RULES FOR CLASSIFICATION OF

# High Speed, Light Craft and Naval Surface Craft

PART 3 CHAPTER 4

STRUCTURES, EQUIPMENT

# Hull Structural Design, Fibre Composite and Sandwich Constructions

JANUARY 2013

*The electronic pdf version of this document found through http://www.dnv.com is the officially binding version*



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# FOREWORD

DNV is a global provider of knowledge for managing risk. Today, safe and responsible business conduct is both a license to operate and a competitive advantage. Our core competence is to identify, assess, and advise on risk management. From our leading position in certification, classification, verification, and training, we develop and apply standards and best practices. This helps our customers safely and responsibly improve their business performance. DNV is an independent organisation with dedicated risk professionals in more than 100 countries, with the purpose of safeguarding life, property and the environment.

The Rules lay down technical and procedural requirements related to obtaining and retaining a Class Certificate. It is used as a contractual document and includes both requirements and acceptance criteria.



Any comments may be sent by e-mail to *rules@dnv.com*

# CHANGES

### General

This document supersedes the July 2012 edition.

Text affected by the main changes in this edition is highlighted in red colour. However, if the changes involve a whole chapter, section or sub-section, normally only the title will be in red colour.

### Main changes coming into force 1 July 2013

- **Sec.7 Stiffeners, Web Frames and Girders**

— Sub-section element B300 has been revised for clarification.
— In item C402, Fig.2 has been revised.

### Editorial Corrections

In addition to the above stated main changes, editorial corrections may have been made.

# CONTENTS

# SECTION 1
# STRUCTURAL PRINCIPLES

## A. Definitions

### A 100 Application

**101** These rules apply to structures of fiber reinforced plastic (FRP) single skin and sandwich constructions for assignment of the main class. The plastics used in such applications shall be thermosets.

**102** A single skin construction is considered to be a structure consisting of a FRP shell laminate supported and stiffened locally by a system of closely spaced FRP stiffeners.

**103** A sandwich construction is considered to be a structural element consisting of three components: a FRP skin laminate on each side of a low density core. It is assumed that the properties and the proportions of the component materials are such that when a sandwich panel is exposed to a lateral load the bending moments are carried by the skins and the shear forces by the core.

**104** These rules do not apply of monococque constructions. Acceptance criteria for monococque constructions will have to be agreed in each case.

### A 200 Symbols

**201** The following symbols are used in the formulae in Sec.4, Sec.5, Sec.6 and Sec.7 in this Part:

$t$ = laminate thickness in mm, either for a single skin shell or a sandwich skin laminate.
$t_c$ = sandwich core thickness in mm.
$d$ = distance between centrelines of opposite skin laminates of a sandwich panel in mm.
$E$ = tensile or compressive modulus of elasticity of FRP laminate in N/mm$^2$.
$E_C$ = modulus of elasticity of core material in N/mm$^2$ given on type approval certificate.
$G_C$ = modulus of rigidity (shear modulus) of sandwich core material in N/mm$^2$ given on type approval certificate.
$\sigma_{nu}$ = ultimate normal stress in tension or compression of FRP laminate in N/mm$^2$.
$\sigma_n$ = normal stress in FRP laminate in N/mm$^2$.
$\sigma_c$ = combined bending and membrane stress in N/mm$^2$.
$\sigma_{cr}$ = critical buckling stress in N/mm$^2$.
$\tau$ = shear stress in FRP laminate in N/mm$^2$.
$\tau_{ult}$ = ultimate shear stress in FRP in N/mm$^2$.
$\tau_u$ = ultimate shear stress of sandwich core material in N/mm$^2$ given on type approval certificate.
$\tau_c$ = core shear stress in laterally loaded sandwich panel in N/mm$^2$.
$\omega$ = panel deflection in mm.
$\delta$ = panel deflection factor.
$\nu$ = Poisson's ratio.
$p$ = design pressure in kN/m$^2$ as given in Ch.1.
$a$ = longest side of sandwich or single skin panel in m.
$b$ = shortest side of sandwich or single skin panel in m.

## B. Documentation

### B 100 Required documentation

**101** The following documentation shall be submitted for plan approval:

a) Drawings as per the requirements in these rules.
b) Specifications of all reinforcement fabrics.
c) Specifications of all resins.
d) Details of all laminates and panels: stacking sequence and the mechanical properties used for the design, see 102 and fabrication method (e.g. manual lamination or VARTM etc.).
e) Plan for qualification testing, see Sec.3 C.

All of these documents are subject to approval by DNV. Plan approval may not be initiated until all of the documentation has been submitted.

**102** The laminate details shall be presented in the form of a table or on a equivalent format giving the following information for each laminate and panel:

a) Laminate or panel identification.
b) Stacking sequence including references to specifications of reinforcement and resins.
c) Engineering moduli as relevant. For orthotropic laminates the engineering moduli in the two principal directions and the shear modulus shall be given.
d) Tensile strength and compressive strength or strain.
e) Shear strength.
f) Fibre volume fraction.
g) Laminate thickness.

**103** The plan for qualification testing shall be defined in accordance with Sec.3 C. The plan can be presented as notations on the table giving laminate details, see 102.

## C. Structural Calculations

### C 100 Design principles

**101** The vessel shall be designed such that the load(s) are carried mainly by the fibres. The fibres shall be aligned close to the direction(s) of the main load path(s).

**102** The failure mode of a laminate shall be fibre failure. Matrix failure shall be inhibited by alignment of the fibres according to 101, by having fibres in sufficient directions and by a stacking sequence avoiding fibre clusters.

**103** Deviations from 101 may be accepted in local areas of details that are well proven and for minor loads of secondary nature.

### C 200 Calculation levels

**201** The structural calculations may be performed in one of three different levels. The calculation level can be chosen to best suit the purpose:

*Simplified calculation method:* This is based on rule formulas. May be used for panels, stiffeners and girders as indicated in the respective rule chapters.

*Laminate calculation method:* This is based on the strain failure criteria. Typical application of this method would be in combination with global hull calculations, or calculations of larger structural elements using finite element methods.

*Detailed laminate calculation method:* This is based on ply calculation theory and well accepted failure criteria. Typical use would be where detailed information of stresses in a local area is needed.

### C 300 Calculation basis

**301** The strength values and safety factors are based on ultimate strength as defined below:

*For laminates:* Mean value of representative test data.

The use of a mean value for laminates is based on the assumption that the laminates are of a consistent quality, i.e. a standard deviation of material test values is less than 7%.

*For core materials:* Specified minimum value.

The specified minimum value is defined as “Mean value – 2 standard deviations” as determined from tests. To be taken from Type Approval certificate.

*Secondary bond strength:* Mean value of representative test data.

It is assumed that the production can show consistent secondary bond test values.

### C 400 Simplified calculation methods

**401** Simplified calculation methods based on rule formula in Sec.5, Sec.6 and Sec.7 may be used in accordance with the conditions given in the respective rule sections.

**402** Allowable stresses and deflections to be used in association with the simplified calculation method are given in the respective sections.

### C 500 Laminate calculation method

**501** A strain failure criteria for laminate strength will be accepted based on the conditions given below:

— The load is carried mainly by the fibres. A major part of load-carrying fibres are aligned close to the direction of the main load path. The angle between the main load path and a significant part of the fibres is never more than 25°. The failure mode is fibre failure.
— Matrix failure is inhibited by fibres in sufficient directions, and the fibres are not clustered.
— The strains in the structure are calculated taking into account the laminate stiffness in all in-plane directions.
— All important load combinations for the laminate are to be considered.
— Local deviations between the load path and fibres due to local stress concentrations should be considered separately, possibly by adding local pads or strips in the local load direction.

**Guidance note:**
Construction elements carrying the load mainly by the matrix should be avoided.

A main load path is meant as a load direction giving significant strain for the laminate.

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**502** *Strain failure criterion*

The fiber strain in each fiber direction is to be limited by:

$$\varepsilon_i \leq \frac{\varepsilon_{uf}}{R}$$

$\varepsilon_i$ = laminate strain in direction i
$\varepsilon_{uf}$ = ultimate fibre strain, as defined below
R = safety factor against fibre failure

A reduced compressive strain due to elastic instability shall be used in the criterion provided it is relevant for the laminate and the laminate/core combination as shown in Fig.1.

**503** *Definition of material values*

$$\varepsilon_{uf} = \frac{\sigma_u}{E_r}$$

The $\varepsilon_{uf}$ is to be calculated based on material tests:

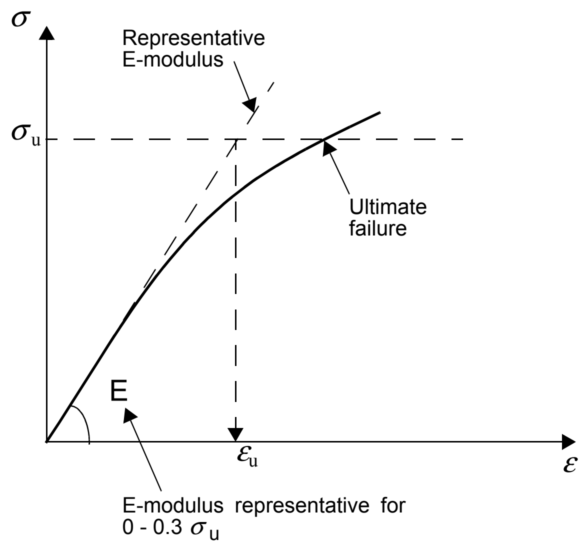


**Fig. 1**
**Stress strain relation**

$\sigma_u$ = ultimate tensile or compressive strength, as required
$E_r$ = representative E modulus for the laminate in the range of allowable stresses. The representative modulus is normally defined as secant modulus at $0.3\sigma_u$ determined either by measurements or by laminate theory.

If the laminate is built up by a combination of different mats, woven rovings etc., the $\varepsilon_{uf}$ may be calculated based on test data from the basic components.

**Guidance note:**

In most cases the E modulus as defined in ISO 527-4 and ISO527-5 will qualify as "representative E modulus"

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### C 600 Detailed laminate calculations

**601** A detailed laminate calculation may be used where detailed information of stresses or strain in a local area is needed. The calculation may be based on ply theory and well accepted failure criteria. In order to use such method, it may be required to justify that the ply input data gives correct output values for all combinations in the failure envelope.

**Guidance note:**

One of the accepted failure criteria is the Tsai-Wu failure criterion.

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### C 700 Allowable stresses and deflections

**701** The factor of safety is to be in accordance with Table C1. Core shear stresses in sandwich panels shall be in accordance with Sec.5 B500. Panel deflections shall not be greater than specified in Sec.5 and Sec.6.

**Table C1 Failure strength ratio, R**

| *Structural member* | *R* |
|---|---|
| Bottom panel exposed to slamming | 3.3 |
| Remaining bottom and inner bottom | 3.3 |
| Side structures | 3.3 |
| Deck structures | 3.3 |
| Bulkhead structures | 3.3 |
| Superstructures | 3.3 |
| Deckhouses | 3.3 |
| All structures exposed to long-term static loads (duration exceeding 3 months) | 4.5 |

### C 800 Direct calculations by finite element methods

**801** Direct calculations of structural strength by use of finite element methods (FEM) may be used as an alternative to the simplified calculation methods. General requirements for the analysis and programs are given in Pt.3 Ch.9. The acceptance criteria used in connection with FEM calculations should preferably be the laminate calculation method (strain criteria) as described in 500.

**802** Safety factors for direct strength calculations shall be as specified in Table C1.

**803** For detailed calculations where all stress concentrations and load combinations are represented by the FEM results, lower R factors may be agreed upon based on an evaluation of each case.

## D. Bottom Structures

### D 100 Longitudinal stiffeners

**101** Single bottoms as well as double bottoms are normally to be longitudinally stiffened in craft built in single skin construction. In craft with sandwich construction the bottom panel stiffening will be considered in each individual case.

**102** The longitudinals should preferably be continuous through transverse members. At their ends longitudinals are to be fitted with brackets or to be tapered out beyond the point of support.

**103** Longitudinal stiffeners are to be supported by bulkheads and/or web frames as shown in Fig.2.

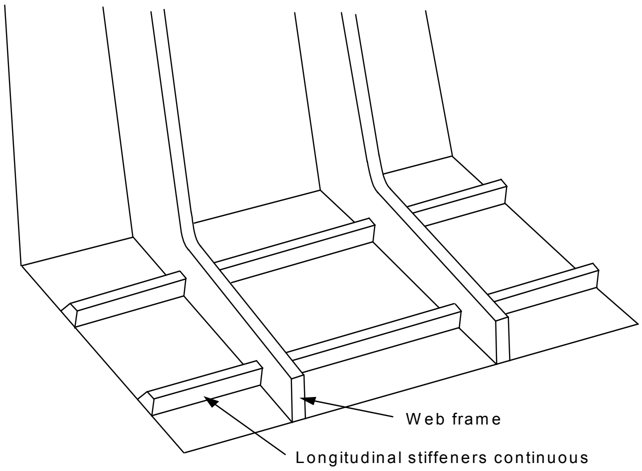


**Fig. 2**
**Stiffener and frame connections**

### D 200 Web frames

**201** Web frames are to be continuous around the cross section of the craft, i.e. web- and flange laminates of floors, side webs and deck beams are to be efficiently connected together. If intermediate bottom frames are fitted their ends should be well tapered or connected to local panel stiffening.

**202** Additional strengthening is to be provided in way of thrust bearings and foundations.

### D 300 Longitudinal girders

**301** Longitudinal girders are to be carried continuously through bulkheads. In craft built in sandwich construction longitudinal girders may be fitted to support the bottom panels.

**302** A centre girder is to be fitted for docking purposes if the external keel or bottom shape does not give sufficient strength and stiffness.

**303** Openings should not be located at ends of girders without due consideration being taken to shear loadings.

### D 400 Engine girders

**401** Main engines are to be supported by longitudinal girders with suitable local reinforcement to take the engine and gear mounting structure. Rigid core materials shall be applied in all through bolt connections.

### D 500 Double bottom

**501** Manholes are to be made in the inner bottom, floors and longitudinal girders to provide access to all parts of the double bottom. The vertical extension of openings is not to exceed one half of the girder height. Exposed edges of openings in sandwich constructions are to be sealed with resin impregnated mat. All openings are to have well rounded corners.

### D 600 Bow impact protection

**601** Vessels built in sandwich construction shall have the fore stem designed so that a local impact at or below the water line will not result in skin laminate peeling due to hydraulic pressure.

**602** To comply with the requirement in 601 outer and inner skin laminate of the hull panel shall be connected together as shown in Fig.3. The distance –a– shall be not less than:

$$a = 0.15 + \frac{1.5\,V^2\Delta}{10^6}\ \text{(m)}$$

The vertical extension of the collision protection shall be from the keel to a point 0.03 L (m) above the water line at operating speed.

**603** The connection of the skin laminates shall be arranged in such a way that laminate peeling is effectively arrested, e.g. as shown in Fig.4.

**604** Other arrangements giving an equivalent safety against laminate peeling may be accepted based on considerations in each individual case.

**605** Within the vertical extension of the collision protection the stem laminate shall be increased to a thickness not less than:

$$t_s = \frac{7 + (0.1V)^{1.5}}{\sqrt{\frac{\sigma_{nu}}{160}}} \quad \text{(mm)}$$

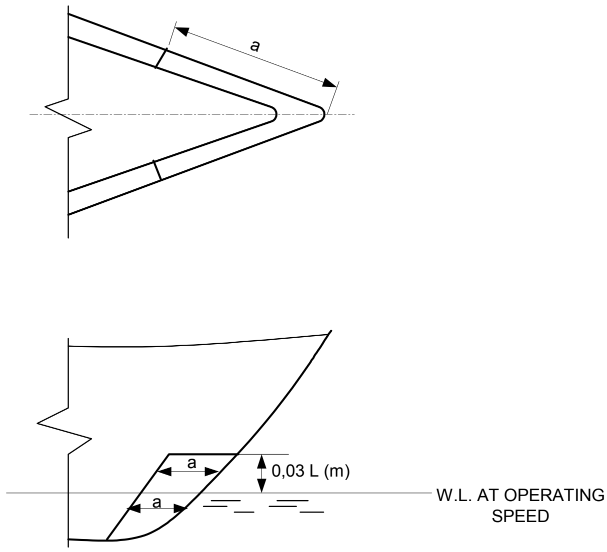


**Fig. 3**
**Collision Protection**

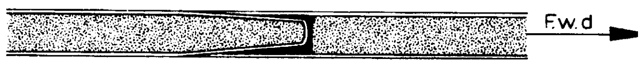


**Fig. 4**
**Laminate connection**

## E. Side Structures

### E 100 Stiffeners

**101** The craft sides may be longitudinally or vertically stiffened.

**102** The continuity of the longitudinals is to be as required for bottom and deck longitudinals respectively.

## F. Deck Structure

### F 100 Longitudinal stiffeners

**101** Decks of single skin construction are normally to be longitudinally stiffened.

**102** The longitudinal stiffeners should preferably be continuous through transverse members. At their ends longitudinals are to be fitted with brackets or to be tapered out beyond the point of support.

**103** The laminate thickness of single skin constructions is to be such that the necessary transverse buckling strength is achieved, or transverse intermediate stiffeners may have to be fitted.

### F 200 Bulwarks

**201** Bulwark sides shall have the same scantlings as required for a superstructure in the same position.

**202** A strong flange is to be made along the upper edge of the bulwark. Bulwark stays are to be arranged in line with transverse beams or local stiffening. The stays are to have sufficient width at deck level. If the deck is of sandwich construction solid core inserts are to be fitted at the foot of the bulwark stays. Stays of increased strength are to be fitted at ends of bulwark openings. Openings in bulwarks should not be situated near the ends of superstructures.

**203** Where bulwarks on exposed decks form wells, ample provision is to be made to facilitate freeing the decks from water.

## G. Bulkhead Structures

### G 100 Watertight bulkheads

**101** The number and location of transverse watertight bulkheads are to be in accordance with the requirements given in Ch.1 Sec.1 B.

### G 200 Supporting bulkheads

**201** Bulkheads supporting decks are to be regarded as pillars. The buckling strength will be considered in each individual case.

## H. Superstructures and Deckhouses

### H 100 Definitions

**101** Superstructure is defined as a decked structure on the freeboard deck, extending from side to side of the ship or with the side plating not inboard of the shell plating more than 4% of the breadth (B).

**102** Deckhouse is defined as a decked structure above the strength deck with the side plating being inboard of the shell plating more than 4% of the breadth (B).

*Long deckhouse* – deckhouse having more than 0.2 L, of its length within 0.4 L amidship.

*Short deckhouse* – deckhouse not defined as a long deckhouse.

### H 200 Structural continuity

**201** In superstructures and deckhouses, the front bulkhead is to be in line with a transverse bulkhead in the hull below or be supported by a combination of girders and pillars. The after end bulkhead is also to be effectively supported. As far as practicable, exposed sides and internal longitudinal and transverse bulkheads are to be located above girders and frames in the hull structure and are to be in line in the various tiers of accommodation. Where such structural arrangement in line is not possible, there is to be other effective support.

**202** Sufficient transverse strength is to be provided by means of transverse bulkheads or girder structures.

**203** At the break of superstructures, which have not set-in from the ship’s side, the side plating is to extend beyond the ends of the superstructure, and is to be gradually reduced in height down to the deck or bulwark. The transition is to be smooth and without local discontinuities.

**204** In long deckhouses, openings in the sides are to have well rounded corners. In deckhouses of single skin construction horizontal stiffeners are to be fitted along the upper and lower edge of large openings for windows. Openings for doors in the sides are to be substantially stiffened along the edges.

**205** Casings supporting one or more decks above are to be adequately strengthened.

# SECTION 2
# MANUFACTURING

## A. General Requirements

### A 100 Introduction

**101** In this Section requirements related to the manufacturing, quality assurance and quality control of FRP structures are given. It is to be recognised by the yard that there are limited or no means for non-destructive examination of FRP structures available. The yard is therefore to recognise the importance of exercising a rigorous control of all steps of the fabrication to ascertain that the finished product complies with its specification(s).

**102** The use of fabricating procedures differing from those specified in this Section will be subject to special consideration.

## B. Storage of Raw Materials

### B 100 Storage

**101** Storage premises are to be so equipped and arranged that the material supplier's directions for storage and handling of the raw materials can be followed.

**102** Storage premises for reinforcement materials are to be kept dry and clean so that the raw material is not contaminated. The materials shall be stored in unbroken original packaging before being used. Materials on which the original packaging has been broken shall be adequately protected against contamination when stored again after use.

**103** Reinforcement materials shall normally be stored at the same temperature and humidity as the workshop in which they are going to be used. If the storage temperature is not the same the material shall be acclimatised at the workshop temperature and humidity prior to being deployed. The time of acclimatisation shall be adequate for the amount of reinforcement: for unbroken packages the acclimatisation shall have duration of at least two days.

**104** Resins, gelcoat, hardeners, additives etc. shall be stored according to the manufacturers recommendations as regards temperature, shelf life etc. Raw materials which are stored at temperatures lower than + 18°C shall be acclimatised to the temperature of the workshop prior to being used. Tanks for resins etc. are to be handled during storage according to the manufacturers recommendations and equipped and arranged accordingly.

**105** Core materials are to be stored dry and protected against contamination and mechanical damage. Core materials shall normally be stored at the same temperature as the workshop in which they are going to be used. If the storage temperature is not the same the material shall be acclimatised for at the workshop temperature and humidity prior to being deployed.

**106** Core materials shall be stored in such a way that out-gassing of the material is ensured prior to being used. Outgassing shall be carried out according to the manufacturers recommendations. When new free surfaces is created in the material, e.g. by sanding, cutting or machining, proper outgassing shall be ensured again.

**107** Pre-pregs shall be stored according to the manufacturer's recommendation. For pre-pregs stored in refrigerated conditions a log shall be carried for each package showing the time and at which temperature the package has been stored/used outside its normal storage conditions.

### B 200 Manufacturing premises and conditions

**201** Manufacturing premises are to be so equipped and arranged that the material supplier's directions for handling the materials, the laminating process and curing conditions can be followed.

**202** The manufacturing premises shall be free from dust and other contamination that may in any way impair the quality of the end product.

**203** The air temperature in the moulding shops is not to be less than +18°C. The stipulated minimum temperature is to be attained at least 24 hours before commencement of lamination, and is to be maintainable regardless of the outdoor air temperature.

The temperature in the moulding shop is not to vary more than ± 5°C. This limit can be exceeded provided it has no detrimental effect on the product and provided there is no risk for condensation of humidity.

**204** The relative humidity of the air is to be kept so constant that condensation is avoided and is not to exceed 80%. A higher relative humidity can be accepted on a case by case basis provided an adequate margin against the risk for condensation of humidity is provided.

In areas where spray moulding is taking place, the air humidity is not to be less than 40%. The stipulated air humidity is to be maintainable regardless of outdoor air temperature and humidity.

More stringent requirements to humidity shall be adhered to if recommended by the manufacturer.

**205** Other manufacturing conditions may be accepted based on special agreement with the Society provided that condensation of humidity can be safely avoided.

**206** Air temperature and relative humidity are to be recorded regularly and the records filed for a period of at least two years. In larger shops there is to be at least one thermohydrograph for each 1500 $m^2$ where lamination is carried out. The location of the instruments shall be such as to give representative measurement results.

**207** Draught through doors, windows etc. and direct sunlight is not acceptable in places where lamination and curing are in progress.

**208** The ventilation plant is to be so arranged that the curing process is not negatively affected.

**209** Sufficient scaffoldings are to be arranged so that all lamination work can be carried out without operators standing on the core or on surfaces on which lamination work is taking place.

**210** During lamination of larger constructions the temperature should be recorded at least at two levels vertically in the workshop and the curing system should be adjusted to compensate for possible temperature differences.

**211** Prefabrication of panels and other components is to be carried out on tables, fixtures etc. above the shop floor level. No fabrication shall be carried out on the shop floor.

## C. Production Procedures and Workmanship

### C 100 General requirements

**101** Raw materials for all structural members covered by the Rules are to be of approved type in accordance with Sec.4. The supplier's directions for application of the materials are to be followed.

**102** Specified procedures shall be implemented for all tasks with significance to the quality of the end product. Where necessary to exercise a satisfactory control of the quality, these procedures shall be documented in writing in controlled documents.

**103** The reference direction of reinforcement shall after being laid not deviate from the specified by more than ± 5°.

**104** Adjacent sheets of reinforcement shall in the normal case overlap to give structural continuity. The overlap length shall be such that the shear capacity of the overlap is not smaller than the tensile strength (perpendicular to the overlap) of the overlapping plies. The shear strength of the matrix shall not be assumed larger than 8 MPa. A higher shear strength can be assumed subject to the approval of the Society. (E.g. for a 0/90° 1 000 $g/m^2$ type glass reinforcement the overlap shall not be smaller than 30 mm.) In areas of low utilisation, overlaps may be dispensed with subject to the approval of the Society. Overlaps shall be staggered through the thickness of the laminate. The distance between two overlaps in adjacent plies shall not be smaller than 100 mm.

**105** Thickness changes in a laminate should be tapered over a minimum distance equal to 10 times the difference in thickness.

**106** Thickness changes in core materials should be tapered over a minimum distance equal to 2 times the difference in thickness. A larger distance may be required to maintain structural continuity of the skins.

### C 200 Sandwich lay-up

**201** Sandwich constructions can be fabricated either by lamination on the core, application of the core against a wet laminate, by bonding the core against a cured skin laminate using a core adhesive, by resin transfer, or by resin transfer moulding of the core together with one or both of the skin laminates.

**202** An efficient bond is to be obtained between the skin laminates and the core and between the individual core elements. The bond strength shall not be smaller than the tensile and shear strength of the core. The application of a light CSM between core and skin laminate may be advantageous in this respect.

**203** Approved tools for cutting, grinding etc. of various types of core material shall be specified in the production procedure.

**204** All joints between skin laminates and core and between the individual core elements are to be completely filled with resin, adhesive or filler material. The joint gap between core blocks should generally not be larger than 3 mm. Larger gaps may be accepted if necessary, based on the characteristics of the adhesive or filler (e.g. its viscosity) and the thickness of the core. For slamming exposed areas a larger gap width should also be reflected in the qualification testing of the core material and the adhesive, i.e. during slamming testing, c.f. Pt.2 Ch.4 and DNV Type Approval Program for core materials.

**205** Core materials with open cells in the surface, should normally be impregnated with resin before it is applied to a wet laminate or before lamination on the core is commenced.

**206** When the core is applied manually to a wet laminate the surface shall be reinforced with a chopped strand mat of 450 $g/m^2$ in plane surface and 600 $g/m^2$ in curved surfaces.

If vacuum is applied for core bonding the surface mats may be dispensed with provided it is demonstrated in the qualification tests that an efficient bond between core and skin laminate is obtained.

**207** If the core is built up by two or more layers of core and any form of resin transfer is used, arrangements shall be made to ensure proper resin transfer and filling between the core blocks. This should be achieved by scoring or holing the core blocks and by placing a reinforcement fabric between the core blocks to facilitate resin distribution.

**208** Frameworks for core build up shall give the core sufficient support to ensure stable geometrical shape of the construction and a rigid basis for the lamination work.

**209** When a prefabricated skin laminate is bonded to a sandwich core measures are to be taken to evacuate air from the surface between skin and core.

**210** The core material is to be free from dust and other contamination before the skin laminates are applied or core elements are glued together. The moisture content shall be sufficiently low not to have any adverse effect on curing. The acceptable moisture content shall be specified by the manufacturer of the core material.

**211** When vacuum-bagging or similar processes are used it shall be ensured that curing in the core adhesive has not been initiated before vacuum is applied.

### C 300 Manual lamination

**301** The reinforcement material is to be applied in the sequence stated on the approved plan(s).

**302** When the laminate is applied in a mould a chopped strand mat of max. 450 $g/m^2$ is to be applied next to the gelcoat.

The mat can be dispensed with provided a satisfactory resistance against water can be ensured.

**303** The resin is to be applied on each layer of reinforcement. Gas and air pockets are to be worked out of the laminate before the next layer is applied. Rolling of the layers are to be made carefully, paying special attention to sharp corners and transitions.

The viscosity and gel-time of the resin shall be adequate to prevent drain-out of resin on vertical and inclined surfaces.

The tools and methods used when working the laminate shall not damage the fibres.

**304** The time interval between applications of each layer of reinforcement is to be within the limits specified by the resin supplier. For thicker laminates care is to be taken to ensure a time interval sufficiently large to avoid excessive heat generation.

**305** Curing systems are to be selected with due regard to the reactivity of the resin and in accordance with the supplier's recommendations. Heat release during curing is to be kept at a safe level in accordance with the material manufacturer's recommendations. The quantity of curing agents is to be kept within the limits specified by the supplier.

**306** After completion of lamination, polyester laminates are to cure for at least 48 hours at an air temperature of minimum +18°C. Curing at a higher temperature and a shorter curing time may be accepted on the basis of control of the curing rate. For other types of resins curing shall be carried out according to the specified cure cycle and according to the resin manufacturer's recommendations.

### C 400 Vacuum assisted resin transfer moulding (VARTM) and vacuum-bagging

**401** Points of resin injection shall be located and opened and closed in a sequence such that complete filling of the mould without any air being trapped is ensured.

**402** The resin shall be formulated, based on the resin manufacturer's recommendations, such that an adequate viscosity and gel-time is obtained to enable filling of the complete mould and such that the maximum temperature during cure is kept within acceptable limits, e.g. with respect to the temperature sensitivity of core materials.

**403** The pressure level (vacuum) in the mould shall be specified prior to infusion. The pressure shall be adequate to ensure adequate consolidation of the laminate and that the specified mechanical properties are reached and that the mould is properly filled. The pressure shall be maintained throughout the mould during the cure cycle of the laminate, at least past the point of maximum temperature in the laminate, and the specified hold time. The vacuum shall be monitored by the use of pressure gauges distributed throughout the mould such that a reliable indication of the pressure distribution is obtained. This means that pressure gauges shall be placed far away from vacuum suction points. Adequate means to locate and repair leakage shall be deployed.

### C 500 Spray moulding

**501** The term spray moulding is understood to mean the simultaneous deposit of resin and fibreglass reinforcement. Manufacturers using this method are subject to special approval.

**502** When approval of the spray moulding process is considered, special attention will be paid to production arrangement, ventilation equipment, the manufacturer's own quality control and other factors of significance to the quality of the finished product.

**503** Spray moulding of structural members is to be carried out only by specially approved operators.

**504** The equipment used for spray moulding is to give an even and homogenous build up of the laminate. Any dosage devices are to ensure an even application of additives to the polyester resin. No fibres are to be shorter than 20 mm.

**505** When spray moulding there is to be an even application over the entire surface. Regular rolling out of the sprayed-on layers is to be carried out. Next to the gelcoat rolling out is to be done for max. 1.5 mm thickness of finished laminate thickness, subsequently for at least each 2.5 mm of finished laminate thickness. The rolling out is to be done thoroughly to ensure adequate compression and removal of gas and air pockets. Special care is to be taken at sharp transitions and corners.

### C 600 Curing

**601** Cure cycles shall be documented by temperature records.

**602** For cure taking place at room temperature in the workshop the registrations made in the workshop are sufficient to document the cure cycle.

**603** For cure at elevated temperature, fans with ample capacity shall be operated in the compartment in which the cure is carried out to ensure an even distribution of temperature. Continuous records of temperature throughout the complete cure cycle shall be provided. Recording points shall be distributed throughout out the length, width and height of the cure compartment to the extent necessary to verify that the temperature distribution is even.

### C 700 Secondary bonding

**701** A secondary bonding is defined as any bond between two FRP structures which is made after one or both of the individual structures has effectively cured.

**702** The surface ply of a laminate subject to secondary bonding and the first ply of the bonding laminate is normally to be of chopped strand mat. This mat can be dispensed with provided the necessary bond strength is reached.

**703** Surfaces in way of secondary bonding are to be clean and free from dust and other forms of contamination.

**704** Laminates on which secondary bonds are to be carried out shall have an adequate surface preparation, normally including grinding.

**705** If «peel strips» are used in the bonding surface the required surface treatment may be dispensed with.

### C 800 Adhesive Bonding

**801** Adhesive bonds shall be carried out according to the same procedure(s) as on which the design and qualification testing has been based, ref. Sect. 8 and according to the recommendations from the manufacturer of the adhesive. Procedure(s) shall be submitted to the Society prior to commencement of the bonding work. The procedure(s) shall give clear requirements to all factors that can affect the quality of the bond. As a minimum the following shall be covered: working conditions, surface preparation, application, clamp-up, curing cycle etc.

## D. Quality Assurance and Quality Control

### D 100 Quality assurance

**101** The shipyard is to have implemented an efficient system for quality assurance to ensure that the finished product meets the specified requirements. The person or department responsible for the quality assurance shall have clearly established authority and responsibility and be independent of the production departments.

**102** The system should be formalized through a quality handbook or similar document at least containing the following main objects:

— organisation of all quality related activities
— identification of key personnel and their responsibilities
— procedures for documentation
— qualification of personnel
— manufacturing conditions including recording of temperature and humidity
— receipt and storage of raw materials
— working procedures and instructions
— formulation of resins
— lamination records
— procedures for quality control and inspection or testing
— repair procedures
— defect acceptance criteria.

The quality handbook shall be made available to the surveyor.

### D 200 Quality control

**201** A written quality plan shall be established for the production of each hull and superstructure. The quality plan is subject to approval of the surveyor prior to commencement of the production.

**202** The quality plan shall address at least the following items:

— relevant specifications, rules, statutory requirements etc.
— drawings
— list of raw materials
— procedures for handling of raw materials
— manufacturing procedures and instructions
— procedure for keeping and filing of lamination records
— procedure for keeping and filing of cure logs:
temperature and vacuum (for VARTM)
— procedures for quality control and inspection or testing
— inspection points
— witness points by the DNV surveyor
— production testing of laminates, joints and panels in accordance with 300
— procedures for corrective actions when deficiencies are identified.

The quality plan may contain copies of all the necessary documentation or may refer to documents in the quality handbook or other controlled documentation. The relevant drawings may e.g. be identified by a list of drawings.

### D 300 Production testing

**301** The purpose of production testing is to verify that a consistent level of quality is maintained throughout production. (Requirements for testing for qualification of material properties to be used in design are given Sec.3).

**302** The yard is to specify a production test plan, as part of the quality plan, which as a minimum is to address the following items:

— mechanical strength of sandwich skin laminates, single skin laminates, flanges (caps) of stringers and girders
— bond strength between core and skin laminates in sandwich panels
— mechanical strength of major attachments and joints
— acceptance criteria.

The extent of testing is not to be smaller than given in Table D1.

**Table D1 Extent of testing**

| *Area* | *Testing* |
|---|---|
| Hull bottom, sandwich | 5 parallel tensile tests of outer skin |
| Hull bottom, single skin | 5 parallel tensile tests of bottom panel |
| Main deck, sandwich | 5 parallel tensile tests of outer skin |
| Main deck, single skin | 5 parallel tensile tests of panel |
| 1 off main girder or stringer | 5 parallel tensile tests of top flange/cap |
| Hull bottom, sandwich | 5 parallel through-thickness tensile tests |

The test methods specified in Sec.3 are to be used. Through-thickness tests shall be carried out according to ASTM C297. The through thickness tensile tests of sandwich may be replaced by peel tests subject to the approval by the Society. For details considered critical with respect to compressive loads compression tests may be required instead of or in addition to the tensile tests.

In case more extensive testing is considered necessary by the Society, reliable NDT methods may be considered as an alternative to destructive testing.

**303** The test samples shall be taken from cut-outs in the hull and main deck. All such cut-outs shall be identified by marking and stored until used for testing purposes or until completion of the vessel. If adequate cut-outs are not possible to obtain alternative methods to verify the mechanical strength of the structures shall be agreed upon with the Society.

**304** Material selection, design, fabrication methods and QA/QC procedures may differ significantly between different vessels and yards. A larger or different extent of testing may therefore be required by the Society. The extent of testing may also be made dependent on the degree of utilisation of the particular component or the consequences of a failure of the component.

**305** The test plan is subject to approval by DNV hull plan approval engineer prior to commencement of fabrication.

**306** The test results shall be in accordance with the values of mechanical strength used in the design and indicate a level of workmanship in line with good industry standard. The test results shall be submitted to and approved by the responsible hull plan approval engineer.

# SECTION 3 MATERIALS

## A. General

### A 100 Introduction

**101** In this Section requirements regarding the application of the various structural materials as well as material protection and material testing are given.

### A 200 Material certificates

**201** Reinforcement, matrix, fillers and core materials for major hull structural elements are normally to be delivered with DNV product certificate or be type approved by DNV.

**202** Adhesives used for bonded joints shall be type approved by DNV.

## B. Application of Materials

### B 100 Hull and superstructure

**101** The resin in hull and superstructure may be polyester, vinylester or epoxy. Other types of resins may be accepted based on special consideration.

**102** When using polyester, Grade 1 polyester is to be used for the hull shell laminate in single skin constructions and for the outer hull skin laminate in sandwich construction. For the inner skin laminate and superstructure Grade 2 polyester may be accepted. Specifications for Grade 1 and Grade 2 resins are given in Pt.2 Ch.4.

**103** The outer reinforcement ply of the hull laminate (outer skin on sandwich panels) shall provide an adequate barrier against the penetration or absorption of water in the laminate. This also applies for areas inside the hull expected to be continuously exposed to water submersion (i.e. bilge wells, etc.).

### B 200 Tanks for storage of liquids

**201** The inside coating layer of tanks shall provide an adequate barrier against the penetration or absorption of fluids in the laminate.

**202** The surface lining is as far as practicable to be laid continuously in the tanks side and bottom.

### B 300 Surface coating

**301** The underwater part of the hull, the inside of tanks for liquids and other areas exposed to permanent liquid submergence are to have an efficient surface coating, such as gelcoat, topcoat or an epoxy based painting, of sufficient thickness.

**302** Other weather exposed surfaces are to have a suitable surface coating.

**303** For inspection purposes the surface coating internally in the hull bottom is wherever feasible to be unpigmented.

Where pigments are used, light colours should be used to expose damage and cracks more readily.

## C. Material Properties and Qualification Testing

### C 100 Basis for strength calculations

**101** The design of the vessel is to be based on mechanical properties that are representative for the raw materials, production method(s), workshop conditions, lay-up sequence etc. that are used. The mechanical properties are to be based on mechanical qualification tests carried out on representative samples. For well known materials and production methods the mechanical properties may be based on standard engineering analytical methods, such as micro mechanics, laminate theory etc., substantiated by a reduced amount of qualification testing.

**102** The qualification testing is normally to be carried out and approved by the Society prior to carrying out the design of the vessel. The yard shall submit a plan for qualification testing for approval by the Society prior to hull plans being approved. The plan for testing may invoke results from previous representative and well documented testing. The test methods specified in 200 shall be used.

**103** The required extent of qualification testing will be considered in each individual case in accordance with 101. The following parameters shall be addressed:

| | | |
|---|---|---|
| Single skin laminates | Tensile strength | Note 1. |
| | Compressive strength | Note 2. |
| | Shear strength | Note 3. |
| Sandwich skin laminates | Tensile strength | Note 1. |
| | Compressive strength | Note 2. |
| | Shear strength | Note 3. |
| Flanges of girders, web frames, stiffeners | Tensile strength | Note 1. |
| | Compressive strength | Note 2. |
| Bond between core and skin in sandwich panels | Shear strength | |

Note 1: Shall be carried out on a selection of laminates.

Note 2: Shall be carried out on a selection of laminates. For carbon laminates in sandwich skins the compression tests shall include the effect of the core.

Note 3: The shear strength of laminates may be calculated based on laminate theory and the results from the compression tests.

**Guidance note:**

Compression testing of laminates may not be required if the compression strength used in design does not exceed a given percentage of the tensile strength of the same laminate. The following requirements shall be complied with in that case:

| | |
|---|---|
| Glass reinforcement: | design compression strength ≤ 75% of design tensile strength |
| Carbon reinforcement: | design compression strength ≤ 60% of design tensile strength |
| Aramid reinforcement: | design compression strength ≤ 45% of design tensile strength |

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**104** Five parallel valid test results shall be obtained for each test.

**105** For material combinations or lay-ups for which sufficient data with respect to fatigue, environmental effects, etc. is not available appropriate additional testing may be required.

**106** If considered necessary, the strength of the bonds between structural members or other structural details may be subject to static or dynamic qualification testing.

**107** If direct strength calculations in accordance with Sec.1 B are carried out the extent of material testing will be specially considered.

### C 200 Qualification testing

**201** Tensile strength and modulus of single skin and sandwich skin laminates shall be carried out in accordance with ISO 527-4 or ASTM D638. Compressive properties shall be determined according to the same standards, as applicable, using adequate fixtures for prevention of buckling of the specimens. The properties shall be established for the main directions of reinforcement. Alternative test standards may be considered.

**202** The shear strength and modulus of core materials are to be specified and verified by testing in accordance with DNV's requirements for type approval for such materials. For core materials already type approved testing of the core material itself is not required, but the values stated on the type approval certificate shall be used in design. Core materials for use in slamming exposed areas shall be specially tested in accordance with DNV's requirements for type approval for such service.

**203** It shall be verified by shear testing in accordance with ISO 1922 or ASTM C 273-61 that the bond between skin and core and between individual core elements have at least the same shear strength as specified for the core material in question.

Alternatively, the test specified in 204 can be used to demonstrate that the full shear strength of the core material is reached.

**204** It shall be verified by four point sandwich beam bending tests in accordance with ASTM C 393 that the applied core bonding adhesive does not crack or debond at a lower load level than the core material itself.

**205** The testing is normally to be carried out at room temperature. If relevant to the operation of the vessel the testing may be required to be carried out at other representative operating temperatures.

# SECTION 4
# HULL GIRDER STRENGTH

## A. General

### A 100 Introduction

**101** In this section requirements to longitudinal and transverse hull girder strength is given. In addition, buckling control may be required.

**102** Longitudinal strength has generally to be checked for the craft types and sizes mentioned in the introduction to Ch.1 Sec.3, «Hull Girder Loads».

**103** For new designs (prototypes) of large and structurally complicated craft (f.i. multi-hull types) a complete 3-dimensional global analysis of the transverse strength, in combination with longitudinal stresses, is to be carried out.

**104** Buckling strength in bottom and deck may, however, have to be checked also for the other craft. For this purpose formulae for estimate of section modulus to deck and bottom based on bottom and deck cross-sectional areas have been given in Ch.1 Sec.3 A700.

**105** When calculating the section modulus of a composite structure possible differences in the E-modulus of various structural members are to be taken into account.

The stresses are to be corrected accordingly.

### A 200 Definitions

**201** *Moulded deck line, Rounded sheer strake, Sheer strake and Stringer plate* are as defined in Fig.1.

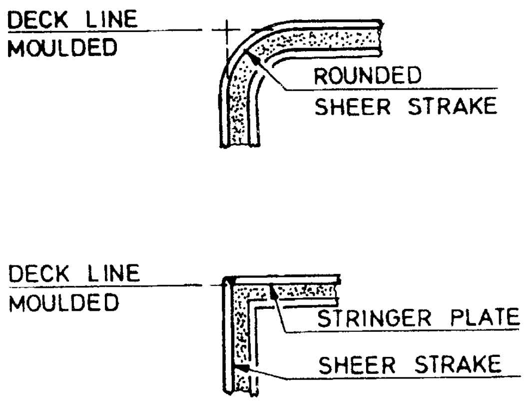


**Fig. 1**
**Deck corners**

## B. Vertical Bending Strength

### B 100 Hull section modulus requirement

**101**

$$Z = \frac{M}{\sigma} \cdot 10^3 \ (\text{cm}^3)$$

M = the longitudinal midship bending moment in kNm from Ch.1 Sec.3.
= $M_H$ for monohulls, catamarans and side wall craft in crest and hollow landing condition
= max. total moment for hydrofoil on foils
= max. still water + wave bending moment for hydrofoils and air cushion vehicles and some other craft in the slowed-down condition
= max. still water + wave bending moment for high speed displacement craft and semi-planing craft $(V/\sqrt{L} < 5)$ in the displacement mode.

$\sigma$ = 0.3 $\sigma_{nu}$ N/mm$^2$ in general.
= 0.27 $\sigma_{nu}$ N/mm$^2$ for hydrofoil on foils.
= 0.24 $\sigma_{nu}$ N/mm$^2$ in slowed-down condition for planing craft.

**Guidance note:**

Simultaneous end impacts over a hollow are considered less frequent and giving lower moments than the crest landing.

Need not be investigated if deck buckling resistance force is comparable to that of the bottom.

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### B 200 Effective section modulus

**201** Where calculating the moment of inertia and section modulus of the midship section, the effective sectional area of continuous longitudinal strength members is in general the net area after deduction of openings. The effect of varying E-moduli over the cross section is to be included.

Superstructures which do not form a strength deck are not to be included in the net section. This applies also to deckhouses and bulwarks.

**202** The effect of openings are assumed to have longitudinal extensions as shown by the shaded areas in Fig.2, i.e. inside tangents at an angle of 30° to each other. Example for transverse section III:

$$b_{III} = b' + b'' + b'''$$

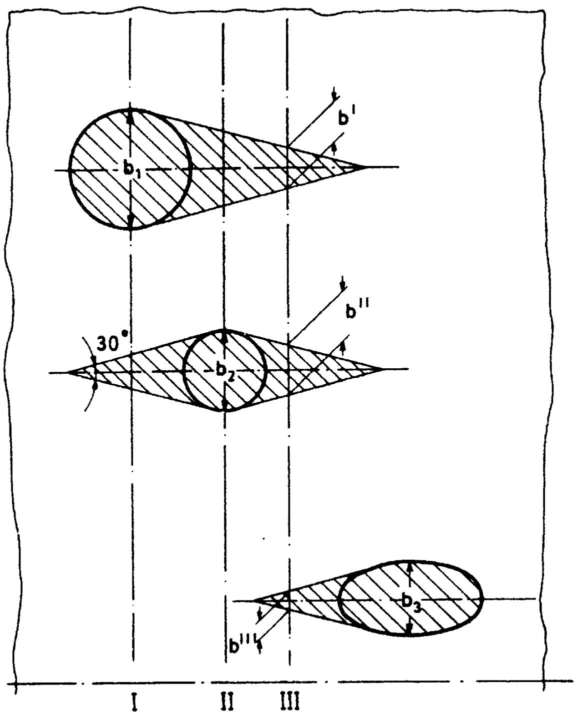


**Fig. 2**
**Effect of openings**

**203** For twin hull vessels the effective breadth of wide decks without longitudinal bulkhead support will be considered.

### B 300 Hydrofoil on foils

**301** For hydrofoils in addition to the calculation for the midship section, the sections in way of the foils are required to be checked.

### B 400 Longitudinal structural continuity

**401** The scantling distribution of structures participating in the hull girder strength in the various zones of the hull is to be carefully worked out so as to avoid structural discontinuities resulting in abrupt variations of stresses.

**402** At ends of effective continuous longitudinal strength members in deck and bottom region large transition brackets are to be fitted.

### B 500 Openings

**501** A keel laminate for docking is normally not to have openings. In the bilge laminate, within 0.5 L amidships, openings are to be avoided as far as practicable. Any necessary openings in the bilge laminate are to be kept clear of a bilge keel.

**502** Openings in strength deck are as far as practicable to be located well clear of ship’s side and hatch corners.

**503** Openings in strength members should generally have an elliptical form. Larger openings in deck may be accepted with well rounded corners and are to be situated as near to the craft’s centreline as practicable.

**504** For corners with rounded shape the radius is not to be less than:

$$r = 0.025\ B_{dk}\ (m)$$

$B_{dk}$ = breadth of strength deck.

r need not be taken greater than 0.1 b (m) where b = breadth of opening in m. For local reinforcement of deck plating at circular corners, see Sec.5 B.

**505** Edges of openings are to be smooth. Small holes are to be drilled.

## C. Shear Strength

### C 100 Cases to be investigated

**101** If doors are arranged in the ship’s side, the required sectional area of the remaining side panel will be specially considered.

**102** If rows of windows are arranged below strength deck, sufficient horizontal shear area must be arranged to carry down the midship tension.

## D. Cases to be investigated

### D 100 Inertia induced loads

**101** Especially transversely framed parts of forebody may need a check for the axial inertia force given in Ch.1 Sec.3 A700.

$$F_L = \Delta g_0 a_l \quad (kN)$$

$a_l$ = max. surge acceleration, not to be taken less than:

$0.4\ g$ for $\frac{V}{\sqrt{L}} \geq 5$

$0.2\ g$ for $\frac{V}{\sqrt{L}} \leq 3$

The height distribution of stresses will depend on instantaneous forward immersion and on height location of cargo.

**102** Bottom structure in way of thrust bearings may need a check for the increased thrust when vessel is retarded by a crest in front.

**103** Allowable axial stress and associated shear stresses will be related to the stresses already existing in the region.

## E. Transverse Strength of Twin Hull Craft

### E 100 Transverse strength

**101** The twin hull connecting structure is to have adequate transverse strength related to the design loads and moments discussed in Ch.1.

**102** When calculating the moment of inertia, and section moduli of the longitudinal section of the connecting structure, the effective sectional area of transverse strength members is in general the net area with effective flange after deduction of openings.

The effective shear area of transverse strength members is in general the net web area after deduction of openings.

**E 200 Allowable stresses**

**201** If direct calculations using the full stiffness and strength properties of the laminate are carried out requirements for the failure strength ratio, R, are given in Sec.1 Table C1.

**202** When a simplified calculation method is used, the total normal stresses in the two main directions shall comply with the requirements of Sec.5 and Sec.6.

In plane laminate shear stresses shall be less than $0.25\tau_{ult}$.

# SECTION 5
# SANDWICH PANELS

## A. General

### A 100 Introduction

**101** In this Section the general requirements for local strength of sandwich panels are given.

**102** Buckling strength of sandwich panels related to longitudinal hull girder strength or local axial loads will be dealt with individually.

**103** The reinforcement of skin laminates is to contain at least 25% continuous fibres by volume.

**104** The mechanical properties of the core material of structural sandwich panels are to comply with the minimum requirements given in Table A1:

**Table A1**

| *Structural member* | *Core properties (N/mm$^2$)* | |
|---|---|---|
| | *Shear strength* | *Compression strength* |
| Hull bottom, side and transom below deepest WL or chine whichever is higher | 0.8 | 0.9 |
| Hull side and transom above deepest WL or chine whichever is higher | 0.8 | 0.9 |
| Weather deck not intended for cargo | 0.5 | 0.6 |
| Cargo deck | 0.8 | 0.9 |
| Accommodation deck | 0.5 | 0.6 |
| Structural/watertight bulkheads/double bottom | 0.5 | 0.6 |
| Superstructures and deck-houses | 0.5 | 0.6 |
| Tank bulkheads | 0.5 | 0.6 |

**105** Core material to be used in areas exposed to bottom slamming shall be type approved by the Society for such use. Cross-linked PVC foam core materials for use in such areas shall normally have a density not less than 130 kg/m$^3$.

**106** The amount of reinforcement (g/m$^2$) in skin laminates in structural sandwich panels shall normally not be less than:

$W \geq W_0 (1 + k (L–20))$ *for $L > 20$ m*
$W = W_0$ *for $L \leq 20$ m*

W = mass of reinforcement pr unit area, g/m$^2$
$W_0$ = given in Table A2 (For mixed material reinforcements $W_0$ can be found by linear interpolation in the table according to the relative percentage of each material with respect to weight pr unit area.)
k = given in Table A2
L = length between perpendiculars.

**Table A2 Minimum requirements for amount of reinforcement**

| | $W_0$ *(g/m²)* | | *k* |
|---|---|---|---|
| | *Glass* | *Carbon/ Aramid* | |
| Hull bottom, side and transom below deepest WL or chine whichever is the higher | 2400 | 1600 | 0.025 |
| Hull side, and transom above deepest WL or chine whichever is higher | 1600 | 1100 | 0.025 |
| Hull bottom and side, inside of hull | 1600 | 1100 | 0.013 |
| Stem and keel, (width to be defined) | 6000 | 4000 | 0.025 |
| Weather deck (not for cargo) | 1600 | 1100 | 0.0 |
| Wet deck | 1600 | 1100 | 0.0 |
| Cargo deck | 3000 | 2000 | 0.013 |
| Accommodation deck, if adequately protected | 1200 | 800 | 0.0 |
| Accommodation deck, other | 1600 | 1100 | 0.0 |
| Decks, underside skin | 750 | 500 | 0.0 |
| Tank bulkheads / double bottom | 1600 | 1100 | 0.0 |
| Structural bulkheads | 1200 | 800 | 0.0 |
| Watertight bulkheads | 1600 | 1100 | 0.0 |
| Superstructure and deckhouse, outside | 1200 | 800 | 0.013 |
| Inside void spaces without normal access | 750 | 500 | 0.0 |

**107** Deviation from the minimum requirements may be accepted by the Society on consideration of craft type, design and service restriction. Smaller amounts of reinforcement may e.g. be accepted when a high density core material is used, or if the laminate is covered (by e.g. deck planking)

**108** The minimum thickness requirements given in 106 are intended to give panels that are adequate for carrying the distributed loads specified in the rules and to give an adequate resistance to wear and tear. These minimum thicknesses may be inadequate for carrying highly localised loads like loads from girder supports, attachments and similar. The need for local reinforcement of the sandwich skins shall therefor be carefully evaluated by the yard, and is subject to the Society's approval, in each particular case.

## B. Bending

### B 100 Application

**101** The formulas for core and skin stresses given below are valid under the following assumptions:

— the principal directions of the skin laminate reinforcement are parallel to the edges of the panel
— the difference in the modulus of elasticity in the two principal directions is not more than 20%. Larger differences may be accepted if an efficient aspect ratio of the panel is used in the calculation in accordance with standard textbook methods for orthotropic plates
— the skin laminates are thin, i.e. d/t > 5.77.

**102** For panels not complying with the above, see alternatives in Sec.1 C.

### B 200 Normal stresses in skin laminates and core shear stresses

**201** Maximum normal stresses in the skin laminates of a sandwich panel subject to uniform lateral pressure is given by:

$$\sigma_n = \frac{160\, p\, b^2}{W} C_N C_1 \quad (N/mm^2)$$

$C_N$ = $C_2 + \nu C_3$, for stresses parallel to the longest edge, see Fig.1.
$C_N$ = $C_3 + \nu C_2$, for stresses parallel to the shortest edge, see Fig.1.
W = Section modulus of the sandwich panel pr. unit breadth in mm³/mm. For a sandwich panel with skins of equal thickness W = dt.

Maximum values for $\sigma_n$ for the various structural members are given in B500.

$C_1$ = 1.0 for panels with simply supported edges.
$C_1$ = C1L or C1S according to Fig.2 for panels with fixed edges or partially fixed edges. C1L for stresses parallel to the longest edge. C1S for stresses parallel to shortest edge.

For panels in continuous structures (e.g. the hull shell, decks or bulkheads) $C_1$ shall be chosen according to the curve for partially fixed edges, to account for the edge restraint of rotation of the adjoining panels. For other panels $C_1$ shall be chosen based on the relevant edge fixity. For panels in the hull shell below the lowest waterline when analysed for static sea pressure $C_1$ shall be chosen according to the curve for "Fixed edges".

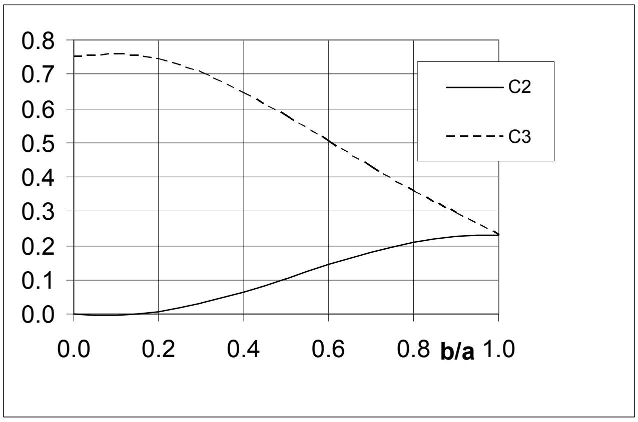


**Fig. 1**
**Sandwich panels: Factors $C_2$ and $C_3$**

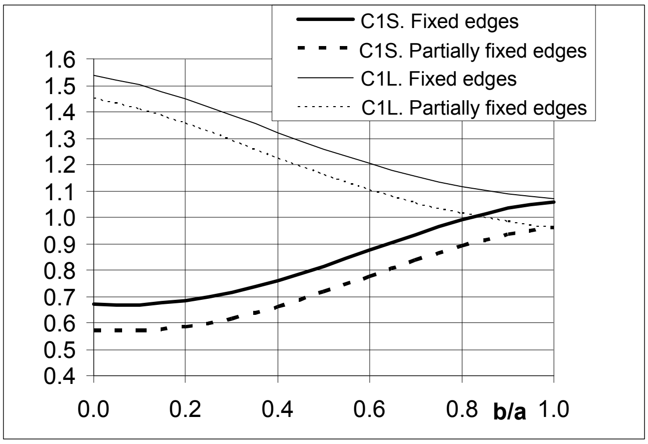


**Fig. 2**
**Sandwich panels: Factor $C_1$**

The curves can be approximated by the following polynomial expressions:

$C1S = A0 + A1(b/a)^1 + A2(b/a)^2 + A3(b/a)^3 + A4(b/a)^4 + A5(b/a)^5$
$C1L = A0 + A1(1 - b/a)^1 + A2(1 - b/a)^2 + A3(1- b/a)^3 + A4(1 - b/a)^4 + A5(1 - b/a)^5$

Fixed edges:

C1S: A0 = 0.67; A1 = -0.1; A2 = 0.8; A3 = 0.3; A4 = -0.8; A5 = 0.19

C1L: A0 = 1.07; A1 = 0.15; A2 = 0.4; A3 = 0.2; A4 = -0.1; A5 = -0.18

Partially fixed edges:

C1S: A0 = 0.57; A1 = -0.1; A2 = 0.8; A3 = 0.3; A4 = -0.8; A5 = 0.19

C1L: A0 = 0.96; A1 = 0.17; A2 = 0.4; A3 = 0.2; A4 = -0.1; A5 = -0.18

$C2 = A0 + A1(b/a)^1 + A2(b/a)^2 + A3(b/a)^3 + A4(b/a)^4 + A5(b/a)^5$
A0 = 0.0; A1 = -0.1; A2 = 0.71; A3 = 0.16; A4 = -0.86; A5 = 0.32

$C3 = A0 + A1(1 - b/a)^1 + A2(1 - b/a)^2 + A3(1- b/a)^3 + A4(1 - b/a)^4 + A5(1 - b/a)^5$
A0 = 0.23; A1 = 0.6; A2 = 0.2; A3 = 0.4; A4 = -0.49; A5 = -0.18

**202** The maximum core shear stresses at the midpoints of the panel edges of a sandwich panel subject to lateral pressure is given by:

$$\tau_c = \frac{0.52\ p\ b}{d} C_S \quad (\text{N/mm}^2)$$

$C_S =$ $C_4$, for core shear stress at midpoint of longest panel edge, see Fig.3.
$C_S =$ $C_5$, for core shear stress at midpoint of shortest panel edge, see Fig.3.
Maximum values for $\tau_c$ for the various structural members are given in B 500.

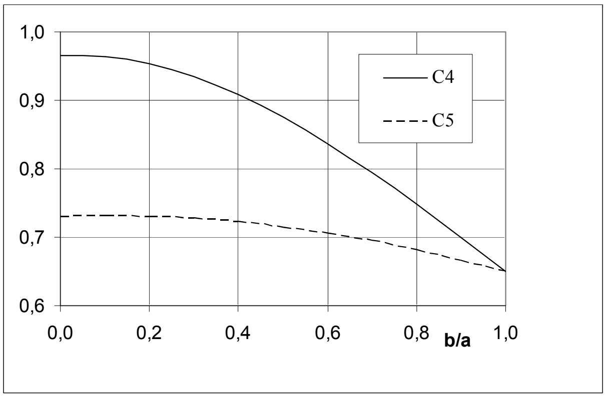


**Fig. 3**
**Sandwich panels: Factors $C_4$ and $C_5$**

The curves can be approximated by the following polynomial expression:

$C4 = A0 + A1(1 - b/a)^1 + A2(1 - b/a)^2 + A3(1 - b/a)^3 + A4(1 - b/a)^4 + A5(1 - b/a)^5$

A0 = 0.65; A1 = 0.5; A2 = -0.02; A3 = -0.13; A4 = -0.07; A5 = 0.035

$C5 = A0 + A1(1 - b/a)^1 + A2(1 - b/a)^2 + A3(1 - b/a)^3 + A4(1 - b/a)^4 + A5(1 - b/a)^5$

A0 = 0.65; A1 = 0.17; A2 = -0.07; A3 = -0.03; A4 = 0.01; A5 = 0.0

## B 300 Local skin buckling

**301** The critical local buckling stress for skin laminates exposed to compression is given by:

$$\sigma_{cr} = 0.5\ (E\ E_C\ G_C)^{\frac{1}{3}}\ \ (N/mm^2)$$

The relation between $\sigma_{cr}$ and the allowable compressive stress is given in B500.

## B 400 Deflections

**401** The deflection at the midpoint of a flat panel is given by:

$$w = \frac{10^6\ p\ b^4}{D_2}(C_6 C_8 + \rho\ C_7)$$

For panels with skin laminates with equal thickness and modulus of elasticity:

$$D_2 = \frac{E\ t\ d^2}{2\ (1 - \nu^2)}$$

For panels with skin laminates with different thickness and modulus of elasticity:

$$D_2 = \frac{E_1\ E_2\ t_1\ t_2\ d^2}{(1 - \nu^2)\ (E_1 t_1 + E_2 t_2)}$$

The indexes 1 and 2 denotes inner and outer skin respectively.

$$\rho = \frac{\pi^2 D_2}{10^6\ G_C\ d\ b^2}$$

$C_6$ and $C_7$ to be found from Fig.4.

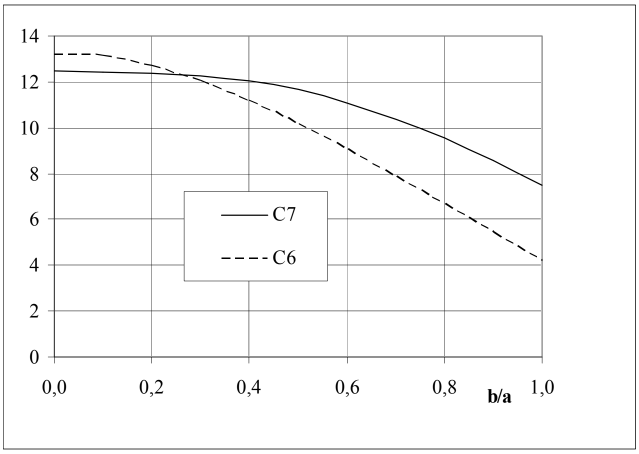


**Fig. 4**
**Sandwich panels: Factors $C_6$ and $C_7$**

$C_8$ = 1.0 for panels with simply supported edges.
$C_8$ = according to Fig.5 for panels with fixed edges or partially fixed.

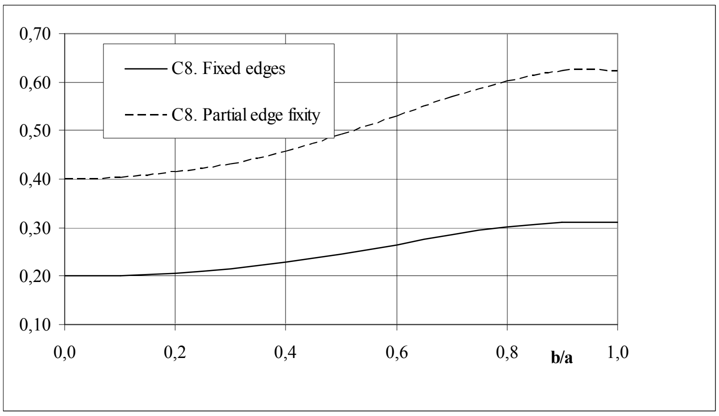


**Fig. 5**
**Sandwich panels: Factor $C_8$**

For panels in continuous structures (e.g. the hull shell, decks or bulkheads) $C_8$ shall be chosen according to the curve for “Partial edge fixity”, to account for the edge restraint of rotation of the adjoining panels. For other panels $C_8$ shall be chosen based on the relevant edge fixity. For panels in the hull shell below the lowest waterline when analysed for static sea pressure $C_8$ shall be chosen according to the curve for “Fixed edges”.

Maximum allowable values for w for the various structural members are given in B500.

The curves can be approximated by the following polynomial expression:

$$C6 = A0 + A1(1 - b/a)^1 + A2(1 - b/a)^2 + A3(1 - b/a)^3 + A4(1 - b/a)^4 + A5(1 - b/a)^5$$

A0 = 4.2; A1 = 12.5; A2 = -0.4; A3 = 0.0; A4 = -2.7; A5 = -0.4

$$C7 = A0 + A1(1 - b/a)^1 + A2(1 - b/a)^2 + A3(1 - b/a)^3 + A4(1 - b/a)^4 + A5(1 - b/a)^5$$

A0 = 7.5; A1 = 11; A2 = -3; A3 = -5.5; A4 = 0.0; A5 = 2.5

$$C8 = A0 + A1(b/a)^1 + A2(b/a)^2 + A3(b/a)^3 + A4(b/a)^4 + A5(b/a)^5$$

Fixed: A0 = 0.2; A1 = 0.008; A2 = 0.06; A3 = 0.39; A4 = -0.36; A5 = 0.013
Partial: A0 = 0.4; A1 = 0.016; A2 = 0.12; A3 = 0.78; A4 = -0.72; A5 = 0.026

**B 500 Allowable stresses and deflections**

**501** The maximum normal stresses in skin laminates, core shear stresses and deflection are not to be greater than given in Table A3:

**502** The maximum core shear stress for bottom panels subjected to slamming loads are to be related to the core ultimate dynamic strength $\tau_{ud}$. This is the dynamic shear strength of the core material subjected to a slamming type impact load.

**Table A3 Allowable stresses and deflections**

| *Structural member* | $\sigma_n$ | $\tau_c$ | *w/b* |
|---|---|---|---|
| Bottom panels exposed to sea pressure | $0.3\ \sigma_{nu}$ | $0.4\tau_u$ | 0.02 |
| Bottom panels exposed to slamming loads | $0.3\ \sigma_{nu}$ | $0.4\tau_{ud}$ | 0.02 |
| Remaining bottom and inner bottom | $0.3\ \sigma_{nu}$ | $0.4\tau_u$ | 0.02 |
| Side structures | $0.3\ \sigma_{nu}$ | $0.4\tau_u$ | 0.02 |
| Deck structures | $0.3\ \sigma_{nu}$ | $0.4\tau_u$ | 0.02 |
| Bulkhead structures | $0.3\ \sigma_{nu}$ | $0.4\tau_u$ | 0.02 |
| Superstructures | $0.3\ \sigma_{nu}$ | $0.4\ \tau_u$ | 0.02 |
| Deckhouses | $0.3\ \sigma_{nu}$ | $0.4\tau_u$ | 0.02 |
| All structures exposed to long time static loads | $0.20\ \sigma_{nu}$ | $0.15\tau_u$ | 0.01 |

$\sigma_{nu}$ = the ultimate tensile stress for skin laminates exposed to tensile stresses
= the smaller of the ultimate compressive stress and the critical local buckling stress, according to B300, for skin laminates exposed to compressive stresses.
$\tau_u$ = the minimum ultimate shear stress of sandwich core material given on the type approval certificate.
$\tau_{ud}$ = the minimum ultimate dynamic shear stress of sandwich core material under slamming type load. given on the type approval certificate.

**Guidance note:**

Experience and material tests have shown that some core materials or qualities have lower strength and more scatter under dynamic loads than for static loads. Both the reduced strength and the increased scatter must be considered in the shear strength values used in the design.

The dynamic shear strength is defined as the static strength multiplied with a dynamic reduction factor. This is done in order to have the same reference level for static and dynamic strength. The reduction factor is determined from four point bend tests made with static (slow) load, and dynamic load with a load rate giving a shear stress rate of minimum 65 MPa/s. The test is to be made with a longitudinal adhesive joint. Dynamic reduction factor cd = (dynamic test values)/(static test values). The values for static and dynamic test values used are to be the "mean value – 2 standard deviations" obtained in the tests. For cases where the dynamic strength is higher than the static strength, the dynamic strength is to set equal to the ultimate static strength. The dynamic shear strength is then defined as: $\tau_{ud} = 1.0\tau_u$, where $\tau_u$ is the ultimate static strength from material certificate.

It may also be required to prove that the material is not sensitive to slamming fatigue loads by a fatigue test with strain rates of minimum 65 MPa/s. Standards for test procedures will be given in DNV type approval program for sandwich core materials.

Materials where dynamic test values are not available may be accepted upon special consideration provided the shear fracture elongation is at least 20%.

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**503** For end grain balsa used below the water line at deepest draft the shear strength shall be determined on specimens saturated with water.

**504** For end grain balsa the shear strength shall be corrected for the effect of thickness by multiplying the shear strength obtained for a thickness of 50 mm by the factor $f_c$:

$$f_c = \left(\frac{50}{c}\right)^{0.27}$$

c = core thickness of the actual panel being analysed (mm).

**505** For end grain balsa the shear strength shall be corrected for the effect of panel size by multiplying the shear strength obtained as described above by the factor $f_{ib}$:

$$f_{ib} = \left(\frac{1.6}{a}\right)^{0.25}$$

$f_{ib}$ shall be equal to 1.0 for $a \leq 1.6$ m.

# SECTION 6
# STIFFENED SINGLE SKIN CONSTRUCTION

## A. General

### A 100 Introduction

**101** In this section the general requirements for local strength of stiffened single skin constructions are given.

**102** Buckling strength of single skin panels subjected to longitudinal hull girder or local compression loads will be dealt with individually.

### A 200 Minimum requirements for structural single skin plates

**201** The reinforcement of single skin laminates are to contain at least 25% continuous fibres by volume.

**202** The thickness of single skin laminates fabricated from glass are in general not to be less than:

$$W = W_0 \ (1 + k \ (L - 20)) \text{ for } L > 20 \text{ m}$$

$$W = W_0 \ \text{ for } L \leq 20 \text{ m}$$

W = mass of reinforcement pr. unit area, g/m$^2$
$W_0$ = given in Table A1
k = given in Table A1
L = length between perpendiculars.

**Table A1 Minimum amount of reinforcement**

| *Structural member* | *$W_0$ (g/m$^2$)* | *k* |
|---|---|---|
| Hull bottom, side and transom below deepest WL or chine whichever is higher | 4200 | 0.025 |
| Hull side and transom above deepest WL or chine whichever is higher | 4200 | 0.025 |
| Stem and keel to 0.01 L from centreline | 7500 | 0.025 |
| Chine and transom corners to 0.01 L from chine edge | 5800 | 0.025 |
| Bottom aft in way of rudder, shaft braces, and shaft penetrations | 6600 | 0.025 |
| Weather deck not intended for cargo | 4200 | 0.0 |
| Cargo deck | 5400 | 0.013 |
| Accommodation deck | 2900 | 0.0 |
| Structural/watertight bulkheads/double bottom | 4200 | 0.0 |
| Tank bulkheads | 4500 | 0.0 |
| Other bulkheads | 2500 | 0.0 |
| Superstructures and deckhouses | 4200 | 0.013 |

**203** The minimum thickness of single skin laminates fabricated from other types of reinforcements are subject to special consideration.

## B. Laterally Loaded Single Skin Laminates

### B 100 Assumptions

**101** The formulae given below are valid under the following assumptions:

1) The principal directions of reinforcement are parallel to the edges of the panel.
2) The difference in the modulus of elasticity in the two principal direction of reinforcement is not more than 20%.
3) The load is uniformly distributed.

**102** For laminates not complying with the above reference is made to Sec.1 C.

**103** Laminates may be analysed disregarding the membrane effect according to the requirements given in 200 and 300 or including the membrane effect according to the requirements given in 400 and 500.

### B 200 Laminates exposed to lateral loads

**201** A laminate deflection factor is defined as $\delta$ = w/t.

The deflection factor, $\delta$, of the panel is given by:

$$\delta = 10^9 \frac{b^4 p}{t^4 E C_1}$$

The factor $C_1$ is found in Fig.1. For panels in continuous structures (e.g. the hull shell or decks) $C_1$ shall be chosen according to the curve for “Partial edge fixity”, to account for the edge restraint of rotation of the adjoining panels. For other panels $C_1$ shall be chosen based on the relevant edge fixity. For panels in the hull shell below the lowest waterline when analysed for static sea pressure $C_1$ shall be chosen according to the curve for “Fixed edges”.

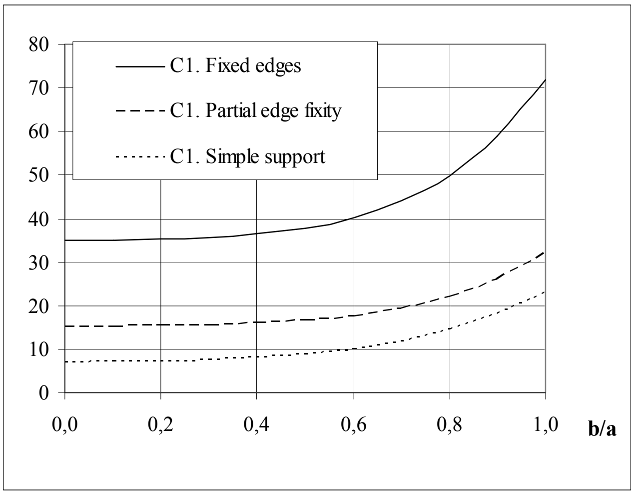


**Fig. 1**
**Single skin laminates: Factor $C_1$**

The curves can be approximated by the following polynomial expression:

$C_1$ = A0 + A1(b/a)$^1$ + A2(b/a)$^2$ + A3(b/a)$^3$ + A4(b/a)$^4$ + A5(b/a)$^5$

Fixed: A0 = 35.0; A1 = 1.0; A2 = 1.0; A3 = 8.0; A4 = 7.0; A5 = 20.0
Partial: A0 = 15.0; A1 = 1.0; A2 = 1.0; A3 = 2.0; A4 = 3.0; A5 = 10.0
Simple: A0 = 7.0; A1 = 1.0; A2 = 1.0; A3 = 5.0; A4 = 5.0; A5 = 4.0

**202** The bending stress is given by:

$$\sigma = C_3\, 1000 \frac{b^2}{t^2} p$$

The factor $C_3$ is found in Fig.2. For panels in continuous structures (e.g. the hull shell, decks or bulkheads) $C_3$ shall be chosen according to the curve for “Partial edge fixity”, to account for the edge restraint of rotation of the adjoining panels. For other panels $C_3$ shall be chosen based on the relevant edge fixity. For panels in the hull shell below the lowest waterline when analysed for static sea pressure $C_3$ shall be chosen according to the curve for “Fixed edges”.

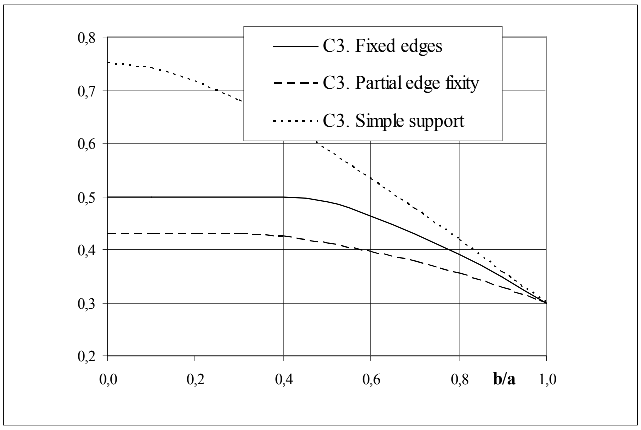


**Fig. 2**
**Single skin laminates: Factor $C_3$**

$$C_3 = A0 + A1(1 - b/a)^1 + A2(1 - b/a)^2 + A3(1 - b/a)^3 + A4(1 - b/a)^4 + A5(1 - b/a)^5$$

Fixed: A0 = 0.3; A1 = 0.5; A2 = -0.2; A3 = -0.08; A4 = 0.0; A5 = 0.0 for b/a > 0.45
Partial: A0 = 0.3; A1 = 0.3; A2 = -0.15; A3 = 0.0; A4 = -0.004; A5 = 0.0 for b/a > 0.40
Simple: A0 = 0.3; A1 = 0.58; A2 = 0.04; A3 = -0.06; A4 = -0.07; A5 = -0.04

### B 300 Allowable stresses and deflections (when excluding membrane effects)

**301** The maximum values for $\delta$ is 2.0. For a panel for which its deflection will not interfere with other parts of the structure or with equipment installed in the vessel $\delta$ may be increased to 3.0 after special consideration by the Society.

**302** The maximum bending stress $\sigma$ shall not exceed 0.3 $\sigma_{nu}$ where $\sigma_{nu}$ is equal to the tensile or compressive stress of the laminate as relevant. For panels exposed to long term static loads $\sigma$ shall not exceed 0.2 $\sigma_{nu}$.

### B 400 Laminates exposed to combined bending and membrane stresses

**401** The contribution to the capacity of a panel from the membrane stress may be included if the panel has sufficient in-plane support along all edges. In such a case a detailed analysis shall be carried out taking properly into account the in-plane and bending stiffness of the panel, the rotational stiffness and stiffness in the plane of the panel of the supporting stiffeners/girders and the adjoining panels. The analysis shall be detailed enough to quantify all stress concentrations along the panel edges.

### B 500 Allowable stresses and deflections (when including membrane effects)

**501** The maximum values for $\delta$ is 2.0. For a panel for which its deflection will not interfere with other parts of the structure or with equipment installed in the vessel $\delta$ may be increased to 3.0 after special consideration by the Society provided the panel predominantly carries the lateral load as plate bending.

**502** The maximum combined membrane and bending stress $\sigma_c$ shall not exceed 0.3 $\sigma_{nu}$ where $\sigma_{nu}$ is equal to the tensile or compressive stress of the laminate as relevant. For panels exposed to long term static loads $\sigma_c$ shall not exceed 0.2 $\sigma_{nu}$.

# SECTION 7
# STIFFENERS, WEB FRAMES AND GIRDERS

## A. General

### A 100 Introduction

**101** In this section the general requirements for stiffeners, web frames and girders are given. Buckling strength of these elements will be individually considered.

### A 200 Continuity of strength members

**201** Structural continuity is to be maintained at the junction of primary supporting members of unequal stiffness by fitting well rounded brackets.

Brackets ending at unsupported sandwich panels are to be tapered smoothly to zero and the panels skin laminate to be locally reinforced at the end of the bracket.

Girders are to be fitted with bracket or tapered to zero at their ends. See Fig.2.

**202** Where practicable, deck pillars are to be located in line with pillars above or below. Massive or high density core inserts are to be fitted at the foot of pillars.

**203** Below decks and platforms, strong transverses are to be fitted between verticals and pillars, so that rigid continuous frame structures are formed.

## B. Bending and Shear

### B 100 General

**101** The requirements for section modulus and web area given in 500 are applicable to simple girders supporting stiffeners, panels or other girders exposed to linearly distributed lateral pressure. It is assumed that the girder satisfies the basic assumptions of simple beam theory and that the supported members are approximately evenly spaced and similarly supported at both ends. Other loads, spacings and end supports will have to be specially considered.

**102** When boundary conditions for individual girders are not predictable due to dependence of adjacent structures, requirements as given in C will be required.

### B 200 Loads

**201** The bending moment for a member subjected to pressure load is given in the general form:

Pressure loads:

$$M = \frac{p\, b_1\, l^2}{c_1} \quad \text{(kNm)}$$

Point loads (from crossing beams, attachment points for equipment etc.):

$$M = \frac{F_p\, l}{c_2} \quad \text{(kNm)}$$

$b_l$ = breadth of load area (m) $b_l = 0.5\ (l_1 + l_2)$
$l_1$ and $l_2$ = the c/c spans in m of the supported panels
p = design pressure (kN/m$^2$)
$F_p$ = point load (kN)
$l$ = length of beam (m)
$c_1$ and $c_2$ = bending moment factor depending on support conditions and position on the beam.

The factor $c_1$ and $c_2$ may be fond from textbook formula for standard load-cases and support conditions.

The most common factors to be used for hull calculations are listed in 202 to 207.

**202** *Sea pressure loads on continuous members*

It is assumed that the sea pressure is acting continuously on several lengths of the member.

Each length is to be considered with fixed ends.

Bending moment factor to be used:

$c_1$ = 12 at ends
$c_1$ = 24 at midspan.

Fixation at the end of a continuous beam must be considered specially.

**203** *Sea slamming loads on continuous members*

It is assumed that the slamming pressure is acting on a local area and that the support at each length is partly active.

Bending moment factor to be used:

$c_1$ = 18 at ends
$c_1$ = 14 at mid-span.

**204** *Sea pressure on beams with freely supported ends*

$c_1$ = 8 at mid-span.

**205** *Point load on freely supported beam*

$c_1$ = 4 at mid-span of beam.

**206** *Point load on beam with fixed ends*

$c_2$ = 8 at mid-span and at ends.

**207** *Shear load*

The distribution of shear loads along the beam may be fond from textbook formula for standard load-cases and support conditions.

## B 300 Effective flange

**301** The effective panel flange is defined as the cross-sectional area of the panel within the effective flange width. For sandwich panels only the skin laminate at which the beam is attached shall be considered.

$$\frac{b_{eff}}{b} = \frac{1}{1 + 3.3\,\frac{E}{G}\left(\frac{b}{2l}\right)^2}$$

$b_{eff}$ = effective width of flange
$b$ = c-c distance between the stiffeners or girders
$E$ = E modulus of flange laminate in the beam direction
$G$ = shear modulus of flange laminate
$l$ = length between moment inflexion points i.e. between zero bending moments.

For a beam with fixed ends, the length between inflection points is 0.58 $l$. The effective flange outside the inflexion points (i.e. at the ends) is to be taken as 0.67 time the effective flange calculated above. See Fig.1.

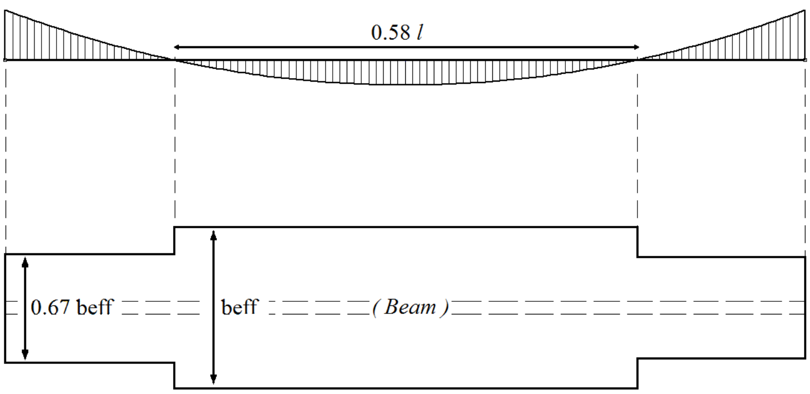


**Fig. 1**
**Effective flange for beam with fixed ends, rule value**

**Guidance note:**
For top hat stiffeners with UD tabbing underneath, and the tabbing width is less than 2 times the width of the top hat base, the full width of the tabbing may be used.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

### B 400 Effective web

**401** Holes in girders will generally be accepted provided the shear stress level is acceptable and the buckling strength is sufficient. Holes are to be kept well clear of end of brackets and locations where shear stresses are high.

**402** For ordinary girder cross-sections the effective web area is to be taken as:

$$A_W = 0.01\ h_n\ t_w\ (cm^2)$$

$h_n$ = net girder height in mm after deduction of cutouts in the cross-section considered.

If an opening is located at a distance less than h/3 from the cross-section considered, $h_n$ is to be taken as the smaller of the net height and the net distance through the opening. See Fig.3.

**403** Where the girder flange is not perpendicular to the considered cross section in the girder, the effective web area is to be taken as:

$$A_w = 0.01\ h_n t_w + 1.3\ A_{FL} \sin 2\Theta\ \sin\Theta\ \ (cm^2)$$

$h_n$ = as given in 402
$A_{FL}$ = flange area in $cm^2$
$\Theta$ = angle of slope of continuous flange.

See also Fig.4.

### B 500 Effective bond area

**501** For girders attached to other structural members at their supports by secondary bonding the effective bond area is determined by the following formula:

$$A_B = B\ H - b\ h$$

See Fig.5.

### B 600 Strength requirements

**601** *Bending strength of beams of uniform cross section*

Beams of uniform cross section are defined as having the same material properties for the web, flange and the overlay material. The laminate used in simple beams must be able to carry both tension loads in the flange and shear loads in the web.

**Guidance note:**

A laminate with [0, 90°] or [± 45°] is not suitable for both tension and shear loading found in a beam. A chopped strand mat or a multi-axial laminate would be suitable.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

The section modulus of beams with uniform material properties in the cross section subjected to lateral pressure is not to be less than:

$$Z = \frac{M}{\sigma_d}$$

M = bending moment at the cross section
$\sigma_d$ = design stress (see Table C1)

**602** *Built-up beams*

Beams with different lay-up in web and flange is considered to be built-up beams. Typical example is a beam with unidirectional capping on top.

Variation in the modulus of elasticity is to be taken into account when calculating cross section properties of the beam.

Bending stress is to be checked both at the mid-span and at the ends. For beams with mechanical properties varying along the beam, the weakest sections must be checked.

The stress level in each laminate shall not exceed the design stress values given in Table C1.

**Guidance note:**

The acceptance requirement may also be expressed in traditional terms:

The effective section modulus is not to be less than:

$$Z_e = \frac{M}{\sigma_d}$$

M = bending moment at the cross section
$\sigma_d$ = allowable design stresses (see Table C1)
$Z_e$ = effective section modulus taking into account the variations in elastic moduli over the cross section.
Formula for calculation of effective modulus is not given here. Please refer to recognised textbooks.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

| **Table C1 Allowable design stress in beams** | |
|---|---|
| *Structural element* | *Design stress $\sigma_d$* |
| Stiffener | 0.3 $\sigma_u$ |
| Web frames | 0.3 $\sigma_u$ |
| Girders | 0.3 $\sigma_u$ |
| $\sigma_u$ = ultimate laminate strength (tensile or compressive) | |

**603** *Web shear strength*

The web of a beam carries primarily shear loads and the lay-up in the web must be arranged to carry this load. The shear loads shall be distributed to each support based on general beam theory.

**Guidance note:**

A laminate with [0, 90°] lay-up is not considered suitable to carry the shear loads in the web, as the load in this case is carried by the matrix and not by the fibres.

The shear loads in the web should preferably be carried by ± 45° fibres.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

The shear stress level in each laminate of the web shall not exceed the design stress values given in Table C2.

**Guidance note:**

The acceptance requirement may also be expressed in traditional terms:

The web area of a beam subjected to lateral pressure is not to be less than:

$$A_w = Q/\tau_d$$

Q = shear force at the cross section
$\tau_d$ = allowable design stress as defined in Table C2.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

| **Table C2 Allowable shear stress for stiffeners and girder webs** | |
|---|---|
| *Structural element* | *Design stress $\tau_d$* |
| Stiffener | 0.25 $\tau_u$ |
| Web frames | 0.25 $\tau_u$ |
| Girders | 0.25 $\tau_u$ |
| $\tau_u$ = ultimate laminate shear stress | |

**604** *Web buckling strength*

When relevant, web buckling strength is to be considered.

**605** *Bond strength*

The bond area, between girders and their supporting structure, at the girders ends is not to be less than:

$$A_{bond} = Q / \tau_b$$

The effective bond area is determined by the following formula:

$$A_{bond} = B\ H - b\ h \text{ (See Fig.5)}$$

$\tau_b$ = $0.25\tau_{bu}$
$\tau_{bu}$ = the ultimate bond shear stress for the secondary bonding.

The following value may normally be used:

$A_{bond}$ = $0.35Q$ (mm$^2$)
Q = shear force in (N).

**606** *Stiffener to plate attachment*

The bonding width of stiffener attachment to the plate is normally not to be less than:

$b_{bond}$ = $0.35\, t_{web}\, \tau_{u\text{-}web}$
$t_{web}$ = laminate thickness of web
$\tau_{u\text{-}web}$ = ultimate shear strength of web laminate.

**607** *Deflection*

The deflection of engine girders (sum of shear and bending deflection) is to be limited by the tolerances for machinery and shafting arrangement.

## C. Complex Girder Systems

### C 100 General

**101** For girders which are parts of complex 2- or 3-dimensional structural systems, a complete structural analysis may have to be carried out to demonstrate that the stresses are acceptable when the structure is loaded as described in 300.

**102** Calculations as mentioned in 101 may have to be carried out for:

- transverse and vertical girders
- bottom structures
- other structures when deemed necessary by the Society.

### C 200 Calculation methods

**201** Calculation methods or computer programs applied are to take into account the effects of bending, shear, axial and torsional deformations together with material anisotropy.

The calculations are to reflect the structural response of the 2- or 3-dimensional structure considered, with due attention to boundary conditions.

For systems consisting of slender girders, calculations based on beam theory (frame work analysis) may be applied, with due attention to:

- shear area variation,
- moment of inertia variation,
- effective flange.

**202** For deep girders, bulkhead panels, bracket zones, etc. where results obtained by applying the beam theory are unreliable, finite element analysis or equivalent methods may have to be applied.

**203** Acceptable calculation methods are indicated in various Classification Notes on «Strength Analysis of Hull Structures».

### C 300 Design load conditions

**301** The calculations are to be based on the most severe realistic load condition for the craft:

- fully loaded
- partly loaded
- loading/discharging.

For sea-going conditions realistic combination of external and internal dynamic loads at design level as given in Ch.1 Sec.2 are to be considered. The mass of deck structures may be neglected when less than 5% of the applied loads.

### C 400 Allowable stresses

**401** If direct calculations using the full stiffness and strength properties of the laminate are carried out requirements for the failure strength ratio, R, are given in Sec.1 Table C1.

**402** When a simplified calculation method is used for constructions complying with Sec.1 C the total normal stresses in the two main directions shall comply with the requirements of B500.

In plane laminate shear stresses shall be less than $0.25\ \tau_u$.

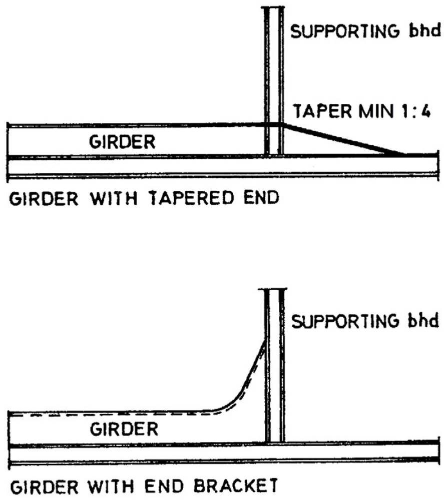


**Fig. 2**
**Ends of girders**

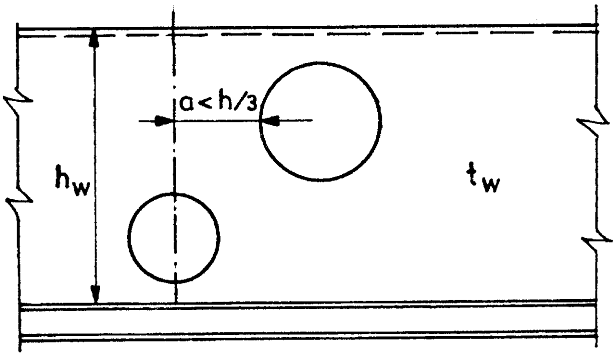


**Fig. 3**
**Effective web area in way of openings**

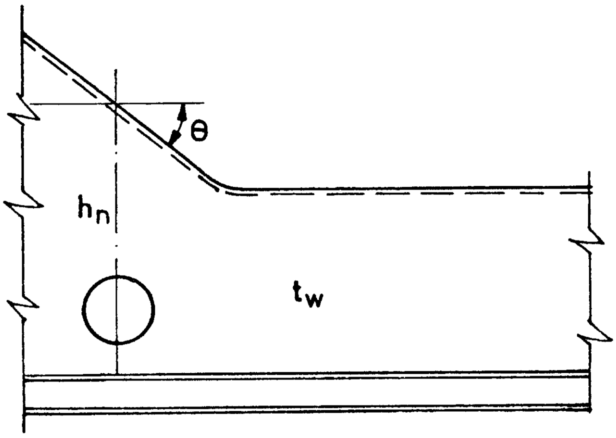


**Fig. 4**
**Effective web area in way of brackets**

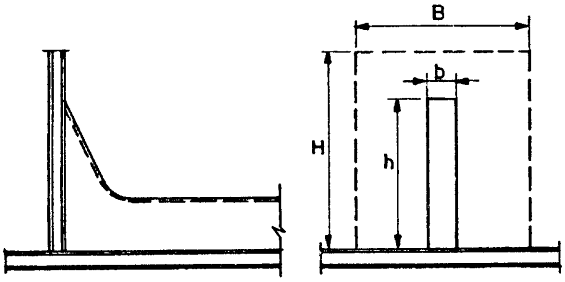


**Fig. 5**
**Effective bond area**

# SECTION 8
# BONDED JOINTS

## A. General

### A 100 Application

**101** This Section applies to a bonded joint defined as follows: a joint where adherents are bonded either by placing a layer of adhesive or resin material between the adherents or by producing a bond between one adherent and the second adherent as an integral part of the manufacturing of the joint or the structure, e.g. by applying laminates or laminating directly onto a metal surface, or any combination of the above. Secondary bonds in FRP constructions are not covered by this section.

**102** The use of bonded joints is subject to the approval of the Society. Bonded joints are not accepted for transfer of the global loads on the hull or on joints the failure of which would compromise the watertight integrity of the vessel.

**103** Adhesives used for bonded joints shall be type approved by DNV.

## B. Design

### B 100 Design of bonded joints

**101** The function(s) of the joint shall be clearly specified.

**102** The nominal shear stress over the bond surface shall not by itself be used as a characteristic of the load level in the joint. The design shall be based on line load, global load or an analysis of the shear stress taking due account of the stress concentrations in the joint.

**103** The physical environment of the joint shall be specified and considered in the design. As a minimum the following factors shall be considered:

— humidity
— UV-light
— temperature
— chemicals (e.g. fuel etc.)
— welding
— fire.

Welding on adjacent structures and fire may increase the temperature at the bond. This effect shall be considered when specifying short and long term service temperature for the joint.

**104** The design of bonded joints shall be based on qualification tests carried out on realistic samples, see C100. The properties obtained in a yard may differ significantly from the properties measured on specimens tested under laboratory conditions. Causes for such differences may be different working environment, scaling effects etc. This difference shall be reflected in the design strength of the joint: the strength of the joint cannot be assumed to be as high as determined in the qualification tests.

**105** The load on the joint shall not exceed the characteristic strength determined in the qualification tests divided by a factor of 5.0.

**106** The adherents, surface preparation and fabrication procedures shall be identical to the joint as for the samples on which the qualification tests have been carried out.

**107** The joint cross section and the direction of the load transfer shall for all parameters influencing the strength and durability of the joint be identical to the joint geometry tested in the qualification tests. Alternatively, a change in any of these parameters may be accepted if they do not lead to a reduction of the strength or durability of the joint.

Special attention shall be given to the length of the overlap, the stiffness of the adherents and the out-of plane forces in the joint. The length of the overlap shall not be smaller than on the tested joint. The thickness of the adherents shall not be smaller than used in the qualification tests.

# C. Qualification

## C 100 Qualification tests

**101** Qualification tests shall be carried out on samples representing the actual adherents, surface preparation, joint geometry and fabrication conditions in a realistic manner. Great care shall be taken to represent out-of-plane forces in the joint, also in a joint designed to transfer in-plane loads only.

Adhesive properties shall not be determined as bulk properties of the adhesive itself, but always including the effect of joint configuration, adherents etc.

**102** Both initial properties and time dependent properties of materials shall be determined or tested as relevant. The environmental conditions specified for the design of the joint shall be considered, B103.

**103** The samples shall be tested after realistic ageing considering the factors above. Alternatively, the ageing effect on the actual combination of adhesive and substrate determined in previous tests may be used to quantify the degradation over time of the bond strength.

**104** For each test condition, five parallel tests shall be carried out. The characteristic strength shall be determined as the second lowest value obtained. The lowest value shall not be lower than 80% of the second lowest. It shall be recorded for each specimen whether the failure is cohesive or adhesive.

# SECTION 9
# BOLTED CONNECTIONS

## A. General

### A 100 Introduction

**101** In this Section the general requirements for strength of the following bolted connections are given:

— bolted connections for transfer of in-plane loads (shear connections)
— bolted connections for transfer of out-of-plane loads
— bolt inserts and similar attachments (not participating in the structural strength of the hull and superstructure).

The definition of in-plane and out-of-plane loads refers to the load components on each individual bolt.

**Guidance note:**
A bollard may be subjected to a load parallel to the laminate plane. However, due to the bending moment on the bollard (the point of attack of the load is some distance above the panel) the individual bolts securing the bollard to the panel may be subjected to an out-of-plane load, additional to the in-plane load. Such bolted connections shall be designed with respect to both in-plane and out-of-plane loads.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

**102** The thickness of the laminates may have to be increased to accommodate the localised loads from a bolted connection, see Sec.5 A108.

## B. In-plane Loads (Shear Connections)

### B 100 Introduction

**101** *Definitions* (see Fig 1):

d = bolt diameter
$e_1$ = edge distance transverse to the direction of the load
$e_2$ = edge distance in the direction of the load
$p_1$ = bolt pitch transverse to the direction of the load
$p_2$ = bolt pitch in the direction of the load.

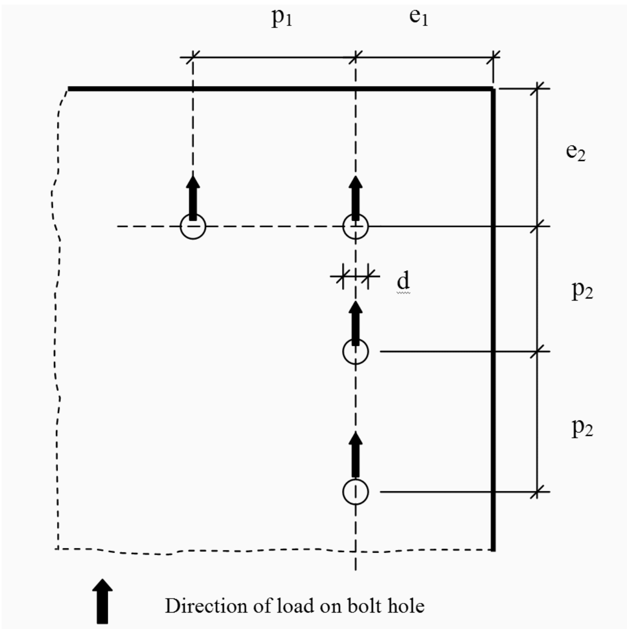


**Fig. 1**
**Direction of load on bolt hole**

### B 200 Minimum requirements

**201** Bolted shear connections are only accepted in laminates with reinforcement placed in at least two directions. The smallest angle between at least two reinforcement directions shall not be smaller than 75° (does not apply to pure CSM laminates). CSM plies in a combined laminate shall not be included in the calculation of the capacity of the connection.

**202** The surface of the part of the bolt inside the laminate shall be smooth. No threads are allowed in this area.

**203** A washer with an outer diameter not smaller than 3 d shall be used under the bolt head and the nut. The washer shall have adequate stiffness such that the bolt pretension is distribute under the area of the washer. Only flat-face bolts shall be used. Countersunk/tapered bolt heads are not accepted due to the risk for splitting the laminate by the wedge effect of the bolt head.

**204** The bolt shall be tightened with such a force that the laminate is subjected to a nominal compressive stress under the washers, exceeding 15 MPa but not exceeding 30 MPa. The nominal stress is calculated as compressive load in the bolt divided by the surface area of the washer. Due to the creep (and thus stress relaxation) that can be expected in the laminate, bolts should be re-torqued after a period of time not shorter than 2 weeks.

**205** The pitch transverse to the direction of the load shall satisfy $p_1 \geq 5$ d.

The pitch in the direction of the load shall satisfy $p_2 \geq 4$ d.

The edge distance transverse to the direction of the load shall satisfy $e_1 \geq 3$ d.

The edge distance in the direction of the load shall satisfy the following requirement:

$e_2 \geq 4$ d.

**206** The nominal bearing stress shall satisfy the following requirement:

$$\sigma_{bear} = \frac{R_{bear}}{3\gamma}$$

$\sigma_{bear}$ = shear load divided by $d \cdot t$
t = thickness of structural laminate
$\gamma$ = 1.0 for holes with a difference between bolt and hole diameter less than 0.1 mm
$\gamma$ = 1.6 for holes with a difference between bolt and hole diameter of less than 1.0 mm

The default values of the bearing stress capacity given in Table B1 can be used.

**Table B1 Default values of the bearing stress capacity**

| *Type of reinforcement* | *Nominal bearing stress strength, $R_{bear}$ (MPa)* |
|---|---|
| Glass, woven rowing | 200 ($V_f$/0.33) |
| Glass, multiaxial laminates | 250 ($V_f$/0.33) |
| Glass, CSM | 75 ($V_f$/0.33) |
| Carbon, woven rowing | 275 ($V_f$/0.50) |
| Carbon, multiaxial laminates | 325 ($V_f$/0.50) |
| Aramid, woven rowing | Considered specially |
| Aramid, multiaxial laminates | Considered specially |
| $V_f$ = volume fraction of reinforcement in laminates excluding CSM | |

Higher bearing stress capacity can be used based on representative test results.

For hybrid laminates $R_{bear}$ can be found by liner interpolation based on the volume fraction of the respective types of fibre.

**Guidance note:**

The requirements are such that it is highly probable that the failure mode will be that the bearing stress will exceed the capacity around the edge of the hole.

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## C. Out-of-plane Loads

### C 100 General

**101** A connection for out-of–plane loads shall be bolted through the panel, in sandwich panels through both skins. For attachments not participating in the structural strength of the hull and superstructure other arrangements may be accepted by the Society.

**102** Washers or plates shall be provided on both sides of the panel to distribute the load from bolt heads and nuts. These washers or plates may be fabricated from metallic materials or from fibre reinforced thermosets.

Their bending stiffness shall be large enough to ensure a distribution of the load from each bolt over a sufficiently large area to prevent compressive overloading of the panel in-between the washers or plates. The compressive stress under the washer or plates shall not anywhere exceed 30% of the compressive strength of the skin and core, respectively.

**103** The global effect of the out-of-plane load on the panel (in-plane bending moments and through thickness shear) shall be calculated according to recognised methods for the calculation of load effects in panels subjected to concentrated loads. The stress levels in laminates, skins and core shall not exceed the stress level accepted for hull panels in bottom exposed to slamming.

**104** Other arrangements may be accepted based on test results. Such testing shall be carried out on connections with representative design on representative panels subjected to representative loads including all in-plane and out-of-plane components. The allowable loads on the connection shall not exceed the lowest strength recorded from at least three such test divided by the factor of 3.

## D. Inserts and Attachments

### D 100 General

**101** Inserts and attachments may be used for transferring in-plane and out-of-plane loads for connections not participating in the structural strength of the hull and superstructure.

**102** Where adequate, the methods for design described above may be used. Where these methods are not adequate the allowable load shall be determined by testing. Such testing shall be carried out on inserts or attachments with representative design on representative panels subjected to representative loads including all in-plane and out-of-plane components. The allowable loads on the insert/attachment shall not exceed the lowest strength recorded from at least three such test divided by the factor of 3.

# SECTION 10
# BUCKLING

## A. General

### A 100 General

**101** For panels, beams and columns with stress levels not exceeding the allowable stress levels given in these Rules, global buckling may be assumed to be linear, i.e. a linear analysis may be used when calculating the critical buckling load or stress.

**102** Standard textbook formulas using a conservative estimate of in-plane and bending moduli of the laminate may be used considering the requirements given in this Section. More rigorous formulas based on the complete stiffness matrix of the laminate may also be used.

**103** The effect of imperfections, i.e. deviations from the idealised geometry shall be considered in the analysis.

**104** It is assumed that the laminates in the components are orthotropic. For other types of laminates a more rigorous analysis is necessary.

**105** The edge or end constraints of the component (e.g. constraints against out-of-plane rotation at the edges of a panel) shall be reflected in the analysis in a manner that is as realistic as practical. In a carefully modelled and executed FEM-analyses it may be assumed that edge or end constraints are realistic.

When using standard textbook formulas, solutions for correct edge constraints are seldom available (e.g. the partial constraint against out-of-plane rotation at the edges of a panel in a continuous plate field). For components with significant but partial edge or end restraint the critical buckling load can be calculated as 1.8 times the critical load for the cases of no restraint against rotation, except as specified by other requirements in this Section.

**106** The allowable load or stress level with respect to buckling shall be equal to the critical load or stress, based on a conservative analysis, reduced by the safety factor given in Table A1. For analysis where the effect of geometrical imperfections has been included in a realistic manner the factor may be increased, subject to the approval by the Society.

**Table A1 Safety factors**

| *Buckling mode* | *Safety factor* |
|---|---|
| Global buckling of sandwich and single skin panels | 0.40 |
| Shear buckling of sandwich panels | 0.40 |
| Global buckling of girders, frames, stiffeners | 0.33 |
| Local buckling of top flanges of girders, frames, stiffeners | 0.40 |
| Local shear buckling of webs girders, frames, stiffeners | 0.40 |
| Global buckling of columns | 0.40 |

## B. Single Skin Panels

### B 100 Single skin panels

**101** The global buckling resistance of single skin panels may be analysed applying recognised textbook buckling formulations available for isotropic materials. The lowest modulus of the laminate in its two principal directions shall be chosen as representative of the laminate. Due regard shall be given to the possible difference of the bending modulus to the in-plane modulus of the panel.

**102** In lieu of a more rigorous analysis the critical buckling stress for a rectangular orthotropic plane panel in a larger plate field, loaded parallel to it's longest edge, can be calculated according to the following equation:

$$\sigma_{cr} = K\frac{E}{1-\nu^2}\left(\frac{t}{b}\right)^2$$

b = length of shortest edge of the panel (mm)
t = plate thickness (mm)
$\sigma_{cr}$ = critical buckling stress (MPa)

E = smallest flexural modulus of the two principal directions of the panel (MPa)
= largest Poisson ratio
K = 3.3 when all edges simply supported
K = 6.0 when all edges clamped
K = 4.4 when all edges partially fixed 1)

1) Panel being supported along its four edges and connected to adjacent panels providing a partial rotational restraint.

**103** For panels where the difference between the modulus in the two principal directions is large a more rigorous analysis may be necessary to determine a more realistic buckling resistance.

## C. Sandwich Panels

### C 100 Sandwich panels

**101** All relevant buckling modes shall be considered: global buckling, shear buckling, face wrinkling and face dimpling.

**102** The global buckling resistance of sandwich panels shall be analysed using standard textbook formulas for buckling of sandwich panels. When relevant, the combined effect of global and shear buckling shall be considered.

**103** In lieu of a more rigorous treatment the critical buckling stress for a rectangular orthotropic plane sandwich panel in a larger plate field, loaded parallel to it’s longest edge, can be calculated according to the following equation:

$$\frac{1}{\sigma_{cr}} = \frac{1}{\sigma_{cr}^{b}} + \frac{1}{\sigma_{cr}^{S}}$$

$$\sigma_{cr}^{b} = K\frac{D}{2tb^2}$$

$$\sigma_{cr}^{S} = \frac{S}{2t}$$

b = length of shortest edge of the panel (mm)
t = thickness of skin laminates (mm)
$\sigma_{cr}$ = critical buckling stress (MPa)
$\sigma_{cr}^{b}$ = critical buckling stress with respect to global buckling (MPa)
$\sigma_{cr}^{S}$ = critical buckling stress with respect to shear buckling (MPa)
D = bending stiffness per unit of length, E I (Nmm)
I = moment of inertia pr unit of length ($mm^4/mm$)
E = modulus in the loaded direction of the skin laminates (MPa)
S = $G_c\, d^2/t_c$ (N/mm)
$G_c$ = core shear modulus (MPa)
$t_c$ = core thickness (mm)
d = distance between centre of skin laminates (mm)
K = 40

The equation is based on the panel being supported along its four edges and that it is connected to adjacent panels providing partial rotational restraint.

**104** For panels where the difference between the modulus in the two principal directions is very large a more rigorous analysis may be necessary to determine a more realistic buckling resistance.

## D. Beams, Girders and Stringers

### D 100 Beams, girders and stringers

**101** Beams, girders, stringers etc. shall be analysed with respect to global buckling due to axial compression. The flanges and webs shall be analysed with respect to local buckling due to axial load, bending moment and shear load.

**102** For closed section beams with adequate stiffness or support with respect to tripping, the critical axial global buckling load is given by:

$$P_a = \frac{\pi^2}{l^2} \frac{D}{\left(1 + \frac{\pi^2 D}{l^2 D_Q}\right)}$$

$D$ = bending stiffness of the beam with associated plating, EI ($Nmm^2$)
$l$ = the free span of the beam (mm)
$D_Q$ = $t_w\, h_w\, G_w$ ($Nmm^2$)
$t_w$ = combined thickness of stiffener web(s) (sum of all web thicknesses) (mm)
$h_w$ = height of the beam web (mm)
$G_w$ = shear modulus of the beam web (MPa)

**103** The critical axial stress in the top flange of top-hat cross sections not supported by a structural core can be calculated as for single skin panels.

**104** The critical shear stress with respect to shear buckling in the webs of stiffeners not supported by structural core material may be calculated according to the following equation for ±45° lay-ups:

$\tau_{cr}$ = $90 \cdot D_{11}/(h_w^2 \cdot t_w)$ ($N/mm^2$) carbon fibre
$\tau_{cr}$ = $80 \cdot D_{11}/(h_w^2 \cdot t_w)$ ($N/mm^2$) glass fibre
$h_w$ = height of web (mm)
$t_w$ = thickness of web laminate (mm)
$D_{11}$ = flexural stiffness of the web laminate in the longitudinal direction of the web/stiffener = (Nmm)
(For ±45° lay-ups $D_{11} = D_{22}$)

For other laminate lay-ups the critical shear stress, $\tau_{cr}$, may be calculated according to the following equation:

$\tau_{cr}$ = $K \cdot (D_{11} \cdot D_{22}^3)^{1/4}/(h_w^2 \cdot t_w)$ ($N/mm^2$)
$K$ = $44.0 + 25.8 \cdot \alpha - 2.95 \cdot \alpha^2 + 0.25 \cdot \alpha^3$
valid for a < 5
$\alpha$ = $(D_{12} + 2 \cdot D_{66})/(D_{11} \cdot D_{22})^{1/2}$
$D_{22}$ = flexural stiffness of the web laminate perpendicular to the longitudinal direction of the web/stiffener (Nmm)
$D_{12}$ = $\upsilon_{12} \cdot D_{22} = \upsilon_{21} \cdot D_{11}$ (Nmm)
$D_{66}$ = twisting stiffness of the laminate (Nmm)
$\upsilon_{12}$, $\upsilon_{21}$ = Poisson's ratios for the web laminate

The shear stress shall not exceed $\tau_{cr}$.

Alternative more rigorous methods for calculating the buckling capacity of webs may be accepted.

## E. Stiffened Plate Field

### E 100 Stiffened plate field

**101** Stiffened plate fields can be analysed using formulas developed for such structures fabricated from steel provided conservative assumptions are made regarding the stiffness of cross sections of stiffeners and plating are made.

## F. Columns

### F 100 Columns

**101** The critical load of columns can be calculated according the standard Euler formulas for global buckling of columns.