Base Load Power Hub (BLPH)

BLPH Platform – FE 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.

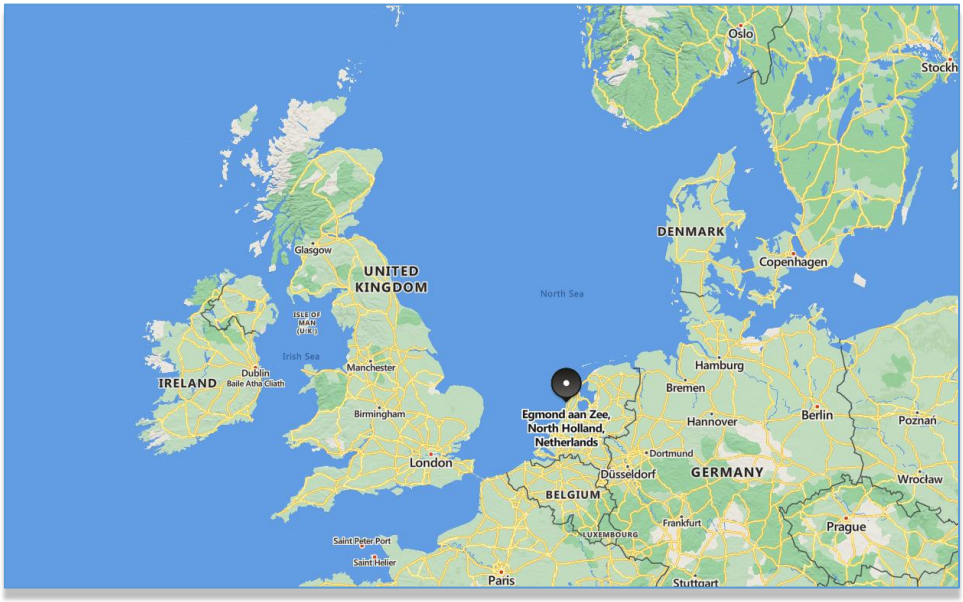


Figure 1.1 - HOLLANDSE KUST NOORD WIND PARK Location Map

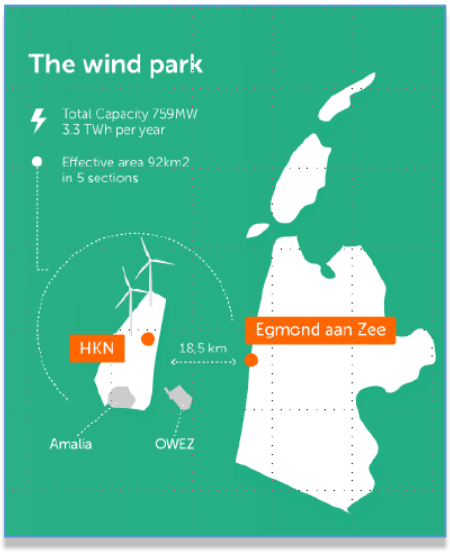


Figure 1.2 - Wind Park Details

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.

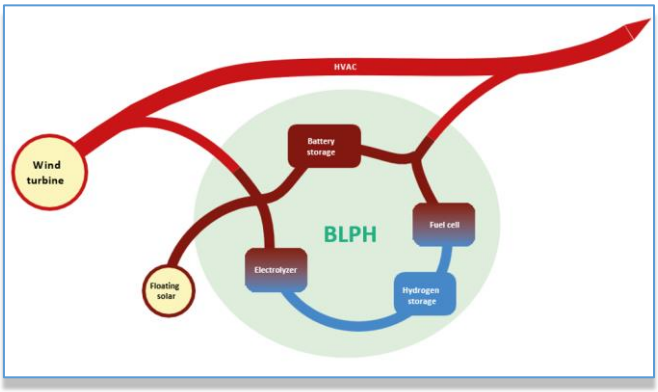


Figure 1.3 – BLPH Concept

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 FEM analyses performed on Transition Piece framing for in-service conditions.

Dedicated report presents the MP-TP flanged connection verification, Ref. /25/.

TP verification for transport condition is performed in a separate document, Ref. /26/.

The checks of the stabbing and installation guides are covered by a separate document, Ref. /24/.

The analysis has been performed in compliance with the requirements, criteria and parameters reported in the Structural Design Premises, Ref./17/.

Structural Code checks are performed according to EN ISO 19902 for tubular members and tubular joints, Ref./6/, and according to Eurocode 3 for non-tubular structural elements, Ref./8/.

Structural analyses have been carried out using the Finite Element Analysis software ANSYS, developed by ANSYS Inc., Ref./42/.

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-C208	DNV, Determination of structural capacity by non-linear finite element analysis methods, September 2021.
/14/ DNV-ST-0126	Support structures for wind turbine, 2018

3.2 COMPANY SPECIFICATIONS

Doc. No.	Description
/15/ DEP 37.19.00.12	Gen - Offshore Topsides Structures
/16/ DEP 37.19.00.30	Gen - Fixed Steel Offshore Structures (Adoption of IOGP S-631-11, Amendments / Supplements to ISO 19902:2020).

3.3 PROJECT DOCUMENTS

Doc. No.	Description

/17/ 123A90-DDL-ST-SP-90017	Structural Design Basis
/18/ 123A90-DDL-MD-RE-01006	Monthly Weight Report
/19/ 123A90-DDL-PP-DS-70070	Plot Plans
/20/ 123A90-DDL-ST-SP-90018	Structural Material Specification for Topside and TP
/21/ 123A90-DDL-ST-TN-90119	Evaluating ISO and DNV approaches
/22/ 123A90-DDL-ST-RE-90000	BLPH Platform – In service Analysis
/23/ 123A90-DDL-ST-RE-90006	BLPH Platform – Secondary Structures Design Report
/24/ 123A90-DDL-ST-RE-90012	BLPH Platform – TP-Joint Check Design Report
/25/ 123A90-DDL-ST-RE-90013	BLPH Platform – TP-MP Flange Connection Verification
/26/ 123A90-DDL-ST-RE-90009	BLPH Platform - TP Transportation Analysis
/27/ 123A90-DDL-ST-DD-90078	BLPH TP – Primary Steel – Elevation Row -A-
/28/ 123A90-DDL-ST-DD-90081	BLPH TP – Primary Steel – Elevation Row -2-
/29/ 123A90-DDL-ST-DD-90083	BLPH TP – Primary Steel – Flange Connection
/30/ 123A90-DDL-ST-DD-90085	BLPH TP – Primary Steel – Plan at El.-21710 T.O.S.
/31/ 123A90-DDL-ST-DD-90086	BLPH TP – Topside Support Point
/32/ 123A90-DDL-ST-DD-90090	BLPH TP – Walkways & Stairs – Access Platform - Assembly
/33/ 123A90-DDL-ST-DD-90091	BLPH TP – Walkways & Stairs – Access Platform – Sections – Sheet 1
/34/ 123A90-DDL-ST-DD-90092	BLPH TP – Walkways & Stairs – Access Platform – Plans
/35/ 123A90-DDL-ST-DD-90093	BLPH TP – Walkways & Stairs – Access Platform – Sections – Sheet 2
/36/ 123A90-DDL-ST-DD-90101	BLPH TP – Primary Steel – Sections
/37/ 123A90-DDL-ST-DD-90106	BLPH TP – Walkways & Stairs – Joint – 1, 2, 3, 4 & 5 – Detail
/38/ 123A90-DDL-ST-DD-90107	BLPH TP – Walkways & Stairs – Joint – 6 & 7 – Detail
/39/ 123A90-DDL-ST-DD-90108	BLPH TP – Walkways & Stairs – Typical Beam Connections
/40/ 123A90-DDL-ST-DD-90123	BLPH TP – Waste Water tank – Assembly and Details

3.4 OTHER DOCUMENTS

Doc. No.	Description
/41/ 144671-VOOW-TF-ENG-REP-1054	Foundation Load Document for BLPH, Rev.1, 07 April 2022

3.5 SOFTWARE

Doc. No.	Description
/42/ 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
BESS	BATTERY ENERGY STORAGE SYSTEM
BG	Box Girder
BLPH	Base Load Power Hub
CL	Concentrated Load
CoG	Centre of Gravity
CW	CrossWind
DAF	Dynamic Amplification Factor
DLB	Ductility Level Blast
DNV	Det Norske Veritas
DP	Dynamic Positioning
El.	Elevation
EPCI	Engineering Procurement Construction and Installation
FEED	Front End Engineering Design
FEA	Finite Element Analysis
FEM	Finite Element Method
HAT	Highest Astronomical Tide
HKN	Hollandse Kust Noord
ICCP	Impressed Current Corrosion Protection
LAT	Lowest Astronomical Tide
LRFD	Load and Resistance Factor Design
MSL	Mean Sea Level
NTE	Not-to-Exceed
OD	Outside Diameter
PAU	Pre-Assembled Unit (H2 Vessels)

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PG	Plate Girder
SHL	Static Hook Load
T&I	Transport & Installation
ToS	Top of Steel
TP	Transition Piece
UC	Unity Check
UDL	Uniformly Distributed Load
VM	Von Mises
VMS	Von Mises Stress
WTG	Wind Turbine Generator
W2W	Walk to Work

Table 4-1 - Definitions and Abbreviations

5 SUMMARY AND CONCLUSIONS

The analyses performed show that the Transition Piece framings, as configured, can withstand the maximum loads results derived by the combinations of environmental and operational imposed by the structure.

The TP is checked against the maximum in-service loads acting simultaneously on support columns at Topside-TP interface and TP-Stair interface.

Globally von-Mises stresses are largely lower than the allowable stress except some local peaks occurring on support columns at Topside-TP interface which lead only to elastic strains.

The connection flange at monopile-topside interface is also checked for the not-to be exceeded forces and moment provided by VOOW, ref./41/ .

Flange detail checks are covered by a dedicated report, Ref./25/.

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6 BLPH TOPSIDE AND TRANSITION PIECE DESCRIPTION

The BLPH Topside comprises of two main deck levels with overall deck plan dimensions of 40 m x 16 m, excluding external walkways, laydown areas and stairs, with an overall deck height of 7 m between decks. There are currently 6 hydrogen storage vessels which lie horizontally, aligned north - south, within the PAU structure located above the upper deck.

The Topsides layout is shown in Figure 6.1.

The Topsides in unmanned and there is no helideck. Main access is via Walk to Work (W2W) vessel with W2W platforms provided on the lower deck. Ladder access to sea for small Crew Transfer Vessel (CTV) access is also provided.

Main Deck elevations are:

- Target top of TP, El. + 22.310 m;
- Lower Deck, El. + 23.310 m ToS;
- Upper Deck, El. + 30.310 m ToS.

The PAU steel module 12m x 9m for the storage of 6 H2 Vessel 60t each is located on top of Topside Upper Deck.

The connection of 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 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.

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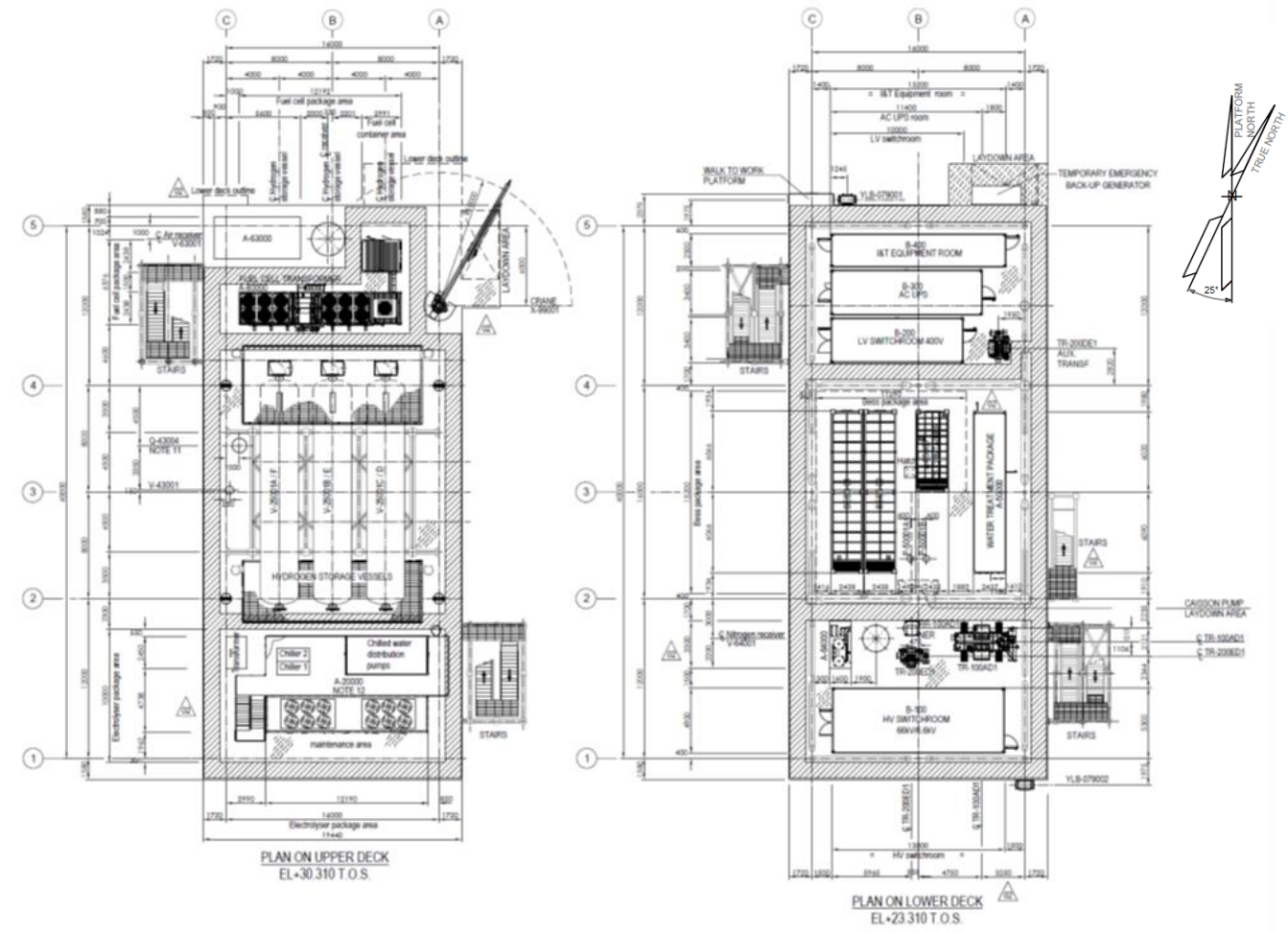


Figure 6.1 - Base Load Power Hub Plot Plan

6.1 MONOPILE-TOPSIDES INTERFACE

The interface level between Monopile and Topsides (comprising TP) is at El.+17.050 m relative to LAT, as shown in Figure 6.2.

The TP will be connected to the monopile in offshore. The connection for applied TP in-place condition loads is within CONTRACTOR's scope and is checked in a dedicated report, ref. /25/.

VOOW has developed serviceability and ultimate limit state design forces and moments on the BLPH monopile, ref./41/, not to be exceeded.

The monopile has been surveyed on 29 May 2023 showing as-built interface connection as reported in Design Basis, Ref./17/.

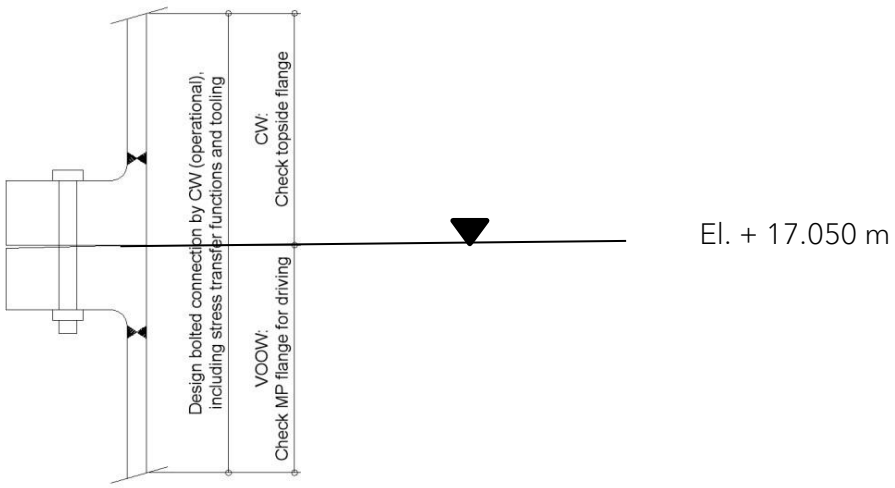


Figure 6.2– Monopile-to-Transition Piece Flange

7 DESIGN LOADS

The general basic load cases of BLPH Platform are defined in the In-Service and Secondary Structure reports Ref./22/ and Ref./23/.

For the basic load cases and load combinations, the same sets of loads and combinations are maintained.

Refer to the aforementioned reports for the definition of basic load cases and load combinations of the models for each analysis.

7.1 LOADS AT TP-TOPSIDE INTERFACE

The maximum internal forces of structural members at TP-Topside interface are provided by the reported in the following tables.

The following figure shows the support joints.

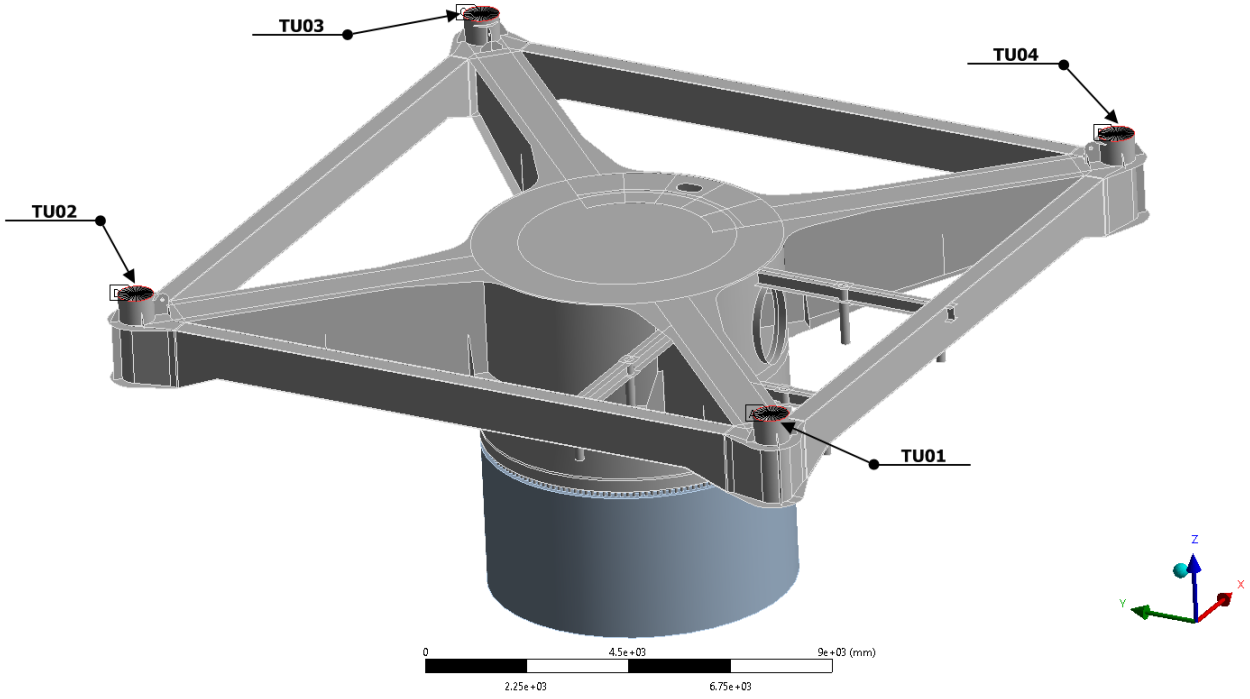


Figure 7.1 – Topside joints supports

- *TU01*

	MEMBER	MEMBER END	GROUP	LOAD CASE	Fx [kN]	Fy [kN]	Fz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
SET 1	TC24-TU01	TU01	TPS	OA1B	**-3273**	-1451	-2397	32	1422	1990
	TC24-TU01	TU01	TPS	OA4F	**-6375**	-883	-1979	47	1116	2335
	TC24-TU01	TU01	TPS	OA1E	-4217	**-621**	-2045	55	1390	1977
	TC24-TU01	TU01	TPS	OA4A	-5431	**-1712**	-2332	24	1147	2348
	TC24-TU01	TU01	TPS	OA2G	-5589	-1178	**-1693**	12	**1025**	2281
	TC24-TU01	TU01	TPS	OA3C	-4059	-1156	**-2684**	67	**1513**	2044
	TC24-TU01	TU01	TPS	OA1A	-3395	-1524	-2131	20	1350	2003
	TC24-TU01	TU01	TPS	OA4B	-5309	-1639	-2598	37	1220	2336
	TC24-TU01	TU01	TPS	OA1F	-4340	-695	-1778	42	1318	1989
	TC24-TU01	TU01	TPS	OA3D	-4450	-813	-2538	**76**	1499	2038
	TC24-TU01	TU01	TPS	OA2H	-5198	-1521	-1839	**3**	1038	2287
	TC24-TU01	TU01	TPS	OA4H	-5794	-1521	-2040	22	1087	**2353**
	TC24-TU01	TU01	TPS	G001	-4389	-962	-1849	37	1144	**1940**
	TC24-TU01	TU01	TPS	OA4C	-5499	-1344	-2684	52	1262	2323
SET 2	TC24-TU01	TU01	TPS	EA1B	**-2605**	-1914	-2800	28	1490	1990
	TC24-TU01	TU01	TPS	EA4F	**-7043**	-420	-1577	51	1047	2335
	TC24-TU01	TU01	TPS	EA1E	-4716	**-74**	-1985	76	1415	1961
	TC24-TU01	TU01	TPS	EA4A	-4932	**-2260**	-2391	3	1123	2364
	TC24-TU01	TU01	TPS	EA2G	-6035	-1070	**-1183**	-3	**904**	2298
	TC24-TU01	TU01	TPS	EA3C	-3614	-1264	**-3194**	82	**1634**	2027
	TC24-TU01	TU01	TPS	EA1A	-2897	-2072	-2190	-1	1325	2019
	TC24-TU01	TU01	TPS	EA4B	-4641	-2102	-3001	32	1288	2336
	TC24-TU01	TU01	TPS	EA1F	-5007	-232	-1375	47	1250	1990
	TC24-TU01	TU01	TPS	EA3D	-4488	-501	-2857	**102**	1603	2015
	TC24-TU01	TU01	TPS	EA2H	-5160	-1832	-1520	**-23**	935	2310
	TC24-TU01	TU01	TPS	EA4H	-5756	-1833	-1721	-3	983	**2376**
	TC24-TU01	TU01	TPS	EA1D	-3892	-501	-2655	82	1554	**1949**
	TC24-TU01	TU01	TPS	EA4C	-5053	-1452	-3194	67	1383	2307
	TC24-TU01	TU01	TPS	EA1G	-4595	-882	-1183	12	1154	2018

Table 7.1- Maximum loads at TP-Topside interface – Support TU01

- *TU02*

	MEMBER	MEMBER END	GROUP	LOAD CASE	Fx [kN]	Fy [kN]	Fz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
SET 1	TA24-TU02	TU02	TPS	OA3D	**-3606**	1415	-2505	-142	1531	-1929
	TA24-TU02	TU02	TPS	OA2H	**-6706**	874	-2051	-176	1228	-2262
	TA24-TU02	TU02	TPS	OA4E	-5168	**1693**	-2218	-117	1212	-2214
	TA24-TU02	TU02	TPS	OA1A	-5143	**597**	-2338	-201	1547	-1978
	TA24-TU02	TU02	TPS	OA4G	-5918	1175	**-1756**	-120	**1135**	-2208
	TA24-TU02	TU02	TPS	OA1C	-4394	1115	**-2799**	-198	**1624**	-1983
	TA24-TU02	TU02	TPS	OA3E	-3725	1501	-2218	-120	1460	-1936
	TA24-TU02	TU02	TPS	OA2D	-5646	1606	-2704	-171	1337	-2269
	TA24-TU02	TU02	TPS	OA3H	-4666	684	-1852	-147	1422	-1922
	TA24-TU02	TU02	TPS	OA4F	-5528	1514	-1908	**-109**	1151	-2214
	TA24-TU02	TU02	TPS	OA1B	-4784	776	-2647	**-209**	1608	-1977
	TA24-TU02	TU02	TPS	G001	-4652	1048	-1997	-143	1212	**-1894**
	TA24-TU02	TU02	TPS	OA2F	-6125	1512	-2107	-141	1204	**-2277**
	TA24-TU02	TU02	TPS	OA2C	-5837	1306	-2799	-195	1376	-2260
SET 2	TA24-TU02	TU02	TPS	EA3D	**-2944**	1863	-2930	-141	1603	-1933
	TA24-TU02	TU02	TPS	EA2H	**-7368**	427	-1626	-177	1156	-2258
	TA24-TU02	TU02	TPS	EA4E	-4670	**2241**	-2273	-86	1192	-2227
	TA24-TU02	TU02	TPS	EA1A	-5642	**49**	-2282	-233	1567	-1964
	TA24-TU02	TU02	TPS	EA4G	-6356	1090	**-1210**	-91	**1014**	-2216
	TA24-TU02	TU02	TPS	EA1C	-3956	1200	**-3345**	-227	**1745**	-1975
	TA24-TU02	TU02	TPS	EA3E	-3227	2049	-2274	-88	1440	-1950
	TA24-TU02	TU02	TPS	EA2D	-4984	2054	-3129	-170	1408	-2273
	TA24-TU02	TU02	TPS	EA3H	-5328	236	-1427	-148	1351	-1918
	TA24-TU02	TU02	TPS	EA4F	-5486	1841	-1561	**-66**	1051	-2230
	TA24-TU02	TU02	TPS	EA1B	-4826	449	-2994	**-252**	1708	-1962
	TA24-TU02	TU02	TPS	EA3B	-4229	450	-2795	-220	1655	**-1899**
	TA24-TU02	TU02	TPS	EA2F	-6082	1839	-1761	-98	1104	**-2292**
	TA24-TU02	TU02	TPS	EA2C	-5399	1392	-3345	-224	1497	-2252
	TA24-TU02	TU02	TPS	EA3G	-4913	898	-1211	-94	1262	-1939

Table 7.2- Maximum loads at TP-Topside interface – Support TU02

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- *TU03*

	MEMBER	MEMBER END	GROUP	LOAD CASE	Fx [kN]	Fy [kN]	Fz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
SET 1	TA44-TU03	TU03	TPS	OA4F	**-4052**	1540	2517	103	-1352	-2073
	TA44-TU03	TU03	TPS	OA1B	**-7128**	943	2065	129	-1039	-2411
	TA44-TU03	TU03	TPS	OA3E	-5620	**1828**	2221	74	-1037	-2357
	TA44-TU03	TU03	TPS	OA2A	-5560	**655**	2361	158	-1353	-2128
	TA44-TU03	TU03	TPS	OA1G	-6272	1408	**2831**	143	-1182	-2412
	TA44-TU03	TU03	TPS	OA4C	-4908	1076	**1751**	89	-1209	-2073
	TA44-TU03	TU03	TPS	OA4E	-4176	1634	2216	82	-1288	-2078
	TA44-TU03	TU03	TPS	OA1F	-6093	1732	2722	119	-1150	-2418
	TA44-TU03	TU03	TPS	OA4B	-5087	751	1859	114	-1241	-2067
	TA44-TU03	TU03	TPS	OA2H	-5206	848	2678	**164**	-1413	-2128
	TA44-TU03	TU03	TPS	OA3D	-5974	1636	1903	**69**	-978	-2357
	TA44-TU03	TU03	TPS	OA3C	-6351	1270	1756	82	**-959**	-2352
	TA44-TU03	TU03	TPS	OA2G	-4828	1213	2826	151	**-1432**	-2133
	TA44-TU03	TU03	TPS	G001	-4746	991	1903	106	-1089	**-1989**
	TA44-TU03	TU03	TPS	OA1E	-6217	1826	2421	97	-1086	**-2422**
SET 2	TA44-TU03	TU03	TPS	EA4F	**-3403**	2028	2937	96	-1424	-2076
	TA44-TU03	TU03	TPS	EA1B	**-7777**	455	1644	136	-967	-2409
	TA44-TU03	TU03	TPS	EA3E	-5140	**2429**	2247	38	-1027	-2364
	TA44-TU03	TU03	TPS	EA2A	-6040	**54**	2334	194	-1364	-2121
	TA44-TU03	TU03	TPS	EA1G	-5833	1497	**3399**	169	-1294	-2409
	TA44-TU03	TU03	TPS	EA4C	-5347	986	**1183**	63	-1097	-2076
	TA44-TU03	TU03	TPS	EA4E	-3697	2235	2242	46	-1278	-2084
	TA44-TU03	TU03	TPS	EA1F	-5444	2220	3143	112	-1222	-2421
	TA44-TU03	TU03	TPS	EA4B	-5736	263	1439	121	-1169	-2064
	TA44-TU03	TU03	TPS	EA2H	-5235	486	3061	**208**	-1499	-2121
	TA44-TU03	TU03	TPS	EA3D	-5945	1997	1521	**24**	-892	-2364
	TA44-TU03	TU03	TPS	EA3C	-6790	1180	1188	56	**-847**	-2356
	TA44-TU03	TU03	TPS	EA2G	-4390	1303	3394	177	**-1544**	-2129
	TA44-TU03	TU03	TPS	EA4H	-4637	488	2860	185	-1450	**-2055**
	TA44-TU03	TU03	TPS	EA1D	-6543	1995	1721	47	-941	**-2429**
	TA44-TU03	TU03	TPS	EA1E	-5737	2427	2448	61	-1076	-2429
	TA44-TU03	TU03	TPS	EA4A	-5442	56	2133	171	-1315	-2056

Table 7.3- Maximum loads at TP-Topside interface – Support TU03

- *TU04*

	MEMBER	MEMBER END	GROUP	LOAD CASE	Fx [kN]	Fy [kN]	Fz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
SET 1	TC44-TU04	TU04	TPS	OA2H	**-3726**	-1531	2391	-118	-1373	2160
	TC44-TU04	TU04	TPS	OA3D	**-6804**	-908	1959	-158	-1067	2498
	TC44-TU04	TU04	TPS	OA2E	-4639	**-632**	2046	-153	-1325	2146
	TC44-TU04	TU04	TPS	OA3A	-5891	**-1807**	2305	-124	-1115	2512
	TC44-TU04	TU04	TPS	OA4G	-4501	-1213	**2694**	-171	**-1459**	2215
	TC44-TU04	TU04	TPS	OA1C	-6029	-1227	**1657**	-106	**-981**	2443
	TC44-TU04	TU04	TPS	OA2A	-3853	-1614	2107	-100	-1309	2169
	TC44-TU04	TU04	TPS	OA3H	-5763	-1725	2589	-142	-1179	2503
	TC44-TU04	TU04	TPS	OA2D	-4767	-715	1761	-135	-1261	2155
	TC44-TU04	TU04	TPS	OA1B	-5650	-1599	1800	**-92**	-1001	2449
	TC44-TU04	TU04	TPS	OA4F	-4879	-840	2551	**-185**	-1439	2209
	TC44-TU04	TU04	TPS	OA3B	-6249	-1602	2002	-122	-1056	**2514**
	TC44-TU04	TU04	TPS	G001	-4707	-1077	1943	-130	-1144	**2107**
	TC44-TU04	TU04	TPS	OA3G	-5940	-1403	2689	-164	-1211	2493
SET 2	TC44-TU04	TU04	TPS	EA2H	**-3072**	-2038	2792	-106	-1445	2161
	TC44-TU04	TU04	TPS	EA3D	**-7458**	-401	1558	-171	-995	2497
	TC44-TU04	TU04	TPS	EA2E	-5118	**-26**	2015	-189	-1335	2133
	TC44-TU04	TU04	TPS	EA3A	-5411	**-2413**	2336	-88	-1106	2525
	TC44-TU04	TU04	TPS	EA4G	-4056	-1325	**3230**	-190	**-1571**	2204
	TC44-TU04	TU04	TPS	EA1C	-6474	-1115	**1120**	-87	**-869**	2454
	TC44-TU04	TU04	TPS	EA2A	-3374	-2219	2138	-64	-1299	2182
	TC44-TU04	TU04	TPS	EA3H	-5109	-2232	2990	-130	-1252	2505
	TC44-TU04	TU04	TPS	EA2D	-5420	-207	1360	-147	-1188	2153
	TC44-TU04	TU04	TPS	EA1B	-5626	-1948	1443	**-52**	-915	2465
	TC44-TU04	TU04	TPS	EA4F	-4904	-491	2908	**-224**	-1525	2193
	TC44-TU04	TU04	TPS	EA3B	-6224	-1951	1645	-82	-970	**2531**
	TC44-TU04	TU04	TPS	EA2F	-4305	-488	2705	-194	-1470	**2127**
	TC44-TU04	TU04	TPS	EA3G	-5495	-1515	3226	-184	-1323	2482
	TC44-TU04	TU04	TPS	EA2C	-5035	-924	1125	-93	-1118	2176

Table 7.4- Maximum loads at TP-Topside interface – Support TU04

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7.2 LOADS AT TP-STAIRS

The maximum internal forces of structural members at TP-stairs interface are in according to the Secondary Structure Design Report, /23/.

The following figure shows the support joints.

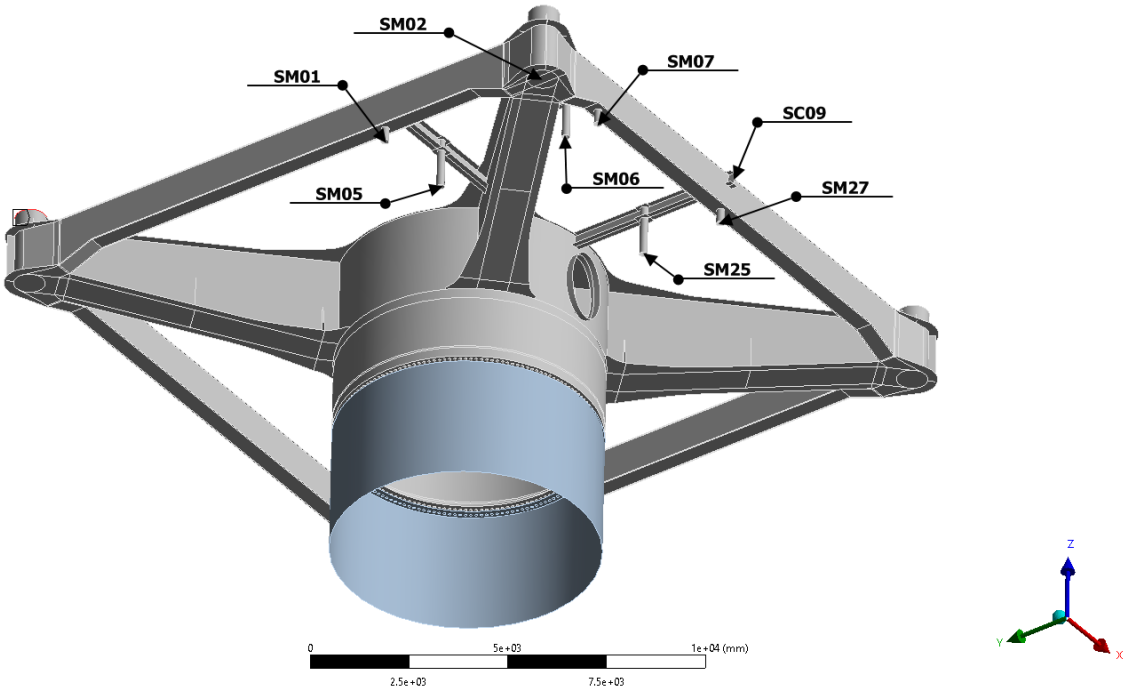


Figure 7.2 – TP-Stair Joints

	MEMBER	MEMBER END	GROUP	LOAD CASE	Fx [kN]	Fy [kN]	Fz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
ALL LC	SM01-SC01	SM01	ST5	EQYP	**43**	0	11	2	-3	0
	SM01-SC01	SM01	ST5	EN3F	**-62**	2	-6	1	1	-2
	SM01-SC01	SM01	ST5	EN3E	-44	**3**	0	4	0	-2
	SM01-SC01	SM01	ST5	WEXA	15	**-1**	2	-3	-1	0
	SM01-SC01	SM01	ST5	EN3C	23	1	**15**	2	-3	-2
	SM01-SC01	SM01	ST5	E44G	-51	1	**-7**	-3	1	-1
	SM01-SC01	SM01	ST5	WPER	0	0	2	0	-1	0
	SM01-SC01	SM01	ST5	TTPX	0	0	0	0	0	0
	SM01-SC01	SM01	ST5	WFLO	-1	0	0	0	0	0
	SM01-SC01	SM01	ST5	E44D	-6	2	9	**5**	-2	-2
	SM01-SC01	SM01	ST5	EN3H	-22	0	-1	**-5**	-1	-1
	SM01-SC01	SM01	ST5	EQZN	6	-1	-3	0	**1**	**1**
	SM01-SC01	SM01	ST5	EN3B	32	0	14	-2	**-3**	-1
	SM01-SC01	SM01	ST5	ON2E	-35	2	4	2	-1	**-2**
	SM01-SC01	SM01	ST5	EN3A	14	-1	8	-5	-2	-1
	SM01-SC01	SM01	ST5	AOPB	4	0	1	0	0	0

	MEMBER	MEMBER END	GROUP	LOAD CASE	Fx [kN]	Fy [kN]	Fz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
ALL LC	SM05-SC02	SM05	ST5	EN3G	**60**	0	**-20**	2	**4**	0
	SM05-SC02	SM05	ST5	EQYP	**-37**	0	**16**	-2	**-4**	0
	SM05-SC02	SM05	ST5	E44A	18	**2**	0	1	-1	**-4**
	SM05-SC02	SM05	ST5	EN3E	39	**-2**	-10	-1	2	**4**
	SM05-SC02	SM05	ST5	TTPX	0	0	0	0	0	0
	SM05-SC02	SM05	ST5	E44G	56	0	-19	**2**	4	0
	SM05-SC02	SM05	ST5	EN3C	2	0	9	**-3**	-4	0
	SM05-SC02	SM05	ST5	WPER	12	0	-1	0	0	0
	SM05-SC02	SM05	ST5	WFLO	1	0	0	0	0	0
	SM05-SC02	SM05	ST5	EN3F	57	-1	-19	1	4	3

	MEMBER	MEMBER END	GROUP	LOAD CASE	Fx [kN]	Fy [kN]	Fz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
ALL LC	SM06-SC04	SM06	ST5	EQXP	**21**	13	0	1	0	-6
	SM06-SC04	SM06	ST5	EN3D	**-48**	**-24**	0	-5	0	**10**
	SM06-SC04	SM06	ST5	E44H	13	**20**	0	5	0	**-10**
	SM06-SC04	SM06	ST5	TTPY	-1	-1	**0**	0	**0**	0
	SM06-SC04	SM06	ST5	EN3C	-41	-18	**0**	-7	0	7
	SM06-SC04	SM06	ST5	AOPB	0	0	0	0	0	0
	SM06-SC04	SM06	ST5	EN3A	0	13	0	1	0	-7
	SM06-SC04	SM06	ST5	WFLO	-1	0	0	0	0	0
	SM06-SC04	SM06	ST5	EN3G	2	13	0	**7**	0	-7
	SM06-SC04	SM06	ST5	E44C	-38	-17	0	**-7**	0	7
	SM06-SC04	SM06	ST5	EQYP	-12	-9	0	-4	**0**	4

	MEMBER	MEMBER END	GROUP	LOAD CASE	Fx [kN]	Fy [kN]	Fz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
ALL LC	SM07-SC05	SM07	ST5	ON2D	**165**	-13	**4**	-6	-7	-4
	SM07-SC05	SM07	ST5	EQZN	**-49**	-2	**-1**	0	1	3
	SM07-SC05	SM07	ST5	EN3H	103	**40**	3	12	-2	**-14**
	SM07-SC05	SM07	ST5	E44D	106	**-33**	3	-12	-6	3
	SM07-SC05	SM07	ST5	AOPB	0	0	0	0	0	0
	SM07-SC05	SM07	ST5	TTPY	0	-1	0	-1	0	0
	SM07-SC05	SM07	ST5	EN3G	104	28	3	**16**	-1	-11
	SM07-SC05	SM07	ST5	E44C	105	-21	3	**-15**	-7	0
	SM07-SC05	SM07	ST5	WEXG	-6	15	0	10	**2**	-3
	SM07-SC05	SM07	ST5	ON2C	165	-7	4	-8	**-7**	-6
	SM07-SC05	SM07	ST5	WEXD	6	-22	0	-7	-2	**5**
	SM07-SC05	SM07	ST5	EN3C	122	-20	3	-15	-7	-1
	SM07-SC05	SM07	ST5	TTNX	1	-5	0	0	0	2
	SM07-SC05	SM07	ST5	WPER	11	0	0	0	0	0

	MEMBER	MEMBER END	GROUP	LOAD CASE	Fx [kN]	Fy [kN]	Fz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
ALL LC	SC08-SM25	SM25	ST5	EQZN	**12**	**19**	0	0	0	**7**
	SC08-SM25	SM25	ST5	ON2C	**-39**	**-62**	0	-5	0	**-23**
	SC08-SM25	SM25	ST5	E44C	-29	-46	**1**	-9	0	-17
	SC08-SM25	SM25	ST5	EN3G	-18	-28	**-1**	8	**0**	-10
	SC08-SM25	SM25	ST5	AOPB	0	0	0	0	0	0
	SC08-SM25	SM25	ST5	E44G	-14	-21	-1	**8**	0	-8
	SC08-SM25	SM25	ST5	EN3C	-32	-52	1	**-9**	0	-19
	SC08-SM25	SM25	ST5	WEXC	-5	-8	0	-5	**0**	-3
	SC08-SM25	SM25	ST5	AOPX	0	1	0	0	0	0
	SC08-SM25	SM25	ST5	TTNX	0	0	0	0	0	0

	MEMBER	MEMBER END	GROUP	LOAD CASE	Fx [kN]	Fy [kN]	Fz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
ALL LC	SC09-SM27	SM27	ST5	ON2D	**209**	-22	10	3	9	-3
	SC09-SM27	SM27	ST5	EQZN	**-69**	**7**	-3	-1	-4	1
	SC09-SM27	SM27	ST5	ON2C	207	**-23**	9	2	7	-2
	SC09-SM27	SM27	ST5	ON2G	198	-18	**15**	4	24	-1
	SC09-SM27	SM27	ST5	EQYP	5	-4	**-5**	-1	**-12**	-1
	SC09-SM27	SM27	ST5	AOPY	0	0	0	0	-1	0
	SC09-SM27	SM27	ST5	TTNX	0	1	0	0	0	0
	SC09-SM27	SM27	ST5	ON2B	203	-23	10	1	9	-2
	SC09-SM27	SM27	ST5	AOPX	-1	0	0	0	0	0
	SC09-SM27	SM27	ST5	EN3F	144	-10	13	**6**	23	-1
	SC09-SM27	SM27	ST5	WEXB	1	-3	-3	**-2**	-7	0
	SC09-SM27	SM27	ST5	EN3G	135	-9	15	4	**28**	0
	SC09-SM27	SM27	ST5	EQXP	-15	3	0	-2	0	**1**
	SC09-SM27	SM27	ST5	EN3D	157	-18	4	3	-1	**-3**
	SC09-SM27	SM27	ST5	TTPY	1	0	-1	0	-1	0

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	MEMBER	MEMBER END	GROUP	LOAD CASE	Fx [kN]	Fy [kN]	Fz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
ALL LC	SC09-SM35	SC09	HA3	ON2A	**177**	-7	20	0	-33	5
	SC09-SM35	SC09	HA3	EQZN	**-51**	2	**-8**	0	**11**	-2
	SC09-SM35	SC09	HA3	E44G	71	**22**	10	0	-15	**-31**
	SC09-SM35	SC09	HA3	EN3C	123	**-33**	17	0	-27	**40**
	SC09-SM35	SC09	HA3	ON2C	157	-22	**21**	**0**	-34	25
	SC09-SM35	SC09	HA3	AOPD	-1	-1	0	0	0	1
	SC09-SM35	SC09	HA3	AOPX	2	0	0	0	0	0
	SC09-SM35	SC09	HA3	EQXP	23	2	0	**0**	-1	-3
	SC09-SM35	SC09	HA3	ON2B	175	-17	21	0	**-34**	19

JOINT	Rx [kN]				Ry [kN]				Rz [kN]			
	MAX	LCOND	MIN	LCOND	MAX	LCOND	MIN	LCOND	MAX	LCOND	MIN	LCOND
SM02	125	EN3F	-118	E44B	179	E44G	-180	EN3C	205	ON2E	-66	EQZN

Table 7.5- Maximum loads at TP-Stairs interface – Supports

8 MATERIALS

8.1 STRUCTURAL STEEL – LINEAR PROPERTIES

For the structural analyses, steel types and grades to be used for the platform structures are summarised in Table 8.1 and specified in Ref. /20/. 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	-40	DC1-I-420-40_Z	2, 7, 8, 11, 12, 17, 18
							t > 50	-40		
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	0	NA	-
							12 < t <= 25	-20	DC2-II-420-20	2, 7, 8, 11 17 for t > 40mm
							25 < t <= 50	-40	DC2-II-420-40	
							t > 50	-40		
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	0	DC3-II-355-0 / DC3-II-X52-0	2, 7, 8 11 for plate 17 for t > 40mm
							12 < t <= 25	-20	DC3-II-355-20 / DC3-II-X52-20	
							25 < t <= 50	-40	DC3-II-355-40 / DC3-II-X52-40	
							t > 50	-40		
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	0	DC4-III-355-0 / DC4-III-X52-0 / DC4-III-X60-0	-
							12 < t <= 25	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	10	DC5-IV-235-10 / DC5-IV-275-10 / DC5-IV-355-10 / DC5-IV-GRB-10	-
							12 < t <= 25	10		

Table 8.1 - Material Selection, Ref /20/

Mechanical properties for structural materials are presented in Table 8.2, Table 8-3 and Table 8.4.

- Young's Modulus = 205000 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

8.2 STRUCTURAL STEEL – NON-LINEAR PROPERTIES

For non-linear FEAs, the assumed constitutive law for steel is according to DNV-RP-C208, Ref. /13/.

The assumed constitutive law for both materials is the one proposed by DNV-RP-C208 (Ref./13/) for S420 steel:

$$\sigma = K\left(\varepsilon_p + \left(\frac{\sigma_{yield\ 2}}{K}\right)^{\frac{1}{n}} - \varepsilon_{p_y2}\right)^n \quad \text{for} \quad \varepsilon_p > \varepsilon_{p_y2}$$

Parameters of the previous equations for S420 are reported in Multilinear Isotropic Hardening constitutive law.

S420			
Thickness [mm]	*t≤ 16*	*16< t ≤ 40*	*40< t ≤ 63*
E [MPa]	210000	210000	210000
σ_{prop} **[MPa]**	378.7	360.6	351.6
σ_{yield} **[MPa]**	422.5	402.4	392.3
σ_{yield2} **[MPa]**	426.3	406	395.9
ε_{p_y1}	0.004	0.004	0.004
ε_{p_y2}	0.012	0.012	0.012
K[MPa]	738	703	686
n	0.14	0.14	0.14

Table 8.5 – S420 steel constitutive law parameters

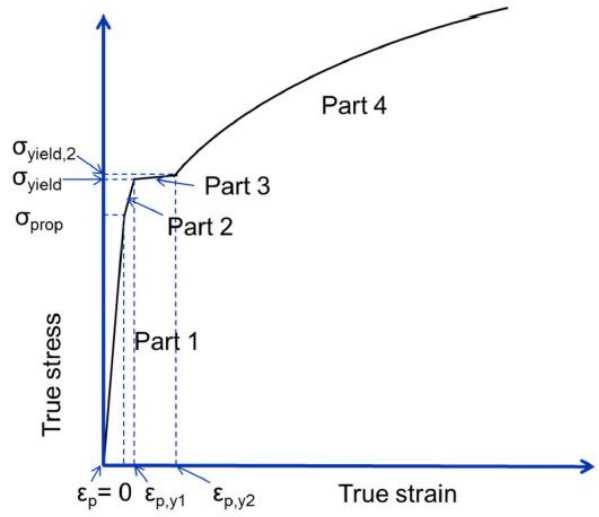


Figure 8.1 – Steel constitutive law according to DNV-RP-C208

9 FE MODEL

The FE model of the Transition Piece is created within Ansys environment.

The built model does not include fabrication and installation tolerances.

The Transition Piece is modelled in according to the structural drawings. Plates elements are used. The TP is connected to the monopile through bolts which are modelled using beam elements. The resulting model is shown in the figure below.

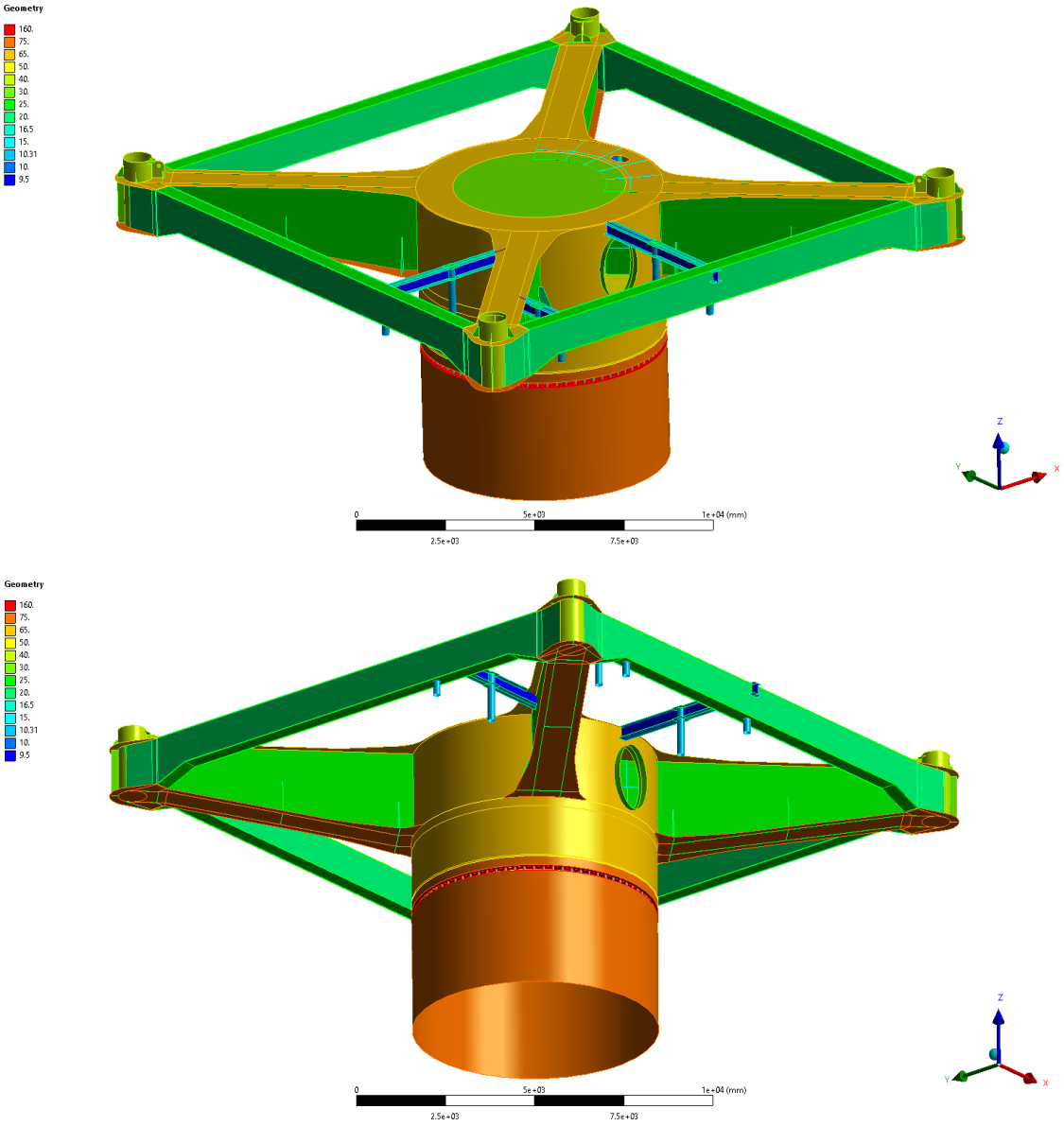


Figure 9.1 – Transition Piece - FE Model

9.1 MESH

9.1.1 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.

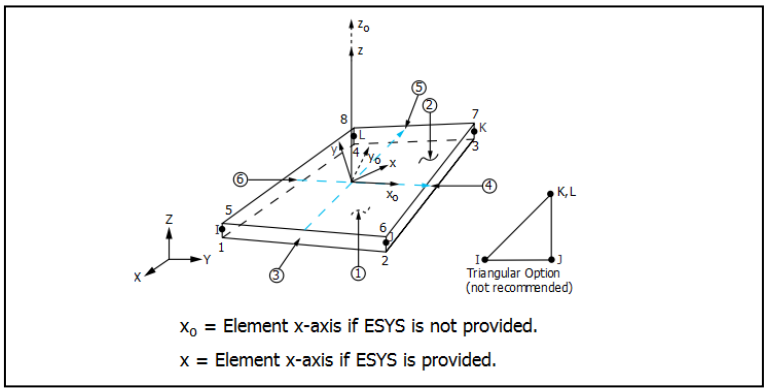


Figure 9.2 – Mesh elements – SHELL181

- *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.

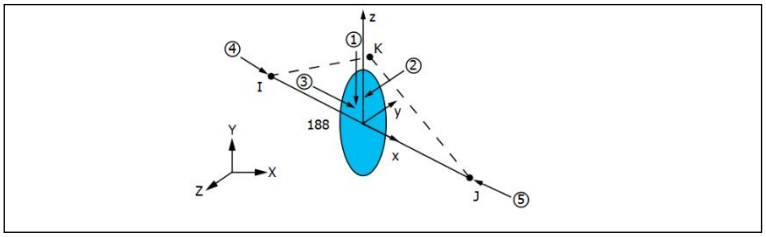


Figure 9.3 – Mesh elements – BEAM188

- *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.

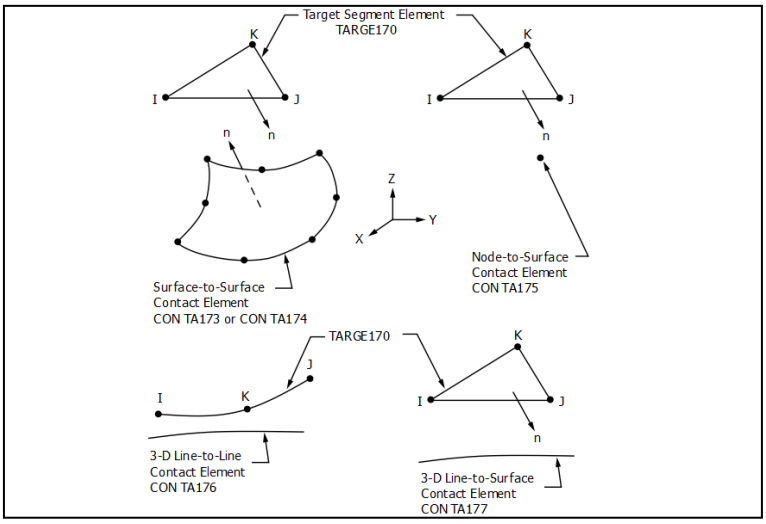


Figure 9.4 – Mesh elements – TARGE170

- *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.

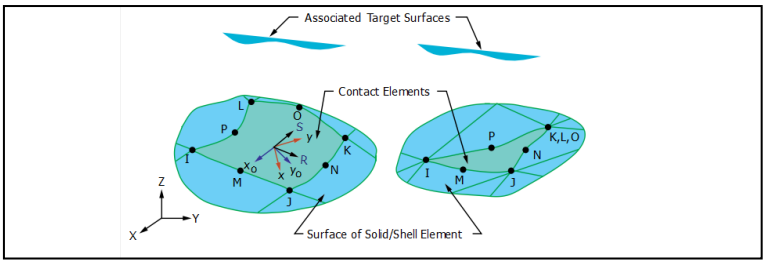


Figure 9.5 – Mesh elements – CONTA174

9.1.2 Model Mesh

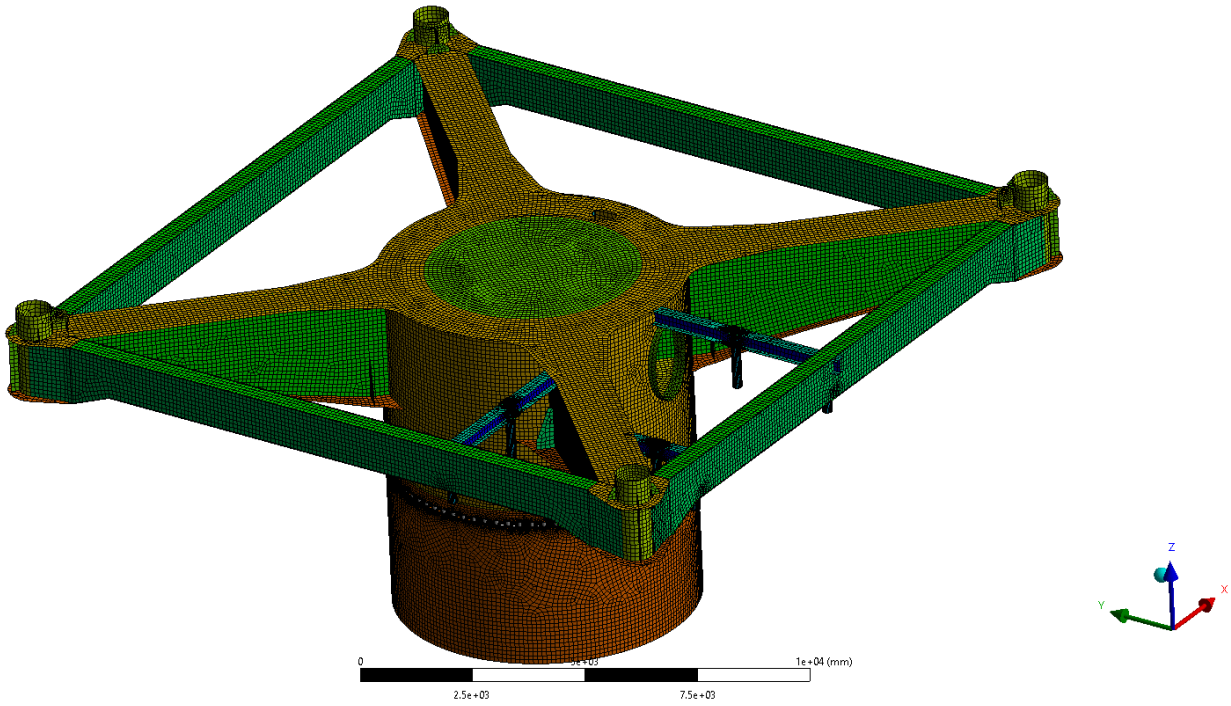
The table below reports the main mesh data characterizing the model.

MESH STATISTICS	NUMBER
Nodes	162108
Elements	162598

Table 9.1 – 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.



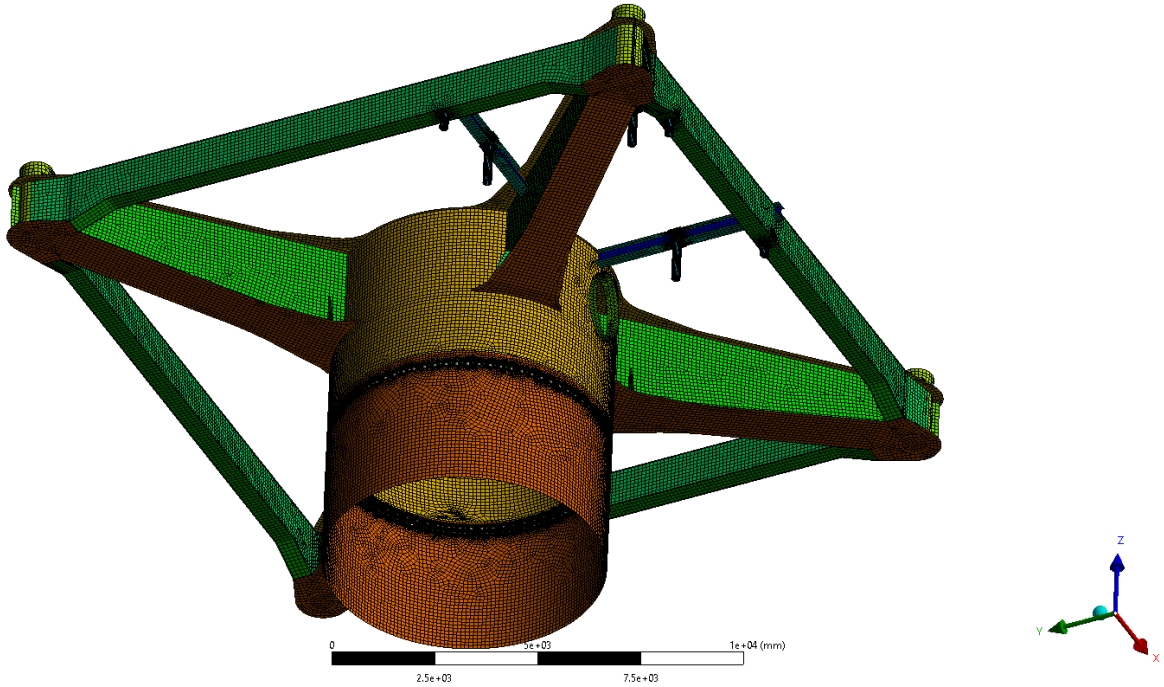
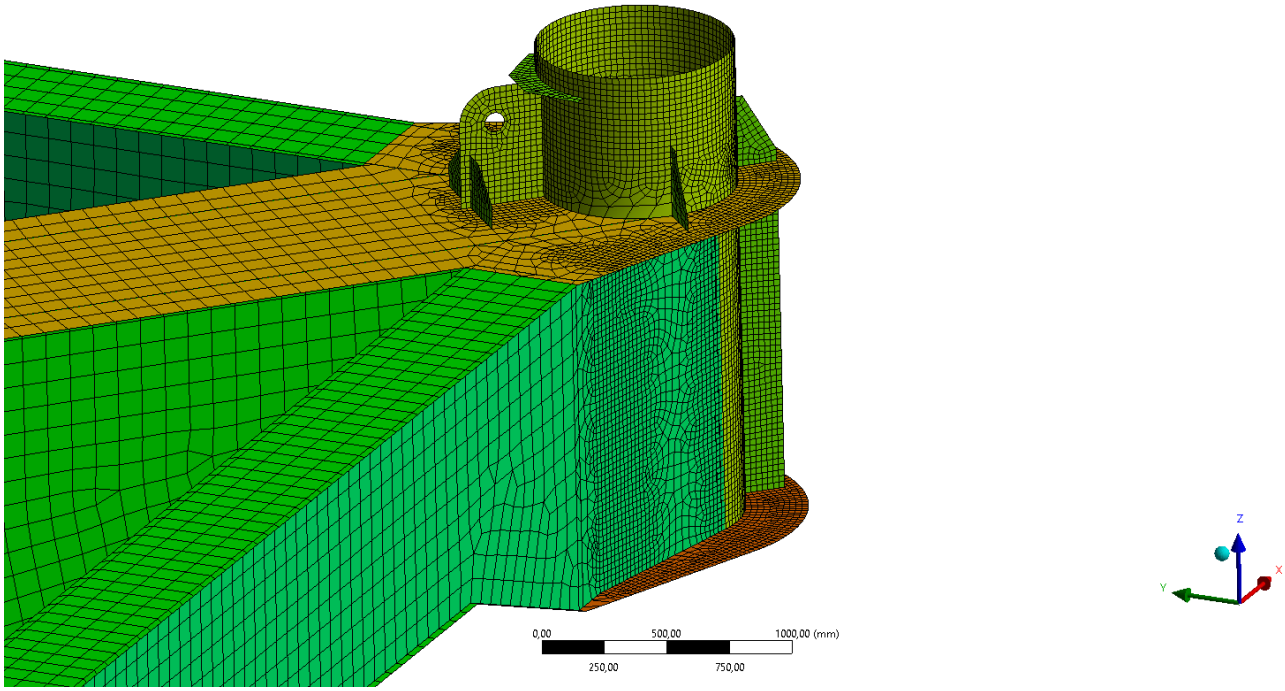


Figure 9.6: – Model Mesh



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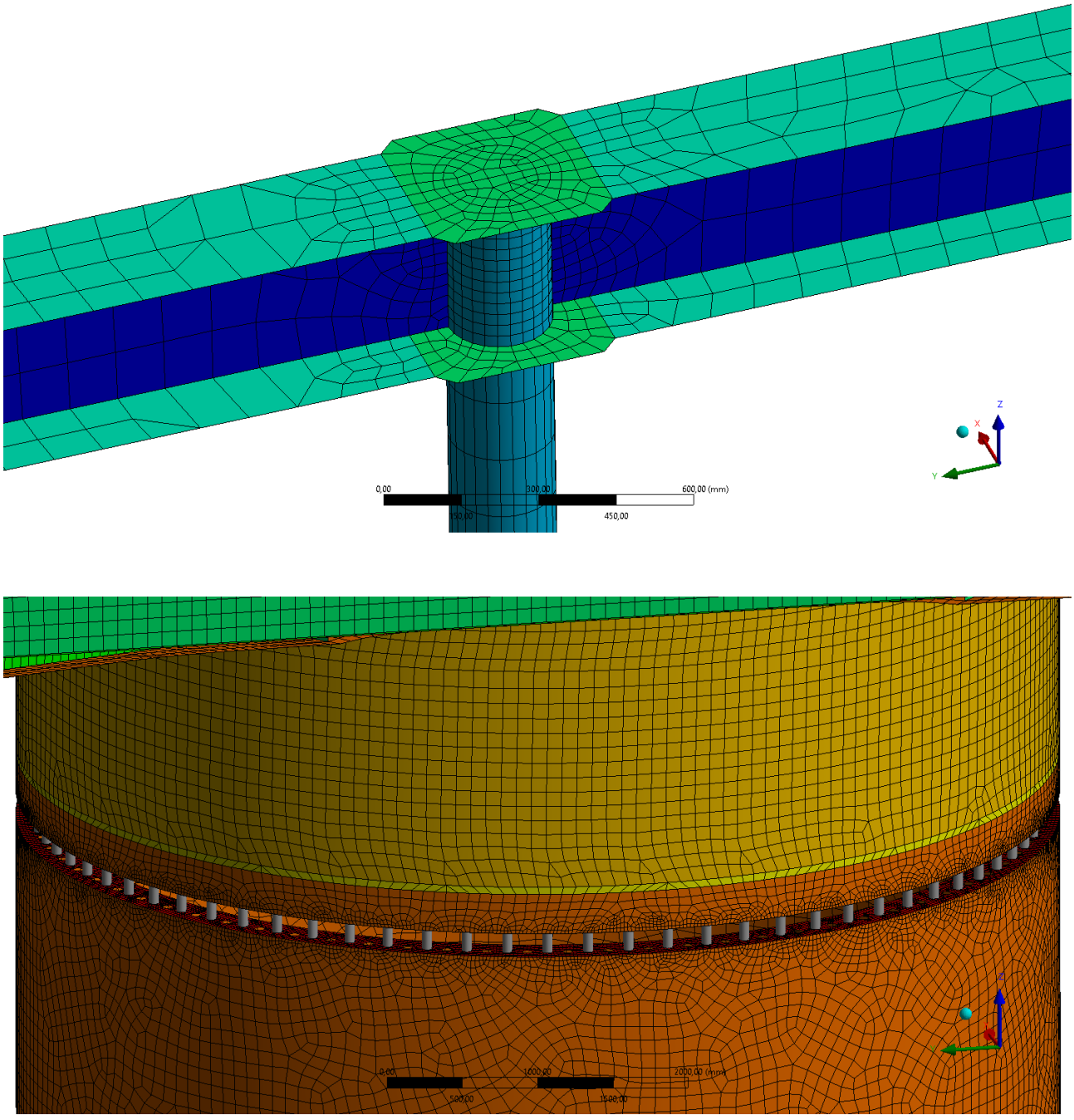


Figure 9.7: – Model refinements – Detail view

9.2 REMOTE POINTS & LOCAL REFERENCE SYSTEM

To correctly apply the loads a series of Remote Points and the corresponding Local Coordinate Systems (LCS) are defined at each support and load points.

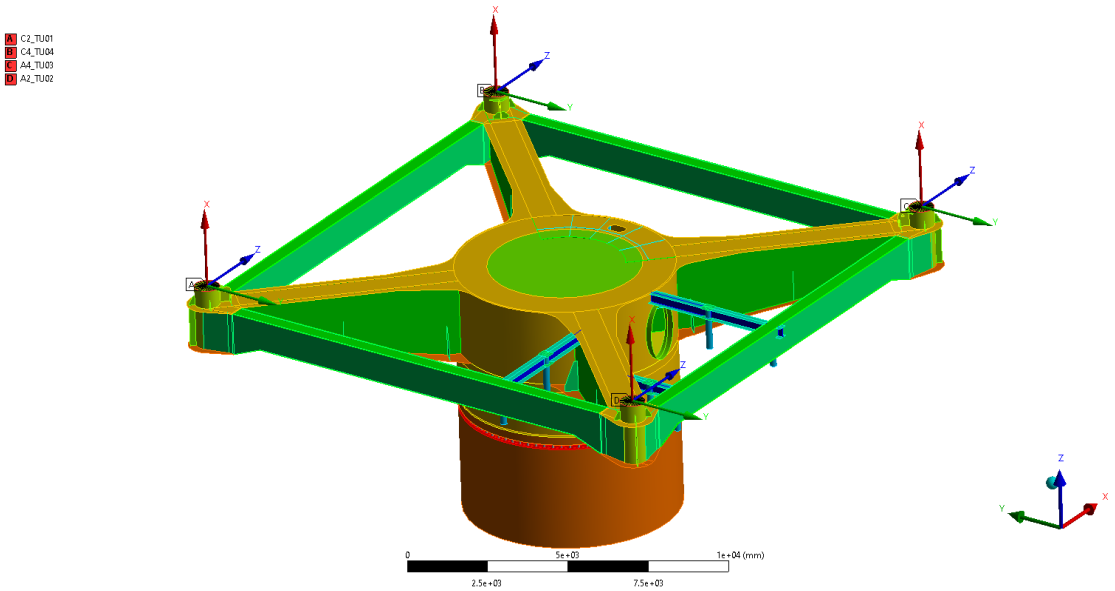
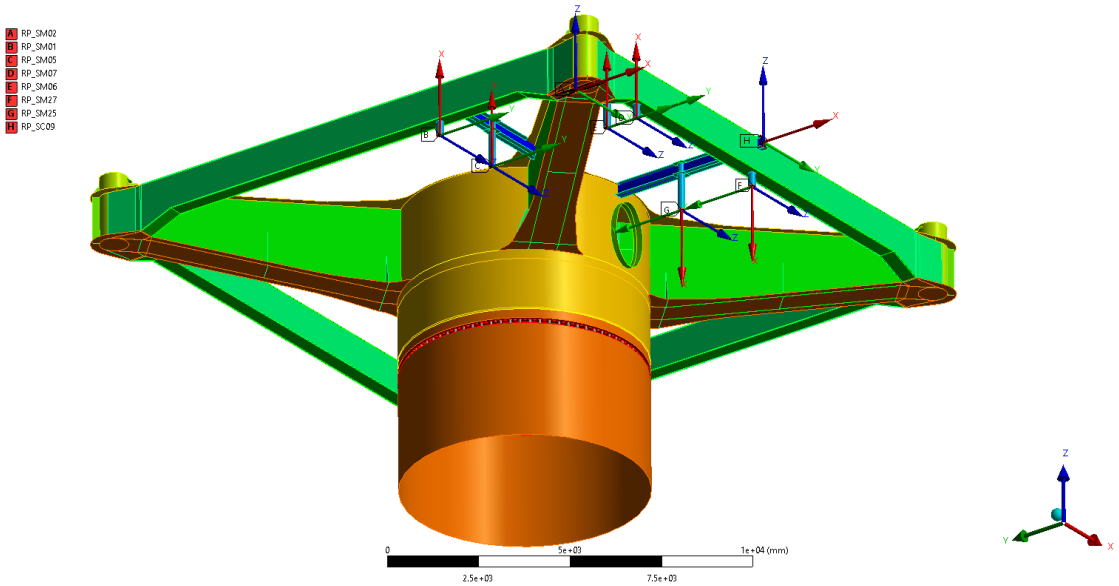


Figure 9.8 – BLPH Topside to TP interface – Remote Points and Local Coordinate System



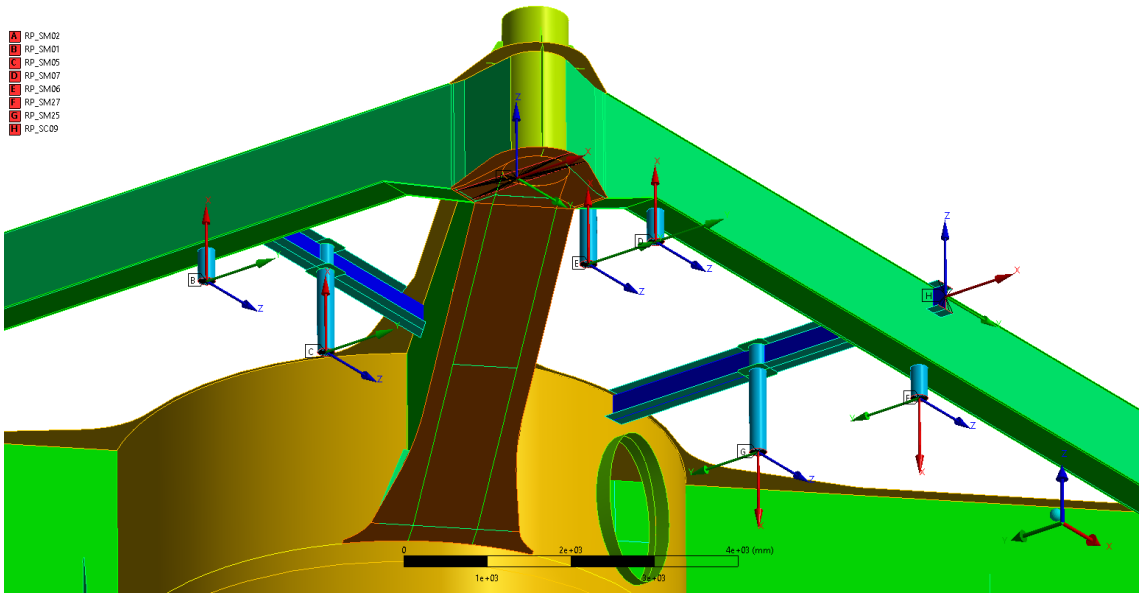


Figure 9.9 –TP to Stairs interface – Remote Points and Local Coordinate System

10 LOADS

10.1 STRUCTURAL SELF-WEIGHT

The structural self-weight of the modeled BLPH structures is automatically evaluated by the ANSYS software according to the geometry and the defined thicknesses. The density of steel is increased by a factor equal to 1.3

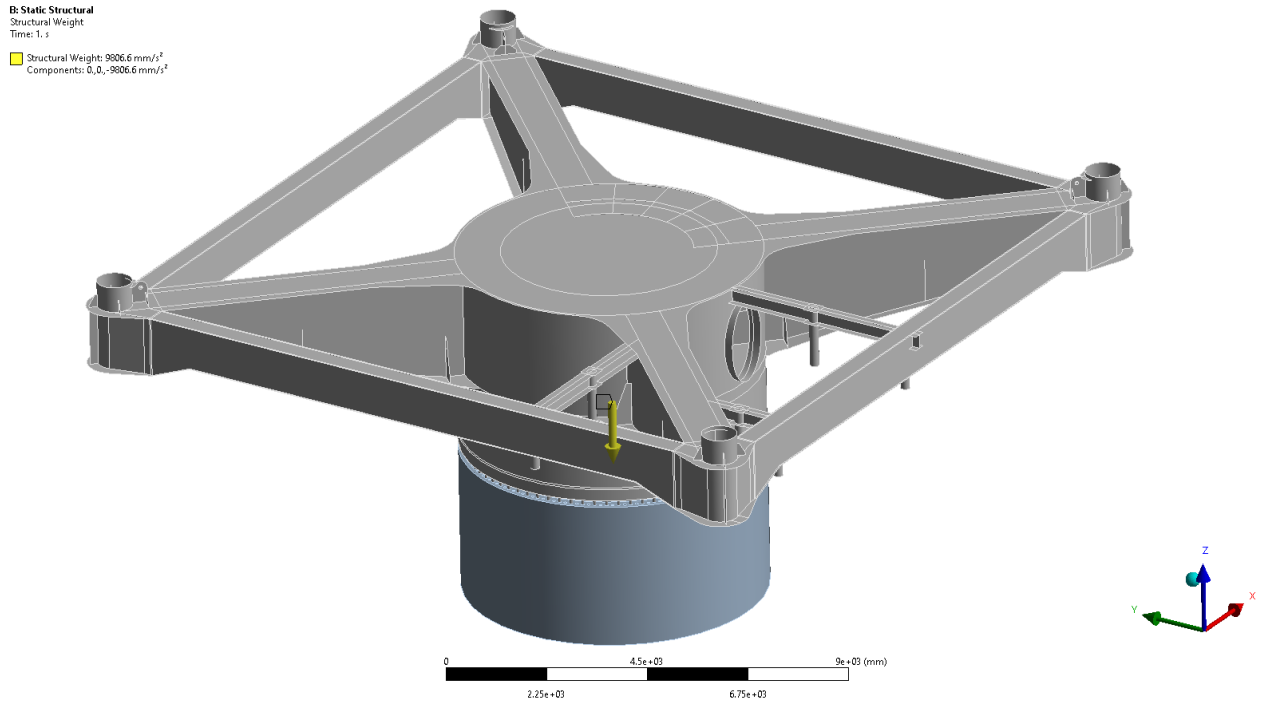


Figure 10.1 – TP FE model – Structural Self-Weight

10.2 LOADS FROM BLPH TOPSIDE

The TP is checked applying at the same time the maximum design loads on each support. Loads are applied on remote points properly defined at the barycentre of the supports end sections.

The following table summarizes the applied force and moments applied on proper remote points.

SUPPORT JOINT	NOTE	FORCES [kN]			MOMENTS [kNm]		
TU01	Topside-TP Interface – Column C2	-7043	-2260	-3194	102	1634	2376
TU02	Topside-TP Interface – Column A2	-7368	2241	-3345	-252	1745	-2282
TU03	Topside-TP Interface – Column A4	-7777	2429	3399	208	-1544	-2429
TU04	Topside-TP Interface – Column C4	-7458	-2413	3230	-224	-1571	2531
SM01	TP-Stairs Interface – El.+20310 TOS	-62	3	15	-5	-3	-2
SM02	TP-Stairs Interface – Welds at El.+20310 TOS	125	-180	205	-	-	-
SM05	TP-Stairs Interface – El.+20310 TOS	60	-2	-20	-3	-4	-5
SM06	TP-Stairs Interface – El.+20310 TOS	-48	-24	-	-7	-	-10
SM07	TP-Stairs Interface – El.+20310 TOS	165	40	4	16	-7	-14
SM25	TP-Stairs Interface – El.+20310 TOS	-39	-62	-1	-9	-	-23
SM27	TP-Stairs Interface – El.+20310 TOS	209	-23	15	6	28	-3
SC09	TP-Stairs Interface – Beam at El.+21710 TOS	177	-33	21	-	-34	40

Table 10.1 – TP FE model – Applied Loads

The following figures show the applied loads on the different support columns (Topside-TP and TP-stairs interfaces).

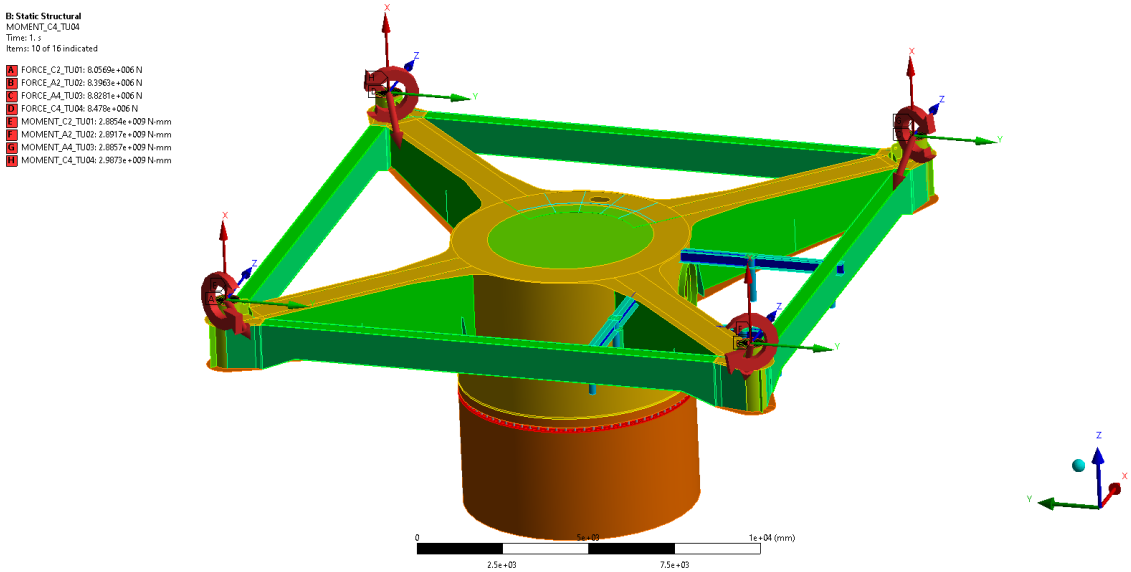


Figure 10.2 – TP FE model – Applied load at Topside-TP interface

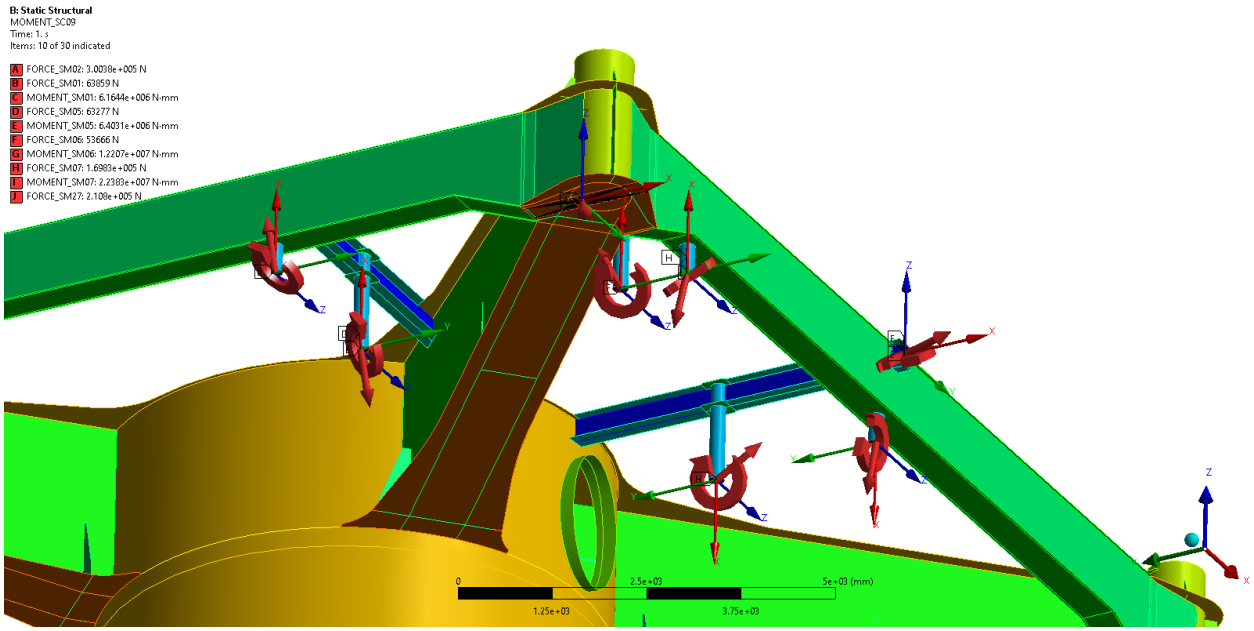


Figure 10.3 – TP FE model – Applied load at TP-stairs interface

10.3 LIVE LOADS

A live load equal to 5.0kN/m² is applied as pressure on the surface of the upper plates as shown by the following figure.

A coefficient of 1.5 is applied to the pressure value to account for ULS load combination factor.

The applied live loads are shown in the following figure.

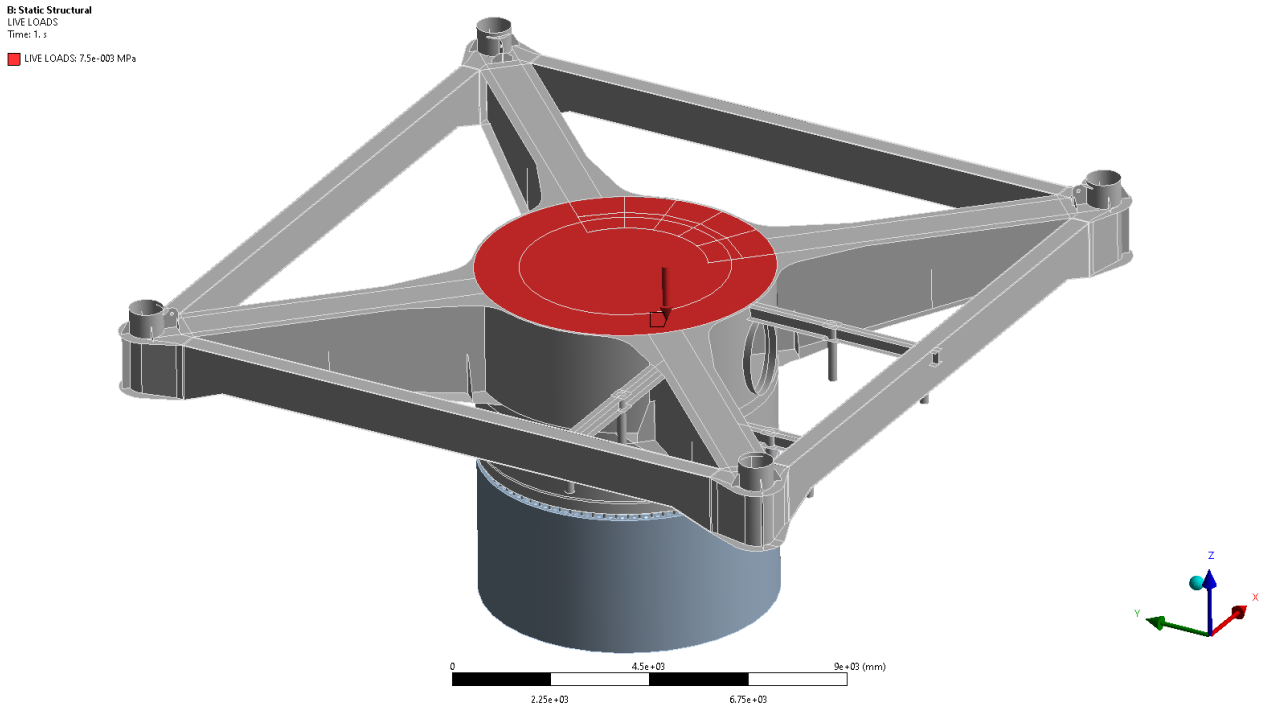


Figure 10.4 – TP FE model – Live loads

10.4 WASTE WATER TANK LOADS

The loads acting from on the internal surfaces of the waste water tank are added on the FE analysis. The tank is considered completely full of a fluid characterized by a density of 1tons/m³. The loads are applied as hydrostatic pressure acting normally to the surfaces with a triangular distribution on vertical plates and a constant value on the horizontal ones. A coefficient of 1.5 is applied on density to account the ULS load combination factor.

The following figures show the applied loads.

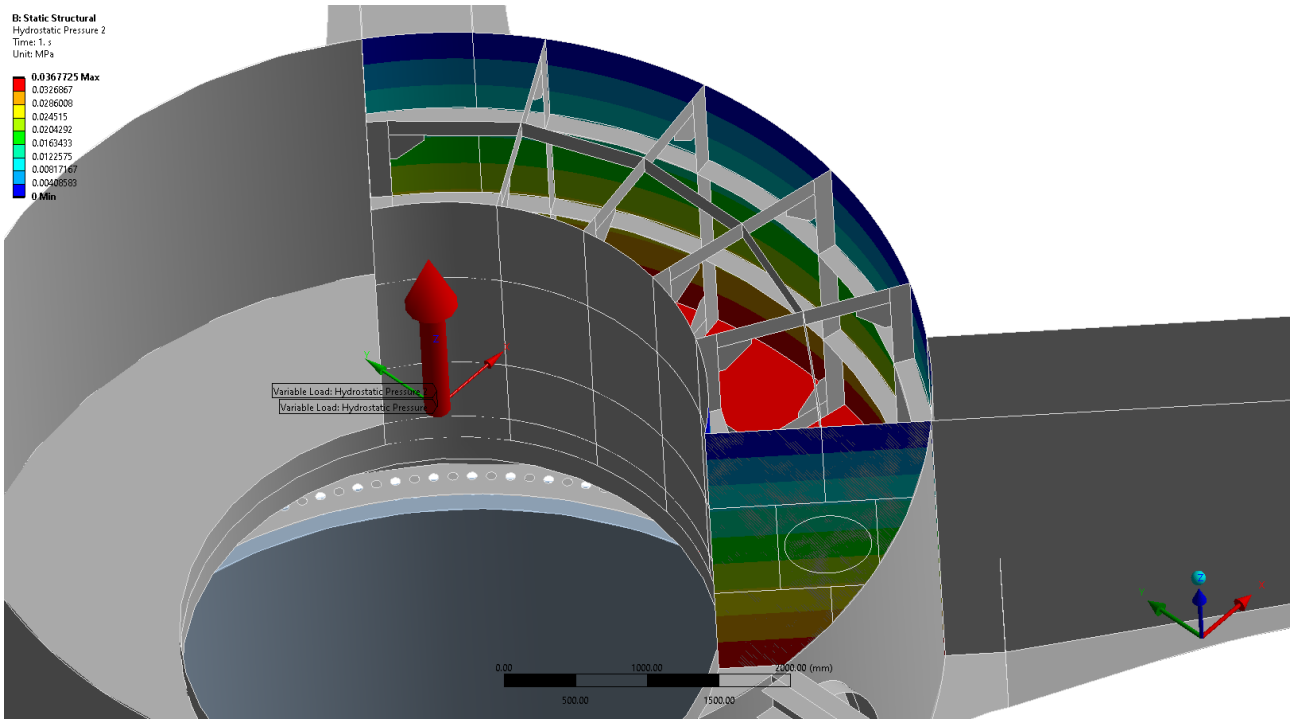


Figure 10.5 – TP FE model – Hydrostatic pressure

11 CONSTRAINT

External constraint is applied at the bottom edge of the modelled portion of monopile using proper defined "remote point". All translations and rotation are restrained.

The applied restraint is displayed in the figure below.

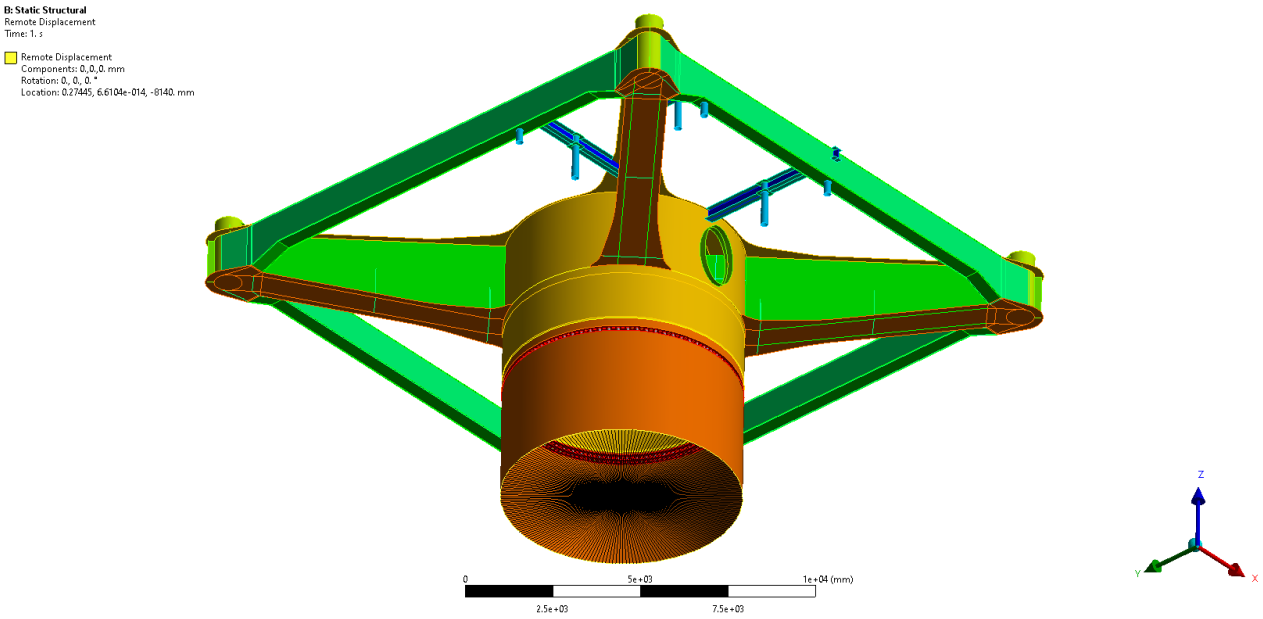


Figure 11.1 – TP FE model – Applied Restraint

12 CONTACTS

The TP framing is connected to the bottom modelled part of monopile through the following contact type:

- *Frictional*: the two contacting geometries can carry shear stresses up to a certain magnitude across their interface before they start sliding relative to each other. This state is known as "sticking". The model defines an equivalent shear stress at which sliding on the geometry begins as a fraction of the contact pressure. Once the shear stress is exceeded, the two geometries will slide relative to each other. The applied coefficient of friction corresponds to 0.20 which is a safe value of dynamic friction provided by literature and standards. Used to simulate the connection between the two opposite flange surfaces.

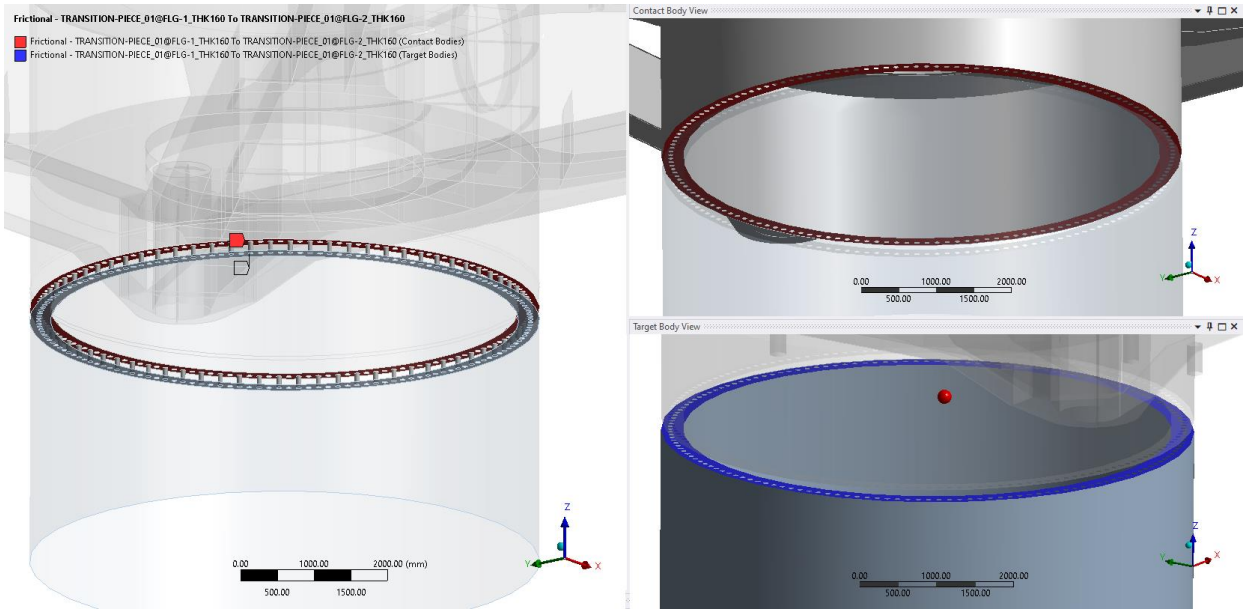


Figure 12.1 – TP-MP frictional interface

- *Bolts*: modeled as beam element which section properties properly defined. Bolts ends are connected to the hole edges modeled on the two opposite connected flanges.

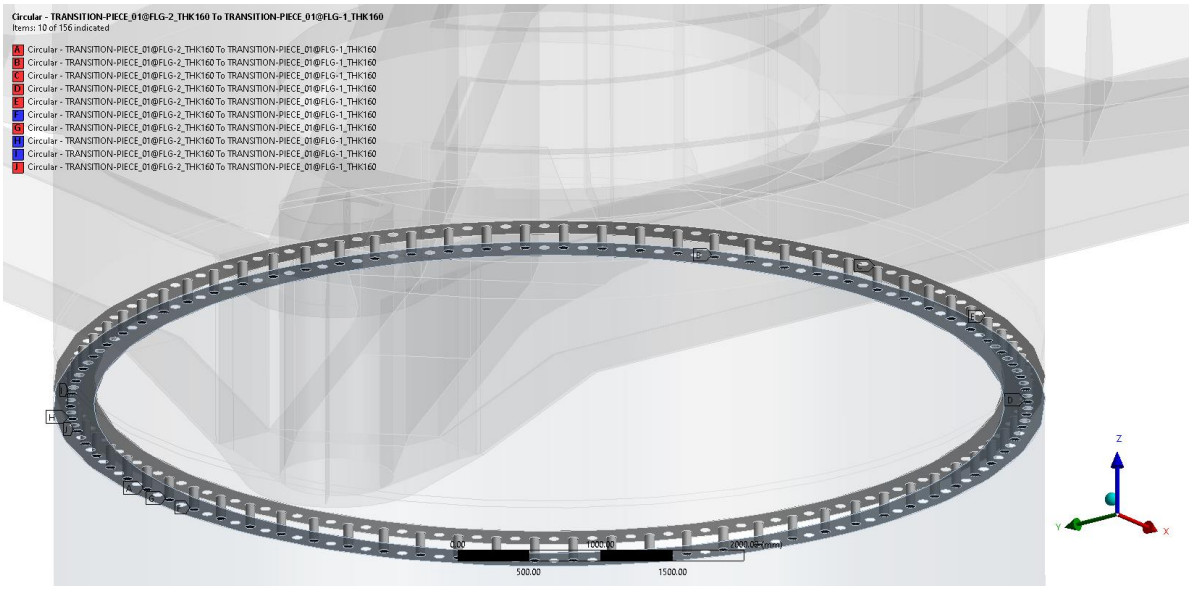


Figure 12.2 – TP-MP Bolts

13 DESIGN CRITERIA AND REQUIREMENTS

13.1 GENERAL

Structures in SOW is 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.
Member forces and moments derived from the global analyses are used for checking member strength and stability, and joint strength.

The general requirement of ISO code, ref./6/, is that, for the structure as a whole and for each component, the following is satisfied:

$$R_d = \frac{R_k}{\gamma_M} > \gamma_F F_r = F_d$$

Where:

- R_d is the design resistance;
- R_k is the characteristic resistance;
- γ_M is the partial resistance factor reported in section 13.2;
- F_d is the design value of action;
- F_r is the characteristic value of action;
- γ_F is the partial action factor.

Design according to the provisions for load and resistance factor design (LRFD) of EC3, ref. /8/, shall be performed in accordance with following equation:

$$R_u \leq \phi R_n$$

Where:

- R_u = required strength using LRFD load combinations
- R_n = nominal strength
- ϕ = resistance factor reported in Sec.13.2
- ϕ Rn = design strength.

13.2 PARTIAL RESISTANCE FACTORS

13.2.1 Partial Resistance Factors for Tubular Sections:

The partial resistance factors for tubular sections from ISO 19902, Ref./6/, are listed below.

Resistance factor	Value	Definition
$\gamma_{R,t}$	1.05	Partial resistance factor for axial tensile strength
$\gamma_{R,c}$	1.18	Partial resistance factor for axial compressive strength
$\gamma_{R,b}$	1.05	Partial resistance factor for bending strength
$\gamma_{R,v}$	1.05	Partial resistance factor for shear strength
$\gamma_{R,h}$	1.25	Partial resistance factor for hoop buckling strength

Table 13.1- Resistance Factors for Tubular Sections

13.2.2 Partial Resistance Factors for Non-tubular Sections

The partial resistance factors for non-tubular sections from Eurocode 3, Ref./8/, are listed below.

Resistance factor	Value	Definition
Resistance of members and cross sections		
γ_{M0}	1.00	Cross-section resistance to excessive yield strain including local buckling
γ_{M1}	1.00	Resistance of unstable elements measured during element inspection
γ_{M2}	1.25	Tensile cross-section resistance to mechanical breakdown
Resistance of connections		
γ_{M2}	1.25	Bolts, rivets, pins, welds and slabs on supporting surface
γ_{M3}	1.25	Sliding resistance at Ultimate Limit State Category C
$\gamma_{M3,SER}$	1.10	Sliding resistance at Serviceability Limit State
γ_{M4}	1.10	Injection bolt collapse resistance
γ_{M5}	1.10	Resistance of connections in open lattice trusses
$\gamma_{M6,SER}$	1.00	Resistance of pins at Serviceability Limit State
γ_{M7}	1.10	Preload of high strength bolts

Table 13.2- Resistance for Non Tubular Section

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13.3 ACCEPTANCE CRITERIA

FE checks are performed comparing the resulting Von Mises stresses for each analysis with the allowable stresses defined as per Eurocode, Ref./8/, and ISO 19902, Ref./6/. Allowable stresses in terms of ultimate strength (LRFD) are defined using the material strengths listed in Sec.8.1 and the partial resistance factors listed in Sec.13.2:

$\sigma_{VM} \leq \sigma_{adm} = F_Y/\gamma$

Being:

- σ_{VM} = Von Mises Stress
- F_y = Material Yielding Stress
- γ = Partial resisting factor

Stresses greater than the admissible limits are accepted up to the material yield strength F_y, provided that such stresses remain confined to small superficial areas (2tx2t, being t the thickness of the plate considered), thus demonstrating that the corresponding resisting section is not significantly affected.

In the areas where stress checks are not satisfied, plastic checks are performed.

The total strain must fulfill the criterium according to EC3-1-5 (Ref./9/) and must be lower than 5%:

$\varepsilon_t = \leq \varepsilon_{adm} = 0.05$ mm/mm

Being:

- ε_t = Total Strain (elastic + plastic)

The fulfilment of one of the two checks (VM stress, strain) guarantees the structural integrity of the considered joint.

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14 RESULTS

The TP framing is checked for the most critical in-service loads acting on each support as reported in previous Section 10.

The FE results are evaluated in terms of:

- Von-Mises stress
- Total strains (elastic plus strain)
- Buckling Resistance

14.1 VON-MISES STRESS

In the following figures, the Von Mises stresses for the TP structure are plotted.

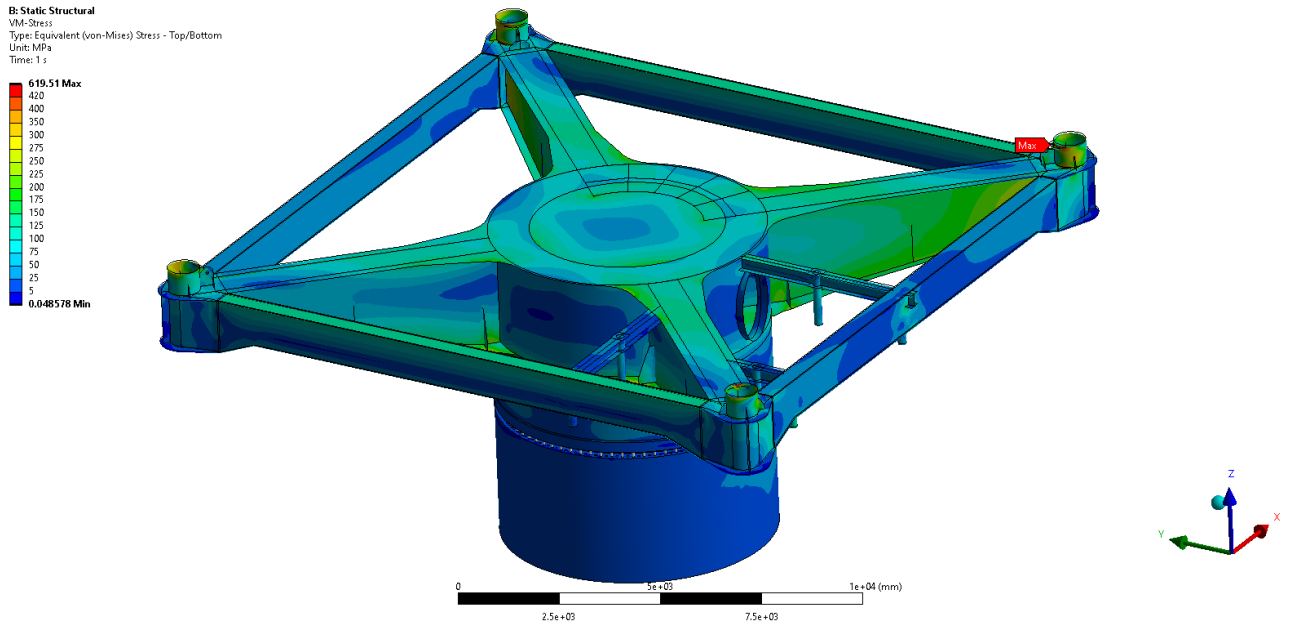


Figure 14.1 – TP FE model – VM Stresses

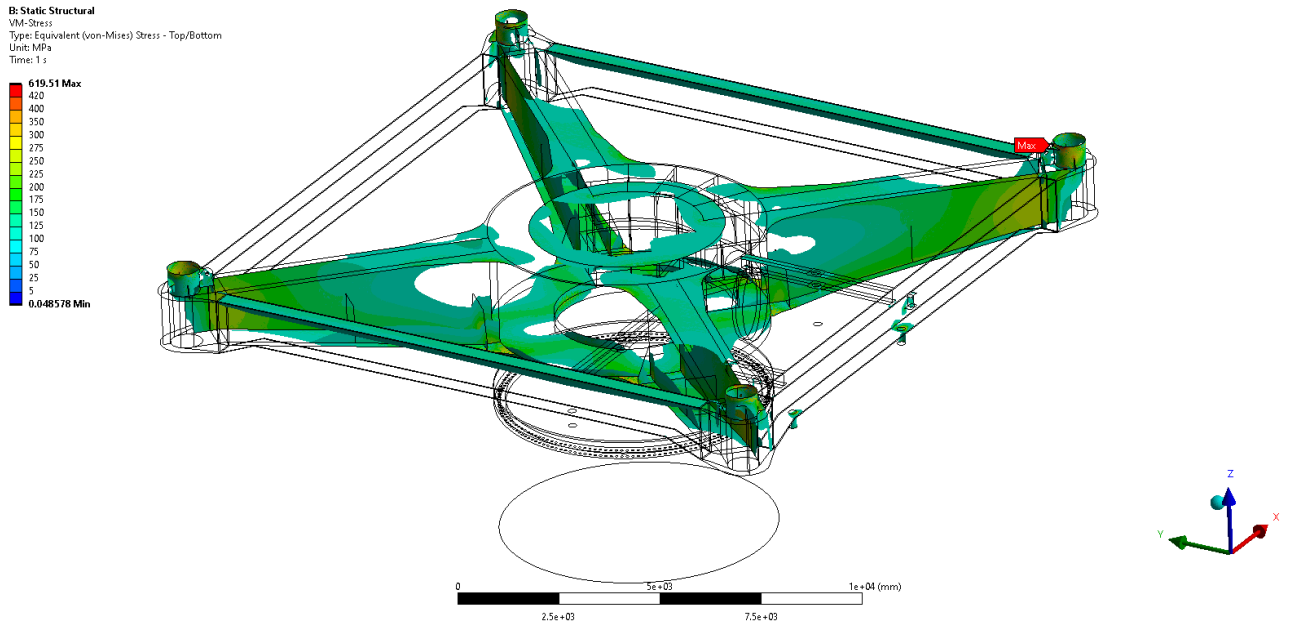


Figure 14.2 – TP FE model – VM Stresses > 100 MPa

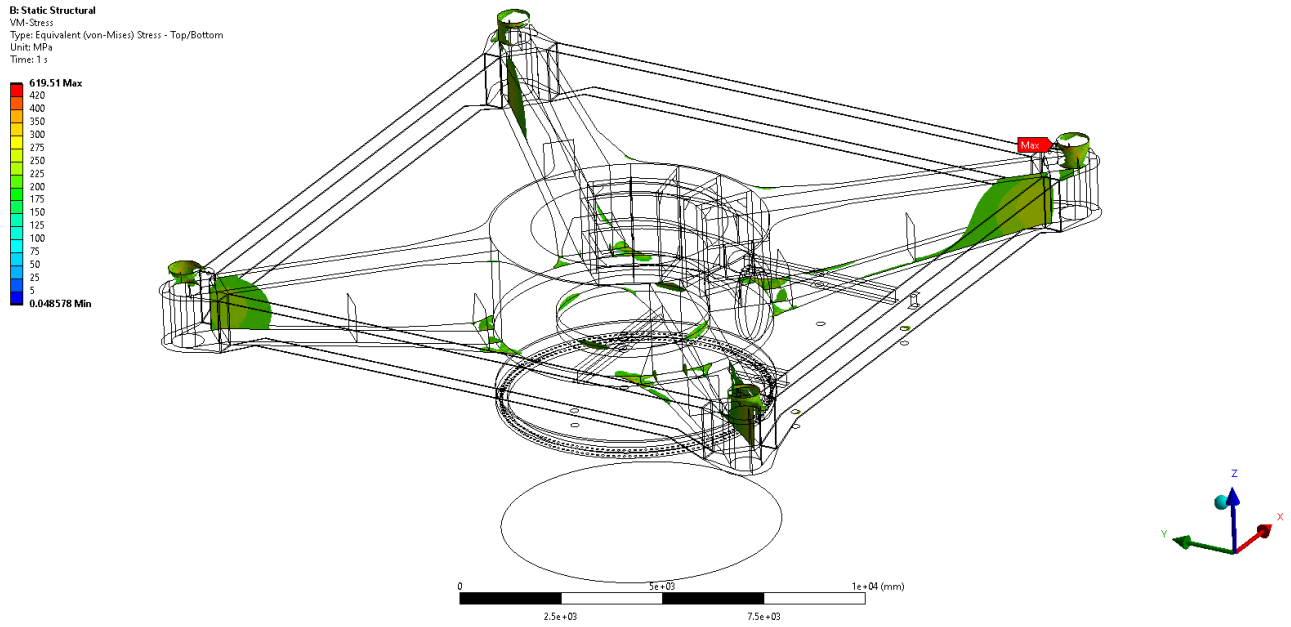


Figure 14.3 – TP FE model – VM Stresses > 200 MPa

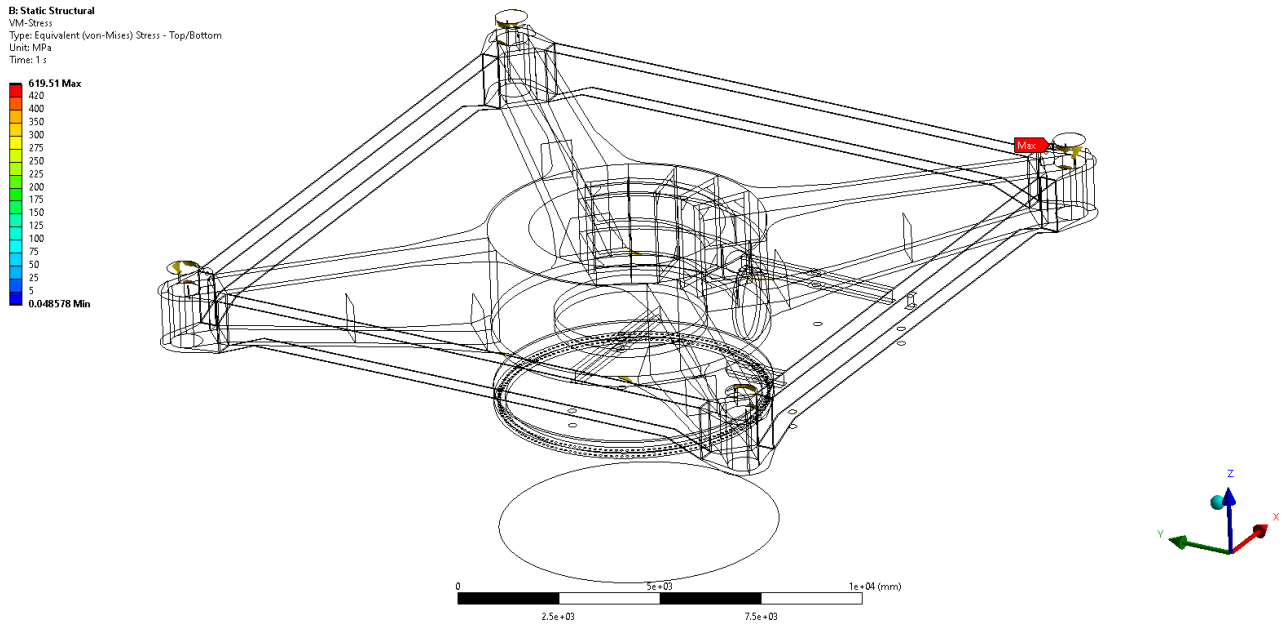


Figure 14.4 – TP FE model – VM Stresses > 300 MPa

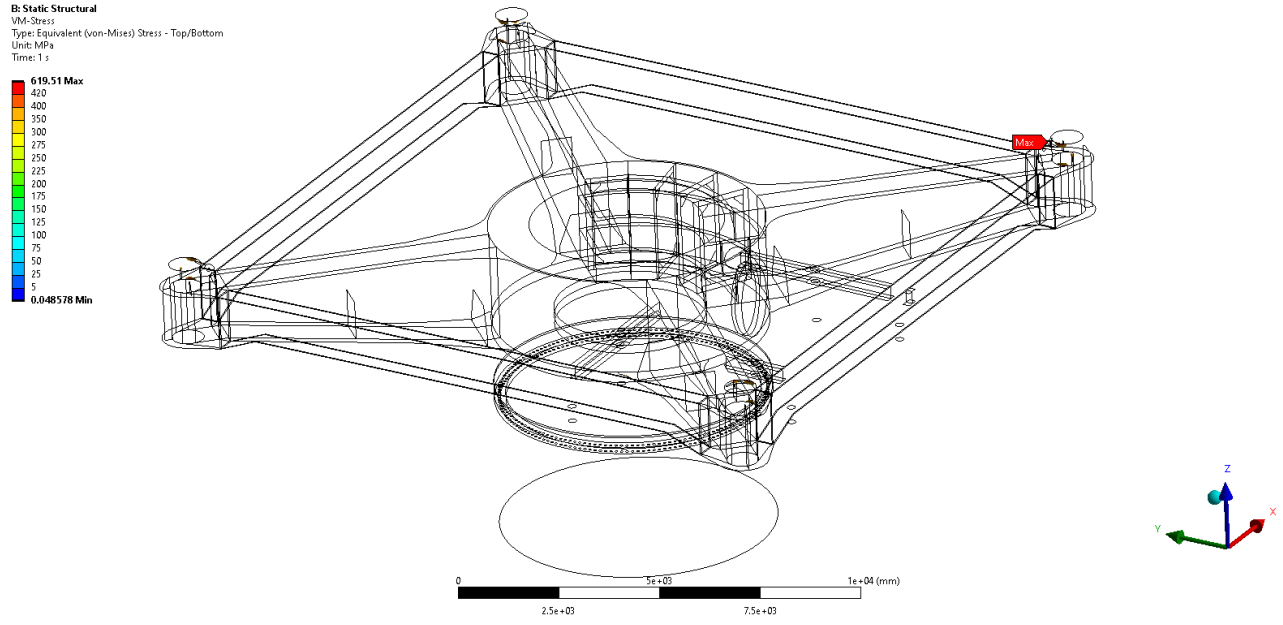


Figure 14.5 – TP FE model – VM Stresses > 340 MPa

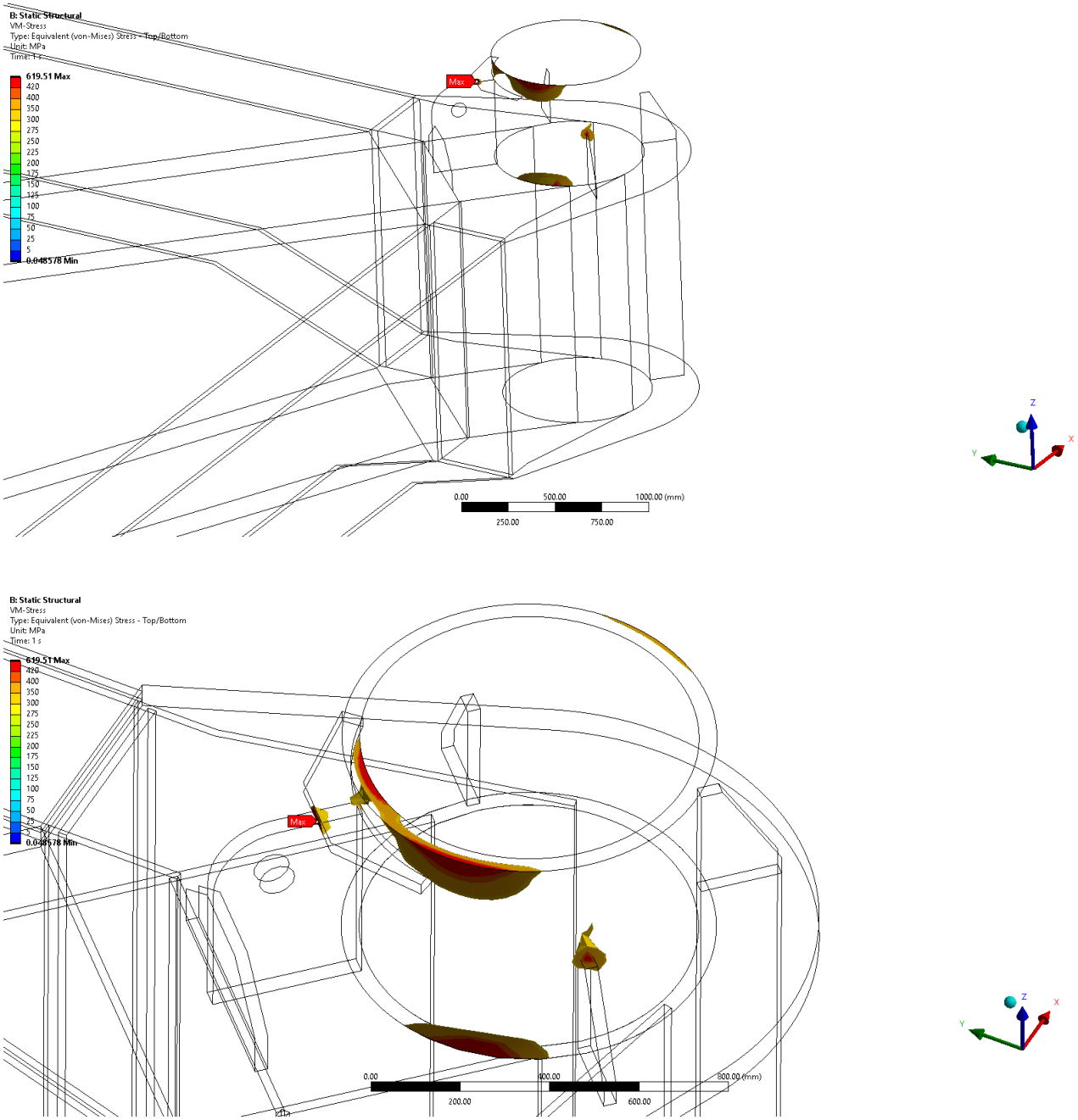


Figure 14.6 – TP FE model – VM Stresses > 340 MPa – Detail view

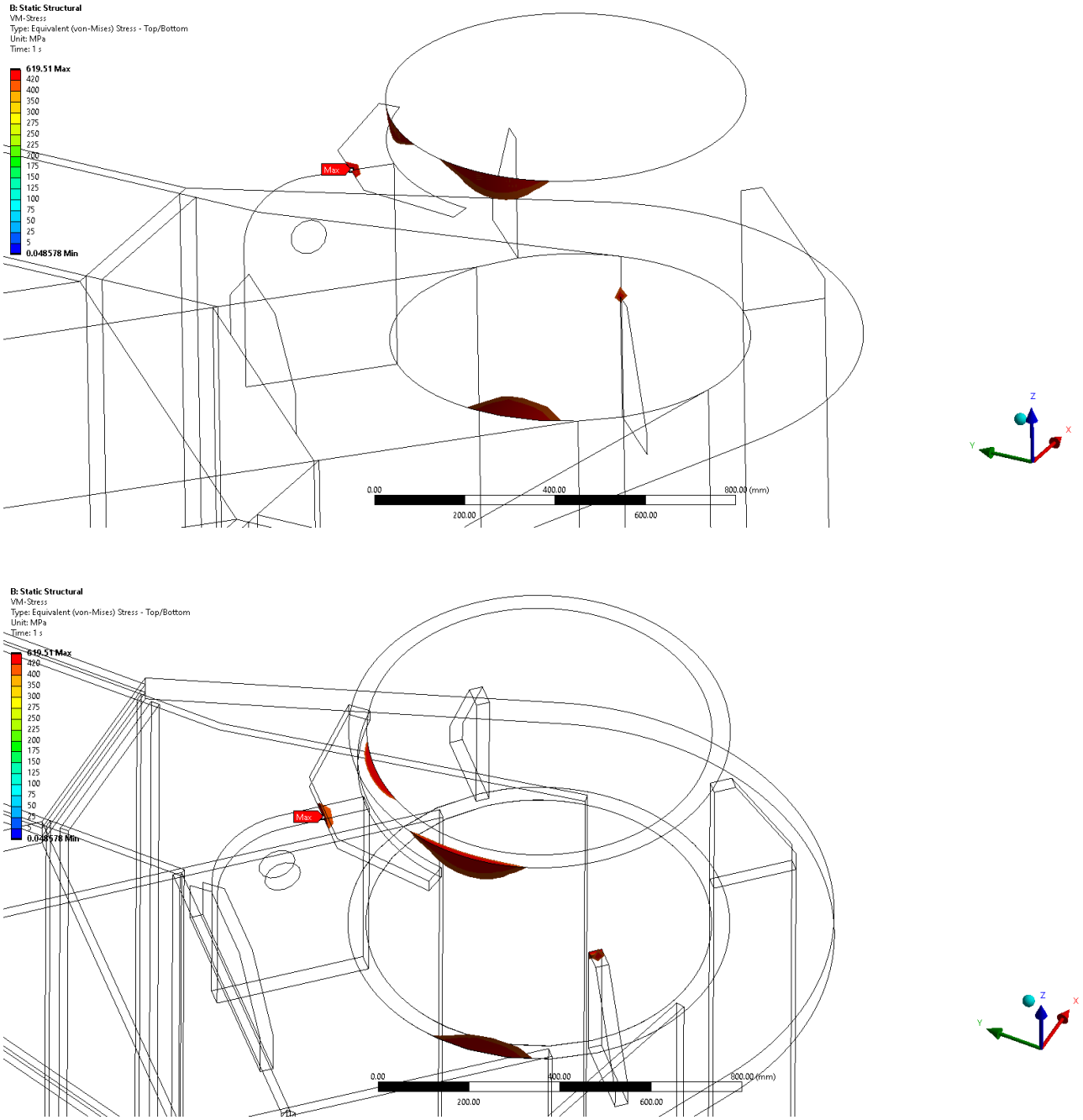


Figure 14.7 – Trunnion Joint FE model – VM Stresses > 400 MPa – Detail View

For structural checks, it is taken the most restrictive value of admissible stress, both for tubular and non-tubular elements, on the safe side: for t>16 mm, F_y = 400 MPa, therefore:

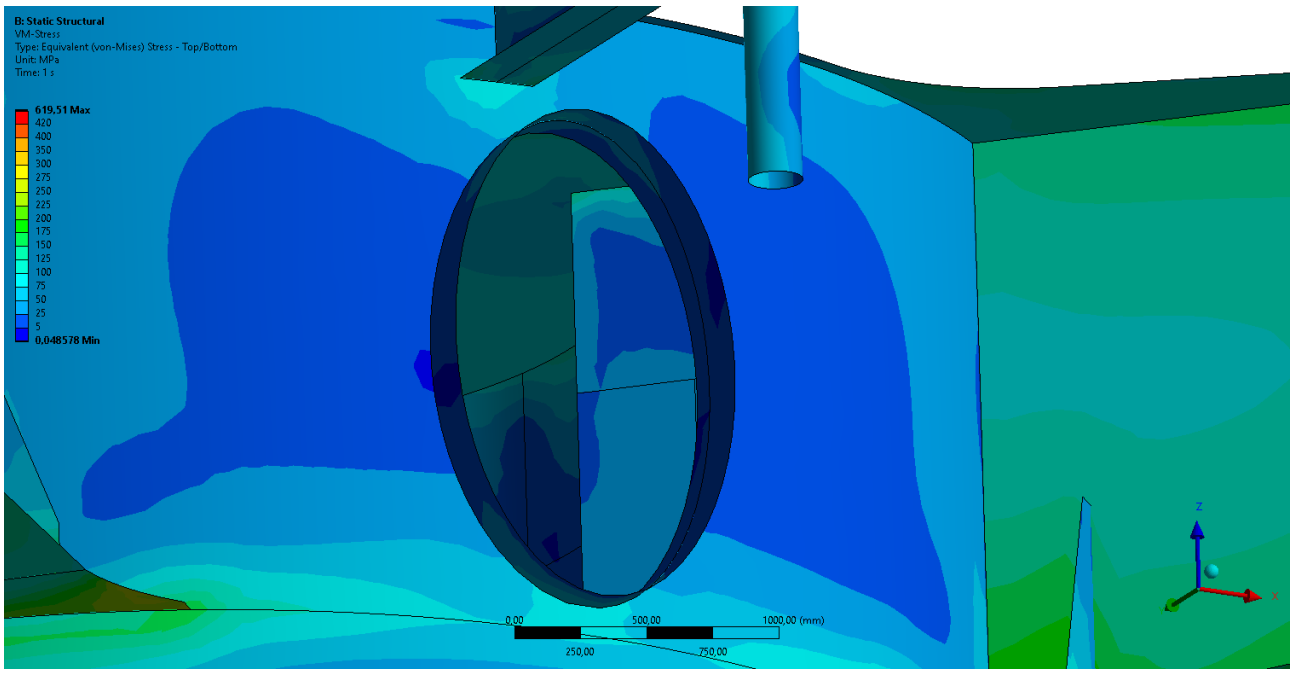
$\sigma_{adm} = \Phi * F_y = 0.85*390 = 340$ MPa

It can be observed that the VM stresses are largely lower than the admissible stress σ_{adm} = 340 MPa for global checks, and they are exceeded in few local portions in correspondence of the loaded support columns at the TP-Topside interface.

These portions are confined in the limit area 2tx2t and do not interesting the whole thickness of the plates. The cross sections of the elements are then considered have the required capacity to bear the in-service stresses.

The F_y value is exceeded in very limited portion areas, with a peak max. value of σ_{VM} = 493 MPa, so total strains (elastic plus plastic) in these portions are investigated as well.

The following figures focus the attention on the entry hole to show the stress distribution around its.



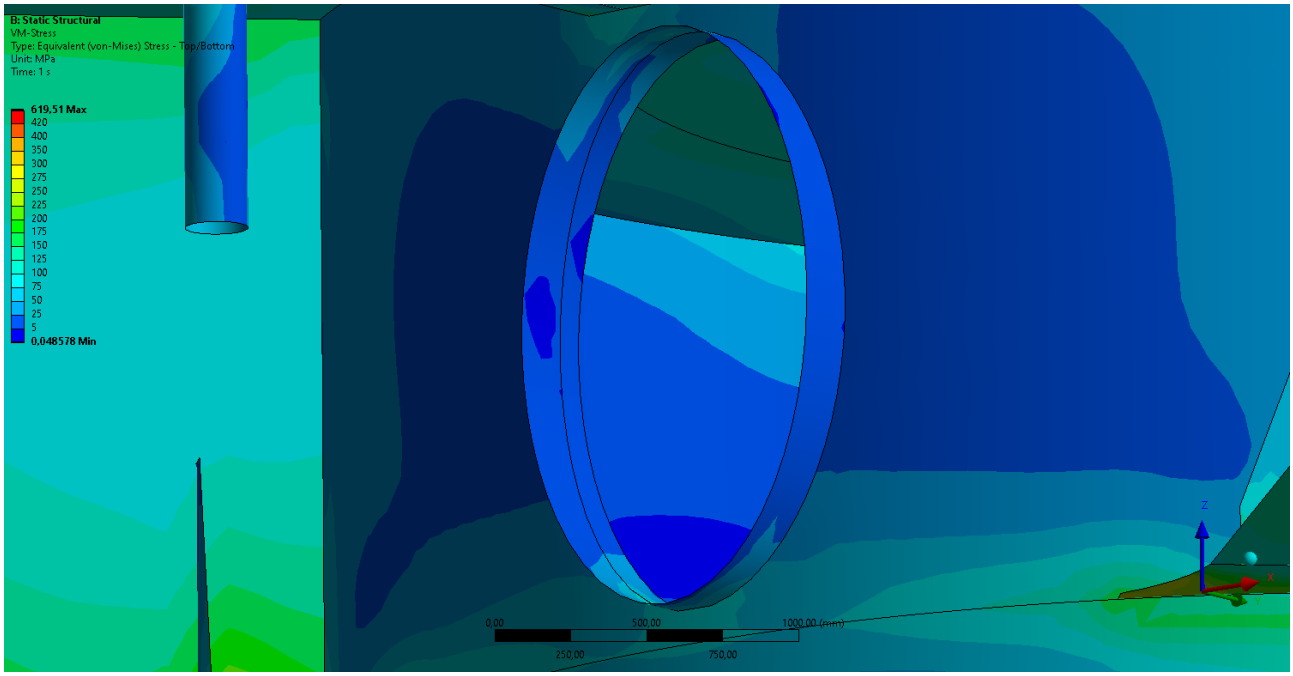


Figure 14.8 – TP - FE Model –VM Stresses – Detail View of Entry Hole

14.2 TOTAL STRAINS

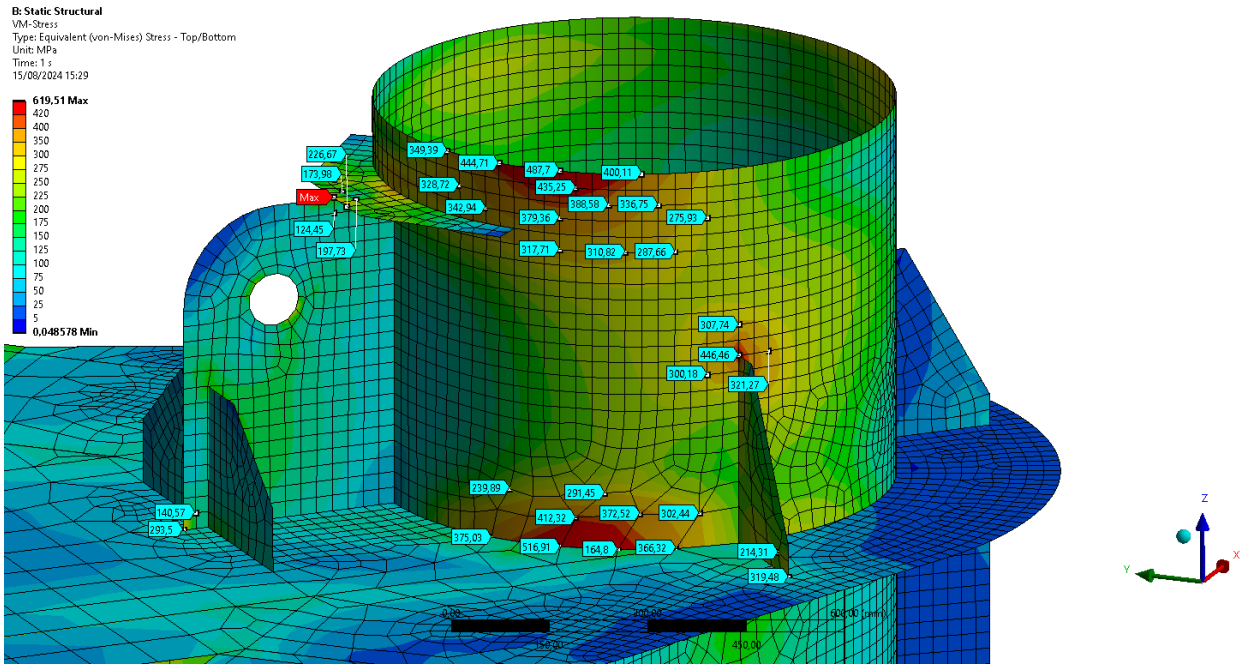


Figure 14.9 – TP FE model – Peak VM Stresses on support columns

For the hot spot areas, elasto-plastic strains are measured according to the performed non-linear analysis. They shall be less than 5% mm/mm, as per design criteria defined in /13/.

In the following figures plastic strains and total strains (elastic + plastic) are plotted.

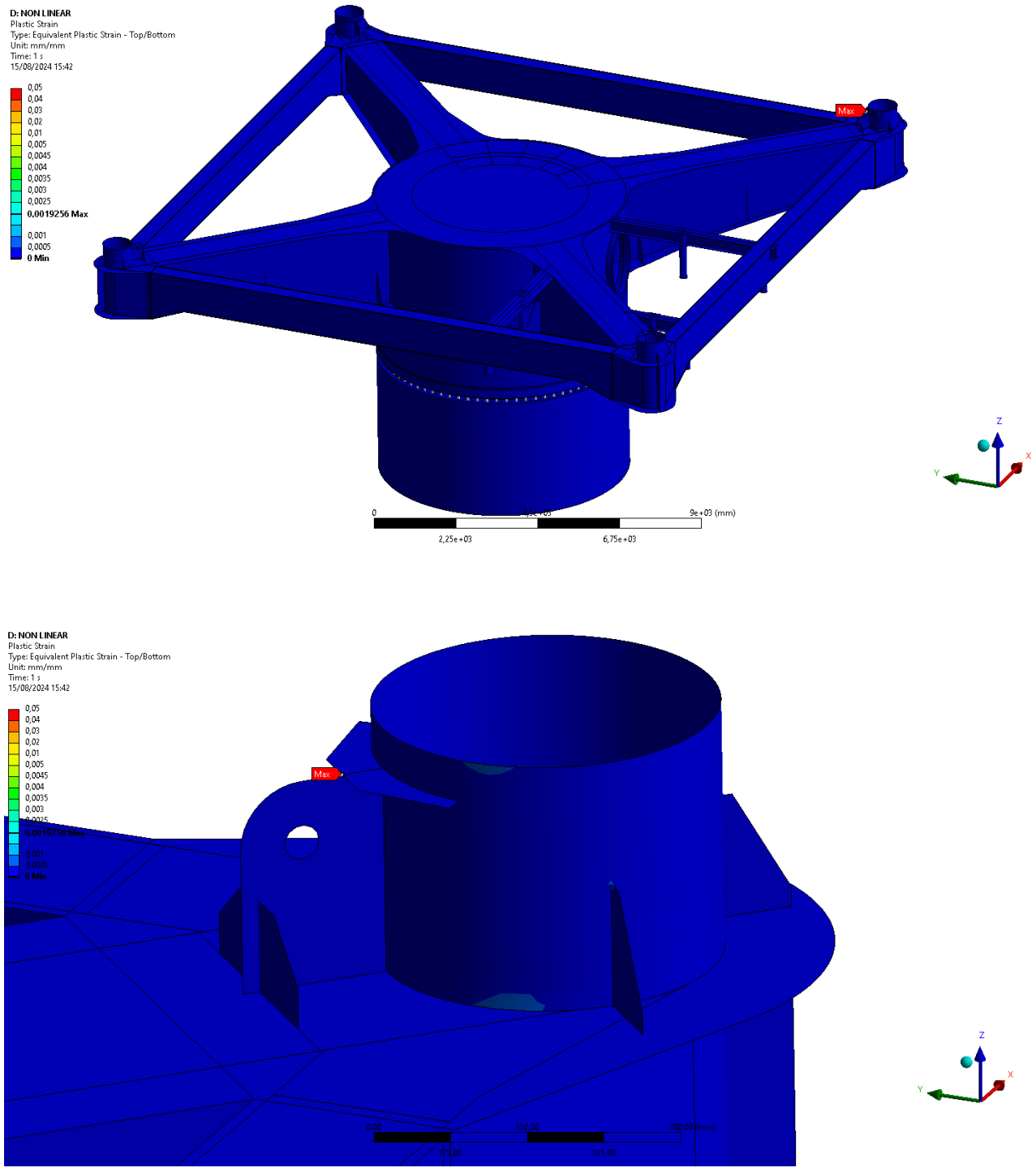


Figure 14.10 – TP FE model – Plastic strains

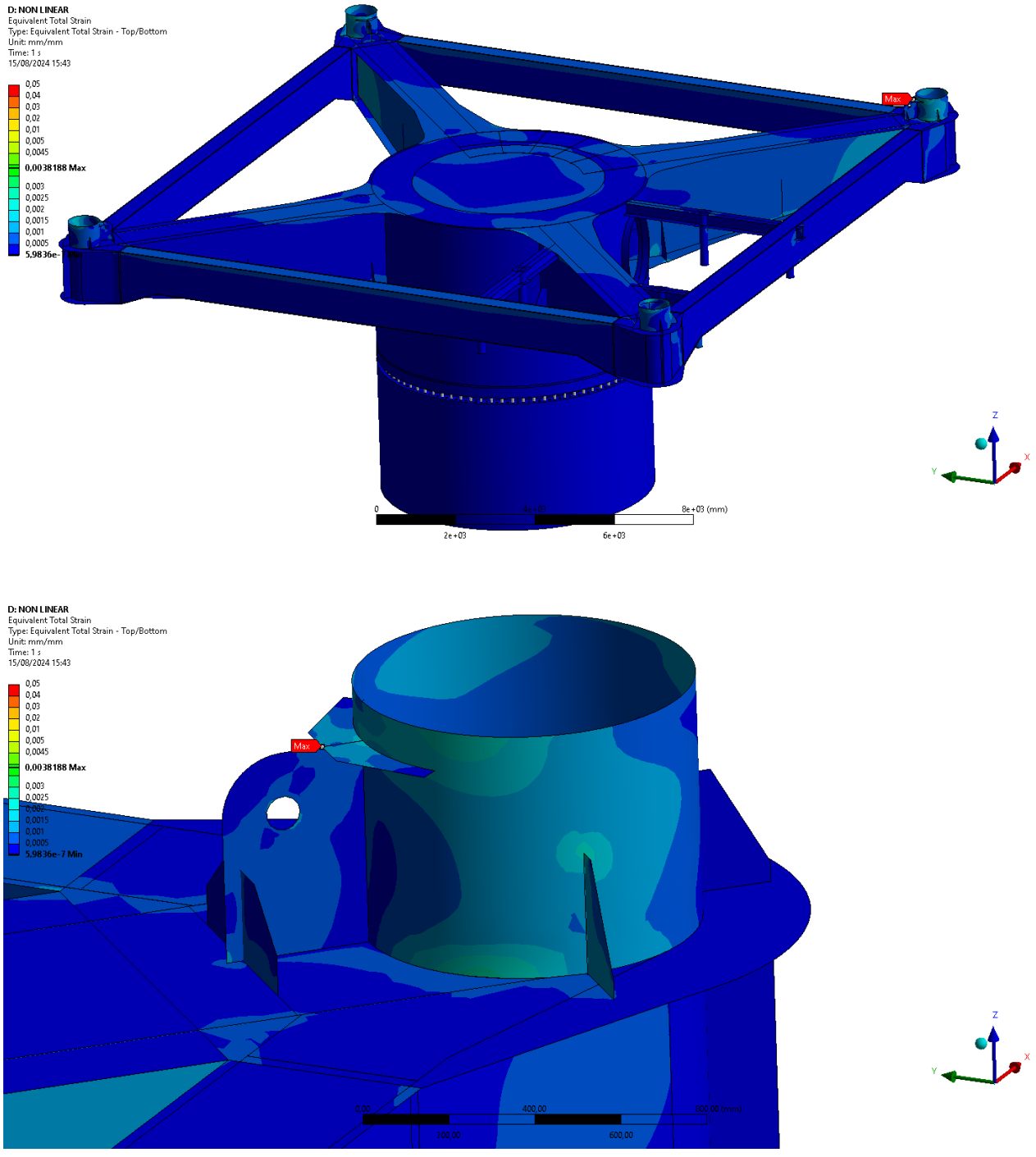


Figure 14.11 – TP FE model – Total strains

It is observed that the local peaks stresses do not lead to plastic strains. The TP structure is subject only to elastic strains which interest in particular the support columns and the end the beams converged on them.

The max. value of total strains is ε_t = 0.0038 mm/mm < ε_{adm} =0.05 mm/mm (UC=0.08). Strains are within the admissible value.

Checks are fulfilled.

The TP structure has enough resistance capacity to withstand the maximum loads acting for the in-service conditions.

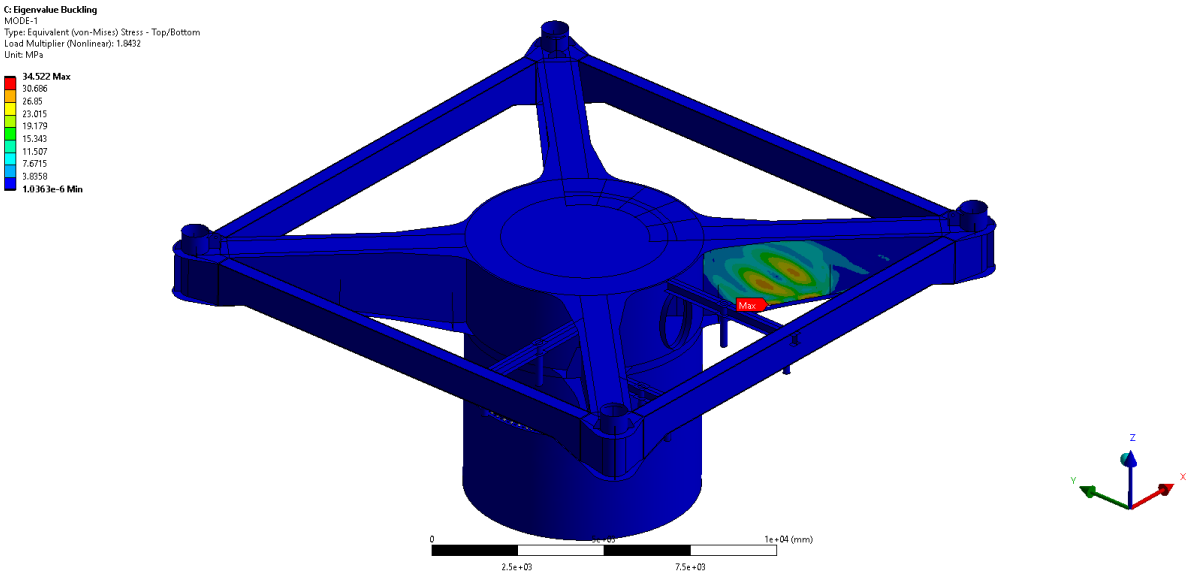
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14.3 BUCKLING RESISTANCE

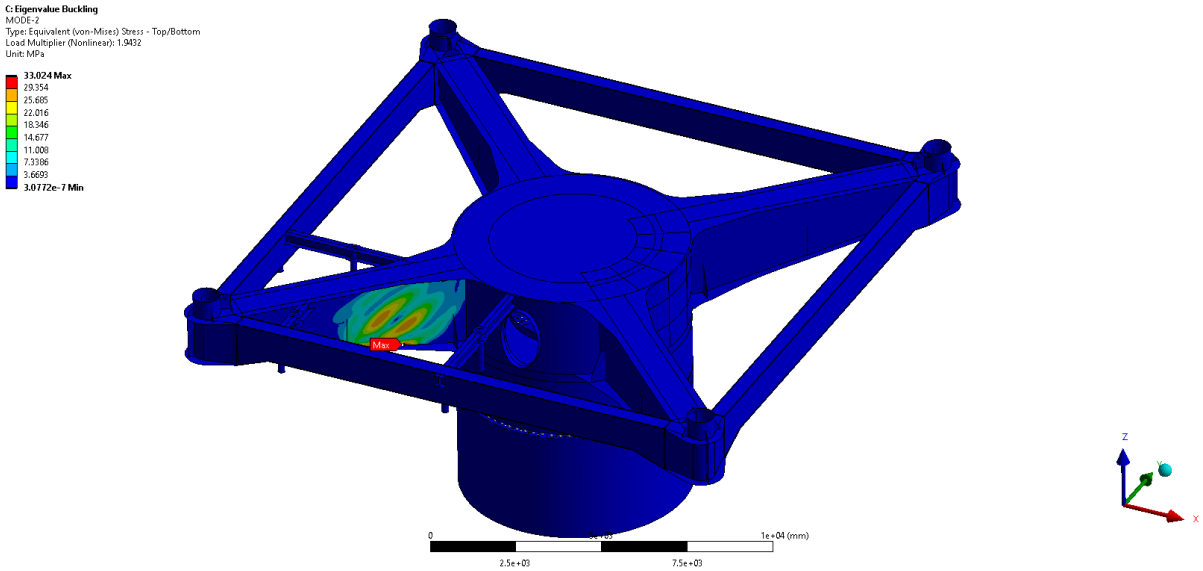
Buckling analyses have been performed to check the TP elements instability. The buckling checks are performed by calculating the buckling resistance for the first ten buckling modes according to the DNV-RP-C208, Ref./13/.

The following figures show the first ten buckling modes and the associated load factor resulting from the analyses.

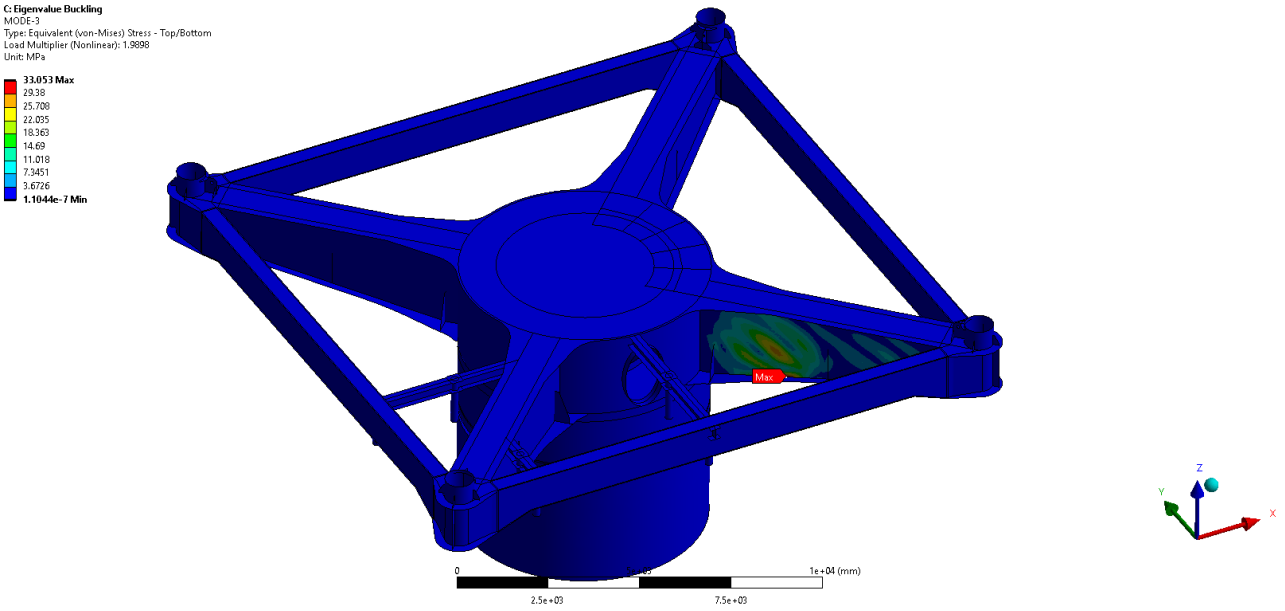
- *Mode N.1: Load factor 1.843*



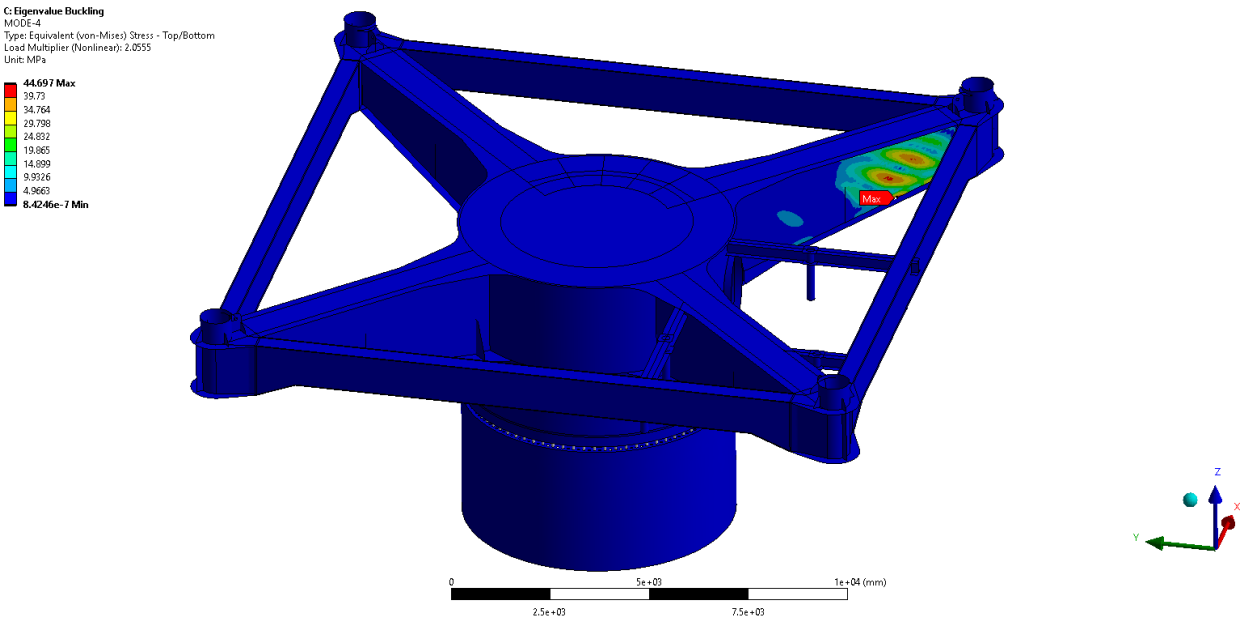
- *Mode N.2: Load factor 1.943*



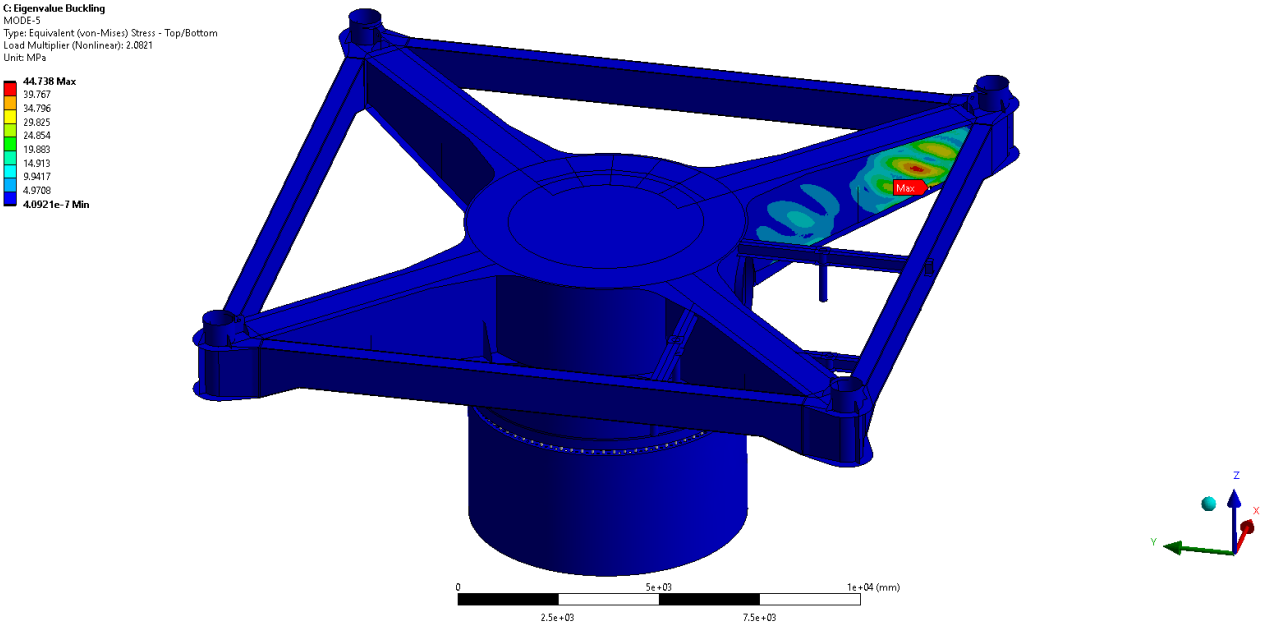
- *Mode N.3: Load factor 1.980*



- *Mode N.4: Load factor 2.056*

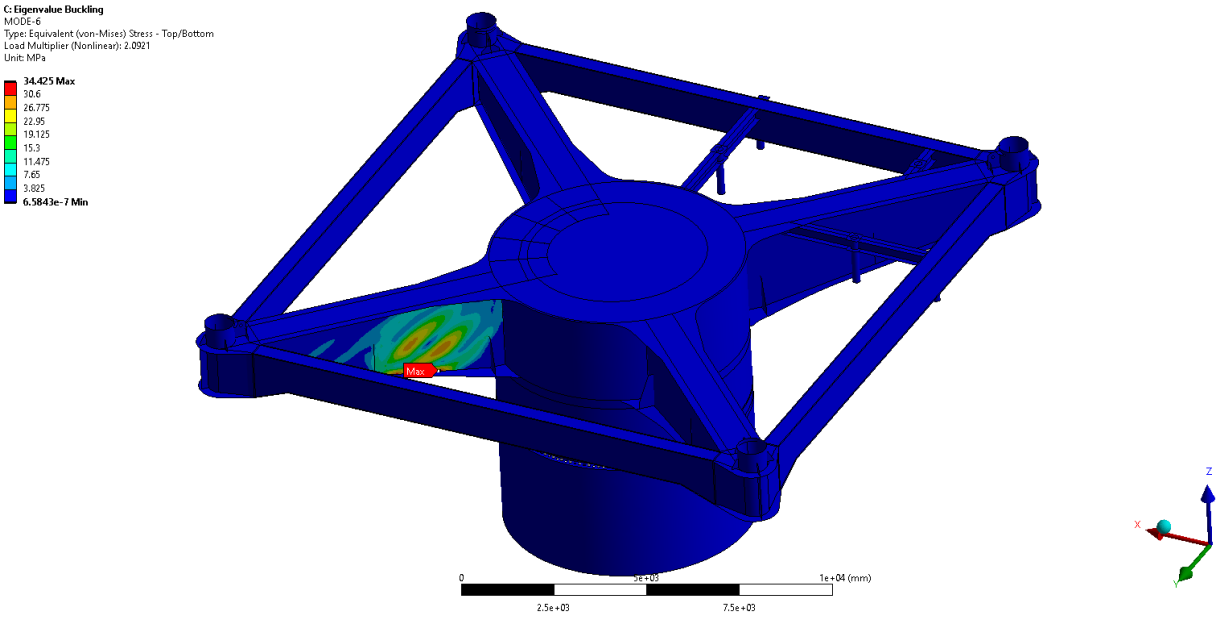


- *Mode N.5: Load factor 2.082*

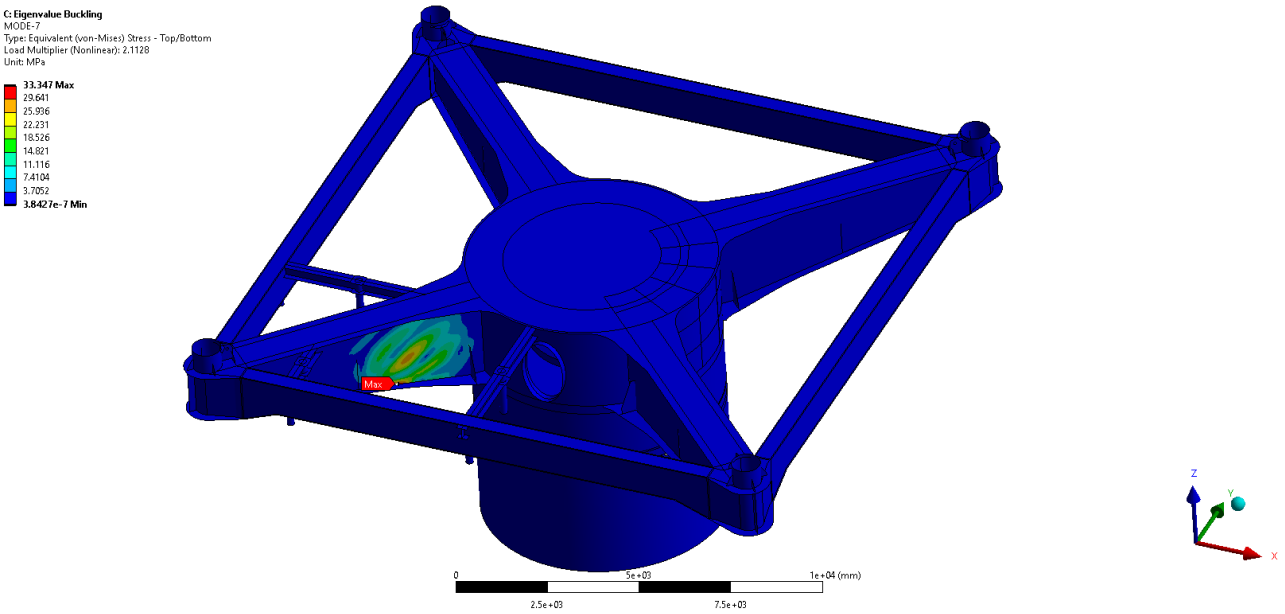


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- *Mode N.6: Load factor 2.092*

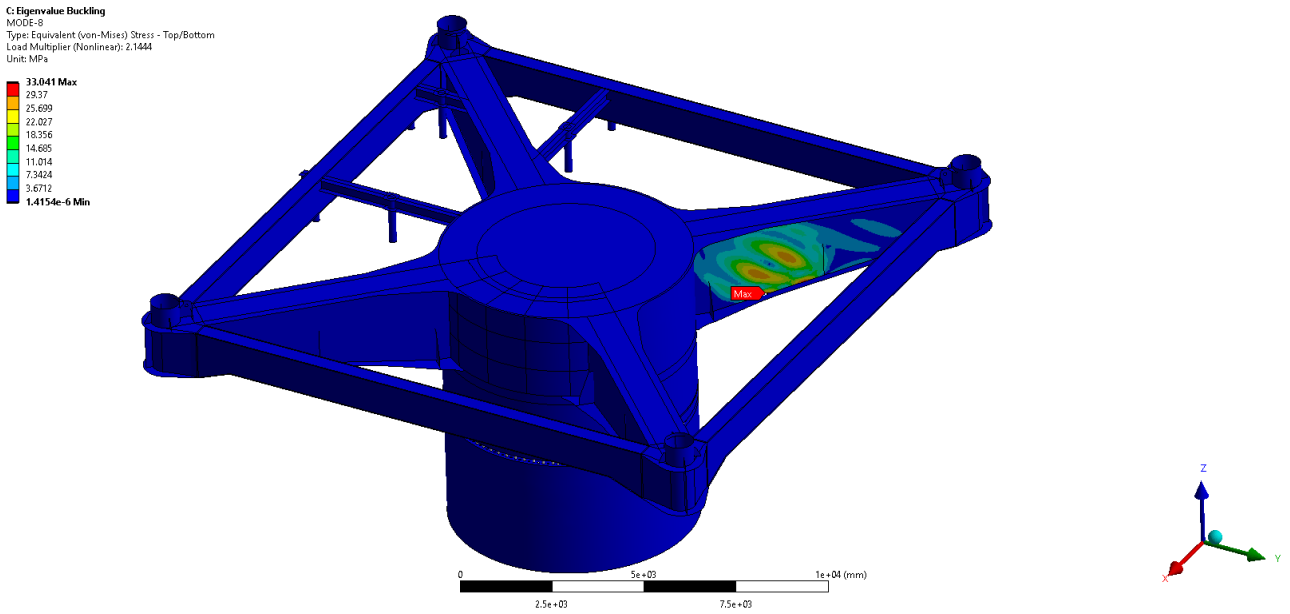


- *Mode N.7: Load factor 2.113*

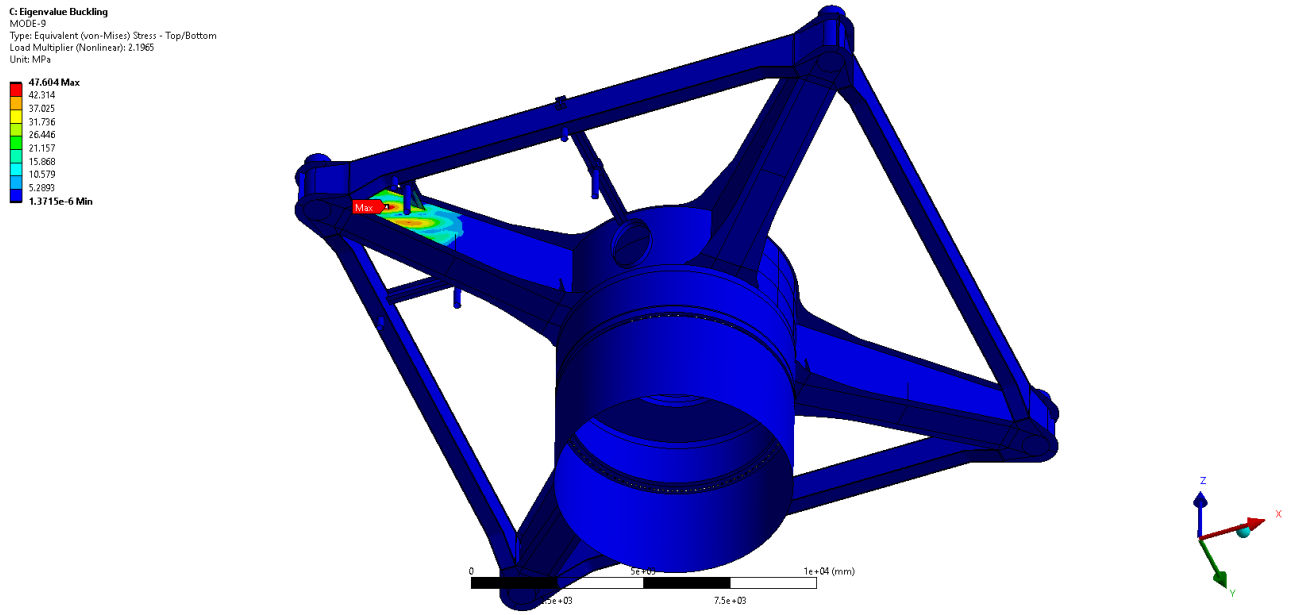


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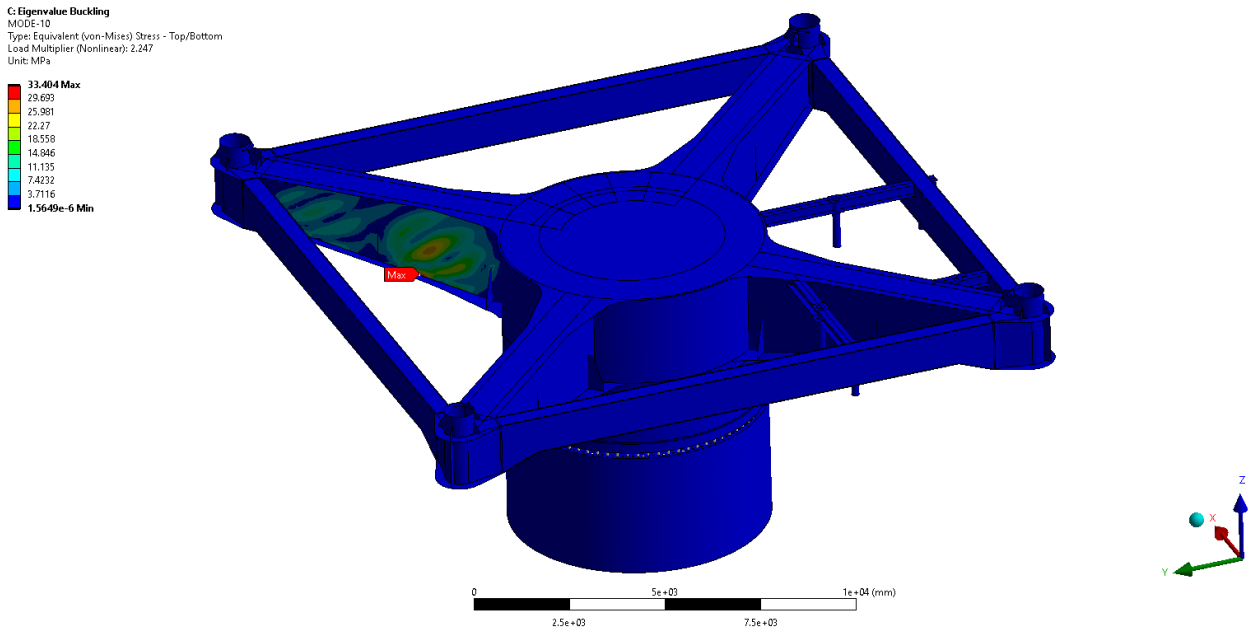
- *Mode N.8: Load factor 2.144*



- *Mode N.9: Load factor 2.197*



- *Mode N.10: Load factor 2.247*



The following table report the resultant buckling resistance and the associated buckling factor.

TRANSITION PIECE													
MODE	LOAD FACTOR	ELEMENT	DESIGN LOAD [tons]	MAT. FACTOR	REPR. STRESS [MPa]	YIELD STRESS [MPa]	α	CRIT. STRESS [MPa]	λ	ρ	BUCKLING FACTOR	BUCKLING RESIST. [kN]	BUCKLING FACTOR
1	***1.843***	***Tappered Beam - Web***	2965	1.15	***35***	390	0.30	64	2.48	3.91	0.37	***10719***	***3.62***
1	***1.943***	***Tappered Beam - Web***	2965	1.15	***33***	390	0.30	64	2.47	3.88	0.37	***11248***	***3.79***
3	***1.990***	***Tappered Beam - Web***	2965	1.15	***33***	390	0.30	66	2.44	3.80	0.37	***11365***	***3.83***
4	***2.056***	***Tappered Beam - Web***	2965	1.15	***45***	390	0.30	92	2.06	2.90	0.43	***9754***	***3.29***
5	***2.082***	***Tappered Beam - Web***	2965	1.15	***45***	390	0.30	93	2.05	2.87	0.44	***9803***	***3.31***
6	***2.092***	***Tappered Beam - Web***	2965	1.15	***34***	360	0.30	72	2.24	3.30	0.40	***10873***	***3.67***
7	***2.113***	***Tappered Beam - Web***	2965	1.15	***33***	235	0.30	70	1.83	2.41	0.48	***8751***	***2.95***
8	***2.144***	***Tappered Beam - Web***	2965	1.15	***33***	360	0.30	71	2.25	3.35	0.40	***11245***	***3.79***
9	***2.197***	***Tappered Beam - Web***	2965	1.15	***48***	360	0.30	105	1.86	2.47	0.48	***9263***	***3.12***
10	***2.247***	***Tappered Beam - Web***	2965	1.15	***33***	360	0.30	75	2.19	3.20	0.41	***11413***	***3.85***

Table 14.1 – TP – Buckling Resistance Factor

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