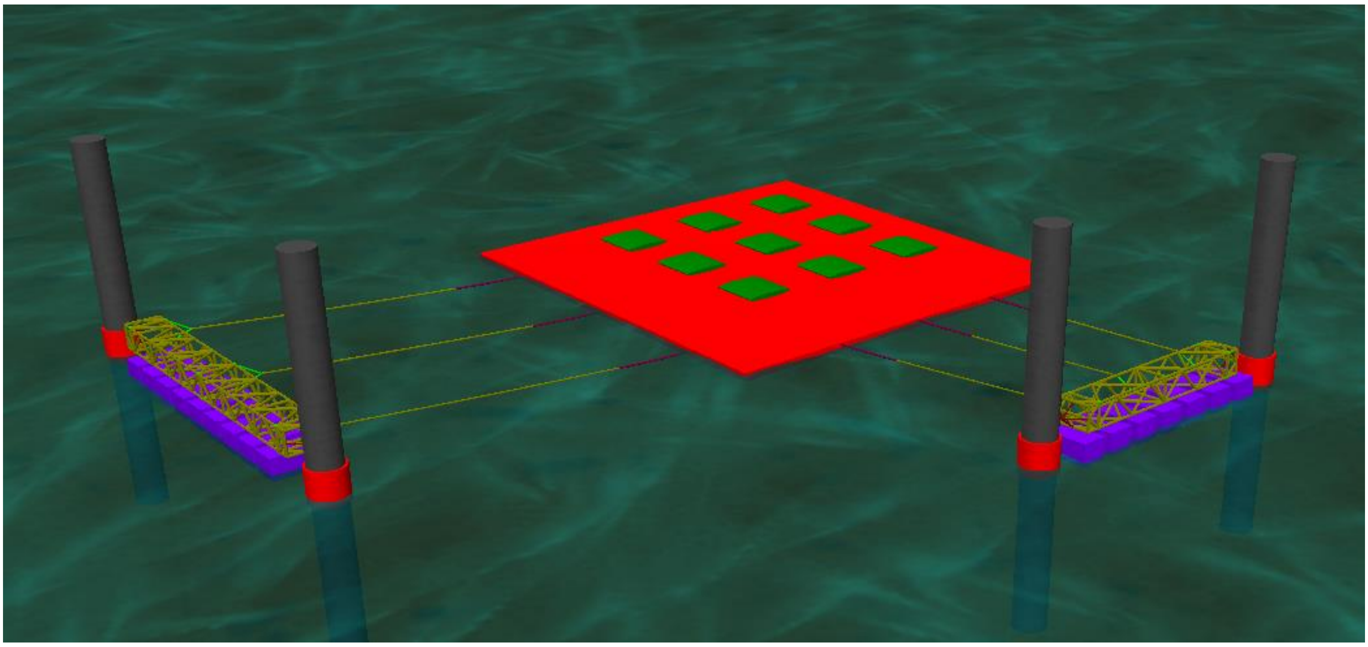
TECHNICAL REPORT

CHANGBIN TRUSS FATIGUE ANALYSIS

for



Reference Name : WDZ_C&T_A_CHANGBIN TRUSS FATIGUE ANALYSIS
Date : **03/03/2022**
Revision : **Version A**

Contents

Figures

Nomenclature

C&T : Ciel et Terre International
WDZ : Windglaz
SCF : Stress Concentration Factor
DFF : Design Fatigue Factor

References

[1]. Pillar anchoring material and detailed presentation_20220121
[2]. Dyneema ropes and Pile calculations Section03_20211206
[3]. Pillar Anchoring System Presentation 20210608_FS
[4]. wind_data.xlsx
[5]. 3.9M-v5.STL
[6]. 6.3M成品-v7.STL
[7]. Changbin configuration
[8]. SDESIGN_V002.xlsm
[9]. WDZ_C&T_A_SDESIGN_manual_150421
[10]. https://eurocodes.jrc.ec.europa.eu/doc/WS2008/EN1999_7_Kosteas

1 Introduction

Ciel et Terre International is currently investigating an innovative farm configuration for installation at Changbin site in Taiwan. Solar Farm is connected to piles and wind and wave loads experienced by the farm are transferred to the piles through mooring lines connected to an aluminium truss supported by buoys.

The truss is subject to motions due to wave and wind loadings.

Truss structures with a several welded connections can have fatigue issues when loaded with a large number of cycles during their lifetime.

Ciel et Terre international requires Windglaz to perform a fatigue analysis of the truss elements.

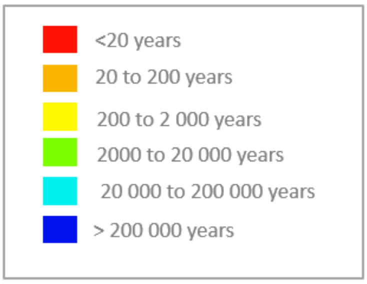
This document aims to present the results of this fatigue assessment:

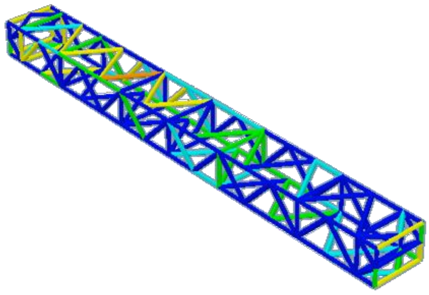
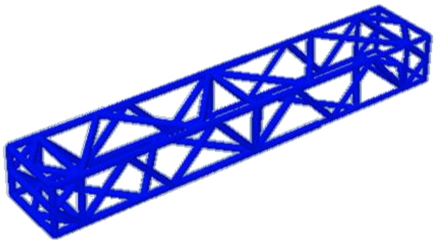
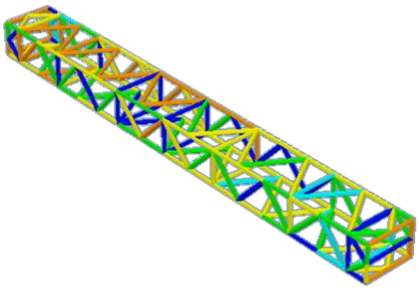
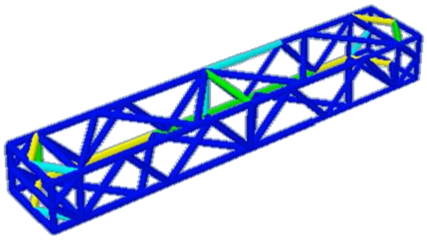
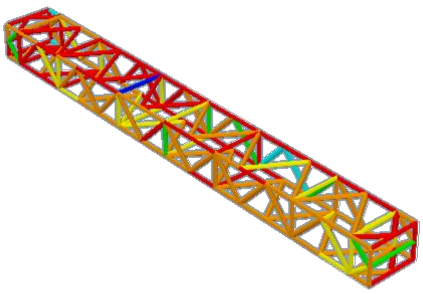
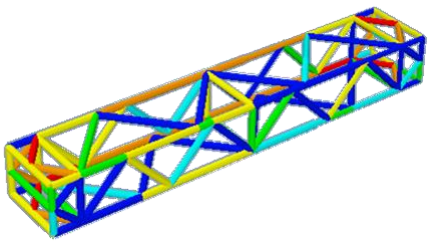
- Assumptions for the model
- Site data and simulation conditions
- Fatigue results

2 Summary

Fatigue lifetime has been assessed in both 6.3 and 3.9m truss for solar farm at Changbin site.

With available data, following minimum lifetime have been calculated in both truss :



		West Truss	South Truss
		Minimum lifetime	Minimum lifetime
Base material	SN curve m = 7 SCF1.1 DFF1	169 years	1 913 705 years
			
Weldings	SN curve m = 4.3 SCF1.1 DFF1	25.4 years	249.7 years
			
Weldings	SN curve m = 3.4 SCF1.1 DFF1	1.3 years	11.9 years
			

Following main conclusion can be done:

- Fatigue lifetime is acceptable in base material for both truss types.
- Fatigue lifetime is below expected life duration in weldings for a large number of beams in the truss.
- South truss has a longer fatigue lifetime, what can be explained by lower wave occurrences parallel to its main axis (meaning in East-West direction) due to lower wind occurrence and fetch in this direction.
- Special care should be given to the quality of the weldings, to improve their fatigue lifetime.

3 Assumptions

This study was made with OrcaFlex 11.2a.

3.1 Truss assumptions

The truss 6.3 and 3.9 m truss have following properties:

鋁合金材料 6005-T5	$Ftu=$	$260\ N\,mm^{-2}$	=	$260\ Mpa$
	$Fty=$	$240\ N\,mm^{-2}$	=	$240\ Mpa$
	$Fcy=$	$240\ N\,mm^{-2}$	=	$240\ Mpa$
	$Fsu=$	$165\ N\,mm^{-2}$	=	$165\ Mpa$
	$Ea=$	$70000\ N\,mm^{-2}$	=	$70000\ Mpa$
	$\gamma a=$	$2700\ Kgf\,m^{-3}$	=	$26460\ N\,mm^{-3}$
桿件	$A=$	$1400\ mm^{2}$		
	$Ix=$	$621667\ mm^{4}$		
	$Iy=$	$614067\ mm^{4}$		
	$Sx=$	$20722\ mm^{3}$		
	$Sy=$	$20469\ mm^{3}$		
	$rx=$	$21.1\ mm^{3}$		
	$ry=$	$20.9\ mm^{3}$		

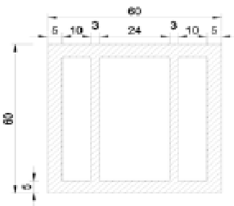


Figure 1 : beam characteristics

Beams are modelled in Orcaflex, using following assumptions:

- Cylindrical elements are used in the model (Stress are nevertheless calculated considering a square beam, as highlighted in §7.1)
- Diameter : 0.6 m
- Isotropic inertia : Ixx = Iyy = 617 867 mm^4 (corresponding to the average value between Ixx and Iyy provided in above figure)
- Bending stiffness : EI = 43.25 kN/m²
- Axial stiffness : EA = 98 000 kN
- Lineic mass : 29.1 kg/m (mass is corrected to fit the global truss weight report)
    - Total weight 6.3 m truss : 250 kg
    - Total weight 3.9 m truss : 150 kg

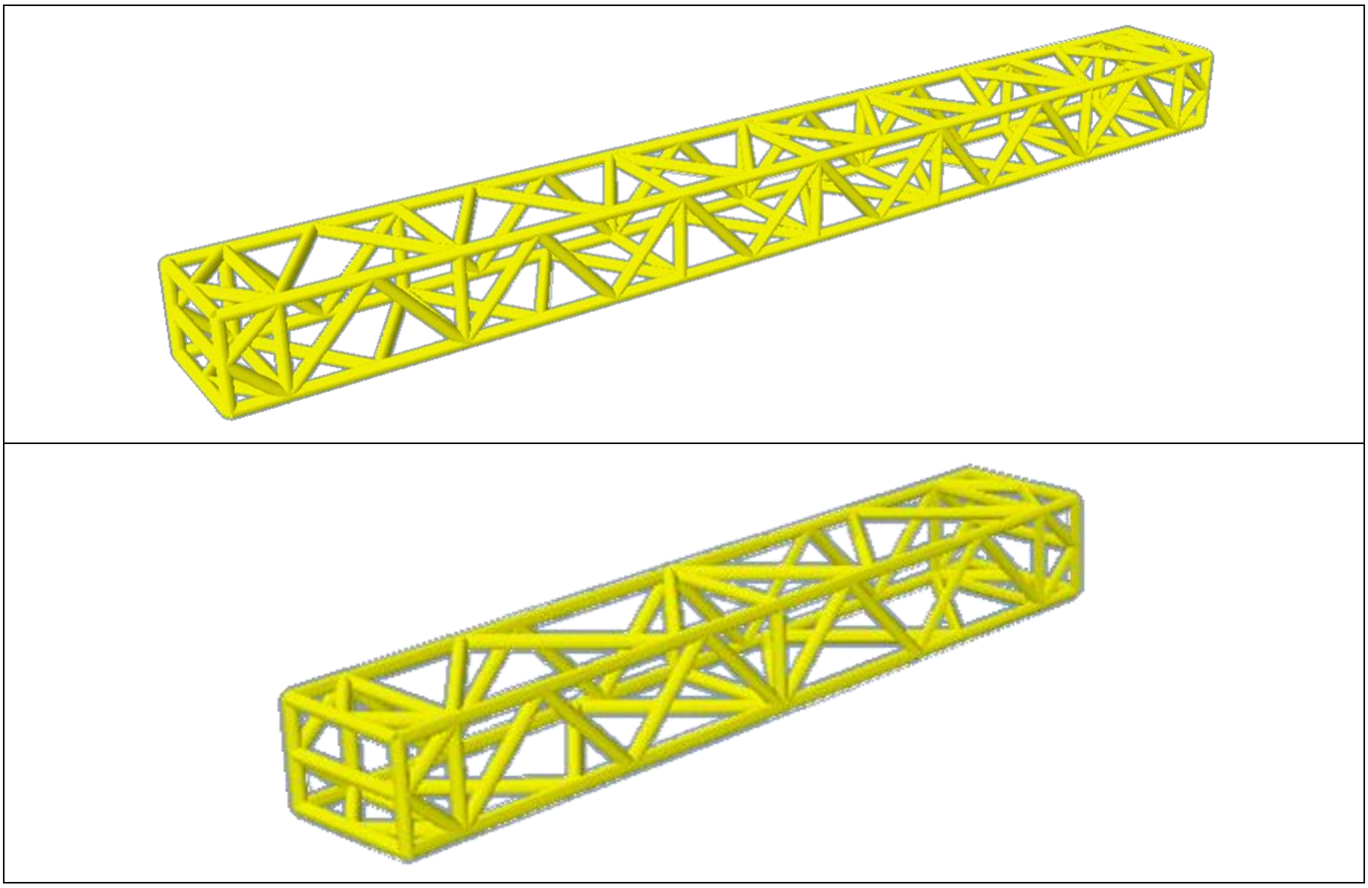


Figure 2 : Orcaflex model of the truss (6.3 truss on top, 3.9 truss on bottom)

3.2 Floats supporting the truss

The truss are supported with buoys modelled with following assumptions:

- Individual Volume : 100 L
- Mass : 10 kg
- Mass moment of inertia around COG : 0.16 kg.m²
- Net buoyancy : 90 kg
- Drag coefficient : Cd = 1
- Inertia coefficient : Ca = 1
- Number of buoys per truss
  - Truss 6.3 m : 18
  - Truss 3.9m : 14

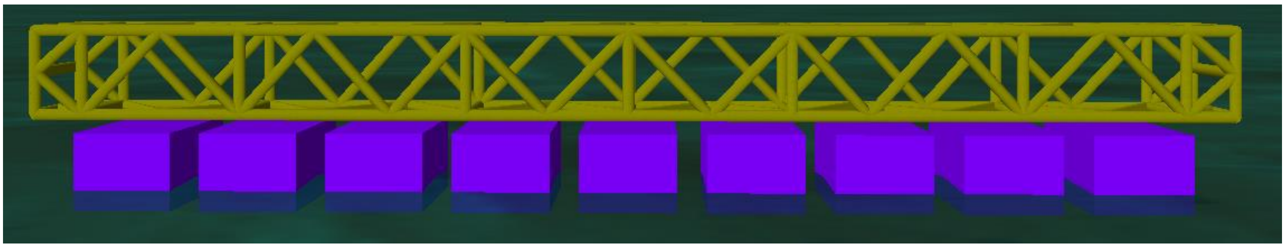


Figure 3 : Buoys supporting the truss

3.3 Truss to pile connection

Connection from truss to piles is modelled as follows:

- 4 Dyneema ropes linked on a shackle
    - Axial stiffness : 436 kN
- Shackle connected to a buoy
- Buoy connected to a constraint whose available displacement are heave and yaw to simulate the possible sliding along the pile and rotation around pile axis.
    - This assumption could be optimistic as potential blocking of the buoy could occur depending on the wave loadings and motions of the buoy.
    - Blocking of the buoys has not been considered in the analysis

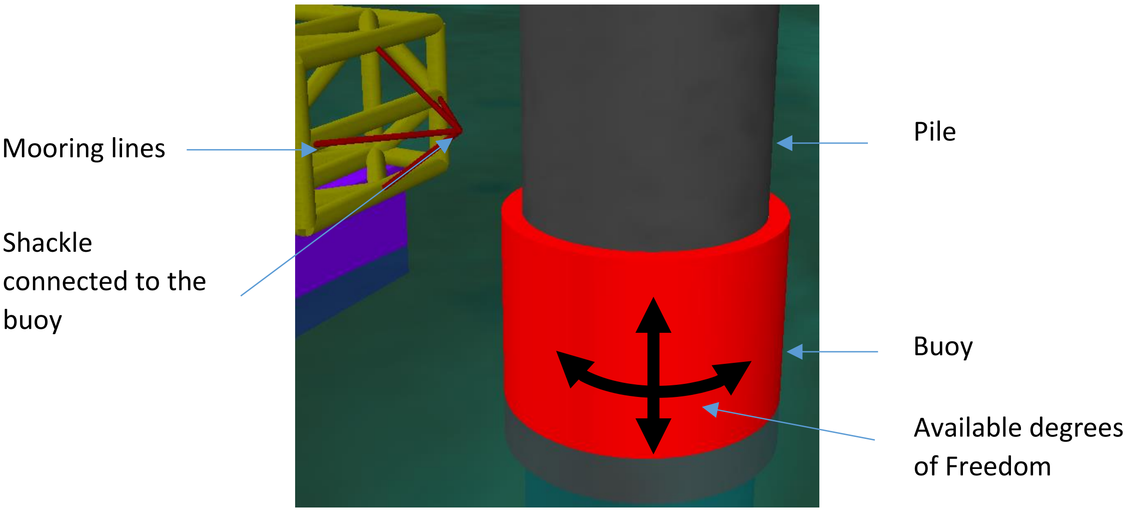


Figure 4 : truss to pile connection

3.4 Truss to farm connection

Connection between truss and farm is modelled as follows:

- Winch having a constant length to simulate the possibility of the dyneema rope to turn around truss structure
    - Stiffness is the dyneema axial stiffness, 436 kN
    - Length : 2.7 m
    - Contact with 4 points around truss
- Polyester rope connected to the dyneema rope
    - Stiffness curve is provided below
    - Length : 5.3 m (Left/Right)
    - Length : 3.5 m (Back/Face)
- Chain 12 mm
    - Length : 1.5 m

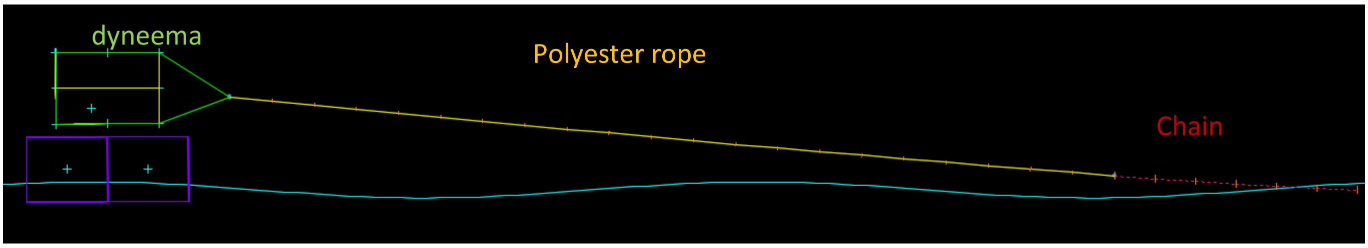


Figure 5 : truss to farm connection

Stiffness of polyester is provided below:

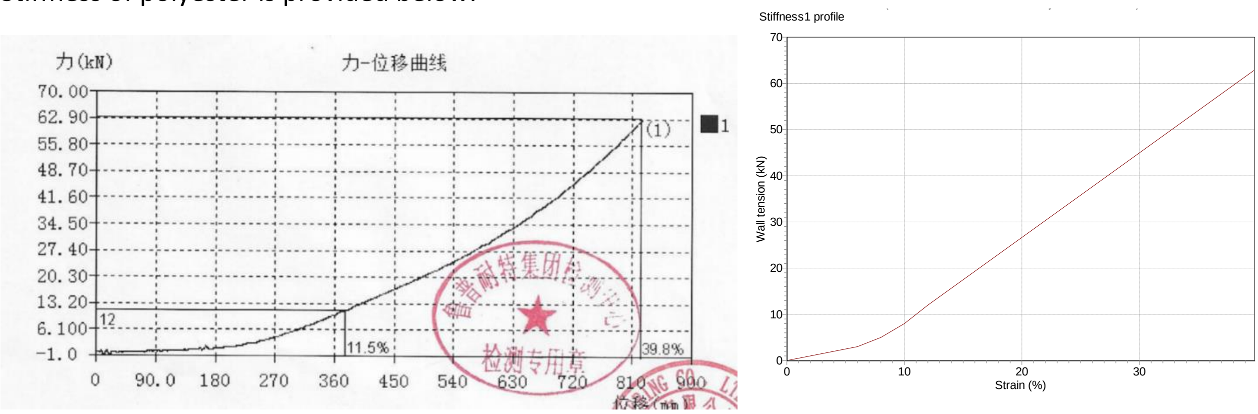


Figure 6 : Polyester stiffness curve (input data at left, orcaflex model at right)

3.5 Farm

The farm is initially modelled by considering all floats, each modelled with 5 buoys, as illustrated below:

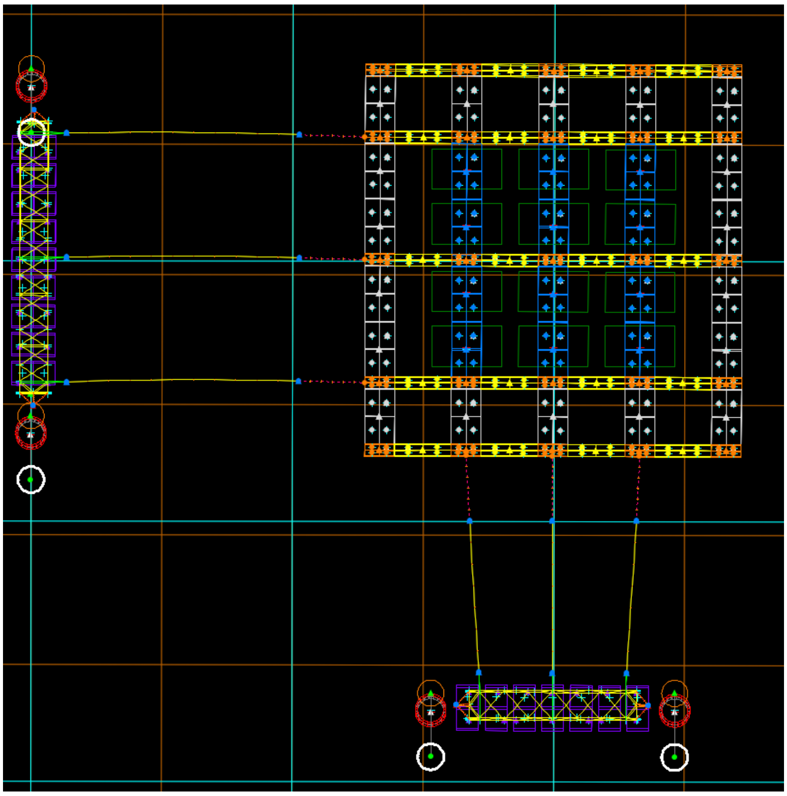


Figure 7 : detailed farm modelling

Sensitivity study done during model validation, proved that it is possible to use a simplified model for the farm, as detailed in § 5.1.

4 External loads modelling

4.1 Equilibrium loading

Loads at equilibrium are applied as a point loading on the farm, to reach 1.5 kN load on each mooring line at equilibrium, without other external loads.

4.2 Wind loads

Loads are applied with wings linked to the farm and whose drag coefficients and areas are calibrated to produce 12 kN load in the mooring lines for a constant wind at reference speed of 25m/s. This reference wind speed has been selected as it corresponds to the highest wind speed observed in the wind data for changbin area.

This is illustrated on following picture.

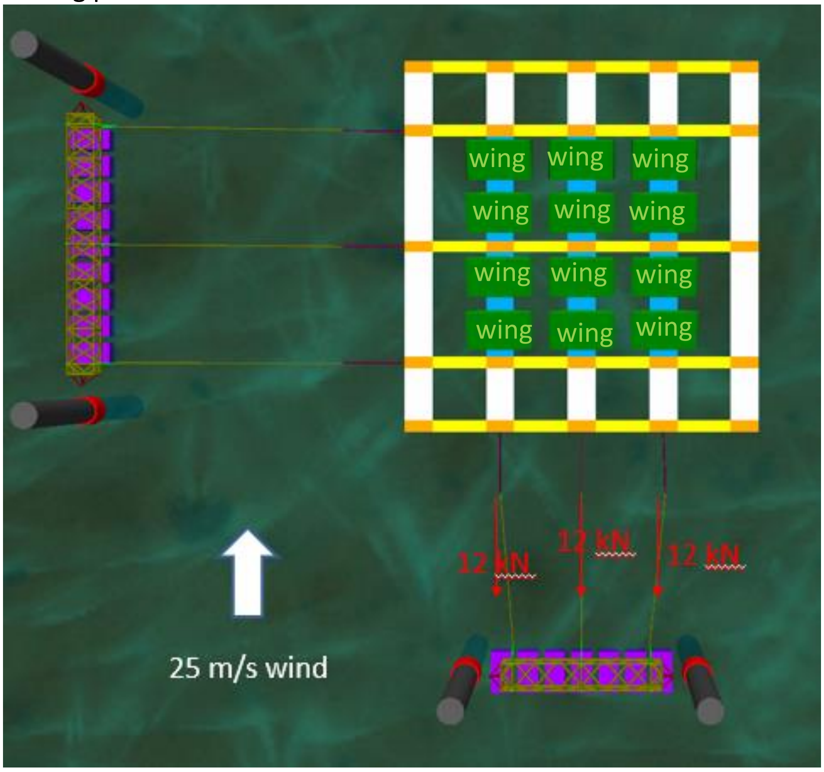


Figure 8 : wind load implementation

4.3 Wave loads

Wave loads are applied on the model, through:

- Hydrostatics loads applied on the buoys supporting the truss (with variation of sea surface, the buoys have vertical motions)
- Hydrodynamic loads applied on the buoys with Morison coefficients and geometric data (surface and volume)
    - Drag force
    - Inertia force

5 Model validation and sensitivities

This paragraph aims to present the assumption that are done to run the full loop of dynamic simulations with wind and wave loadings.

5.1 Simplified farm model

A turbulent wind is applied on the full farm model.

Following graph plots the time history of applied wind speed and resulting tension in the moorings lines connecting the farm to the truss.

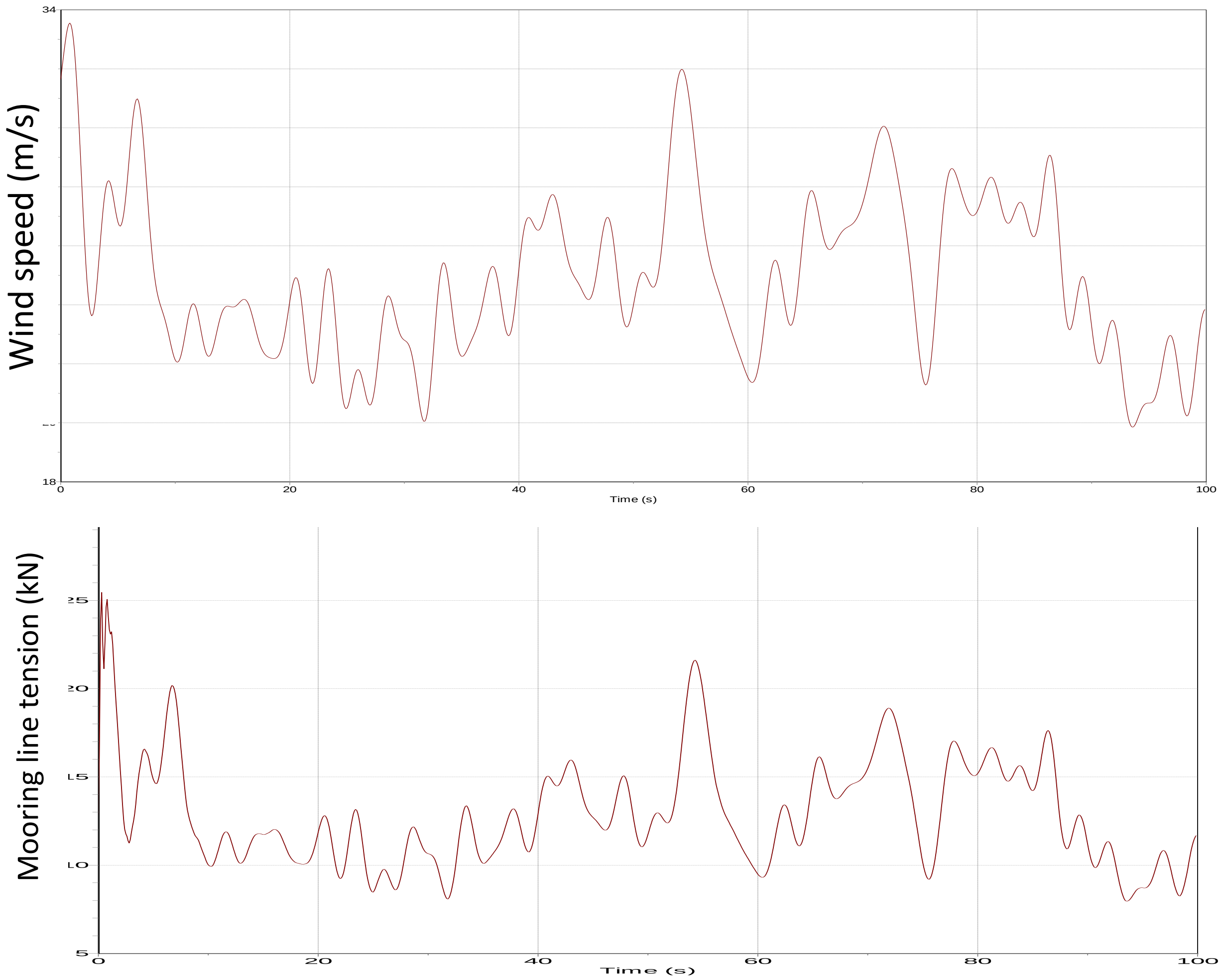


Figure 9 : mooring line tension during a turbulent wind event

It can be noted that tension is directly correlated to the wind speed intensity.
Wind speed force create horizontal motions of the farm, leading to horizontal force variation in the mooring lines. Additionally, vertical motions of the farm are not influencing the tension in the mooring lines, due to their negligible impact on line elongation due to horizontal line configuration, as illustrated below.

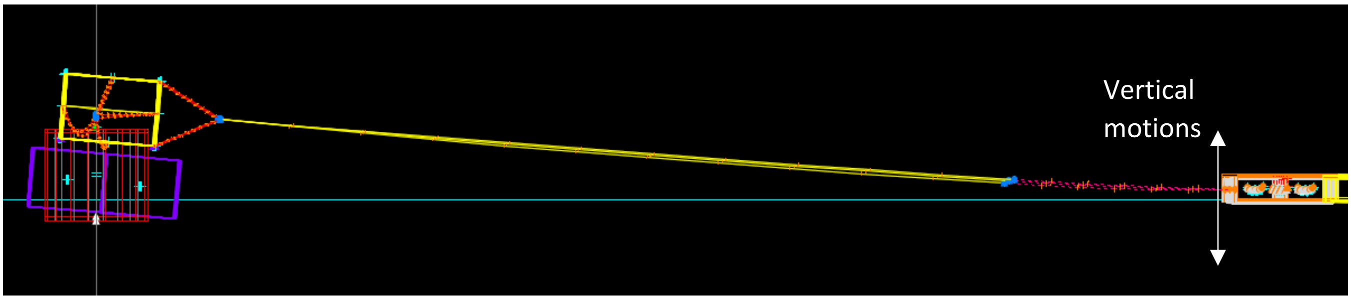


Figure 10 : Horizontal mooring line configuration

As vertical motion do not influence the mooring line tension, and then the motions of the truss, it is proposed to model the farm as a single buoy, whose horizontal motions are allowed and vertical motion not enabled.

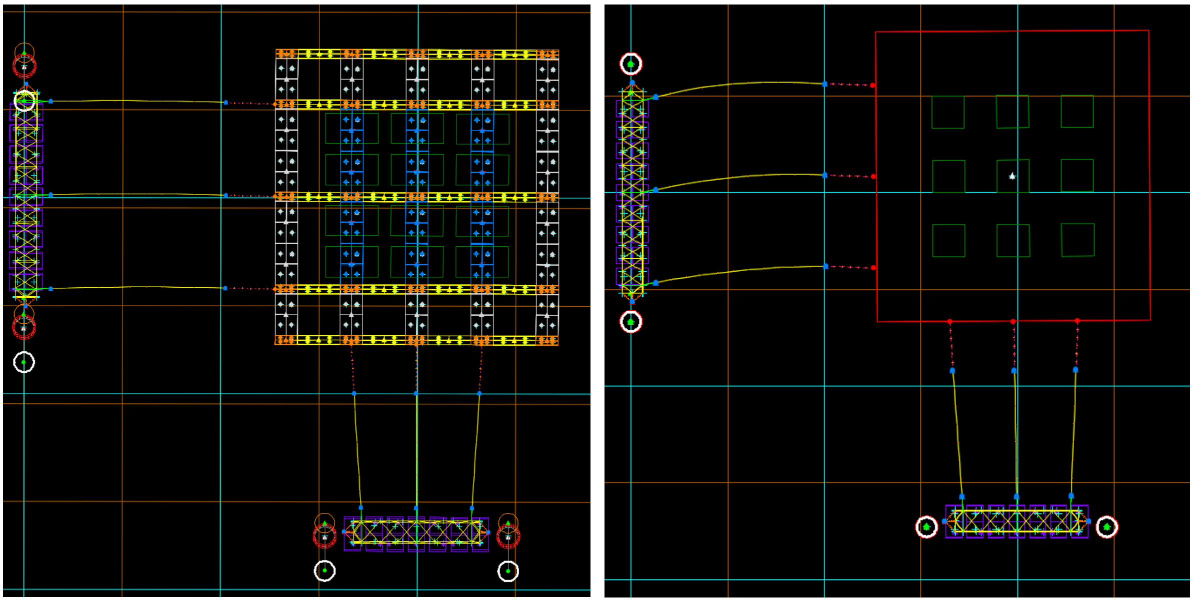


Figure 11 : Detailed farm modeling (left), simplified farm modelling (right)

The farm is one buoys with following assumptions:

- Rigid body
- Horizontal motions allowed (x, y)
- Vertical motion and rotation not enabled

Wind loads are applied on the farm equivalent buoy with wings, in the same way that the detailed farm modelling.

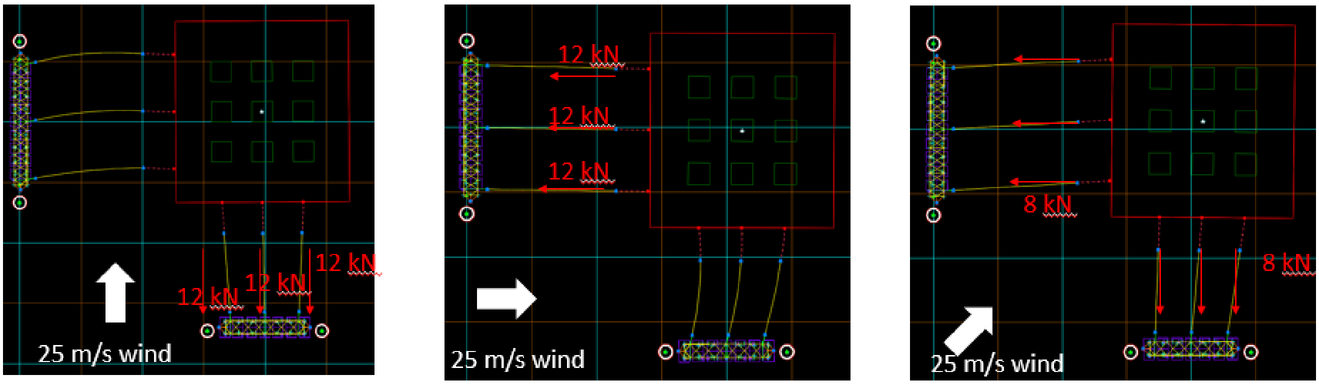


Figure 12 : wind modelling on the simplified farm

The simplified farm assumption is validated by comparing the mooring line tension and stress in one beam of the truss, for a same turbulent wind condition for the full farm model and the simplified model. Comparison is done for a case with wind only and a case with wind and waves.

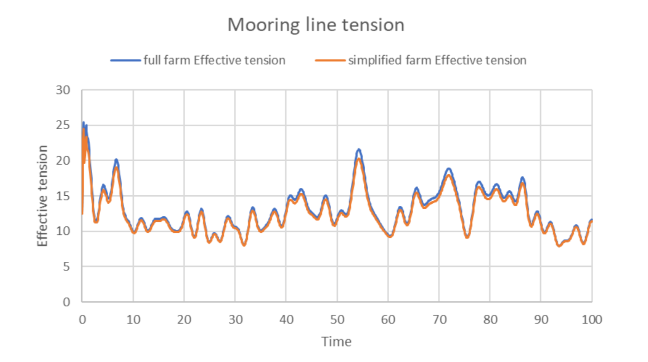
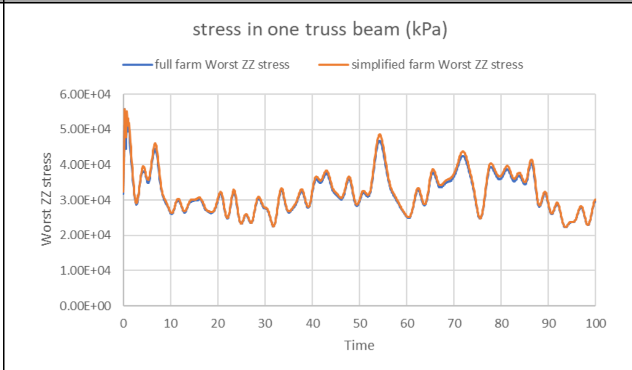
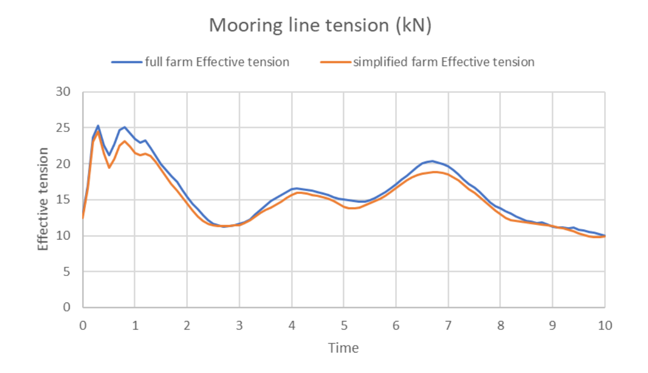
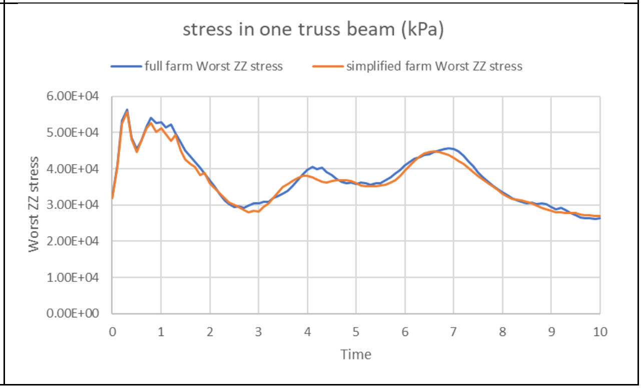
<table>
<tr><th></th><th>Mooring line tension</th><th>Stress in beam longitudinal beam close to mooring line connection</th></tr>
<tr><td>Wind only</td><td>
</td><td>
</td></tr>
<tr><td>Wind + waves</td><td>
</td><td>
</td></tr>
</table>

Figure 13 : simplified farm modelling validation

Comments:

- Differences are very limited between the two assumptions for the tension in mooring lines and the stress in the beam
- Slight differences occur for wind and wave conditions

Simplified farm model will be used for the fatigue assessment.

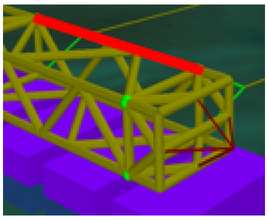
5.2 Turbulent wind vs constant wind

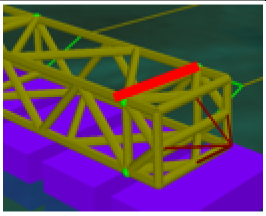
A comparison is done to assess the impact of turbulent wind, compared to constant wind.
Two representative environmental conditions are assessed:

1. Average wind condition
   a. 3 m/s wind speed
   b. Wave : H = 0.05m, T = 0.75s
2. Extreme wind condition
   a. 25 m/s wind speed
   b. Wave : H = 0.1m, T = 1.5s

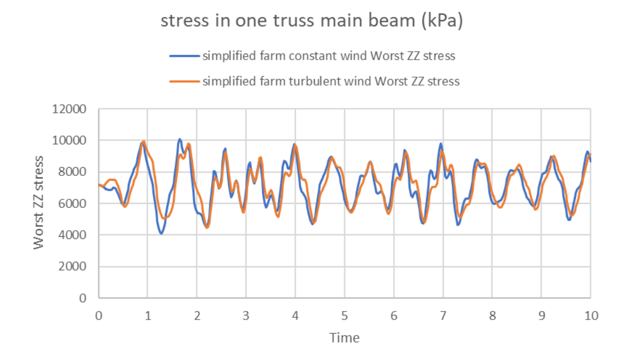
The comparison is done with the simplified farm model.

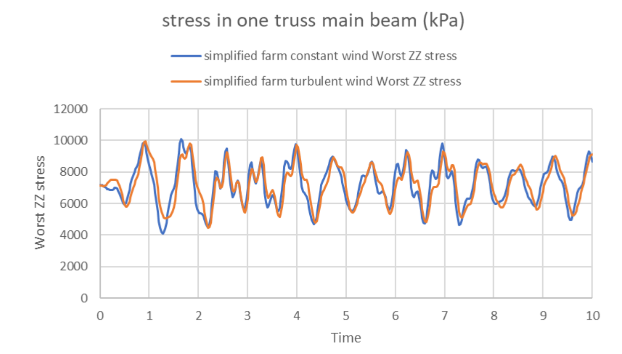
For each conditions, stress in two beams are compared at two locations of the truss



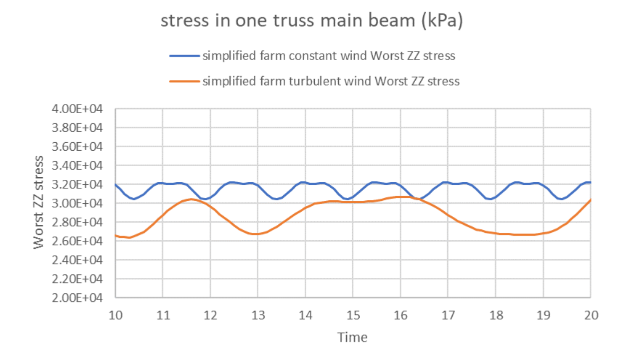


Average wind (3m/s)





Extreme wind (25 m/s)



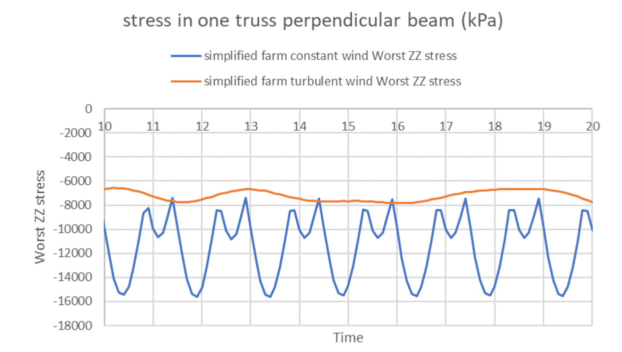


Figure 14 : Turbulent vs constant wind comparison

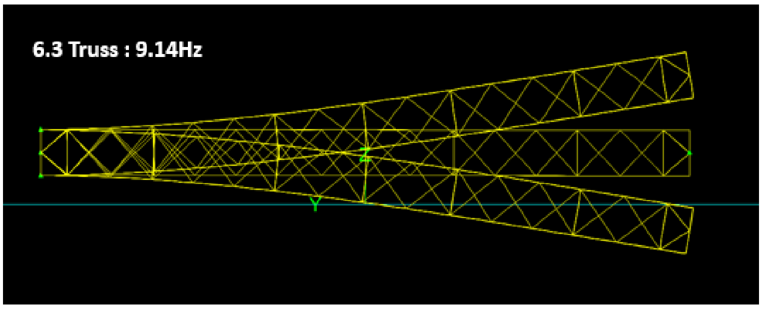
Comments

- Stress time series are very close for average conditions
- For extreme conditions, difference occur due to the fact that wind speed is not the same in both models. In turbulent wind model, wind speed vary with a low frequency and tends to suppress the wave induced motions. As these wave induced motions have a higher frequency than wind motions, they create a larger number of cycles and more fatigue loads. For fatigue assessment, wave induced motions and loads are more relevant and it is more conservative to consider them than low frequency motions due to turbulent wind varying loads.
- It can be seen on above graphs, that wind intensity has an impact on the stress level in the beams, due to different mooring line tension. Modelling this variation of wind speed is then required for the fatigue assessment.

Constant wind model will be used for the fatigue assessment, and fatigue will be assessed for different wind speeds.

5.3 Modal analysis

Modal analysis of the truss is performed.



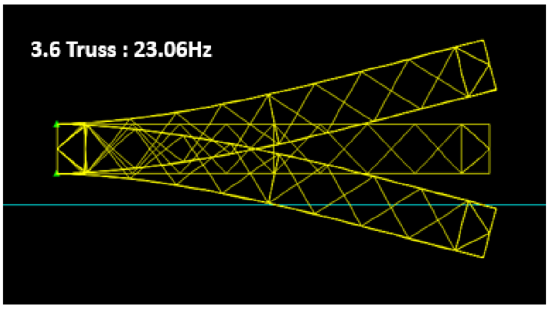


Figure 15 : Turbulent vs constant wind comparison

The two truss have their first modes above 9 Hz, what is a frequency far from wind excitation frequency (0.01Hz to 0.05 Hz) and from wave excitation frequency (0.1 Hz to 3Hz).
No resonance of the structure due to external loading is then observed during the wind/wave loading simulations.

6 Site data and list of simulations

6.1 Changbin Site Environmental data

The farm is installed in Changbin, in Taiwan.

Water depth, wind speed and fetch are available in [4].
Occurrences are plotted on following graphs.

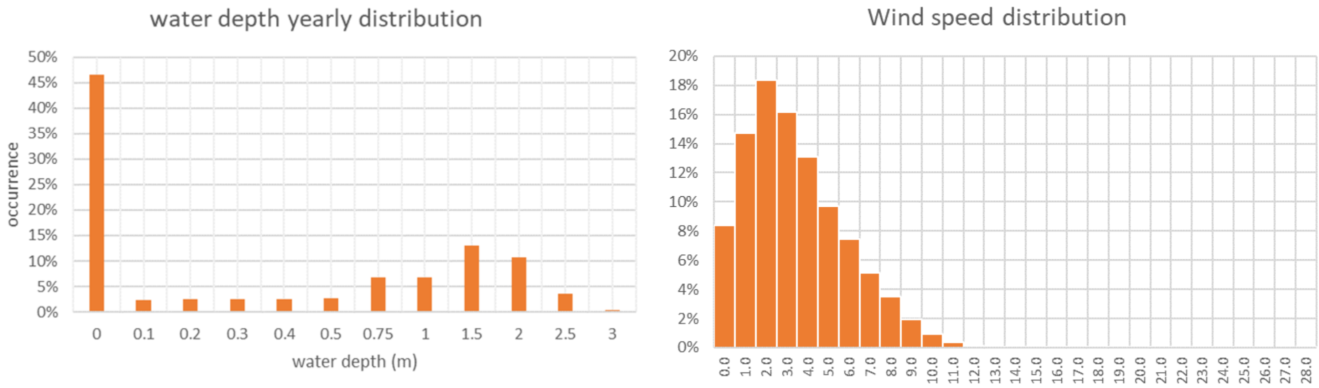


Figure 16 : Water depth distribution and wind speed distribution

Below 0.1 m water depth, the buoy will lay on the seabed. This occurs approximately 50% of the lifetime.

Following graph plots the wind occurrence and fetch as a function of direction.

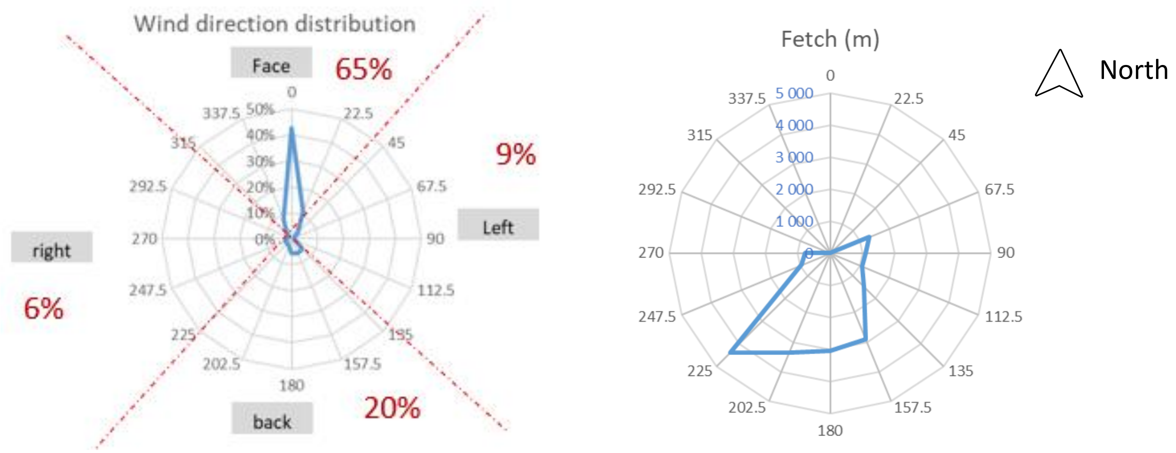


Figure 17 : directional wind occurrence and fetch

6.2 Regular wave calculation

Using SDesign tool, regular waves are counted for each direction, as a function of wind speed and fetch (cf [8],[9])

A summary of calculated parameters is provided below:

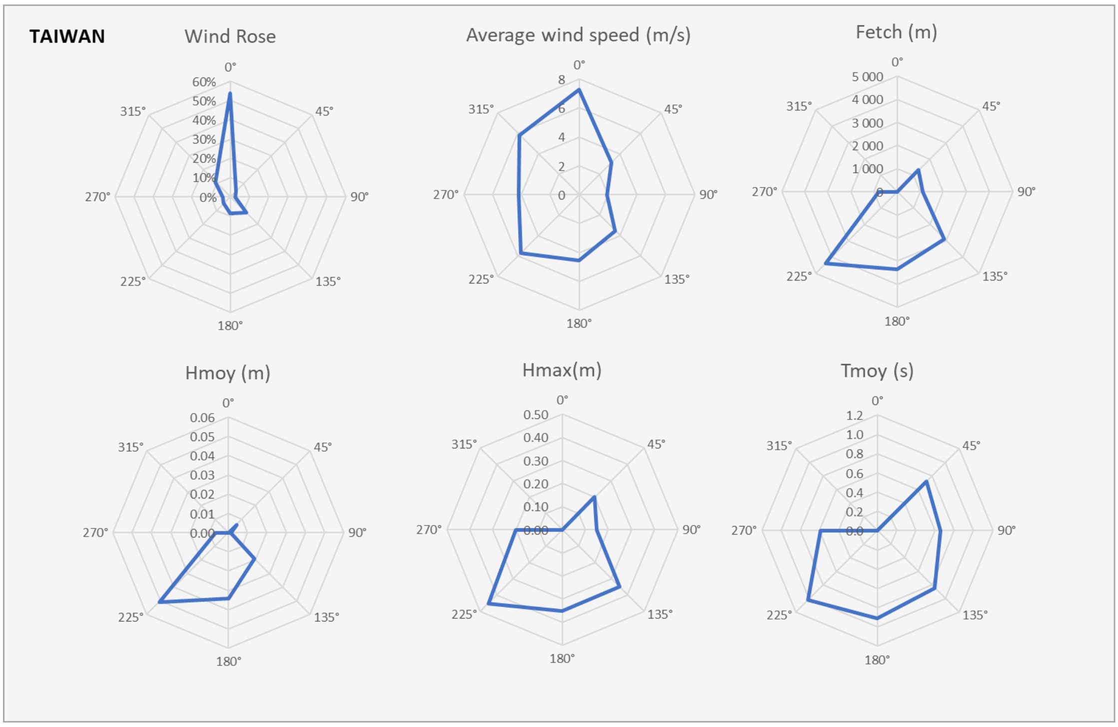
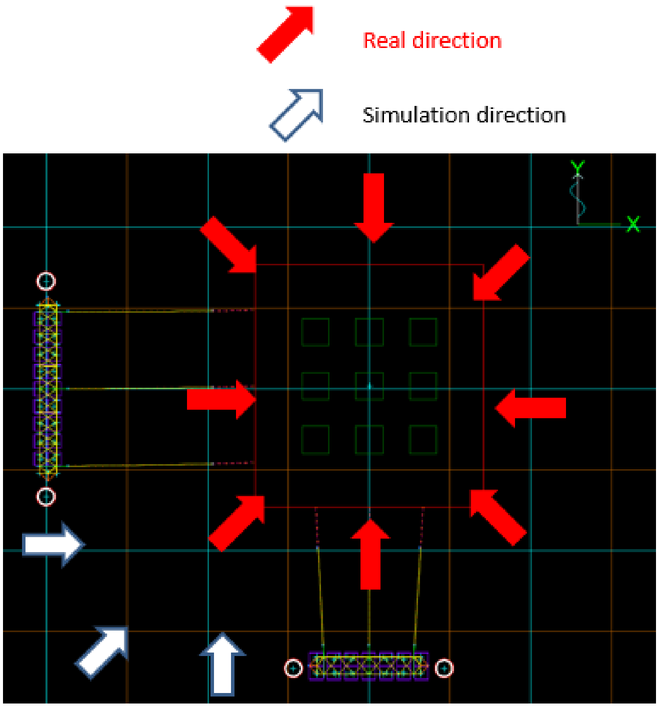


Figure 18 : site data parameters

Due to farm symmetries, each direction will be represented by one simulation direction, as follows



Real direction (from North)	Simulation direction
0°	0°
45°	45°
90°	90°
135°	45°
180°	0°
225°	45°
270°	90°
335°	45°

Figure 19 : real direction and simulation direction

This leads to the following number of waves, as a function of wind direction (0°, 45° and 90°)

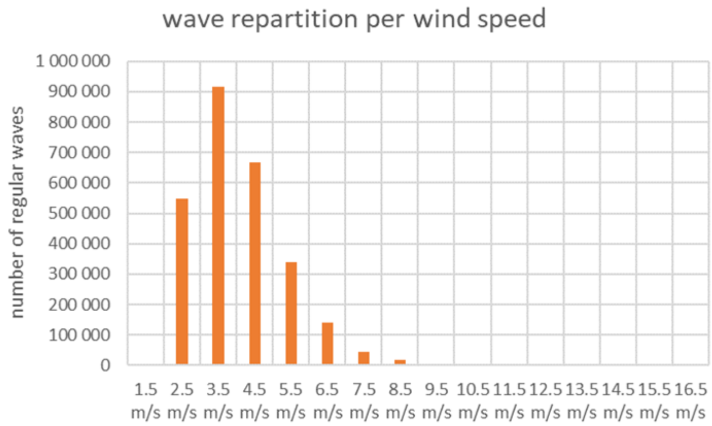


Figure 20 : Total number of wave as a function of wind speed (all directions)

Following tables plots the scatter diagram of regular wave height and periods for the three simulation direction. Values provided are the number of regular wave per year.

It should be noted, that number of waves account for the fact that no wave occur on the structure when it is laid on the seabed, when the water depth is below 0.2m.

0°

		T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)
		0.3	0.5	0.8	1.0	1.1	1.3	1.3	1.5	1.6	1.8	2.0	2.3	2.5	2.8	3.0	3.5	4.0	5.0	6.0	7.0	8.0	9.0	10.0
H (m)	3.00																							
H (m)	2.50																							
H (m)	2.00																							
H (m)	1.50																							
H (m)	1.00																							
H (m)	0.60																							
H (m)	0.55																							
H (m)	0.50																							
H (m)	0.45													0										
H (m)	0.40																							
H (m)	0.35							1																
H (m)	0.30						7	7	3	1														
H (m)	0.25					64	36	34	14	5	3													
H (m)	0.20				488	345	173	148	61	22	16	5	1											
H (m)	0.15				3 812	1 858	789	657	286	114	91	36	12	4	1									
H (m)	0.10			17 626	26 093	9 491	3 722	3 121	1 483	657	575	284	119	56	29	25	12	8	2	1				
H (m)	0.05		19 620	560 553	172 387	60 351	26 056	23 744	13 974	7 191	7 232	4 596	2 415	1 383	849	838	539	442	224	105	56	33	20	13

45°

		T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)
		0.3	0.5	0.8	1.0	1.1	1.3	1.3	1.5	1.6	1.8	2.0	2.3	2.5	2.8	3.0	3.5	4.0	5.0	6.0	7.0	8.0	9.0	10.0
H (m)	3.00																							
H (m)	2.50																							
H (m)	2.00																							
H (m)	1.50																							
H (m)	1.00																							
H (m)	0.60																							
H (m)	0.55																							
H (m)	0.50																							
H (m)	0.45								1	1	1			0										
H (m)	0.40								3	1	1													
H (m)	0.35							12	9	4	4	1												
H (m)	0.30						31	34	26	11	10	4	1											
H (m)	0.25					158	113	119	68	29	24	9	3	1										
H (m)	0.20				913	883	527	485	227	91	72	30	9	2	1									
H (m)	0.15				7 924	4 965	2 426	2 125	978	399	317	130	46	17	7	5	1	1						
H (m)	0.10			25 533	46 744	20 424	9 208	8 226	4 316	1 988	1 786	903	383	181	92	79	37	26	8	3	1			
H (m)	0.05		62 739	867 112	248 110	88 779	39 534	36 765	22 682	12 047	12 477	8 339	4 556	2 695	1 698	1 711	1 133	951	495	236	129	75	48	32

90°

		T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)
		0.3	0.5	0.8	1.0	1.1	1.3	1.3	1.5	1.6	1.8	2.0	2.3	2.5	2.8	3.0	3.5	4.0	5.0	6.0	7.0	8.0	9.0	10.0
H (m)	3.00																							
H (m)	2.50																							
H (m)	2.00																							
H (m)	1.50																							
H (m)	1.00																							
H (m)	0.60																							
H (m)	0.55																							
H (m)	0.50																							
H (m)	0.45																							
H (m)	0.40																							
H (m)	0.35																							
H (m)	0.30																							
H (m)	0.25																							
H (m)	0.20				4	1																		
H (m)	0.15				15	4	1	1																
H (m)	0.10			1 253	118	26	7	5	2															
H (m)	0.05		102 140	45 413	3 905	1 010	353	292	144	67	64	36	16	8	3	3	2	1						

Figure 21 : regular wave number per year

6.3 Alternative site

Occurrence of regular waves, provided in previous paragraph, depend on following parameters:

- Wind speed distribution
- Wind direction distribution
- Fetch per direction
- Water depth distribution

For a site with different conditions, number of wave per direction should be recalculated using SDesign, and fatigue should be recalculated with the spread sheet provided in Appendix.

7 Post processing assumptions

7.1 Stress calculation

The normal stress are calculated in each beam of both truss, as follows:

- $$\Delta\sigma_{xx} = \left(\frac{\Delta M_{xx}}{I_{xx}} \upsilon_{xx} + \frac{\Delta Fa}{A}\right) \times SCF$$
- $$\Delta\sigma_{yy} = \left(\frac{\Delta M_{yy}}{I_{yy}} \upsilon_{yy} + \frac{\Delta Fa}{A}\right) \times SCF$$

With

- ΔMxx = Difference in Bending moment at 0°, over last wave period
- ΔMyy = Difference in Bending moment at 90°, over last wave period
- Ixx = Iyy = 617 867 mm^4
- νxx = νyy = 30 mm
- ΔFa = Difference in axial load over last wave period
- A = section area
- SCF = Stress Concentration Factor (see next paragraph)

7.2 Stress Concentration factor

Two values of stress concentration factors are assessed.

- SCF = 1.1
- SCF = 1.0

Stress concentration factors in weldings depends on:

- Shape of the connection (angles between brace and chord, overlap)
- Welding procedure (single side, double side)
- Condition and quality of the welding
  - Grinding
  - Hammer peening

7.3 SN curves

SN curves for aluminium are not provided in standards as it can be for steel structures.
Following SN curves are extracted from [10] based on Eurocodes.

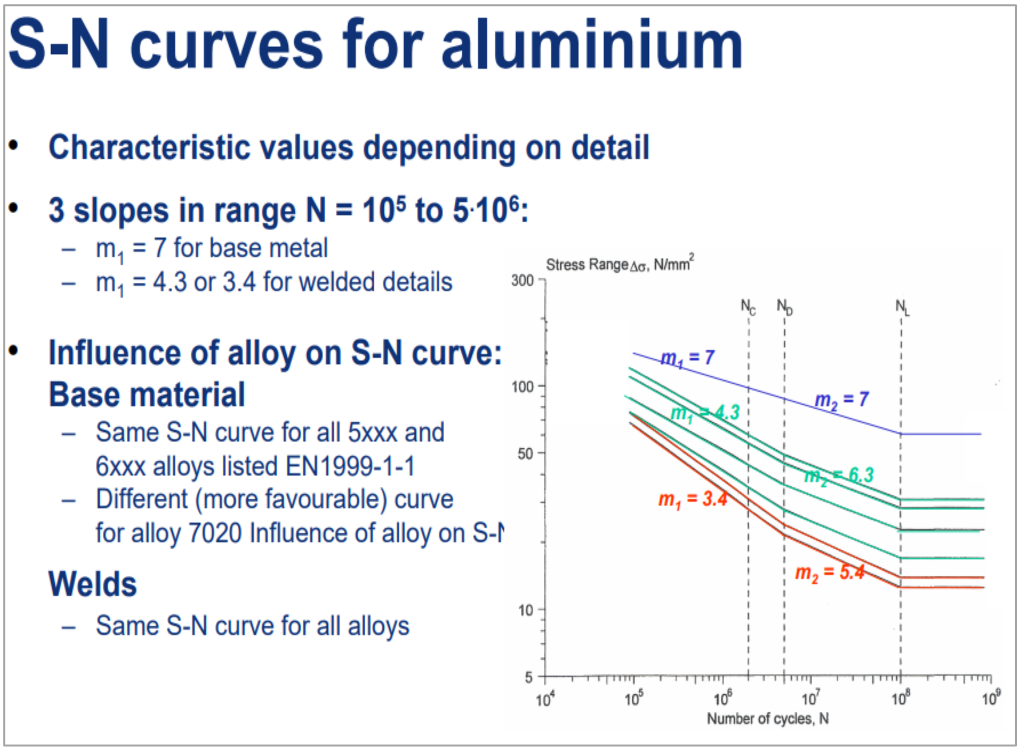


Figure 22 : SN curve assumption for aluminium (from Eurocode 9)

Within these available SN-curves, three curves are considered :

- m = 3.4 for welded details
- m = 4.3 for welded details
- m = 7 for base materials

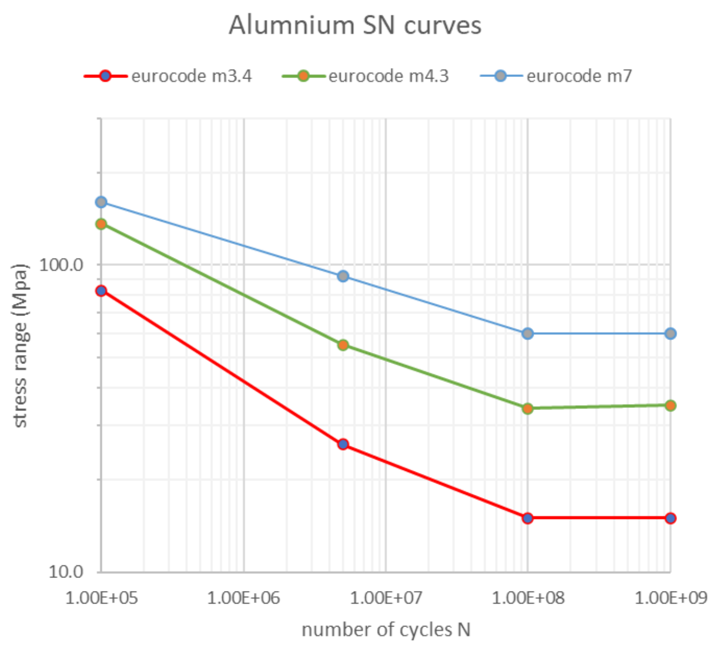


Figure 23 : SN curve selection for postprocessing

It should be noted that these SN curves have an endurance limit, meaning that stress range below a certain level will produce zero damage whatever their number of cycles (example 15 MPa for SN curve Eurocode m=3.4).

7.4 Lifetime calculation

Damage is calculated in each beam of the truss, for both local axis direction (x and y).
For each beam damage is calculated at different location along the beam.

For each beam, one damage N is reported corresponding to :

- Largest damage between x and y axis
- Largest damage along beam length

N = max (Nxx(l), Nyy(l)) x DFF

With :

- Nxx(l) = damage in xx direction at length l along the beam
- Nyy(l) = damage in yy direction at length l along the beam
- DFF= Design fatigue factor = 1

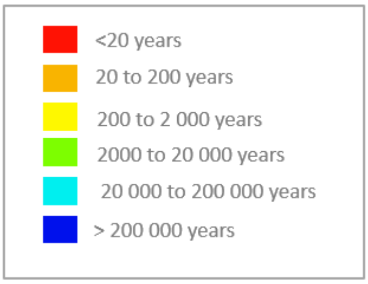
Life time of the beam is then :

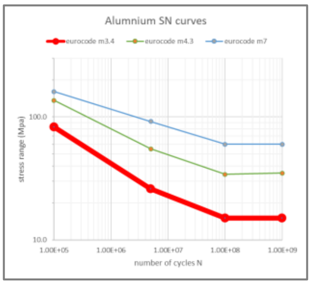
L = 1/N

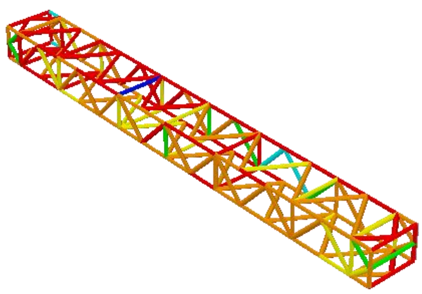
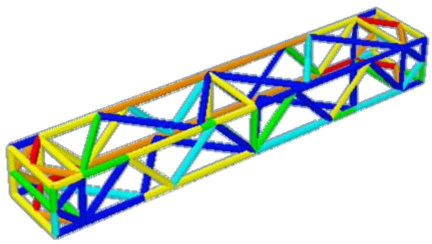
8 Fatigue results

Fatigue results are provided with a design fatigue factor (DFF) of 1, meaning without safety factor regarding fatigue lifetime.
Results are provided in lifetime duration in years for each beam of the model, for different sets of SN curve and SCF.

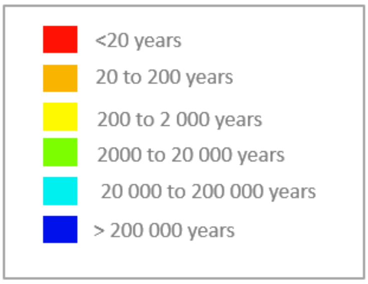
8.1 SN Curve m=3.4 / SCF = 1.1

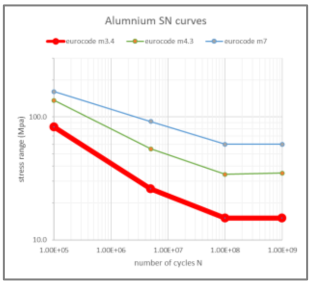


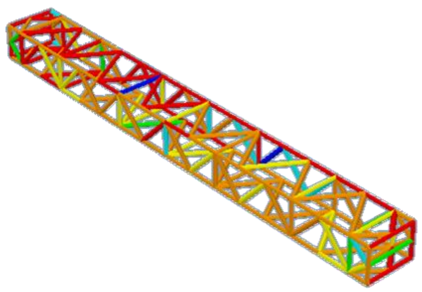
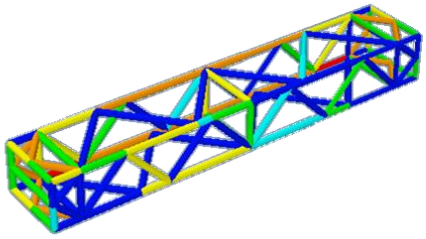


West Truss	South truss
	
Minimum life : 1.3 years	Minimum life : 11.9 years

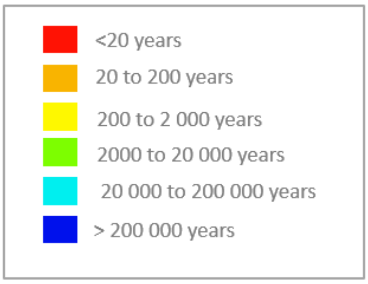
8.2 SN Curve m=3.4 / SCF = 1.0

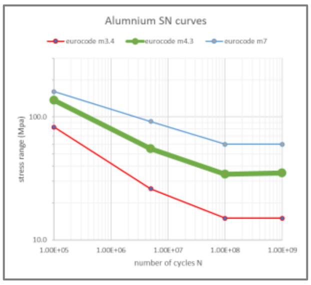


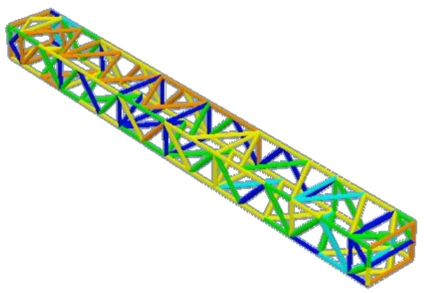
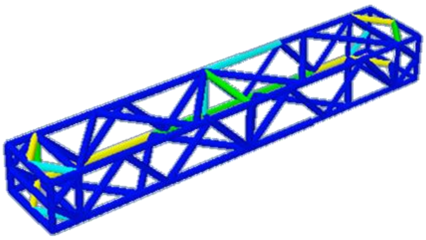


West Truss	South truss
	
Minimum life : 1.8 years	Minimum life : 16.9 years

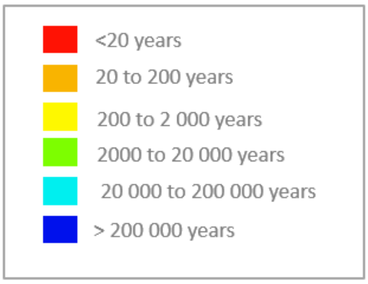
8.3 SN Curve m=4.3 / SCF = 1.1

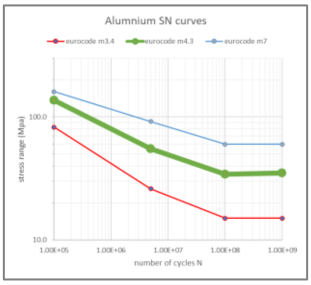


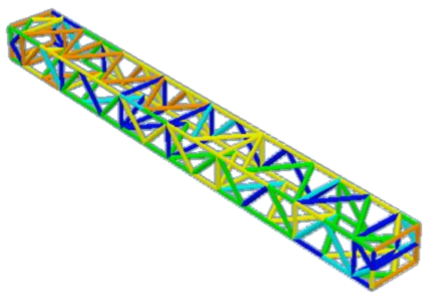
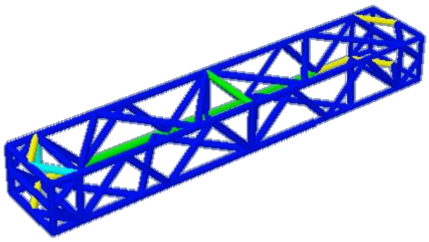


West Truss	South truss
	
Minimum life : 25.4 years	Minimum life : 249.7 years

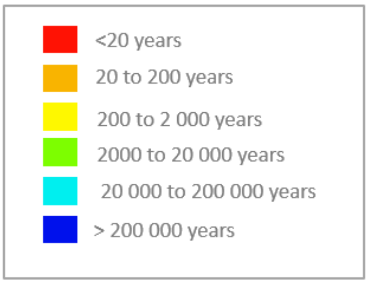
8.4 SN Curve m=4.3 / SCF = 1.0

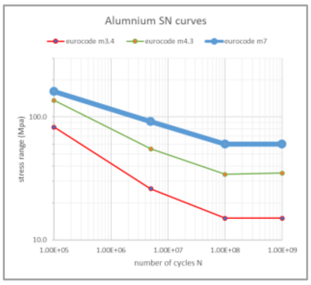


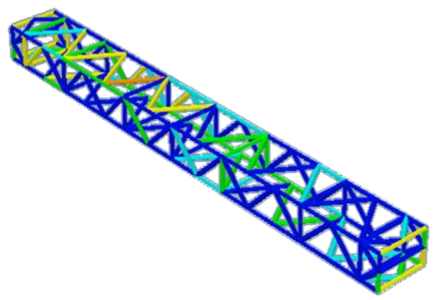
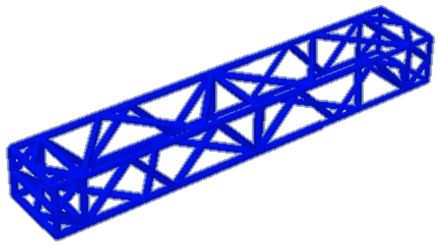


West Truss	South truss
	
Minimum life : 39.6 years	Minimum life : 455.55 years

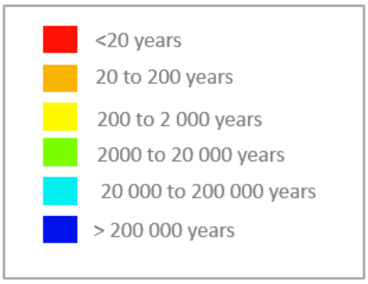
8.5 SN Curve m=7 / SCF = 1.1

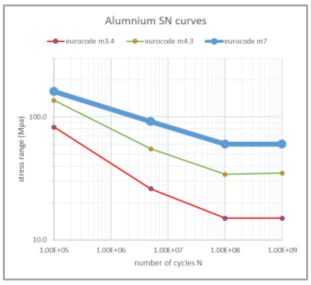


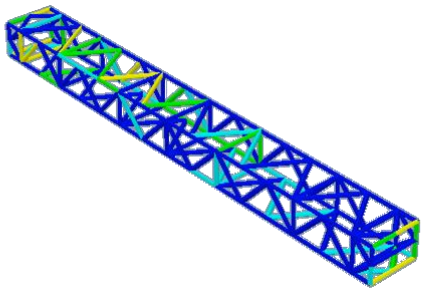
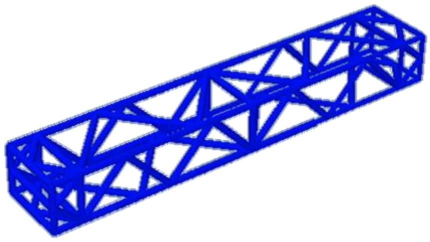


West Truss	South truss
	
Minimum life : 169 years	Minimum life : 1 913 705 years

8.6 SN Curve m=7 / SCF = 1.0





West Truss	South truss
	
Minimum life : 331.9 years	Minimum life : 5 301 939 years

8.7 Fatigue contribution and analysis

Fatigue contribution is analyzed as a function of environmental parameters:

- Wind/wave direction
- Wind speed
- Wave characteristics (height and period)

For each parameter, following are compared:

- Average individual damage (without influence of the occurrence)
- Occurrence of the wave
- Contribution in global damage, including the combination of the individual damages associated to their occurrences

Assessment is done for one beam of each truss, for the SN curve m=3.4 with SCF = 1.1

8.7.1 West truss

direction	average indiviual damage	Wave occurrence	global damage contribution
0 °	3.66E-07	36%	48%
45 °	2.63E-07	58%	52%
90 °		6%	0%
All	-	100%	100%

wind speed	average indiviual damage	Wave occurrence	global damage contribution
1.5 m/s	6.52E-08	0.2%	0.0%
2.5 m/s	1.23E-07	20.4%	5.2%
3.5 m/s	1.79E-07	34.1%	9.1%
4.5 m/s	6.55E-07	24.8%	29.8%
5.5 m/s	4.29E-07	12.6%	29.2%
6.5 m/s	3.74E-07	5.2%	17.9%
7.5 m/s	2.72E-07	1.7%	6.6%
8.5 m/s	2.35E-07	0.6%	1.6%
9.5 m/s	2.24E-07	0.2%	0.3%
10.5 m/s	2.15E-07	0.1%	0.1%
11.5 m/s	2.97E-07	0.0%	0.1%
12.5 m/s	2.52E-07	0.0%	0.0%
13.5 m/s	2.70E-07	0.0%	0.0%
14.5 m/s	1.61E-07	0.0%	0.0%
15.5 m/s	2.72E-08	0.0%	0.0%
16.5 m/s	6.31E-08	0.0%	0.0%
All	-	100%	100%

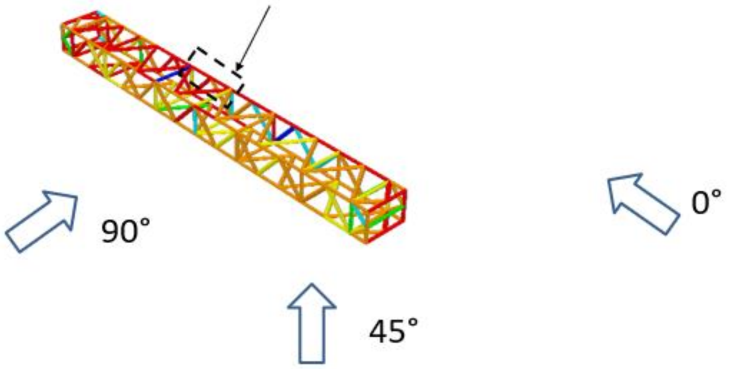


Figure 24 : West Truss wind speed and direction contribution

Comments :

- No damage for waves perpendicular to truss axis occur because the truss is free to rotate around its own axis, leading to low bending moments. Main loads involved are coming from the tension due to mooring lines
- Highest damage occur for wave direction aligned with truss axis, due to truss bending caused by the wave hydrostatic forces and motions applied on the buoys supporting the truss. These are not in phase and parts

of the buoys experience positive buoyancy (wave crest), whereas other parts experience buoyancy decrease (wave though). Relative contribution depend on wavelength and wave periods.

- Highest damage occur between 4.5 and 5.5 m/s

Average individual damage

		T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)
		0.25	0.5	0.75	1	1.125	1.25	1.325	1.5	1.625	1.75	2	2.25	2.5
H (m)	3													
H (m)	2.5													
H (m)	2													
H (m)	1.5													
H (m)	1													
H (m)	0.6													
H (m)	0.55													
H (m)	0.5													
H (m)	0.45								7.1E-07	1.7E-06	3.0E-06			3.4E-08
H (m)	0.4								7.6E-07	1.2E-06	1.8E-06			
H (m)	0.35							7.2E-07	4.1E-07	9.4E-07	1.6E-06			
H (m)	0.3						2.4E-06	7.3E-07	8.5E-07	8.6E-07	5.5E-07	3.7E-08		
H (m)	0.25					1.2E-06	1.2E-06	4.5E-07	4.1E-07	1.0E-06	4.3E-07	1.1E-07		
H (m)	0.2				9.3E-07	1.6E-06	1.8E-06	2.5E-07	1.5E-07	2.9E-07	2.3E-07	2.9E-08	5.0E-09	
H (m)	0.15				6.3E-07	1.1E-06	4.8E-07	1.5E-07	1.5E-08	1.9E-08	9.4E-09	1.0E-09		
H (m)	0.1			2.0E-07	7.2E-07	4.8E-07	1.9E-07	1.1E-08						
H (m)	0.05		5.0E-08	5.4E-09										

Global damage contribution

		T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	
		0.25	0.5	0.75	1	1.125	1.25	1.325	1.5	1.625	1.75	2	2.25	2.5	
H (m)	3														0.0%
H (m)	2.5														0.0%
H (m)	2														0.0%
H (m)	1.5														0.0%
H (m)	1														0.0%
H (m)	0.6														0.0%
H (m)	0.55														0.0%
H (m)	0.5														0.0%
H (m)	0.45								0.0%	0.0%	0.0%			0.0%	0.0%
H (m)	0.4								0.0%	0.0%	0.0%				0.0%
H (m)	0.35							0.0%	0.0%	0.0%	0.0%				0.0%
H (m)	0.3						0.0%	0.0%	0.0%	0.0%	0.0%	0.0%			0.0%
H (m)	0.25					0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%			0.2%
H (m)	0.2				1.0%	1.5%	0.3%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%		2.9%
H (m)	0.15				6.5%	8.3%	0.8%	0.4%	0.0%	0.0%	0.0%	0.0%			16.1%
H (m)	0.1			4.9%	43.0%	16.5%	2.0%	0.1%							66.5%
H (m)	0.05		5.2%	9.1%											14.3%
		0.0%	5.2%	14.0%	50.6%	26.3%	3.2%	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	

Figure 25 : West Truss wave height and period contribution

Comments:

- Damage is increasing with increasing wave height and is highest between 1.125s and 1.25s

8.7.2 South Truss

direction	average indiviual damage	Wave occurrence	global damage contribution
0 °		36%	0%
45 °	3.74E-08	58%	97%
90 °	1.52E-08	6%	3%
All	-	100%	100%

wind speed	average indiviual damage	Wave occurrence	global damage contribution
1.5 m/s	2.27E-09	0.2%	0.0%
2.5 m/s	8.55E-09	20.4%	1.1%
3.5 m/s	4.17E-09	34.1%	7.1%
4.5 m/s	4.11E-09	24.8%	38.1%
5.5 m/s	7.26E-09	12.6%	47.3%
6.5 m/s	6.77E-09	5.2%	2.2%
7.5 m/s	9.26E-09	1.7%	1.3%
8.5 m/s	1.13E-08	0.6%	1.3%
9.5 m/s	1.14E-08	0.2%	0.4%
10.5 m/s	2.07E-08	0.1%	0.5%
11.5 m/s	2.39E-08	0.0%	0.2%
12.5 m/s	3.85E-08	0.0%	0.1%
13.5 m/s	4.41E-08	0.0%	0.1%
14.5 m/s	6.95E-08	0.0%	0.2%
15.5 m/s	5.24E-08	0.0%	0.0%
16.5 m/s	5.48E-08	0.0%	0.0%
All	-	100%	100%

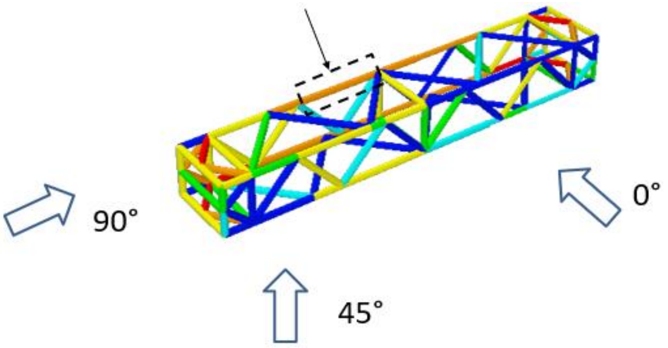


Figure 26 : South Truss wind speed and direction contribution

Comments :

- No damage for waves perpendicular to truss axis, in the same way as for West truss

Average individual damage

		T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)
		0.25	0.5	0.75	1	1.125	1.25	1.325	1.5	1.625	1.75	2	2.25	2.5
H (m)	3													
H (m)	2.5													
H (m)	2													
H (m)	1.5													
H (m)	1													
H (m)	0.6													
H (m)	0.55													
H (m)	0.5													
H (m)	0.45									7.5E-07	3.1E-07			2.4E-07
H (m)	0.4								4.2E-08	1.4E-06	2.1E-07			
H (m)	0.35							5.5E-08	4.8E-07	5.7E-07	3.8E-07			
H (m)	0.3						2.7E-08	1.5E-07	1.8E-07	2.2E-07	2.8E-07	1.3E-08		
H (m)	0.25					1.1E-09	2.3E-08	4.1E-08	7.4E-08	8.0E-08	8.4E-08	3.9E-08	3.6E-09	
H (m)	0.2				1.2E-08	4.1E-09	2.1E-09	6.8E-09	1.7E-08	2.4E-08	2.1E-08	1.3E-09	5.3E-09	
H (m)	0.15				3.7E-09	3.9E-09	4.4E-10	4.2E-10			6.0E-10		6.3E-09	
H (m)	0.1				1.1E-08	3.9E-08	2.4E-08						2.7E-08	
H (m)	0.05		3.5E-08	2.3E-08		3.0E-10								

Global damage contribution

		T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	T(s)	
		0.25	0.5	0.75	1	1.125	1.25	1.325	1.5	1.625	1.75	2	2.25	2.5	
H (m)	3														0.0%
H (m)	2.5														0.0%
H (m)	2														0.0%
H (m)	1.5														0.0%
H (m)	1														0.0%
H (m)	0.6														0.0%
H (m)	0.55														0.0%
H (m)	0.5														0.0%
H (m)	0.45									0.0%	0.0%			0.0%	0.0%
H (m)	0.4								0.0%	0.0%	0.0%				0.0%
H (m)	0.35							0.0%	0.1%	0.0%	0.0%				0.1%
H (m)	0.3						0.0%	0.1%	0.1%	0.1%	0.0%	0.0%			0.2%
H (m)	0.25					0.0%	0.1%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%		0.4%
H (m)	0.2				0.0%	0.8%	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%	0.0%		1.1%
H (m)	0.15				0.0%	3.5%	0.2%	0.0%			0.0%		2.4%		6.1%
H (m)	0.1				0.6%	6.9%	1.4%						78.3%		87.2%
H (m)	0.05		0.6%	4.3%		0.0%									4.9%
		0.0%	0.6%	4.3%	0.7%	11.2%	1.8%	0.1%	0.2%	0.3%	0.1%	0.1%	80.7%	0.0%	

Figure 27 : South Truss wave height and period contribution

Comments:

- Damage is increasing with increasing wave height and is highest between 1.5s and 1.75s, showing a different response period than west truss, what can be explained by the length difference between the truss

8.7.3 Conclusion

Fatigue are mainly created by waves parallel to truss axis, due to bending of the truss caused by deformation linked to wave motions.

When loaded perpendicular to truss axis, no damage occur.

Difference in the loading of the west truss compared to South truss, can be explained by difference of occurrences. With Changbin site data, only 6% of total waves comes from Left/Right (west/East), creating fatigue parallel to the South truss axis. South truss has then a longer lifetime.

At the opposite, 36% of waves comes from back/Face (North/South), creating fatigue parallel to the West truss axis. West truss has then a shorter lifetime.

This is illustrated on following picture.

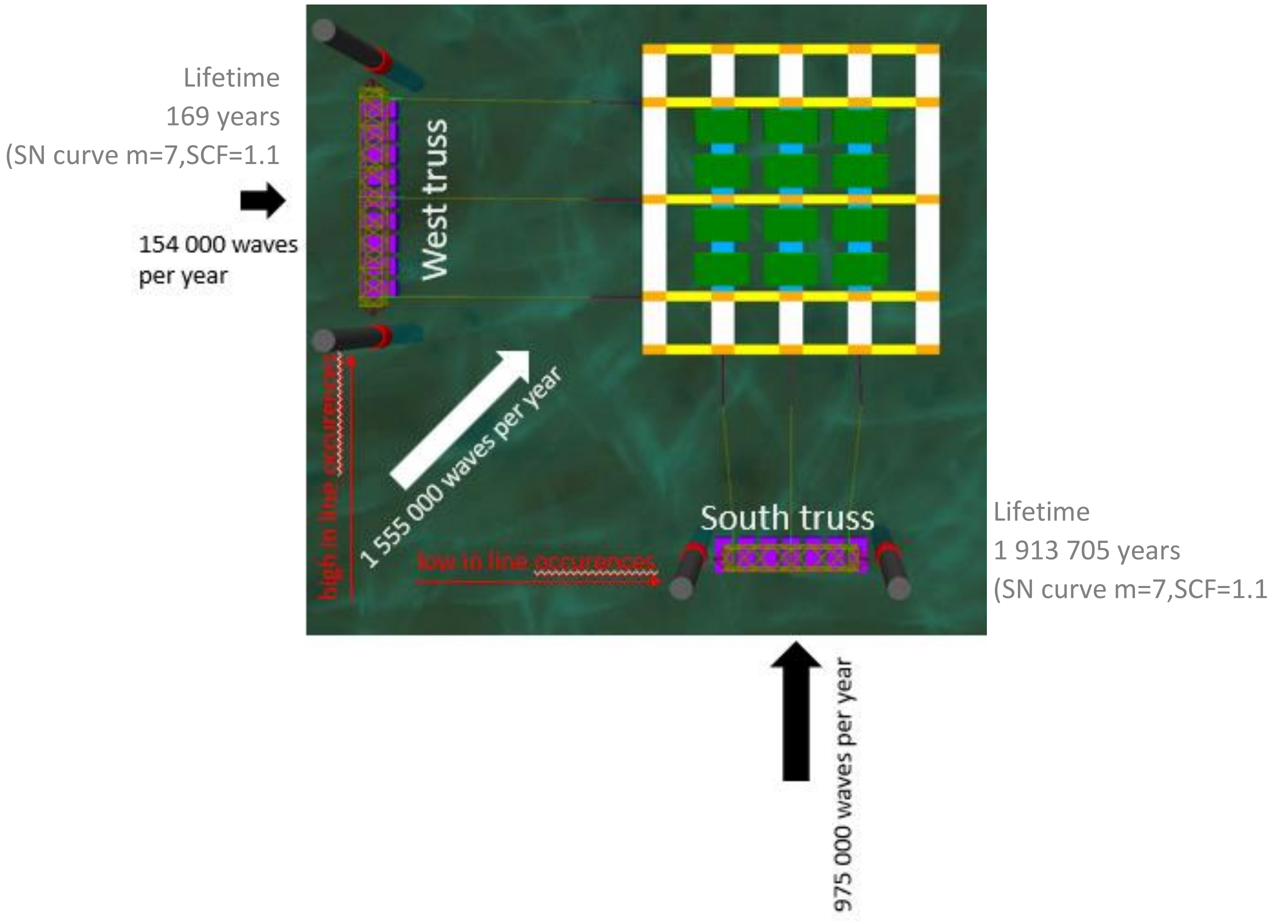


Figure 28 : Lifetime difference between West and South truss

8.8 Lifetime

Minimum calculated lifetime for both truss are summarized in next table:

		West Truss	South Truss
		Minimum lifetime	Minimum lifetime
Base material	SN curve m = 7	169 years	1 913 705 years
Weldings	SN curve m = 4.3	25.4 years	249.7 years
Weldings	SN curve m = 3.4	1.3 years	11.9 years

Comments:

- It can be noted that SN-curve selection has a large influence on the results. If additional data would be available from tests, this could improve accuracy of the results
- Base material have lifetime duration far above 20 years, which means that no fatigue issue is expected in Base material for Changbin site
- Weldings have lifetime duration shorter than 20 years, which means that following recommendation should be considered:
    - Take importance of the quality of the weldings and perform grinding if possible
    - Inspect regularly the weldings as fatigue propagation should start in the weldings

Appendix

Orcaflex model

CHANGBIN TRUSS FATIGUE ANALYSIS.dat

Excel spreadsheet

HOLD