 (partial material safety factor)

The design punching shear stress τ_{Sd} acting in the chord may be calculated as follows:

$$\tau_{Sd} = \frac{t}{T} \cdot \sin(\Theta) \cdot \sigma_{Sd} \qquad (6.5.3)$$

σ_{Sd} = design stress in the brace



Θ	=	brace angle (measured from chord)
g	=	gap
t	=	brace thickness
T	=	chord thickness
D	=	brace diameter
D	=	chord diameter
β	=	d / D
γ	=	0.5 D / T

Fig. 6.5.3 Terminology and geometric parameters for simple tubular connections

(4) Strength check

The adequacy of the joint shall be determined on basis of factored loads in the brace.

Note:

Brace axial loads and bending moments essential to the integrity of the structure shall be included in the calculations. Reductions in secondary (deflection-induced) bending moments due to joint flexibility or inelastic relaxation may be considered.

The capacity shall be evaluated separately for each component of brace loading. The design loads in the brace shall satisfy the following requirements:

$$N_{Sd} \le \frac{N_{Rk}}{\gamma_M} = N_{Rd} \tag{6.5.4}$$

$$M_{Sd} \le \frac{M_{Rk}}{\gamma_M} = M_{Rd} \tag{6.5.5}$$

N_{Sd}, M_{Sd} = the factored design axial force and bending moment in the brace member in force/moment units respectively

N_{Rk} = the characteristic joint axial capacity (in terms of brace load) in force units

M_{Rk} = the characteristic joint bending moment capacity (in terms of brace load) in moment units

γ_M = 1.1 (partial material safety factor)

For combined axial loads and bending moments in the brace the above given equations shall be satisfied along with the following interaction equation:

$$1-\cos\left[\frac{\pi}{2}\left(\frac{N_{Sd}}{N_{Rd}}\right)\right]+ \left[\left(\frac{M_{Sd}}{M_{Rd}}\right)_{IPB}^2+\left(\frac{M_{Sd}}{M_{Rd}}\right)_{OPB}^2\right]^{\frac{1}{2}} \le 1.0 \tag{6.5.6}$$

IPB = in-plane bending

OPB = out-of-plane bending

The characteristic capacities are defined as follows:

$$N_{Rk} = \frac{f_{yk}\cdot T^2}{\sin(\Theta)}\cdot K_u \cdot K_f \tag{6.5.7}$$

$$M_{Rk} = \frac{f_{yk}\cdot T^2}{\sin(\Theta)}\cdot (0.8d)\cdot K_u \cdot K_f \tag{6.5.8}$$

f_{yk} = minimum specified yield strength (of the chord member); f_{yk} is not to be taken greater than 0.75 f_{uk}

f_{uk} = minimum tensile strength

K_u = strength factor which varies with the joint and load type as given in Tab. 6.5.1

K_f = design factor to account for the presence of longitudinal factored load in the chord

$$K_f = 1.0 - \lambda \cdot \frac{D}{2T}\cdot A^2 \tag{6.5.9}$$

set K_f = 1.0 when all extreme fiber stresses in the chord are tensile.

λ = 0.030 for brace axial stress

= 0.045 for brace in-plane bending stress

= 0.021 for brace out-of-plane bending stress

Tab. 6.5.1 Values for factor K_u

<table>
<tr><th rowspan="2">Type of joint[1)]</th><th colspan="4">Type of load in the brace</th></tr>
<tr><td>AX Tension</td><td>AX Compression</td><td>IP Bending</td><td>OP Bending</td></tr>
<tr><td>K</td><td colspan="2">$(3.4 + 19\ \beta)\ K_{gap}$</td><td rowspan="3">$(3.4 + 19\ \beta)$</td><td rowspan="3">$(3.4 + 7\ \beta)\ K_\beta$</td></tr>
<tr><td>T, Y</td><td colspan="2">$(3.4 + 19\ \beta)$</td></tr>
<tr><td>Cross</td><td>$(3.4 + 19\ \beta)$</td><td>$(3.4 + 13\ \beta)\ K_\beta$</td></tr>
<tr><td colspan="2">$K_{gap} = 1.8 - 0.1 \cdot \frac{g}{T}$ for $\frac{D}{2T} \le 20$</td><td colspan="3">$K_\beta = 1.0$ for $\beta \le 0.6$</td></tr>
<tr><td colspan="2">$K_{gap} = 1.8 - 4.0 \cdot \frac{g}{D}$ for $\frac{D}{2T} > 20$</td><td colspan="3">$K_\beta = \frac{0.3}{\beta \cdot (1 - 0.833 \cdot \beta)}$ for $\beta > 0.6$</td></tr>
<tr><td colspan="2">But in no case shall K_{gap} be taken less than 1.0</td><td colspan="3">1) all joints: without diaphragm</td></tr>
</table>

$$A = \frac{\sqrt{\sigma_{Sd,c,AX}^2 + \sigma_{Sd,c,IPB}^2 + \sigma_{Sd,c,OPB}^2}}{f_{yk}/\gamma_M} \quad (6.5.10)$$

$\sigma_{Sd,c,AX}$, $\sigma_{Sd,c,IPB}$, and $\sigma_{Sd,c,OPB}$ are the factored axial, in-plane bending, and out-of-plane bending stresses in the chord

Note:

Care shall be taken while using the above given and still common equation to derive the design factor K_f. In the scope of ISO 19902 [5.10] code development a completely new approach is discussed allowing for a more reliable consideration of the loads in the chord.

(5) Joint classification

Joint Classification as K, T and Y or cross (X) shall apply to individual braces according to their load pattern for each load case. For braces which carry part of their load as K-joints, and part as T and Y or cross (X) joints, interpolate K_u based on the portion of each in total.

Note:

To be considered a K-joint, the punching load in a brace shall be essentially balanced by loads on other braces in the same plane on the same side of the joint. In T and Y joints the punching load is reached as beam shear in the chord. In cross joints the punching load is carried through the chord to braces on the opposite side.

(6) Increased wall thickness

If an increased wall thickness in the chord at the joint is required, it shall be extended past the outside edge of the bracing a minimum of one quarter of the chord diameter or 300 mm including taper, whichever is greater.

Where increased wall thickness or special steel is used for braces in the tubular joint area, it shall extend a minimum of one brace diameter or 600 mm from the joint, including taper, whichever is greater. See Fig. 6.5.5.

The requirements regarding welding and fabrication details are to be observed (see Sections 3.4.1 and 3.4.2).

6.5.3.3 Overlapping joints

(1) Definition

Overlapping joints are joints in which part of the load is transferred directly from one brace to another brace through their common weld connection.

(2) Design

The overlap shall be designed for at least 50 % of the load component acting perpendicular to the chord, see Fig. 6.5.6.

(3) In no case the brace wall thickness shall exceed the chord wall thickness.

For examples refer to e.g. ISO 19902 [5.10] or API RP 2A [6.2] where the following figure is taken from:

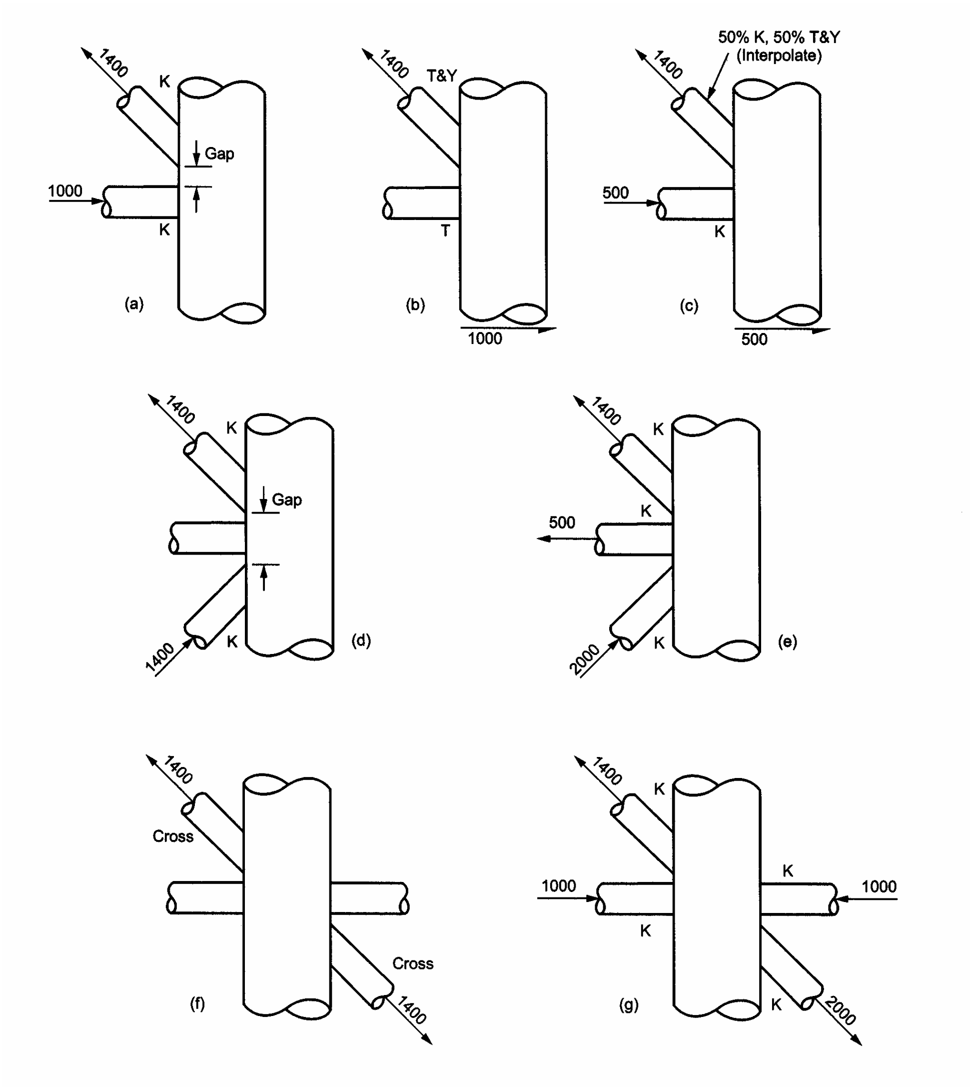


Fig. 6.5.4 Example of joint classification

(4) Moments caused by eccentricity of the brace centrelines shall be accounted for in the structural analysis.

(5) Punching shear resistance

For overlapping joints in which brace moments are insignificant and part of the axial load is transferred directly from one brace to another through their common weld the axial design load component perpendicular to the chord $N_{Sd,p}$ shall not exceed the punching shear resistance $N_{Rd,p}$.

$$N_{Sd,p} \leq \frac{N_{Rk,p}}{\gamma_M} = N_{Rd,p} \qquad (6.5.11)$$

(6) For preliminary design purposes the characteristic punching shear resistance $N_{Rk,p}$ may be calculated as follows:

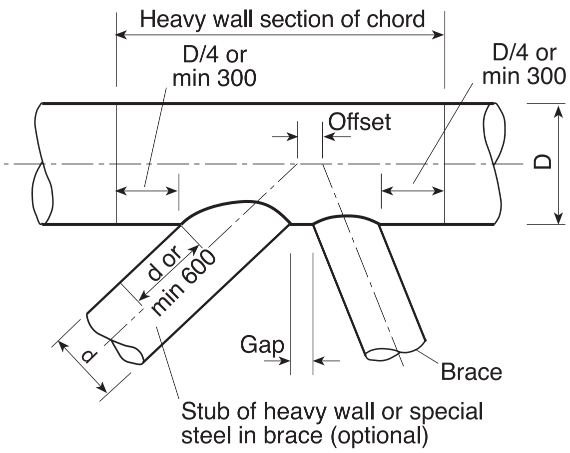
$$N_{Rk,p} = N_{Rk} \cdot \frac{l_1}{l} \cdot \sin(\Theta) + 2 \cdot \tau_{Rk,a} \cdot t_w \cdot \ell_2 \qquad (6.5.12)$$

ℓ_1 = circumference for that portion of the brace which contacts the chord

ℓ = circumference of brace contact with chord, neglecting presence of overlap

$\tau_{Rk,a}$ = characteristic shear resistance of the weld connection between braces

$$= \frac{f_{yk}}{\sqrt{3}}$$



Offset not to exceed ± D/4
Gap: Separation of 50 mm minimum

Fig. 6.5.5 Heavy wall section of chord

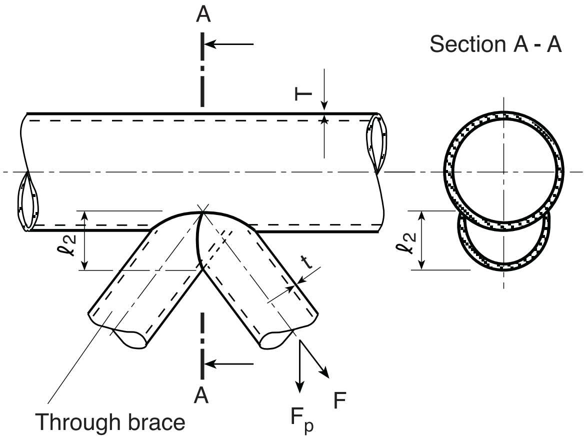


Fig. 6.5.6 Overlapping Joint

t_w = the lesser of the weld throat thickness or wall thickness t of the thinner brace

ℓ_2 = the projected chord length (one side) of the overlapping weld, measured perpendicular to the chord

These terms are illustrated in Fig. 6.5.6.

(7) For the final design a more comprehensive approach may be required. This approach has to be agreed with GL Wind.

6.5.3.4 Fatigue design

(1) The welds at tubular joints are among the most fatigue sensitive areas in offshore structures due to the high local stress concentrations.

(2) One appropriate way to derive the local stress concentrations is to calculate the sum of the nominal stresses due to the individual load components, each multiplied by a corresponding stress concentration factor (*SCF*). When combining the contributions from the various loading patterns, the phase differences between them shall be accounted for.

Note:

In general, the SCFs depend on the type of variable loading, the type of joint, and details of the joint geometry. Loading due to brace axial forces, brace in-plane bending and brace out-of-plane-bending moments cause different patterns of variable stresses around the joint.

(3) *SCF*s may be derived from Finite Element analyses, model tests or empirical equations based on such methods and stated in recognized standards to be agreed with GL Wind.

Note:

E.g. the equations provided by Efthymiou have been proven to be a good approximation compared to Finite Element analyses within their range of validity. A more actual and also recognized approach is given in e.g. [6.3].

(4) Care shall be taken while using *SCF*s from other standards together with the general requirements for fatigue considerations (SN-Curves, thickness of plate effect, etc.) given in these GL Wind Guidelines (see Section 6.6.6). It shall be examined carefully that the desired safety level is achieved.

6.6 Steel Support Structures

6.6.1 General design considerations

(1) The analyses are performed with the aid of the ultimate and serviceability limit states in accordance with Sections 5.3.2, 6.1.3 and 6.6.

(2) The analyses shall be performed with the least favourable of all the combination of actions according to Table 4.3.1. For the analyses in the ultimate and serviceability limit states, both the characteristic loads and the design loads adapted by partial safety factors are needed.

(3) The partial safety factors for the loads shall be determined as per Section 4.3.7.

(4) The analyses shall be performed with the design loads for the least favourable of all combinations of actions of the groups N, A and T according to Table 4.3.4.

(5) The increase in the internal forces and moments as a result of nonlinear influences (e.g. second order theory, state II) shall be taken into account. It may be determined from a quasi-static calculation.

(6) For an analysis with internal forces and moments calculated in a simplified manner according to Section 6.1.3 para 4 to 6, the design values of the actions shall be determined by multiplication of the characteristic values with the partial safety factors γ_F according to Table 4.3.4; for unfavourable actions of the largest partial safety factor γ_F , the actions of the corresponding load combination may be used.

(7) Determination of scantlings, using the following indications or equivalent design methods, is based on the supposition that an accepted corrosion protection system is provided (see Section 3.5) and adequate corrosion allowances are agreed upon, depending on the environmental and operating conditions. The same applies to structural elements prone to wear, e. g. by chafing of cables or chains.

(8) Components whose dimensioning is not covered by standard codes shall be designed and analysed according to the currently accepted procedures upon agreement with GL Wind.

(9) In this chapter, the emphasis is on stress analysis. Additionally stability analysis, such as that concerning

– buckling of plates and shells

– buckling and tipping of girders and bars

– lifting-off, toppling over or slipping of component parts

may have to be carried out and deformation limits considered.

(10) For this purpose draft ISO 19902 [5.10], Eurocode 3, DIN 18800, or equivalent international standards may be used in agreement with GL Wind. Some of the basic requirements for stability analyses as stated in DIN 18800 are given in Section 6.6.5.

(11) For buckling analysis, the partial safety factor γ_M may be taken as

$$\gamma_M = 1.1$$

For buckling of shells, see additionally Section 6.6.5.4

(12) For fatigue analysis, γ_M is listed in Table 6.6.3 for the support structure and in Tab. 5.3.1 for the topsides structure.

(13) Specific structural details such as joints of tubes or rolled sections, may be designed according to proven standards and codes (e. g. [6.1]). See also Section 6.5.3, Tubular Joint Design. Fatigue considerations shall be observed additionally (see Section 6.6.6).

(14) Admissible stresses for elements of special purpose installations such as cranes may be taken from acknowledged regulations relating to such equipment. The applicability of relevant loading conditions, in comparison with those defined in Section 6.1.3 shall be carefully checked.

(15) Ultimate limit state for strength
For steel structures, the statements made in Section 5.3.3 shall be taken into account. For tubular steel towers with a cylindrical or conical shape, the stresses needed for the ultimate limit state verification may be calculated according to the shell membrane theory. This means, for example, that for the transfer of the wind loads the elementary pipe bending theory may be applied. Shell bending moments arising from wind pressure distributed unevenly over the tower circumference, or secondary stresses from edge disturbances at flanges or stiffeners, need not be taken into account. At transitions between cylindrical and conical tower sections, the local circumferential membrane forces and shell bending moments arising from the force deflection shall be taken into account, insofar as no ring stiffeners are arranged there. If this is not the case, adequate dimensioning of the ring stiffeners shall be

verified. For tower areas that are weakened by openings, Section 6.6.5.4.4 shall be observed.

Note:

The analysis procedure described here corresponds in the terminology of DIN 18800-1 to an elastic/plastic analysis for the local internal forces and moments of the tower wall, but to an elastic/elastic analysis for the global internal forces and moments of the tower.

6.6.2 Additional issues (consider other regulations/guidelines)

(1) Recognized international or national standards relating to steel structures may be used as a basis for design, analysis and construction alternatively to the following sections in agreement with GL Wind.

(2) For example the following standards and regulations may be used:

– ENV1993: Eurocode 3, Design of steel structures

– DIN 18800, part 1-4: Steel structures

– API RP 2A LRFD [6.2]: Planning, Designing and Constructing Fixed Offshore Platforms – Load and Resistance Factor Design

– Draft ISO 19902 [5.10]: Petroleum and Natural Gas Industries — Fixed Steel Offshore Structures

6.6.3 Assessment documents

6.6.3.1 Calculation documents

The calculation documents serve to document the computational analyses. They shall be structured to be complete, comprehensible and clear.

6.6.3.2 Drawings

True-to-scale working drawings shall be produced to contain all the necessary information and technical requirements. These include in particular:

– representation of the overall geometry, including a general view

– detailed presentation of the design details

– material specifications

– welding seam specifications and acceptance criteria

– tolerance data

– specifications of the corrosion protection system

6.6.3.3 Description of erection

A brief description of the erection sequence, with the boundary conditions specific to erection, shall be appended to the assessment documents. Boundary conditions specific to erection include in particular:

– maximum wind speed for erection

– min/max erection temperature, if applicable

– maximum interval between erection of the tower and mounting of the nacelle with rotor blades

Further requirements regarding the erection instructions are given in Section 9.1.

6.6.3.4 Interfaces

(1) Within the scope of the calculation, the internal forces and moments at the nacelle/tower interface and the associated wind speeds and airflow angles shall be summarized in a table for the characteristic and the design loads. In the case of an aeroelastic calculation, the geometry, stiffnesses, natural frequencies and damping factors of the relevant complete system “tower with foundation” shall be specified in addition. The following shall be stated additionally for this interface:

– masses and moments of inertia for the machinery part of the offshore wind turbine

– internal forces and moments of the load cases for the fatigue analysis of tower and foundation

– influences resulting from tower top eccentricities

(2) Regarding the tower/foundation interface, see Section 6.7.

6.6.4 Dynamic analysis

6.6.4.1 General

A dynamic investigation is required in case of risk of resonance of global or local structural vibration modes with energy-rich dynamic loads (periodic excitation forces). This applies to almost all offshore wind turbines.

6.6.4.2 Excitations

(1) Dynamic loads may be imposed by environmental loads such as

– wind

– waves

– current

– earthquake

and by variable functional loads, i.e. the rotation of the rotor.

6.6.4.2.1 Rotor-induced vibrations

(1) The ratio of the natural frequencies f_0 of the complete system to the excitation frequencies f_R of the turning rotor shall be determined. Excitation frequencies are in particular the rotor speed and the blade frequency. In general, the following condition shall be fulfilled:

$$\frac{f_R}{f_{0,n}} \leq 0.95 \text{ or } \frac{f_R}{f_{0,n}} \geq 1.05 \qquad (6.6.1)$$

where:

f_R excitation frequency, in particular the rotating frequency range of the rotor in the normal operating range and transition frequency of the rotor blades

$f_{0,n}$ n-th natural frequency of the tower

The number of natural frequencies to be determined n shall be selected large enough so that the highest calculated natural frequency lies at least 20 % higher than the blade transition frequency.

(2) The natural frequencies of the tower shall be determined and specified for the vibration system to be investigated, assuming elastic behaviour for the material. The influence of the foundation shall also be taken into account. Dynamic soil parameters shall be used for the ground.

Note:

Particularly in the case of pile foundations, the rotation about the vertical axis and the horizontal displacement of the foundation shall be considered in addition to the rotation about the horizontal axis.

(3) In order to take account of the uncertainties in calculating the natural frequencies, they shall be varied by ± 5 %.

(4) In the case of turbines which do not satisfy equation (6.6.1) in continuous operation, i.e. are operated near the resonance range, operational vibration monitoring shall be performed; see Section 2.3.2.6.

6.6.4.2.2 Wind-induced transverse vibrations

The loading on circular or near-circular towers arising from vortex-induced vibrations transverse to the wind direction can for example be determined by using the procedure in accordance with DIN 1055-4.

6.6.4.3 Global design

(1) For fixed structures a dynamic analysis will be necessary in case of a support structure’s natural frequency close to the excitation frequency and its higher harmonics of functional loads or the frequency of energy-rich environmental loads.

(2) The loads of the overall system shall be determined according to the elasticity theory by means of a overall dynamic calculation. It shall be noted that action components may also have a favourable effect for some analyses. The individual components of the internal forces and moments are generally not in phase, so that here the least favourable time step shall be picked out.

(3) For an overall dynamic calculation in the time domain, it is possible that the partial safety factor procedure cannot be applied. In this case, the procedure shall be as described in Section 1.3.3.

(4) The overall dynamic calculation yields time series of all internal forces and moments for the investigated load combinations in the relevant cross-sections. These are to be used for the design of tower and foundation. These internal forces and moments shall be determined for the analyses in the ultimate and serviceability limit states.

(5) For the analysis regarding strength and stability failure as well as for analysis in the serviceability limit state, it is permissible to state, by way of simplification, only the extreme values of the internal forces and moments together with the remaining internal forces and moments occurring simultaneously for the cross-sections investigated.

(6) The internal forces and moments for the fatigue safety analysis may, as a simplification, be specified in the form of load spectra, and for bolted connections with mean values (see Appendix 4.B, Section 4.B.2.3).

(7) Dynamic analyses will generally be necessary for structures with large motions, e. g. floating structures, articulated towers or guyed structures.

(8) For structures installed in seismically active areas a dynamic investigation is required to investigate the inertia induced forces.

6.6.4.4 Local design

(1) The design of larger structural components, e. g. rotor blades, tower, substructure, heli-deck, and of local structural members shall take account of possible dynamic loads, e. g. due to wind, waves, currents, ice-flow or wave slamming.

(2) Due regard shall be paid to dynamic loads on slender structures such as support structures, towers and rotor blades. Wind and/or wave induced vortex shedding and also variable wind speeds (gustiness) and irregular sea states may cause dynamic stress amplifications and reduce the fatigue life.

(3) For structural components supporting rotating equipment with free excitation forces and moments resonance shall be avoided. If this is not possible, the dynamic stress level shall be proven in a forced vibration investigation.

(4) For structures which may be subject to earthquake loading the natural frequencies of appurtenances or equipment supports should be substantially larger than the frequencies of the basic structure modes, see also Sections 4.2.4.5 and 4.3.5.

(5) For parts of the support structure that are close to the sea level, the possibility of collision with a small vessel (e.g. maintenance ship) shall be considered. The loads due to the impact energy shall be applied at the most unfavourable of the possible positions. For the impact energy, see Section 4.3.2.7.

6.6.4.5 Analysis of the structure

(1) The structural modelling shall take account of the requirements outlined in Sections 5.2 and 6.1.

(2) Special regard shall be paid to the structure/ soil interaction. The structure/soil interaction may behave non-linearly resulting in a possible reduction of the foundation stiffness as a function of load level and type (see Section 6.7).

(3) Besides all effective structural masses, the hydrodynamic masses accounting for increased member thickness due to marine growth and water enclosed in submerged members are to be considered, too.

(4) Equivalent viscous damping may be used for dynamic investigations of fixed steel structures.

6.6.4.6 Method of analysis

(1) The analysis method to be used will depend on the type of loading and on the structural response.

(2) Response spectrum analysis will be used for structures with a linear elastic response to random loading, e. g. due to non-deterministic wave loads or seismic loads, provided a linearisation of the non-linear load effects is possible. The method may be appropriate to determine dynamic amplification effects.

6.6.5 Stability

6.6.5.1 General indications

(1) Structural elements subjected to predominantly compressive or shear stresses, which may also result from bending or torsion, are to be investigated for overall and/or local buckling failure as indicated below.

(2) Deformations due to loads (e. g. lateral load producing bending) or manufacture (fabrication tolerances, welding distortion) shall be taken into account where they may be important, using e. g. second order theory. Buckling calculations may result in special manufacturing instructions regarding tolerable imperfections (see e.g. Section 6.6.5.4.2 para 3).

(3) Local buckling may be admitted where the structure is designed with sufficient redundancy, i. e. where adjoining elements are designed to take over the load originally carried by the buckled part with sufficient safety. Serviceability considerations have to be kept in mind, however.

(4) Detailed buckling analysis shall be carried through according to recognized codes and standards such as DIN 18800, AISC (Specification for the Design, Fabrication and Erection of Structural Steel for Buildings, and Manual of Steel Construction); BS 5400. Some specifications are given in the following, e. g. regarding the correlation between the load conditions defined in this Guideline and the buckling standard applied.

(5) For plastic design see Section 5.2.2.2.5.

6.6.5.2 Buckling of bar elements

6.6.5.2.1 General

Depending on type of element (cross-section), slenderness, type and application of load(s), and boundary conditions, several buckling modes are possible. The critical mode, corresponding to the lowest buckling load, shall be established by comparative calculations.

6.6.5.2.2 Overall buckling

General remarks

(1) Overall buckling of bar elements is usually to be investigated for the flexural or combined flexural-torsional mode.

(2) For hollow sections and for hot rolled steel members with the types of cross section commonly used for compression members the relevant buckling mode under compression load is generally flexural.

Specifications for the proof of buckling strength are given in the following.

(3) However, in some cases, i. e. open, thin-walled cross sections, the torsional or flexural-torsional modes have to be considered by application of relevant standards as mentioned in Section 6.6.5.1 para 4.

(4) For rolled I-sections the proof of flexural-torsional buckling strength is not necessary, if

– bending occurs about the z-axis only (vertical axis parallel to the web)

– bending occurs about the y-axis (horizontal axis parallel to the flanges) and the compression flange is supported in y-direction at distances c:

$$c \leq \frac{\pi}{2} \cdot \sqrt{\frac{E}{f_{yk}}} \cdot i_z \cdot \frac{M_p}{M_y} \qquad (6.6.2)$$

where:

E = Young's modulus (steel: 210 kN/mm^2),

f_{yk} = characteristic yield strength

i_z = radius of gyration about z-axis of the flange including 20 % of the web area,

M_y = maximum design bending moment within the length considered (y-axis),

M_p = plastic resistance moment, see para 9.

(5) The proof of flexural buckling strength is not necessary, if one of the following requirements is fulfilled:

a) $$\frac{N_d}{0.1 \cdot N_{ki,d}} \leq 1 \qquad (6.6.3)$$

where

N_d = design load

$N_{ki,d}$ = Elastic buckling force (Euler),see para 8

b) $$\frac{\bar{\lambda}_k}{0.3 \cdot \sqrt{f_{yd} / \sigma_{N,d}}} \leq 1 \qquad (6.6.4)$$

where:

$$\bar{\lambda}_k = \frac{s_k}{i \cdot \lambda_a} \quad \text{with} \quad \lambda_a = \pi \cdot \sqrt{E / f_{yk}}$$

$$\sigma_{N,d} = N_d / A$$

s_k = buckling length according to para 6

c) $\beta \cdot \varepsilon \leq 1$ for all members;

$$\varepsilon = l \cdot \sqrt{\gamma_M \cdot N_d / EI} \qquad (6.6.5)$$

where:

β = buckling length coefficient (buckling length = β × member length), see para 6

(6) Definitions

Buckling length s_k:

The buckling length s_k has to be established according to recognized standards and manuals depending on the end supports and constraint conditions.

For members effectively held in position laterally, normally the full member length is taken, i.e. β = 1. If the member is constrained by relatively stiff adjacent elements, e. g. a brace between platform legs, 80 % of the member length may be assumed as buckling length, i.e. β = 0.8.

(7) Cross section properties:

A = cross-sectional area,

I = moment of inertia about the considered axis (normally the smallest I).

For thin-walled members the effective cross-section properties have to be evaluated by taking into account the effective widths b' of the compression plate elements as follows:

For internal compression plate elements (supported at both sides):

$$b' = \left(\frac{s_k}{\bar{\lambda}_p} - \frac{0.22}{\bar{\lambda}_p^2} \right) \cdot b \qquad b' \leq s_k / 6 \qquad (6.6.6)$$

b = unsupported plate breadth

$\bar{\lambda}_p$ = reduced plate slenderness given by

$$\bar{\lambda}_p = \sqrt{\frac{f_{yk}}{K \cdot \sigma_e}}$$

K = buckling factor of the plate element of width b, according to the standards and literature stated in Section 6.6.5.3

σ_e = 0.9 · E · (t/b)^2, ideal elastic buckling

t = plate thickness

E = Modulus of elasticity

Note:

For greater economy, the maximum calculated compressive design stress in the considered plate element σ_d may be used instead of f_{yk}, provided that this stress is based on the effective width of all compression elements

For outstanding compression plate elements (having one free edge):

$$b' = \frac{0.7}{\bar{\lambda}_p} \cdot b; \qquad b' \le s_k / 6 \qquad (6.6.7)$$

When the cross-section is subjected to axial load N, the shift e of the neutral axis due to the reduced effective widths b' has to be taken into account by means of the additional moment ΔM:

$$\Delta M = N_d \cdot e \qquad (6.6.8)$$

(8) Elastic Buckling Force $N_{ki,d}$:

$$N_{ki,d} = \frac{\pi^2 \cdot (E \cdot I)}{1.1 \cdot s_k^{\,2}} \qquad (6.6.9)$$

For thin-walled members the moment of inertia I shall be based on the effective cross-section.

(9) Plastic resistance:

Plastic compression resistance N_p

$$N_p = A \cdot f_{yk} / \gamma_M \qquad (6.6.10)$$

Plastic resistance moment M_p

$$M_p = W_p \cdot f_{yk} / \gamma_M \qquad (6.6.11)$$

where W_p is the plastic section modulus. For thin-walled members the cross-sectional area and the elastic section modulus of the effective cross section have to be applied.

The effect of shear forces on the plastic section modulus has to be considered.

(10) Reduced slenderness $\bar{\lambda}$:

$$\bar{\lambda} = \sqrt{\frac{N_p \cdot \gamma_M}{N_e}} \qquad (6.6.12)$$

(11) Reduction factor κ for flexural buckling (buckling curves):

$$\kappa = \frac{1}{\Phi + \sqrt{\Phi^2 - \bar{\lambda}^2}} \le 1 \quad \text{for} \quad \bar{\lambda} > 0.2 \qquad (6.6.13)$$

$$\kappa = 1 \qquad \text{for} \quad \bar{\lambda} \le 0.2$$

where

$$\Phi = 0,5 \cdot \left[1 + \alpha \cdot \left(\bar{\lambda} - 0,2\right) + \bar{\lambda}^{\,2}\right] \qquad (6.6.14)$$

α = imperfection factor depending on the appropriate buckling curve

curve a: α = 0.21
curve b: α = 0.34
curve c: α = 0.49
curve d: α = 0.76

The selection of the buckling curve is shown in Fig. 6.6.1 for various cross-sections.

Fig. 6.6.2 shows the four different buckling curves.

(12) Buckling under axial compression
The axial compression force N_d - derived from factored loads - in the structural element, according to the first order elastic theory, is to fulfil the condition

$$\frac{N_d}{\kappa \cdot N_p} \le 1 \qquad (6.6.15)$$

where κ and N_p are as defined in para 11 and para 9 respectively.

(13) Buckling under axial compression and lateral bending
The proof of buckling strength for a structural element subjected to axial compression force N and bending moment M, according to the first order elastic theory, is to be carried out by the following formula

$$\frac{N_d}{\kappa \cdot N_p} + \frac{\beta_m \cdot M_d}{M_p} + \Delta n \le 1 \qquad (6.6.16)$$

where κ, N_p and M_p are as defined in para 11 and para 9 respectively (κ and Mp are related to the considered bending axis, normally the weakest axis).

$ß_m$ = moment coefficient as given in Fig. 6.6.3

$$\Delta n = 0,25\,\kappa \cdot \bar{\lambda}^{\,2} \le 0,1. \qquad (6.6.17)$$

Values for $ß_m$ less than unity may be applied only for structural elements without transverse loads, with rigid supports at both ends, constant cross section and constant axial load.

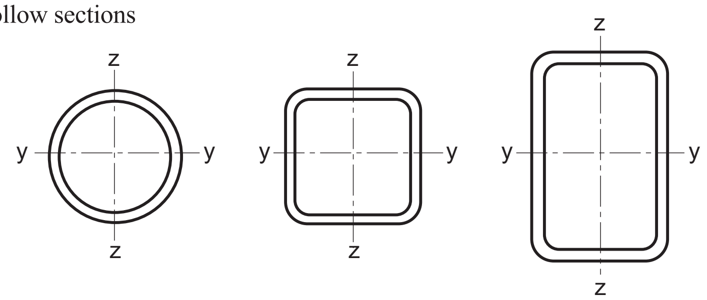
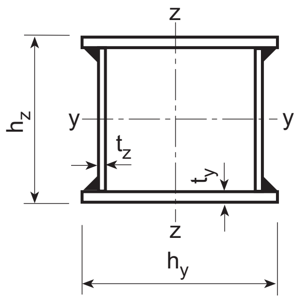
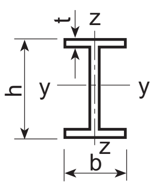
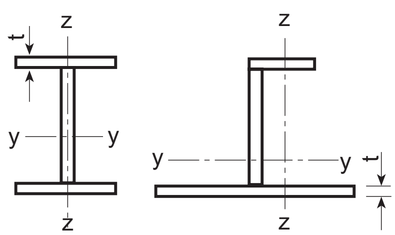
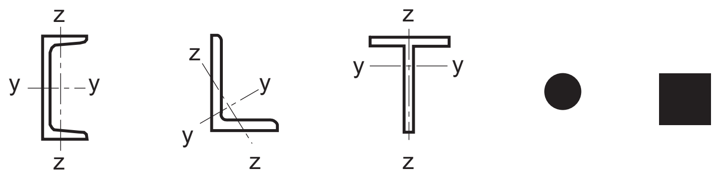
Cross section		Buckling perpendicular to axis	Buckling curve (Fig. 5.2.5)
Hollow sections 		y - y z - z	a
Welded box sections 	Generally	y - y z - z	b
	Thick welds and $h_y / t_y < 30$ $h_z / t_z < 30$	y - y z - z	c
Rolled I sections 	h / b > 1,2 t - 80mm	y - y z - z	a b
	h / b - 1,2 t - 80mm	y - y z - z	b c
Welded I and ⊥ sections 	t - 40mm	y - y z - z	b c
	t > 40mm	y - y z - z	c d
U, L, T and solid sections 		y - y z - z	c
Sections not contained in this table shall be classified analogously			

Fig. 6.6.1 Selections of buckling curves for different cross-sections

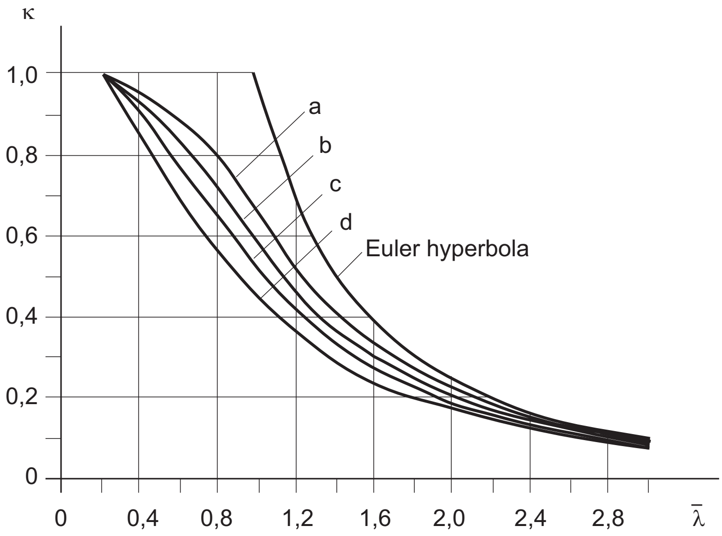


Fig. 6.6.2 Buckling curves a – d

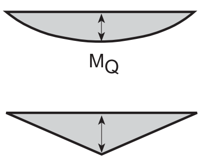
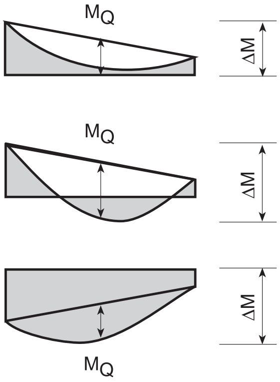
Moment distribution	Bending moment coeffient β_m
End Moments  M_1 $\psi \cdot M_1$ $-1 \le \psi \le 1$	$\beta_{m,\psi} = 0.66 + 0.44\,\psi$ but $\ge 1 - \dfrac{1}{N_{ki,d} / N}$ and ≥ 0.44
Moments from lateral loads  M_Q M_Q	$\beta_{m,Q} = 1.0$
Moments from lateral loads with end moments  M_Q M_1 ΔM M_Q M_1 ΔM M_1 ΔM M_Q	$\psi \le 0.77$: $\beta_m = 1.0$ $\psi > 0.77$: $\beta_m = \dfrac{M_Q + M_1 \text{ á } \beta_{m,\psi}}{M_Q + M_1}$

Fig. 6.6.3 Moment coefficient, β_m

For pipes the bending moment M shall be the maximum resultant bending moment

$$M = \sqrt{M_y^2 + M_z^2} \tag{6.6.18}$$

For the consideration of bi-axial bending of other sections the relevant standards as mentioned in Section 6.6.5.1 para 4 should be applied.

(14) Changes of cross section and/or axial load
For members with changes of cross-section and/or axial load all relevant cross-sections have to be checked using the respective sectional properties, axial forces and bending moments.

Alternatively, the check of buckling strength may be carried through by application of relevant standards taking into account the effects of changes of cross section and/or axial load.

6.6.5.2.3 Local buckling

(1) Bars or columns incorporating thin-walled parts in their cross-sections may fail by local plate or shell buckling. Such local failure may lead to subsequent overall buckling.

(2) Maximum b/t values for built-up sections, for which buckling need not be considered, are given in the following:

flatbar stiffeners and free flanges

$$\frac{b}{t} = 0.4 \cdot \sqrt{\frac{E}{f_{yk}}} \tag{6.6.19}$$

web plates

$$\frac{b}{t} = 1.2 \cdot \sqrt{\frac{E}{f_{yk}}} \tag{6.6.20}$$

For definitions of b, t, E, f_{yk} see Section 6.6.5.2.2 para 4 and para 7.

The b/t values are valid for shear stresses not exceeding $0.2 \cdot f_{yk}$.

(3) Checks for local buckling can be carried through as indicated in Section 6.6.5.3 under consideration of the stress distribution over the cross section.

(4) In addition, web crippling has to be considered in way of supports and other points of concentrated load transfer.

6.6.5.3 Buckling of plate elements

(1) The verification of plate elements against buckling shall be performed in accordance with acknowledged standards.

(2) The verification may be done according to Eurocode 3 or DIN 18800, part 3.

(3) Other standards to be applied shall be agreed upon by GL Wind.

(4) Buckling factors may be derived from literature, e.g. GL “Rules for Classification and Construction, I - Ship Technology”. The use of these factors shall also be agreed upon by GL Wind.

6.6.5.4 Buckling of shell elements

6.6.5.4.1 General indications

(1) Shell buckling investigations according to acknowledged standards are based on assumptions e. g. regarding geometrical imperfections and residual stresses, which have to be considered in the design and manufacturing process (see also Section 6.6.5.1para 4).

(2) Local discontinuities affecting stress distribution, such as weld seams, openings and welded-on fittings, shall be carefully investigated for their possible influence on buckling initiation. Local stiffening may be necessary.

(3) For the buckling check of long unstiffened cylindrical shells (tubes) the procedure given in Section 6.6.5.4.2 may be adopted. For short cylindrical shells or other type of loads not covered by the formulae given below the same standard may be referred to.

(4) A buckling check with the help of other analysis methods, e. g. FEM, is generally acceptable provided the influence of imperfections and the non-linear material behaviour are accounted for. A prerequisite for this is that the application conditions for the specific variants named in Sections 8.6 to 8.8 of ENV 1993-1-6:2002-05 are considered.

(5) As an approximation the buckling behaviour of shells may be calculated using the formulae for plane plate panels, see Section 6.6.5.3. In this case the curvature of the shell needs not to be considered. The actual boundary conditions and shell membrane stresses are to be accounted for.

6.6.5.4.2 Buckling of long unstiffened cylindrical shells

(1) The following basic requirements have to be fulfilled:

$$\sigma_d \le \frac{\sigma_u}{\gamma_M} \tag{6.6.21}$$

σ_d = design stress

σ_x, σ_φ	=	characteristic stress component due to axial loads (x) or external pressure (φ)
σ_u	=	σ_{xu}; $\sigma_{\varphi u}$: ultimate buckling stresses, see para 10

(2) Limitation of imperfections for cylindrical shells

The reduction factor $\kappa_{1,2}$ given in para 10 applies when the tolerances given in the following are not exceeded.

(3) Imperfections

The values "e" of the imperfections are measured from a straight rod, Fig. 6.6.4 a and c, and a circular template, Fig. 6.6.4 b and d held anywhere over the weld, respectively against any meridian and against any parallel circle.

The length ℓ_m of the rod and the template is as given in Fig. 6.6.4.

The imperfection shall not exceed one percent of the measuring length

$$e \le 0.1 \cdot \ell_m \qquad (6.6.22)$$

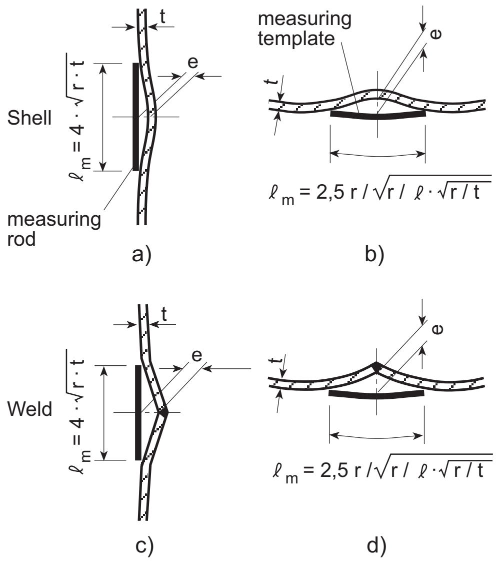


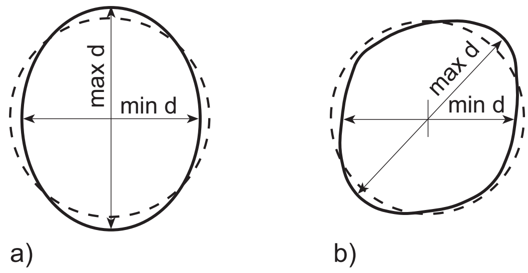
Fig. 6.6.4 Imperfections, measuring length ℓ_m

r	=	radius of shell curvature
ℓ	=	unsupported length (i. e. length between bulkheads or ring stiffener)

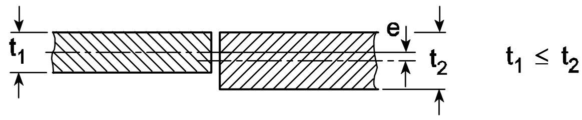
(4) Out-of-roundness

The out-of-roundness "w" shall fulfil the requirement

$$w = 2 \cdot \frac{\max d - \min d}{\max d + \min d} \cdot 100 \le 0.5 \ \%$$



(5) Misalignment of butt joints "e"



$e \le 0{,}15\ t_1$; max. 3 mm

$e \le 1$ mm for $t_1 \le 6{,}5$ mm

If the imperfections specified above are exceeded, possible corrective measures have to be implemented in each specific case. In case the imperfections exceed the specified limiting imperfections by up to two times, the reduction factors κ_1, κ_2 have to be reduced as follows:

$$\kappa_{1,2_{red}} = \kappa_{1,2} \cdot \left[1 - \frac{\bar{\lambda}_{sx,\varphi}}{3}\left(\frac{exist\ e}{allow\ e} - 1\right)\right] \qquad (6.6.23)$$

$$for\ \bar{\lambda}_{sx,\varphi} < 1.5$$

$$\kappa_{1,2_{red}} = \kappa_{1,2} \cdot \left[1.5 - 5 \cdot \left(\frac{\text{exist e}}{\text{allow e}}\right)\right] \qquad (6.6.24)$$

$$\text{for } \bar{\lambda}_{sx,\varphi} \ge 1.5$$

$\kappa_{1,2}$	=	reduction factors, see para 10
$\bar{\lambda}_{sx,\varphi}$	=	reduced slenderness for axial or circumferential loads, see para 10

(6) Ideal buckling stresses for axial compressive loads

The following formulae apply to cylinders which are fixed in radial direction.

– No buckling check is required if

$$\frac{r}{t} \le \frac{E}{40\ R_{eH}} \cdot C_x \qquad (6.6.25)$$

r	=	radius of the middle surface of the shell
t	=	plate thickness of the shell

The ideal buckling stress is to be calculated according to the following formula:

$$\sigma_{xi} = 0.605 \cdot C_x \cdot E\frac{t}{r} \qquad (6.6.26)$$

σ_{xi} = ideal buckling stress for axial compressive loads

– For cylinders with short and medium lengths, i. e.

$$\frac{\ell}{r} \le 0.5\sqrt{\frac{r}{t}}\,,\,,\quad C_x = 1 + 1.5 \cdot \left(\frac{r}{l}\right)^2 \cdot \frac{t}{r} \qquad (6.6.27)$$

Cx = may alternatively be taken as 1.0

ℓ = buckling length, see Section 6.6.5.2.2 para 6

– For long cylinders, i. e.

$$\frac{\ell}{r} > 0.5\sqrt{\frac{r}{t}} \qquad (6.6.28)$$

the factor C_x is to be calculated as follows:

$$C_x = 1 - \frac{0.4\frac{\ell}{r}\sqrt{\frac{t}{r}} - 0.2}{\eta} \ge 0.6$$

η reflects the end restraint condition and is to be chosen as follows:

– both ends clamped: η = 6

– one end simply supported – one end clamped: η = 3

– both ends simply supported: η = 1

(7) For long cylinders the bar buckling requirements of Section 6.6.5.2 are additionally to be observed.

For very long cylinders (tubular bars), with

$$\frac{\ell}{r} \ge 6\sqrt{\frac{r}{t}} \qquad (6.6.29)$$

no check of local buckling is required, for definition of s_k see Section 6.6.5.2.2 para 6.

(8) For long cylinders such as tower sections under combined axial compression and bending moment, C_x may be taken as defined in equation (6.6.30):

$$C_x = 1.0 \cdot \frac{\sigma_{x,M}}{\sigma_x} + C_{x,N} \cdot \frac{\sigma_{x,N}}{\sigma_x} \qquad (6.6.30)$$

where:

σ_x meridional stress

$\sigma_{x,N}$ component of the meridional stress from the tower perpendicular force

$\sigma_{x,M}$ component of the meridional stress from the tower bending moment

$C_{x,N}$ coefficient C_x acc to DIN 18800-4:1990-11 (408) as per para 6

The above formulation applies for:

r/t ≤ 150

$$\frac{l}{r} \cdot \left(\frac{t}{r}\right)^{0.5} \le 6$$

Structural steel types S 235 to S355, or equivalent

where:

l length of shell segment

r radius of the middle surface

t wall thickness

(9) Ideal buckling stresses for circumferential compressive loads

– No buckling check is required if

$$\frac{r}{t} \le \sqrt{\frac{E}{23\,R_{eH}}} \qquad (6.6.31)$$

– For cylinders with short and medium lengths, i. e.

$$\frac{\ell}{r} \le 1.63 \cdot C_\varphi \cdot \sqrt{\frac{r}{t}} \qquad (6.6.32)$$

the ideal buckling stress is to be calculated as follows:

$$\sigma_{\varphi i} = 0.92 \cdot C_\varphi \cdot \sqrt{\frac{r}{t}} \qquad (6.6.33)$$

$\sigma_{\varphi i}$ = ideal buckling stress for circular compressive loads,

C_φ = see Table 6.6.1

– For long cylinders, i. e.

$$\frac{\ell}{r} \le 6.63 \cdot C_\varphi \cdot \sqrt{\frac{r}{t}} \qquad (6.6.34)$$

$$\sigma_{\varphi i} = E \left(\frac{t}{r}\right)^2 \cdot \left[0.275 + 2.03 \left(\frac{C_\varphi}{\frac{\ell}{r}\sqrt{\frac{t}{r}}}\right)^4\right] \qquad (6.6.35)$$

Table 6.6.1 Factor C_φ

Support condition	C_φ
Both ends clamped	1.5
One end simply supported, One end clamped	1.25
Both ends simply suply supported	1.0
One end free, one end clamped	0.6

(10) Ultimate buckling stresses
The ultimate buckling stresses are determined with regard to inelastic material behaviour and geometric as well as structural imperfections as follows.

Calculate the reduced slenderness of the shell:

$$\bar{\lambda}_{sx} = \sqrt{\frac{R_{eH}}{\sigma_{xi}}} \qquad (6.6.36)$$

$$\bar{\lambda}_{s\varphi} = \sqrt{\frac{R_{eH}}{\sigma_{\varphi i}}} \qquad (6.6.37)$$

The ultimate buckling stresses, σ_u, are calculated for the different directions as follows:

a) $\sigma_{xu} = \kappa_2 \cdot f_{yk} / \gamma_m$ (6.6.38)

with $\gamma_M = 1.1$ for $\bar{\lambda}_{sx} \le 0.25$

and $\gamma_m = 1.1 \cdot \left(1 + 0.318 \frac{\bar{\lambda}_{sx} - 0.25}{1.75}\right)$

for $0.25 < \bar{\lambda}_{sx} < 2.0$

and $\gamma_m = 1.45$

for $2.0 \le \bar{\lambda}_{sx}$

b) $\sigma_{\varphi u} = \kappa_1 \cdot f_{yk} / \gamma_M$ (6.6.39)

with $\gamma_M = 1.1$

The reduction factors κ_1, κ_2 have to be established as a function of the reduced slenderness:

κ_2	=	1.0	for $\bar{\lambda}_{sx} \le 0.25$
κ_2	=	$1.233 - 0.933\,\bar{\lambda}_{sx}$	for $1.0 \ge \bar{\lambda}_{sx} > 0.25$
κ_2	=	$\frac{0.3}{\bar{\lambda}_{sx}^3}$	for $1.5 \ge \bar{\lambda}_{sx} > 1.0$
κ_2	=	$\frac{0.2}{\bar{\lambda}_{sx}^2}$	for $\bar{\lambda}_{sx} \ge 1.5$
κ_1	=	1.0	for $\bar{\lambda}_{s\varphi} \le 0.4$
κ_1	=	$1.274 - 0.686\,\bar{\lambda}_{s\varphi}$	for $1.2 > \bar{\lambda}_{s\varphi} > 0.4$
κ_1	=	$\frac{0.65}{\bar{\lambda}_{s\varphi}^2}$	for $\bar{\lambda}_{s\varphi} \ge 1.2$

A decrease of these reduction factors may be required if the limiting imperfections are exceeded, see para 2 to para 5.

(11) Combined axial compression and external pressure
For combined loading, axial compressive stresses and circumferential stresses due to external pressure, the following interaction equation shall be satisfied:

$$\left(\frac{\sigma_x}{\sigma_{xu}}\right)^{1,25} + \left(\frac{\sigma_\varphi}{\sigma_{\varphi u}}\right)^{1,25} \le 1.0 \qquad (6.6.40)$$

6.6.5.4.3 Stiffened cylindrical shells

(1) The buckling check of stiffened shells may be performed according to acknowledged codes (see e. g. API [6.2]).

(2) Stiffening of cylindrical elements should be so designed that buckling of the shell panel between stiffeners would occur prior to stiffener failure.

(3) Local buckling of a panel between stiffeners may be checked analogously to a plate panel if

$$\frac{b^2}{r \cdot t} \le 6 \text{ (b: stiffener spacing).}$$

In other cases, the indications in the codes mentioned in Section 6.6.1 para 10 may be followed.

Table 6.6.2 Coefficients for equation 6.6.42

	S 235		S 355	
	A_1	B_1	A_1	B_1
$\delta = 20°$	1.00	0.0019	0.95	0.0021
$\delta = 30°$	0.90	0.0019	0.85	0.0021
$\delta = 60°$	0.75	0.0022	0.70	0.0024
Intermediate values may be interpolated linearly. Extrapolation is not permissible.				

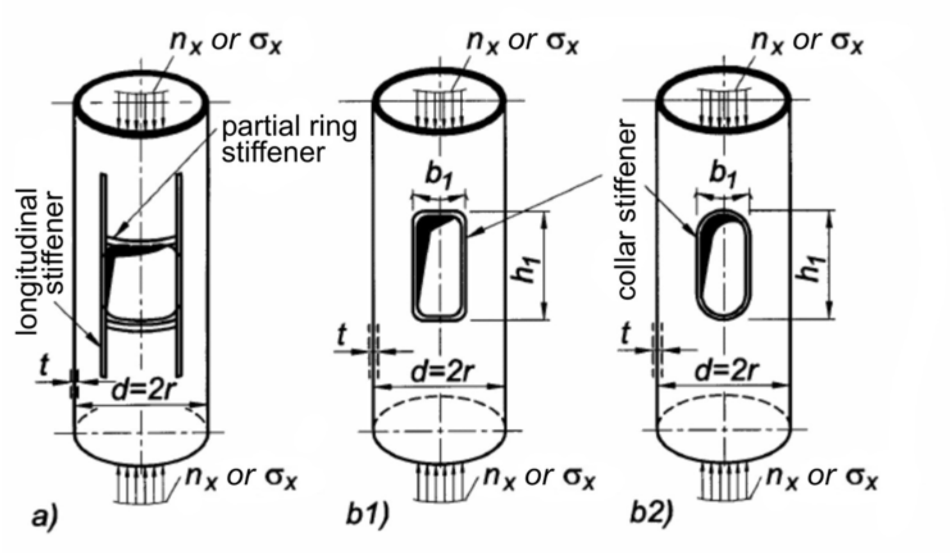


Fig. 6.6.5 a) Openings with added longitudinal stiffeners,
b1), b2) Circumferentially edge-stiffened openings (semiplan views)

6.6.5.4.4 Openings in tubular steel towers

(1) If the buckling safety of the tower wall in the area of an opening is to be verified with the aid of FE analyses, a "numerically supported buckling safety analysis with global calculation" (LA) or a "geometrically nonlinear elastic calculation (GNA)", e.g. according to DINV ENV 1993-1-6:2002-05, 8.6, shall be performed. Here the elastic critical buckling resistance R_{cr} shall be determined from a geometrically nonlinear elastic calculation (GNA). When deciding on the reference point for determination of the plastic reference resistance R_{pl}, the immediate area around the opening may be neglected; this immediate area shall not be set to be wider than $2(r{\cdot}t)^{0.5}$.

(2) In the area of edge-stiffened openings with added longitudinal stiffeners (Fig. 6.6.5, a), the buckling safety analysis may be carried out in simplified form according to DASt Guideline 017 [6.4]. The design-related boundary conditions and validity limits specified for this shall be observed.

(3) In the area of circumferentially edge-stiffened openings without added longitudinal stiffeners ("collar stiffeners", see Fig. 6.6.5, b1), b2) and Fig. 6.6.6), the buckling safety analysis may in simplification be performed as for an unweakened tower wall if, instead of the critical meridional buckling stress according to DIN 18800-4, the reduced critical meridional buckling stress according to equation 6.6.41 is used:

$$\sigma_{xS,R,d} = C_1 \cdot \sigma_{xS,R,d\text{-}DIN} \quad (6.6.41)$$

where:

$\sigma_{xS,R,d\text{-}DIN}$ critical meridional buckling stress according to DIN 18800-4

C_1 reduction factor as per equation 6.6.42 to consider the influence of the opening

$$C_1 = A_1 - B_1 \cdot (r/t) \quad (6.6.42)$$

with A_1 and B_1 according to Table 6.6.2

where:

δ opening angle along the girth

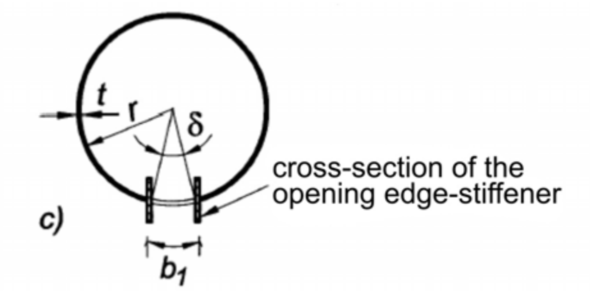


Fig. 6.6.6 Circumferentially edge-stiffened opening (cross-section)

The above rules are valid for

– tower walls with (r/t) ≤ 160,

– opening angle $\delta \leq 60°$, and

– opening dimensions h_1 / b_1 ≤ 3,

whereby the opening angle and opening dimensions refer to the cut-out of the tower wall without considering the opening edge-stiffener (see Fig. 6.6.6), and also for opening edge-stiffeners

– which exhibit a constant cross-section around the entire opening or are considered with their smallest cross-section,

– whose cross-section area is at least one-third of the missing opening area,

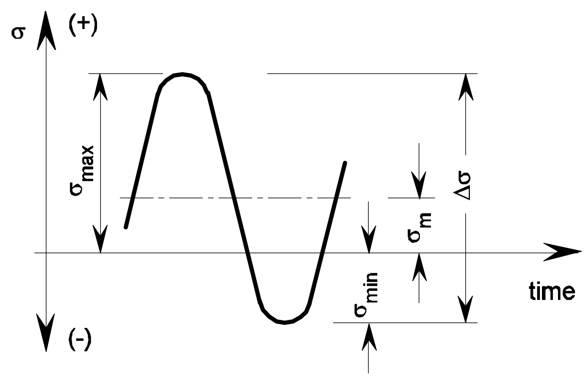
– whose cross-section at the opening edges is arranged centrally with regard to the wall mid-plane (see Fig. 6.6.6),

– whose cross-sectional parts meet the limiting (b/t) values according to DIN 18800-1:1990-11, Table 15.

(4) For openings in tubular steel towers, the stress concentration at the opening edge shall on principle be considered in respect of the stress analysis as well as the fatigue strength analysis, in addition to the buckling safety.

6.6.6 Fatigue

6.6.6.1.1 Definitions



$\Delta\sigma$	=	applied stress range ($\sigma_{max} - \sigma_{min}$) [N/mm^2]
σ_{max}	=	maximum upper stress of a stress cycle [N/mm^2]
σ_{min}	=	maximum lower stress of a stress cycle [N/mm^2]
$\Delta\sigma_{max}$	=	applied peak stress range within a stress range spectrum [N/mm^2]
σ_m	=	mean stress ($\sigma_{max}/2 + \sigma_{min}/2$) [N/mm^2]
$\Delta\sigma_p$	=	permissible stress range [N/mm^2]
$\Delta\tau$	=	corresponding range for shear stress [N/mm^2]
n	=	number of applied stress cycles
N	=	number of endured stress cycles according to S-N curve (= endured stress cycles under constant amplitude loading)
$\Delta\sigma_R$	=	fatigue strength reference value of S-N curve at $2 \cdot 10^6$ cycles of stress range [N/mm^2] (= detail category number according to Appendix 6.A)
f_a	=	correction factor for misalignment effects
f_t	=	correction factor for plate thickness
f_c	=	correction factor for corrosion effects
f_m	=	correction factor for material effects
f_R	=	correction factor for mean stress effect
f_w	=	correction factor for weld shape effect
f_i	=	correction factor for importance of structural element
f_n	=	factor considering stress spectrum and number of cycles for calculation of permissible stress range
$\Delta\sigma_{Rc}$	=	corrected fatigue strength reference value of S-N curve at $2 \cdot 10^6$ stress cycles in [N/mm^2]
γ_M	=	partial material safety factor (Table 6.6.3)
D	=	cumulative damage ratio.

6.6.6.1.2 General considerations, definitions and limitations

(1) A fatigue strength analysis is to be performed for all structures which are subjected to cyclic loading, in order to ensure structural integrity and to assess the relative importance of possible fatigue damages for the establishment of an efficient inspection programme. The extent of the analysis is influenced by the local stress range and/or the number of cycles due to fluctuating loads on the structure. Wind loading on the turbine in combination with wave loading on the structure is the main source of potential fatigue cracking. However, any other cyclic loading may contribute to fatigue failure and should therefore be considered.

(2) If the fatigue safety analysis is performed on the basis of load spectra, then these shall be determined by computational means for the corresponding cross-sections through simulation of the decisive requirements for the fatigue, if necessary supported by load measurements; see Section 10.5. The ranges of the internal forces and moments shall be superposed in the least favourable manner.

(3) As a simplification, the spectra can be represented by envelopes (e.g. in trapezoidal form) of the load spectra obtained from the simulation. Here uniform load cycle numbers should be defined for all action components.

Note:

In general, consideration of the action components rotor thrust F_x , tilting moment M_y and tower torsional moment M_z is sufficient in case the wind and wave direction is assumed to be constant over the lifetime of the structure. The tilting and tower torsional moments may be assumed to act with a phase difference of 90° to each other.

(4) The notched details, i.e. the welded connections at tubular joints, plates and beams as well as notches at free plate edges are to be considered individually. The fatigue strength assessment is to be carried out either on the basis of a permissible peak stress range for standard stress spectra (see Section 6.6.6.6) or on the basis of a cumulative damage ratio (see Section 6.6.6.5).

(5) The following rules are applicable to structural steels up to a specified yield strength of 700 N/mm^2. Bolts are acceptable up to a tensile yield strength of 1000 N/mm^2. Other materials such as cast steel, and hybrid joints, can be treated in an analogous manner by adopting appropriate stress concentration factors and design S-N curves.

(6) Low cycle fatigue problems in connection with extensive cyclic yielding have to be specially considered. When applying the following rules, the calculated nominal stress range should not exceed 1.5 times the minimum nominal upper yield point. In special cases the fatigue strength analysis may be performed by considering the local elasto-plastic stresses.

(7) No fatigue assessment is required if one of the following conditions is satisfied:

– The maximum stress range $\Delta\sigma_{max}$ due to wind, wave and other loads satisfies the following criterion and adequate protection exists in the case of corrosive environment:

$$\Delta\sigma_{\max} \le \Delta\sigma_R \cdot f_t \cdot f_c \cdot f_w \cdot f_m \cdot f_R \cdot f_i \cdot f_a / \gamma_M \quad (6.6.43)$$

– Additional stress ranges due to other load effects may be admitted if they remain below the endurable stress range at N = 2 · 10^8 cycles (see Section 6.6.6.7.1 para 1).

– The above criterion is based on the conservative assumption that the long term distribution of stress range resembles a Weibull distribution with a shape parameter h ≤ 2 and that the total number of cycles is below 10^9 (see also Section 6.6.6.6).

– The expected number of cycles during the lifetime of the structure is less than

$$2 \cdot 10^6 \cdot \left[\frac{\Delta\sigma_R \cdot f_t \cdot f_c \cdot f_w \cdot f_m \cdot f_R \cdot f_i \cdot f_a}{\left(\gamma_M \cdot \Delta\sigma_{\max}\right)} \right]^3 \quad (6.6.44)$$

where:

$\Delta\sigma_{max}$ = the maximum nominal stress range or, for tubular joints, the maximum hot spot stress range (see Section 6.6.6.3.) [N/mm^2]

$\Delta\sigma_R$ = the fatigue strength reference value, i. e. the category number of the detail considered (minimum 36, see Appendix 6) or, for tubular joints, $\Delta\sigma R$ = 100 N/mm^2, [N/mm^2]

f_t, f_c, f_w, f_m, f_R, f_i, f_a see Section 6.6.6.7.2

(8) It should be noted that uncertainties may exist in the determination of the stresses at the considered location as well as in the fatigue resistance of the structural details. While performing a fatigue analysis, special care should be taken to ensure that the calculated stresses are not underestimated, and the fatigue strength not overestimated.

(9) In order to achieve good fatigue behaviour, the structure should be designed and fabricated such that stress concentrations are reduced to a minimum. Plate thickness, structural stress concentration, weld shape and post-welding treatment as well as corrosion are some of the factors affecting the fatigue behaviour of structural details. Detailed information is given in the following.

Table 6.6.3 Partial material safety factors γ_M on stress ranges for the fatigue assessment

Inspection and accessibility	**part of a non "fail-safe" structure**	**part of a "fail-safe"structure**
Periodic monitoring and maintenance; good accessibility; manufacturing and installation surveillance, see Section 6.6.6.1.3, para 2	1.15	1.0
No periodic monitoring and maintenance possible or poor accessibility (e.g. under water or subsoil)	1.25	1.15

Note:

– *The towers of wind turbines as a rule contain components that are exclusively not fail-safe. Easily accessible components are e.g. the bolts of ring flange connections and butt welds in the tower wall.*

– *Members equipped with a Condition Monitoring or "Flooded Member Detection" System may be defined as easily accessible.*

6.6.6.1.3 Material safety factors for the fatigue assessment

(1) Partial material safety factors for the fatigue assessment may be assumed according to Tab.6.6.3.

(2) The values of the upper line of Tab. 6.6.3 may only be used in connection with an approved monitoring and maintenance concept (see Chapter 9) and if surveillance and periodic monitoring are carried out by GL Wind or GL Wind acknowledged third parties.

6.6.6.2 Fatigue assessment procedure

(1) The fatigue assessment shall verify that within an acceptable probability level the performance of the structure during its design life is satisfactory so that fatigue failure is unlikely to occur. An assessment should be made for every potential crack location. The fatigue assessment shall be carried out either in terms of calculated damage by comparing the applied damage ratio to the limit damage ratio (see Section 6.6.6.5), or in terms of maximum permissible stresses for standard stress distributions (see Section 6.6.6.6). In both cases the fatigue strength is based on design S-N curves as described in Section 6.6.6.7.

(2) The number of stress cycles which may be endured by the structural element depends mainly on the magnitude of the stress ranges $\Delta\sigma$. The influence of the mean stress σ_m is generally small and may be taken care of by the correction factor f_R defined in Section 6.6.6.7.2.

(3) A long term distribution of stress range due to the load effects has to be established in terms of complete cycles using an appropriate cycle counting method. "Rainflow" counting with consideration of the residuals (half cycles) is recommended.

(4) The long term distribution of stress ranges shall take into account all stress fluctuations of relevance to the fatigue behaviour during the planned life of the structure. Some important sources of cyclic stresses are waves, wind, currents, varying hydrostatic pressure, crane loads, deck live loads and mechanical vibration. Construction, transport and installation loads may also be of relevance to the fatigue life.

(5) Fatigue load spectra shall be established using guidance given in Chapter 4 and Section 6.1.2 of the present Guideline including load safety factors (see Section 4.3.7). The long-term distributions of the external conditions (including directionality) as well as dynamic amplification have to be chosen carefully with respect to their contribution to fatigue damage of the structural member under consideration. Global and local forces due to vortex induced vibrations and impact loads due to slamming in the splash zone or slap due to breaking waves shall be taken into account.

(6) The analyses shall be performed with the combination of actions of group F according to Section 4.3.3, Table 4.3.4.

(7) Regular maintenance and the Periodic Monitoring according to Chapter 11 are regarded as prerequisites.

(8) The fatigue strength analysis is, depending on the detail considered, based on one of the following types of stress:

– For tubular joints with full penetration welds the stress to be used in the fatigue analysis should be the hot spot stress σ_s at the weld toe as defined in Section 6.6.6.3. The hot spot stress can be derived by calculating the nominal stress in the structural member (normally by a frame analysis of the structure) and applying appropriate stress concentration factors (SCF), see Section 6.5.3.4.

– For other welded joints the fatigue strength analysis is normally based on the nominal stress σ_n at the structural detail considered and on an appropriate detail classification as given in Appendix 6.A, which defines the detail category (or the fatigue strength reference value $\Delta\sigma_R$).

– For those welded joints, for which the detail classification is not possible or where additional stresses occur, which are not or not adequately considered by the detail classification, the fatigue strength analysis may alternatively be performed on the basis of the hot spot stress σ_s as described in Section 6.6.6.3 para 5.

– For notches of free plate edges the relevant notch stress σ_k is determined for linear-elastic material behaviour; σ_k can normally be calculated from a nominal stress σ_n and a theoretical stress concentration factor K_t. The fatigue strength is determined by the detail category (or $\Delta\sigma_R$) according to Table 6.A.1.

(9) For the fatigue assessment procedure the stress ranges shall be multiplied by a safety factor γ_M which covers uncertainties of the procedure, the accessibility of the detail considered and the consequences of failure. Concerning the consequences of failure, the following two types of structures are to be considered:

– "fail-safe" structures, with reduced consequences of failure, i.e. local failure of a component does not result in a catastrophic failure of the structure

– "non fail-safe" structures, where local failure of a component leads rapidly to a catastrophic failure of the structure

The safety factors to be applied are given in Table 6.6.3.

6.6.6.3 Hot spot stress definition

(1) As mentioned above, tubular joints shall be assessed on the basis of the hot spot stress range at the weld toe. This is the largest stress value at the intersection of the brace and chord and is defined as the extrapolation of the structural or geometric stress distribution to the weld toe (Fig. 6.6.7). With this definition the hot spot stress incorporates the effects of the overall geometry (structural or geometric stress concentration) but omits the influence of the notch at the weld toe (local stress concentration). The hot spot stress has to be considered in connection with a particular design S-N curve as described in Section 6.6.6.7.1 para 3, which reflects the microscale effect occuring at the weld toe.

(2) The hot spot stress can be calculated as the sum of nominal stresses due to the individual load components (i.e. axial load, in-plane and out-of-plane bending moment), each multiplied by a corresponding stress concentration factor (SCF). Stress concentration factors for the individual load components may be derived from finite element analyses, model tests or semi-empirical parametric equations based on such methods. Parametric equations should be used with caution in view of their accuracy and inherent limitations.

(3) At least four different locations around the chord/brace intersection should be considered because the individual load components produce different stress peaks at the crown and saddle points (Fig. 6.6.7). Both the chord and the brace side of the weld should be checked in the fatigue analysis.

(4) Tubular joints with complex geometry (braces overlapping or stiffened by gusset plates or ring stiffeners) have to be investigated by a special analysis. Finite element analysis is recommended.

(5) In plate structures, the hot spot stress at a weld toe is defined accordingly. It can be determined by measurements or numerically, e.g. by the finite element method using shell or volumetric models under the assumption of linear stress distribution over the plate thickness. This stress, containing membrane and bending components, may be linearly extrapolated to the weld toe over two points, $0.5 \times t$ and $1.5 \times t$ away from the weld toe (t = plate thickness).

(6) In addition to the assessment of the hot spot stress at the weld toe, the fatigue strength with regard to root failure has to be considered for partial penetration welds by application of the respective detail classification, see also Section 6.6.6.4.1 para 6 (e.g. Type No. 414 in Table 6.A.1).

6.6.6.4 Nominal stress definition and classification of other details

6.6.6.4.1 Fatique Analysis of Welded Connections

(1) Corresponding to their notch effect, welded joints are normally classified into detail categories considering particulars in geometry and fabrication, including subsequent quality control, and definition of nominal stress. Table 6.A.1 shows the detail classification based on recommendations of the International Institute of Welding (IIW) giving the detail category number (or $\Delta\sigma_R$), representing the fatigue strength reference value (at $2 \cdot 10^6$ cycles) for structures made of steel.

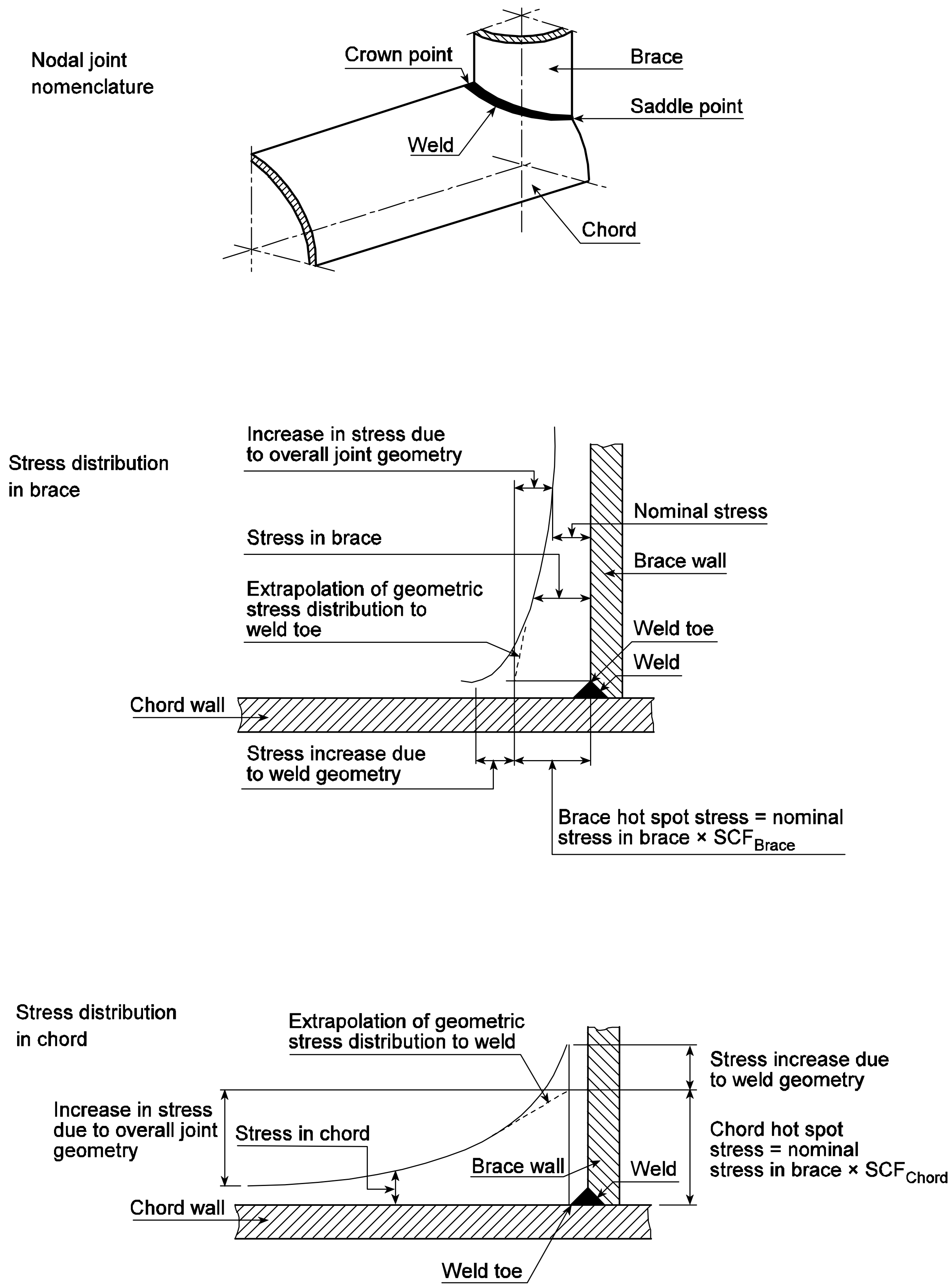


Fig. 6.6.7 Example of hot spot stresses in a tubular joint

Note:

Some influence parameters cannot be considered by the detail classification, a large scatter of fatigue strength has therefore to be reckoned with.

(2) Details which are not contained in Appendix 6.A may be classified either on the basis of hot spot stresses (see Section 6.6.6.3) or, by reference to published experimental work or by carrying out special fatigue tests, assuming a sufficiently high confidence level (see Section 6.6.6.7.1 para 1) and taking into account the correction factors as given in Section 6.6.6.7.2.

(3) Regarding the definition of nominal stress, the arrows in the tables of Appendix 6.A indicate the location and direction of the stress for which the stress range is to be calculated. The potential crack location is also shown in the tables. Depending on this crack location, the nominal stress range has to be determined by using either the cross sectional area of the parent metal or the weld throat thickness, respectively.

(4) Bending stresses in plate and shell structures have to be incorporated into the nominal stress, taking the nominal bending stress acting at the location of crack initiation.

Note:

The factor K_s for the stress increase at transverse butt welds between plates of different thickness (see Type No. 221 to 223 in Table 6.A.1) can be estimated in a first approximation as follows:

$$K_S = \frac{t_2}{t_1} \qquad (6.6.45)$$

t_1 = *smaller plate thickness*

t_2 = *larger plate thickness*

(5) Additional stress concentrations which are not characteristic of the detail category itself, e.g. due to cut-outs in the neighbourhood of the detail, have also to be incorporated into the nominal stress.

(6) In the case of combined normal and shear stress the relevant stress range may be taken as the range of the principal stress at the potential crack location which acts approximately perpendicular to the crack front as shown in Appendix 6.A.

(7) Where solely shear stresses are acting, the largest principal stress $\sigma_1 = \tau$ may be used in combination with the relevant detail category.

6.6.6.4.2 Fatigue Analysis of Bolted Connections

(1) For the fatigue analysis of bolted connections, the indications stated in Section 5.3.4.4.1 have to be considered.

(2) Further detail categories for bolted connections may be derived from acknowledged standards, e.g. Eurocode 3, in consultation with GL Wind.

6.6.6.5 Calculation of cumulative damage ratio

(1) If the fatigue strength analysis is based on the calculation of the cumulative damage ratio, the stress range spectrum expected during the envisaged service life is to be established (see Section 6.6.6.2) and the cumulative damage rate D is to be calculated as follows:

$$D = \sum_{i=1}^{I}\left(\frac{n_i}{N_i}\right) \le 1 \qquad (6.6.46)$$

I = total number of blocks of the stress range spectrum for summation (normally I ≥ 20)

n_i = number of stress cycles in block i

N_i = number of endured stress cycles determined from the corrected design S-N curve (see Section 6.6.6.7) taking $\Delta\sigma = (\gamma_M \cdot \Delta\sigma_i)$

$\Delta\sigma_i$ = stress range of block i

γ_M = safety factor for material, see Table 6.6.3.

(2) In general the design fatigue life of each joint and member shall be at least the planned service life of the structure. This means that the cumulative damage ratio D shall not exceed the limit damage ratio of 1.

6.6.6.6 Permissible stresses for standard distributions of long term stress ranges

(1) For standard distributions of long term stress ranges the calculation can be simplified by using tabulated values of permissible peak stress ranges meeting the requirements stated above.

(2) In many cases the two-parameter Weibull distribution applies having a cumulative stress distribution in the following form (see also Fig. 6.6.8):

$$\Delta\sigma = \Delta\sigma_{\max}\left[1-\frac{\log(n)}{\log(n_{\max})}\right]^{1/h} \qquad (6.6.47)$$

where:

n = number of stress cycles exceeding $\Delta\sigma$

$\Delta\sigma_{max}$ = maximum stress range which is exceeded once within n_{max} stress cycles

n_{max} = total number of stress cycles

h = shape parameter (h = 1 corresponds to a linear distribution in a $\Delta\sigma$-log(n) diagram)

(3) For the two-parameter Weibull distributions, the permissible peak stress range can be calculated as follows:

$$\Delta\sigma_p = f_n \cdot \Delta\sigma_{Rc} \qquad (6.6.48)$$

$\Delta\sigma_p$ = permissible peak stress range

$\Delta\sigma_{Rc}$ = detail category or fatigue strength reference value, respectively, corrected according to Section 6.6.6.7.2

f_n = factor as given in Table 6.6.4.

(4) The peak stress range of the spectrum shall not exceed the permissible value, i.e.

$$\Delta\sigma_{max} \leq \Delta\sigma_p \qquad (6.6.49)$$

Table 6.6.4 is based on a cumulative damage ratio D = 1 (see Section 6.6.6.5) and on the S-N curves as shown in Fig. 6.6.9 and 6.6.10, type “M”. Therefore, the permissible stresses in Table 6.6.4 are not applicable to structural details without adequate corrosion protection.

6.6.6.7 Design S-N curves

6.6.6.7.1 Description of the design S-N curves

(1) The design S-N curves for the calculation of the cumulative damage ratio according to Section 6.6.6.5. are shown in Fig. 6.6.9 for welded joints and in Fig. 6.6.10 for notches at free plate edges. The S-N curves represent the lower limit of the scatter band of 95 % of all test results available (corresponding to 97.5 % survival probability) considering further detrimental effects in large structures.

(2) To account for different influence factors, the design S-N curves have to be corrected according to Section 6.6.6.7.2.

(3) The S-N curves represent sectionwise linear relationships between $\log(\Delta\sigma)$ and log(N):

log(N) = $6.69897 + m \cdot Q$

Q = $\log(\Delta\sigma_R/\Delta\sigma) - 0.39794/m_o$

m_o = 3.5 ÷ 5for free plate edges (see Fig. 6.2.7)

m = inverse slope of S-N curve

m_o = inverse slope in the range $N \leq 5 \cdot 10^6$

m_o = 3 for welded joints

(4) The S-N curves for detail category 160 forms the upper limit also for free plate edges with detail categories 100 – 140 in the range of low numbers of stress cycles, see Fig 6.6.10.

(5) For the fatigue strength analysis based on hot spot stress, the S-N curves shown in Fig. 6.6.9 apply with the following reference values:

$\Delta\sigma_R$ = 100, for K-butt welds with fillet welded ends, e.g. tubular joints or joints according to Type No. 411 in Table 6.A.1, and for fillet welds which carry no load or only part of the load of the attached plate, e.g. Type No. 511 in Table 6.A.1

$\Delta\sigma_R$ = 90, for fillet welds, which carry the total load of the attached plate, e.g. Type No. 413 in Table 6.A.1.

(6) For butt welds, the values given for Type No. 211 – 216 and 221 – 225 in Table 6.A.1 apply.

(7) The correction of the design S-N curves according to Section 6.6.6.7.2 shall include the factor f_a (see Section 6.6.6.7.2, para 8).

(8) For structures in a mildly corrosive environment or in corrosive environment where an adequate protection is provided and which are subjected to variable stress ranges, the S-N curves shown by the solid lines in Fig. 6.6.9 and Fig. 6.6.10 have to be applied (S-N curves of type “M”), i.e.

m = m_o for $Q \leq 0$

m = $2\,m_o - 1$ for $Q > 0$

(9) For stress ranges of constant magnitude in non-corrosive environment the stress range given at $N = 5 \cdot 10^6$ cycles may be taken as fatigue limit (S-N curves of type “O” in Fig. 6.6.9 and 6.6.10), thus:

m = m_o for $Q \leq 0$

m = ∞ for $Q > 0$

(10) For unprotected members exposed to corrosive environment the curves have to be extended without a change in slope and without fatigue limit, thus

m = m_o, for all values of Q

(11) The minimum weld quality levels required for the use of detail classification according to the tables of Appendix 6.A are defined in Section 3.4.2. If any of these levels are not achieved, the use of the S-N curves is not appropriate. In such cases, the fatigue assessment shall be carried out by suitable adaption of this Guideline.

Table 6.6.4 Factor f_n for the determination of the permissible stress range for Weibull stress range spectra

Shape parameter h	Welded Joints $(m_o = 3)$ n_{max} =			Plates Edges type 28 $(m_o = 5)$ n_{max} =			Plates Edges type 29 $(m_o = 4)$ n_{max} =			Plates Edges type 30 $(m_o = 3{,}5)$ n_{max} =		
	10^7	10^8	10^9	10^7	10^8	10^9	10^7	10^8	10^9	10^7	10^8	10^9
0.5	(17,1)	(10,7)	6,86	9,27	7,62	6,16	(12,3)	9,14	6,73	(14,4)	9,94	6,88
0.6	(12,3)	7,50	4,79	7,78	6,17	4,85	9,69	6,94	5,01	(10,9)	7,27	4,98
0.7	9,45	5,65	3,62	6,63	5,12	3,97	7,88	5,51	3,96	8,63	5,64	3,85
0.8	7,56	4,49	2,90	5,74	4,36	3,36	6,59	4,55	3,26	7,07	4,57	3,13
0.9	6,26	3,71	2,41	5,06	3,79	2,91	5,65	3,86	2,78	5,96	3,83	2,64
1.0	5,33	3,16	2,06	4,52	3,36	2,58	4,94	3,36	2,43	5,15	3,30	2,28
1.2	4,11	2,44	1,61	3,74	2,76	2,13	3,96	2,69	1,96	4,05	2,60	1,82
1.4	3,36	2,01	1,34	3,21	2,36	1,83	3,33	2,26	1,66	3,36	2,22	1,53
1.6	2,86	1,72	1,15	2,84	2,08	1,63	2,89	1,97	1,46	2,89	1,87	1,33
1.8	2,51	1,52	1,02	2,56	1,88	1,48	2,57	1,76	1,31	2,56	1,66	1,18
2.0	2,25	1,37	0,91	2,34	1,72	1,36	2,33	1,60	1,20	2,30	1,51	1,07

The values given in parentheses may be applied for interpolation.

For interpolation between any pair of values (n_{max1}; f_{n1}) and (n_{max2}; f_{n2}), the following formula may be applied

$$\log f_n = \log f_{n1} + \log\left(n_{max} / n_{max1}\right)\frac{\log\left(f_{n2} / f_n\right)}{\log\left(n_{max2} / n_{max1}\right)}$$

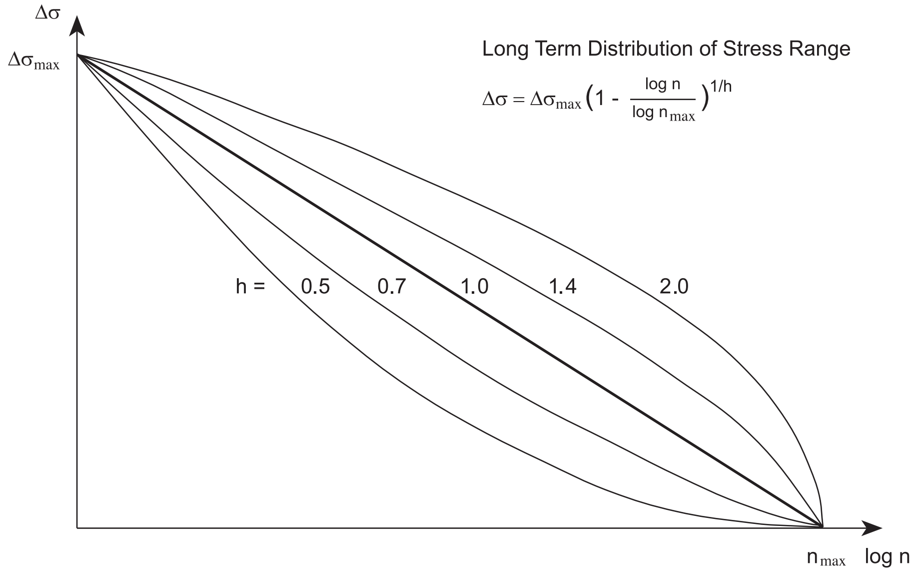


Fig 6.6.8 Two-Parameter Weibull Distribution of Stress Range

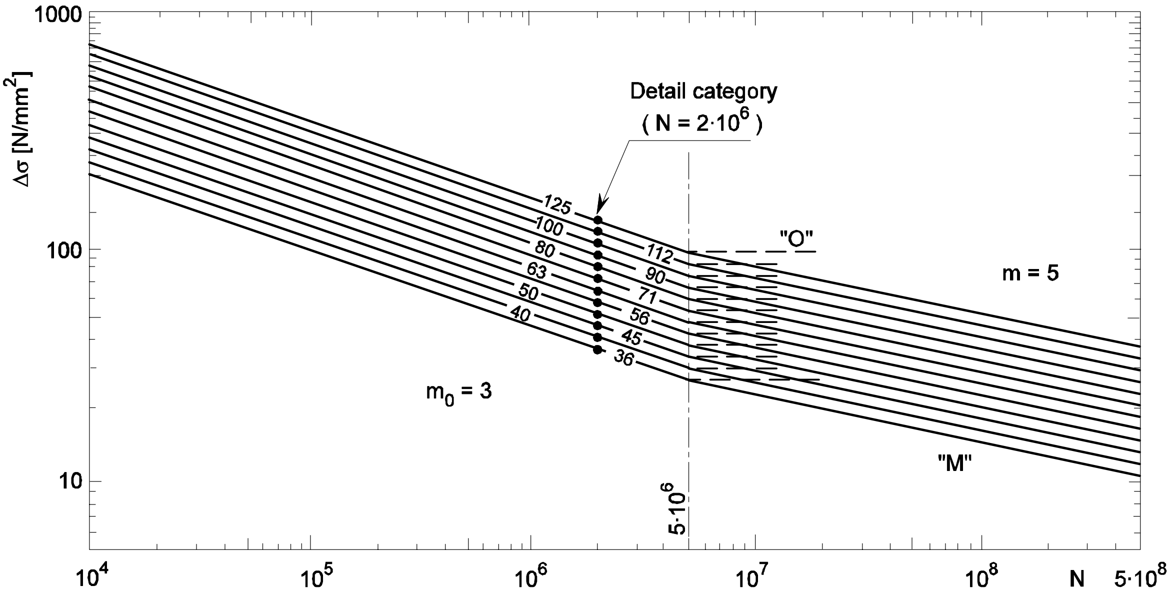


Fig. 6.6.9 S-N curves, welded joints

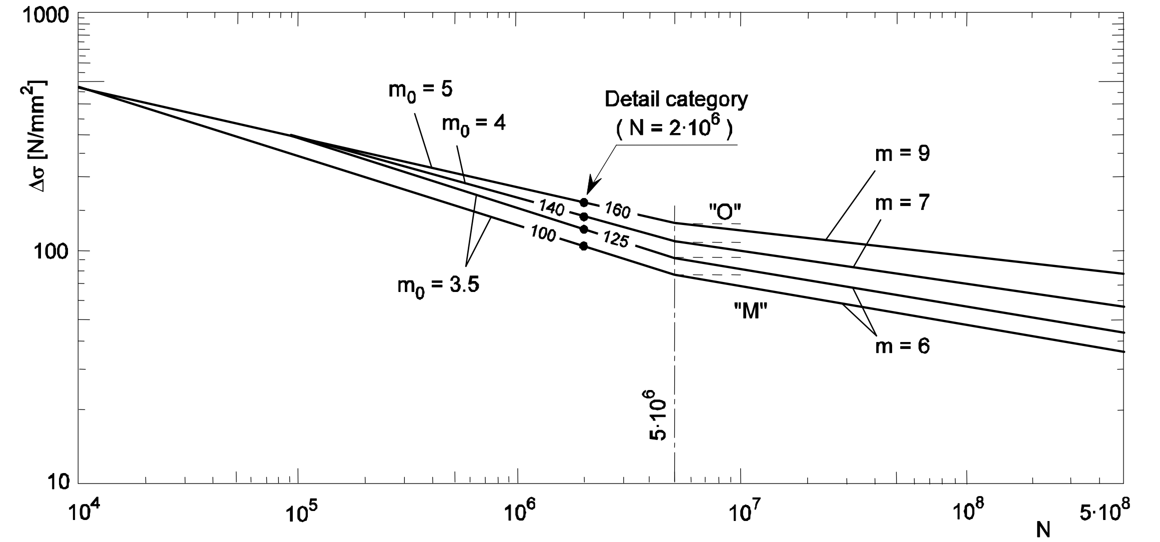


Fig. 6.6.10 S-N curves, plate edges

6.6.6.7.2 Correction of the reference value of the design S-N curve

(1) A correction of the reference value of the S-N curve (or detail category) is required to account for additional influence factors on fatigue strength as follows:

$$\Delta\sigma_{Rc} = f_t \cdot f_c \cdot f_m \cdot f_R \cdot f_w \cdot f_i \cdot f_a \cdot \Delta\sigma_R$$

f_t, f_c, f_m, f_R, f_w, f_i, f_a, as defined in para 2 to para 8.

For the description of the corrected design S-N curve, the formulae given in Section 6.6.6.7.1 para 2 may be used, replacing $\Delta\sigma_R$ by $\Delta\sigma_{Rc}$.

(2) Thickness effect (f_t)

For base material and welded connections oriented to the direction of the applied stress as specified below, with a plate thickness t [mm], exceeding 25 mm at the potential crack locations:

$$f_t = \left(\frac{25}{t}\right)^n \qquad (6.6.50)$$

n = 0.3 for cruciform joints, transverse T-joints, plates with transverse attachments, as-welded

0.2 for cruciform joints, transverse T-joints, plates with transverse attachments, toe ground

0.2 for transverse butt welds, as-welded

0.1 for butt welds ground flush, base material, longitudinal welds or attachments

For all other cases:

$f_t = 1.0$

(3) Corrosion effect (f_c)
For parts of a structure in corrosive environment without adequate corrosion protection:

$$f_c = 0.7$$

For all other cases:

$$f_c = 1.0$$

(4) Material effect (f_m)
For welded joints it is generally assumed that the fatigue strength is independent of steel strength i.e.:

$$f_m = 1.0$$

For free plate edges the effect of the material's yield point is accounted for as follows:

$$f_m = 1 + \frac{f_{yk} - 235}{1200} \qquad (6.6.51)$$

f_{yk} = minimum nominal upper yield point of the steel [N/mm^2].

(5) Effect of mean stress (f_R)
The correction factor is calculated as follows:

– in the range of tensile pulsating stresses:

$$f_R = 1.0 \quad ; \quad \sigma_m \geq \frac{\Delta\sigma_{\max}}{2} \qquad (6.6.52)$$

– in the range of alternating stresses:

$$f_R = 1 + c\left(1 - \frac{2 \cdot \sigma_m}{\Delta\sigma_{\max}}\right) \quad ;$$

$$-\frac{\Delta\sigma_{\max}}{2} \leq \sigma_m \leq \frac{\Delta\sigma_{\max}}{2} \qquad (6.6.53)$$

– in the range of compressive pulsating stresses:

$$f_R = 1 + 2 \cdot c \quad ; \quad \sigma_m \leq -\frac{\Delta\sigma_{\max}}{2} \qquad (6.6.54)$$

c = 0 for welded joints subjected to constant stress cycles

= 0.15 for welded joints subjected to variable stress cycles

= 0.3 for free plate edges

(6) Effect of weld shape (f_w)
In normal cases:

$$f_W = 1.0$$

A factor $f_w > 1.0$ applies for welds treated e.g. by grinding. By this surface defects such as slag inclusions, porosity and crack-like undercuts shall be removed and a smooth transition from the weld to the base material shall be achieved. Final grinding shall be performed transversely to the weld direction. The depth should be approx. 0.5 mm larger than that of visible undercuts. For ground weld toes of fillet and K-butt welds:

$$f_W = 1.15$$

For butt welds ground flush either the corresponding detail category has to be chosen, e.g. Type No. 211 in Table 6.A.1, or a weld shape factor

$$f_W = 1.25$$

may be applied in case of effective protection from sea water corrosion.

For endings of stiffeners or brackets, e.g. Type No. 523 or 524 in Table 6.A.1, which have a full penetration weld and are completely ground flush to achieve a notch-free transition, the following factor applies:

$$f_W = 1.40$$

The assessment of a local post-weld treatment of the weld surface and the weld toe by other methods has to be agreed on in each case.

(7) Influence of importance of structural element (f_i)
The influence of importance is usually covered by the safety factor γ (see Table 6.6.3), i.e.:

$$f_i = 1.0$$

For notches at plate edges in general the following correction factor is to be used which takes into account the radius of rounding:

$$f_i = 0.9 + \frac{5}{r} \leq 1.0 \qquad (6.6.55)$$

r = notch radius in [mm]; for elliptical roundings the mean value of the main half axes may be taken.

(8) Effect of misalignment (f_a) for nominal stress approach

Misalignment in axially loaded joints leads to an increase of stress in the welded joint due to the occurrence of secondary shell bending stresses. The resulting stress is calculated by stress analysis or by using a stress magnification factor k_m. The factor k_m may be derived e.g. on basis of the formulas given in the IIW Recommendations [5.5].

In general it is to be distinguished between design misalignments (e.g. thickness step) and misalignments from manufacturing tolerances (e.g. due to unintended production-caused deviations in shape and/or alignment).

The stress magnification due to design misalignments is always to be taken into account.

The stress magnification due to misalignments from manufacturing tolerances is to be taken into account if the misalignment due to manufacturing tolerances is larger than 10% of the smaller thicknesses t of the connected plates. Generally only the fraction above 0.1 t has to be considered. This is because the misalignment from manufacturing tolerances below 0.1 t can be considered to be covered by the detail categories (see below). However, in this case the actual misalignment shall be measured and documented.

Note:

For cruciform joints the misalignment from manufacturing tolerances below 0.15 t can be considered to be covered by the detail categories.

It is important to note that in cases where no misalignments are specified, measured and documented, at minimum the misalignments given in Section 3.4.1.14 are to be considered.

The overall stress magnification factor k_m may be computed on basis of the total eccentricity - derived by direct summation of the contributions from the different sources - respectively k_m may be derived by summation of the single specific factors $k_{m,i}$ associated to the single different contributions to the total eccentricity:

$$k_m = 1 + (k_{m,1} - 1) + (k_{m,2} - 1) + \ldots \tag{6.6.56}$$

A more comprehensive approach might lead to a less conservative result.

To account for the allowance for misalignment which in some cases is already included in the table of the details categories (Appendix 6.A) the effective stress magnification factor $k_{m,eff}$ may be calculated as given below:

Table 6.6.5 Stress magnification factor k_m

Type of welded joint	k_m already covered	$k_{m,eff}$
for butt welds, transverse stiffeners or tee-joints (corresponding to types 211 – 126, 221 – 225 and 411 – 413 in Table 6.A.1)	1.30	$k_m / 1.30 \geq 1.0$
for cruciform joints (corresponding to types 411 – 413 in Table 6.A.1)	1.45	$k_m / 1.45 \geq 1.0$
in all other cases	1.00	$k_m \geq 1.0$

When using the above given equations to derive the reduced stress magnification factor $k_{m,eff}$ care shall be taken that besides the design misalignments the misalignments due to fabrication tolerances are accurately known and not underestimated. If this cannot be guaranteed the stress magnification factor k_m shall in no case be reduced:

$$k_{m,eff} = k_m \geq 1.0 \tag{6.6.57}$$

The correction factor f_a may be derived as follows:

$$f_a = 1/k_{m,eff} \tag{6.6.58}$$

(9) Effect of misalignment (f_a) for hot spot stress approach

If the hot spot stress is assessed f_a describes the influence of misalignment which is not contained in $\Delta\sigma_R$ given in Section 6.6.6.7.1 para 3.

The correction factor f_a for fabrication related misalignment may be derived as follows:

$$f_a = \frac{k_m^*}{k_m - \frac{\Delta\sigma_{s,b}}{\Delta\sigma_{s,\max}}\left(k_m - 1\right)} \tag{6.6.59}$$

$\Delta\sigma_{s,max}$ = applied peak stress range within a stress range spectrum

$\Delta\sigma_{s,b}$ = bending portion (in plate) of $\Delta\sigma_{s,max}$

k_m = stress increase factor due to misalignment under axial loading, at least:

= 1.3 for butt welds, transverse stiffeners or tee-joints

= 1.45 for cruciform joints

= 1.0 in all other cases (incl. tubular joints)

k_m^* = stress increase factor already contained in the fatigue strength reference value $\Delta\sigma R$:

= 1.3 for butt welds (corresponding to Type No. 211 – 216 and 221 – 225 in Table 6.A.1)

= 1.0 in all other cases (incl. tubular joints)

Design misalignments are usually considered in the analysis model and therefore in the applied stress. Alternatively it can be included in k_m.

For simplification,

$$f_a = k_m^* / k_m \qquad (6.6.60)$$

may be applied.

6.6.6.8 Pile driving fatigue

(1) Pile driving fatigue has to be considered on the basis of the load spectra for the pile driving impact under consideration of pile dynamics. The fatigue portion due to the pile driving process D_P has to be calculated with the maximum number of driving impacts that can occur to ensure the design embedment depth of the pile using the same partial safety factor γ_M as for the fatigue calculation due to operation of the offshore wind turbine.

Note:

In general, the number of load cycles as well as the impact energy is not well known in the design phase. In these cases, a preliminary fatigue analysis can be performed on the basis of conservative assumptions which have to be verified after the pile driving based on the driving record.

(2) Stress increase due to the pile design as well as due to the pile driving process has to be taken into account. If the impact is directly imposed on a flange, possible local stress increase has to be considered taking the distribution of forces between hammer and flange as well as the dynamics of the pile driving process into account.

(3) The fatigue portion due to the pile driving process D_P has to be summarised with the other relevant fatigue portions to the cumulative fatigue D.

6.6.6.9 Wind-induced transverse vibrations

(1) Damage contributions from wind-induced transverse vibrations D_Q shall always be taken into account. Here the damage contributions from the two states “standstill with machine mounted” $D_{Q,1}$ and “tower standing without machine” $D_{Q,0}$ shall be calculated as per Section 6.1.3.

(2) When calculating the damage contribution $D_{Q,1}$, a standstill period of 1/20 of the operating life shall be applied.

(3) When calculating the damage contribution $D_{Q,0}$, the time the tower stands without machine shall be specified by the manufacturer and taken into account in the calculation. The damage contribution $D_{Q,0}$ shall only then be taken into account if the time the tower stands without machine exceeds one week. For a non-verified standstill time of up to one week, the wind speed shall be at most 90 % of the critical wind speed calculated when determining the internal forces and moments. It this is not the case, measures shall be taken against transverse vibrations.

(4) The damage contributions D_Q do not need to be accumulated with the damage contributions of the actions from the operating states D_F if the wind direction for the determination of D_F was assumed to be constant for the entire action duration.

(5) If the wind direction distribution is taken into account when determining D_F, then D_F and D_Q shall be accumulated. Here the less favourable value of the two equations 6.6.61 and 6.6.62 shall be taken into account:

$$D = D_F \qquad (6.6.61)$$

$$D = \frac{19}{20} \cdot D_F + D_Q \qquad (6.6.62)$$

6.7 Foundation and Subsoil

6.7.1 General

(1) This Chapter applies to the foundations of fixed offshore wind turbines and covers piled as well as gravity type designs.

(2) The foundation designs of fixed offshore wind turbines shall consider all types of loads which may occur during installation and operation of the structure.

(3) The nature of the soil, about which there shall be adequate knowledge before construction starts, is decisive for the type of foundation.

(4) A distinction shall be made between internal and external load-bearing behaviour, as well as to static, dynamic and transient analysis.

(5) Insofar as the "foundation" subsystem was replaced by torsion and displacement springs at the tower base when calculating the natural frequencies of the overall system, these assumed spring values shall be confirmed during the foundation calculation, e.g. by suitable approximation formulae.

6.7.2 Assessment documents

6.7.2.1 Calculation documents

(1) The calculation documents serve to document the computational analyses. They should be structured to be complete, comprehensible and clear.

(2) The origin of unusual equations and calculation methods shall be stated.

6.7.2.2 Drawings

True-to-scale working drawings shall be produced to contain all the necessary information and technical requirements. These include in particular:

- representation of the foundation geometry
- detailed presentation of the reinforcement plan
- material specifications
- requirements for the soil
- statement of the turbine type and type class

6.7.3 Analysis concept

(1) For the analyses of components made of reinforced concrete and preloaded concrete as well as components of steel, the safety concept described in Sections 5.3 and 5.4 shall be applied.

(2) For the external load-bearing (soil) capacity, a general safety concept with partial safety factors, as e.g. the DIN 1054:2003-01 or API RP 2A-LRFD of July 1993 or comparable standards, shall be applied.

The design requirement may be expressed as follows:

$$\Sigma\left(\gamma_F \cdot F_k\right) < \Sigma\left(R_k / \gamma_M\right) \qquad (6.7.1)$$

where:

γ_F = partial safety factor for the loads

F_k = characteristic load

R_k = characteristic ultimate resistance of soil or structure or its combination

γ_M = partial safety factor for the soil, the material, or its combinations

(3) Nonlinear influences shall be taken into account.

6.7.4 Loads to be applied

(1) The analyses shall be performed with the least favourable of all the combinations of actions according to Section 4.3.

(2) For loads from the soil and from subsurface currents, the partial safety factors of e.g. the DIN 1054:2003-01 or API RP 2A-LRFD of July 1993 or comparable standards have to be applied. If the applied standard is based on global safety factors, partial safety factors have to be recalculated from the overall safety factor of the soil standard and the partial load factors.

(3) For the analysis as per DIN 1054, the load cases 1, 2 or 3 in the sense of DIN 1054:2003-01, 6.3.3 shall be assigned to the combinations of actions according to Table 4.3.1 as per Table 6.7.1.

(4) The partial safety factors of soil resistance follow the classification of loads which act in the respective analysis. For other soil standards chosen the interpretation shall be done accordingly and in accordance with GL Wind.

Tab. 6.7.1 Assignment of combinations of actions according to Table 4.3.1 to the load cases according to DIN 1054:2003-01

Combination of actions according to Table 4.3.1 (DLC)	Load case according to DIN 1054
3.1, 4.1, 1-hour mean value of DLC 1.1 with $V=V_r$	1
8.1, 8.3, 8.4, 8.5, 1-hour mean value of DLC 6.4	2
N, E, A, T (all without F)	3

6.7.5 Foundation

6.7.5.1 Structural steel components

Structural steel components shall be verified according to Section 5.3 or 6.6.

6.7.5.2 Reinforced concrete components

(1) Reinforced concrete components shall be verified according to Section 5.4.

(2) Areas of concentrated load introduction shall be considered.

(3) Areas of the foundation above an integration depth of 0.5 m in the earth shall be verified for a crack width of 0.2 mm, and all other areas for a crack width of 0.3 mm (see also Section 5.4.2.3.2).

(4) The assessment of concrete-attacking waters and soils can be carried out as per DIN 4030.

6.7.6 Soil investigations and geotechnical report

(1) The “Standard for Geotechnical Site and Route Surveys” (BSH S) of the “Bundesamt für Seeschiffahrt und Hydrographie” in its latest official version shall be applied (current version at time of issuing this Guideline see [6.5]) as minimum requirement. Other Standards than those cited in BSH S may be used upon agreement with GL Wind. GL Wind reserves the right to determine the scope of documentation to be submitted.

(2) Any parameters stated in the geotechnical report shall be given as characteristic values. The characteristic values shall represent a careful estimation of the basis of the mean values obtained from testing. In case of large variations, i.e. variation coefficient > 0.1, for natural frequency analysis or for analysis in which the critical loads depend on soil stiffness, upper and lower limits of the parameters shall be stated.

6.7.7 Soil, general demands

6.7.7.1 Nature of the soil

(1) It shall be ensured that the properties of the soil correspond to the assumptions in the static and dynamic calculation.

(2) Insofar as no soil investigation report is available yet when the foundation is designed, conservative assumptions shall be made for the soil, and these shall be confirmed by a soil expert before the start of construction.

(3) For the dynamic analysis, the distance of the natural frequency for the overall structure from the excitation frequencies is decisive in avoiding resonance. In the assessment of the expected natural frequencies, a parameter study is needed for the dynamic soil parameters; this shall be defined so that a range of possible soil types and soil properties is covered.

6.7.7.2 Soil-structure interaction

The short and long term interaction between structure and surrounding soil, especially settlements and displacements, have to be taken into account in the analyses. Upper and lower limits for the stiffness of soil and structure for different times during their life have to be chosen with great care.

6.7.7.3 Soil, hydraulic stability and cyclic loads

(1) If necessary, due to existing slope or due to installation effects, the risk of slope failure or the possibility of a deep slip shall be investigated.

(2) Total or effective stress analysis shall be used for soil stability investigations.

(3) The effect of cyclic loading which may cause a reduction of shear strength, bearing capacity and stiffness of the soil shall be investigated.

(4) The effects of possible liquefaction of the soil shall be considered, especially for structures installed in seismic active areas.

(5) Especially for soft, normal consolidated clays or, for loose sand deposits a careful consideration of the seafloor instability is required.

(6) Seabed movements due to waves’ action, earthquake or operational effects, e. g. driving, dredging, may cause reduced resistance or increased loading and shall be investigated.

(7) The hydraulic stability shall be investigated for those types of foundations which may exhibit significant hydraulic gradients within the supporting soils.

6.7.7.4 Scour

(1) The possibility of scour or undermining around the foundation shall always be investigated and shall be an explicit part of the analysis.

(2) Two main principles of scour protection may be devised:

– Permanent scour protection:
  A scour protection shall be installed which is expected to last for the whole life time of the offshore wind turbine with reasonable safety. The design of the permanent scour protection has to be backed up by model tests.

– Dynamic scour protection:
  A scour protection of the same general outline as of the permanent protection (design also backed up by model tests) is installed, but with lower level of safety. The level of safety may be so low that damage is to be expected after some time. Therefore, a regular monitoring and inspection program has to be carried out. A monitoring of the seabed level, the local scour and the condition of the scour protection at each turbine by means of appropriate methods has to be carried out 6 weeks and 18 weeks after erection of the foundation. If no damage of the scour protection system is observed the inspection intervals can be successively doubled but they shall be conducted after heavy storm periods, but at least annually. The scour protection system has to be maintained and in case of damage it shall be properly repaired in such a way that it is able to fulfil its protective values for the offshore wind turbine foundations. A written report about each monitoring and the performed maintenance and repairs shall be compiled.

(3) As an alternative, the foundation has to be considered to be partly unsupported. If no other data are available for the specific site conditions, the scour depth at pile foundations may be estimated as $2.5 \cdot d$ (d = pile diameter) for design purposes. Less conservative estimates may be made, but have to be verified by a regular monitoring and inspection program as in para 2 for the dynamic scour protection.

6.7.8 Pile foundations

6.7.8.1 General

(1) Among several existing types of pile foundations the following are most frequently used offshore:

– driven, open ended piles

– driven and underreamed piles

– drilled and grouted piles.

(2) Many other designs are used to suit the individual site conditions.

6.7.8.2 Pile design

(1) The design of piled foundations shall fulfil requirements for axial and lateral load capacity and stiffness. The design shall consider bending moments as well as axial and lateral forces.

(2) Among others the following factors will affect the design: Diameter, penetration, spacing, material, pile footing, installation method, soil conditions and stiffness, scour protection.

(3) The design methods shall incorporate the pile geometries, properties, and arrangement. It should be capable of simulating the non-linear properties of the soil and shall be compatible with the load deflection behaviour of the structure and pile foundation system.

(4) Regarding the safety concept and its associated partial safety factors for soil, structural material and loads refer to Section 6.7.3 and 6.7.4.

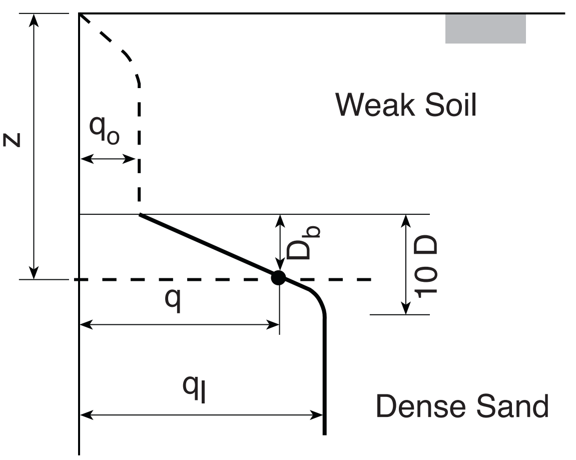
(5) Characteristic soil input values required for all analyses of the piles shall definitively be stated in the geotechnical report; they shall not automatically be taken from tables in any standards. The geotechnical report has to state explicitly the analysis model for which the values could be used. The installation methods, e. g. drilling or jetting shall be taken into account which may greatly affect the soil/rock strength and rock/grout bond.

(6) Deflections and rotations shall be checked for individual piles and pile groups regarding geometrical compatibility.

6.7.8.3 Axially loaded piles

(1) For the calculation of ultimate pile resistance for short term static and for long term cyclic loads various methods may be used. One acknowledged method is outlined in the API RP 2A-LRFD of July 1993, chapter G.4, G.5, G.6 and G.7. The analysis methods given there can be treated as models for characteristic states and input values. The characteristic resistance value(s) gained from the API analysis model have to be divided by the material safety factor(s).

(2) The applicability of other design methods for the specific site conditions and their limitations shall be carefully investigated and agreed upon with GL Wind.



q_o = limiting unit end bearing capacity in weak soil

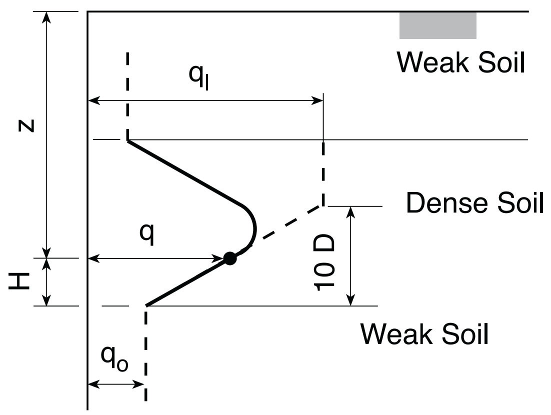
q_l = limiting unit end bearing capacity in dense sand

D = pile diameter

D_b = depth of penetration into dense layer

z = penetration depth

Fig. 6.7.1 End bearing capacity



H = distance of pile tip from weak soil layer

Fig. 6.7.2 End bearing capacity

(3) It has to be observed that for tension loads the skin friction capacity in general is considerably lower than for compression. Unless it can be proven, the skin friction for tension shall be taken less or equal to 2/3 of the skin friction for compressive loadings.

(4) For piles with an inner driving shoe values for inner unit skin friction above the shoe may be taken as 50 % to 70 % of the outer unit skin friction.

(5) The capacity of the steel/grout bond and shear key design shall be examined with great care, see Sections 5.4.4 and 6.5.2, para 1.

(6) Instead of a precise analysis of fatigue with regard to the external load-bearing capacity, a substitute analysis may be provided to the effect that, with the combinations of actions DLC 1.0 and 1.1 according to Table 4.3.1 with γ_F=1.0, no tensile forces occur in the piles.

6.7.8.4 Piles driven in non-homogeneous soils

(1) For piles penetrating non-homogeneous soils an average value of the tip resistance may be chosen from para 2 and para 3.

(2) Pile tip penetrating a dense layer from a weak layer, see Fig. 6.7.1. For unit end bearing capacity the following is valid:

$$q = q_o + \frac{(q_1 - q_o)}{10\,D} \cdot D_b \leq q_1. \qquad (6.7.2)$$

(3) Pile tip penetrating a thin dense layer lying over a weak layer, see Fig. 6.7.2. Possible punch through effects shall be considered.

(4) The unit end bearing capacity may be calculated as follows:

$$q = q_o + \frac{(q_1 - q_o)}{10D} \cdot H \leq q_1. \qquad (6.7.3)$$

(5) The applicability of other design methods for the specific site conditions and their limitations shall be carefully investigated and agreed upon with GL Wind and the geotechnical consultant.

6.7.8.5 Laterally loaded piles

(1) It shall be ensured that the pile foundation is capable to sustain all static and cyclic loads acting in lateral direction. The soil resistance in the vicinity of the mudline contributes significantly to the lateral capacity of a pile foundation. Any disturbance of the soil e. g. due to scouring, or to the installation of piles or conductors shall therefore be considered with great care.

(2) The design shall fulfil two main criteria:

– The load-deflection behaviour for short term static and for long term cyclic loads shall meet the requirements of offshore wind turbine operability.

– The eigenfrequency of the total system “offshore wind turbine-pile-soil” for any load state and any erection state shall not be near any excitation frequencies. Regarding the details of frequency spacing refer to Section 6.6 (especially 6.6.4).

(3) For the calculation of ultimate horizontal pile resistance and of load-deflection relations under short term static loads various methods may be used. Their applicability for the specific site conditions and their limitations shall be carefully checked and agreed upon with GL Wind. If the conditions for a relevant project exceed the data bases on which the various methods are based, a prudent and careful extrapolation may be made.

Note:

One acknowledged method for short term static loads for a limited pile diameter range is outlined in the API RP 2A-LRFD of July 1993, chapter G.8. This may, under certain circumstances, be cautiously adapted to larger pile diameters. The analysis methods given there can be treated as models for characteristic states and input values. The lower limit characteristic resistance value(s) gained from the API analysis model have to be divided by the material safety factor(s) if necessary.

(4) For the calculation of ultimate horizontal pile resistance against overturning and load-deflection relations under long term cyclic loads, neither a proven analysis method nor even a theory exist . The effects of these loads have to be considered with great care and sound engineering judgement, always taking the special site conditions and experience from similar projects into account. Methods to approach this problem may be deflection criterions under design or characteristic maximum loads and may utilize the rules API RP 2A-LRFD of July 1993, chapter G.8, as analysis basis (The manner of handling the cyclic loads given in chapter G.8 may not be conservative and should only be adapted after an expressive statement of the geotechnical consultant).

Note:

A criterion may be, for example, the maximum deflected neutral line of the pile under maximum horizontal and accompanying vertical short time design loading (i.e. including load safety factors) for lower characteristic limits of soil conditions shall be vertical at least at one location.

There may be additional maximum deflection criteria at the design mudline and at the toe for reasons of operational limits of the turbine. This can be a calculated deflection under soil conditions (upper / lower limits) to be defined for design mudline and toe of, for example, pile embedment depth/500 resp. /5000

(5) For the phenomenon of liquefaction no generally accepted analysis method for practical design use exists. The effects of liquefaction have to be considered with great care and sound engineering judgement, always taking the special site conditions and experience from similar projects into account. Liquefaction means an increased pore water pressure gradient at distinct locations which locally decrease the effective body to body stresses and the ability to transfer shear loads, thus reducing the external load-bearing capacity of the pile. Pore water pressure gradients are increased by wave action, body (structure) movements, earthquakes and surrounding soil material with low free-flooding pore volume. Any practical approach can lean on these items.

Note:

For example, the upper part of soil surrounding the vicinity of pile should be composed of material of big individual size and large pore volume between individual stones (single size material), e.g. scour protection material. This decreases the danger of body motion induced pore pressure increase.

(6) The eigenfrequency analysis, on which the loading of the whole structure may be based, shall be performed with special considerations. The range of horizontal soil stiffness shall be determined by full scale tests; extrapolating to higher or lower load levels shall be made with great care. If full scale tests are not possible, the geotechnical report has to state conservative upper and lower limits of characteristic soil stiffness and the analysis method with which to compute the eigenfrequency analysis. The range between upper and lower limits has to take into account the following:

– uncertainty of soil density
– uncertainty of soil elastic properties
– uncertainty of the calculation model describing the soil behaviour
– extend of soil investigations

6.7.8.6 Pile groups

(1) Chapter G.9 of the API RP 2A-LRFD of July 1993 shall be applied.

(2) The tip of all piles of a group shall be founded in the same soil layer or it should be shown that the different tip levels are acceptable for piles capacities and (relative) settlements and displacements.

6.7.8.7 Pile structure design

(1) The pile structure design shall consider all types of loads which may occur during installation and operation phases; regarding the general safety concept refer also to Section 6.7.3 and Chapter 5. For general remarks refer to API RP 2A-LRFD of July 1993, chapter G.10 and G.11.

(2) Chapter G.10.4.3 of the API RP 2A-LRFD of July 1993 shall be adapted for the concept given in para 1.

(3) A pile driving analysis shall be made according to an accepted method to derive the fatigue damage sustained by the pile during driving, which may attain a substantial proportion of the damage suffered during the whole operational lifetime, see also Section 6.6.6.8.

(4) The soil stiffness has to be accounted for when calculating the bending moment distribution (see Section 6.7.7.2). Due regard shall be given to the effect of scour and lack of soil adhesion due to large pile deflections.

(5) The axial load transfer may be calculated according to the "axial soil resistance - pile deflection" characteristics or alternatively according to the skin friction capacity of the pile, see Section 6.7.8.3.

(6) For piles having large horizontal deflections a stress increase due to second order effects shall be considered.

(7) For pile sections embedded in the soil column local buckling need not be investigated in most cases.

6.7.9 Gravity type foundations

6.7.9.1 General

(1) Gravity type foundations are characterized as foundations with relatively small penetration into the soil compared to the width of the foundation bases and relying predominantly on compressive contact with the supporting soil.

(2) If soil layers of sufficient strength are found at some depth below the sea bed, skirts may be required in order to ensure the suitability of the foundation. In some cases skirts will be used to protect the foundation against scouring.

6.7.9.2 Analysis

(1) Gravity type foundations shall be verified against

- tilting (eccentricity of load / gaping joint)
- bearing capacity failure
- sliding
- buoyancy
- settlement
- dynamic behaviour,
- soil liquefaction,
- hydraulic instability,
- scour,
- installation and removal.

Verification can be in accordance with e.g. DIN 1054:2003-01 or according to the following standards:

- Bearing capacity failure calculation
  DIN V 4017-100:1996-04
- Soil pressure distribution
  DIN 4018
- Settlement calculation
  DIN V 4019-100:1996-04

The calculative substitute area for the vertical stresses shall be determined in such a way that the relevant resulting vertical characteristic force (i.e. $\gamma_F = 1{,}0$) acts in its centre.

Other Standards than above may be used upon agreement with GL Wind.

For structures without skirts the contact design stresses between foundation and soil shall always be compressive.

(2) It has to be observed that the effective soil stresses may be reduced due to cyclic loading or hydraulic gradients, induced for example by foundation rocking.

(3) The analysis of sliding stability is set out in e.g. DIN 1054:2003-01 Section 7.5.3.

(4) For the analyses in the ultimate and serviceability limit states as per DIN 1054:2003-01, Section 7, the following procedure shall be observed:

- Permanent loads in the sense of DIN 1054:2003-01, Section 7.6.1 are the loads of load case 1 (see Table 6.7.1).
- Under permanent loads (γ_F=1.0), no ground gap may occur.

(5) The force resulting from the loads of load case 2 (see Table 6.7.1, γ_F=1.0) is permitted to cause a ground gap only up to the centre of gravity of the bottom area of the foundation.

(6) For loads of load case 3 (see Table 6.7.1), the safety against bearing capacity failure on the residual contact area shall be verified with γ_{Gr}=1.5.

Other Standards than above may be used upon agreement with GL Wind.

6.7.9.3 Soil reaction on foundation structure

(1) Grouting of voids beneath the foundation base may be required in order to ensure the predetermined load distribution and sufficient bearing capacity.

(2) Materials and methods used for filling of voids have to be agreed upon with GL Wind.

6.7.9.4 Dynamic behaviour

(1) The requirements of Section 6.7.9.2 shall be considered in design.

(2) Dynamic loads due to wind, offshore wind turbine operation, waves, earthquake etc. may significantly influence the integrity of the foundation. Their effects on the foundation behaviour have to be thoroughly evaluated.

(3) In many cases, especially when the stress level is fairly low, the dynamic foundation behaviour may be investigated using the continuous "half space" approach which assumes the soil to be a homogeneous linearly elastic material.

(4) In case of non-uniform soil profiles with the risk of energy reflection at the interfaces of soil layers, or dynamic loads with large amplitudes which cause non-linear soil behaviour, more appropriate analyses are required which are to be agreed by GL Wind.

(5) The foundation stiffness has influence on the determination of the natural frequencies of the offshore wind turbine. In practical analysis this influence can be taken into account by replacing the sub-system "foundation" with elastic springs which represent the foundation response for the different conditions.

6.7.9.5 Hydraulic instability

(1) Scour
Depending on current conditions (influence of the geometry of the structure) and soil conditions, measures shall be taken to prevent scouring and wash-out phenomena, e. g. with the help of scour skirts, concrete mats, rock riprap or other suitable means. A certain level of inevitable scouring has to be taken into account in the basic design assumptions.

(2) Piping
The foundation design shall take account of possible excessive hydraulic gradients in the soil with consequent formation of piping channels and a reduction of bearing capacity.

6.7.9.6 Installation of gravity foundations

(1) Careful planning is necessary in order to ensure a proper installation of the foundation base.

(2) When scour skirts and other installation aids (dowels etc.) have to penetrate into the sea bottom, a penetration analysis has to be performed using the soil characteristics of the relevant soil layers.

(3) The requirements on ballasting facilities have to be investigated in order to ensure a well balanced seating of the foundation base without excessive disturbance of the supporting soil (see also Chapter 12, Marine Operations).

(4) The resistance to penetration R [kN] of scour skirts is given by their end resistance and skin friction resistance and may be calculated by the following formula:

$$R = K_p(d) \cdot A_p \cdot q_c(d) + A_s \int_0^d K_f(z) \cdot q_c(z) \cdot dz \, [kN] \qquad (6.7.4)$$

where:

z	=	depth of the soil layer under consideration [m]
d	=	penetration depth [m]
K_p	=	empirical coefficient relating to end resistance
K_f	=	empirical coefficient relating to skin friction
q_c	=	cone penetration resistance [kN/m^2]
A_p	=	end area of scour skirt [m^2]
A_s	=	skin area of scour skirt per unit penetration depth [m^2/m]

(5) For K_p and K_f the coefficients shown in Table 6.7.2 may be taken to calculate an upper limit of penetration resistance.

Table 6.7.2 Soil coefficient

Type of soil	K_p	K_f
Clay	1,0	0,1
Sand	1,0	0,01

(6) For penetration depths lower than 1 to 1,5 m, the values shown in Table 6.7.2 may be reduced by 25 to 50 % due to local piping or lateral movements of the platform.

(7) When friction reducers both at the inside and outside skin of dowels are used, the coefficient K_f for sand may be reduced.

(8) The end resistance of plugged dowels may be calculated in the same way as for plugged open ended piles.

6.7.9.7 Removal of gravity foundations

In case a removal is agreed between owner/operator, designer and the relevant administration, investigations shall be carried out regarding, e. g.

– method and phases of removal
– environmental conditions
– risks involved
– necessary equipment to be provided during operations
– structural arrangements and mechanical devices (pipes, fittings etc.) to be provided already during construction phase, and measures required to ensure that removal operations will be possible at the expected time.

6.8 Concrete Structures

(1) Concrete Structures shall be analysed using the procedure given in Section 5.4.

(2) Requirements on the material quality and the execution of the construction are given in Section 3.3.5 and 3.4.8.

6.8.1 Ultimate limit state for strength

Structures of reinforced concrete and preloaded concrete shall be verified in accordance with Section 5.4.2.1. Here the internal forces and moments of the tower shaft may be determined according to the pipe bending theory, provided that the wall thickness is at least 1/20 of the radius. This does not apply to local analyses in the vicinity of tower openings. To determine the loading resulting from heat influences on towers made of steel or preloaded concrete, a temperature component of ΔT_M = 15 K acting uniformly over the circumference and varying linearly through the wall thickness shall be applied together with a temperature component of ΔT_N = 15 K acting with a cosine distribution over a circumferential sector of 180° and remaining constant through the wall thickness.

6.8.2 Stability

The stability analysis for the buckling and bulging of structures made of reinforced concrete and preloaded concrete can be performed according to e.g. ENV 1992, 4.3.5.

6.8.3 Ultimate limit state for fatigue

(1) The analyses shall be performed with the combination of actions of group F according to Table 4.3.4.

(2) Structures of reinforced concrete and preloaded concrete shall be verified in accordance with Section 5.4.2.2.

(3) Regarding the selection of S/N curves; regarding concrete, reinforcing steel and preloading steel, see Section 5.4.2.2.

6.8.4 Wind-induced transverse vibrations

For analysis of the loading of reinforced concrete and preloaded concrete towers, the provisions of e.g. DIN 4228:1989-02, A.2.2 shall be applied.

6.9 Floating Structures

(1) The analysis of floating structures is only partly covered by the present Guideline. The designer of the floating offshore wind turbine shall define in consultation with GL Wind the additional requirements, i.e. regarding loading, stability, mooring and structural design.

(2) For the analysis of floating offshore wind turbines, the following Guidelines may be used additionally in consultation with GL Wind:

– GL “Rules for Classification and Construction, III Offshore Technology, 2 Offshore Installations”, Edition 1999.

– GL “Guidelines for the Construction / Certification of Floating Production, Storage and Off-Loading Units“.

Appendix 6.A Detail Categories for the Fatigue Assessment

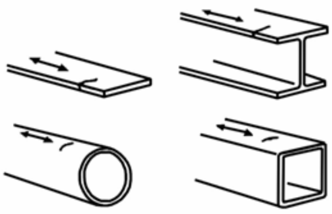
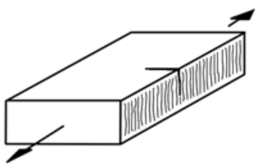
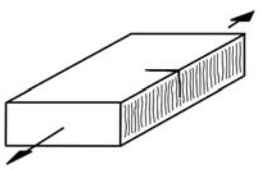
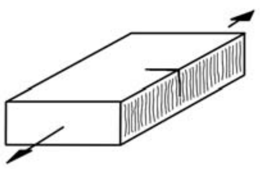
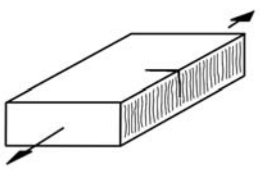
6.A.1 Preliminary remarks

(1) The following tables contain detail categories for the fatigue assessment of steel structures. The detail categories listed in Table 6.A.1 are taken from the ”Recommendations for Fatigue Design of Welded Joints and Components”, International Institute of Welding (IIW/IIS), IIW document XIII-1965-03 / XV-1127-03, Update July 2004 by Prof. Dr. A. Hobbacher.

(2) Deviations to the specifications given in the above mentioned reference are marked in the following tables.

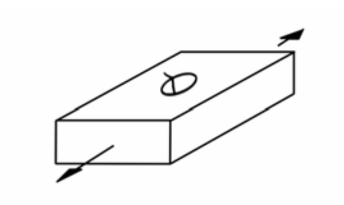
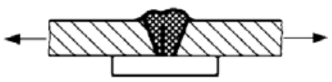
(3) Detail categories from other editions of the above mentioned reference may only be used in consultation with GL Wind.

Table 6.A.1 Detail Categories for Welded and Unwelded Parts of a Component (published with the authorisation of the International Institute of Welding (IIW)

Type No.	Structural Detail	Description, Requirements and Remarks (St. = steel; Al. = aluminium)	Detail category $\Delta\sigma_R$ (FAT class) Steel	Al
100	**Unwelded parts of a component**			
111		Rolled or extruded products, components with mashined edges, seamless hollow sections. $m_o = 5$ St.: For high strength steels a higher FAT class may be used ifverified by test. Al.: AA 5000/6000 alloys AA 7000 alloys Sharp edges, surface and rolling flaws to be removed by grinding. Any machining lines or groves to be parallel to stresses! For high strength steels a higher FAT class may be used if verified by test.	160	70 80
121[r]		Machine gas cut or sheared material with subsequent dressing, no cracks by inspection, no visible imperfections. $m_o = 4$ All visible signs of edge imperfections to be removed. The cut surfaces to be mashined or ground, all burrs to be removed. No repair by welding refill! Notcheffects due to shape of edges have to be considered.	140	---
122[r]		Machine thermally cut edges, corners removed, no cracks by inspection. $m_o = 3.5$ Notcheffects due to shape of edges have to be considered.	125	40
123[r]		Manually thermally cut edges, free from cracks and severe notches. $m_o = 3.5$ Notcheffects due to shape of edges have to be considered.	100	---
124[r]		Manually thermally cut edges, uncontrolled, no notch deeper than 0.5 mm. $m_o = 3.5$ Notcheffects due to shape of edges have to be considered.	80	---

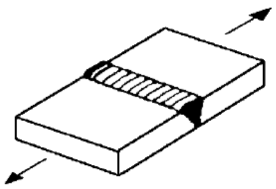
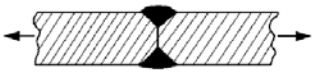
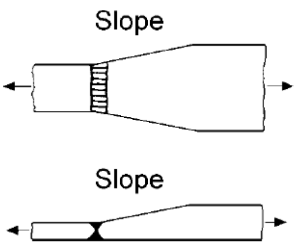
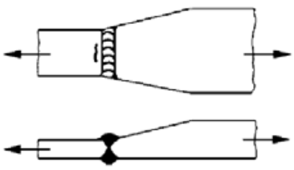
[r] requirements deviating from the IIW recommendations (different Wöhler slopes)

Table 6.A.1 (continued)

Type No.	Structural Detail	Description, Requirements and Remarks (St. = steel; Al. = aluminium)	Detail category $\Delta\sigma_R$ (FAT class) Steel	Al
131[a]		Rolled or extruded products with holes. $D \le 1.5$ t and $D \le 50$ mm Holes machine gas cut or drilled, with subsequent dressing, no cracks by inspection, no visible imperfections. $m_o = 3.5$ $\Delta\sigma$ to be calculated on the net cross-section. End or edge distance: $e \ge 1.5$ D, spacing: $p \ge 2.5$ D	90	---
200	**Butt welds, transverse loaded**			
211[f]		Transverse loaded butt weld (X or V-groove) ground flush to plate, 100 % NDT All welds ground flush to surface, grinding paralell to direction of stress. Weld run-on and run-of pieces to be used and subsequently removed. Plate edges to be ground flush in direction of stress. Welded from both sides. No misalignement. Required quality cannot be inspected by NDT !	112	40
212[r]		Transverse butt weld made in shop in flat position, height of weld convexity ≤ 10% of the weld width, NDT Weld run-on and run-off pieces to be used and subsequently removed. Plate edges to be ground flush in direction of stress. Welded from both sides. Misalignment < 5%	90	36
213[r]		Transverse butt weld not satisfying conditions of 212, height of weld convexity ≤ 20% of the weld width, NDT Weld run-on and run-off pieces to be used and subsequently removed. Plate edges to be ground flush in direction of stress. Welded from both sides. Misalignment < 10%	80	32
214		Transverse butt weld, welded on ceramic backing, root crack. Backing removed, root visually inspected. Misalignment < 10%	80	28
215		Transverse butt weld on permanent backing bar terminating > 10 mm from plate edge, else Misalignment < 10%	71 63	25 22

[a] additional structural detail not included into the IIW recommendations
[f] FAT class deviating from the IIW recommencations
[r] requirements deviating from the IIW recommendations (weld convexity limit instead of toe angle)

Table 6.A.1 (continued)

Type No.	**Structural Detail**	**Description, Requirements and Remarks (St. = steel; Al. = aluminium)**	**Detail category $\Delta\sigma_R$ (FAT class)**	
			Steel	**Al**
216		Transverse butt welds welded from one side without backing bar, full penetration root controlled by NDT no NDT Misalignment < 10%	 71 36	 28 12
217		Transverse partial penetration butt weld, analysis based on stress in weld throat sectional area, weld overfill not to be taken into account. The detail is not recommended for fatigue loaded members. Assessment by notch stress or fracture mechanics is preferred.	36	12
221[f]		Transverse butt weld ground flush, NDT, with transition in thickness and width slope 1:5 slope 1:3 slope 1:2 All welds ground flush to surface, grinding paralell to direction of stress. Weld run-on and run-off pieces to be used and subsequently removed. Plate edges to be ground flush in direction of stress. Misalignment <10% Exceeding misalignment due to thickness step to be considered, see chapter 6.2.3.7.2	 112 100 90	 40 32 28
222		Transverse butt weld made in shop, welded in flat position, weld profile controlled, NDT, with transition in thickness and width slope 1:5 slope 1:3 slope 1:2 Weld run-on and run-off pieces to be used and subsequently removed. Plate edges to be ground flush in direction of stress. Misalignment <10% Exceeding misalignment due to thickness step to be considered, see chapter 6.2.3.7.2	 90 80 71	 32 28 25

[f] FAT class deviating from the IIW recommencations

Table 6.A.1 (continued)

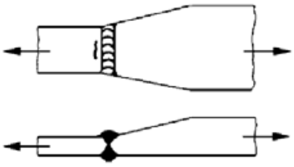
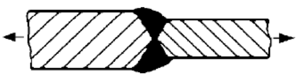
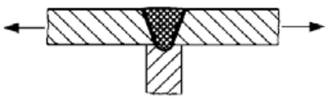
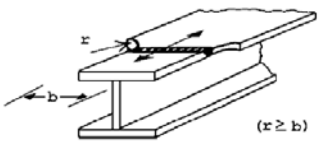
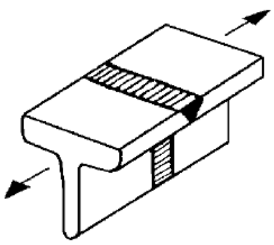
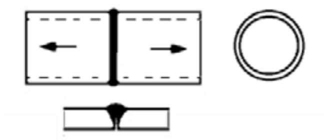
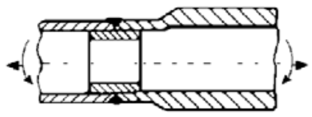
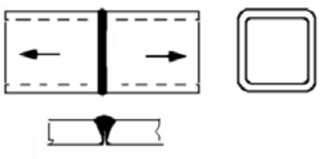
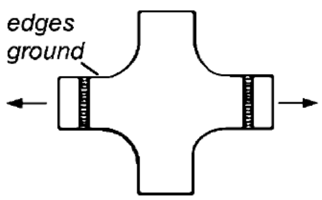
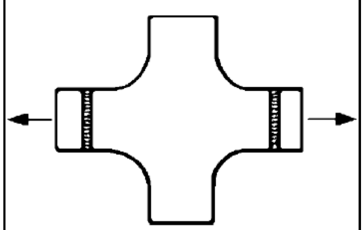
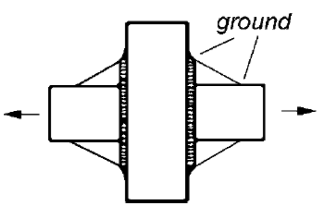
Type No.	Structural Detail	Description, Requirements and Remarks (St. = steel; Al. = aluminium)	Detail category $\Delta\sigma_R$ (FAT class)	
			Steel	**Al**
223		Transverse butt weld, NDT, with transition in thickness and width slope 1:5 slope 1:3 slope 1:2 Weld run-on and run-off pieces to be used and subsequently removed. Plate edges to be ground flush in direction of stress. Misalignment <10% Exceeding misalignment due to thickness step to be considered, see chapter 6.2.3.7.2	 80 71 63	 25 22 20
224		Transverse butt weld, different thicknesses without transition, centres aligned. In cases, where weld profile is equivalent to a moderate slope transition, see no. 222 Misalignment <10% of smaller plate thickness.	71	22
225		Three plate connection, root crack Arc welds: Misalignment < 10%	71	22
226		Transverse butt weld flange splice in built-up section welded prior to the assembly, ground flush, with radius transition, NDT All welds ground flush to surface, grinding paralell to direction of stress. Weld run-on and run-off pieces to be used and subsequently removed. Plate edges to be ground flush in direction of stress.	100	40
231		Transverse butt weld splice in rolled section or bar besides flats, ground flush, NDT All welds ground flush to surface, grinding paralell to direction of stress. Weld run-on and run-off pieces to be used and subsequently removed. Plate edges to be ground flush in direction of stress.	80	28
232		Transverse butt weld splice in circular hollow section, welded from one side, full penetration, root crack root inspected by NDT no NDT Welded in flat position.	 71 36	 28 12

Table 6.A.1 (continued)

Type No.	Structural Detail	Description, Requirements and Remarks (St. = steel; Al. = aluminium)	Detail category $\Delta\sigma_R$ (FAT class)	
			Steel	**Al**
233		Tubular joint with permanent bacing. Welded in flat position.	71	28
234		Transverse butt weld splice in rectangular hollow section, welded from one side, full penetration, root crack root inspected by NDT no NDT Welded in flat position.	 56 36	 25 12
241[f]		Transverse butt weld ground flush, weld ends and radius ground, 100% NDT at crossing flanges, radius transition. All welds ground flush to surface, grinding paralell to direction of stress. Weld run-on and run-off pieces to be used and subsequently removed. Plate edges to be ground flush in direction of stress. Welded from both sides. No misalignment. Required weld quality cannot be inspected by NDT	112	40
242		Transverse butt weld made in shop at flat position, weld profile controlled, NDT, at crossing flanges, radius transition. Weld run-on and run-off pieces to be used and subsequently removed. Plate edges to be ground flush in direction of stress. Welded from both sides.Misalignment <5%	90	36
243		Transverse butt weld ground flush, NDT, at crossing flanges with welded triangular transition plates, weld ends ground. Crack starting at butt weld. For crack of throughgoing flange see details 525 and 526! All welds ground flush to surface, grinding paralell to direction of stress. Plate edges to be ground flush in direction of stress. Welded from both sides. Misalignment <10%	80	32

[f] FAT class deviating from the IIW recommencations

Table 6.A.1 (continued)

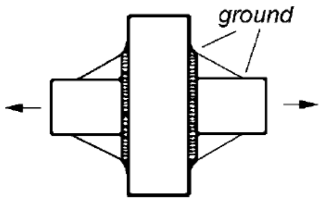
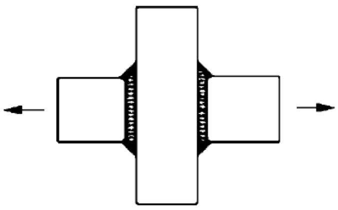
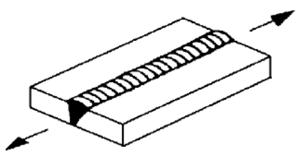
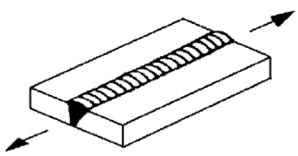
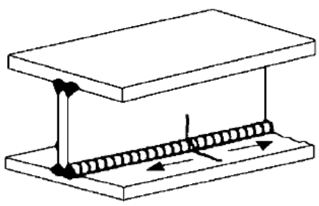
Type No.	**Structural Detail**	**Description, Requirements and Remarks (St. = steel; Al. = aluminium)**	**Detail category $\Delta\sigma_R$ (FAT class)**	
			Steel	**Al**
244		Transverse butt weld, NDT, at crossing flanges, with welded triangular transition plates, weld ends ground. Crack starting at butt weld. For crack of throughgoing flange see details 525 and 526! Plate edges to be ground flush in direction of stress. Welded from both sides.Misalignment <10%	71	28
245		Transverse butt weld at crossing flanges. Crack starting at butt weld. For crack of throughgoing flange see details 525 and 526! Welded from both sides.Misalignment <10%	50	20
300	**Longitudinal load-carrying welds**			
311		Automatic longitudinal seam welds without stop/start positions in hollow sections with stop/start positions	125 90	50 36
312		Longitudinal butt weld, both sides ground flush parallel to load direction, 100% NDT	125	50
313		Longitudinal butt weld, without stop/start positions, NDT with stop/start positions	125 90	50 36
321		Continuous automatic longitudinal fully penetrated K-butt weld without stop/start positions (based on stress range in flange), NDT No start-Stop position is permitted except when the repair is performed by a specialist and inspection is carried out to verify the proper execution of the weld.	125	50

Table 6.A.1 (continued)

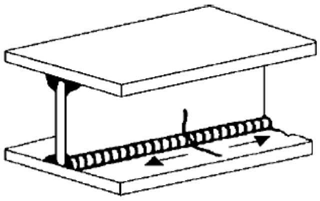
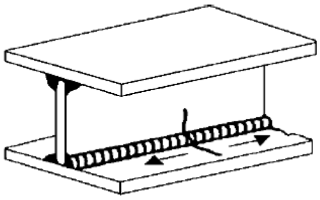
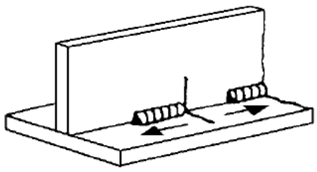
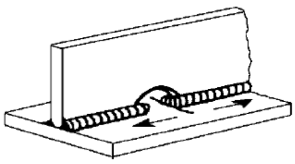
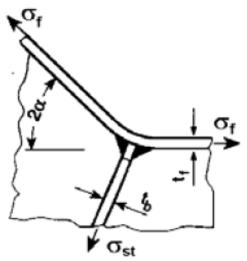
Type No.	**Structural Detail**	**Description, Requirements and Remarks (St. = steel; Al. = aluminium)**	**Detail category $\Delta\sigma_R$ (FAT class)**	
			Steel	**Al**
322		Continuous automatic longitudinal double sided fillet weld without stop/start positions (based on stress range in flange).	100	40
323		Continuous manual longitudinal fillet or butt weld (based on stress range in flange).	90	36
324		Intermittent longitudinal fillet weld (based on normal stress in flange σ and shear stress in web τ at weld ends). σ/τ = 0 0.0 - 0.2 0.2 - 0.3 0.3 - 0.4 0.4 - 0.5 0.5 - 0.6 0.6 - 0.7 > 0.7	80 71 63 56 50 45 40 36	32 28 25 22 20 18 16 14
325		Longitudinal butt weld, fillet weld or intermittent weld with cope holes (based on normal stress in flange σ and shear stress in web τ at weld ends), cope holes not higher than 40% of web. σ/τ = 0 0.0 - 0.2 0.2 - 0.3 0.3 - 0.4 0.4 - 0.5 0.5 - 0.6 > 0.6	71 63 56 50 45 40 36	28 25 22 20 18 16 14

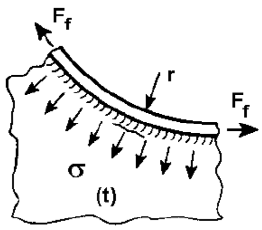
Table 6.A.1 (continued)

<table>
<tr><th rowspan="2">Type No.</th><th rowspan="2">Structural Detail</th><th rowspan="2">Description, Requirements and Remarks
(St. = steel; Al. = aluminium)</th><th colspan="2">Detail category
$\Delta\sigma_R$ (FAT class)</th></tr>
<tr><th>Steel</th><th>Al</th></tr>
<tr><td>331</td><td>
</td><td>Joint at stiffened knuckle of a flange to be assessed according to no. 411 - 414, depending on type of joint.

Stress in stiffener plate:

$$\sigma = \sigma_f \cdot \frac{A_f}{\sum A_{St}} \cdot 2 \cdot \sin\alpha$$
A_f = area of flange
A_{St} = area of stiffener

Stress in weld throat:

$$\sigma_w = \sigma_f \cdot \frac{A_f}{\sum A_w} \cdot 2 \cdot \sin\alpha$$
A_w = area of weld throat</td><td>---</td><td>---</td></tr>
<tr><td>332</td><td>
</td><td>Unstiffened curved flange to web joint, to be assessed according to no. 411 - 414, depending on type of joint.

Stress in web plate:

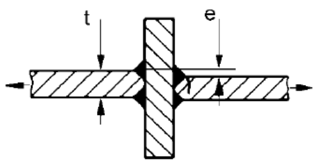
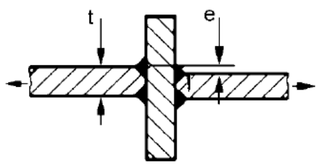
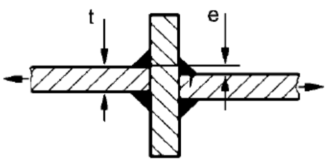
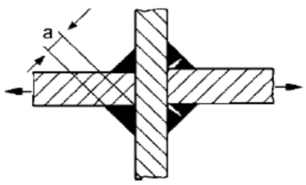
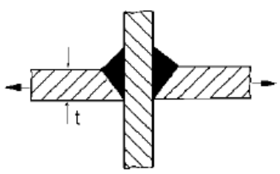
$$\sigma = \frac{F_g}{r \cdot t}$$
Stress in weld throat:

$$\sigma_w = \frac{F_f}{r \cdot \sum a}$$
F_f axial force in flange
t thickness of web plate
a weld throat

The resulting force of Ff-left and Ff-right will bend the flange perpenticular to the plane of main loading. In oder to minimize this additional stressing of the welds, it is recommended to minimize the width and to maximize the thickness of the flange.

Stress longitudinally to the weld is to be considered. At additional shear, principle stress in web is to be consired (see 321 to 323).</td><td>---</td><td>---</td></tr>
</table>

Table 6.A.1 (continued)

Type No.	Structural Detail	Description, Requirements and Remarks (St. = steel; Al. = aluminium)	Detail category $\Delta\sigma_R$ (FAT class)	
			Steel	**Al**
400	**Cruciform joints and/or T-joints**			
411[s]		Cruciform joint or T-joint, K-butt welds, full penetration, no lamellar tearing, weld toes ground, toe crack. Cruciform joint Misalignment e <15% of t and primary plate. T-joint Material quality of intermediate plate has to be checked against susceptibility of lamellar tearing.	 80 90	 28 32
412[s]		Cruciform joint or T-joint, K-butt welds, full penetration, no lamellar tearing, toe crack. Cruciform joint Misalignment e <15% of t and primary plate. T-joint Material quality of intermediate plate has to be checked against susceptibility of lamellar tearing.	 71 80	 25 28
413[s]		Cruciform joint or T-joint, fillet welds or partial penetration K-butt welds, no lamellar tearing, toe crack. Cruciform joint Misalignment e <15% of t and primary plate. T-joint Material quality of intermediate plate has to be checked against susceptibility of lamellar tearing.	 63 71	 22 25
414		Cruciform joint or T-joint, fillet welds or partial penetration K-butt welds, including toe ground joints, weld root crack. Analysis based on stress in weld throat.	36	12
414		Cruciform joint or T-joint, single-sided arc or laser beam welded V-butt weld, full penetration, no lamellar tearing, misalignment e< 0.15 t, toe crack. Root inspected. If root is not inspected, then root crack.	71 36	25 12

[s] specifications of detail category more detailed than in the IIW recommendations (separate DC for T-joints)

Table 6.A.1 (continued)

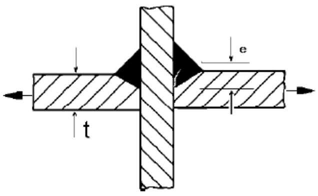
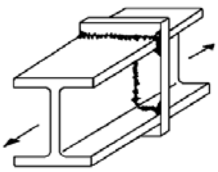
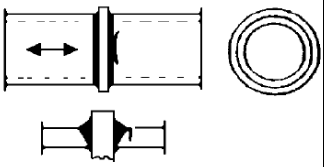
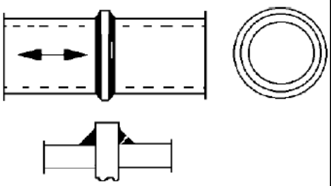
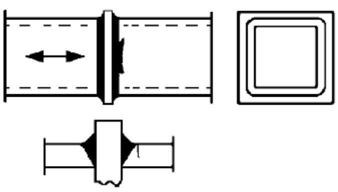
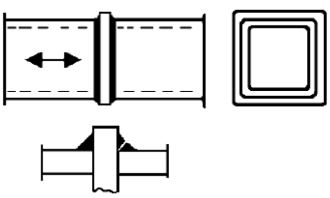
Type No.	Structural Detail	Description, Requirements and Remarks (St. = steel; Al. = aluminium)	Detail category $\Delta\sigma_R$ (FAT class)	
			Steel	Al
416		Cruciform joint or T-joint, single-sided arc welded fillet or partial penetration V-butt weld, no lamellar tearing, misalignment of plates e< 0.15 t, root crack. Root inspected. Excentricity e of plate t and weld throat a midpoints to be considered in analysis. Stress at root: $\Delta\sigma_{root} = \Delta\sigma_{plate} \cdot \left(1 + 3 \cdot \frac{e}{t}\right) \cdot \frac{t}{a}$ An analysis by effective notch procedure is recommended.	36	12
421		Splice of rolled section with intermediate plate, fillet welds, weld root crack. Analysis base on stress in weld throat.	36	12
422		Splice of circular hollow section with intermediate plate, singlesided butt weld, toe crack wall thickness > 8 mm wall thickness < 8 mm Welds NDT inspected in order to ensure full root penetration.	 56 50	 22 20
423		Splice of circular hollow section with intermediate plate, fillet weld, root crack. Analysis based on stress in weld throat wall thickness > 8 mm wall thickness < 8 mm Welds NDT inspected in order to ensure full root penetration.	 45 40	 16 14
422		Splice of circular hollow section, singlesided butt weld with intermediate plate, toe crack wall thickness > 8 mm wall thickness < 8 mm Welds NDT inspected in order to ensure full root penetration.	 50 45	 20 18
423		Splice of circular hollow section with intermediate plate, fillet weld, root crack. Analysis based on stress in weld throat wall thickness > 8 mm wall thickness < 8 mm Welds NDT inspected in order to ensure full root penetration.	 40 36	 16 14

Table 6.A.1 (continued)

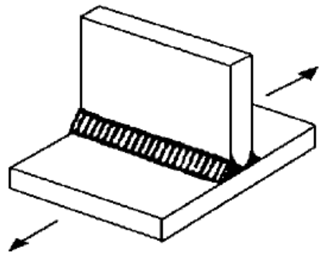
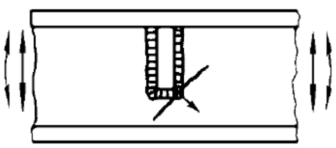
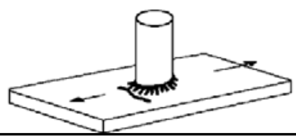
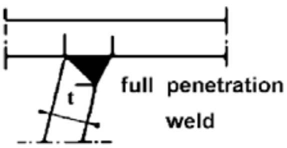
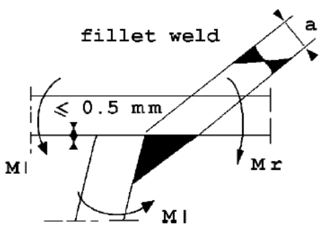
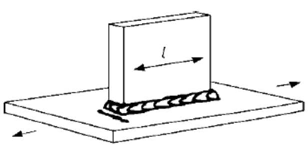
Type No.	Structural Detail	Description, Requirements and Remarks (St. = steel; Al. = aluminium)	Detail category $\Delta\sigma_R$ (FAT class) Steel	Al
500	**Non-load-carrying attachments**			
511		Transverse non-load-carrying attachment, not thicker than main plate. K-butt weld, toe ground Two-sided fillets, toe ground Fillet weld(s), as welded thicker than main plate Grinding parallel to stress. At one sided fillet welds, an angular misalignment corresponding to k_m = 1.2 is already covered.	 100 100 80 71	 36 36 28 25
512		Transverse stiffener welded on girder web or flange, not thicker than main plate. K-butt weld, toe ground Two-sided fillets, toe ground Fillet weld(s), as welded thicker than main plate For weld ends on web principle stress to be used.	 100 100 80 71	 36 36 28 25
513		Non-load-carrying stud as welded.	80	28
514		Trapezoidal stiffener to deck plate, full penetration butt weld, calculated on basis of stiffener thickness, out of plane bending.	71	25
515		Trapezoidal stiffener to deck plate, fillet or partial penetration weld, out of plane bending. Calculation on basis of stiffener thickness and weld throat, whichever is smaller.	50	16
521		Longitudinal fillet welded gusset at length l l < 50 mm l < 150 mm l < 300 mm l > 300 mm For gusset near edge: see 525 “flat side gusset”. If attachment thickness > 1/2 of base plate thickness, then one step higher allowed (not for welded on profiles!)	 80 71 63 50	 28 25 20 18

Table 6.A.1 (continued)

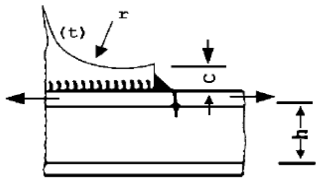
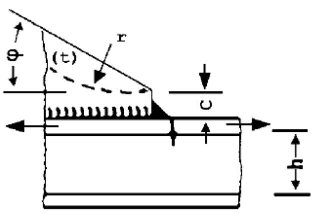
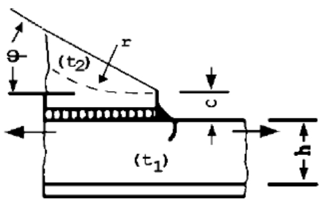
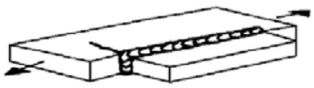
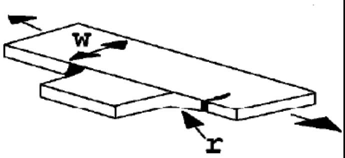
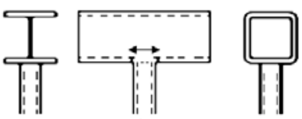
Type No.	**Structural Detail**	**Description, Requirements and Remarks (St. = steel; Al. = aluminium)**	**Detail category $\Delta\sigma_R$ (FAT class)**	
			Steel	**Al**
522		Longitudinal filled welded gusset with radius transition, end of fillet weld reinforced and ground, e < 2 t , max 25 mm r > 150 mm t = thickness of attachment	90	32
523		Longitudinal filled welded gusset with smooth transition (sniped end or radius) welded on beam flange or plate, e < 2 t , max 25 mm r > 0.5 h r < 0.5 h or φ < 20° t = thickness of attachment If attachment thickness < 1/2 of base plate thickness, then one step higher allowed (not for welded on profiles!)	 71 63	 25 20
524		Longitudinal flat side gusset welded on plate edge or beam flange edge, with smooth transition (sniped end or radius), e < 2 t , max 25 mm r > 0.5 h r < 0.5 h or φ < 20° t = thickness of attachment. For $t_2 < 0.7\ t_1$, FAT rises 12%	 50 45	 18 16
525		Longitudinal flat side gusset welded on plate or beam flange edge, gusset length l l < 150 mm l < 300 mm l > 300 mm For $t_2 < 0.7\ t_1$, FAT rises 12%	 50 45 40	 18 16 14
526		Longitudinal flat side gusset welded on edge of plate or beam flange, radius transition ground. r > 150 or r/w > 1/3 1/6 < r/w < 1/3 r/w < 1/6 Smooth transition radius formed by grinding the weld area in transition in order to remove the weld toe completely. Grinding parallel to stress.	 90 71 50	 36 28 22
531		Circular or rectangular hollow section, fillet welded to another section. Section width parallel to stress direction < 100 mm, else like longitudinal attachment. Non load-carrying welds. Width parallel to stress direction < 100 mm.	71	28

Table 6.A.1 (continued)

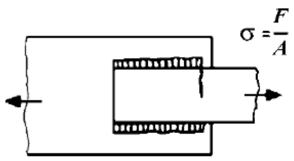
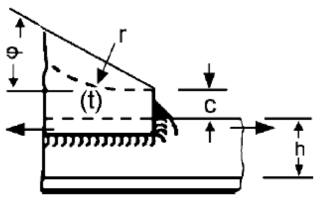
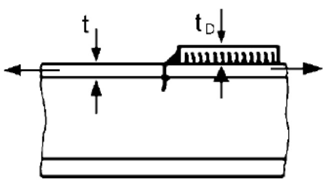
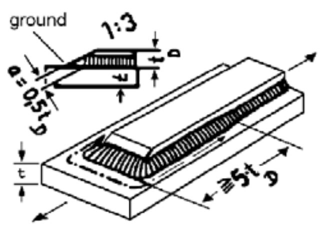
Type No.	**Structural Detail**	**Description, Requirements and Remarks (St. = steel; Al. = aluminium)**	**Detail category $\Delta\sigma_R$ (FAT class)**	
			Steel	**Al**
600	**Lap joints**			
611		Transverse loaded lap joint with fillet welds. Fatigue of parent metal Fatigue of weld throat Stresses to be calculated in the main plate using a plate width equalling the weld length. Buckling avoided by loading or design!	 63 45	 22 16
612		Longitudinally loaded lap joint with side fillet welds. Fatigue of parent metal Fatigue of weld (calc. on max. weld length of 40 times the throat of the weld) Weld terminations more than 10 mm from plate edge. Buckling avoided by loading or design!	 50 50	 18 18
613		Lap joint gusset, fillet welded, non-load-carrying, with smooth transition (sniped end with φ < 20° or radius), welded to loaded element c < 2 t , but c ≤ 25 mm to flat bar to bulb section to angle section t = thickness of gusset plate	 63 56 50	 22 20 18
700	**Reinforcements**			
711		End of long doubling plate on I-beam, welded ends (based on stress range in flange at weld toe) $t_D \leq 0.8$ t 0.8 t < $t_D \leq 1.5$ t $t_D > 1.5$ t End zones of single or multiple welded cover plates, with or without frontal welds. If the cover plate is wider than the flange, a frontal weld is needed. No undercut at frontal welds!	 56 50 45	 20 18 16
712		End of long doubling plate on beam, reinforced welded ends ground (based on stress range in flange at weld toe) $t_D \leq 0.8$ t 0.8 t < $t_D \leq 1.5$ t $t_D > 1.5$ t Grinding parallel to stress direction.	 71 63 56	 28 25 22

Table 6.A.1 (continued)

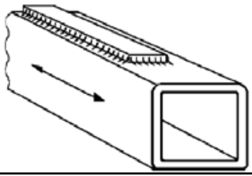
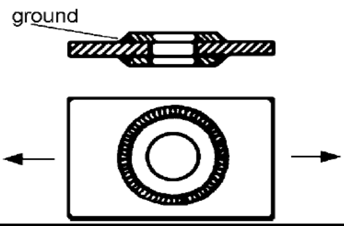
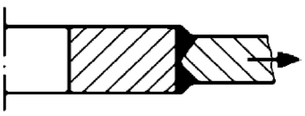
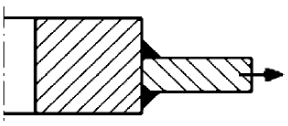
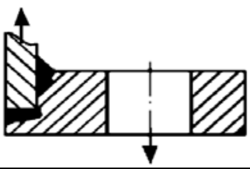
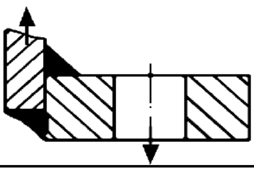
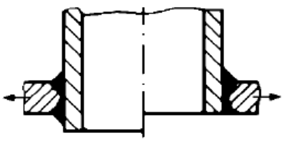
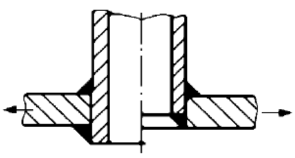
Type No.	Structural Detail	Description, Requirements and Remarks (St. = steel; Al. = aluminium)	Detail category $\Delta\sigma_R$ (FAT class)	
			Steel	**Al**
721		End of reinforced plate on rectangular hollow section. Wall thickness t < 25 mm No undercut at frontal weld!	50	20
731		Reinforcements welded on with fillet welds toe ground toe as welded Grinding in direction of stress! Analysis based on modified nominal stress, however, structural stress approach recommenced.	 80 71	 32 25
800	**Flanges, branches and nozzles**			
811		Stiff block flange, full penetration weld.	71	25
812		Stiff block flange, partial penetration or fillet weld toe crack in weld root crack in weld throat	 63 36	 22 12
821		Flat flange with > 80% full penetration butt welds, modified nominal stress in pipe, toe crack.	71	25
822		Flat flange with fillet welds, modified nominal stress in pipe, toe crack.	63	22
831		Tubular branch or pipe penetrating a plate, K-butt welds. If diameter > 50 mm, stress concentration of cutout has to be considered. Assessment by structural stress is recommended.	80	28
832		Tubular branch or pipe penetrating a plate, fillet welds, toe cracks. Root cracks (analysis based on stress in weld throat). If diameter > 50 mm, stress concentration of cutout has to be considered. Assessment by structural stress is recommended.	71 36	25 12

Table 6.A.1 (continued)

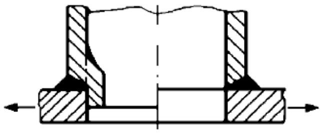
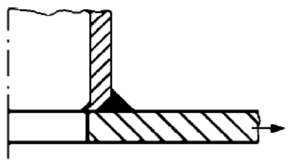
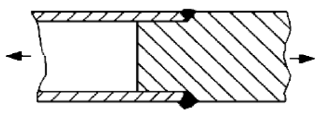
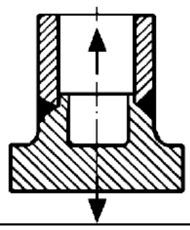
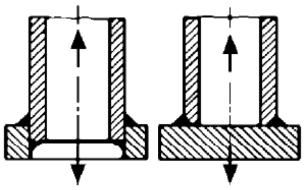
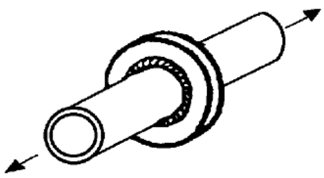
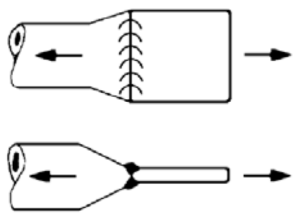
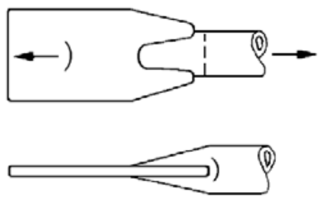
Type No.	**Structural Detail**	**Description, Requirements and Remarks (St. = steel; Al. = aluminium)**	**Detail category $\Delta\sigma_R$ (FAT class)**	
			Steel	**Al**
841		Nozzle welded on plate, root pass removed by drilling. If diameter > 50 mm, stress concentration of cutout has to be considered. Assessment by structural stress is recommended.	71	25
842		Nozzle welded on plate, root pass as welded. If diameter > 50 mm, stress concentration of cutout has to be considered. Assessment by structural stress is recommended.	63	22
900	**Tubular joints**			
911		Circular hollow section butt joint to massive bar, as welded. Root of weld has to penetrate into the massive bar in order to avoid a gap perpendicular to the stress direction.	63	22
912		Circular hollow section welded to component with single side butt weld, backing provided. Root crack. Root of weld has to penetrate into the massive bar in order to avoid a gap perpendicular to the stress direction.	63	22
913		Circular hollow section welded to component with single side butt weld or double fillet welds. Root crack. Impairment of inspection of root cracks by NDT may be compensated by adequate safety considerations (see e.g. IIW recommendations) or by downgrading down to 2 FAT classes.	50	18
921		Circular hollow section welded on disk with K-butt weld, toe ground fillet weld, toe ground fillet weld, as welded. Non-load-carrying weld.	 90 90 71	 32 32 25

Table 6.A.1 (continued)

Type No.	Structural Detail	Description, Requirements and Remarks (St. = steel; Al. = aluminium)	Detail category $\Delta\sigma_R$ (FAT class)	
			Steel	**Al**
931		Tube-plate joint, tubes flattened, butt weld (X-groove). Tube diameter < 200 mm and plate thickness < 20 mm	71	25
932		Tube-plate joint, tube splitted and welded to plate. Tube diameter < 200 mm and plate thickness < 20 mm Tube diameter < 200 mm and plate thickness < 20 mm	63 45	18 14

No.	Fatigue resistance values for structural details on the basis of shear stress	Detail category $\Delta\sigma_R$ (FAT class)	
		Steel	**Al**
1	Parent metal or full penetration butt weld; **m = 5 down to 1E8** cycles.	100	36
2	Fillet weld or partial penetration butt weld; **m = 5 down to 1E8** cycles.	80	28

Rules and Guidelines

IV *Industrial Services*

2 Guideline for the Certification of Offshore Wind Turbines

7 Machinery Components

Edition 2005

Germanischer Lloyd
WindEnergie

Table of Contents

7.1 General

7.1.1 Assessment documents

(1) The following documents are required for assessment of the ultimate and serviceability limit states of machinery components of offshore wind turbines.

(2) For the important components, parts lists are required with data about materials, data from the manufacturer in the case of mass-produced parts, about the standard in the case of standardized parts etc.

(3) Engineering drawings (assembly drawings and individual-part drawings) of the important elements of the plant, executed in standard form; clear identification shall be assured (parts designation, drawing number, modification index). They shall contain data about surface finish, heat treatment, corrosion protection etc.

(4) For mass-produced parts which have proved their suitability for use by successful service in comparable technical applications, type/data sheets are generally sufficient. However, further documentation / verification may be necessary in individual cases for such parts. Main gearboxes do not count as mass-produced in this sense. The documentation required for this is set out in Section 7.4.

(5) Strength calculations for all components and means of connection shall verify the ultimate limit state and serviceability limit state totally, clearly and confirmably. The analyses shall be complete in themselves. They shall contain adequate data concerning:

– design loads
– static systems (analogous models)
– materials
– permissible stresses
– references used

(6) Fatigue analyses shall be carried out in accordance with Section 5.3 using the codes and technical literature listed there.

(7) All lubricants and hydraulic fluids shall be specified with the corresponding type sheets. Oil collecting trays for the possible spilling of operating media shall be provided in the offshore wind turbine (hub and nacelle).

(8) The design of the cooling and heating systems for operation of the offshore wind turbine shall be specified.

(9) The specifications (requirements) of the offshore wind turbine manufacturer for the design of the machinery components shall be appended to the verifications.

7.1.2 Materials

Requirements, verification and inspection certification are laid down in Section 3.3. Additional data are to be found in the following sections of this Chapter.

7.1.3 Drive train dynamics

When determining the design loads (see Section 4.3.2.1), the dynamic behaviour of the drive train shall be considered in a suitable manner. For this, the drive train is as a rule modelled in an idealized form within the load simulation through a system comprising few rotating masses and torsion springs. The reduction of the complex drive-train system and the determination of the values of torsion springs, rotating masses, and possibly damping values shall be presented during the assessment of the machinery components.

7.2 Blade Pitching System

7.2.1 General

(1) This section applies for the blade pitching systems of offshore wind turbines as described below. In the event of other designs, the wording shall apply with the necessary changes.

(2) In systems with rotary actuation, the torque needed for the pitching of the rotor blades is applied by a motor with the associated rotary drive. The torque is transmitted by the driving pinion to a live ring fixed to the rotor blade.

(3) In systems with a blade pitching mechanism actuated e.g. by one or more hydraulic cylinders, the torque needed for the pitching of the rotor blades is applied by a hydraulic cylinder. The torque is transmitted by the piston rod directly or indirectly to a linking point fixed to the rotor blade.

(4) A locking arrangement shall be provided for the blade pitching system (see also Sections 2.2.2.10 and 2.3.3), with which this system is locked in place during maintenance and repair work, in order to exclude the risk of personal injury. This locking arrangement need not necessarily be located permanently at the blade pitching system; it may also be an external lock which is mounted whenever required.

7.2.2 Assessment documents

(1) General information on the assessment documents to be submitted is given in Section 7.1.

(2) For the components of the blade pitching system, type sheets, specifications and assembly drawings shall be submitted.

(3) Statements shall be made on the calculation data (e.g. input data for the calculation, presentation of the results with the relevant safety margins) and on the components of the drives.

(4) For the evaluation of the transmission stage “driving pinion / live ring”, the individual-part drawing of the pinion shaft and the live ring are required in the case of systems with rotary drive, together with a toothing calculation for this combination and the verifications for the pinion shaft and its bearing arrangement.

(5) Assembly and sectional drawings, including the associated parts lists and if applicable individual-part drawings, shall be submitted together with a description explaining the functional principle of the blade pitching system.

(6) In the case of systems with a blade pitching mechanism, dimensioned drawings shall be submitted additionally, in which the pitching mechanism is shown with various blade angle positions. At least the maximum and minimum positions, and the positions in which the greatest loads act on the blade pitching mechanism, shall be shown.

(7) For the components of the blade pitching mechanism, a fatigue strength analysis and a static strength analysis shall be submitted.

7.2.3 Loads to be applied

(1) For the calculation of the loading of the blade pitching system, the design loads as per Chapter 4 shall be applied.

(2) The static and load-dependent bearing friction moments shall be taken into account.

(3) For the fatigue analysis, the load duration distributions (LDD) and the load spectra shall be used. A distinction shall be made between operation with and without blade pitching. Here additional inertial loads – resulting from the rotor rotation – and dynamic vibration-exciting loads shall also be considered.

(4) The static strength analysis – with and without blade pitching operation – shall be performed for the design loads of the dimensioning load case as per Chapter 4.

(5) In systems with rotary drive, an application factor of $K_A = 1.0$ is used for the static strength analysis.

7.2.4 Strength analysis

7.2.4.1 Verification of load capacity of gears

(1) The toothing calculation of the driving pinion / live ring stage and of the pitch gear shall be based on ISO 6336.

(2) The calculation of the load capacity from the fatigue loads shall be performed according to ISO TR 10495. For Method II, a damage ratio of $D \leq 1$ shall be achieved in compliance with the safety factors listed in Table 7.2.1.

Table 7.2.1 Safety factors for the fatigue strength analysis

Minimum Safety of toothings in pitch gears and pitch bearings:	
pitting S_H	1.0
tooth root fracture S_F	1.25

Table 7.2.2 Safety factors for the static strength analysis

Minimum Safety of toothings in pitch gears and pitch bearings:	
pitting S_H	1.0
tooth root fracture S_F	1.2

(3) Alternatively, equivalent loads can be determined from the load/time distribution (as per DIN 3990 Part 6, Method III) with which – in compliance with the safety factors listed in Table 7.2.1 – the fatigue analysis shall be performed.

(4) Furthermore, an analysis of the static strength against forced rupture and pitting in compliance with the safety factors according to Table 7.2.2 is also required.

(5) According to ISO TR 10495 the predominantly alternating load of the toothing is to be considered. A reduction factor for the respective S/N curve is given e.g. in DIN 3990 part 6 with a value of 0.7. More favourable values may be used, e.g. based on the diagram in Fig. 21.7/15 on page 155 in Niemann/Winter, vol. 2, edition 1989 [7.1].

(6) The toothings of the blade bearings are stressed on a very small part of their circumference during a large portion of operation. The maximum utilisation for start and stop procedures amounts generally to 90°. According to this the calculative number of load cycles in the toothing calculation is at least to be multiplied with the factor 4.

7.2.4.2 Shafts and connecting elements

(1) For the output shaft of the pitch drive and for the connecting elements, a fatigue strength analysis and a static strength analysis shall be submitted. The analyses shall be performed in accordance with DIN 743, DIN 6892 and DIN 7190, or equivalent codes.

(2) Strength analyses for rotary drive housings and planet carriers can be demanded if necessary (see also Section 7.1.1 para 4).

(3) In the case of systems with a blade pitching mechanism, a fatigue strength analysis and a static strength analysis shall be submitted for all load-transmitting components and connecting elements.

(4) Spring elements also tensioned during the loading process are not regarded as being effective protection for non-methodically prestressed bolted connections of the load-transmitting and safety-relevant components. Instead, friction-locked elements shall be used as protection against loss, and locking elements as protection against loosening of the bolted connections. Bonded elements are not recommended, since their effectiveness depends on the operating and application temperature, the surface condition of the component, the curing time and the dynamic loading taking place during operation. If bonded elements are used for securing the above-mentioned component after all, a specification of the bonding material shall be submitted and a loss protection arrangement shall be provided to prevent separation of the corresponding components.

(5) Strength analyses for bolted connections are necessary wherever the bolts are essential to the distribution of forces (see Section 6.5.1).

Note:

The output pinion of the rotary drive should be forged-on.

7.2.4.3 Blade bearings

(1) With regard to the calculation and execution of the blade bearing, reference is made to Section 7.3.

(2) The seals shall be so executed or protected in a way that they are not damaged by the prevailing environmental conditions.

Notes:

A single seal is not deemed to be adequate protection against external influences for the rolling body and track surface. The level of protection can be increased e.g. by a spinner or an additional seal.

It should be possible to exchange the seals of the blade bearing in the installed condition.

(3) It shall be shown that adequate lubrication and removal of the old lubricant is ensured for the blade bearing, and if applicable also for the toothing. Considering service intervals not less than one year (see also Section 7.10.1) this will in general require automatic lubrication devices. The functionality of such devices is to be documented.

(4) It shall be shown that an adequate film of lubricant is always provided between the rolling bodies and the track surface.

(5) If necessary, this requirement shall be met by means of a test run e.g. taking place once within 24h and during which the rotor blades and thus also the blade bearings are rotated by the maximum possible pitching angle.

7.2.4.4 Additional verifications

(1) In the case of systems with electrical actuating drive, Chapter 8 shall also be considered.

(2) For the verification of the hydraulic system, Section 7.9 shall be considered.

(3) The design of the drives and brakes shall be verified for proper function in accordance with the system concept.

7.3 Bearings

7.3.1 General

The guidelines of this Section apply for roller bearings intended as rotor, gearbox or generator bearings in drive train of an offshore wind turbine, as blade or yaw bearings, and as the bearings for other force-transmitting components. The requirements for plain bearings shall be determined for each individual case in consultation with GL Wind.

7.3.2 Assessment documents

Installation drawings, calculation documents and if appropriate the relevant individual-part drawings (if the bearings are of a special type) shall be submitted for the bearings listed in Section 7.3.1. For each bearing point in the drive train and for blade and yaw bearings, the bearing manufacturer shall be named clearly. Furthermore, details are required on the lubricants used, the calculated lubricant demand and if applicable also on the geometry of the rolling bodies and track surfaces.

7.3.3 Assessment of materials

(1) The scope of the material tests (insofar as the bearings are not of a standard type) shall be determined in consultation with GL Wind and with due consideration of Section 3.3.

(2) The verifications of the bearing materials for the blade and yaw bearings shall be provided as per Section 3.3.1.2. For these bearings, which are predominantly loaded by small back and forth motions, the following shall be fulfilled:

– The notched-bar impact work in the case of the ISO-V test shall have a 3-test mean value ≥ 27 Joule at -20 °C: The lowest individual value shall be more than 70 % of the mean value. Deviation from these values is possible after discussion with GL Wind, if a lower stress level can be proved or on the basis of test results.

– The minimum hardness of the bearing track surfaces is 55 HRC.

7.3.4 Loads to be applied

(1) For the design of the bearings, two parameters shall be taken into consideration:

– bearing size determination based on static load-bearing capacity

– bearing size determination based on rating life

(2) Blade and yaw bearings are designed for static load-bearing capacity. For the static load-bearing capacity, the extreme load shall be used. If applicable, a simplified rating life calculation may be performed on the basis of the operational loads.

(3) For the rating life calculation, the normal operating load shall be used. Using a duration counting method, the representative loads for the calculation of the bearing rating life shall be determined from the time series of the fatigue loads as per Chapter 4 (see also Appendix 4.B, Section 4.B.2.3). With this counting method, the sum of the revolutions ni of the bearing is determined, during which the equivalent dynamic bearing load Pi acts within the individual class limits. For the analysis of the basic rating life as per DIN ISO 281, the equivalent dynamic bearing load P averaged over the lifetime can be calculated as follows:

$$P = \sqrt[p]{\frac{\sum P_i^p \, n_i}{N}} \qquad (7.3.1)$$

where:

P_i = equivalent dynamic bearing load

p = 10/3 for roller bearings; 3 for ball bearings

n_i = number of revolutions during which P_i acts

N = total number of revolutions for the design lifetime of the offshore wind turbine

(4) The operational loading of generator bearings and of bearings for gearbox output shafts shall be superposed by the calculated restoring forces from the maximum permissible dynamic misalignment between the generator and gearbox.

(5) The extreme loads of generator bearings and of bearings for gearbox output shafts shall be superposed by the calculated restoring forces from the maximum permissible static misalignment between the generator and gearbox.

7.3.5 Calculations

7.3.5.1 General

(1) For roller bearings used in the drive train a rating life calculation as per Amendment 4 to DIN ISO 281 shall be submitted by each bearing manufacturer named according to Section 7.3.2 (see Section 7.3.5.3 para 3 to 6).

(2) For all other bearings, simplified analyses as per DIN ISO 281 (nominal or extended) can be performed after consultation with GL Wind (see Section 7.3.5.3 para 1 to 2).

(3) The analysis of the static load carrying capacity at extreme load is to be calculated for all bearings according to 7.3.5.2. Positive and negative extreme loads shall be considered.

7.3.5.2 Analysis of the static load-bearing capacity under extreme load

(1) The static load-bearing capacity f_s for predominantly dynamical stressed bearings is defined as the ratio of the static load number of the bearing C_0 and the equivalent static load P_0. For bearings in the drive train f_s shall not be less than 2.0 under extreme load. For the actuators of pitch and yaw systems the limit value is 1.1.

(2) For blade and yaw bearing, which are predominantly loaded by small back and forth motions, the static bearing capacity is derived directly from the calculated pressure between rolling element and raceway. The minimum safety factor γ_M = 1.1 (see Section 5.3.3.1 para 4) is to be verified regarding the maximum permissible Hertzian contact stress. The maximum permissible Hertzian contact stress is to be defined by the bearing manufacturer considering surface hardness and hardening depth and shall be documented in the design calculation.

7.3.5.3 Verification of rating life

(1) Simplified analysis of bearings rating life is admissible according to ISO 281 as Basic Rating Life calculation or as Extended Basic Rating Life calculation. The probability of failure shall be set to 10 %. A factor for material and operating conditions a_{23} respectively a_{DIN} shall be limited to 3.8. Is the factor to be calculated smaller than 1, an analysis performed as Basic Rating Life calculation is not admissible anymore. The calculated rating life may not be less than 130,000 hours.

(2) The following input parameters required for the extended rating life calculation shall be set out in the calculation:

– bearing temperature
– lubricant additive treatment and viscosity
– measures taken to maintain the lubricant's qualities (lubricant change intervals, lubrication checks etc.)

(3) The calculations of the nominal reference rating life by the bearing manufacturers shall be performed for each load level of the load duration distribution. A reduction of the specified spectrum to 10 load levels in accordance with Miner's Rule is permissible to minimize the computing effort. The life exponent for reducing the number of load levels shall correspond to the exponent in the bearing calculation.

(4) The combined nominal reference rating life as per Amendment 4 to DIN ISO 281 for the corresponding bearing is then obtained as:

$$L_{nmr} = \frac{\sum q_i}{\sum \frac{q_i}{L_{nmr\,i}}} \qquad (7.3.2)$$

where:

L_{nmr} = combined modified reference rating life of the bearing

q_i = time share on the i-th load level

$L_{nmr\,i}$ = modified reference rating life of the bearing in the i-th load level

(5) The rating life calculation of the bearing manufacturer shall consider at least the following effects in addition to the loads:

– internal geometry of the bearings
– operating clearance of the bearings
– deformation of the shafts and bearings
– load sharing between rolling elements
– load distribution along roller length, considering actual roller and raceway profiles
– lubricant viscosity and cleanliness under realistic operating conditions

(6) The combined nominal reference rating life of a bearing determined in this way shall not be less than 175,000 h or the operating life of the offshore wind turbine.

(7) The simplified rating life calculation as well as the calculation according to DIN ISO 281 Amendment 4 shall be based on an oil cleanliness class of -/17/14 according to ISO 4406 edition 1999 for filtered systems. For unfiltered systems, a cleanliness class of -/21/18 shall be assumed.

(8) If the bearings of the plant are easily exchangeable on site and the corresponding bearing replacement intervals are specified, a shorter rating life may be permissible independent of the calculation method after consultation with GL Wind.

7.3.5.4 Minimum loading

Compliance with the minimum load shall be agreed between the component manufacturer and the bearing supplier in accordance with the general structural and operational conditions.

7.3.6 Miscellaneous

(1) On principle, the greases and oils recommended by the offshore wind turbine manufacturer shall be used, whereby these shall comply with the prescribed component manufacturer's specification.

(2) During assembly, the bearing manufacturer's instructions shall be observed. The transport of bearings shall be undertaken in such a way that damage to roller and raceway profiles is prevented.

(3) The bearings shall be sealed in such a way that there is no detrimental effect on the function of adjoining components.

(4) Owing to the special operating conditions for offshore wind turbines, it should be possible to exchange generator bearings on the plant itself.

7.4 Gearboxes

7.4.1 General

7.4.1.1 Scope

The requirements in this Section apply for spur and planetary gearboxes intended for installation in the drive train of offshore wind turbines.

7.4.1.2 Assessment documents

(1) Assembly and sectional drawings of the gearbox, drawings of the casing, individual-part drawings of the shafts and the gearwheels, plus parts lists with data on materials, shall be submitted for the assessment. The individual-part drawings of the toothed components shall contain at least the data as per Table 7.4.2, otherwise this table shall be completed and appended to the assessment documents.

(2) Strength analyses, and possibly also deformation analyses, shall be provided for all torque-transmitting components. Verification of the adequate dimensioning of gearbox bearings and of any bolted connections which play a significant part in the transmission of power shall be provided.

(3) Also required are specifications for the lubricant used and admissible temperature ranges, instructions for envisaged maintenance work and intervals, plus information about the monitoring appliances and auxiliary units (lubricating oil cooler, lubricating oil pump etc.) installed. A specification of the corrosion protection provided shall be included. Furthermore, the gearbox specification of the offshore wind turbine manufacturer as well as the operating and maintenance manual (see Section 7.4.10) shall be appended.

7.4.2 Materials

7.4.2.1 Approved materials

All toothed parts shall be made of materials conventionally used for making gearboxes – but at least complying with material quality MQ as per ISO 6336-5 (see also Section 3.3).

7.4.2.2 Assessment of materials

(1) All torque-transmitting components of the gearbox shall be tested in accordance with the GL Rules for materials or equivalent standards. Appropriate verification according to EN 10204 shall be provided for the materials. The material test documents (statements of compliance) as per Section 3.3 shall be available at the manufacturer and shall be submitted on request.

(2) The tests laid down in the regulations for materials may be curtailed with the consent of GL Wind, if execution of the prescribed tests is not practicable because of the small size or particular manufacturing processes of individual components. For such components, GL Wind shall be provided with quality verification in some other way.

7.4.3 Loads to be applied

7.4.3.1 General

(1) The force-transmitting parts of the gearbox are statically and dynamically loaded by the driving torque. The dynamic portion depends on the characteristics of the driving side (rotor) and the driven side (generator, pump) and also on the masses, stiffnesses and damping values in the driving and driven portions (shafts and couplings) and the external operating conditions imposed on the offshore wind turbine. Depending on the drive train concept of the offshore wind turbine, additional loads in the form of forces and bending moments may be introduced at the slow-running gearbox input shaft and the fast-running gearbox output shaft, and these shall be taken into account.

(2) The fatigue and extreme loads shall comply with at least the requirements set out in Chapter 4.

7.4.3.2 Fatigue loads

(1) Using the time series of the fatigue loads (e.g. torque), the load duration distributions (LDD) shall be determined for the calculation of the toothing, shafts and bearings. These specify the sums of the times during which the torque remains within the class limits to be defined.

(2) In the LDD, all operating conditions described in Chapter 4 shall be considered for the determination of the fatigue loads to be applied. Apart from normal operating conditions, these also include connections and disconnections, load shedding of the generator, use of the mechanical brake and also standstill loading of the offshore wind turbine. The torque levels shall have a clear relation to the rotational speed. Additional loads, inter alia through deformations, alignment errors and asymmetrical arrangements of the mechanical brakes, shall also be taken into account if applicable.

(3) Planet carrier, gearbox housing and torque arm are usually verified with the aid of load time series.

7.4.3.3 Extreme loads

The maximum loads occurring in the drive train of the offshore wind turbine as per Chapter 4 shall be taken into account.

7.4.4 Calculation of load capacity of gears

7.4.4.1 General

(1) Through load capacity calculations according to the international standard ISO 6336, sufficient load capacity of the gears shall be verified for all engagement situations in the main gearbox of the offshore wind turbine. The required minimum safety margins regarding flank and root loads are given in Table 7.4.1:

Table 7.4.1 Minimum safety factors

	Safety against pitting S_H	Safety against tooth root fracture S_F
Fatigue analysis	1.2	1.5
Static analysis	1.0	1.4

(2) For the gears of offshore wind turbines, proof of the sufficient mechanical strength of the roots and flanks of gear teeth is linked to the requirement that the accuracy of the teeth shall ensure sufficiently smooth gear operation combined with satisfactory exploitation of the dynamic loading capacity of the teeth.

(3) The toothing quality as per ISO 1328-1 (DIN 3962) shall comply with at least quality 6 for externally toothed parts and at least quality 8 for internally toothed parts (internal gears).

(4) The endurance limits for the materials shall comply with ISO 6336, Part 5.

(5) GL Wind reserves the right to call for proof of the accuracy of the gear-cutting machines used and for testing of the method used to harden the gear teeth.

7.4.4.2 Input data for gear rating

The input data required for a rating of the gear life are compiled in Table 7.4.2. If the profile modifications cannot be obtained from the original drawings, these values shall also be given in tabular form for each meshing.

7.4.4.3 Influence factors for the load calculations

7.4.4.3.1 Application factor K_A

(1) The gears for offshore wind turbines are subjected to additional load fluctuations which are superposed onto the load increments or the constant rated load. These load fluctuations, acting at the gearbox input and output, result in additional dynamic loads in the teeth. The application factor K_A accounts for these additional external dynamic forces.

(2) The application factor K_A shall be determined according to DIN 3990, Part 6 (Method III) for each meshing from the LDD, both for the flank and for the root.

(3) The strength analysis of the gearbox as regards the action of extreme loads is carried out using the application factor $K_A = 1.0$.

7.4.4.3.2 Dynamic load factor K_v

To account for the additional internal dynamic loading, the dynamic load factor K_v is to be calculated in the load capacity calculation according to ISO 6336 method B. Without a detailed dynamic analysis, a use of $K_v < 1.05$ is not permissible.

7.4.4.3.3 Load distribution factor K_γ

(1) The load distribution factor K_γ accounts for deviations in load distribution e.g. in gearboxes with dual or multiple load distribution or planetary stages with more than three planet wheels.

(2) For the planetary stages, the values given in Table 7.4.3 apply in relation to the number of planet wheels:

Table 7.4.3 Load distribution factor K_γ

Number of planet wheels	3	4	5	6	7
K_γ	1.0	1.25	1.35	1.43	1.5

(3) Lower values than given in Table 7.4.3 used in analyses shall be verified by measurements after consultation with GL Wind. Calculations can be accepted, as long as the underlying model has been verified by measurements.

7.4.4.3.4 Face load factors $K_{H\beta}$ and $K_{F\beta}$

(1) The face load factors take into account the effects of uneven load distribution over the tooth flank on the flank contact stress ($K_{H\beta}$) and on the root stress ($K_{F\beta}$).

Table 7.4.2 List of input data for gear rating

Gearbox						Certification No.			
Manufacturer					Stage				
Wind turbine					Gear stage	ϒ	Planetary stage		ϒ
Rated power	P			kW	No. of planets				
Rated speed	n			1/min	Load distribution factor	K_γ			
Application factor	K_A			-	Dynamic factor	K_V			-
Face load factors	$K_{H\beta}$			-	Transverse load factors	$K_{H\alpha}$			-
	$K_{F\beta}$			-		$K_{F\alpha}$			-
Geometrical data		Pinion	Wheel		**Tool data**		Pinion	Wheel	
Number of teeth	z			-	Addendum modification coeff.	x			-
Normal module	m_n			mm	Coefficient of tool tip radius	$\rho_{a0}{}^*$			-
Normal press. angle	α_n			°	Coefficient of tool addendum	$h_{a0}{}^*$			-
Centre distance	a			mm	Coefficient of tool dedendum	$h_{fP0}{}^*$			-
Helix angle	β			°	Protuberance	pr			mm
Face width	b			mm	Protuberance angle	α_{pr}			°
Tip diameter	d_a			mm	Machining allowance	q			mm
Root diameter	d_f			mm	Utilized dedendum coefficient of tool	$h_{FfP0}{}^*$			-
Lubrication data					Measure at tool	Bz0			mm
Kin. viscosity 40 °C	ν_{40}			mm²/s	**Quality**				
Kin. viscosity 100 °C	ν_{100}			mm²/s	Quality acc. to DIN	Q			-
Oil temperature	δ_{Oil}			°C	Accuracy-/tolerance sequence				
FZG class				-	Mean peak to valley roughness of flank	Ra_H			µm
Material data					Mean peak to valley roughness of root	Ra_F			µm
Material type					Initial equivalent misalignment	$F_{\beta x}$			µm
Endurance limit for contact stress	σ_{Hlim}			N/mm²	Normal pitch error	f_{pe}			µm
Endurance limit for bending stress	σ_{Flim}			N/mm²	Profile form error	f_f			µm
Surface hardness				HV	Date:				
Core hardness				HV					
Heat treatment method				-	Signature:				

(2) In the case of flank corrections which have been determined by recognized calculation methods, the face load factors can be preset. Hereby the special operating conditions of an offshore wind turbine on the load distribution shall be taken into account (partial load at low rotational speed and extreme load briefly at higher rotational speed). The use of $KH\beta < 1.15$ is not permissible. Comparison of the calculated load distribution at the flank with a contact pattern taken after a reasonable period of operation in the offshore wind turbine is recommended.

7.4.4.3.5 Transverse load factors $K_{H\alpha}$ and $K_{F\alpha}$

The transverse load factors $K_{H\alpha}$ and $K_{F\alpha}$ take into account the effects of an uneven distribution of force over several tooth pairs engaging at the same time. In the case of gears in the drive train of offshore wind turbines with a toothing quality as required in Section 7.4.4.1, the value of 1.0 may be used for the transverse load factors $K_{H\alpha}$ and $K_{F\alpha}$. For gearboxes with several tooth pairs engaging at the same time, the transverse load factor shall be determined according to ISO 6336 or equivalent codes.

7.4.4.4 Fatigue analysis

7.4.4.4.1 Requirements

Fatigue analysis is to be carried out according to ISO TR 10495 respectively DIN 3990 Part 6. As reference value for the declension of the life factors Z_{NT} according to ISO 6336 Part 2 respectively DIN 3990 Part 2 and Y_{NT} according to ISO 6336 Part 3 respectively DIN 3990 Part 3, the value 0.85 at $N_L = 10^{10}$ is to be used.

7.4.4.4.2 Application of the load duration distribution (LDD) of the torque

(1) The LDD shall be used to establish the stress spectrum, in that the root stress and face pressure is calculated for every load increment. The application factor K_A is not taken into account when calculating the stress, as the dynamic loading of the gearbox is embodied in the LDD.

(2) The calculated stresses (stress spectra) obtained are multiplied by the safety factors in accordance with Table 7.4.1 and the accumulated damage is calculated using the Palmgren-Miner Rule (see also ISO TR 10945, Method II). The Palmgren-Miner sum shall be less than or equal to 1.

7.4.4.4.3 Use of the equivalent torque

(1) From the LDD, an equivalent torque is calculated for the tooth root and flank respectively (procedure as described in Section 7.4.4.3.1, as per DIN 3990 Part 6, Method III).

(2) Taking into account the safety factors in accordance with Table 7.4.1, an endurance limit analysis is to be carried out against tooth root fracture and pitting according to ISO 6336..

7.4.4.5 Analysis of the static strength

(1) The analysis of the static strength shall be based on the load case in Chapter 4 which produces the maximum torque on the gearbox.

(2) The stresses on tooth root and flank shall not exceed the static strength values according to ISO 6336.

(3) The minimum safety factors given in Table 7.4.1 shall be observed.

7.4.4.6 Analysis of the safety against scuffing

(1) ISO 6336 does not provide a rating method for scuffing. For this reason, the analysis of scuffing shall be defined by consultation between the offshore wind turbine manufacturer and the gearbox manufacturer.

(2) For the analysis, a contact temperature method (e.g. as per DIN 3990 Part 4 or ISO/TR 13989-1) shall preferably be used. The calculated safety factor shall be documented.

(3) Only gearbox oils with suitable additive treatment may be used. For the calculation, the input values (including the test torque) corresponding to at most one FZG class lower than that allowed by the specification of the oil used may be applied.

7.4.5 Strength analysis for shafts and connecting elements

7.4.5.1 General

(1) Fatigue and static analyses (general stress analyses) shall be carried out for all shafts. For connecting elements (e.g. fitting keys, slip joints), only a static analysis is needed as a rule.

(2) The analyses shall be performed in accordance with DIN 743 (load capacity calculation for shafts), DIN 6892 (parallel keys) and DIN 7190 (interference fits), or equivalent codes.

7.4.5.2 Analysis of the fatigue strength

(1) If a representative load spectrum is available, a fatigue analysis shall be carried out. Further notes for the fatigue analysis are given in Section 5.3.4.

(2) The fatigue analysis may also be carried out in a simplified form using fatigue limits as per DIN 743. Here rated loads shall be used for computation, with consideration of the application factor determined for the toothing calculation. The theoretical safety S shall then in each case be equal to or greater than the minimum safety S_{min} = 1.2. The theoretical safety is determined with consideration of bending, tension/compression and torsion, assuming phase balance.

7.4.5.3 Analysis of the static strength

(1) The analysis of static strength against forced rupture shall be based on the load case in Chapter 4 which produces the maximum loading on the component.

(2) The component loads shall have a partial safety factor $\gamma_M \geq 1.1$ relative to the yield point of the material.

7.4.6 Additional verifications

7.4.6.1 Gearbox bearings

For design, calculations and assessment documentation to be submitted for gearbox shaft bearings refer to Section 7.3.

7.4.6.2 Bolted connections

Strength analyses for bolted connections are necessary wherever the bolts are essential to the transmission of power (see Section 6.5.1 “Bolted connections”).

7.4.6.3 Housing, torque arm and planet carrier

Regarding the gearbox housing, torque arm and planet carrier, fatigue and static strength analyses and/or deformation analyses shall be performed, insofar as these parts play a significant part in the transmission of power (e.g. introduction of rotor blade loads into the housing, in the case of a hub affixed directly to the gearbox input shaft). General requirements for strength analyses are stated in Section 5.3. The influence of deformations of these components on the meshing and the bearings shall be taken into account. If applicable, deformations determined by computation shall be taken into account for the calculation of the meshing and the bearings.

7.4.6.4 Analysis of the cooling

A heat balance for the gearbox shall be submitted for verification of the thermodynamics of the design. Sufficient cooling of the gear box shall be proved in this balance. All necessary information for this verification, as e.g. the air supply temperature and the available air flow rate at the gear oil cooler, is to be specified unambiguously by the offshore wind turbine manufacturer.

7.4.6.5 Avoidance of unacceptable gear loads

The offshore wind turbine manufacturer has to ensure, that unacceptable gear box loads caused by pendulousness of the rotor are avoided during standstill of the offshore wind turbine. Devices shall be provided, which keep away long lasting alternating standstill loads from the gear box not requiring the presence of service personnel.

Note:

This can for instance be a parking brake, mounted at the slow running rotor shaft or a rotor lock, which can be activated via remote control.

7.4.7 Equipment

(1) For checking the level of the lubricating oil, a mechanical arrangement (e.g. oil level gauge, oil dipstick) shall be provided. The temperature shall be monitored. In the case of gearbox with circulatory lubrication, the oil pressure shall be monitored after the cooler and before entry into the gearbox. Plain bearings shall be fitted with temperature indicators. Adequate lubrication of all teeth and bearing points shall be ensured in every operating state of the offshore wind turbine. For operation at low temperatures, a heating system shall be provided.

(2) An oil purifying appliance (filter system) shall be provided to meet the requirements for the rating life of the gearbox bearings. Flanged lubricating oil pumps shall be mounted accessibly at the gearbox and shall be exchangeable.

(3) The sealing system for the gearbox shall be suited to the operating conditions of the offshore wind turbine and the installation position of the gearbox. Verification shall be provided of the compatibility of the gaskets with the gearbox oil used.

(4) The housing of main gearboxes in offshore wind turbines shall be provided with removable inspection hole covers, so that it is possible to check the teeth.

7.4.8 Inspection of gearboxes

(1) Gearboxes for offshore wind turbines shall be inspected in the manufacturer's works. The final inspection of the mass-produced gearboxes shall take place after a trial run under partial load lasting several hours. The detailed test plan (also regarding noise assessment) shall be agreed by the gearbox manufacturer and the offshore wind turbine manufacturer.

(2) After the trial run, the filtered oil should be left in the gearbox.

(3) Newly developed main gearboxes for offshore wind turbine shall be subjected to a prototype trial at a suitable test bench and also in operation on an offshore wind turbine (see Section 1.2.2.3.3). The precise procedure for the trials of gearboxes for offshore wind turbines is described in Section 10.7.

(4) Following a successful prototype trial, the trials of identical mass-produced gearboxes can be reduced to testing for sufficient production quality.

(5) The detailed scope of the prototype trial shall be specified in consultation with GL Wind before the trial commences. The reduced extent of series testing shall be defined in the documentation of the prototype test.

7.4.9 Offshore wind turbine operation depending on gear box conditions

(1) For new gearboxes of offshore wind turbines, a running-in period at low load shall be defined by the gearbox manufacturer. The offshore wind turbine manufacturer has to limit the power output by the rotor in the control system during this period. During the running-in period, the oil and dedicated bearing temperatures shall be watched closely and the lubrication system shall be kept in constant operation.

(2) Furthermore the gearbox manufacturer has to specify clearly the necessary limitation of the power output of the offshore wind turbine dependent on the oil sump Temperature (see also Section 2.3.2.16). The offshore wind turbine manufacturer has to implement these limits in the operation system of the offshore wind turbine.

7.4.10 Manuals

The gearbox manufacturer shall define, in a written manual, the relevant maintenance, monitoring and precautionary measures for erection, transport and operation of the gearboxes, with a view to ensuring that the design lifetime of the gearbox is reached. According to Section 7.4.1.2, the manual forms part of the assessment documents for the certification of offshore wind turbine gearboxes and shall contain binding statements on at least the following points:

– characteristic values and properties of permissible lubricants

– intervals required for oil analyses (also for oil purity) and oil changes

– required maintenance and inspection intervals, as well as a description of the measures to be performed in each case. These shall be incorporated into the maintenance manual of the offshore wind turbine as per Section 9.4.

– operating parameters to be logged, and the corresponding limiting values

– notes on the proper assembly of the gearbox

– notes on transport by sea, air or land (rail or road), both as separate component and within the nacelle of the offshore wind turbine

– notes on storage of the gearbox over periods exceeding half a year

7.5 Mechanical Brakes and Locking Devices

7.5.1 General

(1) The following guidelines apply to brakes and locking devices of the rotor and the yaw system.

(2) Definitions of the individual terms are given in Section 2.2 and data about the effective, systems-engineering design of braking systems and locking devices in Section 2.3.

(3) Because of the heat generated and the wear arising from continuous operation of mechanical brakes, it is not possible just to limit the rotational speed of the rotor with these brakes. Therefore, the brakes shall be so designed that, once they have been activated, the rotor is safely brought to a standstill (see Section 2.2.3.3.1).

(4) For the torques in the drive train that are relevant to the design of the mechanical brake, the following definition of terms applies (see Fig. 7.5.1):

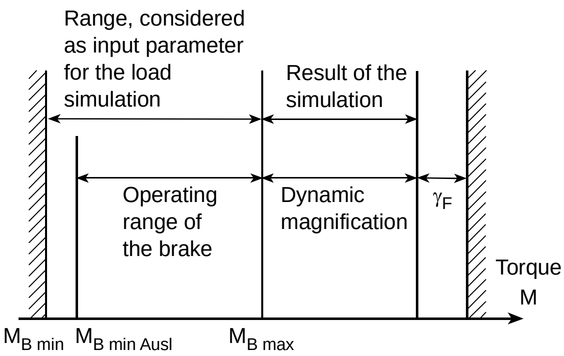


Fig. 7.5.1 Sketch of the relevant torques in the drive train

(5) The minimum required braking moment M_{Bmin} is the braking moment which is needed for the proper function of the brake according to Section 2.2.2.3.

(6) The minimum required braking moment M_{Bmin} and the maximum actual braking moment M_{Bmax} are the braking moments which are considered as input parameters for the load simulations of the offshore wind turbine as per Section 4.3.3.4.

(7) The operating range of the mechanical brake is subject to fluctuations caused by changes in the contact pressure and the coefficient of friction. The operating range varies between the minimum design braking moment $M_{BminAusl}$ and the maximum actual braking moment M_{Bmax}.

(8) During the braking process, a torque is produced in the drive train which exceeds the maximum actual braking moment M_{Bmax} of the brake by the dynamic magnification.

(9) This drive train torque is augmented by the partial safety factor γ_F to be applied as per Section 4.3.

7.5.2 Assessment documents

(1) Installation and general arrangement drawings of all braking systems, circuit diagrams for the hydraulic, pneumatic and electrical equipment plus individual-part drawings of all components playing a significant role in power transmission shall be submitted.

(2) A compilation of the load cases used for the design, and of the braking moments derived from these, is required.

(3) Design calculations shall be based on data provided by the brake manufacturer. Additional calculation documents may be required in individual cases (e.g. spring calculations, bolt calculations).

(4) A data sheet, detailing the coefficients of friction, temperature stability, lining material and wear characteristics, shall be submitted for the brake linings to be used.

7.5.3 Loads

(1) The minimum design braking moment $M_{BminAusl}$ and the maximum actual braking moment (M_{Bmax}) are calculated for the brake. Here the following shall be taken into account:

– fluctuations in the coefficient of friction

– fluctuations in the contact pressure

– warming and wear

(2) Brakes for the yaw system shall be designed in accordance with the requirements of the control concept.

(3) A reduction in braking force resulting from wear shall be taken into account in the design.

(4) The locking devices for blade-pitch system, rotor and yaw system shall be capable of holding the rotor blade, the rotor or the nacelle against

– an annual gust (Section 4.3.3.4, DLC 8.2a), and

– a gust during erection or maintenance (Section 4.3.3.4, DLC 8.1).

7.5.4 Calculations

(1) In general, the conventional analysis tools shall be used for brake calculations. The strength analysis shall be carried out with the maximum actual braking moment M_{Bmax} .

(2) The following data are required for checking purposes:

– type and construction

– spring characteristic (only for spring-operated brakes)

– for hydraulic and pneumatic brakes: operating pressure, type of accumulator, volume of pressure medium, leakage rate

– specific wear of the brake linings

– minimum and maximum dynamic coefficient of friction for the material combination of brake lining and brake drum/disk

– if applicable, the static coefficient of friction for the material combination of brake lining and brake drum/disk

(3) The calculations shall include:

– determination of the minimum design braking moment $M_{BminAusl}$

– calculation of the maximum actual braking moment M_{Bmax}

– verification that the permissible temperatures are not exceeded during the braking process. This analysis shall be performed on the basis of the least favourable braking moment of the operating range.

– strength analysis of the power-transmitting components of the brake (bolted connections, brake disk, brackets etc.)

(4) It shall be shown that the following condition is met:

$$\frac{M_{BminAusl}}{1.1} \geq M_{Bmin} \tag{7.5.1}$$

7.5.5 Miscellaneous

(1) The braking surfaces shall be protected against undesirable influences (e.g. fouling by lubricants) by means of covers, splashguards or suchlike.

(2) Automatic monitoring of the brake may be necessary; see Section 2.3.2.10.

(3) In the case of pressure-actuated braking systems, the brake shall be capable of holding the rotor even if there is no power supply. The period of time for which the grid failure shall be assumed is specified in Section 2.2.2.9.

(4) For the design of locking devices, see also Section 2.3.3.

7.6 Couplings

7.6.1 General

The guidelines in this Section apply to couplings in the drive train.

7.6.2 Assessment documents

Assembly and individual-part drawings of all torque-transmitting components, parts lists with data on materials, documents as per DIN 740 Part 1, 1986, Section 4.12, strength analyses for all torque-transmitting components as well as a record (by way of example) on the function test of a slipping coupling (if present) shall be submitted to GL Wind.

7.6.3 Materials

Reference is made to Sections 3.3 (Materials) and 3.4 (Production and Testing).

7.6.4 Calculations

(1) For all torque-transmitting components, a general strength analysis, a fatigue analysis and an analysis on stress through periodic torque fluctuations shall be submitted. Here the axial, radial and angular misalignment shall be taken into account.

(2) In the general strength analysis, maximum moment from the design loads as per Chapter 4 shall be used as the basis.

(3) Continuous transmission of that maximum moment is not necessary, but the loading caused by its occurrence shall not result in damage to the coupling. If a reduction in that maximum value is achieved by design measures (e.g. a slipping coupling), the reduced value may be used for the coupling design. Here the tolerance of the slipping moment shall be considered.

(4) The general strength analysis is described in Chapter 5.

(5) The fatigue verification may be effected by component testing under conditions resembling operation or by computational analyses.

(6) For computational analysis, the fatigue loads as per Chapter 4 shall be used as a basis. The calculation shall be performed in accordance with Chapter 5.

(7) If it is to be expected that excitation by the rotor or the driven machine can cause alternating torques when passing through a resonance range or when operated at the rated speed, it shall be verified that the coupling is not damaged by these torques.

7.6.5 Miscellaneous

(1) If rubber elements are used, these shall be verified in accordance with Section 7.7 (Elastomer Bushings).

(2) The temperature influence which a brake disk (if present) can have on non-metallic components shall be considered (e.g. fire hazard, damage to the rubber elements of the coupling).

(3) In individual cases, it may be necessary for an expert from GL Wind to inspect a coupling from series production.

7.7 Elastomer Bushings

7.7.1 General

(1) Elastomer bushings are used where it is necessary to reduce the vibration, movement or shock acting at components.

(2) The influences on the behaviour of the elastomers are not limited to the structural mechanics (e.g. type, amplitude and frequency of the load; loading sequence); the properties of the elastomer bushings are also strongly affected by the production and process technology as well as external influences.

(3) Owing to the dynamic loading of the elastomer bushings, an annual inspection is necessary as a rule (e.g. visual inspection).

(4) From the design viewpoint, care shall therefore be taken to provide a possibility for inspecting, and if necessary exchanging, the elastomer bushing without excessive effort.

(5) In order to prevent premature ageing of the elastomer bushings, they shall be selected to ensure that they are resistant to external influences as well as operating media (e.g. escaping oil and aggressive media) and their vapours. Alternatively, a design-based solution shall be provided to ensure that the elastomer bushings do not come into contact with such substances.

(6) In the selection of the elastomer bushings, the environmental conditions (e.g. temperature, humidity, ozone) prevailing at their place of installation within the offshore wind turbine shall be taken into account.

(7) It shall also be noted that, owing to dynamic loading, the internal temperature of the elastomer bushings can exceed the ambient temperature at the place of the installation for the elastomer bushings within the offshore wind turbine, thereby possibly exceeding the allowable ambient temperature of the elastomer bushings.

(8) Elastomer bushings shall preferably be subjected to compressive and/or shear loading.

7.7.2 Assessment documents

(1) General information on the assessment documents to be submitted is given in Section 7.1.

(2) Analyses shall be submitted for the extreme and fatigue loads.

(3) The analyses and technical documents are required for all elastomer bushings that are essential to the distribution of forces. This includes e.g. the elastomer bushings of the

- turbine components located in the drive train
- connection of the nacelle cover to the main frame (simplified analysis)
- components and supply units of the blade pitching system (simplified analysis)

(4) Installation drawings, and if applicable sectional drawings, including the associated parts lists shall be submitted.

(5) It shall be shown at which point in the distribution of forces of the offshore wind turbine the elastomer bushings are arranged.

(6) In addition, a specification and a data sheet shall be submitted for the elastomer bushings or elastomers used, showing the physical (e.g. hardness, density) and mechanical properties (e.g. type of permissible loading) and the admissible operating and environmental conditions, as well as the chemical resistance properties.

(7) The data sheet shall also provide information on the strength values (tensile strength, tear resistance, yield stress, permissible pressure) and deformation parameters (strain at maximum load and yield stress, elongation at tear) of the elastomer or the entire bushing.

(8) A load-deformation diagram shall be submitted.

(9) The effects on the spring characteristic – up to the typical loading of the elastomer bushing and for the temperature range from -20 °C to +50 °C (but at least for -20 °C, +23 °C and +50 °C) or for the extreme temperatures to be expected at the place of installation for the elastomer bushing within the offshore wind turbine – shall be described.

(10) The flow properties of the elastomer bushings shall be stated (see also design lifetime of the offshore wind turbine, Section 4.2.2.1).

(11) If tests are used by way of reference, a description of the tests shall be submitted.

7.7.3 Loads to be applied

For the calculation of the loading of the elastomer bushings, the design loads as per Chapter 4 shall be applied.

7.7.4 Strength analysis

(1) It shall be shown that the elastomer bushings used provide adequate safety against the extreme and fatigue loads.

(2) If the extreme and fatigue load analyses are carried out with the aid of test results, the test procedure and the results derived from the tests shall be presented in a plausible manner.

(3) When transferring the test results to the actual application of the elastomer bushings, the reduction factors assumed here shall be documented.

(4) The analyses shall take account of the environmental conditions usually prevailing at the place of installation for the elastomer bushings within the offshore wind turbine. If necessary, several analyses shall be produced for various sets of environmental conditions. These conditions shall be stated in the analysis.

(5) It shall be shown that environmental conditions occurring rarely at the place of installation of the elastomer bushings are also covered. These conditions shall be stated in the analysis.

(6) Elastomer bushings are frequently used in combination with other materials which provide the connection between the elastomer and the components to be connected (e.g. circular bearings with set screw). In this case, verification shall also be provided for this assembly. For the computational analyses (e.g. with the aid of the finite element method) of the entire component, the material non-linearities of the elastomer shall be taken into account, except for the provisions set out in Chapter 5.

Note:

For the determination of the lifetime of the elastomer, no generally valid computation standard is currently available, since the dynamic characteristics of the elastomer usually depend strongly on

– *the frequency*
– *the environmental conditions*
– *the load amplitudes*
– *the mean load, and*
– *the relationship between surface area and volume.*

For this reason, it will often be necessary to make use of findings from the trial and from tests when performing the analysis.

7.7.5 Additional verifications

(1) Strength analyses for bolted connections are necessary wherever such connections are essential to the distribution of forces (see Section 6.5.1).

(2) Section 7.1.3 “Drive train dynamics” shall also be observed.

Note:

The influence of the elastomer bushings on adjacent components shall be taken into account in a suitable manner. For example, the spring and damping characteristic, which is considered for the load assumptions and used in the design calculation of adjacent components, shall be verified with the data sheet described in Section 7.7.2.

7.8 Yaw System

7.8.1 General

(1) This Section applies for the yaw system of offshore wind turbines as described below. In the event of other designs, the wording shall apply with the necessary changes.

(2) The torque necessary to make the nacelle track the wind is provided by a servomotor with the associated yaw gear. The torque is transmitted by the driving pinion to a live ring fixed to the body of the tower.

(3) The nacelle is supported on the tower head either by a plain bearing or by a roller bearing. The swivelling motion of the nacelle is usually braked either by a brake in the positioning drive and/or by brake blocks acting on a brake disc fixed to the tower head or the nacelle.

(4) To exclude alternating loads on the toothing, which could cause premature damage to the teeth, a braking system shall generally be provided which prevents alternating stressing of the gear teeth due to shaking motions of the nacelle by means of a constantly acting residual braking moment.

(5) This residual braking moment shall be taken into account when designing the yaw drive.

(6) A locking arrangement shall be provided for the yaw system (see also Sections 2.2.2.10 and 2.3.3), with which this system is locked in place during maintenance and repair work, in order to exclude the risk of personal injury. This locking arrangement need not necessarily be located permanently at the yaw system; it may also be an external lock which is mounted whenever required.

(7) Appropriate collecting troughs shall be provided to accommodate excess quantities of lubricant from the toothing of the yaw ring and the drive pinion as well as from the nacelle bearing.

7.8.2 Assessment documents

(1) General information on the assessment documents to be submitted is given in Section 7.1.

(2) For the components of the yaw system, type sheets, specifications and assembly drawings shall be submitted.

(3) Statements shall be made on the calculation data (e.g. input data for the calculation, presentation of the results with the relevant safety margins) and on the components of the gearbox.

(4) For the evaluation of the transmission stage "driving pinion / live ring", the individual-part drawings of the pinion shaft and the live ring are required, together with a toothing calculation for this combination and the verifications for the pinion shaft and its bearing arrangement.

(5) Assembly and sectional drawings, including the associated parts lists and if applicable individual-part drawings, shall be submitted together with a description explaining the functional principle of the yaw system.

7.8.3 Loads to be applied

(1) For the calculation of the loading of the yaw system, the design loads as per Chapter 4 shall be applied.

(2) The static and load-dependent bearing friction moment shall be taken into account. For the fatigue analysis, the load duration distributions (LDD) and the load spectra shall be used. A distinction shall be made between operation with and without yawing.

(3) The static strength analysis – with and without operation of the yaw system – shall be performed for the design loads of the dimensioning load case as per Chapter 4.

(4) For the static strength analysis, an application factor of $K_A = 1.0$ is used.

(5) When determining the number of load cycles or the load duration per tooth occurring during yawing, the statements in Section 4.3.3.5 shall be used as a basis.

7.8.4 Strength analysis

7.8.4.1 Verification of load capacity of gears

(1) The toothing calculation of the driving pinion / live ring stage and of the yaw gear shall be based on ISO 6336.

(2) The calculation of the load capacity from the fatigue loads shall be performed according to ISO TR

10495. For Method II, a damage ratio of D ≤ 1 shall be achieved in compliance with the safety factors listed in Table 7.8.1.

(3) Alternatively, equivalent loads can be determined from the load/time distribution (as per DIN 3990 T6) with which – in compliance with the safety factors listed in Table 7.8.1 – the fatigue analysis shall be performed.

(4) Furthermore, an analysis of the static strength against forced rupture and pitting in compliance with the safety factors according to Table 7.8.2 is also required.

(5) According to ISO TR 10945 the predominantly alternating load of the toothing is to be considered. A reduction factor for the respective S/N curve is given e.g. in DIN 3990 part 6 with a value of 0.7. More favourable values may be used, e.g. based on the diagram in Fig. 21.7/15 on page 155 in Niemann/Winter, vol. 2, edition 1989 [7.1].

Table 7.8.1 Safety factors for the fatigue strength analysis

Minimum Safety of toothings in yaw gears and yaw bearings:	
pitting S_H	1.0
tooth root fracture S_F	1.25

Table 7.8.2 Safety factors for the static strength analysis

Minimum Safety of toothings in yaw gears and bearings:	
pitting S_H	1.0
tooth root fracture S_F	1.2

7.8.4.2 Shafts and connecting elements

(1) For the output shaft of the yaw drive and for the connecting elements, a fatigue strength analysis and a static strength analysis shall be submitted.

(2) The analyses shall be performed in accordance with DIN 743, DIN 6892 and DIN 7190, or equivalent codes.

(3) Strength analyses for rotary drive housings and planet carriers can be demanded if necessary (see also Section 7.1.1, para 4).

(4) Strength analyses for bolted connections are necessary wherever the bolts are essential to the distribution of forces (see Section 6.5.1).

Note:

The output pinion of the rotary drive should be forged-on.

7.8.4.3 Bearings

(1) For the calculation and execution of the nacelle bearing, reference is made to Section 7.3.

(2) The seals shall be so executed or protected that they are not damaged by the prevailing environmental conditions.

Note:

It should be possible to exchange the seal of the nacelle bearing in the installed condition.

(3) It shall be shown that adequate lubrication and removal of the old lubricant is ensured for the nacelle bearing, and if applicable also for the toothing. Considering service intervals not less than one year (see also Section 7.10.1) this will in general require automatic lubrication devices. The functionality of such devices is to be documented.

7.8.4.4 Yaw brake

(1) Notes on the calculation of brakes are given in Section 7.5.

(2) If a permanent application of a braking moment is required according to the system concept, the function of the brakes shall also be ensured in the event of failure of the power supply.

7.8.4.5 Additional verifications

(1) In the case of systems with electrical actuating drive, Chapter 8 shall also be considered.

(2) For the verification of the hydraulic system, Section 7.9 shall be considered.

(3) The design of the drives and brakes shall be verified for proper function in accordance with the system concept.

7.9 Hydraulic Systems

7.9.1 General

(1) The guidelines in this Section apply to hydraulic systems necessary for operation (e.g. yaw motion and rotor blade pitch control) or forming part of a braking system (e.g. blade pitch adjustment in fault situations and rotor brakes).

(2) In addition to the statements made here, national requirements may also have to be observed (e.g. in Germany, the Operational Safety Ordinance and the 14^{th} Ordinance on the Equipment Safety Law).

7.9.2 Assessment documents

The following assessment documentation is required:

a hydraulic functional diagram in standard form (e.g. as per ISO 1219-2) with associated parts list

b electrical circuit diagrams showing the actuation of the hydraulic system valves, insofar as electro-hydraulic control and regulation is planned

c data sheet of the safety-related components

d calculations and data for the actuators (e.g. piston diameter, buckling calculation for the piston rod, moments acting on servomotors, design of articulated joints and levers), accumulators, pipelines, hoses and valves (e.g. flow rates and reaction times)

e data concerning pump unit design (storage volume, limitation of pressure, fluid level check etc.)

f data on the execution of filters

g details on the service life of the component used (e.g. hoses, accumulators), if these are shorter than the design lifetime of the offshore wind turbine (see Section 4.2.2.1)

7.9.3 Materials

(1) In the selection of materials for the force-transmitting components, it shall taken into account that they are possibly subjected to dynamic loading.

(2) Seamless or longitudinally welded steel pipe shall be used for piping. Suitable high-pressure hoses in accordance with DIN EN 853, DIN EN 855, DIN EN 856, ISO 6803 or equivalent international codes may be used as flexible pipe connections.

(3) All components not made of corrosion-proof materials shall be provided with a corrosion protection system.

7.9.4 Design and construction

(1) The design and construction of hydraulic systems shall be in accordance with recognized rules (see e.g. ISO 4413 and AD data sheets).

(2) The following points shall be taken into account:

(3) Adequate dimensioning of the components (e.g. pumps, piping, valves, actuators, accumulators) to guarantee the desired reaction times, actuation speeds and actuating forces.

(4) During operation, pressure fluctuations can arise in hydraulic components which can cause fatigue damage.

(5) A clear separation is required for the components and assemblies of the independent braking systems (see Section 2.2.3.3).

(6) The hydraulic system should be so designed that the offshore wind turbine is in a safe condition in case of no pressure or of failure of the hydraulics.

(7) In the event that hydraulic actuators (e.g. rotor brake or blade pitching system), fulfil their safety function only if there is hydraulic pressure, the hydraulic system shall be so designed that the offshore wind turbine can be kept in a safe condition following failure of the power supply to the pump or the valves. The duration of this failure shall be assumed identical to the duration of the grid failure specified as a fault condition in Section 2.2.2.9, para 2.

(8) The weather conditions under which the installation is intended to operate (oil/fluid viscosity; possible cooling, heating etc.) (see Section 4.2) shall be taken into account.

(9) Leakage shall not impair the system's ability to function. If leakage occurs, this shall be recognized and the offshore wind turbine shall be controlled accordingly.

(10) Actuators shall always be "hydraulically loaded" if they are hydraulically moved in two directions.

(11) In the layout of piping, it shall be taken into account that components may move relative to one another and thereby dynamically stress the pipes.

(12) All components shall be protected in a suitable manner against accidental loads not considered in the dimensioning (e.g. weight of a person on pipes).

(13) Adequately large oil troughs shall be provided to ensure that hydraulic fluid does not pollute the environment in the event of leakage in the hydraulic system, but runs into the collecting troughs instead.

7.10 Offshore Application

7.10.1 General

As the accessibility of the offshore wind turbine is heavily dependent on the weather conditions the maintenance interval of the offshore wind turbine components should be at least 1 year.

7.10.2 Atmosphere

(1) It shall be described what kind of atmosphere is required inside the offshore wind turbine (e.g. nacelle, hub and other rooms where components, which are needed for the operation of the offshore wind turbine, are located) and how these requirements are met. This shall be done according to IEC 60721-3-3.

(2) As the corrosion rate increases exponentially above 70% relative humidity the relative humidity inside the offshore wind turbine (acc. to Section 7.10.2 para 1) should be below 70%. This could be met when e.g. the inside temperature is 5K higher than the outside temperature.

(3) The internals of the rooms (acc. to Section 7.10.2 para 1) shall be protected against the outside air (offshore atmosphere). A verification (e.g. drawings, functional description, data sheets) of the used systems/designs (e.g. filter, heating or air dryer systems) shall be submitted. These systems/designs shall be monitored by the control system of the offshore wind turbine and considered at the maintenance (see also Section 9.4).

(4) The air-flow, cooling and heating concept of the offshore wind turbine (acc. to Section 7.10.2 para 1) and of its components shall be clarified by e.g. drawings, functional description, data sheets (see also Section 8.1.4).

(5) For all components which have an indirect contact by e.g. breather (for e.g. bearings or gear box) with the outside air a verification shall be submitted, where it is stated that these components and materials are adequate for the use at offshore atmosphere and that the function of the components will not be disturbed.

(6) For all operating materials (e.g. lubricants, oil) which are in contact – directly or indirectly – with the offshore atmosphere a verification shall be submitted, where it is stated that these materials are adequate for the use at offshore atmosphere and that the function of the component will not be disturbed.

7.10.3 Covering

(1) For all components which are not protected by a corrosion protection system or covered and which are in contact with the offshore atmosphere (e.g. sealings, elastomer components, hoses, components outside of the nacelle) a verification shall be submitted, where it is stated that these components and materials are adequate for the use at offshore atmosphere and that the function of the components will not be disturbed.

(2) If components are covered this design shall be explained by e.g. drawings, descriptions, data sheets.

7.10.4 Corrosion Protection

(1) In addition Section 3.5 has to be considered.

(2) For all metal parts an appropriate coating or metallic coating according to EN ISO 12944 or an equivalent standard is to be taken.

(3) Parts which are protected according to EN ISO 12944 shall fulfil the following corrosion classes:

– Outside components, fittings, sensors etc. shall be protected against corrosion according to class C5-M (EN ISO 12944).

– Inside surfaces, directly exposed to outside air, shall be protected against corrosion according to class C4 (EN ISO 12944).

– Inside surfaces, not directly exposed to outside air, shall be protected against corrosion according to class C3 (EN ISO 12944).

(4) The corrosion protection is to be described or named.

(5) The corrosion protection shall be considered at the maintenance (see also Section 9.4).

7.10.5 Miscellaneous

(1) Adequately trays in e.g. hub, nacelle, tower for the operating materials (e.g. lubricants, oil, cooling fluid) shall be provided to ensure that these operating materials do not pollute the environment.

(2) The fastening concept of components which are mounted by using a vibration absorber (e.g. elastomer bushings) shall be clarified. These are at least (if applicable):

- generator
- transformer
- cabinets
- fans
- hydraulic station

Rules and Guidelines

IV *Industrial Services*

2 Guideline for the Certification of Offshore Wind Turbines

8 Electrical Installations

Edition 2005

Germanischer Lloyd
WindEnergie

Table of Contents

8.1 Area of Application

8.1.1 Application

The provisions of this Chapter apply to installations for the generation, distribution and transmission of electrical power and to electrical and electronic control equipment in offshore wind turbines, insofar as they are located on the same foundation as the offshore wind turbine itself. Installations beyond the sub sea output transmission cable of the turbine (located on different foundations) belong to the area of application of Section 8.10.

8.1.2 Scope

This Chapter describes the requirements for

– rotating electrical machines

– static converters

– charging equipment and storage batteries

– switchgear and protection equipment

– cables and electrical installation equipment

– power transformers

– medium-voltage switchgear

– lightning protection

8.1.3 Standards

(1) All electrical equipment and individual components shall be designed in accordance with recognized standards, which shall be listed in the technical documentation.

(2) The relevant IEC publications or equivalent national codes shall be taken into account for electrical installations in offshore wind turbines.

(3) Special attention shall be paid to the protective measures, as listed in the IEC series 60364 “Electrical installations of buildings” or VDE 0100 “Erection of power installations with nominal voltages up to 1000 V”.

(4) In addition, IEC 60204-1 (2000-05) “Safety of machinery - Electrical equipment of machines - Part 1: General requirements” or DIN EN 60204-1 (VDE 0113 Part 1) 1998-11 “Sicherheit von Maschinen, Elektrische Ausrüstung von Maschinen, Allgemeine Anforderungen” shall also be applied.

(5) In each case, the latest version shall be used. The publication dates cited below reflect the situation applicable at time this Guideline was printed.

8.1.4 Operating and environmental conditions

8.1.4.1 General

(1) All electrical components shall be designed to comply with the operating and environmental conditions expected at the installation site.

(2) Ambient temperatures and other environmental conditions shall be taken from Section 4.2 “External conditions” if no site-specific data are available. It is pointed out that the corresponding basic specifications for the installed components may deviate in having restricted environmental conditions as a basis. This shall be observed in the design of the plant.

(3) As the minimum degree of protection against foreign matter and water (in accordance with IEC 60529 “Degrees of protection provided by enclosures (IP Code)”), the following shall be provided for equipment such as e.g. switchgear, motors, generators or controls:

– dry operation areas IP 21

– moist operation areas IP 43

– installation outside IP 55

(4) Generators shall generally comply with the degree of protection IP 54.

Note:

The degree of protection for the equipment shall be assured in the installed configuration, regardless of the operating state of the offshore wind turbine. Nacelle covers and other protective measures may be taken into account in evaluating the degree of protection.

(5) The air inside the hub, nacelle and tower shall be preferably not exchanged with outside air to reduce corrosive influence on electrical and other equipment. It is recommended to dehumidify the air, at least at the bottom of the offshore wind turbine.

8.1.4.2 Specification and testing of outside conditions

(1) For all electrical equipment installed outside, the environmental condition of the place of installation shall be specified according to IEC 60721-3-4:1995-01 (former IEC 721-3-4) “Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Section 4: Stationary use at non-weatherprotected locations”.

(2) It shall be proved, for all electrical equipment installed outside, being able to withstand such conditions as specified according to para 1. This shall be done in applying environmental testing procedures as given in IEC 60068 “Environmental testing”. The comprehensiveness of testing is defined in IEC/TR 60721-4-4:2003-08 “Classification of environmental conditions – Part 4: Guidance for the correlation and transformation of environmental condition classes of IEC 60721-3 to the environmental tests of IEC 60068 stationary use at non-weatherprotected locations”.

8.1.4.3 Specification and testing of inside equipment

(1) This Section shall apply only for electrical equipment installed inside and being part of the electrical power transmission (e.g. Generator, Transformer, Frequency Converter etc.).

(2) The environmental condition of the place of installation shall be specified according to IEC 60721-3-3:2002-10 “Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Section 3: Stationary use at weatherprotected locations”.

(3) It shall be proved, for electrical equipment named in para 1, that it is able to withstand conditions as specified according to para 2. This shall be done in applying environmental testing procedures as given in IEC 60068 “Environmental testing”. The comprehensiveness of testing is defined in IEC/TR 60721-4-3:2003 “Classification of environmental conditions – Part 4: Guidance for the correlation and transformation of environmental condition classes of IEC 60721-3 to the environmental tests of IEC 60068 stationary use at weatherprotected locations”.

8.1.5 Parallel operation with public power supply networks

(1) The connection of offshore wind farms will be done mainly to the Transmission System (Power supply networks with highest voltage levels). The relevant rules from the Transmission System Operators in charge have to be considered.

(2) The implementation of the rules mentioned in para 1 can lead to conditions having impact on the loads during the operation of the offshore wind turbine. If such conditions are not covered with the assumptions made in Section 4.3.3.5 para 9, additional assumptions shall be made. It shall be explained, how the condition is handled by the generator, converter and the control and safety system. This shall be considered especially for the following grid failure condition requirements:

– grid voltage drops
– grid frequency changes
– required minimum short circuit current delivered by the offshore wind turbine

(3) With regard to the grid quality expected for offshore wind turbines, reference is made to Section 4.2.4.8.

(4) Offshore wind turbines intended for parallel operation with public power supply networks require additional approval from the relevant grid operator. In general, the “Technische Anschlußbedingungen” (TAB) [Technical Connection Conditions] of the relevant grid operator shall be taken into account for this purpose. In particular for the connection of wind farms to certain voltage levels, special conditions may apply for the electrical behaviour.

(5) Power electronics shall be so designed that the harmonics generated do not affect the function of connected electrical equipment, the equipment does not suffer any damage and no impermissible perturbances occur during parallel operation with the grid.

(6) The admissible limiting values shall be agreed with the grid operator. As a guideline value, a permissible harmonic content of 10 % can be applied.

Note:

For plants in Germany, reference is made to the following publications:

– *“Grundsätze für die Beurteilung von Netzrückwirkungen” (VDEW Vereinigung Deutscher Elektrizitätswerke e.V.) – Fundamentals for the Assessment of Grid Perturbations (Association of German Electricity Utilities – VDEW)*
– *“Technische Richtlinien für Windenergieanlagen, Teil 3: Bestimmung der elektrischen Eigenschaften” (FGW) – Technical Guidelines for Wind Turbines, Part 3: Determination of the Electrical Characteristics (Federation of German Windpower)*
– *“Richtlinie für den Parallelbetrieb von Eigenerzeugungsanlagen mit dem Niederspannungsnetz des Energieversorgungsunternehmens (VDEW)” – Guidelines for Parallel Operation of In-House Generation Plants with the Low-Voltage Grid of the Power Utility (VDEW)*
– *“Richtlinie für den Parallelbetrieb von Eigenerzeugungsanlagen mit dem Mittelspannungsnetz des Energieversorgungsunternehmens (VDEW)” – Guidelines for Parallel Operation of In-House*

Generation Plants with the Medium-Voltage Grid of the Power Utility (VDEW)

- *“Technische Richtlinie Bau und Betrieb von Übergabestationen zur Versorgung von Kunden aus dem Mittelspannungsnetz (VDEW)” – Technical Guidelines for the Construction and Operation of Substations for Supplying Clients from the Medium-Voltage Grid (VDEW)*
- *“Ergänzungen zu den Netzanschlussregeln – Windenergieanlagen” – Supplements to the Grid Connection Rules – Wind Turbines (E.ON Netz GmbH)*

8.1.6 Stand-alone operation

(1) In the absence of specific data, the guideline values given in Table 8.1.1 shall be assumed for the operating conditions in stand-alone operation:

Table 8.1.1 Permissible voltage and frequency deviations in stand-alone operation

Parameter		Deviation	
		permanent	**short-term**
A	Frequency	± 5 %	± 10 % (5 s)
	Voltage	± 10 %	± 20 % (1.5 s)
B	Voltage	± 20 %	
A: General			
B: Storage batteries and static converters			

(2) A generator voltage deviation of ± 2.5 % between idling and full load at rated speed is permissible in stand-alone operation.

Note:

Deviations from this Guideline are permissible if the connected consumers are suitable for this. For DC charging generators, the voltage conditions for battery-charging operation apply.

8.1.7 Assessment documents

(1) The following documentation is required for the assessment of electrical components:

a general functional descriptions of and maintenance instructions for electrical appliances

b general circuit diagrams for the main circuits and the auxiliary circuits, with data on the short-circuit and overcurrent protection gear

c data and functional sequences of the control equipment

d determination of the categories to be applied for safety-related parts of the controls (see Section 8.7.10)

e summary and functional description of the monitoring devices and electrical measuring equipment

f parts lists with the design data and manufacturer’s information for all important electrical appliances, including the sensors and limit switches used

g cable and installation diagrams with data concerning cable and wiring cross-sections and stating the load currents, if these details are not contained in the general circuit diagram

h drawings of the lightning-protection and earthing plans, comprising:

- general arrangement drawing of the offshore wind turbine, including the separate buildings with the lightning protection zones entered therein
- general arrangement drawing of the offshore wind turbine with lightning rods and conductors, as well as arrangement of the earth electrodes and the voltage grading, the location of the bonding bars, and connections to the separate operation buildings
- general arrangement drawing (single-line representation) showing the location of lightning current conductors and surge arresters
- design details of how the lightning current is conducted away from the rotor blades, verification of the lightning-current-carrying capacity of the gearbox and yaw bearing conductors

i drawings of and information about any emergency power systems, fire alarm systems and other electrical equipment, such as drawings of the slip rings

j for generators with a power output exceeding 50 kW: drawings, records of routine tests as per IEC 60034-1 (1999-08) “Rotating electrical machines – Part 1: Rating and performance” with data on the heat run, as well as maintenance instructions

k description of the air flow concept inside the hub, nacelle and tower regarding the protection of electrical equipment against salty humid air from outside; see also Section 7.10

l If a backup power supply is chosen in the concept according to Section 2.1.1 para 1 m, a power consumption schedule is to be submitted, as well as dimensioning calculations according to Section 8.8.3.

m determination of the environmental classes used for specification of electrical equipment according to Section 8.1.4.2 and 8.1.4.3 where applicable

n test certificates according to Section 8.1.4.2 para 2 and 8.1.4.3 para 3

o a sub sea cable list where applicable. The list shall contain all cable details according to Section 8.10.5.

p if applicable a description of the sub sea cable laying procedure taking into account the issues described in Section 8.10.5 and containing the cable tray nautical charts

(2) If power transformers and/or medium-voltage installations are integrated into the offshore wind turbine, the following documents are necessary in addition:

a type test records of the transformer as per IEC 60076-1 (2000-04) “Power transformers – Part 1: General”

b type test records of the medium-voltage installation as per IEC 60298 (1990-12) “A.C. metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV”, with consideration of Appendix AA6

c verification of the erection of the medium-voltage installation in connection with the results of the internal arc test and the effects of the pressure surge

d description of the electrical insulation system of the transformer according to Section 8.3.1 para 4 where applicable

8.2 Electrical Machines

8.2.1 General

Electrical machines in offshore wind turbines (generator, auxiliary electrical drives) shall on principle comply with IEC 60034 (1999-08) “Rotating electrical machines”.

8.2.2 Materials

(1) The materials for the construction of electrical machines shall be suitable for the expected environmental conditions; particular attention shall be paid to the corrosive effect of a marine atmosphere. Materials unsuitable for a marine atmosphere may be used if protected by adequate coating or cladding.

(2) If plastics are used for casings, terminal boxes and fan wheels, materials suited for low temperature shall be used.

(3) If there is a risk that shaft voltages can occur owing to the configuration of the overall plant, the bearings and coupling shall be of an insulated type.

8.2.3 Ventilation and cooling

(1) Electrical machines for offshore wind turbines shall preferably be designed in fully enclosed form with surface cooling. Machines with a power output exceeding 50 kW shall be provided with drain holes to prevent the accumulation of condensed water.

(2) Draught-ventilated machines may be used if the incoming air is free from moisture, oil vapour and dust.

(3) The cooling circuit of liquid-cooled machines shall be monitored in a suitable manner.

8.2.4 Windings

(1) In conjunction with the protective devices provided, electrical machines shall be able to withstand the thermal and dynamic stresses to be anticipated in the event of a short circuit.

(2) Electrical machines shall be so designed and constructed that the permissible over-temperatures for the class of insulation are not exceeded, irrespective of the operating time. The values listed in IEC 60034 Part 1 “Rotating electrical machines” may be used as guideline values.

(3) If the machines are operated at static converters, the increased warming caused by the additional harmonics shall be taken into account. When carrying out the heat run of the machine, the static converters shall be operated at the same time and according to the rated operating conditions. If a heat run is not possible for technical reasons, calculations are permissible as an alternative.

8.2.5 Bearings

The verification of the bearings shall take place in accordance with Section 7.3.

8.2.6 Duty cycles of electrical machines

(1) Generators for offshore wind turbines shall be designed for continuous operation (duty type S1 as per IEC 60034-1).

(2) If the winding temperature is monitored with regard to its limiting values, thermistors or equivalent sensors should be used. Thermal overcurrent relays with bimetallic elements are not suitable.

(3) Motors for auxiliary drives shall be designed according to the operating times to be expected. Reference is made to the duty cycles specified in IEC 60034 Part 1 “Rotating electrical machines” or to equivalent codes.

8.2.7 Earthing

If generators are used having rated voltages above 1 kV, ground bolts shall be installed, to being able to correctly earth during maintenance or repair.

8.2.8 Carbon brushes

(1) The length of the slip ring carbon brushes of the generator shall be monitored continuously.

Note:

This can be achieved e.g. by a limit switch.

(2) The brushes have to be exchanged before total wear.

8.3 Transformers

8.3.1 General

(1) To an increasing extent, the power transformers are being integrated into the offshore wind turbine itself. If this is the case and if transformers are installed within the tower or the nacelle of an offshore wind turbine, they fall within the scope of the assessment and shall meet the requirements set out below. Transformers do not fall within the extent of the assessment if they are set up outside the nacelle and tower and do not form part of the overall system "generator / converter" (i.e. are part of the outside substation).

(2) Transformers shall comply with the international standard IEC 60076-1 (2000-04) "Power transformers – Part 1: General". This shall be verified through type test records of the manufacturer.

(3) In addition, the special standards for dry-type transformers, IEC 60726 (1982-01) "Dry-type power transformers", and for converter transformers, IEC 61378-1 (1997-09) "Convertor transformers - Part 1: Transformers for industrial applications") shall apply.

(4) The Transformer shall be able to withstand the conditions in the offshore wind turbine without accelerated ageing or weakening of the electrical insulation system (EIS) including the insulation of all transformer terminals, to prevent fire caused by the transformer. Such conditions are:

– salty (and / or wet) air from outside which might come in contact with the EIS
– pollution on the EIS from moisture, coal powder and brake lining in the concentration as they occur inside the transformer enclosure
– vibrations
– The environmental condition specification and the testing according Section 8.1.8.1 shall help in achieving the results described here. Nevertheless further measures can be necessary.

Note:

This can be achieved best by using a protection degree of IP 55 for transformer including all transformer terminals and cable. Transformer cooling has to be implemented accordingly, taking into account possible condensation (see Section 2.3.2.16).

(5) The transformer shall be self extinguishing. Fire class shall be F1 according to the harmonized standards SN HD 538.1 S1:1995, SN HD 538.3 S1:1997 and SN HD 538.2 S1:1995 where applicable.

(6) If the transformer is not designed with a protection degree of IP 55 or higher, one of the following issues have to be fulfilled:

– The enclosure of the Transformer, including, if existing, an internal cooling system, has to be designed with protection degree IP 55 or higher.
– regularly cleaning (from salt and dirt) of the EIS surfaces in such a way and such a frequency to achieve sufficient surface resistance on the EIS to maintain the electrical integrity
– increased surface insulation level of the EIS to withstand permanent earthed insulation surface with a permanent very low surface resistance

Note:

The test E2 and C2 according to HD 464 is not a sufficient test when the electrical surface resistance is permanently reduced by pollution and / or condensation on the EIS.

8.3.2 Installation

Transformers shall be installed in separate rooms which can be locked. The installation locations for transformers shall be well ventilated. The access to the transformer room should only be possible with the transformer switched off. Access to unauthorized persons shall be prevented.

Note:

When erecting offshore wind turbines with transformers contained inside the tower or nacelle, the relevant national regulations shall be taken into account.

8.3.3 Dry-type transformers

Dry-type transformers shall be used by preference. Depending on the site, this may even be compulsory according to governmental regulations.

8.3.4 Liquid-cooled transformers

(1) Liquid-cooled transformers shall be provided with a collecting arrangement which permits the proper disposal of the liquid.

(2) Liquid-cooled transformers should be fitted with protection against the outgassing of the liquid.

(3) The liquid temperature shall be monitored. An alarm shall be actuated before the maximum permissible temperature is attained. When the temperature limit is reached, the transformer shall be disconnected.

(4) The liquid filling level should be monitored.

8.3.5 Converter transformers

If the operational concept of the offshore wind turbine involves the use of static semiconductor converters in the transformation of the wind energy into electrical energy (e.g. synchronous generator with full converter, double-fed asynchronous generator), it shall be verified that the transformer is suited to the requirements.

8.3.6 Protection

(1) Transformers shall be protected against short-circuit and overload.

(2) It shall be possible to switch off transformers on either side.

(3) Transformers shall be fitted with temperature monitoring.

8.4 Static Converters

8.4.1 General

(1) Power electronics shall be designed so that the harmonics generated do not affect the function of connected electrical equipment and the equipment does not suffer any damage. Reference is made to the GL guideline on electromagnetic compatibility (EMC).

(2) Power electronics should comply with EN 50178 (VDE 0160) "Electronic equipment for use in power installations".

(3) Furthermore, reference is made to IEC 61800-1 (1997-12) "Adjustable speed electrical power drive systems – Part 1: General requirements – Rating specifications for low voltage adjustable speed d.c. power drive systems" and IEC 61800-2 (1998-03) "Adjustable speed electrical power drive systems – Part 2: General requirements – Rating specifications for low voltage adjustable frequency a.c. power drive systems".

8.4.2 Installation of static converters

(1) Power electronics should be accommodated in separate cabinets.

(2) The units should be easily accessible for measurement and repair. Simulation circuits, test sockets, control lamps etc. are recommended for checking the operation and for fault-finding. For repair purposes, it shall be possible to isolate all components from other live parts. The signal and control electronics shall be electrically isolated from the power circuits.

(3) Naturally ventilated static converters should preferably be used; the use of fans is recommended. Furthermore, the function of forced cooling shall be monitored and its failure shall be annunciated to avoid overheating. If adequate reliability can be demonstrated, liquid cooling may be utilized.

8.4.3 Protection equipment

(1) All power electronics shall be protected against overload and grid short circuit. It shall not be possible for a semiconductor element to be destroyed in the event of a malfunction. Protection of the installation may be effected by fuses, circuit breakers or the intervention of the control system.

(2) The protection equipment shall ensure that in the event of a disconnection the energy stored in the components and the load circuit cannot have a damaging effect, that in the event of a failure of essential components the offshore wind turbine is brought to a standstill in a controlled manner, and that damaged subsystems are switched off as selectively as possible.

(3) Self-test facilities are recommended for overvoltage and overcurrent protection equipment to safeguard the function of the protection equipment.

(4) In accordance with IEC 60364-4-46 "Electrical installations of buildings; Part 4: Protection for safety; Chapter 46: Isolation and switching", semiconductor devices shall not be used for isolating purposes.

8.5 Medium Voltage

8.5.1 General

(1) To an increasing extent, the medium-voltage installations are being integrated into the offshore wind turbine itself. If this is the case and if medium-voltage installations are installed within the tower or the nacelle of an offshore wind turbine, they fall within the scope of the assessment and shall meet the requirements set out below. Medium-voltage installations do not fall within the extent of assessment if they are set up outside the nacelle and tower (i.e. are located in a transformer substation).

(2) Medium-voltage installations shall comply with IEC 60298 (1990-12) "A.C. metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV".

8.5.2 Protective measures

(1) A risk of personal injury through electrical shock and internal arcs shall be excluded independently of the necessary protection against foreign matter and water.

(2) Medium-voltage switchgear shall be subjected to an internal arc test as per IEC 60298 Appendix AA6. Here criteria 1 to 6 shall be met. This test may be dispensed with if the installation has to be isolated before access is given to the place of installation.

(3) Verification of this shall be provided by the corresponding documents of the manufacturer of the medium-voltage installation.

8.5.3 Pressure relief

(1) If the gas pressure resulting from internal arcs within the switchboard is to be vented via pressure-release flaps, the installation space shall be as specified by the switchgear manufacturer and shall have an adequate volume. Suitable measures shall be taken to ensure that the overpressure occurring within the space is limited to physiologically acceptable limits. This overpressure shall be taken into account for the structural design of the installation space.

(2) If the switchboard is designed so that the gas pressure caused by internal arcs is also, or only, released downwards, the floor shall be constructed so that it can withstand this pressure. Care shall be taken to ensure that sufficient volumes of space are available below the floor for the expansion of the internal-arc gases.

(3) Combustible materials and low-voltage cables are not admissible in the endangered area.

(4) Verification of the installation shall be provided by suitable documents.

8.5.4 SF6 switchgear

SF6 switchgear shall only be installed in spaces which are adequately ventilated.

Note:

It shall be taken into account that SF6 is heavier than air and the gases escaping in the event of internal arcing have toxic and corrosive effects.

Reference is made to the instruction sheets of the employer's liability insurance associations on SF6 switchgear.

8.5.5 Medium voltage cables

(1) IEC 60183:1984 "Guide to the selection of high-voltage cables" has to be taken into account.

(2) As far as applicable, the Section 8.8 shall be observed for medium voltage cables as well.

(3) Medium voltage cable run (sleeves, grommets) through the tower shall be made in a way, that no damage can occur to the cable by means of:

– rubbing between cable and the vibrating tower or foundation
– too small bending radius
– pulling forces
– squeezing
– sea water
– animals or animal excrement above or under the water surface
– heat by too small tubes or because of underwater cables going through air above sea level

8.6 Charging Equipment and Storage Batteries

8.6.1 General

Charging equipment and storage batteries are used for the storage of energy in small offshore wind turbines or for the emergency supply of safety systems.

8.6.2 Charging equipment

(1) Battery charging equipment shall be able to accept the irregular energy supply from offshore wind turbines and the possible deviations of voltage and frequency.

(2) Overcharging of the batteries shall be prevented by regulation or, if necessary, by dump loads which can be switched on.

(3) If consumers are supplied while charging is in progress, the maximum charging voltage shall not exceed 20 % of the rated voltage of the battery.

(4) Battery charging equipment shall be designed and adjusted so that even during boost charging the permissible voltage per cell is not exceeded.

(5) Charging equipment shall have its own short-circuit and overcurrent protection equipment on both the input and the output side and should have a system for monitoring its operation.

8.6.3 Storage batteries

(1) Batteries fitted to offshore wind turbines should permit an adequate number of charge/discharge cycles.

(2) Battery casings shall be resistant to electrolytes, mineral oils and cleaning agents, and to corrosion by a marine atmosphere.

(3) Reference is made to the VDE series 0510 and its international equivalents.

8.6.4 Installation and operation of batteries

(1) Batteries shall be installed in well-ventilated rooms, cabinets or boxes.

(2) The VDE regulations for batteries contained in DIN VDE 0510 “VDE specification for electric storage batteries and battery plants” or equivalent regulations shall be observed.

(3) Batteries shall be so installed that they are accessible for the replacement of cells, inspection, topping-up and cleaning.

(4) Lead-acid batteries and alkaline batteries shall not be installed in the same room; furthermore, separate ventilation systems shall be provided.

(5) Batteries shall be so installed or covered that they are effectively shielded against dripping water, fouling and falling parts.

(6) Warning signs indicating the risk of explosion shall be provided at the entrance of battery rooms and on battery boxes. Attention shall be drawn to the fact that there is a risk of explosion within a radius of 0.5 m around the ventilation inlets and outlets of these rooms and boxes.

(7) To avoid sparking, circuits shall be switched off before batteries are connected or disconnected.

(8) Batteries mounted in the hub shall be suitable for the special requirements resulting from the rotating movements.

8.7 Switchgear and Protection Equipment

8.7.1 General

(1) All components of the electrical installation shall be protected against overload and short circuit. If overcurrent or a short circuit occurs, the protection equipment shall be triggered reliably and shall prevent any thermal or electrodynamic overloading of individual components of the offshore wind turbine. The devices used shall comply with the standard IEC 60947 (2001-12) “Voltage switchgear and controlgear”.

(2) The protection equipment and switchgear should be selected so that, after a trip, reconnection is possible immediately by a circuit breaker or after replacement of fuses.

(3) The on/off position of switches shall be recognizable. In the case of pushbuttons, indicator lamps or equivalent displays shall be provided to show that the circuits have been made.

8.7.2 Short-circuit and overload protection devices

(1) The rated breaking capacity of each circuit breaker used for short-circuit protection shall not be less than the maximum possible short-circuit current at the point of installation.

(2) The rated making capacity of a circuit breaker shall not be less than the maximum asymmetric short-circuit current which may occur at the point of installation.

(3) The making and breaking capacity of switchgear shall be stated by the manufacturer and entered in the assessment documentation.

Note:

Reference is made to the GL “List of Type Tested Products and of Approved Products, Procedures and Manufacturers”, which is available on request and contains a large number of type tested appliances.

(4) Switchgear with insufficient making and breaking capacity for the expected maximum short-circuit current may be used in conjunction with suitably rated back-up fuses.

(5) In non-earthed two-phase DC and AC circuits, overload protection shall be provided for at least one conductor.

(6) In non-earthed three-phase systems with a balanced load, overload protection shall be provided in at least two conductors.

(7) Battery systems shall be equipped with short-circuit and overload protection in each non-earthed conductor. The short-circuit protection shall be located close to the battery.

(8) The selection of overload and short-circuit protection devices shall be based on the rated currents in the cable or circuit and on the possible short-circuit current at the relevant points of installation.

Note:

In the case of installations intended for parallel operation with public power supply networks, the short-circuit conditions shall be analysed in consultation with the relevant grid operator.

(9) Suitable overcurrent protection devices are recommended for motors of auxiliary drives with rated outputs greater than 1 kW. Depending on the duty of the motor to be protected, bimetallic relays, thermistors or other temperature sensors with tripping devices may be provided for this purpose.

(10) Regardless of its rating, every motor shall be protected by a suitable short-circuit protection device.

Note:

For the operation and protection of electrical equipment, the following configurations may be provided for the power circuits:

– *circuit breaker or motor protection switch with integrated short-circuit and overload protection*
– *fuses in conjunction with load switches*
– *fuse switch-disconnectors*
– *fuses in conjunction with contactors*
– *circuit breaker and/or motor protection switch in conjunction with contactors*
– *circuit breaker / contactor combination*

8.7.3 Control circuits

(1) Control circuits shall generally be equipped with separate short-circuit protection up to a maximum of 10 A. Joint fuse protection of control and load circuits is permissible if the joint back-up fuse has a maximum rating of 10 A.

(2) If the contacts in control circuits are designed for smaller currents, the back-up fuses shall correspond to the permissible current values.

8.7.4 Measuring and indicating circuits

(1) Measuring and indicating devices shall generally be provided with their own circuits, to be protected by separate fuses against short circuits.

(2) Separate fuses in series are recommended for indicating and control lamps, so that a short circuit in one indicating lamp does not affect the entire system. Deviations from this are permitted if indicating lamps with short-circuit-proof transformers are used or if the operating voltage is less than 30 V.

8.7.5 Earth fault detection and monitoring

For unearthed systems independent of the public power supply network, an earth fault detector or monitor is recommended which indicates the insulation value of the system or permits a check of the values.

8.7.6 Design and rating of the switchgear

(1) Switchgear shall comply with IEC 60947 (2001-12) “Voltage switchgear and controlgear”. Sufficient breaking capacity shall be provided.

(2) Load switches shall be rated at least for the rated current of the back-up fuse.

(3) For the selection of busbars and the design of clearances and creepage distances, reference is made to IEC standards 60439 (1999-09) “Low-voltage switchgear and controlgear assemblies” and IEC 60664 (2002-06) “Insulation coordination within low-voltage systems including clearances and creepage distances for equipment”.

8.7.7 Switchboards and cabinets for low voltage

(1) All units installed in switchboards and cabinets shall be easily accessible for maintenance, repair or replacement.

(2) Terminals and terminal spaces shall be adequately dimensioned. Terminals shall have an adequate clearance from live parts, so as to guarantee safe working conditions.

(3) Live units with voltages above 50 V in the doors of switchboards or cabinets shall be protected against accidental contact.

(4) All lines and connections shall be safeguarded against vibratory stressing. Small screws up to M4 may be locked using varnish.

(5) All lines and insulated live components shall be protected against chafing or cutting through the insulation. This applies particularly to sharp-edged ducting and corners.

(6) Protective earthing shall be provided by means of earth terminals or earth bars. Earth terminals shall be clearly marked as such.

(7) To prevent conductors being squeezed off, terminals shall have backing plates, or the conductors shall be fitted with protective sleeves or equivalent protection for the wires.

(8) It is recommended that all incoming and outgoing cables and lines be permanently labelled at the terminals.

(9) All appliances, instruments and operating elements shall be permanently labelled in accordance with the corresponding circuit diagrams.

(10) The rated current values of fuses shall be stated. The set values of the adjustable protection equipment shall be stated on the circuit diagrams and permanently marked on the device.

(11) Indicator lamps, measuring instruments or equivalent displays shall be used to show whether a system is live. The number of displays required depends on the type of system.

8.7.8 Synchronizing gear and equipment for smooth connection

Offshore wind turbines for parallel operation with the public power supply network shall be fitted with synchronizing or smooth-connection equipment to permit a smooth connection to the network. Special requirements imposed by the relevant grid operator shall be observed.

8.7.9 Electrical / electronic components in the safety system

The selection and application of electrical and electronic components in the safety system as per Section 2.2.2.2 shall comply with the results of the fault consideration in Section 2.1.2. As far as possible, a clear structure of the safety system without the inclusion of several different voltage or control levels shall be obtained. Only fail-safe components shall be considered for use in the safety system.

8.7.10 Circuits for safety-related parts of the controls

The circuits for safety-related parts of the controls shall be executed in accordance with the categories set out in EN 954-1. The analysis used for determining the category in each case shall be submitted for a plausibility check.

8.8 Cables and Electrical Installation Equipment

8.8.1 Selection of cables and lines

(1) Cables and lines shall comply with the IEC publications listed below or with equivalent standards:

– IEC 60227 (1998-03) "Polyvinyl chloride insulated cables of rated voltages up to and including 450 / 750 V"

– IEC 60502 (1998-11) "Extruded solid dielectric insulated power cables for rated voltages from 1 kV up to 30 kV"

– IEC 60228 (1993-01) "Conductors of insulated cables"

(2) Other cables or lines may be approved if their material and construction complies with equivalent standards and verification of their suitability for the application is provided.

(3) Cables and lines shall be selected in accordance with the environmental conditions at the installation site.

Note:

In the case of cables and lines laid in the open, UV resistance shall be assured. Extraordinary mechanical demands, such as increased tensile stress, operationally required mobility and increased risk of mechanical damage, shall be taken into account.

(4) The rated voltage of cables and lines may not be less than the rated operating voltage of the circuit involved. For circuits with variable voltage, the maximum voltage occurring during operation is decisive.

(5) Irrespective of requirements for increased mobility, cables and lines with several or multiple conductors are generally recommended.

(6) The technical documentation shall state the cables and/or lines used, together with their standard designation. Furthermore, the conductor cross-sections and the rated currents shall be entered.

(7) For medium voltage cables see also Section 8.5.5.

8.8.2 Loading, protection and laying of cables and lines

(1) Cables and lines shall be protected against short circuits and overcurrent. If overcurrent protection is already provided in the circuit for the equipment, short-circuit protection shall be added. This shall be designed in accordance with the short-circuit loads at the point of installation.

(2) For the design of lines, IEC 60287(2001-11) "Calculation of the continuous current rating of cables" shall be used.

Note:

See also Beiblatt 5 to VDE 0100 "Errichten von Starkstromanlagen mit Nennspannungen bis 1000 V; Maximal zulässige Längen von Kabeln und Leitungen unter Berücksichtigung des Schutzes bei indirektem Berühren, des Schutzes bei Kurzschluß und des Spannungsabfalls" [Supplement to VDE 0100 "Erection of power installations with nominal voltages up to 1000 V; Permissible lengths of cables and lines, taking into consideration protection against electric shock in case of fault, short circuit or voltage drop"].

(3) For the rating of cables and lines, consideration shall be given to the loads expected during operation corresponding to the consumer demand, taking into account the duty of the electrical units connected. Values on the rating plates of generators and consumers shall be considered as a basis.

(4) Each circuit with its own overcurrent and short-circuit protection shall generally have its own cable. Concentration of circuits into a common cable or line system may take place in accordance with IEC 60364-5-52 (2001-8), "Electrical installations of buildings; Part 5: Selection and erection of electrical equipment; Chapter 52: Wiring systems" or an equivalent standard.

(5) For circuits with protective low voltage, IEC 60364-4-41(2001-08), "Electrical installations of buildings, Part 4: Protection for safety, Chapter 41: Protection against electric shock" or equivalent standards shall be observed.

(6) Multi-core cables or lines shall preferably be used for AC and three-phase systems. If single-core cabling is provided instead, the following points shall be observed:

– The cables shall not be armoured with or sheathed in magnetic material.

– Non-magnetic clamps shall be provided.

– The cables of a given circuit shall be laid contiguously and shall be arranged in the same tube or cable duct.

– Single-core parallel cables shall be of the same type, length and cross-section.

(7) For cables and lines subject to twisting in operation, a control device shall be provided which protects against exceeding permissible limits. In terms of its operation, the installation shall be so designed that resetting to the neutral position is possible (see Section 2.3.2.11).

(8) Cables and lines shall be so secured that no unacceptable tensile, flexural, compressive or crushing stresses arise. Corrosion-proof or permanently corrosion-protected clips or mounts shall be used for outdoor installations.

(9) If cables or lines are laid in metal tubes or ducts, these shall be earthed effectively.

(10) The tubes shall be smooth on the inside and so protected at the ends that there is no damage to the cable sheathing.

(11) As a rule, tubes shall not be filled with cables to more than 40 % of their cross-section. Deviations are permissible if the cable can be pulled through without difficulty and there is no unacceptable mutual heating of the cables. The filling factor should never exceed 60 %.

(12) Where there is a risk of mechanical damage, cables and lines shall be effectively protected by coverings.

(13) Strain relief devices of exposed cables shall be permanently protected against corrosion.

(14) Suspended cables shall be properly protected against damage and unacceptable constriction of the cable sheath.

(15) For cables suspended freely without additional strain relief, the suitability of the type of cable used shall be verified. The possibility of ice loading shall be taken into account in this context.

(16) Metal cable sheaths, armour and screening shall generally be earthed at each end to the metal structure of the offshore wind turbine. In the case of cables and lines for electronic systems, single-sided earthing is acceptable. The continuous connection of the metal cable sheaths shall be ensured in each junction box and distribution box.

8.8.3 Backup power supply

(1) If a backup power supply is chosen according to Section 2.1.1 para 1 m, requirements as given in para 2 to 7 need to be considered.

(2) The power supply shall be dimensioned in such a way, that it will be able supplying the necessary starting or inrush currents and the energy consumption needed. This shall be documented in a power consumption schedule (see Section 8.1.7).

(3) Power consumption management shall be made where necessary to achieve the requirements made in para 2. The simultaneous power consumption according to this management shall be stated in the power consumption schedule.

(4) The fuel storage of the backup power supply has to fit properly on site.

(5) The size of the fuel storage shall be dimensioned in order to achieve the requirements as given in para 2 to para 4 in conjunction with the concept chosen in Section 2.1.1 para 1 m.

(6) The assessment documents shall contain the size of the tank and the fuel consumption calculations of the chosen backup power supply.

(7) The fuel level has to be monitored and alarm levels have to be defined.

Note:

To prevent damages in the gear during grid unavailability and no remote operated rotor lock, energy for fast shaft brake operation and control shall be taken into account.

8.9 Lightning Protection

8.9.1 General

(1) Lightning protection measures shall be provided according to this Guideline; moreover, national requirements in excess thereof shall also be observed. The following standards, technical specifications (TS) and technical reports (TR) in their most recent issue shall be taken into account:

– IEC 61024-1 (1990-04) "Protection of structures against lightning – Part 1: General principles"
– IEC 61024-1-1 (1993-09) "Protection of structures against lightning – Part 1: General principles – Section 1: Guide A: Selection of protection levels for lightning protection systems"
– IEC 61312-1 (1995-03) "Protection against lightning electromagnetic impulse (LEMP) – Part 1: General principles"
– IEC TS 61312-2 (1999-08) "Protection against lightning electromagnetic impulse (LEMP) – Part 2: Shielding of structures, bonding inside structures and earthing"
– IEC TS 61312-3 (2000-07) "Protection against lightning electromagnetic impulse (LEMP) – Part 3: Requirements of surge protective devices (SPDs)"
– IEC TS 61312-4 (1998-09) "Protection against lightning electromagnetic impulse (LEMP) – Part 4: Protection of equipment in existing structures"
– IEC TR 61400-24 (2002-07) "Wind turbine generator systems – Part 24: Lightning protection"

(2) Any additional requirements of the grid operators shall be observed.

8.9.2 Protection concept

8.9.2.1 Requirements

Since the problems encountered with offshore wind turbines are not specially mentioned in the standards as yet, they shall be applied with the necessary changes. Lightning protection measures shall be executed according to the EMC / lightning protection zone concept. This means that, after determination of the protection level, the entire offshore wind turbine has to be subdivided into protection zones, which then results in the corresponding requirements.

8.9.2.2 Definition of protection levels

By applying the standards, protection levels can be determined to derive the protection equipment required for the structure. The required protection level for offshore is:

– protection level I

8.9.2.3 Definition of protection zones

(1) The definitions of the zones are given in the standards. A protection zone has the task of reducing the electromagnetic field and the conducted emission disturbances to the stipulated values. The requirements for the transition to a protection zone depend on the noise immunity of the equipment installed in the higher protection zone. The transition to the equipment to be protected can be implemented by a single zone junction or alternatively also by two junctions.

(2) The lightning protection zones LPZ 0A and LPZ 0B include (see Fig. 8.9.1):

– rotor blades including the rotor hub and the internals (sensors, actuators etc.)
– the outer part of the nacelle cover
– if there is no metallic housing, then all facilities in the nacelle (generator, auxiliary drives, cables, sensors and actuators), the outer parts of metallic switch cabinets, and the inner parts of non-metallic switch cabinets
– sensors of the wind measurement equipment
– non-metallic towers or concrete towers that are not equipped with reinforcement connectors according to the standard
– the interiors of operation buildings and transformer substations, if no shielding measures are provided
– cable connections in the soil or overhead lines between the offshore wind turbine and the operation buildings or transformer substations, if no shielding measures are provided

(3) Lightning protection zone LPZ 1 includes (see Fig. 8.9.1):

– internals of the rotor blades, including the rotor hub (sensors, actuators etc.), provided that effective lightning-conducting and shielding measures are taken

– the interiors of completely metal-clad nacelle housings with the corresponding lightning-conducting measures

– the interior of all metal-clad equipment, insofar as they are connected in a suitable manner to an equipotential bonding system (e.g. the machine foundation as the bonding level)

– shielded cables, or cables which are laid in metallic pipes, whereby mesh shields or metallic pipes shall be connected to the equipotential bonding on both sides

– the sensors of wind measurement facilities, insofar as these are fitted with lightning rods and appropriate conductors

– the interior of metallic towers or concrete towers, the reinforcement of which is designed according to applicable standards and connected to the foundation earth electrode

– the interiors of operation buildings and transformer substations that are either clad with steel sheeting or provided with shielding measures (reinforcement on all sides with foundation or ring earth electrode, metallic doors and windows with wire meshes)

(4) Lightning protection zone LPZ 2 includes facilities within lightning protection zone LPZ 1, if additional shielding measures have to be taken for a further reduction in the effects of interference.

8.9.3 Execution of measures

8.9.3.1 Foundation earth electrode for the tower

(1) The design of the foundation earth electrode (see Fig. 8.9.2) shall comply with IEC 61024-1. The reinforcement and existing piles of the foundation shall be routed twofold to the bonding bar; however, it shall be noted in particular that, in the case of a tower mounting using concrete-encased prestressed anchor bolts, these elements shall not be used for earthing purposes.

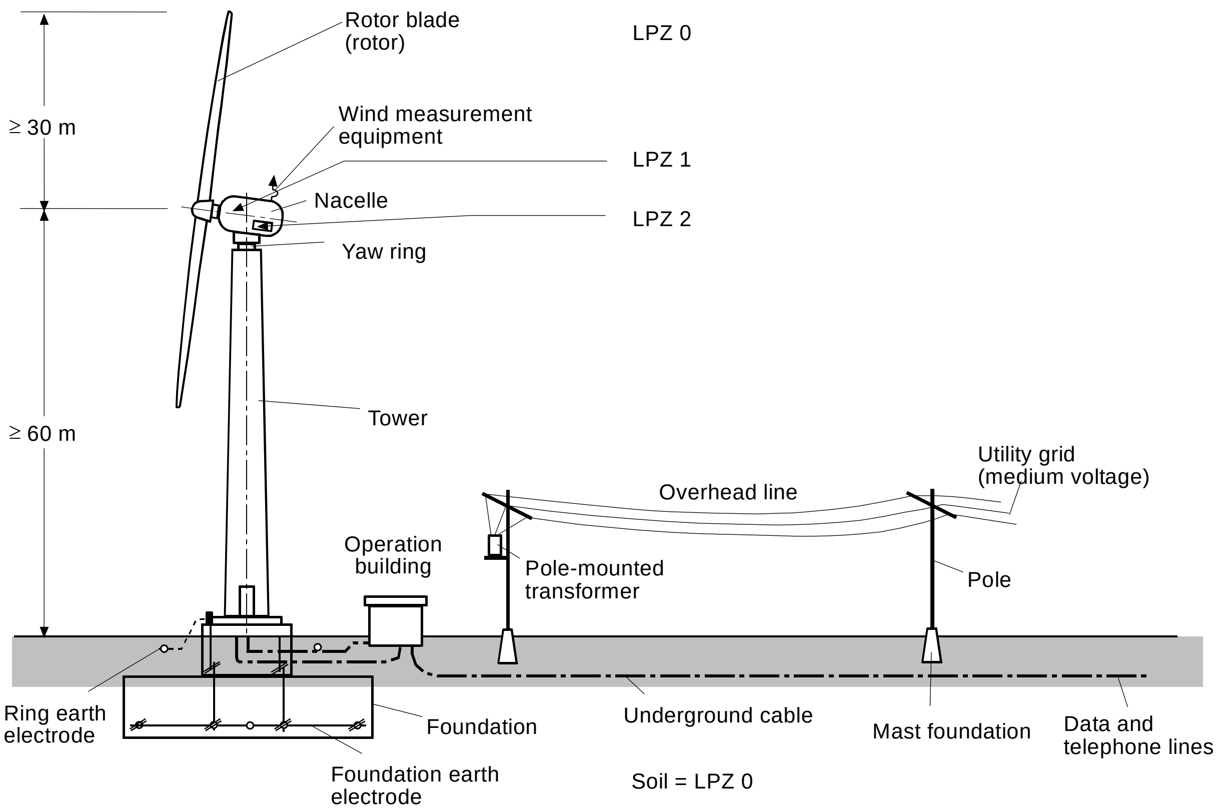


Fig. 8.9.1 Schematic diagram of an offshore wind turbine with lightning protection zones (LPZ)

(2) From the foundation earth electrode to the steel structure of the tower up to a base diameter of three metres, connections shall be made at two points at least, and for larger diameters at three points at least.

(3) Depending on the location and soil characteristics, the foundation earth electrode shall be extendible, in order to connect a ring earth electrode if necessary, or to make connections to existing earthing facilities (wind farms, power distribution systems); see Fig. 8.9.3. In Germany, the earth electrodes shall comply with the national standards DIN VDE 0100 and DIN VDE 0141, since the 50 Hz earth-fault current may have to be considered.

(4) The earth termination shall have a resistance $\leq 10\ \Omega$.

(5) From the foundation (reinforcement) and/or ring earth electrode, a terminal lug shall be routed into the inside of the tower and connected to an appropriately marked bonding bar (see Fig. 8.9.2).

(6) All transitions from the foundation earth electrode or the reinforcement out of the concrete into the air shall be executed with an insulated cable.

(7) If the reinforcement has a highly conductive interconnection and is connected at two points to the bonding bar, it is permissible to dispense with an additional foundation earth electrode.

8.9.3.2 Design of the tower

(1) Steel towers, lattice masts and reinforced concrete towers are especially well suited for lightning protection measures. This type of tower is mounted on the prepared foundation (as described in Section 8.9.3.1). In this way, a continuous earthing and protection of the tower is provided up to the height of the yaw ring. However, protection zone LPZ 1 is only attained by closed steel towers and reinforced concrete towers. Lattice masts satisfy protection zone LPZ 0B only in the interior of the structure.

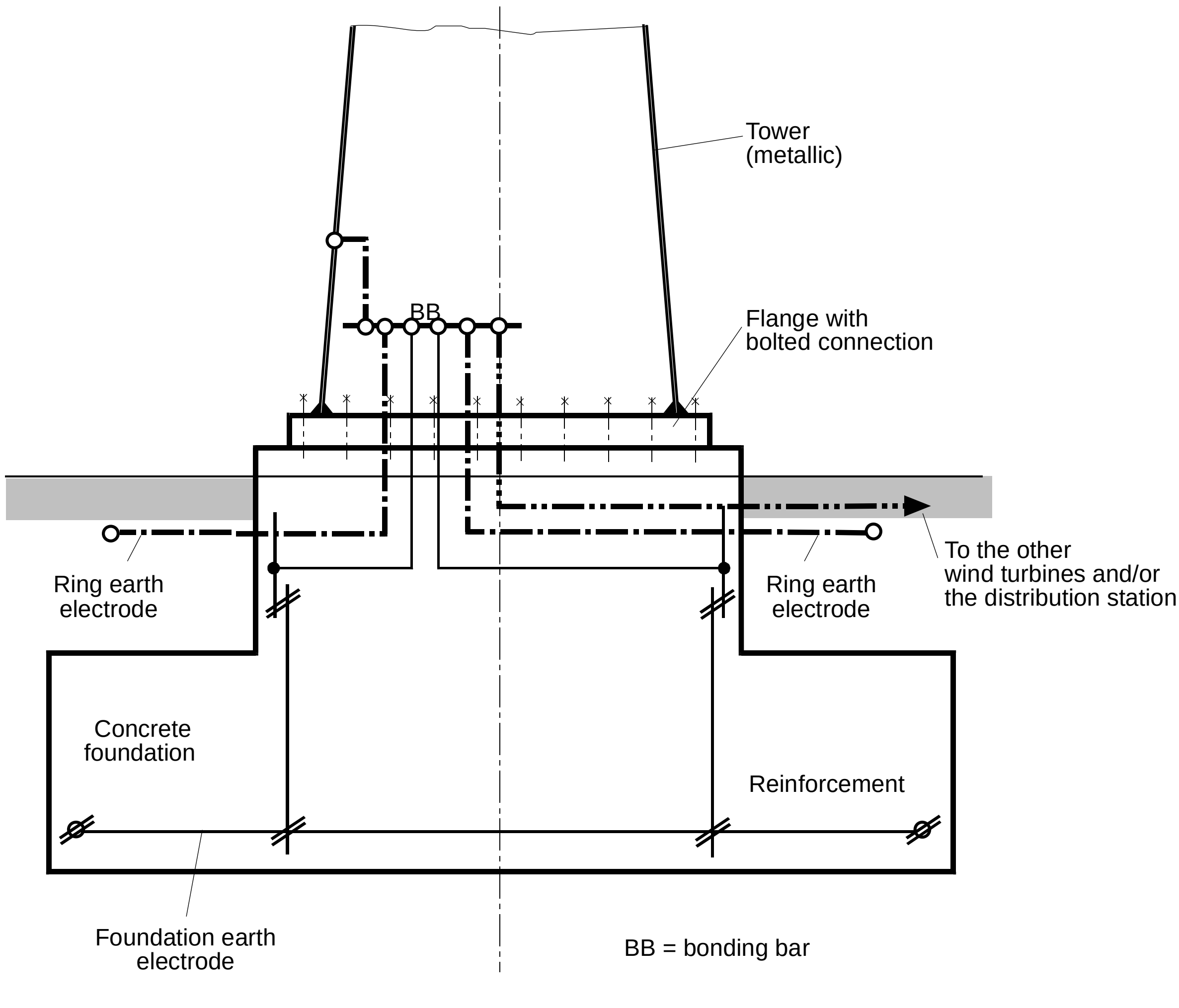


Fig. 8.9.2 Connection of the equipotential bonding to the foundation earth electrode

(2) For reinforced concrete structures, it is necessary during fabrication to ensure that the reinforcement is galvanically interconnected at as many points as possible by means of special clamps, and routed outside via one or more earth reference points in the interior of the tower. Furthermore, the metallic connecting flanges (at the bottom for the foundation and at the top for the yaw ring) shall be connected to the reinforcement. If these conditions are met, the tower interior is recognized as protection zone LPZ 1.

8.9.3.3 Junction at the yaw bearing

In order to achieve a continuous earth connection from the foundation earth electrode via the tower to the machine foundation, a highly conductive low-inductance connection shall be provided. Owing to the cable lengths required within the yaw range, cable connections are not suitable, because a high voltage difference can arise between the tower and machine foundation through the high-frequency lightning current. The following can be approved as suitable measures:

– sliprings that are capable of conducting lightning currents (these may also be arranged on the inside of the yaw ring) with pick-off by a metallic contact slipper

– bearings capable of conducting lightning currents

– spark gaps

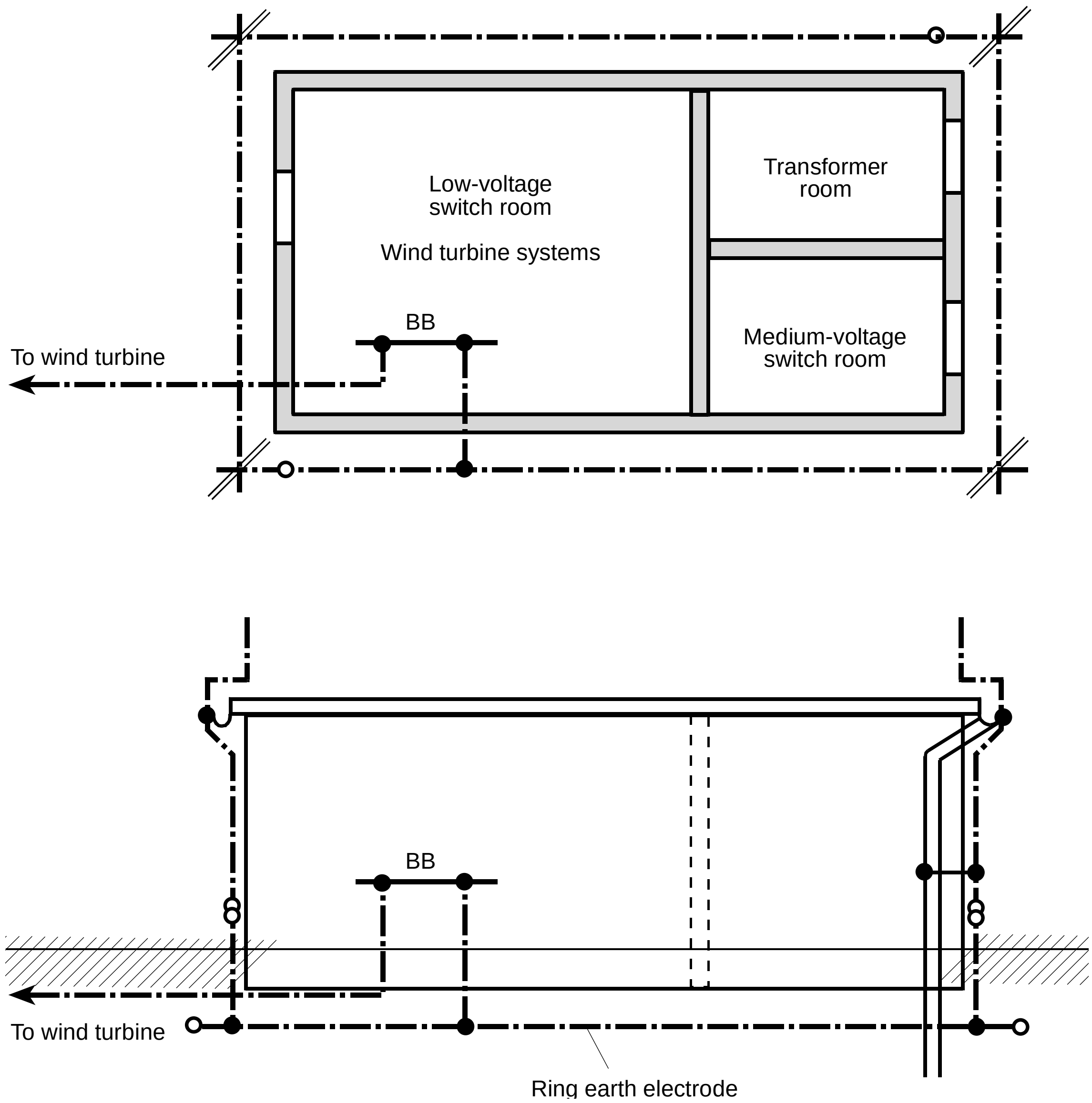


Fig. 8.9.3 Linking up the equipotential bonding from a separate station

8.9.3.4 Connection of the machine foundation to the earthing system

Normally, the machine foundation is satisfactorily linked to the earthing system by means of the bolted connections of the yaw ring. However, if the machine foundation is linked to the yaw ring by means of flexible damping elements, all damping elements shall be bridged over with flat copper bands of sufficient cross-section.

8.9.3.5 Connection of the generator and the gearbox to the earthing system

Normally, the generator and the gearbox are satisfactorily linked to the earthing system through the connecting bolts with the machine foundation. However, if the gearbox and/or generator are connected to the machine foundation by means of flexible damping elements, all damping elements shall be bridged over with flat copper bands of sufficient cross-section.

8.9.3.6 Connection of other components in the nacelle

All parts which contain electrical components (actuators, switchgear, metallic limit switches etc.), shall be galvanically connected to each other and to the machine foundation, if this is not provided reliably by their mountings. For this purpose, the most suitable method is a bonding bar which is galvanically linked to the machine foundation. The bonding conductors shall be kept as short as possible and shall have a minimum copper cross-section of 10 mm².

8.9.3.7 Metallic housings of the nacelle

If metallic housings are used, these shall be included in the equipotential bonding. This should be effected over a large area with steel tape connected at several points to the machine foundation. Any hinges shall be bridged over by flexible copper bands with as wide an area as possible.

8.9.3.8 Non-metallic housings of the nacelle

If non-metallic housings are used, these shall be fitted with lightning rods and the corresponding external conductors, and connected to the machine foundation. The height and number of lightning rods and conductors depends on the dimensions of the nacelle housing and shall be decided separately for each case. When determining the heights of the lightning rods, it shall be assumed that a lightning rod provides a protective cone of max. 45° which has to cover the entire nacelle.

8.9.3.9 Lightning protection on rotor blades

(1) Lightning protection is mandatory on all rotor blades made of fibre-reinforced plastics or wood, independent if they consist of conductive or non-conductive material. On rotor blades made of aluminium or ferrous material a separate lightning protection is not necessary.

(2) The lightning protection system consists at least of the (designated) lightning impact areas (receptors) and their down conductors.

(3) Examples for the construction of lightning protection systems are listed in IEC 61400-24. In choosing the lightning protection system the design layout of the rotor blade as well as the materials designated for fabrication have to be considered.

Notes:

The practicability of possible repairs needed after a lightning stroke should be considered as well.

Especially in the case of mesh used as a lightning conductor the repair will demand a high effort.

(4) Design and number of receptors are to be defined in each individual case and depend on the dimension of the rotor blade and the materials used. As a rule multiple receptors have to be provided for rotor blades of more than 20 m length.

(5) The rotor blades have to be equipped with down conductors in such a way that the lightning current of the protection level I (see also Section 8.9.2.2) can safely be diverted across the hub or the nacelle cover. The design of the down conductors is to be made in such a way that preferably no damages on the rotor blade will occur due to the lightning current. The down conductors should, if possible, be carried out in one piece; if appendages cannot be avoided, they have to be carried out in such a way that no decrease of conductivity occurs, even in long-term operation (e.g. by corrosion). Down conductors should show a straight course. Changes of directions in the form of bending bigger than 30° and radii smaller than 1m should be avoided.

(6) The cross sectional areas of the down conductors have to be at least of the size as given below all the way down:

– on conductors made of copper or aluminium alloys at least 50 mm^2

– on conductors made of steel band at least 60 mm^2

– on round conductors made of steel at least 78 mm^2

– Furthermore while designing the down conductor and its attachment in or at the rotor blade it has to be taken into account that the acceptable temperatures in the rotor blade (material values, see also Section 5.5.2.2 para 2) are not exceeded.

(7) In case a part of the conductor function is taken over by a component of the rotor blade, e.g. by the shaft of the tip brake, the product of cross sectional area and electrical conductivity of the component has at least to comply with the rest of the conductor device.

(8) With rotor blades made of conductive materials or when using conductive materials in the rotor blade, e.g. sensors and their ports it has to be taken into account that they are connected to the lightning protection system (potential equalisation) and that the function of the designated receptors is guaranteed.

(9) Even though the lightning protection systems are normally not relevant for the strength properties in the rotor blade, the components of the lightning protection systems are to be checked regarding the occurring extreme and fatigue loads. Taking into account the according safety and reduction factors, no failure may occur affecting the functionality of the lightning protection system.

8.10 Offshore Grid Devices

8.10.1 General

(1) Offshore wind turbines will be erected mainly in big wind farms. This section shall give the relation between the single offshore wind turbine and the electrical components installed between the offshore wind turbine and the shore. Germanischer Lloyd IV-Industrial Services Part 6 Offshore Installations, Chapter 5 Electrical Installations shall be observed where applicable.

(2) Depending on the site this will contain at least some or all of the components described below.

8.10.2 Transformer station

(1) The transformer station shall maintain the voltage stability inside the whole offshore wind farm grid**.** Voltage stability and other electrical grid conditions shall be defined according to Section 1.2.3.2 (site assessment). Where electrical grid conditions are not defined detailed enough, conditions of Section 4.2.4.8 and EN 50160: 1999 “Voltage characteristics of electricity supplied by public distribution systems” shall be applied. The voltage stability could be done e.g. by means of transformers with on-load tap-changers or manual control tap changers where necessary. Utility requirements can set a maximum voltage change at connection point.

(2) The following standards shall be used where applicable:

– IEC 60071-1:1993 “Insulation co-ordination - Part 1: Definitions, principles and rules”

– IEC 60071-2:1996 “Insulation co-ordination - Part 2: Application guide”

– IEC/TS 60071-5:2002 “Insulation co-ordination - Part 5: Procedures for high-voltage direct current (HVDC) converter stations”

– IEC 60204-11:2000 “Safety of machinery - Electrical equipment of machines - Part 11: Requirements for HV equipment for voltages above 1 000 V a.c. or 1 500 V d.c. and not exceeding 36 kV”

– IEC 60076-3:2000 “Power Transformers - Part 3: Insulation levels, dielectric tests and external clearances in air“

– IEC 60183:1984 “Guide to the selection of high-voltage cables”

– DIN 42508-3:1993 “Transformatoren; Öltransformatoren mit Umsteller oder mit Stufenschalter für Drehstrom 50 Hz, 12500 bis 80000 kVA und U_m bis 123 kV; Anforderungen, Kennzeichnung und Ausrüstung”

– IEC 60542:1988 “Application guide for on-load tap-changers”

(3) The transformer station shall be designed and dimensioned according to the local utility c<onnection requirements.

(4) It shall be possible to disconnect each transformer at both sides safely.

(5) Section 8.5 shall be observed where applicable.

8.10.3 Wind farm switchgear and protection equipment

(1) Switchgear and protection equipment on wind farm level are meant here, switching off e.g. a feeder of several turbines or the cable connection to shore.

(2) Switchgear devices used shall be made according to the following standards:

– IEC 60694:2002 “Common specifications for high-voltage switchgear and controlgear standards”

– IEC 60265-1:1998 “High-voltage switches - Part 1: Switches for rated voltages above 1 kV and less than 52 kV”

– IEC 62271-200:2003 „High-voltage switchgear and controlgear - Part 200: A.C. metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV”

– IEC 62271-203:2003 “High-voltage switchgear and controlgear - Part 203: Gas-insulated metal-enclosed switchgear for rated voltages above 52 kV”

– IEC 62271-102:2003 “High-voltage switchgear and controlgear - Part 102: Alternating current disconnectors and earthing switches”

– IEC 62271-105:2002 “High-voltage switchgear and controlgear - Part 105: Alternating current switch-fuse combinations”

(3) The pressure release for the switch gear shall be done in a way, that no damage from overpressure or fire can occur to the room, ceiling, neighbouring cables etc. Where person can be hurt from pressure release effects, the area shall be locked while the system is under voltage.

(4) The protection equipment shall at minimum protect the sea cables, transformers, and all electrical equipment at the transformer station from over current, short circuit and over voltage.

(5) Protection shall be implemented against dangerous voltage generation after electrical disconnection of single or multiple turbines from the grid (e.g. self-excitation).

(6) Protection against switching on, when phase opposition can occur shall be done. This is necessary, when any power generation can occur without grid parallel operation (e.g. self-excitation).

(7) The protection shall comply with utility regulations during a fault outside the wind farm.

8.10.4 Backup power supply

If a backup power supply at wind farm level is chosen it shall be designed and documented according to Section 8.1.7 and Section 8.8.3.

8.10.5 Sub sea cable

(1) For cable testing requirements the following CIGRE Electra recommendations shall be used:

– “Recommendations for mechanical tests on submarine cables”, pages 59 to 66 in Electra No. 171, April 1997

– “Recommendations for testing of long AC submarine cables with extruded insulation”, pages 29 to 37 in Electra No. 189, April 2000

– “Recommendations for tests on power transmission DC cables for rated voltage up to 800 kV”, pages 39 to 55 in Electra No. 189, April 2000

– “Testing DC extruded cable systems”, pages 47 to 53 in Electra No. 206, February 2003 plus Technical Brochure No. 219

(2) For calculation of cable length, sufficient extra length shall be installed. In the case of sub sea cable damage it is necessary for cable repair above sea level to have reserve length.

(3) The distance between parallel running cables shall be at minimum two times the water depth plus laying depth to allow future cable repair.

(4) The burial depth of cables shall be in accordance with the local requirements concerning sea bed warming.

(5) For calculation in cross section design the following standards shall be applied:

– IEC 60287-1-1:2001 “Electric cables - Calculation of the current rating - Part 1-1: Current rating equations (100 % load factor) and calculation of losses – General”

– IEC 60287-2-1:2001 “Electric cables - Calculation of the current rating - Part 2-1: Thermal resistance - Calculation of thermal resistance”

– IEC 60949:1988 “Calculation of thermally permissible short-circuit currents, taking into account non-adiabatic heating effects”

(6) Fiber optic cable shall be specified according to ITU G.650 “Definition and test methods for the relevant parameters of single-mode fibres”.

(7) During cable laying no unacceptable forces shall occur at the cable. For cable installation offshore, reference shall be made to 1185-1994 IEEE “Guide for Installation Methods for Generating Station Cables”.

(8) The cable shall be designed for carrying the maximum current without being damaged neither thermally nor electrically. This shall be valid for normal operation and for low voltage situations according to the rules given by the local utility.

Note:

Local rules and regulation concerning electromagnetic radiation and soil temperature rise can occur.

(9) Section 8.5.5.1 shall be observed where applicable.

(10) Each cable shall have possibilities to be switched off and earthed effectively at both ends.

(11) When planning sub sea cable trays crossing onshore tubes (e.g. passing an island) the following issues might limit the maximum length of onshore crossings:

– Maximum allowed pulling force of the respective cable shall never be exceeded.

– The pulling force has to be applied to the cable in a steady-going way.

(12) Depending on the soil conditions cables are put under the ground in different ways. The used tools for cable laying have to support the necessary bending radius of the cable. In no situation the allowed maximum bending radius of the respective cable shall be exceeded. The following both bending radii have to be taken into account:

- the bending radius of the cable from horizontal to vertical orientation (into the ground)

- the bending radius of the cable from vertical to horizontal orientation (in final position)

8.10.6 Cable connecting two feeders of several offshore wind turbines each

To decrease the likelihood of failure a second connection between two feeders can be implemented. In cable failure the possibilities of the ring can be used. Maximum possible currents have to be calculated accordingly. Normal operation shall be the open ring.

Rules and Guidelines

IV *Industrial Services*

2 Guideline for the Certification of Offshore Wind Turbines

9 Manuals

Germanischer Lloyd
WindEnergie

Edition 2005

Table of Contents

9.1 Manuals for Sea Transport and Offshore Installation

9.1.1 General

(1) The manuals for sea transport and offshore installation describe all working steps which have to be performed at sea during transport, assembly and erection of the offshore wind turbine.

(2) The manual applies for one type of offshore wind turbines, and if applicable for its variants.

9.1.2 Objective and format of the manuals for sea transport and offshore installation

(1) The objective of the manuals for sea transport and offshore installation is to provide information for the on-sea and offshore activities and procedures to all parties involved including the turbine designer and certification body.

(2) The format and level of detail of the manual shall be such that the resulting loads and risks can be evaluated and that the personnel performing the required tasks are able to understand the documentation.

(3) The manual shall be expressed in a language, which the personnel at the installation site are able to understand, plus a version in English or German.

(4) Notes regarding safety and regulations for the prevention of accidents shall be so arranged in the text that they appear before the operating action in question. They shall be highlighted clearly as being safety and accident-prevention notes.

9.1.3 Scope of the manuals for sea transport and offshore installation

9.1.3.1 Content of the manual

The manuals shall contain the following information at least:

– identification of type of the offshore wind turbine and installation site (see Section 9.1.3.2)

– prerequisites for the sea transportation and installation (see Section 9.1.3.3)

– sequence the sea transport and installation (see Section 9.1.3.4)

– warnings and measures against hazardous situations (see Section 9.1.3.5)

– blank form sheets for the record (see Section 9.1.3.6)

9.1.3.2 Identification of type of the offshore wind turbine and installation site

At least the following information shall be provided:

– manufacturer, supplier, importer

– identification, type and if applicable type variant of the offshore wind turbine

– rated power

– rotor diameter, hub height(s), water depth

– identification and position of the offshore site

9.1.3.3 Prerequisites for sea transport and offshore installation

(1) All prerequisites for the execution of the work shall be stated, e.g. requirements for the weather conditions (wind, temperatures, precipitation, wave height), working area required, adequate curing time of the foundation or any grouted connections.

(2) The precise identifications and dimensions of all plant components to be assembled and erected shall be specified, together with all data needed for erection, such as weights, hoisting points etc.

(3) The maximum admissible time period between installation of the sub structure and erection of the rest of the support structure and the maximum admissible time period until mounting of the topsides structure shall be stated.

(4) Requirements on the vessels (tug power, navigation equipment, etc.) and other equipment used (floating cranes etc.) shall be stated.

(5) A listing including quantities of all equipment and material necessary for the installation shall be given, e.g. grouting material, bolts, mooring and fastening equipment, special tools.

(6) Requirements on the qualification of the personnel shall be stated.

(7) The intended route and duration of sea transport are to be stated.

9.1.3.4 Sequence in sea transport and offshore installation

(1) All sequence steps shall be described including the conditions of all human interventions (divers etc.).

(2) Auxiliary equipment and resources shall be specified (e.g. lubricants, oil for filling up the gearbox, grouting materials).

(3) Arrangement of vessels, buoys, lights, etc. shall be described including the mooring/positioning equipment.

(4) Lifting, lowering, touchdown and ballasting procedures, where relevant, shall be described including admissible draft(s) and/or bottom clearance(s).

(5) The work instructions as per Section 6.5.1.1, item b for making the bolted connections shall be included in the manual.

(6) All necessary tests and checks shall be listed including the measuring and control equipment.

(7) Necessary monitoring of sea bed conditions, scouring etc., where relevant shall be described.

9.1.3.5 Warnings and measures against hazardous situations

(1) Hazardous situations which may arise through deviation from the planned working sequence shall be described and countermeasures shall be specified. Such situations may include: high winds during installation, prolonged periods of the sub structure and/or the support structure standing without topsides structure at critical wind speeds and/or wave frequencies.

(2) Emergency procedures and rescue operations are to be described.

9.1.3.6 Form sheet for the record of sea transport and offshore installation

(1) The record shall document the execution of all checks and working steps of the sea transport and the offshore installation process. For each check and working step, there shall be appropriate spaces to be filled in, together with fields for recording measurement values and test results.

(2) The record shall be on paper or in digital form as appropriate.

(3) All adjustment settings and set values as well as the expected measurement results shall be specified.

(4) The record may consist of several sub-records (e.g. for different assemblies or phases of work).

(5) The following entries shall be provided as a minimum:

– type identification of the offshore wind turbine as per Section 9.1.3.2

– serial number, operator and installation site of the offshore wind turbine

– name of the person carrying out or being responsible for the corresponding working step

– weather conditions

– records of the execution of all working steps

– records of the execution of all tests and checks

– extra space for possible remarks or items outstanding

– date and signature of the person(s) responsible

9.2 Documents for Commissioning

9.2.1 Commissioning manual

(1) The commissioning manual describes all working steps which have to be performed during commissioning in order to ensure safe functioning of the offshore wind turbine.

(2) The commissioning manual applies for one type of offshore wind turbine.

9.2.2 Commissioning record

The commissioning record documents the execution of the individual working steps during the commissioning process. A blank form sheet of the commissioning record shall be included in the commissioning manual.

9.2.3 Format of the documents

(1) The format and level of detail of the commissioning manual shall be such that the technical workmen performing the required tasks are able to understand the documentation.

(2) For the issuance of the project certificate, the commissioning manual shall be expressed in a language which the technical workmen at the installation site of the offshore wind turbine are able to understand.

(3) Notes regarding safety and regulations for the prevention of accidents shall be so arranged in the text that they appear before the operating action in question. They shall be highlighted clearly as being safety and accident-prevention notes.

9.2.4 Scope of the commissioning manual

The commissioning manual shall contain the following information as a minimum:

– precise type designation of the offshore wind turbine (see Section 9.2.4.1)

– checks required before start of commissioning (see Section 9.2.4.2)

– working steps of the commissioning process (see Section 9.2.4.3)

– checks required to conclude the commissioning (see Section 9.2.4.4)

– blank form sheets for the commissioning record (see Section 9.2.4.5)

9.2.4.1 Type designation of the offshore wind turbine

At least the following information shall be provided:

– manufacturer, supplier, importer

– designation, type and if applicable type variant

– rotor diameter, hub height(s)

– rated power

9.2.4.2 Checks before commissioning

All checks required before the start of commissioning shall be listed. The following statements shall be provided as a minimum:

– erection and assembly – completed to full extent

– commissioning of the auxiliary systems and subsequent external equipment needed for operation of the offshore wind turbine (e.g. transformer, grid connection station) – completed

– any trial runs of individual components which may be necessary in the factory or on site – completed

– filling up of all operating media (e.g. lubricants, coolants, hydraulic fluid, nitrogen in pressure tanks) – completed

– any acceptance tests needed according to governmental regulations (e.g. for pressure vessels, lifts) – completed

9.2.4.3 Working steps for commissioning

(1) All working steps needed for commissioning shall be described. For the commissioning of individual assemblies (e.g. yaw system), reference may be made to subordinate commissioning manuals for such assemblies.

(2) All prerequisites for the proper execution of commissioning, e.g. lowest/highest wind speed and necessary outside temperatures, shall be specified.

(3) Tests of all functions of the safety systems and the braking systems shall be described. The switching values to be set and criteria to be met shall be specified. The following tests shall be performed as a minimum:

– function of all emergency off pushbuttons

- function of all sensors and switches which also act on the safety system (e.g. overspeed test)
- measurement of the essential parameters of the braking systems, e.g. speed of blade pitching, hydraulic pressure of the mechanical brake(s)
- response of all necessary plant functions after activation of the safety system (e.g. braking systems, generator disconnection)
- test to verify that the functions responding to the activation of the safety system are independent of the control system
- load shedding
- testing of all limiting values and parameters that have been set for the safety system

(4) All tests regarding the functions of the control system of the offshore wind turbine shall be described. The switching values to be set and criteria to be met shall be specified. The following tests shall be performed as a minimum:

- automatic start up
- shut-down with all braking procedures
- plausibility check of the yaw system
- plausibility check of the measurement values
- comparison of the limiting values and parameters which were set with the prescribed values as documented

(5) Furthermore, the following working steps shall be described:

- registration of the data on the rating plates of the primary components, at least of the rotor blades, gearbox, generator and tower
- possible settings to be made in the control system on the basis of the measurement results (e.g. natural frequency of the tower)
- familiarization of the offshore wind turbine operating personnel

9.2.4.4 Checks to conclude commissioning

All checks required to conclude commissioning shall be listed. The following statements shall be provided as a minimum:

- visual inspections (e.g. rotor blades, corrosion protection, tightness of hydraulic system)
- checking of the required notices and warning plates
- checking of completeness of all tools, spare parts and auxiliary materials that have to be stored permanently in the offshore wind turbine. A list of these parts shall be included.
- checking of all outside lighting and emergency shelter equipment as well as rescue at sea equipment if applicable

9.2.4.5 Form sheet for the commissioning record

(1) The commissioning record shall document the execution of all checks and working steps of the commissioning process. For each check and working step, there shall be appropriate fields to be filled in, together with fields for recording measurement values and test results.

(2) All adjustment settings and set values as well as the expected measurement results shall be specified.

(3) The commissioning record may consist of several sub-records (e.g. for primary components, for familiarization f the operating personnel, …).

(4) The following fields shall be provided as a minimum:

- type designation of the offshore wind turbine as per Section 9.2.4.1
- serial number, operator and installation site of the offshore wind turbine
- persons present during commissioning
- weather conditions on the day of commissioning
- confirmation that all checks required before the start of commissioning as per Section 9.2.4.2 have been completed
- record of the execution of all working steps of the commissioning as per Section 9.2.4.3
- confirmation that all checks required to conclude commissioning as per Section 9.2.4.4 have been completed
- extra space for possible remarks or items outstanding
- date and signature of the person(s) responsible

9.3 Operating Manual

9.3.1 Purpose of the operating manual

The operating manual is intended to provide the operator or his representative with the knowledge necessary for proper operating of the offshore wind turbine.

9.3.2 Format of the operating manual

(1) The format and level of detail of the operating manual shall be such that a skilled workman with technical training is able to understand the documentation. Notes regarding safety and regulations for the prevention of accidents shall be so arranged in the text that they appear before the operating action in question. They shall be highlighted clearly as being safety and accident-prevention notes.

(2) For the issuance of the project certificate, the operating manual shall be expressed in a language which the technical workmen at the installation site of the offshore wind turbine are able to understand.

(3) The material (paper, plastic foil) on which the manual is printed shall be suitable for the conditions under which the offshore wind turbine is operated. This applies particularly to notices affixed directly to the installation.

9.3.3 Scope of the operating manual

The operating manual shall contain the following information:

– description of the offshore wind turbine

– notes for users

– help with fault-finding

9.3.3.1 Description of the offshore wind turbine

– manufacturer, supplier, importer

– designation, type and if applicable type variant(s)

– manufacturer’s number or serial number, and year of manufacture

– rotor diameter, hub height

– rated power, rotor speed, generator rotational speed, generator type

– cone and tilt angles

– cut-in, rated, cut-out wind speeds

– data of the rotor blade

– type of yaw system

9.3.3.2 Notes for users

– description of the operating concept

– starting and stopping procedures

– explanation of fault messages (insofar as these are issued)

– emergency shut-down

– safety measures, e.g. action required in the event of ice formation at the offshore wind turbine

– accident prevention regulations; behaviour during dangerous situations and potentially hazardous malfunctions

– description of the functions and operating modes of all the operating and indicating elements (switches, pushbuttons, lamps, measuring instruments)

– explanation of malfunctions and how to clear them

– description of components and functions that need to be taken into/out of service on a seasonal basis or for other reasons

– description of measures to be taken, if the offshore wind turbine is taken out of operation for a longer period e.g. because of damages to the grid connection. These measures could be e.g. lockage of blade pitch system and/or rotor or installing a backup power supply.

– description of measures to be taken, if the offshore wind turbine is taken into operation after a longer period of standstill. The measures could be e.g. opening of locks and/or drying/heating of components, which need to be dry when repowered.

9.3.3.3 Help with fault-finding

Without carrying out any repairs himself, the operator should be capable of recognizing the cause of a malfunction and – insofar as it cannot be cleared simply by an operating action – of providing the maintenance personnel with useful advance information.

9.4 Maintenance Manual

9.4.1 General

The maintenance manual contains the instructions for maintenance, inspection and repair, as defined in DIN 31052 “Maintenance; instructions for maintenance” or an equivalent standard recognized by GL Wind.

9.4.2 Purpose of the maintenance manual

The maintenance manual is intended to make the information necessary for maintenance, inspection and repair available to the maintenance personnel.

9.4.3 Format of the maintenance manual

(1) DIN 31052 or an equivalent standard recognized by GL Wind shall be observed in addition to this Guideline.

(2) In terms of its contents and form, the maintenance manual shall meet the requirements expressed in Section 9.3.2.

(3) It is useful to compile a maintenance plan presenting the maintenance work required in tabular form and in the appropriate time sequence.

9.4.4 Scope of the maintenance manual

(1) The maintenance manual shall contain the following information, whereby DIN 31052 or an equivalent standard recognized by GL Wind shall be observed in addition:

(2) Information documenting the correspondence between the maintenance manual and the offshore wind turbine (similar to the type designation in accordance with Section 9.2.4.1).

(3) Notes regarding safety and accident-prevention measures which are necessary before or during maintenance, e.g. use of climbing safeguards and locking devices.

(4) Descriptions of all tasks to be carried out. The descriptions may be supplemented by appropriate pictorial representations. The objectives of the individual maintenance operations (oil levels, bolt tightening torques, brake settings, oil pressures etc.) shall be indicated clearly.

(5) All components and auxiliary materials of the offshore wind turbine that have to be exchanged according to schedule during the operating life (e.g. hydraulic hoses, brake pads, sliprings, gear oil) shall be listed. The intervals or criteria for the exchange shall be specified.

(6) In addition, information shall be given about the quality and quantity of spare parts and auxiliary materials, e.g. lubricants, to be used (spare parts list).

(7) The maintenance manual shall be supplemented by a list of maintenance and inspection instructions (maintenance plan) defining the work to be carried out at set intervals. On completion, the tasks shall be recorded in this list.

(8) A detailed listing and description of the necessary tests for the safety system (e.g. overspeed test, emergency shut-down functions, measurement of the nitrogen content in hydraulic accumulators) shall be included in the maintenance manual. The required frequency of these tests shall be indicated (e.g. annually). The completion of the tests shall be recorded in the maintenance plan.

(9) If applicable, the investigations of technical experts and authorized persons, as required by the relevant national regulations (e.g. for lifts, fire-extinguishing systems and pressure vessels) and conditions of the building permits, shall be included in the maintenance plan, and columns/sections shall be provided for the confirmation that these investigations have been carried out.

(10) A detailed listing and description of the necessary inspections and tests of the lightning protection system shall be included in the maintenance manual. The required frequency of these inspections and tests shall be indicated (e.g. annually).

(11) All tools, spare parts and auxiliary materials that have to be stored permanently in the offshore wind turbine shall be listed. The intervals for regular checks for completeness of these parts shall be specified.

(12) A description of all tasks to be carried out at the outside lighting and emergency shelter equipment as well as rescue at sea equipment and possible backup power supply units shall be included in the maintenance manual if applicable.

(13) A detailed listing and description of the necessary inspections to be done at the scouring protection system at the foundation shall be included in the maintenance manual. Actions and corrective measures to be taken in case of damages or inadmissible wear shall be stated.

(14) A description of all inspections and tasks to be carried out at the corrosion protection system (both coating and cathodic protection systems as applicable) shall be included in the maintenance manual.

(15) An instruction to at least yearly take samples of the oil from the main gearbox and analyse these samples (including measurement of the cleanliness) shall be included in the maintenance manual.

Rules and Guidelines

IV *Industrial Services*

2 Guideline for the Certification of Offshore Wind Turbines

10 Testing of Offshore Wind Turbines

Germanischer Lloyd
WindEnergie

Edition 2005

Table of Contents

10.1 General

10.1.1 Prototype test

10.1.1.1 General requirements

(1) The measurements needed for a new turbine type within the scope of a prototype test are listed in Section 1.2.2.6, while further requirements are described in Sections 10.2 to 10.7. For the procedure to be followed after completion of the measurements, see Section 1.2.2.6, para 4. The scope of the prototype test can be reduced for turbine variants or modified turbines after consultation with GL Wind, provided that the prototype test was performed in its entirety for a predecessor turbine.

(2) All measurements as per Sections 10.2 to 10.6 shall be carried out and documented by a test institute accredited for these measurements. Alternatively, the test of the turbine behaviour as per Section 10.5 and the load measurements as per Section 10.6 can be carried out by the manufacturer after prior consultation with GL Wind, and then checked and witnessed by a test institute accredited for these measurements. In all cases, the accredited institute shall be responsible for compliance with the fundamental standards and with the requirements of this Guideline. The influence of a turbine variant on the measurement result shall be assessed by the accredited institute which performed the measurements on the original installation.

(3) The prototype tests as per Section 10.2 through 10.7 performed at a prototype test turbine onshore may be regarded as being sufficient for the offshore turbine with respect to the requirements for prototype testing. The compliance of the design of the test turbine with the design on which the offshore certification is based has to be shown. See also Section 10.1.1.2 para 1.

(4) If a prototype turbine onshore is used for the prototype tests as per para 3, then it is recommended to select a site at the sea coast to achieve the highest possible similarity with marine atmospheric and wind conditions.

(5) The Witnessing of the Commissioning as per Section 10.8 has to be performed on one of the offshore turbines to be certified. If that is not possible because of the issuance of A-Design Assessment before installation of the offshore turbines, then the witnessing may be performed provisionally on a prototype turbine on-shore. The compliance of the design of that prototype turbine with the design on which the offshore certification is based has to be shown. After installation of an offshore turbine the Witnessing of the Commissioning is then to be carried out again on this offshore turbine.

10.1.1.2 Requirements for the offshore wind turbine to be tested

(1) The offshore wind turbines at which the measurements as per Sections 10.2 to 10.6 or the trial as per Section 10.7 are carried out shall conform to the greatest possible extent with the design or variety of designs on which the offshore certification is based. Compliance shall be confirmed in a declaration by the manufacturer. Any deviations shall be reported to GL Wind. If the compliance is adequate for the corresponding test purpose, the measurement can be used for the certification.

(2) The test institute performing the measurements shall record the identifications and data on the nameplates of the surveyed plant and on the nameplates of the primary components (at least the rotor blades, gearbox, generator and tower) and shall include them in the measurement report.

10.1.2 Tests within the scope of the Design Assessment

(1) Blade tests as per Section 6.2.5 are required as part of the assessment of the rotor blade. These blade tests shall be completed before the A-Design Assessment is issued.

(2) The prototype trial of the main gearbox at the test bench as per Section 10.7 shall be completed before the A-Design Assessment is issued; see Section 10.7.1. Under certain circumstances, the trial at the test bench may already be necessary for the B-Design Assessment; see Section 10.7.1.

(3) Within the scope of the Design Assessment, witnessing of the commissioning at one of the first installations of the type is also required as per Section 10.8. This witnessing shall be completed before the A-Design Assessment is issued.

10.2 Power Curve

(1) Measurement of the power performance of the offshore wind turbine shall be carried out in accordance with IEC 61400-12 "Wind turbine generator systems – Part 12: Wind turbine power performance testing" or DIN EN 61400-12, in each case as the latest version.

(2) Deviations from this standard shall be justified and defined in consultation with GL Wind.

(3) On completion of the measurements, the measured power curve shall be compared by the test institute or by the offshore wind turbine manufacturer with the power curve assumed in the design documentation. Here special attention shall be paid to sufficient correspondence with the assumed values for rated wind speed and rated power.

(4) It shall be observed that a renewed measurement of the power performance is always necessary if the rotor blade type or the rotor diameter is changed. In the case of deviation from the rated rotational speed of the rotor, renewed measurement shall as a rule also be carried out.

(5) The report of the accredited test institute and the comparison shall be submitted to GL Wind for assessment.

10.3 Noise Emission

(1) Measurement of the noise emissions of the offshore wind turbine shall be carried out in accordance with IEC 61400-11 “Wind turbine generator systems – Part 11: Acoustic noise measurement techniques” or DIN EN 61400-11, in each case as the latest version.

(2) Deviations from this standard shall be justified and defined in consultation with GL Wind.

(3) It shall be taken into account that especially the rotor blade type, the tower height and the tower type, as well as the type of gearbox (if present) in the drive train of the offshore wind turbine, may have an influence on the noise emissions.

(4) The report of the accredited test institute shall be submitted to GL Wind for evaluation.

10.4 Electrical Characteristics

(1) Measurement of the electrical characteristics of the offshore wind turbine shall be carried out in accordance with IEC 61400-21 “Wind turbine generator systems – Part 21: Measurement and assessment of power quality characteristics of grid connected wind turbines” or DIN EN 61400-21, in each case as the latest version.

(2) Deviations from this standard shall be justified and defined in consultation with GL Wind.

(3) It shall be observed that a renewed measurement of the electrical characteristics is necessary as a rule whenever the generator type and the inverter type (if present) are changed.

(4) The report of the accredited test institute shall be submitted to GL Wind for evaluation.

10.5 Test of Turbine Behaviour

10.5.1 General

(1) The test of turbine behaviour is intended to verify the parameters and characteristics used as the basis for the design of the offshore wind turbine.

(2) The test of turbine behaviour comprises the following individual tests:

– test of the safety system (Section 10.5.3)

– test of the braking systems (Section 10.5.4)

– test of automatic operation (Section 10.5.5)

– test of the switching operations (Section 10.5.6)

– measurement of the natural frequencies (Section 10.5.7)

(3) The tests shall preferably be carried out at the offshore wind turbine fitted with instrumentation for load measurements as per Section 10.6.

(4) The requirements of IEC TS 61 400 – 13 “Wind turbine generator systems – Part 13: Measurement of mechanical loads” shall be applied with the necessary changes to the areas of

– calibration

– requirements for the measurement parameters and the measurement system

– reporting

(5) The test of turbine behaviour shall be carried out by a test institute accredited for load measurements at offshore wind turbines, or shall be verified and witnessed by such an institute (see Section 10.1.1).

(6) On completion of the measurements, the activities set out in Section 1.2.2.6, para 4, shall be performed by the test institute or by the offshore wind turbine manufacturer and the documents specified there shall be presented to GL Wind.

10.5.2 Test plan

Before the start of the tests, a test plan shall be submitted to GL Wind for consultation. The test plan shall contain at least the following information:

a measurement parameters

b extent of the measurements and a precise description of the test, stating the resolution of the measurement data

c envisaged evaluations

10.5.3 Test of the safety system

(1) For these tests, at least the following measurement parameters shall be recorded:

a wind speed

b rotational speed

c electrical power output

d blade angle or position of the aerodynamic brakes (if applicable)

e hydraulic pressure at the mechanical brake(s) (see Section 10.5.8)

f torque of the main shaft or driving torque of the rotor

g blade root bending moments

(2) The tests set out in Table 10.5.1 shall be performed.

10.5.4 Test of the braking systems

(1) For these tests, at least the following measurement parameters shall be recorded:

a wind speed

b rotational speed

c electrical power output

d blade angle or position of the aerodynamic brakes (if applicable)

e hydraulic pressure at the mechanical brake(s) (see Section 10.5.8)

f torque of the main shaft or driving torque of the rotor

g blade root bending moments

(2) After braking of the offshore wind turbine, recording of the measurements shall continue (during the idling condition or at standstill of the turbine) until a steady-state condition has been reached.

(3) The tests set out in Table 10.5.2 shall be performed.

10.5.5 Test of automatic operation

(1) For these tests, at least the following measurement parameters shall be recorded:

a wind speed

b rotational speed

c electrical power output

d blade angle or position of the aerodynamic brakes (if applicable)

e hydraulic pressure at the mechanical brake(s) (see Section 10.5.8)

f torque of the main shaft or driving torque of the rotor

g blade root bending moments

(2) The tests set out in Table 10.5.3 shall be performed.

10.5.6 Test of the switching operations

(1) For these tests, at least the following measurement parameters shall be recorded:

a wind speed

b wind direction at the wind measurement mast (for the test of yaw control)

c nacelle position (for the test of yaw control)

d rotational speed

e electrical power output

f blade angle or position of the aerodynamic brakes (if applicable)

g hydraulic pressure at the mechanical brake(s) (see Section 10.5.8)

h torque of the main shaft or driving torque of the rotor

i blade root bending moments

(2) After the switching operation, the recording of the measurements shall continue until a steady-state condition has been reached.

(3) The tests set out in Table 10.5.4 shall be performed.

10.5.7 Measurement of the natural frequencies

(1) For these tests, the measurement parameters that are appropriate in each case shall be recorded and evaluated. The natural frequencies shall be determined by counting of vibration cycles or by frequency analyses of suitable measurement signals.

(2) The natural frequencies shall be determined as per Table 10.5.5.

(3) If a vibration damper system is fitted in the tower, the natural frequencies for the tower shall be determined in the directions of movement damped by the system both with and without the vibration damper system functioning.

10.5.8 Hydraulic pressure at the mechanical brakes

(1) As an alternative to measurement of the hydraulic pressure, an alternative measurement parameter can be recorded if the signal exhibits a clear relationship to the applied braking moment (e.g. position of a control valve). This relationship shall be documented in the measurement report.

(2) In the case of brakes that are activated at fixed levels (e.g. hard braking / soft braking / off), simple logging of the brake status shall suffice. The status signal shall be sensed at the brake or at the hydraulic system. The pressures or the braking moments of the individual levels shall be documented in the report.

Table 10.5.1 Tests of the safety system

No.	Test	Number of tests for wind speed < 80 % of V_r	Number of tests for wind speed ≥ 80 % of V_r	Remarks
10.5.3.1	Activation of the brakes through exceeding of n_A	-	2	
10.5.3.2	Activation of brakes through actuation of an emergency off pushbutton	2		Activation during power production

Table 10.5.2 Tests of the braking systems

No.	Test	Number of tests for wind speed < 80 % of Vr	Number of tests for wind speed ≥ 80 % of Vr	Remarks
10.5.4.1	Braking with failure of one aerodynamic braking system	2	2	For offshore wind turbines with more than one aerodynamic braking system[1]
10.5.4.2	Braking with failure of braking system I	2	2	For offshore wind turbines with exactly two braking systems
10.5.4.3	Braking with failure of braking system II	2	2	
10.5.4.4	Braking with other assumable malfunctions in the braking systems	2 Tests for each assumable malfunction (wind speeds to be defined realistically)		[2]
10.5.4.5	Effectiveness of the mechanical brake(s)	2		[3]

Remark [1]: The blade root bending moments shall be measured at one of the blades with and at the blade without blade pitching function. If only one blade is fitted with instrumentation, the number of tests shall be doubled in each wind speed range, whereby the failure of the aerodynamic braking system shall be tested at the instrumented blade and then at another.

Remark [2]: These tests may be necessary if other malfunctions have been assumed in the consideration of possible faults as per Section 2.1.2 (e.g. failure of the blade pitching motor to switch off when feathering).

Remark [3]: The magnitude of the braking moment and the build-up curve of the braking moment shall be shown by means of a suitable test.

Table 10.5.3 Tests of automatic operation

No.	Test	Number of tests for wind speed < V_r	Number of tests for wind speed ≥ V_r	Remarks
10.5.5.1	Automatic operation	2	2	Duration of the test: approx. 2 minutes

Table 10.5.4 Tests of the switching operations

No.	**Test**	**Number of tests for wind speed < 80 % of V_r**	**Number of tests for wind speed ≥ 80 % of V_r**	**Remarks**
10.5.6.1	Start-up of the turbine	2	2	
10.5.6.2	Shut-down with all defined braking procedures	2 tests per braking procedure		1)
10.5.6.3	Switch-over of the generator speed	2 switch-overs in either direction		For offshore wind turbines with 2 or more fixed speeds
10.5.6.4	Braking in the case of grid failure or load shedding	2	2	
10.5.6.5	Activation of the yaw system		1 yaw operation in either direction	
Remark 1): For offshore wind turbines with blade pitch control, the blade pitching rates shall be documented in the report.				

Table 10.5.5 Measurement of the natural frequencies

No.	**Component**	**Standstill**	**Production**
10.5.7.1	Rotor blade	1st and 2nd natural mode, flapwise 1st and 2nd natural mode, edgewise	1st and 2nd natural mode, flapwise 1st and 2nd natural mode, edgewise
10.5.7.2	Drive train	1st natural mode for torsion with generator switched off and mechanical brake opened (excitation e.g. through closing and opening of the mechanical brake)	1st natural mode for torsion with generator switched on
10.5.7.3	Tower	1st natural mode for bending in direction XK 1),2) 1st natural mode for bending in direction YK 1),2) 2nd natural mode for bending 1st natural mode for torsion, except for torsionally stiff towers (e.g. tubular towers)	1st natural mode for bending in direction XK 2) 1st natural mode for bending in direction YK 2)
Note 1): The rotor position shall preferably be so selected that one blade points vertically downward. Remark 2): XK and YK as per coordinate system in Appendix 4.A, Section 4.A.5			

10.6 Load Measurements

(1) Load measurements shall be carried out in accordance with IEC TS 61 400 – 13 "Wind turbine generator systems – Part 13: Measurement of mechanical loads", in its latest version.

(2) Deviations from this Technical Specification shall be defined in consultation with GL Wind.

(3) Before the measurements are conducted, the measurement parameter plan and the extent of the measurements shall be agreed with GL Wind as far as possible.

(4) In case the load measurements are carried out offshore, all load relevant marine conditions shall be measured in addition to the requirements as per IEC TS 61 400-13 in order to verify the load impact on the offshore wind turbine.

(5) Additional sensors at the support structure are to be applied and the locations of these shall be determined in consultation with GL Wind.

(6) After completion of the measurements, the activities as per Section 1.2.2.6 para 4 shall be performed by the test institute or by the offshore wind turbine manufacturer and the documents specified there shall be presented to GL Wind.

10.7 Prototype Trial of Gearboxes

10.7.1 General

(1) Gearbox types for installation in the drive train of offshore wind turbines (main gearbox) shall be subjected to a prototype trial at a suitable test bench and also to a trial at the offshore wind turbine for which this gearbox was developed. The trial serves to check the assumptions made in the design of the gearbox and also to obtain important parameters for the execution of series tests during the production of offshore wind turbine gearboxes. The fundamental suitability of the gearbox for use in the offshore wind turbine shall be verified through practical operation and also documented.

(2) In the event of design modifications (e.g. alteration of the transmission ratio) which exert an appreciable effect on the dynamic characteristics of the gearbox or on the load distribution for individual components of the gearbox, a renewed prototype trial is necessary. The corresponding scope shall be determined in relation to the design modification and in consultation with GL Wind.

(3) The entire prototype trial shall be completed and accepted by GL Wind before the type certificate is issued. Before the A-Design Assessment is issued, the trial at the test bench shall have been completed and documented. The test bench set-up and the test plan shall be assessed by GL Wind or by an accredited test laboratory within the scope of an inspection of the test stand lasting at least one day. If major results of the prototype trial have already been incorporated into the calculations of the gearbox according to Section 7.4, completion of the gearbox trial at the test bench may already be required for the B-Design Assessment.

(4) The detailed scope of the prototype trial shall be specified in consultation with GL Wind before the trial commences.

10.7.2 Scope of the prototype trial

The following items at least shall be observed before and during the trials of offshore wind turbine gearboxes:

– The gearbox under test and its essential components shall be uniquely identifiable. The relevant quality documents shall be made available by the time of the trial.

– The purity of the lubricant used shall be ensured and monitored constantly during the trial at the test bench.

– The trial at the test bench shall also include the function of the envisaged cooling system and the lubrication system. A realistic test bench set-up and the simulation of extreme operating conditions shall be provided.

– Measurement parameters such as temperatures, pressures and vibration shall be comprehensively logged. The data shall be stored with an unambiguous relationship to each other and, as far as possible, in a format which can be processed electronically.

– The load spectrum during the trial at the test bench shall be so defined that the actual contact pattern of all tooth engagements permits a meaningful comparison with the assumptions made in the design. The duration of the individual load runs shall be chosen to ensure adequate testing of the thermal design of the gearbox.

– On completion of the trial at the test bench, the gearbox shall be so disassembled that the condition of all bearings and teeth can be assessed and documented.

– The trial at the test bench shall be followed by trial operation at an offshore wind turbine. The duration of this operation at the offshore wind turbine shall be laid down in consultation with GL Wind. Relevant operational parameters such as temperatures, pressures and vibration shall be logged and evaluated, together with parameters concerning the loading of the gearbox. In addition to the torque, these shall include the loads to be derived from the relevant structural integration of the gearbox within the offshore wind turbine.

10.7.3 Documentation of the prototype trial

All phases of the prototype trial shall be comprehensively documented and evaluated, e.g. by means of measurement data files, photographs, oil analyses, and inspection or assembly reports. As an important part of the evaluation, an appropriate plan shall be defined for the trials of the series gearboxes. The documentation and evaluation shall be submitted together with the plan for the trials of series gearboxes to GL Wind for assessment.

10.8 Witnessing of the Commissioning

10.8.1 General

(1) The commissioning procedure shall be witnessed at one of the first offshore wind turbines built in the version to be certified. The objective of this witnessing is the visual inspection of a plant by the certifier and the assessment of the safety-related tests in the commissioning manual (see Section 9.2).

(2) The witnessing of the commissioning shall be performed by experts from GL Wind for the fields of electrical engineering and safety technology.

(3) Successful execution of the witnessing of the commissioning is a prerequisite for issuance of the A-Design Assessment.

10.8.2 Procedure for witnessing

(1) The plant is inspected and the technical execution is compared to the requirements of the design documents.

(2) Compliance with any restrictions expressed in the Certification Report is assessed as far as possible.

(3) Selected tests from the commissioning manual are carried out with a focus on the safety tests. In addition, the practicability of the tests is verified and the turbine behaviour is assessed for compliance with the design documents.

Rules and Guidelines

IV *Industrial Services*

2 Guideline for the Certification of Offshore Wind Turbines

11 Periodic Monitoring

Germanischer Lloyd
WindEnergie

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Table of Contents

11.1 Scope and Execution

11.1.1 General

11.1.1.1 Objective of Periodic Monitoring

(1) Periodic Monitoring is an inspection of the offshore wind turbine by a technical expert of GL Wind. The inspection shall be carried out according to the conditions in the Certification Reports. Inspection intervals are laid down in the corresponding Certification Reports, their annexes, or indirectly in the form of references.

(2) The objective of Periodic Monitoring is the examination (inspection) of the machinery, the safety devices and the structural integrity of the entire offshore wind turbine.

(3) The body responsible for the offshore wind turbine (called the operator in the following) shall arrange for Periodic Monitoring. The Inspection Report shall be appended to the maintenance manual.

11.1.1.2 Requirements for the technical expert

(1) Periodic Monitoring shall be carried out by a technical expert for wind turbines who is approved by GL Wind. The expert shall have the necessary technical knowledge for assessment of the complete offshore wind turbine. The relevant training and a continuous exchange of experience shall be proven. An accreditation according to DIN EN 45004 or 45011 or equivalent is required, or the aptitude of the expert shall be checked by a competent examination board (e.g. Flensburg Chamber of Commerce and Industry).

(2) The technical expert shall be independent and shall have access to the relevant technical documentation of the wind turbine.

11.1.2 Scope and execution

11.1.2.1 Execution of Periodic Monitoring

During Periodic Monitoring, the complete offshore wind turbine including the rotor blades shall be inspected thoroughly. A specific checklist for the inspection shall be prepared on the basis of the documentation. The checklist shall also contain the assessment criteria.

11.1.2.2 Basis of assessment for Periodic Monitoring

Periodic Monitoring shall be assessed on the basis of the “Guideline for the Certification of Offshore Wind Turbines” of GL Wind in its latest edition. Standards and regulations valid at the site shall be observed and applied.

11.1.2.3 Documentation of the wind turbine to be inspected

At least the following documentation shall be perused for Periodic Monitoring:

– approval and/or certification reports including all annexes and supplements
– building and operation permit
– operating manual
– filled out commissioning record
– filled out maintenance checklist (maintenance records) at least of the last maintenance
– reports of previous Periodic Monitorings or condition surveys, e.g. condition based monitoring measurements (if available)
– proof and result of the annual oil quality check (at least the two last ones)
– documentation of modifications/repairs of the turbine and necessary approvals, if relevant
– reports of inspection of scour protection and seabed level (see also 11.1.2.4)
– reports of inspection of the underwater structures and splash zone (see also 11.1.2.4)
– annual report (e.g. trend analysis) of the monitored (by CMS, refer to Chapter 13) wind turbine components (at least the two last reports)

11.1.2.4 Scope of Periodic Monitoring

(1) The turbine shall be checked by visual inspection, whereby the individual components (including the rotor blades) shall be examined closely and the areas to be examined shall be cleaned or uncovered if relevant.

(2) Structural integrity of the offshore wind turbine including machinery, and functioning of the safety and braking systems, shall be checked as well (see Table 11.1.1).

(3) The scour protection, seabed level, underwater structure and splash zone shall be checked by the review of the inspection reports of these components.

(4) The structure within the splash zone shall be inspected visually with regard to corrosion, marine growth and damage, e.g. from collision. Where damage is found that could extend further down, diver inspections may be called for. Plate thickness measurements may be required where there is evidence of excessive corrosion. This shall be reported in the inspection report.

(5) The concrete surfaces shall be inspected for cracks, abrasion, spalling and any signs of corrosion of the steel reinforcement and embedments, particularly in the splash zone, in ice conditions, and where repairs have been carried out previously. Cleaning of the surface may be necessary. The result of the inspection shall be reported in the inspection report.

(6) The type, location and extent of corrosion control (i.e. coatings, cathodic protection system, etc.) as well as it’s effectiveness, and repairs or renewals shall be reported in the inspection report.

Table 11.1.1 Scope of inspections for Periodic Monitoring

Assembly	Inspection for / possible defects
Rotor blade	Surface damage, cracks, structural discontinuities. (Inspection from a lifting or stepping device: visual and structural examination using suitable methods (e.g. tapping, ultrasonic testing)). Pretensioning of bolts. Damage to the lightning protection system.
Drive train	Leakages, unusual noises, condition of the corrosion protection, greasing, pretensioning of bolts, Condition of the gearing (oil sample, if relevant), Damage to the lightning protection system.
Nacelle and force- and moment-transmitting components	Corrosion, cracks, unusual noises, greasing, pretensioning of bolts, lightning protection
Climate control, dehumidify and air filters	Function, contamination, dirt
Hydraulic system, pneumatic system	Damage, leakages, corrosion, function
Support structure (tower, sub-structure and foundation) Monopile or intersection pieces	Corrosion, corrosion protection (e.g. cathodic protection), damages and deformation, cracks, abrasion, spalling, pretensioning of bolts, marine growth Hermetically sealed (visual inspection)
Safety devices, outside lightings, sensors and braking systems	Functional checks, compliance with the limiting values, damage, wear
Control system and electrics including transformer station and switchgear, Condition Monitoring System	Terminals, fastenings, functional checks, corrosion, dirt
Heli hoist, boat landing, fenders	Fastenings, function, corrosion, cracks, dirt, damages and deformation
Emergency shelter	Description of all tasks to be carried out at the outside lighting and emergency shelter equipment as well as rescue at sea equipment and possible backup power supply (if applicable).
Perusal of documentation	Completeness, observance of the conditions, construction according to certified documents, test documents, maintenance carried out at regular intervals. If applicable: execution of modifications / repairs according to approval.

11.2 Technical Experts, Documentation and Actions

11.2.1 Technical experts

(1) Periodic Monitoring is carried out worldwide by technical experts of GL Wind:

Germanischer Lloyd WindEnergie GmbH Steinhöft 9 20459 Hamburg WINDTEST Kaiser-Wilhelm-Koog GmbH Sommerdeich 14 b 25709 Kaiser-Wilhelm-Koog WINDTEST Grevenbroich GmbH Frimmersdorfer Straße 73 41517 Grevenbroich WIND-consult GmbH Reuterstraße 9 18211 Bargeshagen

(2) In consultation with the contractor, several experts may perform the monitoring of large wind farms at the same time.

(3) Reports of other technical experts may be accepted.

11.2.2 Documentation

(1) The Inspection Report on the Periodic Monitoring shall be written and signed by the technical expert. The Inspection Report shall contain the following information at least:

– manufacturer, type and serial numbers of the wind turbine and the tower

– location and operator of the offshore wind turbine

– operating hours and total energy produced

– date and climate conditions (weather) on the day of inspection

– persons present at the inspection

– detailed description of the scope of inspection

– remarks and damage/deficiencies found

– result of inspection

(2) The result, the deficiencies found and the necessary conditions and restrictions shall be stated on the first pages.

(3) Two copies of the report shall be submitted to the operator.

11.2.3 Actions

11.2.3.1 Repairs

(1) In his Report (see Section 11.2.2), the technical expert shall state any deficiencies found and shall prescribe a timeframe for competent repair.

(2) Any repairs necessary shall be carried out on arrangement by the operator.

(3) Repairs shall be carried out by the manufacturer of the offshore wind turbine, by a workshop authorized by the manufacturer, or by a workshop specialized in that field and possessing the necessary knowledge, information and equipment.

11.2.3.2 Decommissioning and recommissioning

(1) If deficiencies endanger the structural integrity of the wind turbine partly or completely, or if deficiencies can be expected to result in greater damage, the technical expert shall recommend the decommissioning of the turbine. Decommissioning shall then be carried out by the operator.

(2) The technical expert shall inform the body responsible for the building and/or operation permit if public safety of the public environment and sea transport is endangered due to the deficiencies and if the operator refuses to decommission the offshore wind turbine.

(3) After repair of the turbine by a specialized workshop according to Section 11.2.3.1, the workshop shall attest the proper repair of the safety shortcomings in writing to the operator. After that, the operator/owner may initiate the recommissioning.

Rules and Guidelines

IV *Industrial Services*

2 Guideline for the Certification of Offshore Wind Turbines

12 Marine Operations

Germanischer Lloyd
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Table of Contents

12.1 Lifting

12.1.1 Scope, general remarks

(1) Marine Operations, i.e. operations associated with moving or transporting an offshore structure or part thereof during the construction and installation process may have decisive influence on the overall design and on the dimensioning of scantlings (see also Chapter 6, 6.2.1 and 6.1.3). Marine operations are therefore normally included in the design review by GL Wind.

(2) Where such operations, i.e. lifting, skidding, towing (either on board of a barge or ship, or afloat on its own), launching and lowering/embedding, impose important loads or critical conditions on the structure, they have to be taken account of in the design. The review and survey by GL Wind will cover the following as far as applicable:

– anticipated environmental conditions

– methods/means of transportation to be used, towing arrangement

– safe design of auxiliary elements such as pad-eyes and loose equipment, lashing and securing elements

– positioning

– lifting, lowering and touchdown procedures (dynamical influences)

– ballasting, venting/deballasting, grouting procedures and installations/equipment

(3) A complete certification of the design and construction of an Offshore Wind Turbine will be based on surveys and attendance to all important transport and installation operations. The necessary extent of such attendance will be agreed upon in each individual case, and certified accordingly. However, the operations will be conducted by the responsible personnel of the service company in charge, which is assumed to be competent and experienced for the respective tasks.

(4) The manuals for sea transport and offshore installation (see Section 9.1) shall cover all relevant procedures and limiting conditions, and shall be approved by GL Wind.

(5) Construction phases of an Offshore Wind Turbine in a floating, moored condition will not be treated in this Regulation.

12.1.2 Lifting operations

12.1.2.1 Design considerations

Overall dimensions, weight and center of gravity (COG) of a unit to be lifted, number of lifting points, arrangement and characteristics of lifting equipment etc. shall be considered at an early design stage in view of the means which are foreseeably available, and of the statical and dynamical loads associated with the anticipated procedure.

12.1.2.2 Calculations

(1) The analysis of the lifting and lowering procedures shall take into account, where adequate, the elastic properties of both the structure itself and the lifting equipment, the dimensional and weight tolerances, and the dynamic conditions which depend on the environment and the type of lifting gear employed. The weight of the rigging/lifting equipment (e. g. spreaders) shall be accounted for where relevant.

(2) Additional external influences and loads such as hydrodynamic and hydrostatic forces acting on submerged structures, wind, tug forces and foreseeable impact forces, shall be considered where they are deemed to be important.

12.1.3 Load assumptions, forces and dynamic amplification

(1) When deriving hook and padeye forces (H and P) from the mass (M) of the lifted object, dynamic amplification shall generally be accounted for (see Fig. 12.1.1).

(2) The lifting weight W_L is defined as follows:

$$W_L = M \cdot g \cdot \gamma_F \cdot k_D \qquad [\mathrm{kN}] \qquad (12.1.1)$$

M = mass for the lifted object [t]

g = gravity acceleration [9.81 m/s^2]

γ_F = safety factor for gravity loads according to Table 4.3.4, see para 5.

k_d = dynamic amplification factor. If no reliable values are available, e. g. from calculations of the motion behaviour, k_d may be taken from Table 12.1.1.

(3) The hook force H may be determined as follows:

$$H = W_L \cdot \gamma_{dL} + W_R \cdot g \cdot \gamma_F \cdot k_d \qquad (12.1.2)$$

γ_F = safety factor for rigging mass according to para 5.

W_R = rigging mass [t]

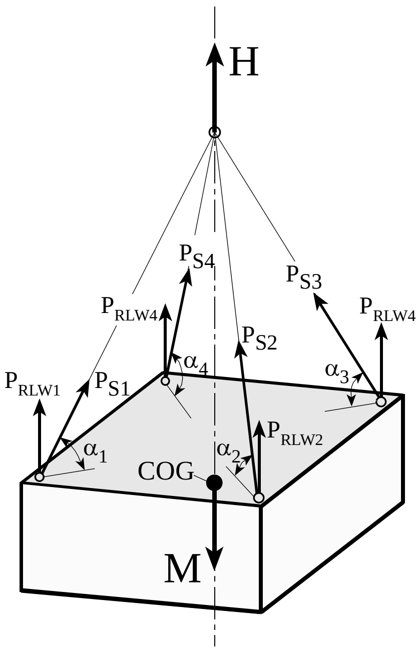

Fig. 12.1.1 System definition

(4) For lifting and lowering procedures involving floating objects and/or two or more crane barges, a special investigation of the motion characteristics of the coupled system will usually be necessary, unless it can be shown that the maximal forces likely to occur are sufficiently smaller than the lifting capacity provided. As a rule an additional safety factor of γ_{dL} = 1.1 shall be applied to take account of rigging in dual lift conditions.

(5) Inaccuracies in estimating component mass shall be taken into account by applying the safety factors γ_F stated in Table 4.3.4 "Gravity". For rigging equipment lower safety factors may be used if weight is exactly known.

(6) The elastic properties of the slings should generally be taken into account, whereas the elasticity of the object to be lifted may be disregarded in many cases.

(7) Depending on the type of structure and possible accuracy of calculation (design stage) a tolerance factor γ_{COG} or appropriate design solutions, shall be chosen to take account of accuracy regarding the position of center of gravity (COG).

$$\gamma_{COG} = 1 + e_{COG} \qquad (12.1.3)$$

where e_{COG} = possible error in position of center of gravity, in relation to the largest distance between supporting points.

(8) The skew load factor γ_{SKL} is applied for dimensional tolerances of the slings and the influence of elasticity of sling length properties. For indeterminate (4-sling) lifts a skew load factor of

$$\gamma_{SKL} = 1.25 \qquad (12.1.4)$$

shall be applied to each diagonally opposite pair of lift points in turn. For determinate (2- and 3-sling) lifts the skew load factor is:

$$\gamma_{SKL} = 1.00 \qquad (12.1.5)$$

(9) The sling load P_{Si} [kN] is the total load acting on the padeye (standard padeye see Fig. 12.1.2) in direction of the sling and is determined as follows:

$$P_{Si} = \frac{P_{RLWi} \cdot \gamma_{COG} \cdot \gamma_{SKL}}{\sin(\alpha_i)} \qquad (12.1.6)$$

P_{RLWi} = padeye resolved lift weight, vertical load on each padeye taking into account the lift weight W_L and the geometric arrangement of the lifting point in relation to the COG only [kN],

α_i = angle between the sling and the horizontal plane (i = 1, 2, … k) [°]

(10) Additional influences e. g. from horizontal forces (see Section 12.1.2.2 para 1) shall be especially considered. At the points of load introduction (padeyes), a force equal to 5 % of $P_{S,max}$ is to be accounted for, acting perpendicular to the padeye plane.

(11) When using spreading frames, the sling forces may be calculated accordingly, α being the angle between sling and (horizontal) spreader plane.

12.1.4 Design of lifted object, padeyes

(1) The structure to be lifted, including the elements introducing the loads (as defined in Section 12.1.3) into the structure shall be designed according to the principles laid down in Chapters 5 and 6. The permissible stresses and safety factors, respectively, should generally be taken according to transport and erection load cases. See also Section 4.3.3.12.

(2) Strength of padeyes shall be analysed according to Sections 5.3 and 6.6 of the present Guideline, considering Section 3.3.2 regarding materials and Section 3.4.2 regarding welds.

Table 12.1.1 Dynamic amplification factor, k_d

	Unprotected areas offshore [1]	**Sheltered areas** [1]
$M \leq 1000$ t	$k_d = 1.15 + 0.15\left(1 - \frac{M}{1000}\right)$	$k_d = 1.05 + 0.10\left(1 - \frac{M}{1000}\right)$
$M > 1000$ t	1.15	1.05

[1] It is assumed that operations are carried out under defined, controlled weather conditions.

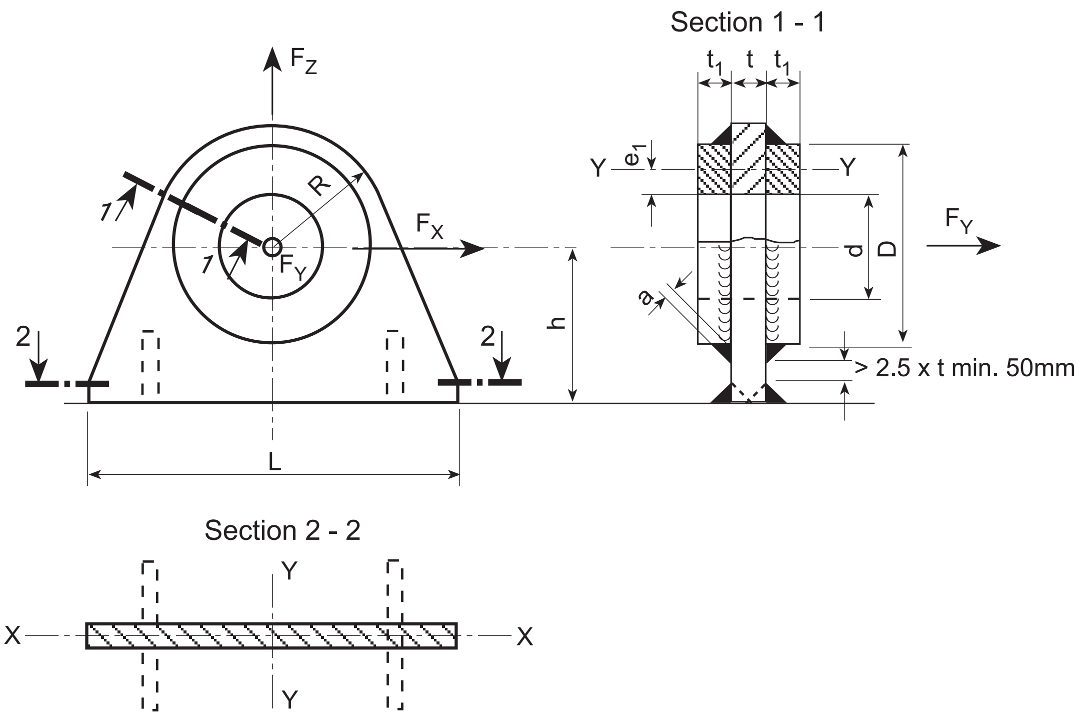

Fig. 12.1.2 Standard padeye

(3) In some cases inaccuracies in the analysis of the stress distribution around the lifting point may occur. In those cases an additional safety factor of $\gamma_{fl} = 1.2$ shall be applied.

(4) The shear stress at the weld connection between doubling plate and web may be assumed to be:

$$\tau \approx \frac{\sqrt{{F_x}^2 + {F_z}^2}}{D \cdot \pi \cdot a} \cdot \frac{t_1}{t + 2t_1} \qquad (12.1.7)$$

The minimum weld thickness is determined as follows but not less than 3 mm:

$$a_{min} = 1.5 \cdot \sqrt{\frac{t + t_1}{3}}, \qquad (12.1.8)$$

(Abbreviations as shown in Fig. 12.1.2)

(5) Padeyes shall be so arranged that the sling direction lies in the plane of the padeye web. A bending force according to Section 12.1.3 in the direction of the eye axis, is to be considered. The padeye web shall be introduced into the structure, avoiding sling forces to be transmitted across girder or deck plates.

(6) Elements which may be subjected to shock loading during the lifting and lowering procedure shall be especially considered and duly strengthened. Protection by guides and in special cases fendering may be necessary.

12.1.5 Design of lifting equipment

(1) Where standard lifting equipment is used, it should be designed or chosen to suit the requirements, as e. g. according to GL Rules and Guidelines, IV-Industrial Services, Part 6 – Offshore Installations, Section 3.4. The adequacy for offshore operations will, however, be ascertained in every individual case.

(2) Slings (steel wire ropes) should generally not stay in service for more than 15 years. The slings may only be longer in use if a “Certificate of Fitness” has been issued by a recognized specialized firm, or the sling maker, based on a respective examination. Furthermore the slings must be discarded if an external damage can be found.

(3) Shackles and similar lifting equipment are to be of an approved design. The safe working load indicated and certified shall at least correspond to the loads given under Section 12.1.3. Shackles shall not be subjected to bending.

(4) Lifting beams, spreaders and similar load distributing devices shall be designed according to the loads as indicated in Section 12.1.3. The safety factors for the loads may be chosen according to Section 4.3.7, applying transport and erection load cases.

(5) Special attention shall be paid to buckling of compression members.

12.1.6 Cranes, crane barges

(1) Barge- or ship-mounted cranes intended for offshore lifting operations shall be of adequate type and design, and certified accordingly. Regarding the crane(s), reference is again made to GL Rules and Guidelines, IV-Industrial Services, Part 6 – Offshore Installations.

(2) The vessel itself shall be adequate for the sea area and kind of loads envisaged. Stability investigations covering the load cases planned will have to be presented.

(3) Regarding operations involving two or more barges or vessels see Section 12.1.3.1 para 4.

12.1.7 Monitoring, measurements

During critical phases of lifting/lowering operations, monitoring e. g. by load or strain measurements may be advisable or necessary. In such cases review of the monitoring installation and control of the measurements during the operations will normally be part of GL Wind survey procedure, and will be certified accordingly.

12.2 Towing and Installation

12.2.1 Towing Operations

12.2.1.1 General

(1) Towing operations during at-shore construction and sea transportation are usually an important part of the design considerations and will therefore have to be included in the safety evaluation procedure. Information shall be provided on essential parameters such as:

– requirements to vessels performing marine operations

– towing route(s) envisaged

– duration of the voyage

– draft(s), bottom clearance(s)

– time of year, environmental conditions

An investigation of the motion behaviour may be required for all draft conditions planned, the degree of sophistication depending on the judgement of risks involved.

(2) For further specification reference is made to the following standards: GL Rules and Guidelines, IV-Industrial Services, Part 6 – Offshore Installations, API Recommended Practice 2A-LRFD. The appliance of the ISO/19901-6 is recommended after its implementation.

12.2.1.2 Float-out

(1) Float-out (i. e. raising and removing of a structure from the construction site, e. g. dry dock) shall be accomplished in a controlled manner, both as regards vertical movement and gradual transition to buoyant state, and horizontal movement when finally afloat. A winch system may be adequate in addition to or instead of tugs. Special attention must be paid to currents which may prevail outside the dock or building site.

(2) Sufficient buoyancy shall be provided to allow the structure to be securely towed out without touching obstructions at the bottom or sides. Where tidal differences exist, the calculated bottom clearance should be at least 0.5 m. Else a minimum of 0.3 m shall be observed. It should be avoided to rely on the coincidence of several favourable conditions such as high tide, fair weather and minimum draft.

(3) Additional temporary buoyancy may have to be provided where the draft of the structure is too large for the existing water depths, or for stability reasons.

(4) In all conditions, including intermediate construction stages, the freeboard must be sufficient to prevent the ingress of water through permanent or temporary openings, caused e. g. by waves and/or traffic. In any case the freeboard shall not be less than 0.3 m.

(5) Sufficient hydrostatic stability is to be provided for all phases of the raising and float-out procedure. The metacentric height (GM) should be at least 0.8 m.

(6) Free surfaces of liquid ballast shall be avoided.

(7) Flooding of one single compartment shall not lead to critical situations regarding stability or down-flooding; the angle of heel shall be limited to a value small enough to prevent the structure from grounding.

(8) Regarding ballasting, mooring and towing equipment and installations see the following and Section 12.2.2.4.

12.2.1.3 Sea transportation

(1) Sea transportation or towage, defined here as the transport of a structure from the last sheltered construction site to the place of final installation, will generally require a survey with a view to the particulars listed in Section 12.2.1.1 and Section 12.1.1 para 2. Sea transportation may be executed carrying a structure on board of a barge or ship, or by towing the self-buoyant structure.

(2) All vessels which are involved in the installation process shall maintain valid class by an approved classification body. Before accomplishment of the operation a certificate of fitness particularly for all security relevant installations and operational equipment has to be carried out.

(3) Sufficient tug power shall be provided to guarantee safe operations under the given conditions (wind, current, restricted waters) within the time schedule foreseen. Towing arrangement and nautical equipment shall be adequate for the intended route and subsequent manoeuvres at the installation site. Weather forecasting shall be observed. Adequate means for navigation through narrow passages shall be provided where applicable.

(4) In case of transportation on board of a barge or ship, the load distribution and the stresses occurring in the load carrying elements of both the vessel and the transported structure have to be investigated taking into account dynamical forces due to the motions (see

Section 12.2.1.1), and the elastic properties of the structural elements involved. Wind and water impact forces may have to be considered.

(5) Securing of the structure has to be effected with regard to sliding and toppling.

(6) Dimensioning of the securing elements shall be carried out considering Sections 5.3 and 6.6 of the present Guideline and Section 3.3.2 regarding materials. Load safety factors in accordance with Section 4.3.7 shall be taken into account.

(7) Securing and supporting elements shall be carefully designed to avoid local buckling. A combination of securing elements with different elasticities should be avoided, unless specifically accounted for in the calculations.

12.2.1.4 Towing of floating structures

(1) Regarding buoyancy, buoyancy aids, bottom clearance, stability and freeboard, the requirements under Section 12.2.1.2 apply in principle. A metacentric height $GM \geq 1.0$ m is recommended.

(2) Before commencing the towage, the structure has to be surveyed for integrity/leakages and closure means.

(3) Depending on the collision risk and on the geometry of the structure, it may be advisable to provide a one-compartment status (the structure remaining afloat in case of flooding of any one compartment likely to be damaged).

(4) Any loose objects carried on board of the floating structure are to be secured against possible accelerations, wind and wave impact.

(5) Fixings for towing wires and mooring chains shall be designed for a force 20 % in excess of the breaking strength of the wire (chain). Failure of a fixing point shall not lead to downflooding.

12.2.2 Installation at Sea

12.2.2.1 General

(1) The following indications apply to the installation of floatable structures by controlled flooding and subsequent founding procedures. Sea installation with the aid of cranes is covered by Section 12.1.2.

(2) Combinations of both types of installation procedures are possible and may be carried through applying the relevant indications of this Section accordingly.

(3) The downflooding procedure is to be investigated by buoyancy, stability and trim calculations for all stages. Model experiments may be advisable especially where the motion behaviour under various possible sea conditions is not sufficiently predictable by calculation.

(4) A thorough evaluation of all essential stages has to be carried through with a view to the time needed and to possible malfunctions or failures. Redundancy has to be provided for all critical operations. A “point of no return” may have to be established. The anticipated environmental conditions will be related to the time study.

(5) The manuals for sea transport and offshore installation (see Section 9.1) shall clearly indicate all safety-related measures and restrictions.

12.2.2.2 Positioning, stand-by vessels

(1) Positioning of the structure before lowering may be accomplished by mooring and/or tug assistance. The required accuracy and hence the possibilities of correction depend on water depth, installation method, environmental conditions (e. g. currents).

(2) Positioning aids (e. g. electro-acoustical systems) may be necessary in order to achieve the required degree of accuracy of final position. Function tests will be required for such equipment.

(3) The forces occurring in mooring chains and wires shall be determined taking into account maximum dislocations of the floating structure under the environmental conditions anticipated, including tidal differences and possible deviations of wire length etc. during the lowering procedure. A safety factor of $\gamma = 3$ against breaking strength is recommended.

12.2.2.3 Launching

(1) In case of launching floatable structures from a barge (including float-off) when arriving at the installation site (see Section 12.2.1.3 para 4), a calculation of the launching procedure will have to be presented, giving a sufficiently accurate prediction of the launching path geometry, the accelerations and the forces acting on the structure. Minimum calculated bottom clearance should be 5 m or 10 % of water depth, whichever is greater.

(2) Before downflooding, the floating structure will be closely examined, especially at locations where temporary fittings have been removed and at points where the transport and/or launching calculations indicated high stresses.

12.2.2.4 Ballasting and pressurizing

(1) All ballasting and pressurizing (deballasting) procedures shall be performed according to thoroughly prepared and checked schedules, and be adequately controlled. Functioning and status of valves should be able to be verified throughout the operation. Back-up fittings must be operable at any instant.

(2) Where deballasting by pressurization of single compartments is unavoidable during the lowering procedure, air pressure and water level shall be monitored, and the process should generally be capable of being interrupted and reversed at any stage.

(3) Where settlement (penetration) and inclination are to be achieved, control by differential ballasting shall be possible, and sufficient reserve capacity is to be provided.

12.2.2.5 Grouting procedures (gravity structures)

(1) Grouting and dewatering (venting) of the single compartments within the skirt boundary shall be carried out in a controlled manner. Flow rate and total grout volume shall be monitored and documented. Venting exits and critical points of the skirt should be observed in order to ensure, as far as possible, complete depletion of water by grout material.

(2) A sufficient reserve of grout material should be provided. Depending on the arrangement and possible protection, a reserve grout line should be provided.

12.2.2.6 Piling operations

(1) The arrangement of auxiliary vessels and piling equipment shall be such that the piling procedures as described in Chapter 6, including measures eventually to be taken (drilling, jetting etc.), can be accomplished within the time schedule prepared and agreed upon. Particularly, vessel and mooring installation shall be adequate for the weather conditions under which piling was considered feasible in the planning stage.

(2) The prescriptions and restrictions imposed by the approved piling specification shall be carefully observed, any unavoidable deviations documented.

(3) For grouting the provisions listed in Section 12.2.2.5 apply in principle.

12.2.2.7 Removal of temporary fittings and structures

The removal of parts no longer needed after installation, such as buoyancy tanks, has to be carried out according to carefully planned and approved procedures. The removal operations shall be controlled in an adequate manner so that any damages which might occur will be detected.

Rules and Guidelines

IV *Industrial Services*

2 Guideline for the Certification of Offshore Wind Turbines

13 Condition Monitoring

Edition 2005

Germanischer Lloyd
WindEnergie

Table of Contents

13.1 General

(1) In general, the requirements stated in the latest edition of GL Wind's "Guideline for the Certification of Condition Monitoring Systems for Wind Turbines" are applicable for offshore wind turbines as well. Special or additional information and requirements for these systems are given in the paragraphs below and in Section 13.2.

(2) A certified Condition Monitoring System (CMS) according to the latest edition of GL Wind's "Guideline for the Certification of Condition Monitoring Systems for Wind Turbines" is required for offshore wind turbines.

(3) This CMS

– can be certified together with the offshore wind turbine (parallel certification of wind turbine and CMS) or

– the CMS has already been certified before by GL Wind. In this case it has to be checked if the conditions, written in the Certification Report of the CMS, will be fulfilled by using the CMS in the specific offshore wind turbine.

13.2 Offshore Application

(1) The following operational parameters, if applicable, shall be measured or read from the control system of the offshore wind turbine, and integrated into the data evaluation by the CMS:

- wind direction
- outside temperature
- nacelle temperature
- temperature of dedicated bearings of the gearbox and the generator
- temperature of the generator windings
- oil temperatures and pressure (e.g. hydraulic oil, gear oil)
- messages about interventions in the control of the turbine (e.g. active adjustment of wind direction, activated hydraulic pump)

(2) Monitoring the blade vibration will be reasonable. A description has to be submitted.

(3) Additional information about the status of the offshore wind turbine and its components can be given by using camera(s) and microphone(s) or other suitable methods at characteristic places of the offshore wind turbine.

(4) The complete CMS incl. sensors, cables, etc. shall be adequate for the use at offshore conditions and that its functions will not be disturbed.

(5) Long period of grid unavailability might occur offshore. Measures have to be taken to save data in such cases. A description according to the latest edition of GL Wind’s “Guideline for the Certification of Condition Monitoring Systems for Wind Turbines” Section “Data Storage” shall take into account such conditions.

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