Base Load Power Hub (BLPH)

BLPH Platform TP Transportation Fatigue Analysis

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1 INTRODUCTION

1.1 PROJECT OVERVIEW

Crosswind, a Shell and Eneco joint venture, was awarded the tender to develop the offshore Hollandse Kust Noord (HKN) wind farm, located 18.5km off the coast of Netherlands near the town of Egmond aan Zee. The consortium plans to have HKN operational in 2023 with an installed capacity of 759MW generating at least 3.3TWh per year. This is sufficient renewable power to supply more than 1 million Dutch households with green electricity.

Offshore wind farms produce intermittent electricity and balancing these dips and peaks and integrating this electricity into the national energy system requires new technologies. For this reason, the offshore wind farm will include several new technologies that could be implemented at full-scale in the future. The new technologies being explored include a floating solar park, a short-duration battery storage as well as long-term storage via green hydrogen produced by water electrolysis and subsequently consumed in a fuel cell. The combination of these individual measures, herein referred to as the Base Load Power Hub (BLPH) will ensure a continuous power supply regardless of the wind situation.

1.1.1 Project Location

The Hollandse Kust Noord (HKN) wind farm is located 18.5km off the coast of the Netherlands near the town of Egmond aan Zee.

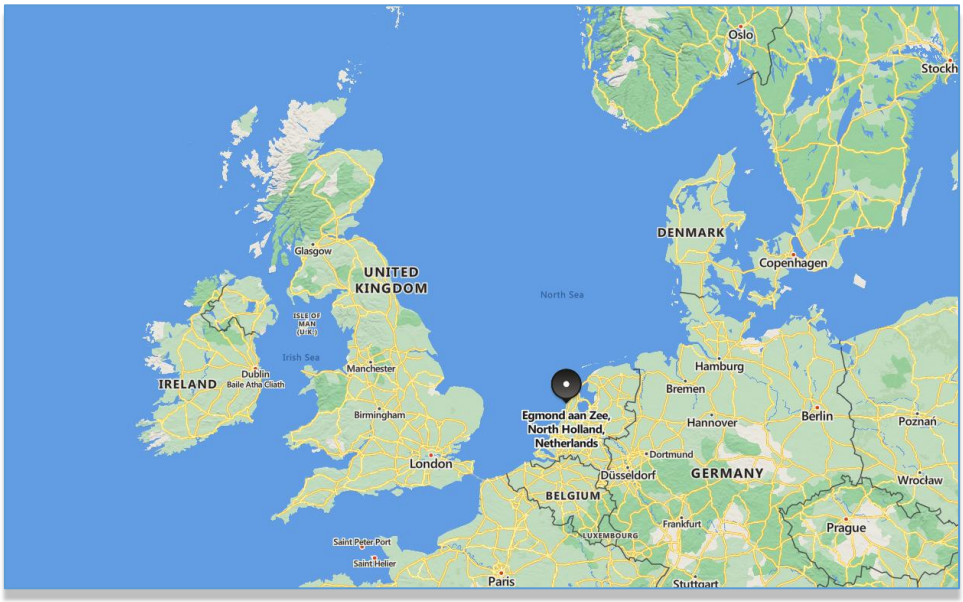


Figure 1.1 - HOLLANDSE KUST NOORD WIND PARK Location Map

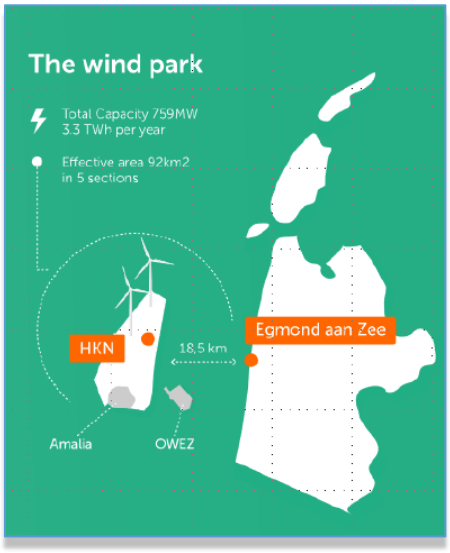


Figure 1.2 - Wind Park Details

The wind farm consist of No. 69 x 11.5MW wind turbine generators each to be installed on a dedicated monopile structure. A 70th monopile located on coordinates E 590719.1, N 5841602.3 is reserved for installing the platform accommodating the BLPH. The monopile structure was designed and installed by Van Oord Offshore Wind (VooW) and therefore not part of the BLPH scope.

1.1.2 Project Concept

All components included in the BLPH will be integrated onshore on a topsides and installed in an offshore location within the boundaries of the HKN wind farm. At its simplest, the BLPH will store energy during periods of high electricity generation from renewable sources (a wind turbine generator and the floating solar PV farm) and release it during periods of low generation. In practice. It is expected that the energy stored will supplement generation from renewable sources to ensure that at least 1.0MW of power is exported to the electrical grid regardless of wind/solar availability.

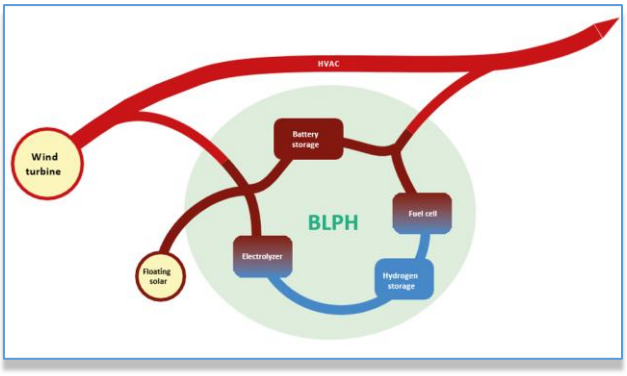


Figure 1.3 – BLPH Concept

Electricity in the BLPH will be stored in the form of electrons in a battery energy storage system (BESS) as well as converted into green hydrogen via water electrolysis. When the power output from the connecting wind turbine drops to below 1 MWe, the BLPH will return its stored energy to supplement the remaining power output. This will be by discharging the BESS, while stored hydrogen will be converted back into electricity using a fuel cell to extend the discharge duration.

The purpose of the BLPH s to function as a testbed for the integration of energy storage technologies with renewable generation. It is expected that equipment installed on the BLPH will operate as Normally Unmanned Installation for at least two (2) years with no or minimal maintenance and it will have its own independent control room with the ability to communicate with Crosswind's control room.

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2 DOCUMENT SCOPE

The objective of this report is to present the results of the Transportation Fatigue Analysis performed for the Transition Piece (TP) of the BLPH platform.

The TP is to be transported on 300 ft Barge and loaded out by means of the hydraulic trailers (SPMT) on board of the cargo barge with the Rows A and C aligned with the barge longitudinal axis.

The analysis has been performed in compliance with the requirements, criteria and parameters reported in the Structural Design Premises, Ref./20/.

Transportation Fatigue analysis is performed in accordance with DNV-ST-0145, Ref. /11/ following the Simplified Fatigue .Approach defined in DNV-RP-C03, Ref. /13/.

All structural analyses have been carried out using the structural analysis program ANSYS, ref. /32/.

The International System of Units (SI) has been used in all engineering assessments and calculations.

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3 REFERENCES

3.1 CODES AND STANDARDS

Doc. No.	Description
/1/ BS EN ISO 19900	General requirements for offshore structures - 2019
/2/ BS EN ISO 19901-1	Specific requirements for offshore structures - Part 1: Metocean design and operating considerations - 2015
/3/ BS EN ISO 19901-3	Specific requirements for offshore structures – Part 3: Topsides structure - 2014
/4/ BS EN ISO 19901-5	Specific requirements for offshore structures – Part 5: Weight Management - 2021
/5/ BS EN ISO 19901-6	Specific requirements for offshore structures – Part 6: Marine Operations – 2009
/6/ BS EN ISO 19902	Petroleum and natural gas industries - Fixed steel offshore structures – 2020
/7/ ISO 19906:2019	Petroleum and natural gas industries – Arctic offshore structures
/8/ UNI EN 1993-1-1	Design of steel structures - Part 1-1: General rules and rules for buildings
/9/ UNI EN 1993-1-5	Design of Steel Structures – Part 1-5: Plated structural elements
/10/ DNV-ST-N001	DNV - Marine operation and marine warranty - 2021
/11/ DNV-ST-0145	DNV, Offshore substations
/12/ DNV-RP-C201	DNV, Buckling Strength of Plated Structures, October 2010.
/13/ DNV-RP-C203	DNV, Fatigue design of offshore steel structures, September 2019 and Amendment January 2020
/14/ DNV-RP-C204	DNV-RP-C204 Design against accidental loads – 2019
/15/ DNV-RP-C205	DNV - Environmental conditions and environmental loads - September 2019, amended September 2021.
/16/ DNV-ST-0126	Support structures for wind turbine, 2018

3.2 COMPANY SPECIFICATIONS

Doc. No.	Description
/17/ DEP 37.19.00.12	Gen - Offshore Topsides Structures
/18/ DEP 37.19.00.30	Gen - Fixed Steel Offshore Structures (Adoption of IOGP S-631-11, Amendments / Supplements to ISO 19902:2020).

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/19/ DEP 37.81.10.19	Gen - Marine Operations Requirements – Loadout, Transportation and Installation of Offshore Structures (Amendments / Supplements to ISO 19901-6)

3.3 PROJECT DOCUMENTS

Doc. No.	Description
/20/ 123A90-DDL-ST-SP-90017	Structural Design Basis
/21/ 123A90-DDL-MD-RE-01006	Weight Control Report – Rev. 03
/22/ 123A90-DDL-PP-DS-70070	BLPH Platform - Plot Plans
/23/ 123A90-DDL-ST-SP-90018	Structural Material Specification for Topside and TP
/24/ 123A90-DDL-ST-RE-90007	BLPH Platform – FE Analysis
/25/ 123A90-DDL-ST-RE-90009	BLPH Platform Transition Piece -Transportation Analysis
/26/ 123A90-DDL-TI-SP-99014	Specification for TP, Topside and Caissons Transportation and Installation
/27/ 123A90-DDL-ST-TN-90119	Evaluating ISO and DNV Approaches
/28/ 123A90-DDL-TI-DD-99015	BLPH Platform – Barge Layout
/29/ 123A90-DDL- TI-DD-99036	BLPH TP – Upper Grillage – Plan View
/30/ 123A90-DDL- TI-DD-99037	BLPH TP – Upper Grillage – Sections
/31/ 123A90-DDL- TI-DD-99038	BLPH TP – Upper Grillage – Section and Details

3.4 SOFTWARE

Doc. No.	Description
/32/ ANSYS	Ansys Inc.

4 DEFINITIONS AND ABBREVIATIONS

COMPANY or Client (CPY)	Crosswind
CONTRACTOR (CTR)	ROSETTI MARINO S.p.A.
PROJECT	HOLLANDSE KUST NOORD WIND PARK Project
T&I CONTRACTOR	DEME
ALS	Accidental Limit State
BEB	Best Estimate Bathymetry
BESS	BATTERY ENERGY STORAGE SYSTEM
BG	Box Girder
BLPH	Base Load Power Hub
CF	Caisson Frame
CL	Concentrated Load
CoG	Centre of Gravity
CW	CrossWind
DAF	Dynamic Amplification Factor
DFF	Damage Fatigue Factors
DNV	Det Norske Veritas
El.	Elevation
FEA	Finite Element Analysis
FEM	Finite Element Method
HKN	Hollandse Kust Noord
LAT	Lowest Astronomical Tide
LRFD	Load and Resistance Factor Design
MSL	Mean Sea Level
NTE	Not-to-Exceed
OD	Outside Diameter
PG	Plate Girder
SCF	Stress Concentration Factor
sk	Characteristic Value of Snow on the Ground/Platform

SHL	Static Hook Load
SPMT	Self-propelled modular Trailer
T&I	Transport & Installation
ToS	Top of Steel
TP	Transition Piece
UC	Unity Check
UDL	Uniformly Distributed Load
VIV	Vortex Induced Vibration
VM	Von Mises
VMS	Von Mises Stress
VOOW	Van Oord Offshore Wind

Table 4.1 - Definitions and Abbreviations

5 SUMMARY AND CONCLUSIONS

The structural model of the TP is the same used for the FE analysis, ref. /24/ with the loads coming from the transportation analysis, Ref./25/.

The analyses performed show that the maximum and minimum principal stresses obtained are 58 MPa and -52 MPa respectively. The resulting maximum peak stress range due to cyclic loading is therefore equal to 110 MPa. The extrapolated stresses correspond to the notch stresses, having therefore the SCF factor already included. DFF factor 10 has been assumed as indicated in /13/, Weibull factor assumed 0.8 with results investigated also with Weibull = 1.0.

Adopting the "Simplified Fatigue Approach" of DNV-RP-C203 - Section 5 and relying on:

- a Weibull shape parameter h=0.80,
- design S-N fatigue curve D

Table 5-2 (component in air, ref. /13/) gives an allowable extreme stress range of 390.7 MPa for 10^8 cycles.

The use of DFF=10 and design life = 20 years, Table 5-8 provides utilization factor η = 0.10.

Concluding the verification entering Table 5-5 with η = 0.10 and Weibull 0.80, it is obtained the Reduction factor = 0.54.

Thus, the resulting allowable extreme stress is 390.7 * 0.54 = 211 MPa > greater than the maximum stress range obtained from FEA equal to 110 MPa.

The use of Weibull parameter = 1.0 leads to:

- allowable extreme stress range = 271.5
- reduction factor = 0.563

271.5*0.563 = 152.8 Mpa that is still greater than 110 Mpa

Details of Tables are given in section 12.

6 BLPH TRANSITION PIECE DESCRIPTION

The connection of BLPH Topside with Monopile is realized through a Transition Piece (TP) structure. The interface level between the Monopile and the Topsides is at El.+17.050m relative to LAT.

TP is composed by a central column with an outer diameter of 7m and four (4) boxed girders with height ranging from 2.5 m to 1.4 m, oriented along the main diagonals of the TP and accommodating at their ends four (4) tubular receptacles for supporting the Topside. The four diagonal arms of the TP are connected along the perimeter by other four (4) boxed girders forming a stiff deck 16m x 16m with TOS. El. +21.71m from LAT.

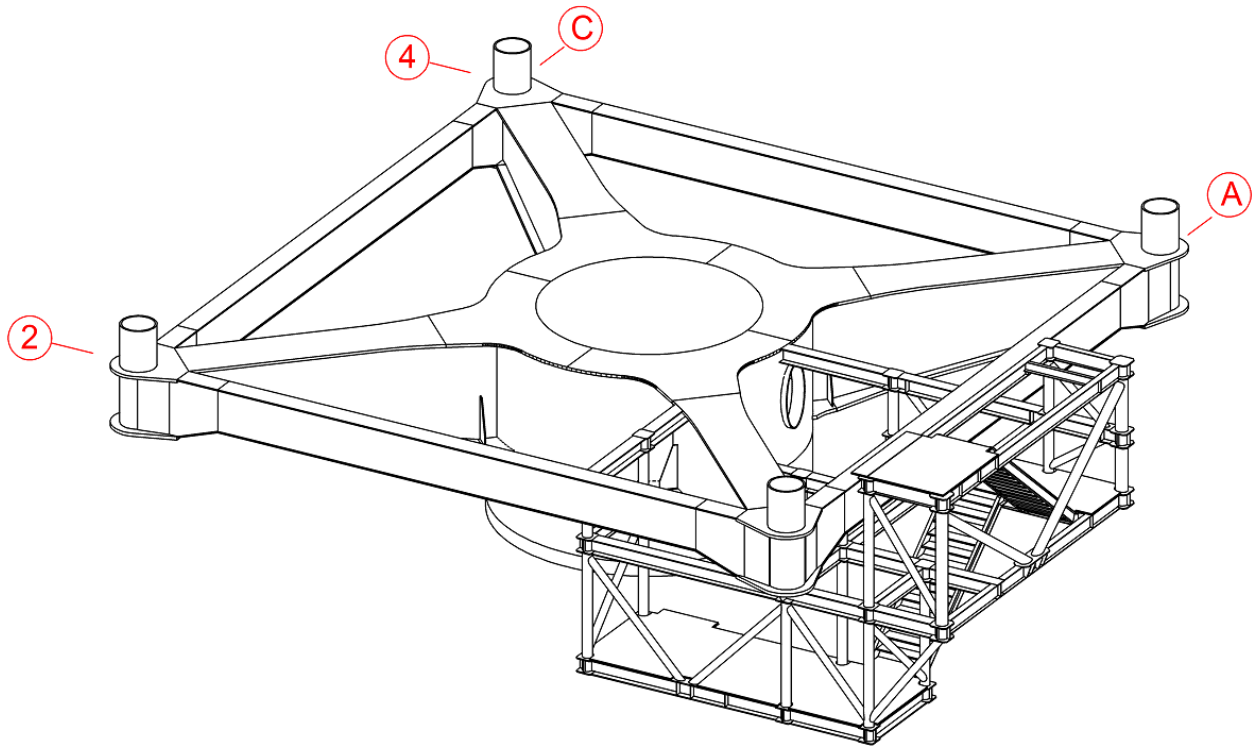


Figure 6.1 - Base Load Power Hub - Transition Piece – 3D View

7 DESIGN DATA

7.1 TRANSPORTATION ARRANGEMENT

The Topsides is to be transported on 300ft cargo barge P-MAK with the Rows A and C aligned with the barge longitudinal axis.

The P-MAK barge is a standard 300ft barge, characterized by following main dimensions:

- Length: 91.50 m
- Breadth 27.40 m
- Side height: 6.10 m

The centre of rotation is assumed to be at the centre of the barge.

An overview of the transportation layout is shown in the following figure from Ref. /28/.

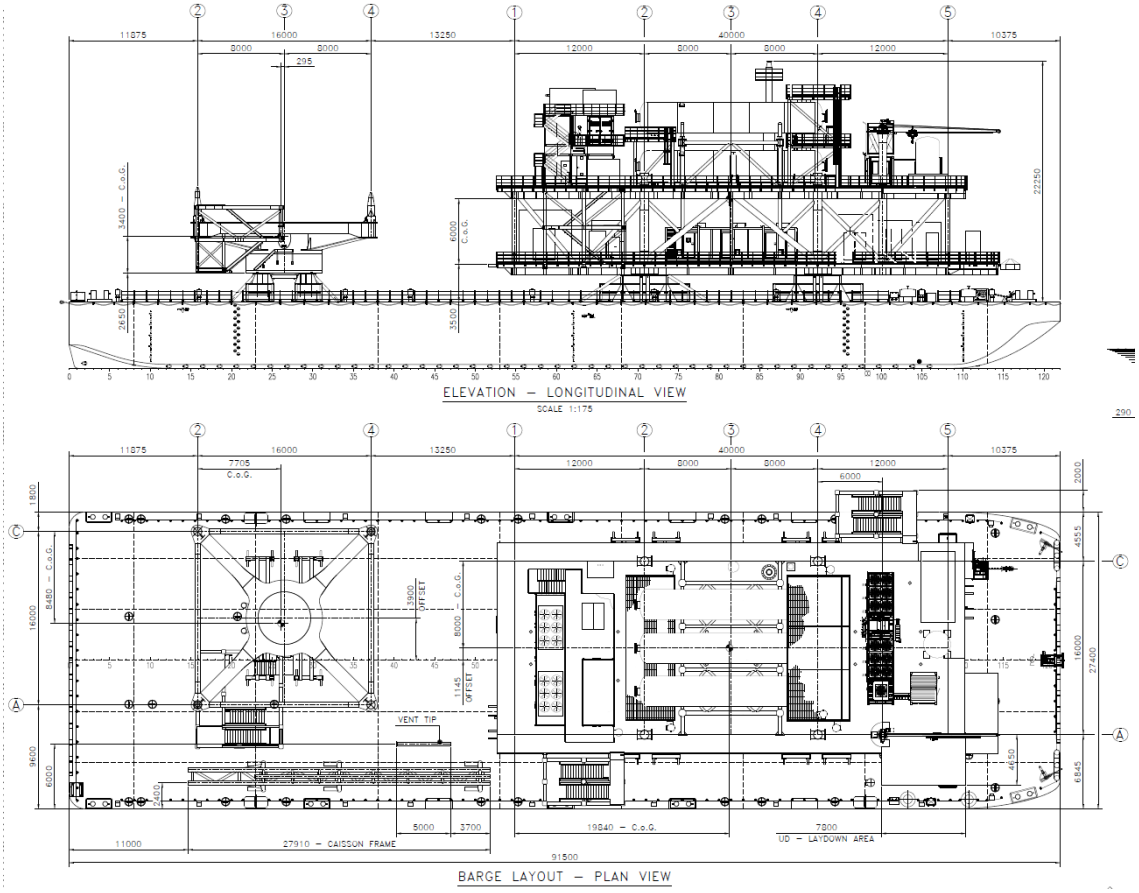


Figure 7.1 – Transportation Arrangement, Ref. /28/ – Side and Plan views

7.2 DESIGN LOADS

The Design loads considered for the transportation fatigue include wind loads and transient actions from barge motions as per data reported in the following from transportation analysis, Ref./25/

8 MATERIALS

8.1 STRUCTURAL STEEL PROPERTIES

For the structural analyses, steel types and grades to be used for the platform structures are summarised in Table 8.1and specified in Ref./23/. The material selection criteria are based on the requirements of ISO 19906:2019, ISO 19902:2020 and ISO 19901-3:2014. The materials are in accordance with the EN standard 10225:2019 and 10025:2019 and are suitable for plates, rolled sections and welded / seamless tubulars.

			EN10025-3	ISO EN 19902:2020						
Design Class	**Complexity**	**SQL**	**Hot rolled bar**	**Plates and Welded Tubular**	**Sections**	**SMLS pipes**	**THK**	**CVN inpact test**	**Material Designation**	**List of Options (EN10225-1 to -4) & EN10025-3**
DC1 TP to monopile flange connection	High	**I (Z properties)**	EN 10025 S420 NL	NA	NA	NA	t > 50	-40	DC1-I-420-40_Z	1, 2, 3, 4, 6, 12, 18, 24, 30
DC1 Complex lift-nodes and element connection to topside, Lift points, main complex joints	High	**I (Z properties)**	NA	EN 10225 S420 QLO / ML	NA	NA	25 < t <= 50 t > 50	-40 -40	DC1-I-420-40_Z DC1-I-460-40_Z	2, 7, 8, 11, 12, 17, 18
DC2 simple joints, primary deck girders and beams of Topside and TP, column and diagonal to lift points, main columns, Davit crane support, Bolts	Low	**II**	NA	EN 10225 S420 QLO / MLO	NA	NA	t < = 12 12 < t <= 25 25 < t <= 50 t > 50	0 -20 -40 -40	NA DC2-II-420-20 / DC2-II-460-20 DC2-II-420-40 DC2-II-460-40	- 2, 7, 8, 11 17 for t > 40mm
DC3 all other columns and diagonals, stiffeners, Secondary deck beams, Grillage and sea fastening	High	**II**	NA	EN 10225 S355 NLO / MLO	EN 10025 S355 MLO	EN 10225 S355 NLHHO / QLHHO API 5L X52	t < = 12 12 < t <= 25 25 < t <= 50 t > 50	0 -20 -40 -40	DC3-II-355-0 / DC3-II-X52-0 DC3-II-355-20 / DC3-II-X52-20 DC3-II-355-40 / DC3-II-X52-40	2, 7, 8 11 for plate 17 for t > 40mm
DC4 Equipment and vessel supports, modules supports, equipment fixing bolts	Low	**III**	NA	EN 10025 S355 J2	EN 10025 S355 J2	API 5L X52 EN 10210 S355 J2H	t < = 12 12 < t <= 25	0 0	DC4-III-355-0 / DC4-III-X52-0 / DC4-III-X60-0	-
DC5 floor plating, grating, Walkways, stairs, handrails	Any	**IV**	NA	EN 10025 S235 JR EN 10025 S275 J0 EN 10025 S355 J0	EN 10025 S235 JR EN 10025 S275 J0 EN 10025 S355 J0	API 5L Gr.B EN 10210 S235 JRH / EN 10210 S275 J0H / EN 10210 S355 J0H	t < = 12 12 < t <= 25	10 10	DC5-IV-235-10 / DC5-IV-275-10 / DC5-IV-355-10 / DC5-IV-GRB-10	-

Table 8.1 - Material Selection, Ref /23/

Mechanical properties for structural materials are presented in Table 8-2, Table 8-3 and Table 8-4.

- Young's Modulus = 205,000 N/mm^2
- Density = 7850 kg/m^3
- Poisson's Ratio = 0.3

Thickness (mm)	Min. Tensile Strength (N/mm^2)	Min. Yield Strength (N/mm2)	Steel Type (1)
t ≤ 16	500	420	I & II
16 < t ≤ 40	500	400	I & II
40 < t ≤ 63	480	390	I & II
63 < t ≤ 100	480	380	I & II
Note: 1) Type I steel has Z (through the thickness) properties.			

Table 8.2 – Mechanical properties of Plates

Thickness (mm)	Min. Tensile Strength (N/mm²)	Min. Yield Strength (N/mm2)	Steel Type
t ≤ 20	460	355	III
20 < t ≤ 40	460	345	III

Table 8.3 – Mechanical properties of Structural Seamless Tubulars

Thickness (mm)	Min. Tensile Strength (N/mm2)	Min. Yield Strength (N/mm2)	Steel Type
t ≤ 16	460/360	355/275	IV
16 < t ≤ 40	460	345	IV

Table 8.4 – Mechanical properties for Structural Sections

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9 DESIGN CRITERIA AND REQUIREMENTS

Structures in SOW are designed in accordance with limit states approach of ISO codes 19901 and 19902, Refs./2/, /3/ and /6/. For non-tubular sections, Eurocode, Ref./8/, is adopted.

10 FE MODEL

The FE model used in the analyses is the same used in FE analysis report, ref./24/, opportunely updated by:

- deleting the modelled part of the monopile and the relevant flange
- defining the grillage footprint areas on the bottom surface of the flange

The resulting model is shown in the figure below.

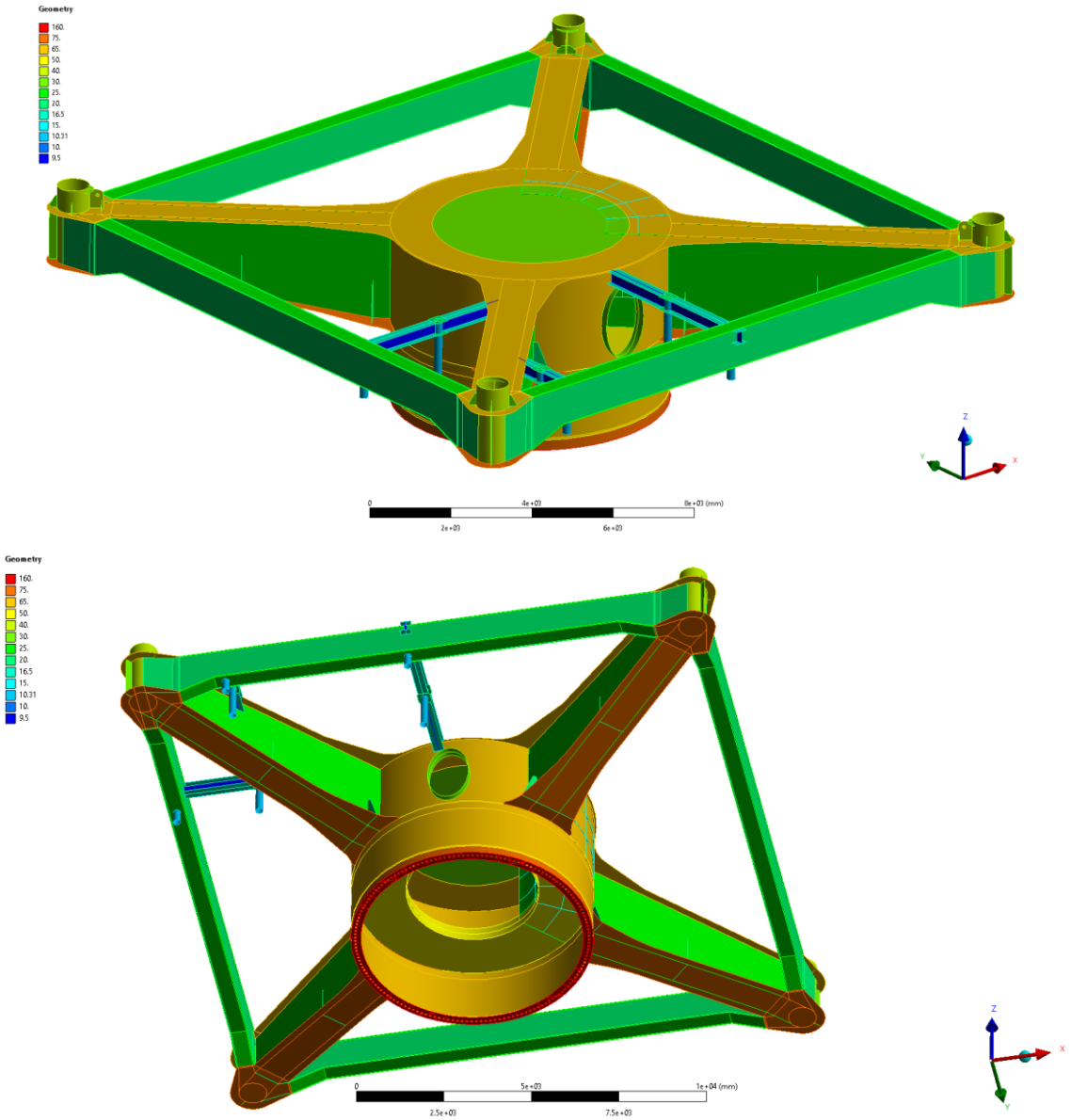


Figure 10.1 - Topside structural model

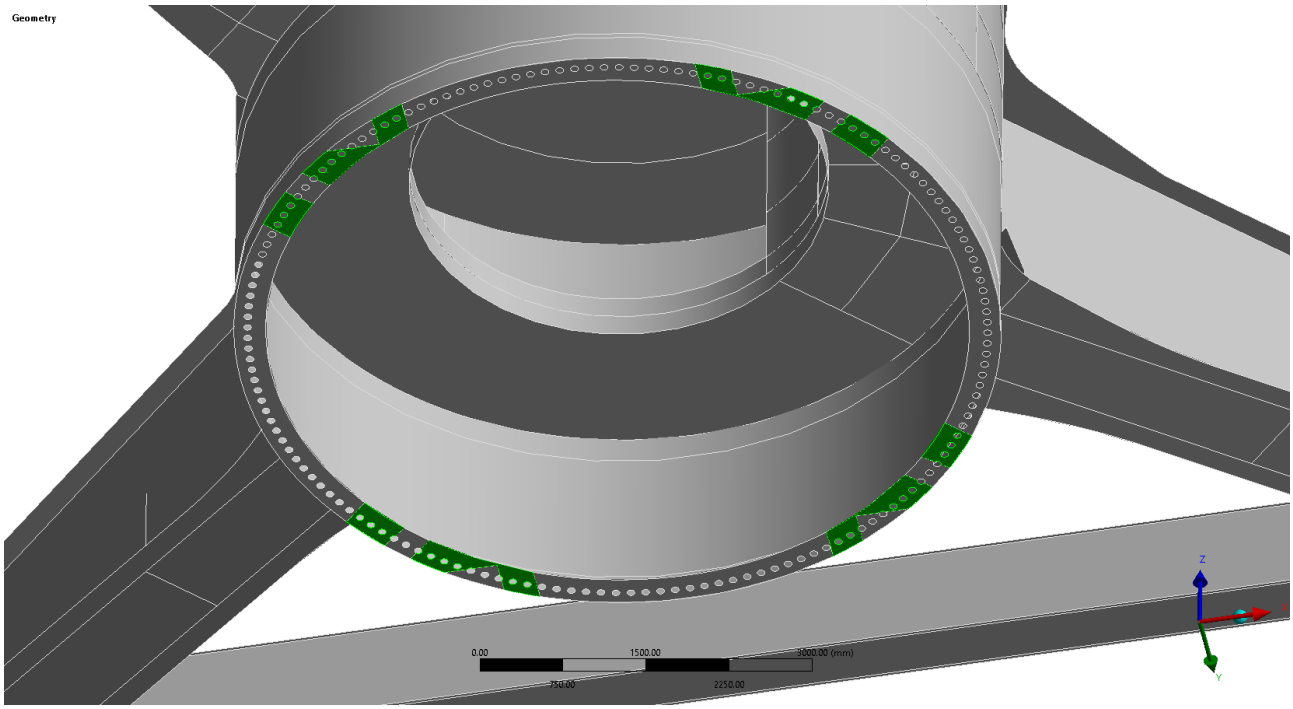


Figure 10.2 – Grillage footprint on the bottom flange surface – in green color

After the LO the TP, supported by its upper grillage, will be set down on Lower Grillage. Shim plates will be inserted to close the gap, if any.

10.1 COORDINATE SYSTEM

The model geometry is referred to a right-handed orthogonal Cartesian coordinate system with the origin located at the centre of the TP upper flange. The X-axis is positive toward East (aligned to Rows A and C), the Y-axis is positive toward North (aligned to Rows 2 and 4) and the Z-axis is positive upward.

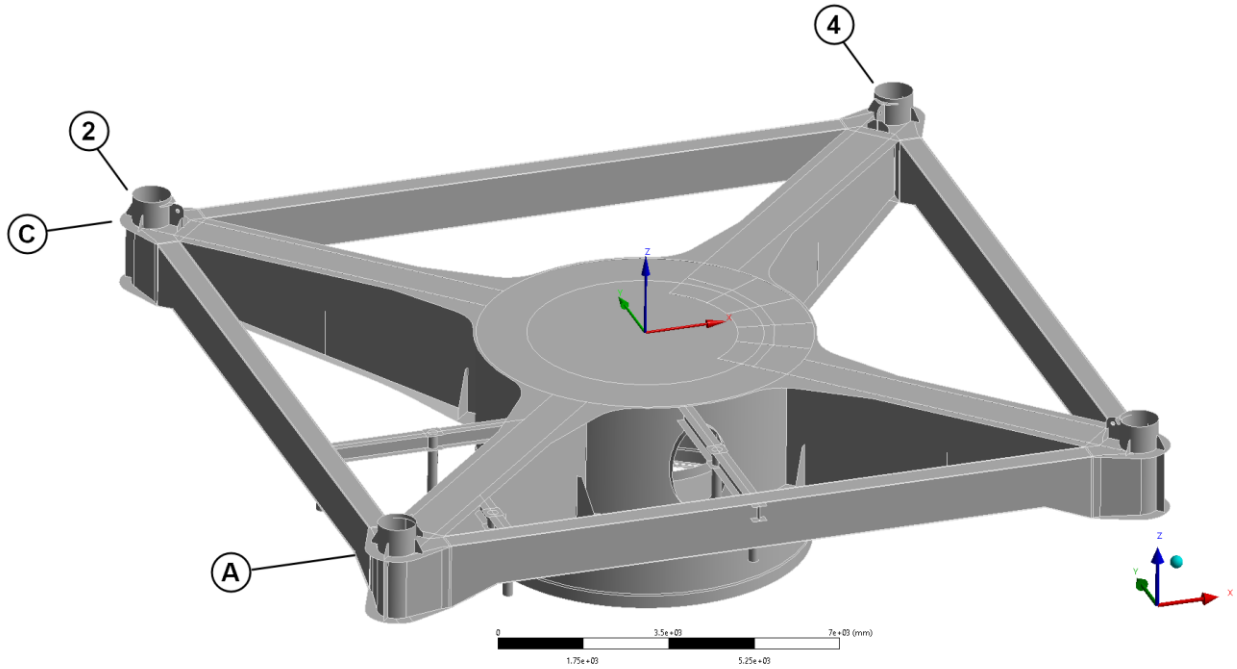


Figure 10.3 - BLPH TP Coordinate System

10.2 MESH

10.2.1 Mesh Elements

The FE model is made by 2D plates. It is meshed with triangles and quadrilateral elements.

The following mesh elements are used for the developed models:

- *SHELL181 (4-Node Structural Shell):* is suitable for analyzing thin to moderately-thick shell structures. It is a four-node element with six degrees of freedom at each node: translations in the x, y, and z directions, and rotations about the x, y, and z-axes. SHELL181 is well-suited for linear, large rotation, and/or large strain nonlinear applications. The accuracy in modeling composite shells is governed by the first-order shear-deformation theory (usually referred to as Mindlin-Reissner shell theory). The element formulation is based on logarithmic strain and true stress measures.

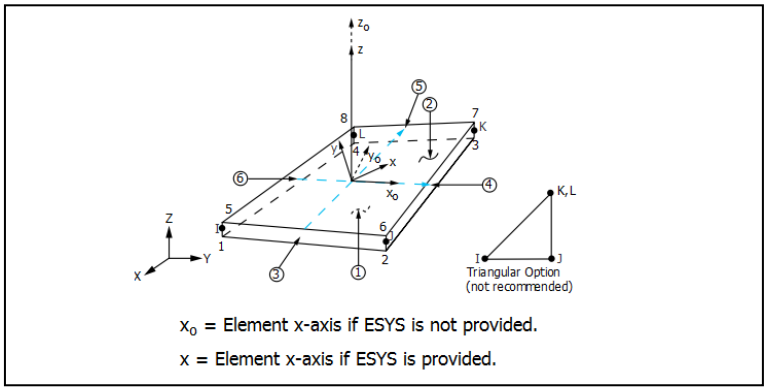


Figure 10.4 – Mesh elements – SHELL181

- *BEAM188 (3-D 2-Node Beam):* it is suitable for analyzing slender to moderately stubby/thick beam structures. The element is based on Timoshenko beam theory which includes shear-deformation effects. The element provides options for unrestrained warping and restrained warping of cross-sections. The element is a linear, quadratic, or cubic two-node beam element in 3-D. BEAM188 has six or seven degrees of freedom at each node. These include translations in the x, y, and z directions and rotations about the x, y, and z directions. This element is well-suited for linear, large rotation, and/or large strain nonlinear applications. This element supports elasticity, plasticity, creep and other nonlinear material models. A cross-section associated with this element type can be a built-up section referencing more than one material.

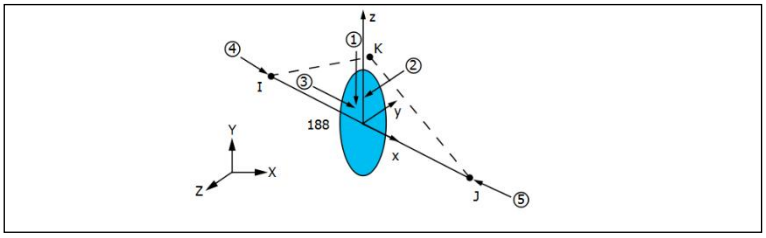


Figure 10.5 – Mesh elements – BEAM188

- *TARGE170 (3-D Target Segment):* it is used to represent various 3-D "target" surfaces for the associated contact elements. The contact elements themselves overlay the solid, shell, or line elements describing the boundary of a deformable body and are potentially in contact with the target surface.

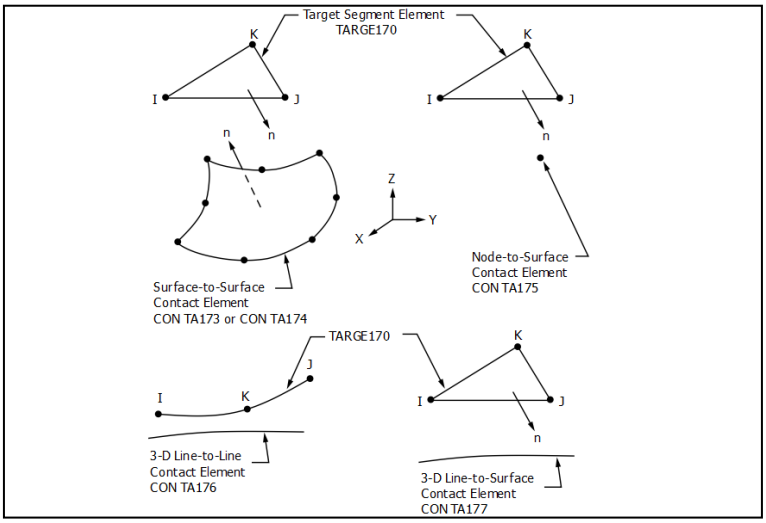


Figure 10.6 – Mesh elements – TARGE170

- *CONTA174 (3-D 8-Node Surface):* it is used to represent contact and sliding between 3-D target surfaces and a deformable surface defined by this element. The element is applicable to 3-D structural and coupled-field contact analyses. It can be used for both pair-based contact and general contact. The element has the same geometric characteristics as the solid or shell element face with which it is connected. Contact occurs when the element surface penetrates an associated target surface.

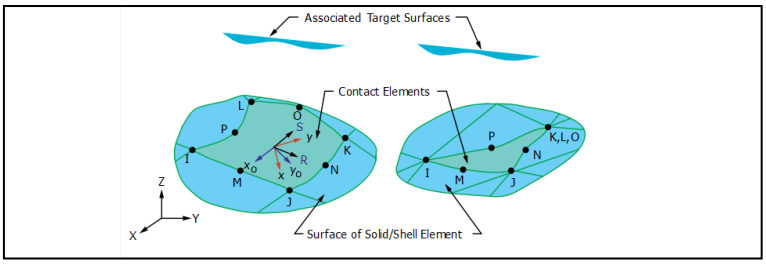


Figure 10.7 – Mesh elements – CONTA174

10.2.2 Model Mesh

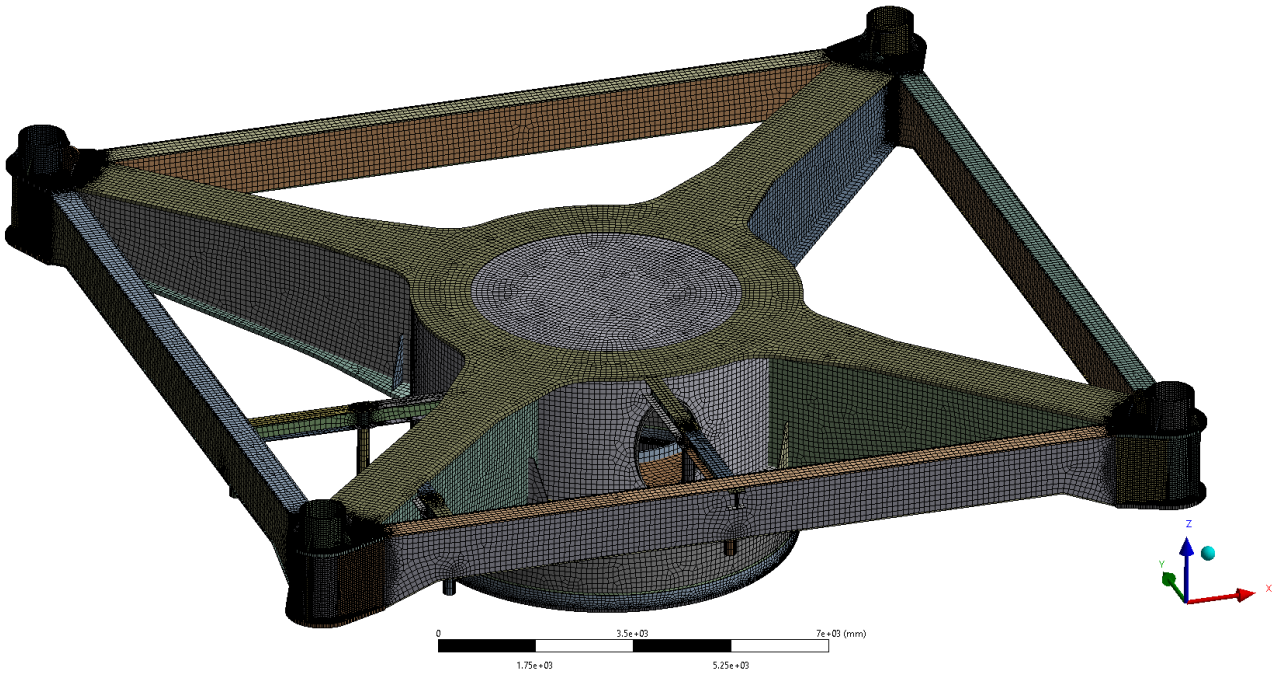
The table below reports the main mesh data characterizing the model.

MESH STATISTICS	NUMBER
Nodes	200744
Elements	203774

Table 10.1 – TP FE model – Mesh Statistics

A uniform mesh size equal to 100x100mm is generally adopted except in proximity of loaded elements (Topside supports, stairs supports and bolted connection flanges) where some refinements are performed imposing a 25x25mm mesh dimension.

The resulting mesh is shown in the following figures.



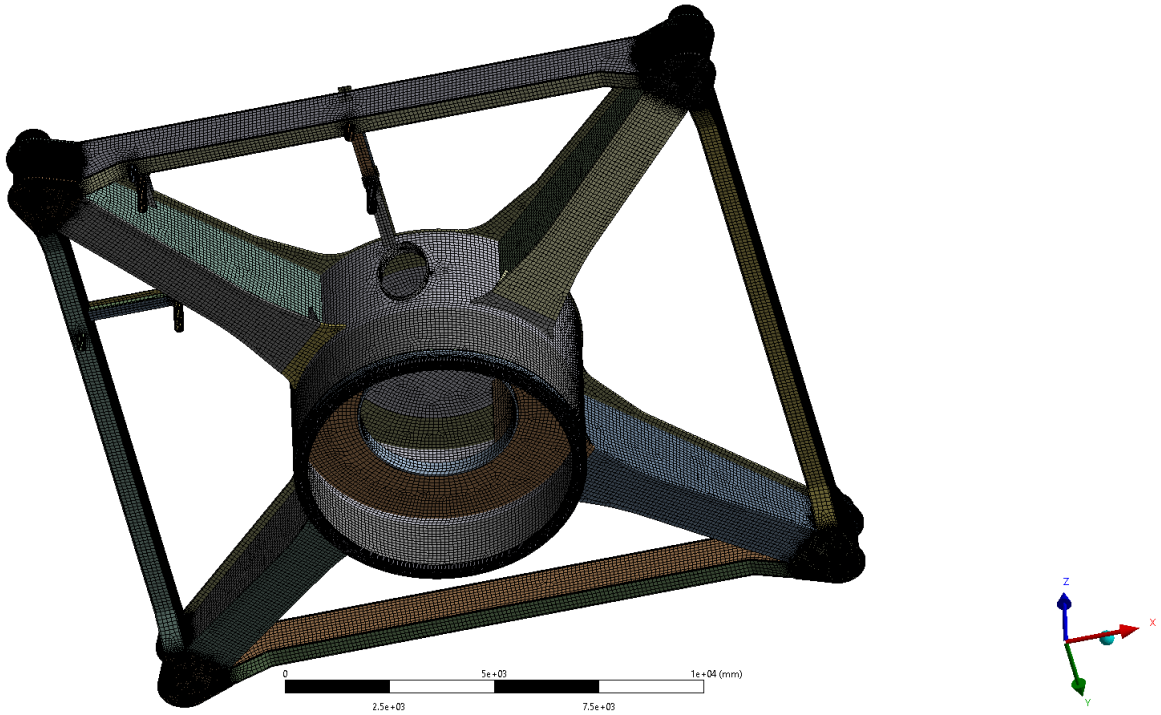


Figure 10.8: – Model Mesh

10.3 REMOTE POINT

To correctly apply the design loads, a Remote Point (RP) is defined in correspondence of the TP CoG. This RP is connected to the modelled structure through link elements.

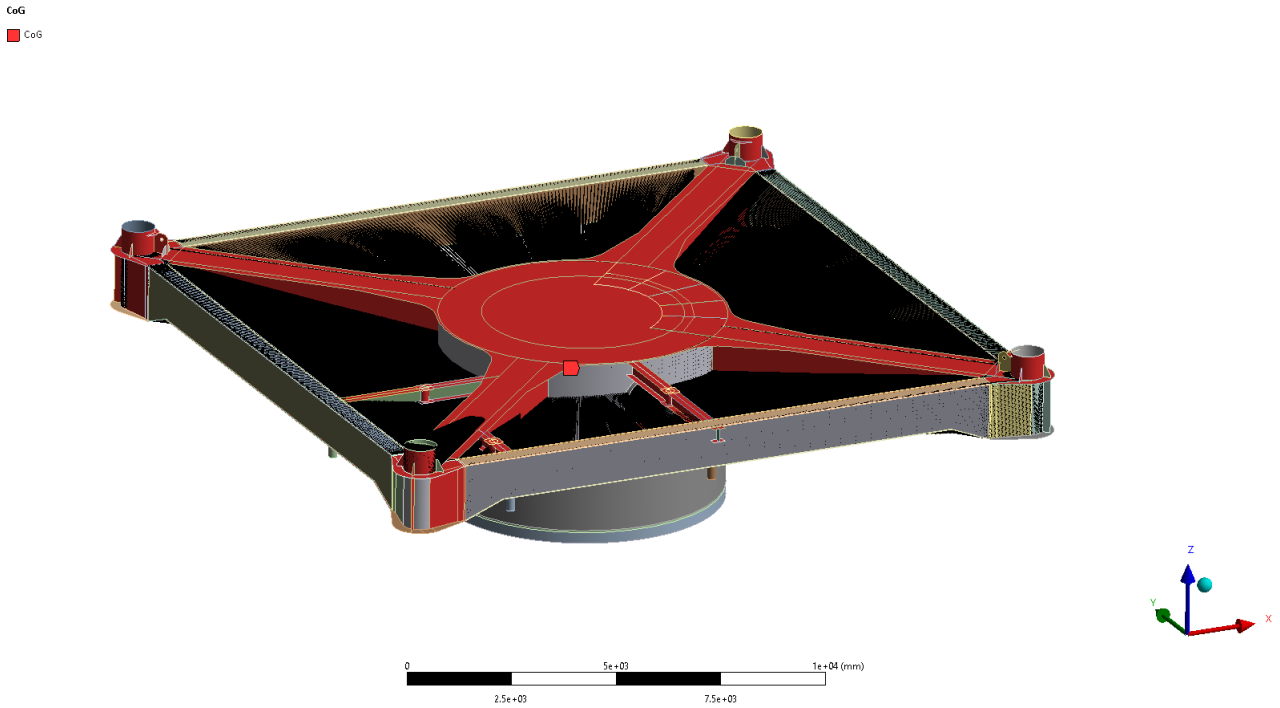


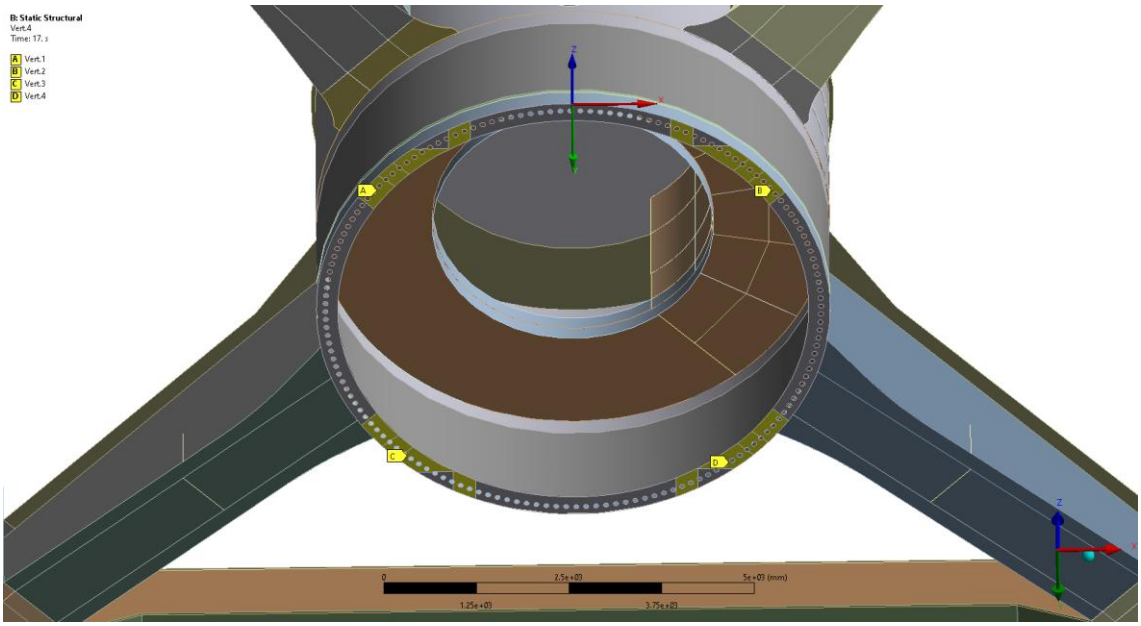
Figure 10.9 – BLPH TP – Remote Point at TP CoG

The RP point was considered necessary to have a single point of application of the loads, given the purpose of the analysis, which is to calculate the stress delta of the structure during transport; both the combinations with gravity load and those with negative gravity, associated with variable transport actions, were applied to this single RP point.

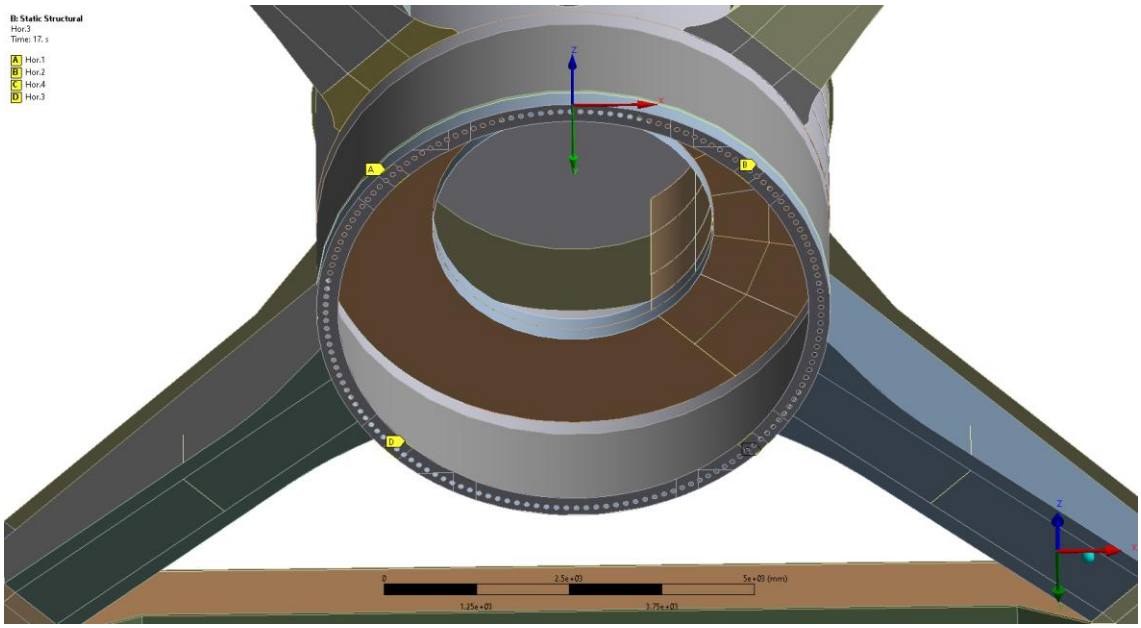
10.4 CONSTRAINTS

External constraints were applied at the bottom surface of the flange as follow:

- *Vertical direction*: in correspondence of the defined grillage footprint areas



- *Horizontal direction*: on edge properly defined in correspondence of the horizontal stoppers



11 LOAD CONDITIONS & COMBINATIONS

Seventeen load cases were analysed; one corresponding to the gravity load (L.C: TPLO) and 16 unfactored load combinations (from L.C: UN01 to UN16) corresponding to inertia and wind loads acting on TP structure as variable loads.

The following table describes the considered load combination.

TP in Transportation conditions – Load Combination TPLO		
Basic Load Cases	Description	Load Factors
G002	TP LOADOUT COMBINATION	1.062

Table 11.1 – Only gravity loads - Loadout Combination TPLO

Following excerpt from SACS output provides the Load Combinations resultants described above.

```
                    ************* SEASTATE LOAD CASE CENTER REPORT *************
                                    RELATIVE TO STRUCTURAL ORIGIN
LOAD       ********* X - DIRECTION *********      ********* Y - DIRECTION *********      ********* Z - DIRECTION *********
LABEL      FORCE      X         Y         Z       FORCE      X         Y         Z       FORCE      X         Y         Z
                (KN)      (M)       (M)       (M)          (KN)      (M)       (M)       (M)          (KN)      (M)       (M)       (M)

TPLO         0.00                                   0.00                                  -2963.35    -0.35     -0.67      5.63
```

Table 11.2 - Only gravity loads – Resultants summary

The application of transport loads, inertia and wind, generate the following combinations:

TRANSPORTATION LOAD COMBINATIONS – UNFACTORED LOADS													
ANSYS LOAD COMB	LOAD CASE												
	TPLO	+P+H	+P-H	-P+H	-P-H	+R+H	+R-H	-R+H	-R-H	WTPX	WTNX	WTPY	WTNY
UN01	1.00	1.00								1.00			
UN02	1.00	1.00									1.00		
UN03	1.00		1.00							1.00			
UN04	1.00		1.00								1.00		
UN05	1.00			1.00						1.00			
UN06	1.00			1.00							1.00		
UN07	1.00				1.00					1.00			
UN08	1.00				1.00						1.00		
UN09	1.00					1.00						1.00	
UN10	1.00					1.00							1.00
UN11	1.00						1.00					1.00	
UN12	1.00						1.00						1.00
UN13	1.00							1.00				1.00	
UN14	1.00							1.00					1.00
UN15	1.00								1.00			1.00	
UN16	1.00								1.00				1.00

Table 11.3 - Transportation Load Combinations – Unfactored

Following excerpts from SACS output provide the Load Combinations resultants described above.

The procedure was the same already presented in the TP Transportation Analysis, ref./25/ but without the combination factors. For the complete description of the basic load cases refer to ref./25/.

FORCES AND MOMENTS SUMMARY
*** MOMENTS SUMMED ABOUT ORIGIN ***

LOAD CASE	FORCE(X) KN	FORCE(Y) KN	FORCE(Z) KN	MOMENT(X) KN-M	MOMENT(Y) KN-M	MOMENT(Z) KN-M
UN01	-1194.307	0.000	2958.072	-1801.882	-6228.563	-908.128
UN02	-899.223	0.000	2958.072	-1801.884	-4467.674	-438.702
UN03	-922.281	0.000	1731.040	-1023.357	-5170.478	-735.540
UN04	-627.197	0.000	1731.039	-1023.359	-3409.588	-266.114
UN05	899.224	0.000	4404.123	-2869.222	6865.329	438.702
UN06	1194.309	0.000	4404.123	-2869.224	8626.217	908.128
UN07	627.198	0.000	3177.090	-2090.693	5007.936	266.115
UN08	922.283	0.000	3177.089	-2090.695	6768.825	735.541
UN09	0.000	1507.826	3398.901	-11407.778	1226.677	-369.025
UN10	0.000	1809.536	3398.901	-13285.916	1226.677	-701.871
UN11	0.000	1077.967	2217.874	-8352.970	842.124	-229.069
UN12	0.000	1379.677	2217.874	-10231.105	842.124	-561.915
UN13	0.000	-1809.529	3687.267	8788.216	1080.774	701.889
UN14	0.000	-1507.818	3687.267	6910.078	1080.773	369.042
UN15	0.000	-1379.670	2506.240	7233.714	696.228	561.918
UN16	0.000	-1077.959	2506.240	5355.577	696.228	229.072

Table 11.4 - Transportation Load Combinations – Resultants summary

All the resultant loads, from 11-4, were applied at the Remote Point described in 10.3 (CoG position).

ANSYS LOAD CASE	SACS OUTPUT	NOTE	FORCE [kN]		
			X	Y	Z (vertical)
1	TPLO	Gravity loads			-2963.5
2	UN01	Gravity loads + Inertia (+P+H) + Wind (+X)	1194.31		2958.07
3	UN02	Gravity loads + Inertia (+P+H) + Wind (-X)	899.22		2958.07
4	UN03	Gravity loads + Inertia (+P-H) + Wind (+X)	922.28		1731.04
5	UN04	Gravity loads + Inertia (+P-H) + Wind (-X)	627.20		1731.04
6	UN05	Gravity loads + Inertia (-P+H) + Wind (+X)	-899.22		4404.12
7	UN06	Gravity loads + Inertia (-P+H) + Wind (-X)	-1194.31		4404.12
8	UN07	Gravity loads + Inertia (-P-H) + Wind (+X)	-627.20		3177.09
9	UN08	Gravity loads + Inertia (-P-H) + Wind (-X)	-922.28		3177.09
10	UN09	Gravity loads + Inertia (+R+H) + Wind (+Y)		-1507.83	3398.90
11	UN10	Gravity loads + Inertia (+P+H) + Wind (-Y)		-1809.54	3398.90
12	UN11	Gravity loads + Inertia (+R-H) + Wind (+Y)		-1077.97	2217.87
13	UN12	Gravity loads + Inertia (+R-H) + Wind (-Y)		-1379.68	2217.87
14	UN13	Gravity loads + Inertia (-R+H) + Wind (+Y)		1809.53	3687.27
15	UN14	Gravity loads + Inertia (-P+H) + Wind (-Y)		1507.82	3687.27
16	UN15	Gravity loads + Inertia (-R-H) + Wind (+Y)		1379.67	2506.24

17	UN16	Gravity loads + Inertia (-P-H) + Wind (-Y)		1077.96	2506.24

Table 11.5 – TP FE model – Applied Loads, ref. Table 11.4

The following figures show the applied loads.

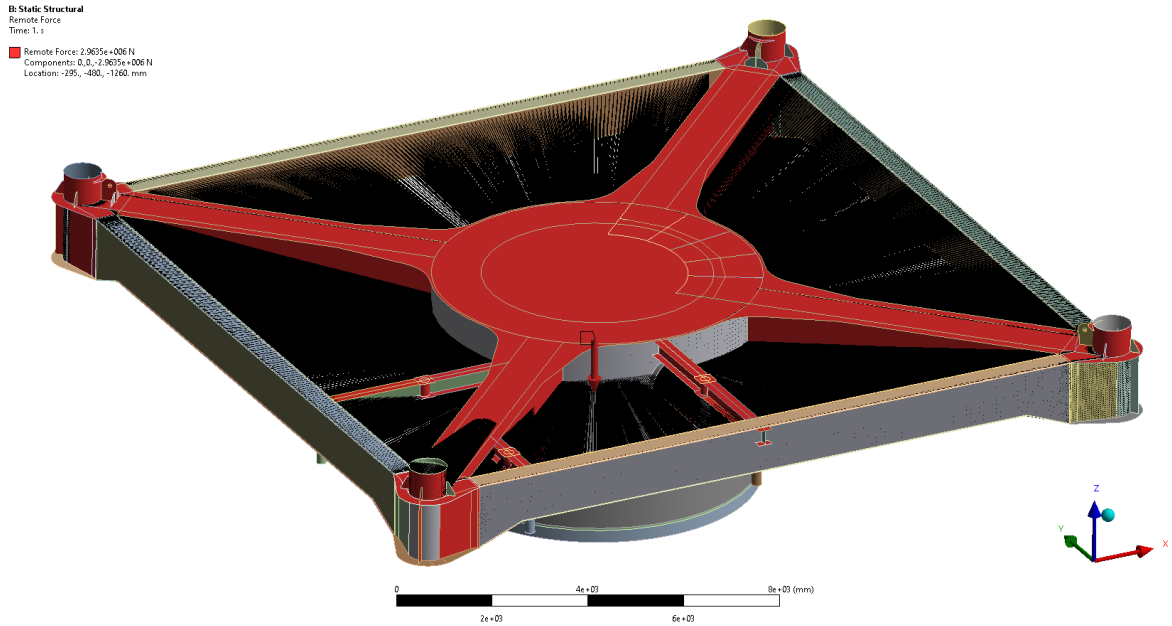


Figure 11.1 – BLPH TP – ANSYS LC: 1 (SACS LC: TPLO)

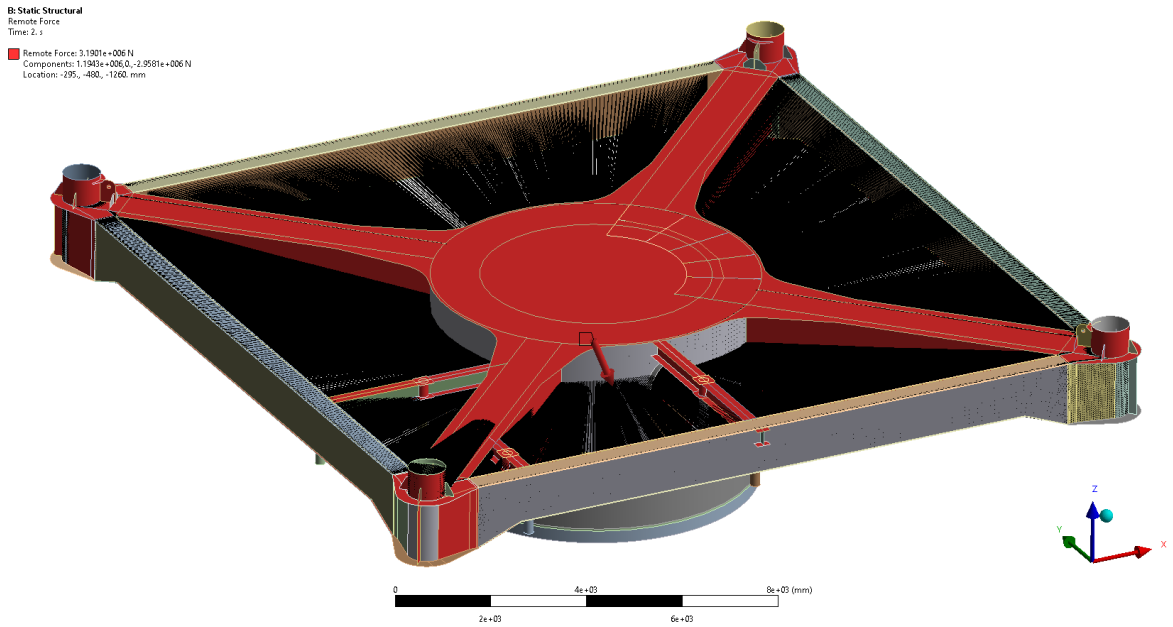


Figure 11.2 – BLPH TP – ANSYS LC: 2 (SACS LC: UN01)

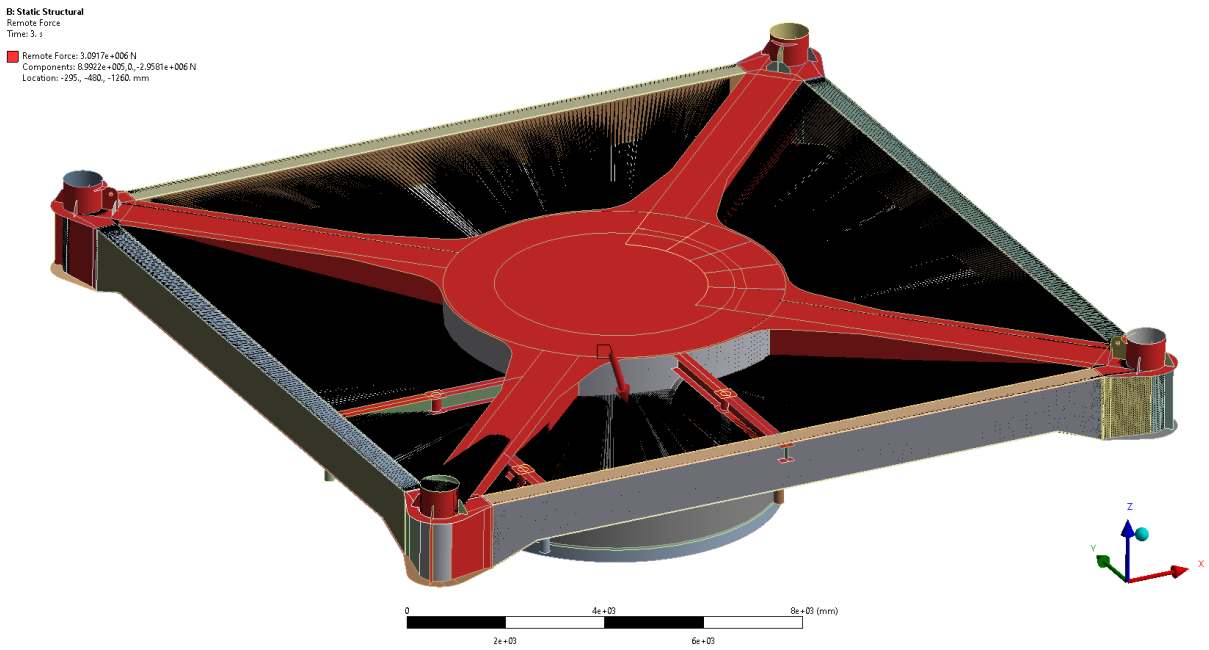


Figure 11.3 – BLPH TP – ANSYS LC: 3 (SACS LC: UN02)

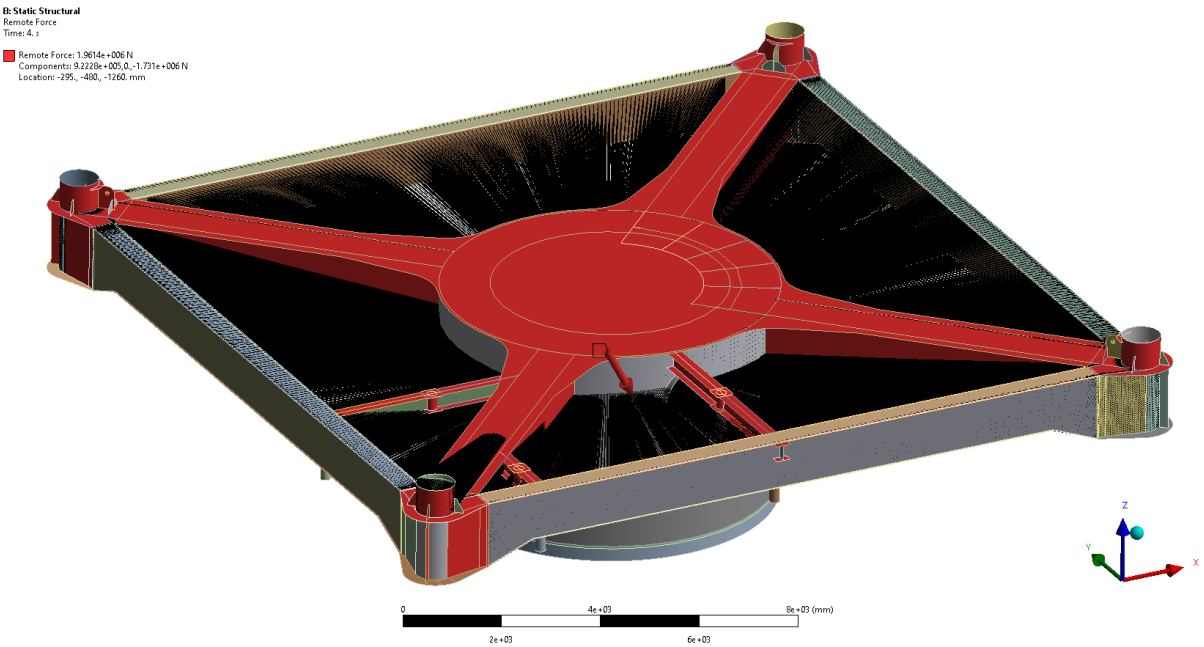


Figure 11.4 – BLPH TP – ANSYS LC: 4 (SACS LC: UN03)

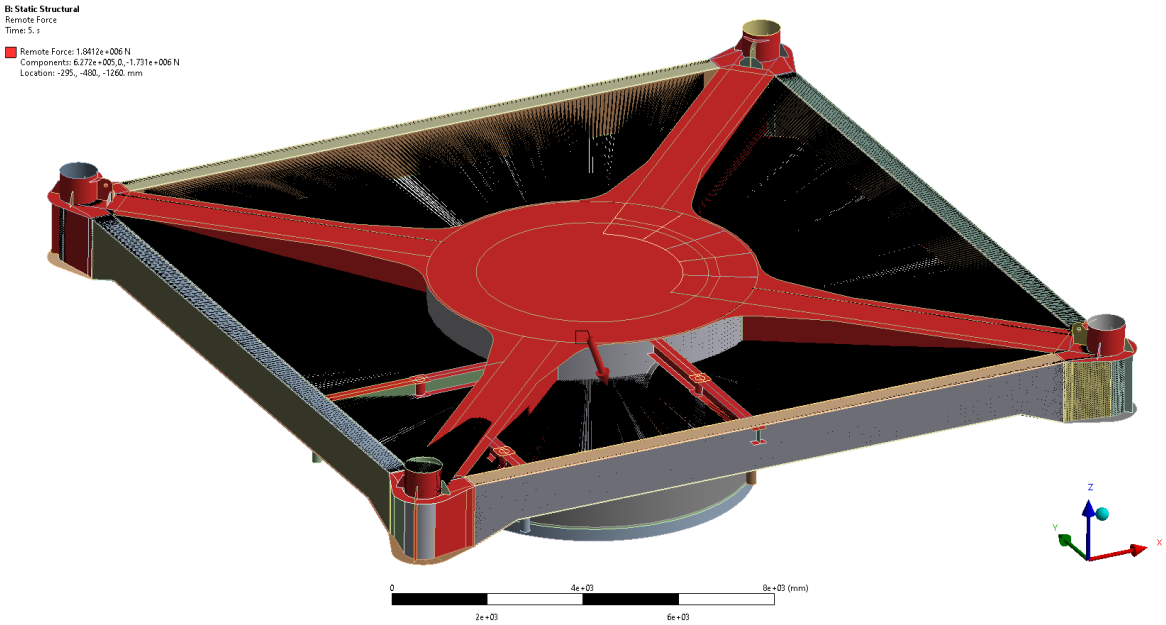


Figure 11.5 – BLPH TP – ANSYS LC: 5 (SACS LC: UN04)

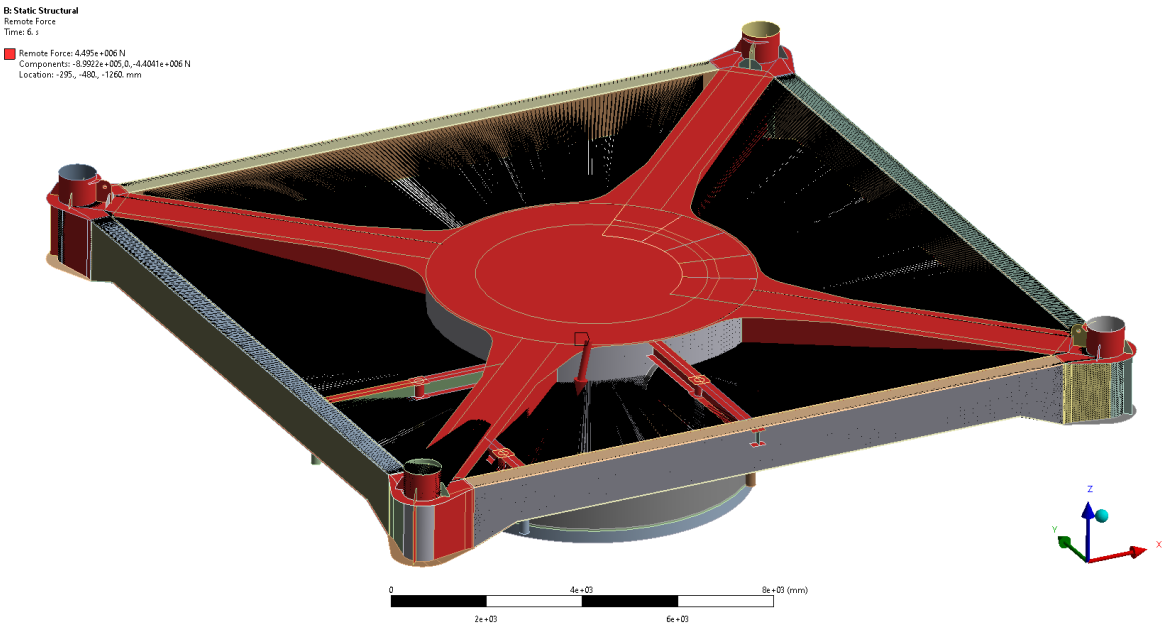


Figure 11.6 – BLPH TP – ANSYS LC: 6 (SACS LC: UN05)

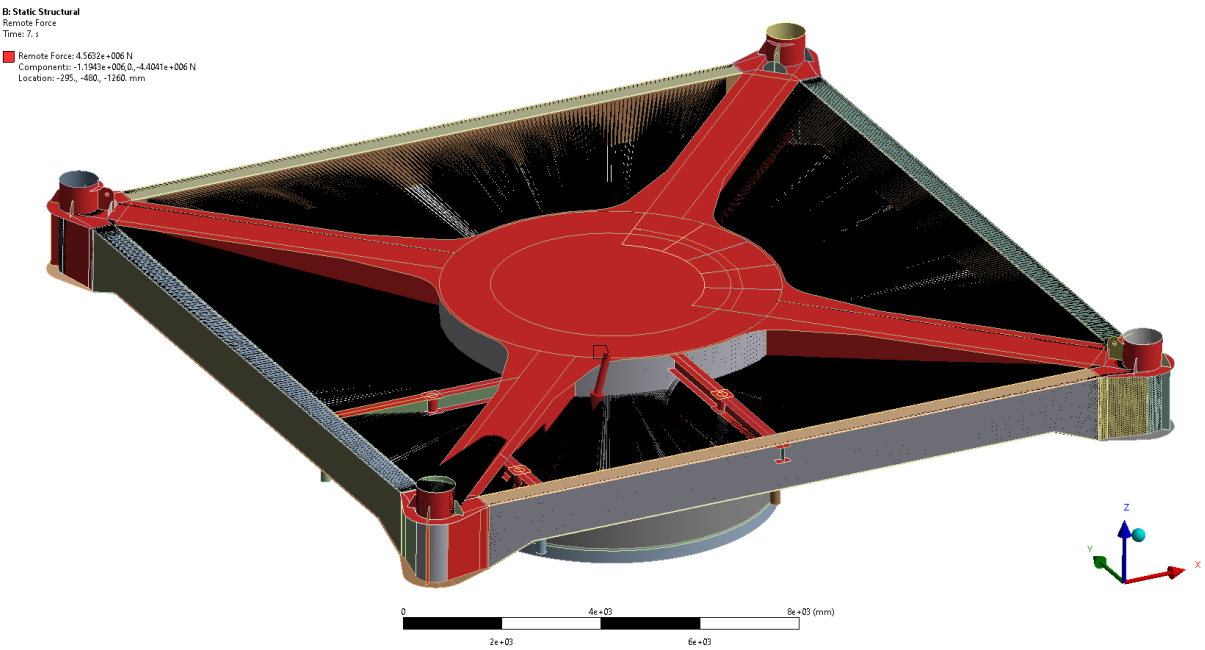


Figure 11.7 – BLPH TP – ANSYS LC: 7 (SACS LC: UN06)

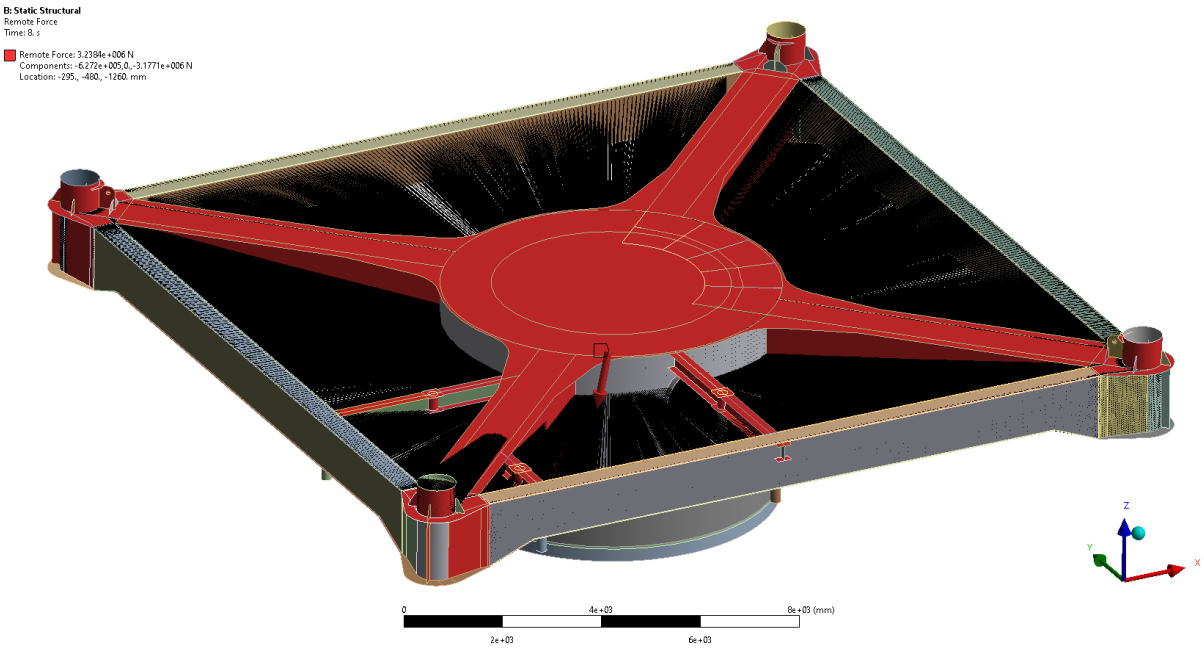


Figure 11.8 – BLPH TP – ANSYS LC: 8 (SACS LC: UN07)

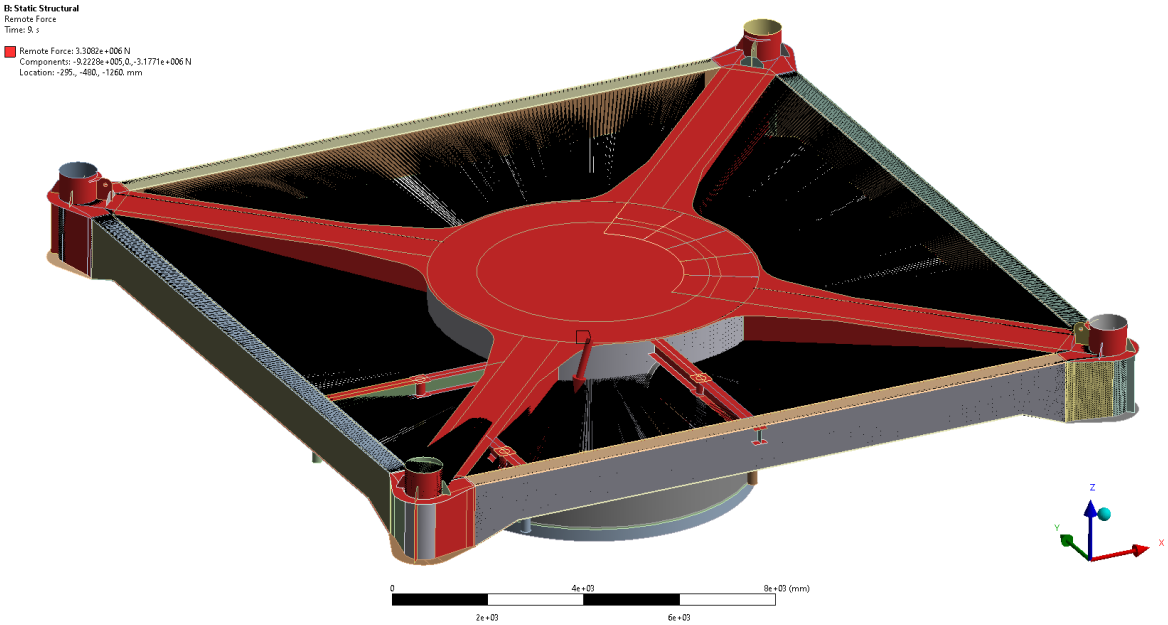


Figure 11.9 – BLPH TP – ANSYS LC: 9 (SACS LC: UN08)

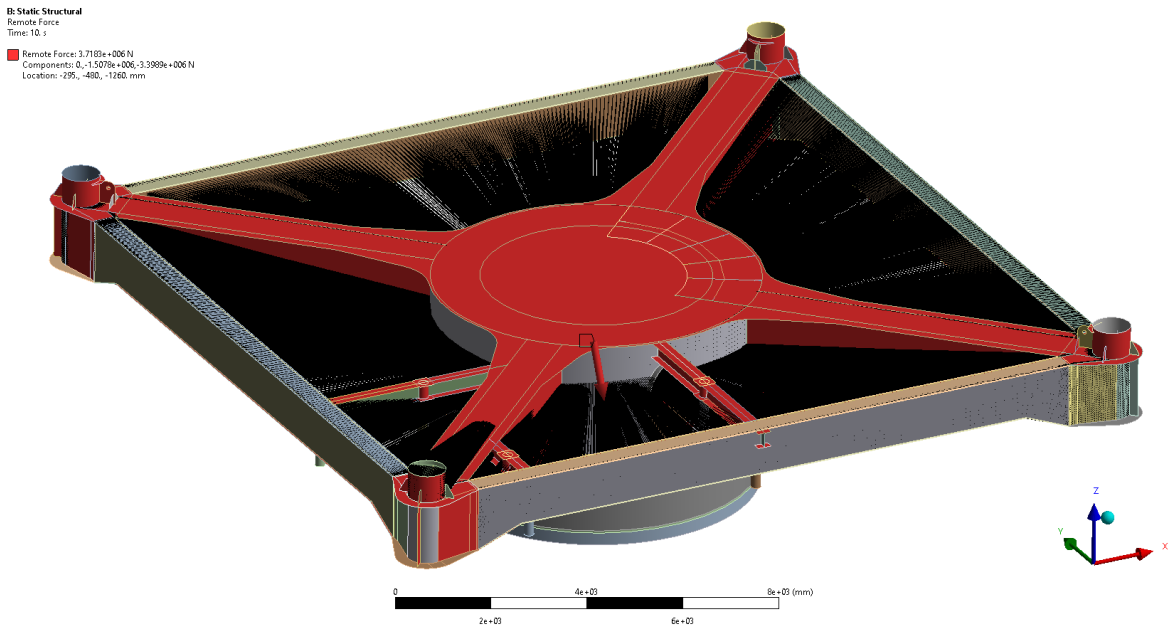


Figure 11.10 – BLPH TP – ANSYS LC: 10 (SACS LC: UN09)

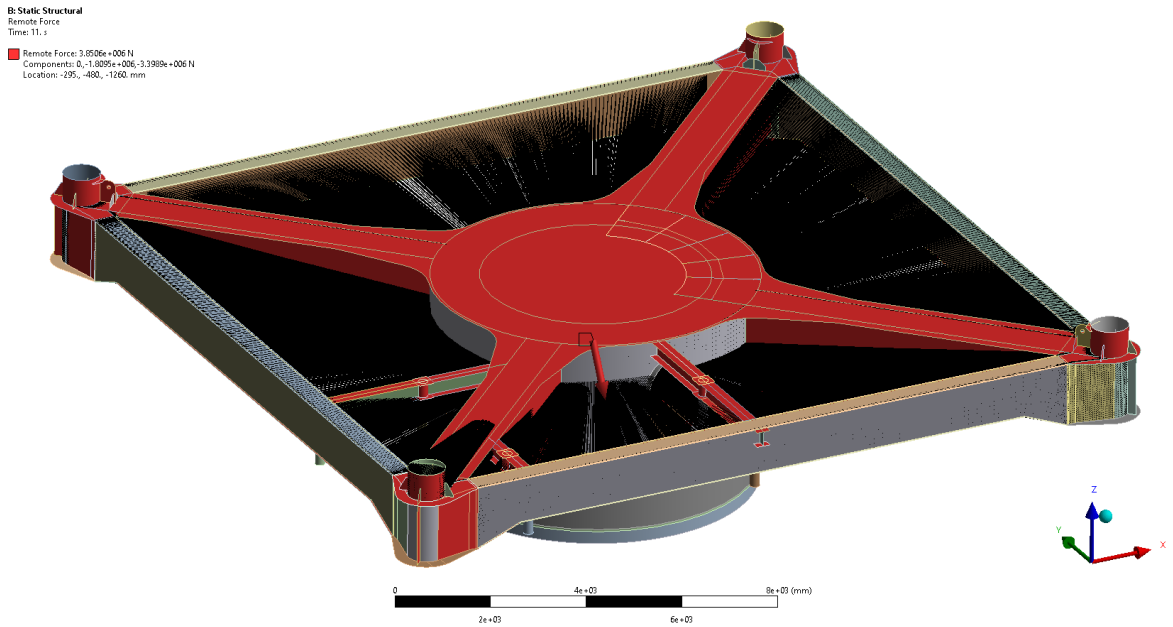


Figure 11.11 – BLPH TP – ANSYS LC: 11 (SACS LC: UN10)

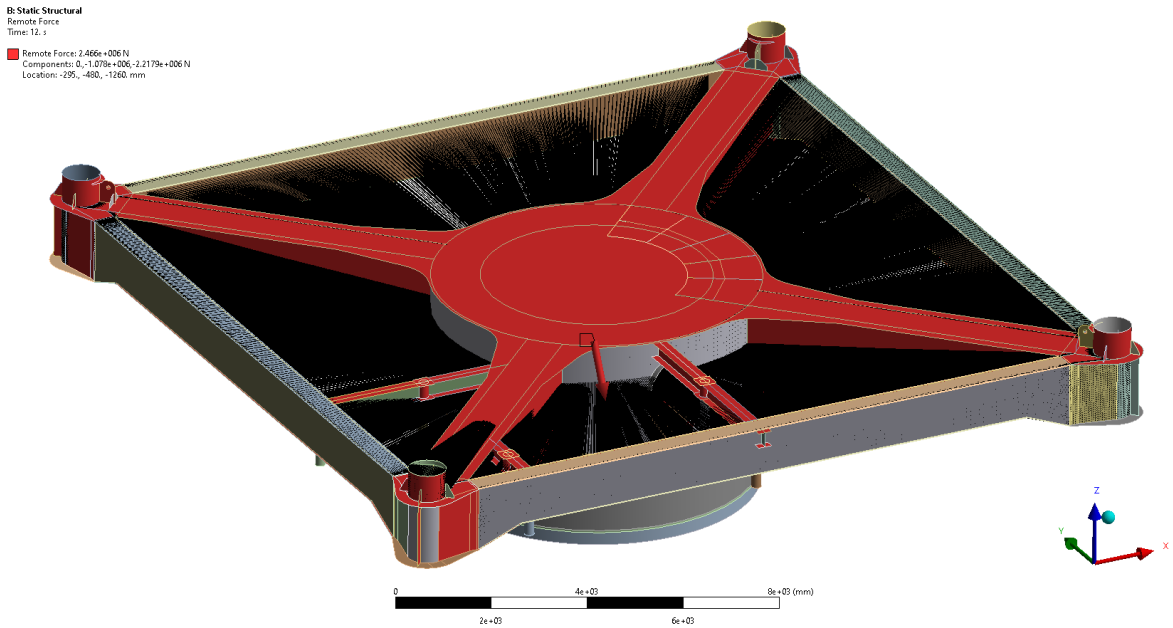


Figure 11.12 – BLPH TP – ANSYS LC: 12 (SACS LC: UN11)

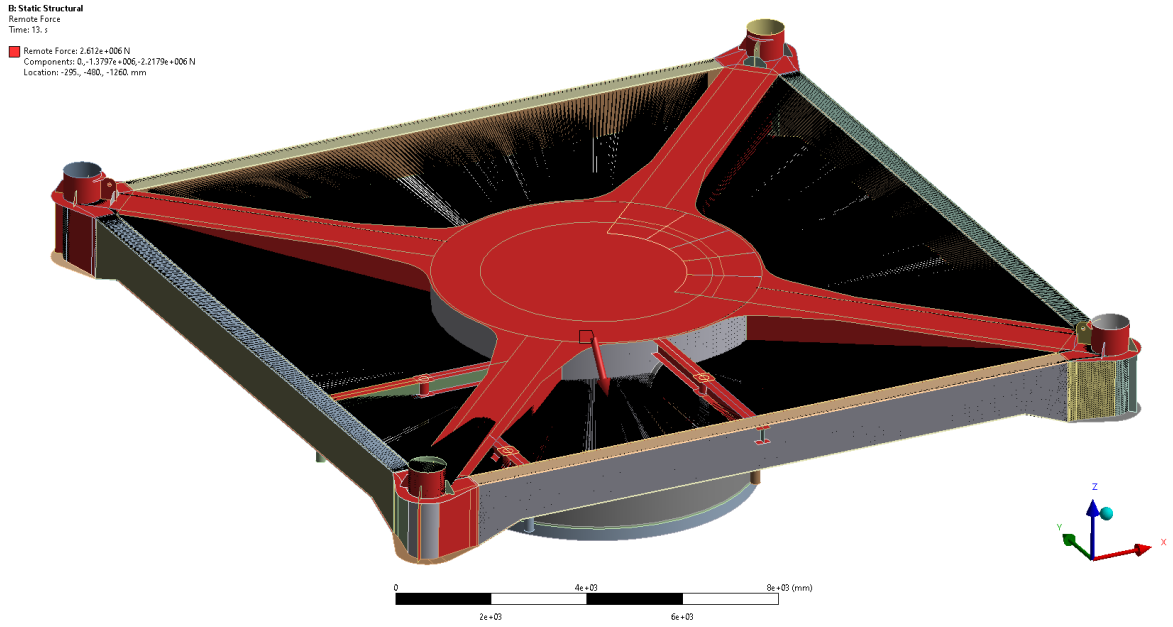


Figure 11.13 – BLPH TP – ANSYS LC: 13 (SACS LC: UN04)

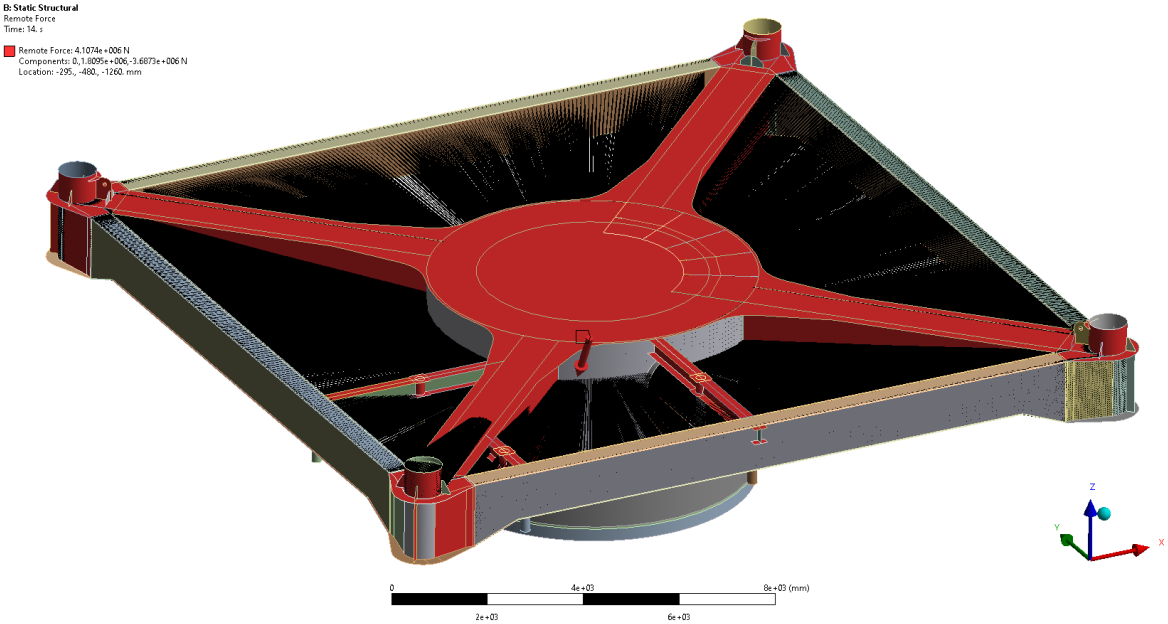


Figure 11.14 – BLPH TP – ANSYS LC: 14 (SACS LC: UN13)

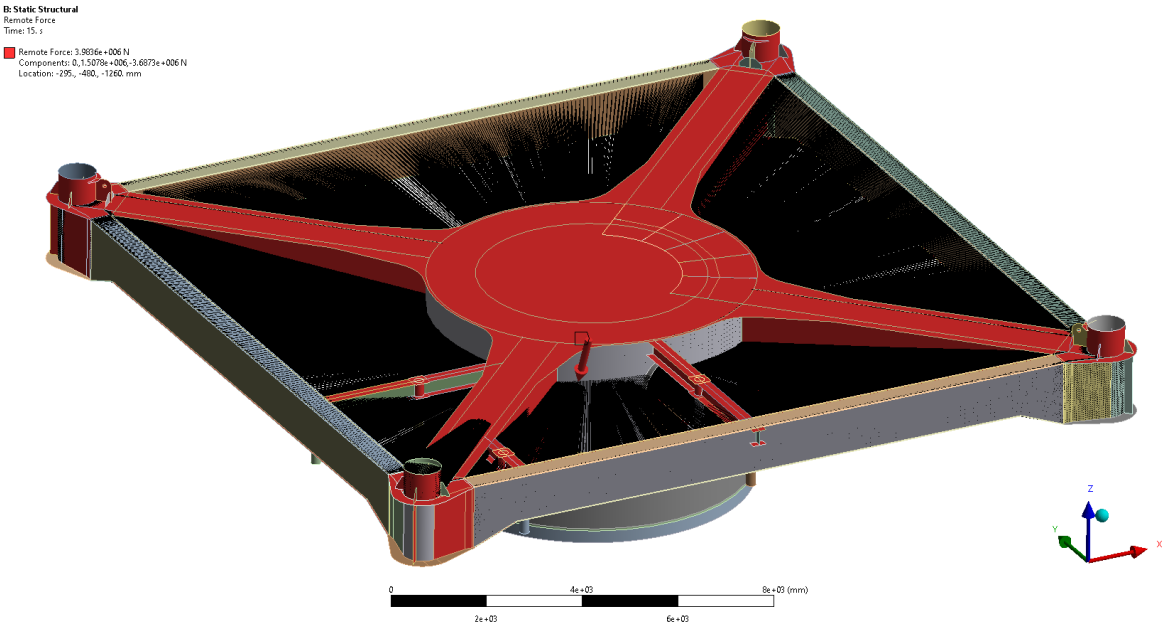


Figure 11.15 – BLPH TP – ANSYS LC: 15 (SACS LC: UN14)

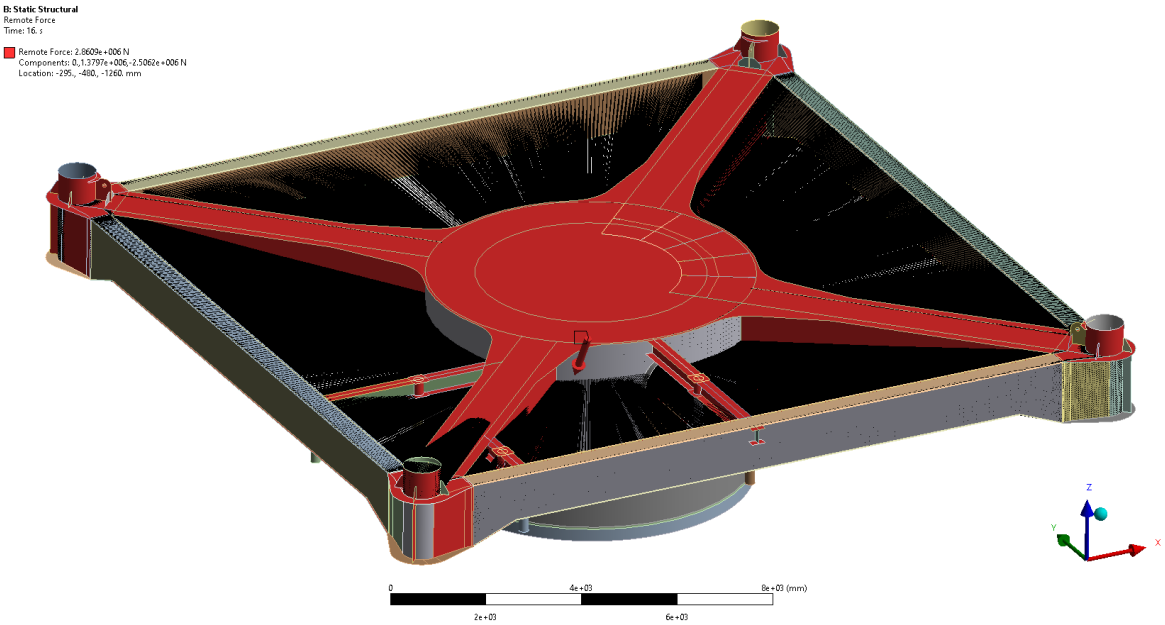


Figure 11.16 – BLPH TP – ANSYS LC: 16 (SACS LC: UN05)

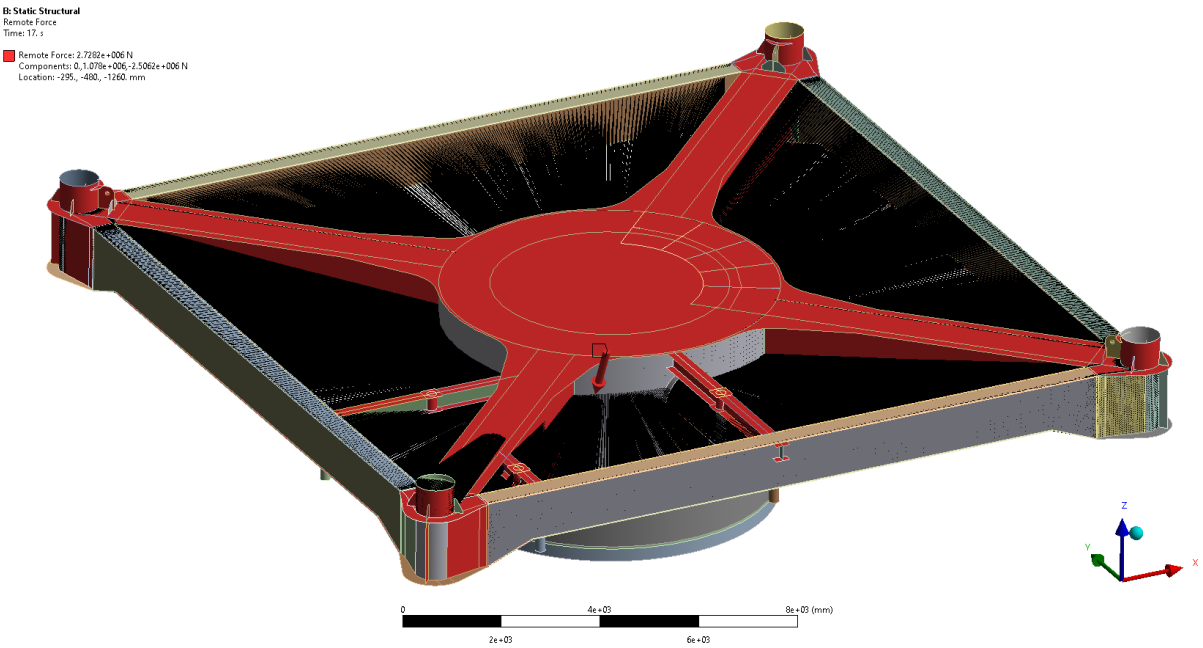


Figure 11.17 – BLPH TP – ANSYS LC: 17 (SACS LC: UN16)

11.1 NEGATIVE LOAD COMBINATIONS

The purpose of the analyses is to evaluate the fluctuating stresses on the TP structure due to the action of the variable loads. For this reason, additional load combinations were defined by subtracting the gravity loads from the SACS unfactored combinations.

ANSYS LOAD COMB	LOAD CASE																
	TPLO	UN01	UN02	UN03	UN04	UN05	UN06	UN07	UN08	UN09	UN10	UN11	UN12	UN13	UN14	UN15	UN16
LC01	-1.00	1.00															
LC02	-1.00		1.00														
LC03	-1.00			1.00													
LC04	-1.00				1.00												
LC05	-1.00					1.00											
LC06	-1.00						1.00										
LC07	-1.00							1.00									
LC08	-1.00								1.00								
LC09	-1.00									1.00							
LC10	-1.00										1.00						
LC11	-1.00											1.00					
LC12	-1.00												1.00				
LC13	-1.00													1.00			
LC14	-1.00														1.00		
LC15	-1.00															1.00	
LC16	-1.00																1.00

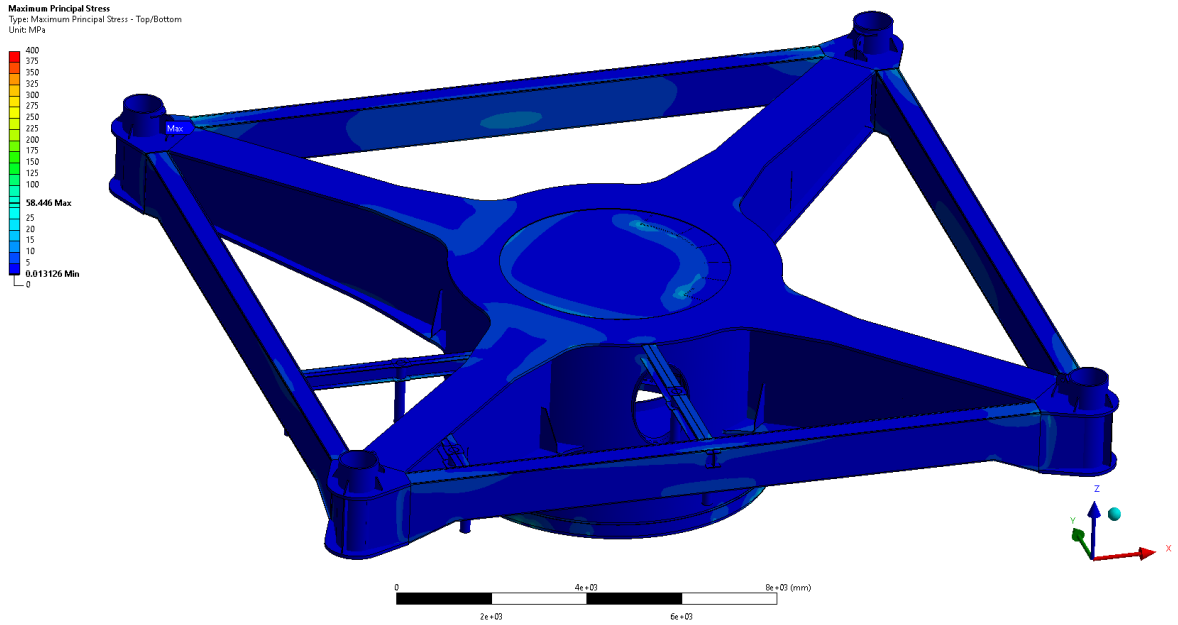
Table 11.6 – TP FE model – ANSYS Analysis Load Combinations

12 ANALYSIS RESULTS

This section presents the results of the analysis performed on the TP FE model in terms of stress range, calculated as the difference between the maximum and minimum principal stress.

12.1 MAXIMUM PRINCIPAL STRESS

The following figures shows the Max Principal Stress occurring on TP due by the cyclic loads. The envelope results were plotted.



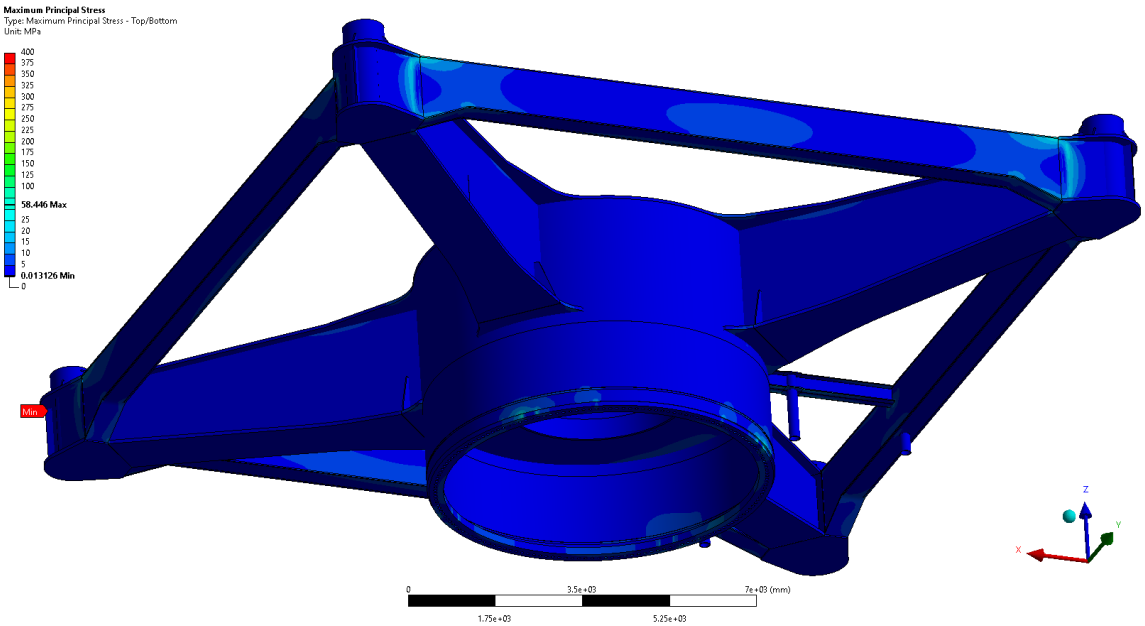
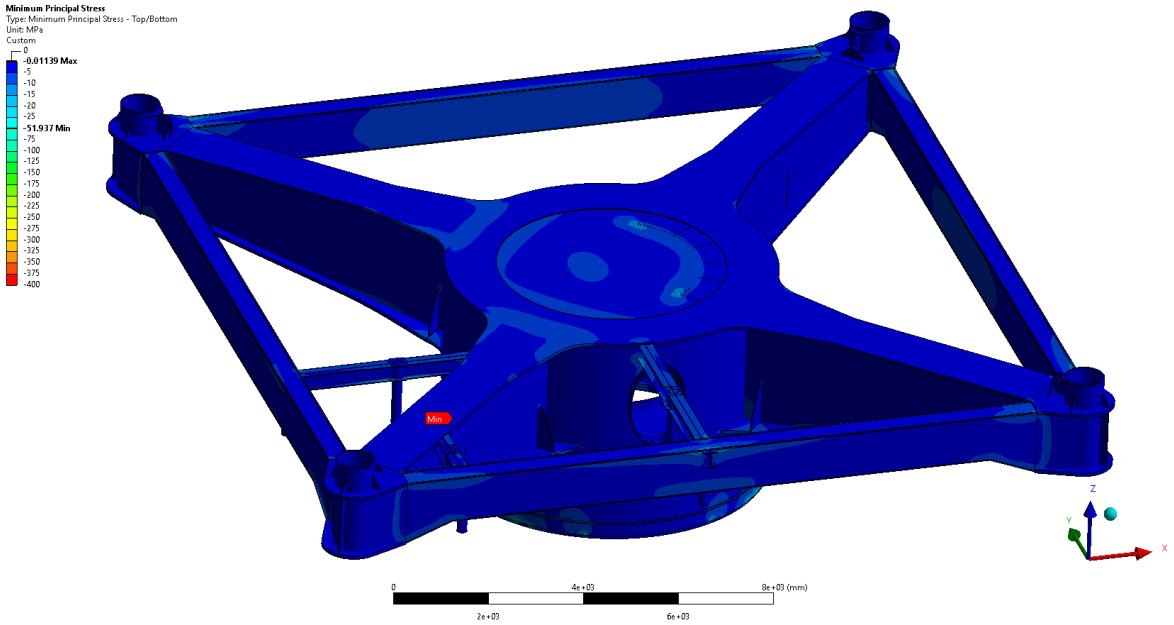


Figure 12.1 – BLPH TP – Envelope Results – Maximum Principal Stress

12.2 MINIMUM PRINCIPAL STRESS

The following figures shows the Min Principal Stress occurring on TP due by the variable loads. The envelope results were plotted.



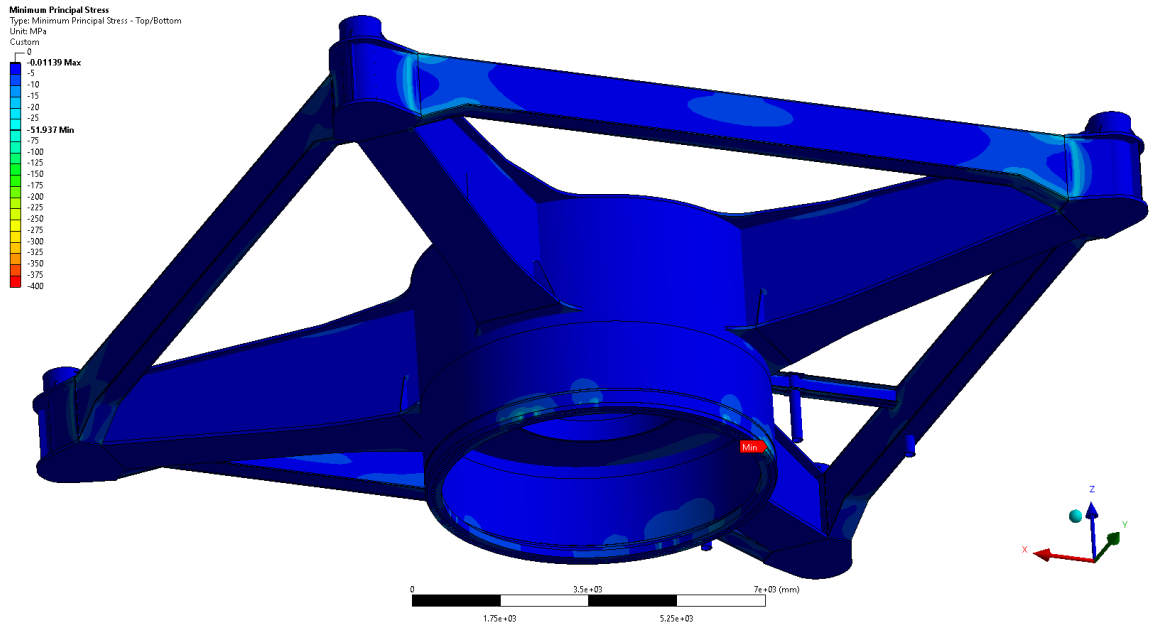


Figure 12.2 – BLPH TP – Envelope Results – Maximum Principal Stress

12.3 CONCLUSION

The maximum and minimum principal stresses obtained are 58 MPa and -52 MPa respectively. The resulting maximum peak stress range due to cyclic loading is therefore equal to 110 MPa.

Adopting the "Simplified Fatigue Approach" of DNV-RP-C203 - Section 5, and relying on:

- a Weibull shape parameter h=0.80,
- design S-N fatigue curve D

Table 5-2 (component in air, ref. /13/) gives an allowable extreme stress range of 390.7 MPa for 10^8 cycles.

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Table 5-2 Allowable extreme stress range in [MPa] during 10^8 cycles for components in air

S-N curves	Weibull shape parameter h							
	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20
B1	1449.3	1092.2	861.2	704.7	594.1	512.9	451.4	403.6
B2	1268.1	955.7	753.6	616.6	519.7	448.7	394.9	353.1
C	1319.3	919.6	688.1	542.8	445.5	377.2	326.9	289.0
C1	1182.0	824.0	616.5	486.2	399.2	337.8	292.9	258.9
C2	1055.3	735.6	550.3	434.1	356.3	301.6	261.5	231.1
D	949.9	662.1	495.4	390.7	320.8	271.5	235.4	208.1
E	843.9	588.3	440.2	347.2	284.9	241.2	209.2	184.9
F	749.2	522.3	390.8	308.2	253.0	214.1	185.6	164.1
F1	664.8	463.4	346.7	273.5	224.5	190.0	164.7	145.6
F3	591.1	412.0	308.3	243.2	199.6	169.0	146.5	129.4
G	527.6	367.8	275.2	217.1	178.2	150.8	130.8	115.6
W1	475.0	331.0	247.8	195.4	160.4	135.8	117.7	104.0
W2	422.1	294.1	220.1	173.6	142.5	120.6	104.6	92.5
W3	379.9	264.8	198.2	156.0	128.2	108.6	94.2	83.2
T	1210.3	843.6	631.2	497.8	408.5	345.8	299.8	264.9

The use of DFF=10 and design life = 20 years, Table 5-8 provides utilization factor η = 0.10

Table 5-8 Utilisation factors η as function of design life and design fatigue factor

Design fatigue factor	Design life in years						
	5	10	15	20	25	30	50
1	4.0	2.0	1.33	1.00	0.80	0.67	0.40
2	2.0	1.0	0.67	0.50	0.40	0.33	0.20
3	1.33	0.67	0.44	0.33	0.27	0.22	0.13
5	0.80	0.40	0.27	0.20	0.16	0.13	0.08
10	0.40	0.20	0.13	0.10	0.08	0.07	0.04

Concluding the verification entering Table 5-5 with η = 0.10 and Weibull 0.80,

Table 5-5 Reduction factor on stress to correspond with utilisation factor η for C - W3 curves in air environment

Fatigue damage utilisation η	Weibull shape parameter h							
	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20
0.10	0.497	0.511	0.526	0.540	0.552	0.563	0.573	0.582
0.20	0.609	0.620	0.632	0.642	0.652	0.661	0.670	0.677
0.22	0.627	0.638	0.648	0.659	0.668	0.677	0.685	0.692
0.27	0.661	0.676	0.686	0.695	0.703	0.711	0.719	0.725

It is obtained the Reduction factor = 0.54.

Thus, the resulting allowable extreme stress is 390.7 * 0.54 = 211 MPa

Greater than the maximum stress range obtained from FEA equal to 110 MPa.

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The use of Weibull parameter = 1.0 leads to:

- allowable extreme stress range = 271.5
- reduction factor = 0.563

271.5*0.563 = 152.8 Mpa that is still greater than 110 Mpa