Base Load Power Hub (BLPH)

BLPH Platform
TP-MP Flange Connection Verification

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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.

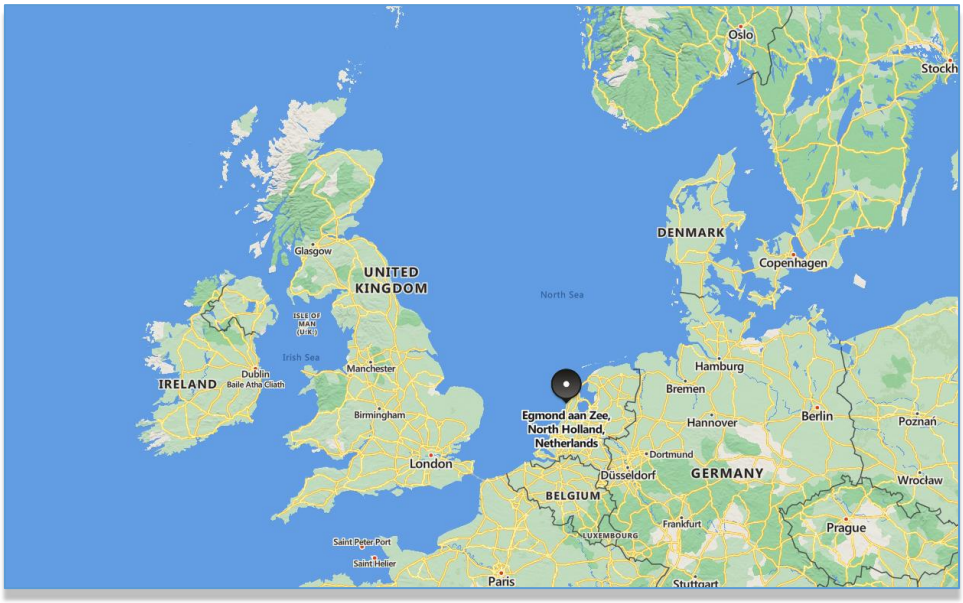


Figure 1.1 HOLLANDSE KUST NOORD WIND PARK Location Map

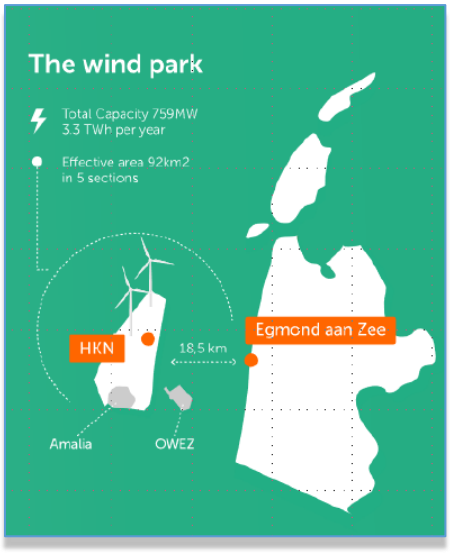


Figure 1.2 - Wind Park Details

The wind farm consists 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.

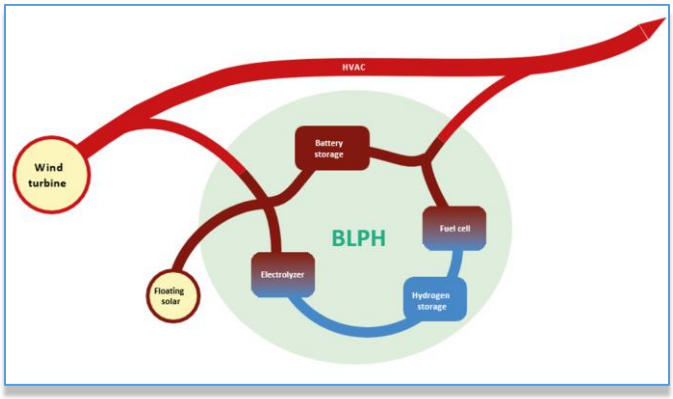


Figure 1.3 – BLPH Concept

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 Structural In-service Analysis performed for the Transition Piece (TP) Flange of the BLPH platform.

The analysis has been performed in compliance with the requirements, criteria and parameters reported in the Structural Design Premises, Ref./23/.

All structural analyses have been carried out using the structural analysis FE program ANSYS, Ref. /41/.

Dedicated reports, with structural analyses performed with ANSYS, Ref. /41/, have been carried out to check the TP global structure, Ref./29/.

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

Structural Code checks are performed according to Eurocode 3 for non-tubular structural elements, Ref./9/, and DNV-ST-0126 for bolts, Ref. /19/.

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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 19901-2	Seismic design procedures and criteria
/4/ BS EN ISO 19901-3	Specific requirements for offshore structures – Part 3: Topsides structure - 2014
/5/ BS EN ISO 19901-5	Specific requirements for offshore structures – Part 5: Weight Management - 2021
/6/ BS EN ISO 19901-6	Specific requirements for offshore structures – Part 6: Marine Operations – 2009
/7/ BS EN ISO 19902	Petroleum and natural gas industries - Fixed steel offshore structures – 2020
/8/ ISO 19906:2019	Petroleum and natural gas industries — Arctic offshore structures
/9/ UNI EN 1993-1-1	Design of steel structures - Part 1-1: General rules and rules for buildings
/10/ API RP 2A-WSD	Recommended practice for planning, designing and constructing fixed offshore platforms – Working stress design – 22nd edition – 2014
/11/ DNV-ST-N001	DNV GL - Marine operation and marine warranty - 2021
/12/ EN 1991-1-3:2003 & A1:2015	EN, Eurocode 1 – Actions on Structures – Part 1-3: General actions – Snow loads - Incorporating corrigenda December 2004 and March 2009, December 2015.
/13/ DNV-ST-0145	DNV, Offshore substations
/14/ DNV-RP-C201	DNV, Buckling Strength of Plated Structures, October 2010.
/15/ DNV-RP-C203	DNV GL, Fatigue design of offshore steel structures, September 2019 and Amendment January 2020
/16/ DNV-RP-C204	DNVGL-RP-C204 Design against accidental loads – 2019
/17/ DNV-RP-C205	DNV GL - Environmental conditions and environmental loads - September 2019, amended September 2021.
/18/ DNV-RP-C208	DNV – Determination of Structural Capacity by Non-linear Finite Element Analysis Methods
/19/ DNV-ST-0126	Support structures for wind turbine, 2018

3.2 COMPANY SPECIFICATIONS

Doc. No.	Description
/20/ DEP 37.19.00.12	Gen - Offshore Topsides Structures
/21/ DEP 37.19.00.30	Gen - Fixed Steel Offshore Structures (Adoption of IOGP S-631-11, Amendments / Supplements to ISO 19902:2020).
/22/ 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
/23/ 123A90-DDL-ST-SP-90017	Structural Design Basis
/24/ 123A90-DDL-MD-RE-01006	Monthly Weight Report
/25/ 123A90-DDL-PP-DS-70070	Plot Plans
/26/ 123A90-DDL-ST-SP-90018	Structural Material Specification for Topside and TP
/27/ 123A90-DDL-ST-SP-90118	Structural Material Specification for Flange and Bolts
/28/ 123A90-DDL-ST-RE-90000	BLPH Platform – In-Service Analysis
/29/ 123A90-DDL-ST-RE-90007	BLPH Platform – FE Analyses
/30/ 123A90-DDL-ST-TN-90119	Evaluating ISO and DNV approaches
/31/ 123A90-DDL-ST-RE-90120	BLPH – Structural verification against accidental loads
/32/ 123A90-DDL-ST-RE-90078	BLPH – TP – Primary Steel – Elevation Row -A-
/33/ 123A90-DDL-ST-RE-90081	BLPH – TP – Primary Steel – Elevation Row -2-
/34/ 123A90-DDL-ST-RE-90083	BLPH – TP – Primary Steel – Flange Connection

3.4 OTHER DOCUMENTS

Doc. No.	Description
/35/ K559–2254-ST-PHI-001	BLPH Structural Topsides Design & Installation Philosophy, Rev.1, 09 December 2022
/36/ 144671-VOOW-TF-ENG-REP-1051	Design Basis Part C for BLPH, Rev. 3, 28 June 2022
/37/ 144671-VOOW-TF-ENG-REP-1052	Wave Loads and Effects for BLPH, Rev. 0, 16 December 2021
/38/ 144671-VOOW-TF-ENG-REP-1016	Wave Run-up Study, Rev.2, 29 November 2021

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/39/ 144671-VOOW-TF-ENG-REP-1054	Foundation Load Document for BLPH, Rev.1, 07 April 2022

3.5 SOFTWARE

Doc. No.	Description
/40/ SACS	Structural Analysis Computer System – BENTLEY Inc- v15
/41/ ANSYS	Ansys Simulation Platform – 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
Ce	Snow Exposure Coefficient
CF	Caisson Frame
CL	Concentrated Load
CoG	Centre of Gravity
CTV	Crew Transfer Vessel
CW	CrossWind
DAF	Dynamic Amplification Factor
DFF	Damage Fatigue Factors
DLB	Ductility Level Blast
DNV	Det Norske Veritas
DOP	Dropped Object Protection
DP	Dynamic Positioning
El.	Elevation
EPCI	Engineering Procurement Construction and Installation
FEED	Front End Engineering Design
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)
PG	Plate Girder
PV	Photovoltaic
SCE	Safety Critical Equipment
sk	Characteristic Value of Snow on the Ground/Platform
SGSI	Shell Global Solutions International
SHL	Static Hook Load
T&I	Transport & Installation
ToS	Top of Steel
TP	Transition Piece
TSO	Transmission System Operator
SLB	Strength Level Blast
UC	Unity Check
UDL	Uniformly Distributed Load
VIV	Vortex Induced Vibration
VOOW	Van Oord Offshore Wind
WTG	Wind Turbine Generator
W2W	Walk to Work

Table 4.1 - Definitions and Abbreviations

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5 SUMMARY AND CONCLUSIONS

The analyses performed show that the TP connection flange, as configured, can withstand the maximum possible loads resulting from the In-Service Analysis Report, Ref./28/, obtained combining the environmental and operational loads imposed to the structure, consistently with the probability of their simultaneous occurrence.

The maximum UC resulting from the performed analyses on the different elements are:

- TP Flange: UC=0.92
- Double Side Weld connecting the TP flange to the TP can: UC=0.37
- Bolt (M64): UC=0.68

6 PLATFORM DESCRIPTION

6.1 LOCATION AND ORIENTATION

The wind farm consists of 69 x 11.5 MW 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 above co-ordinates are referenced to ETRS89 / UTM zone 31N global coordinate system.

Platform (Topsides) north is rotated 25° towards west with reference to True North so that the monopile main access platform is orthogonal to the Topsides, as per Figure 6.1.

6.2 BLPH TOPSIDE AND TRANSITION PIECE

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.

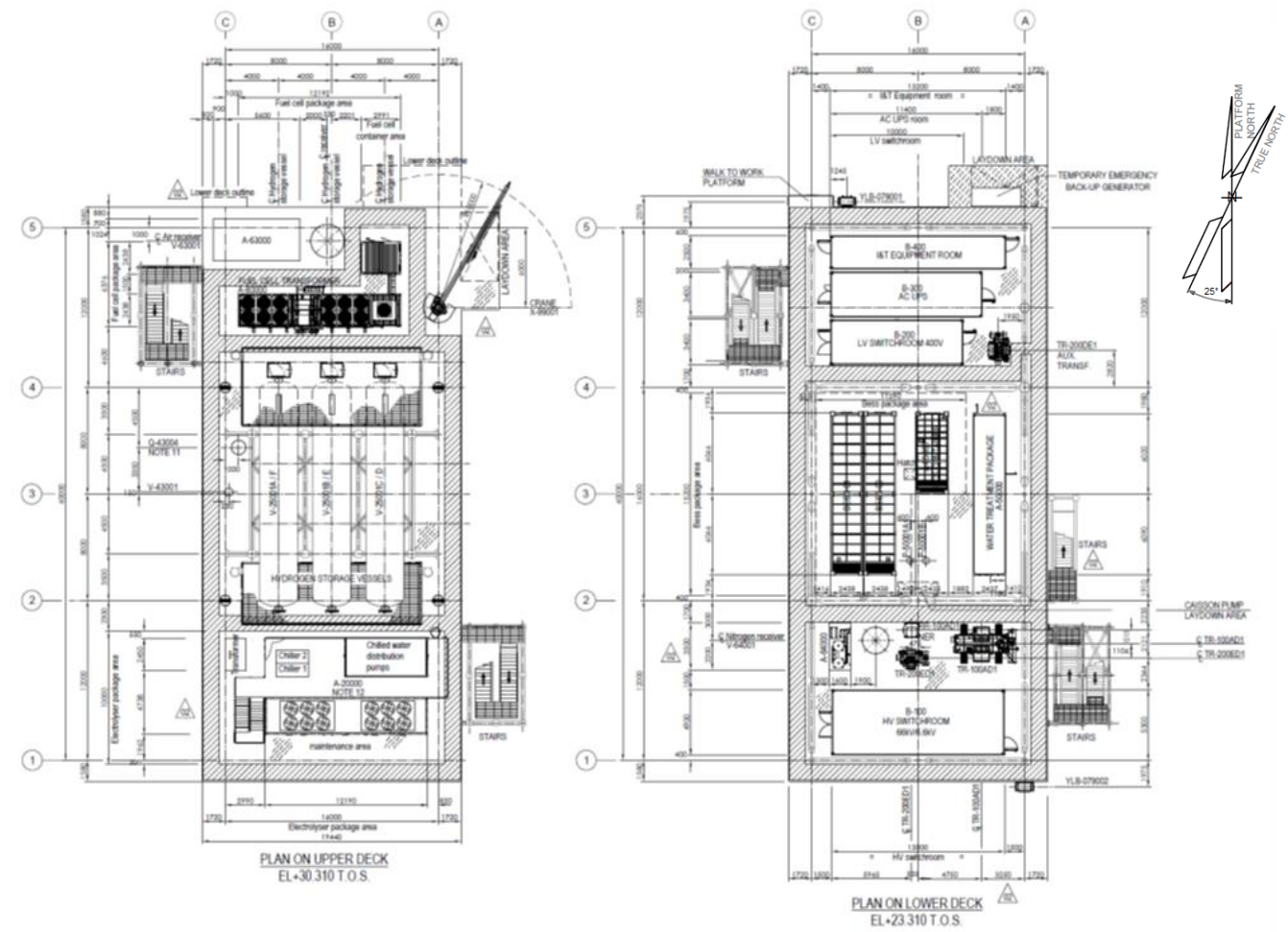


Figure 6.1 - Base Load Power Hub Plot Plan, Ref. /25/

6.3 MONOPILE-TOPSIDES INTERFACE

The interface level between Monopile and Topsides (comprising TP) is at El.+17.050 m relative to LAT, as per Ref. /35/and /36/ and reported in Figure 6.2.

The TP will be connected to the monopile in offshore.

VOOW has developed serviceability and ultimate limit state design forces and moments on the BLPH monopile, ref./39/, not to be exceeded, see report /28/ for comparison.

The monopile has been surveyed on 29 May 2023 showing as-built interface connection as reported in Design Basis, Ref./23/.

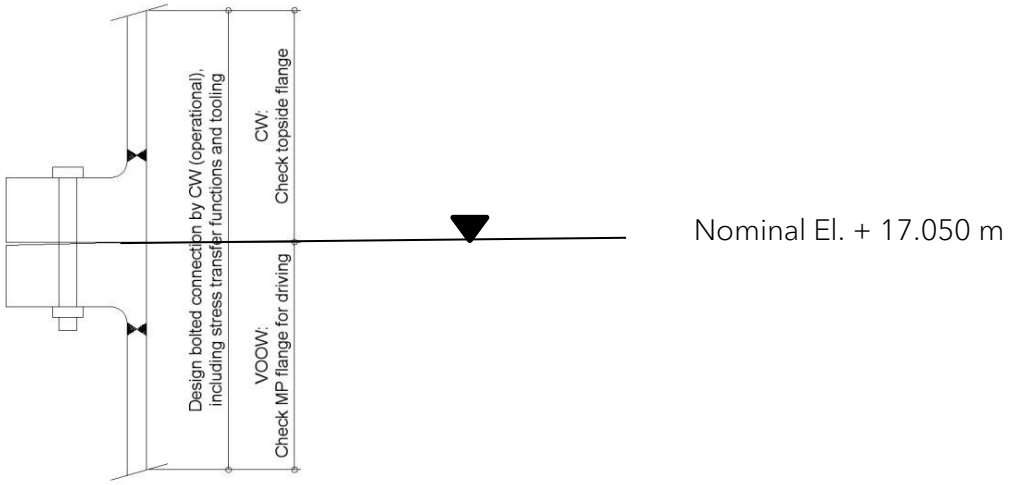


Figure 6.2– Monopile-to-Transition Piece Flange

7 DESIGN DATA

All Design Data are herein collected according to Monopile and BLPH Feed Design, Ref. /35/and /36/.

7.1 FLANGE GEOMETRY

The connection between Monopile and TP at El.+17.050 m relative to LAT is composed by two opposite flanges bolted together in offshore. The upper TP Fange is a forged piece characterized by a flange with base 325mm and height 120mm. The 75 THK pipe is connected to the flange with elliptical radius. 156 holes with diameter of 70mm, for bolts M64, complete the flange geometry.

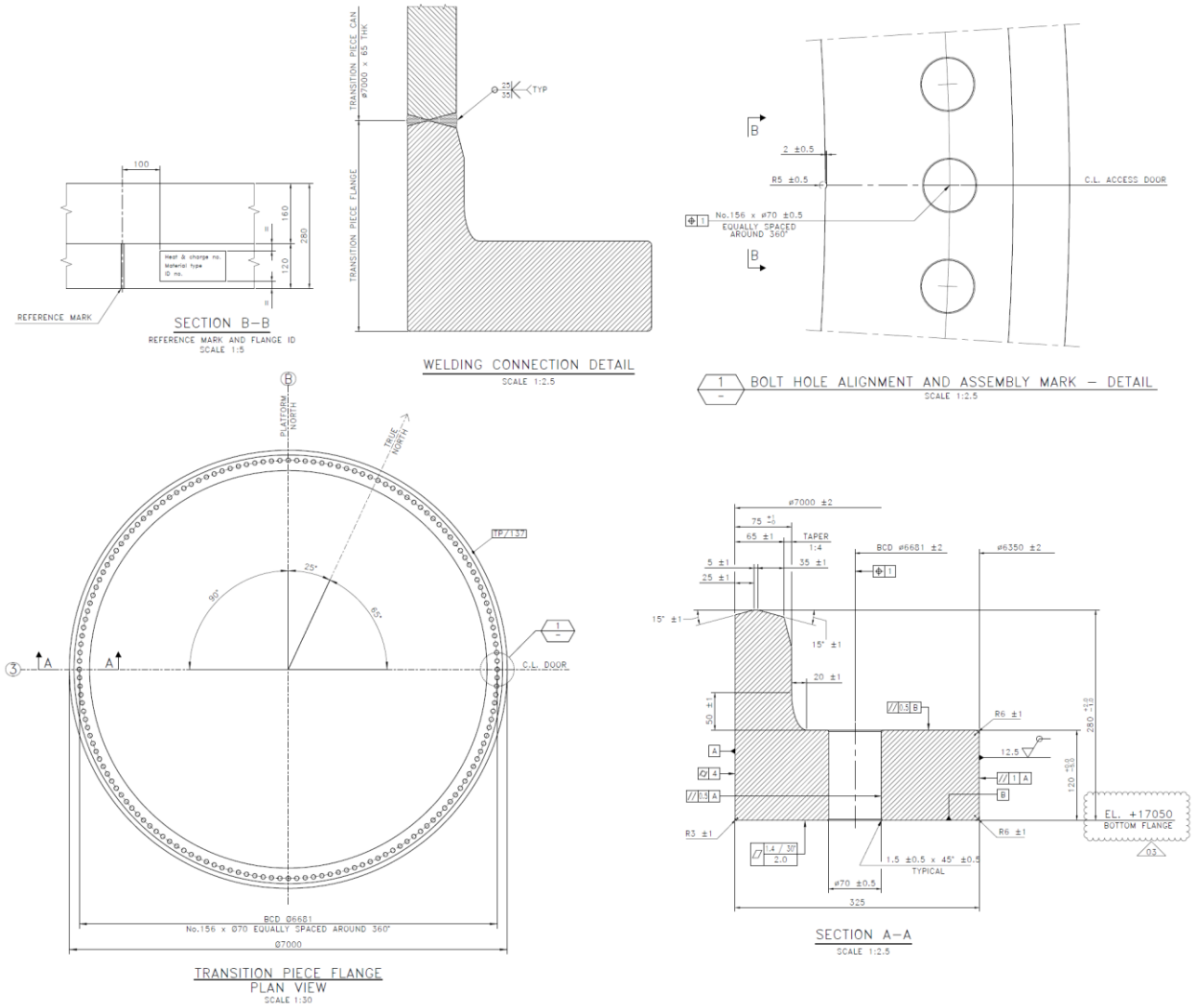


Figure 7.1 – TP Flange geometry

The bottom Monopile flange is a forged piece characterized by a 156mm THK horizontal plate connected to the 7000x75 vertical pile through an elliptical fillet. As for the TP flange, 156 holes equally spaced with diameter of 70mm, for bolts M64, complete the Monopile flange geometry.

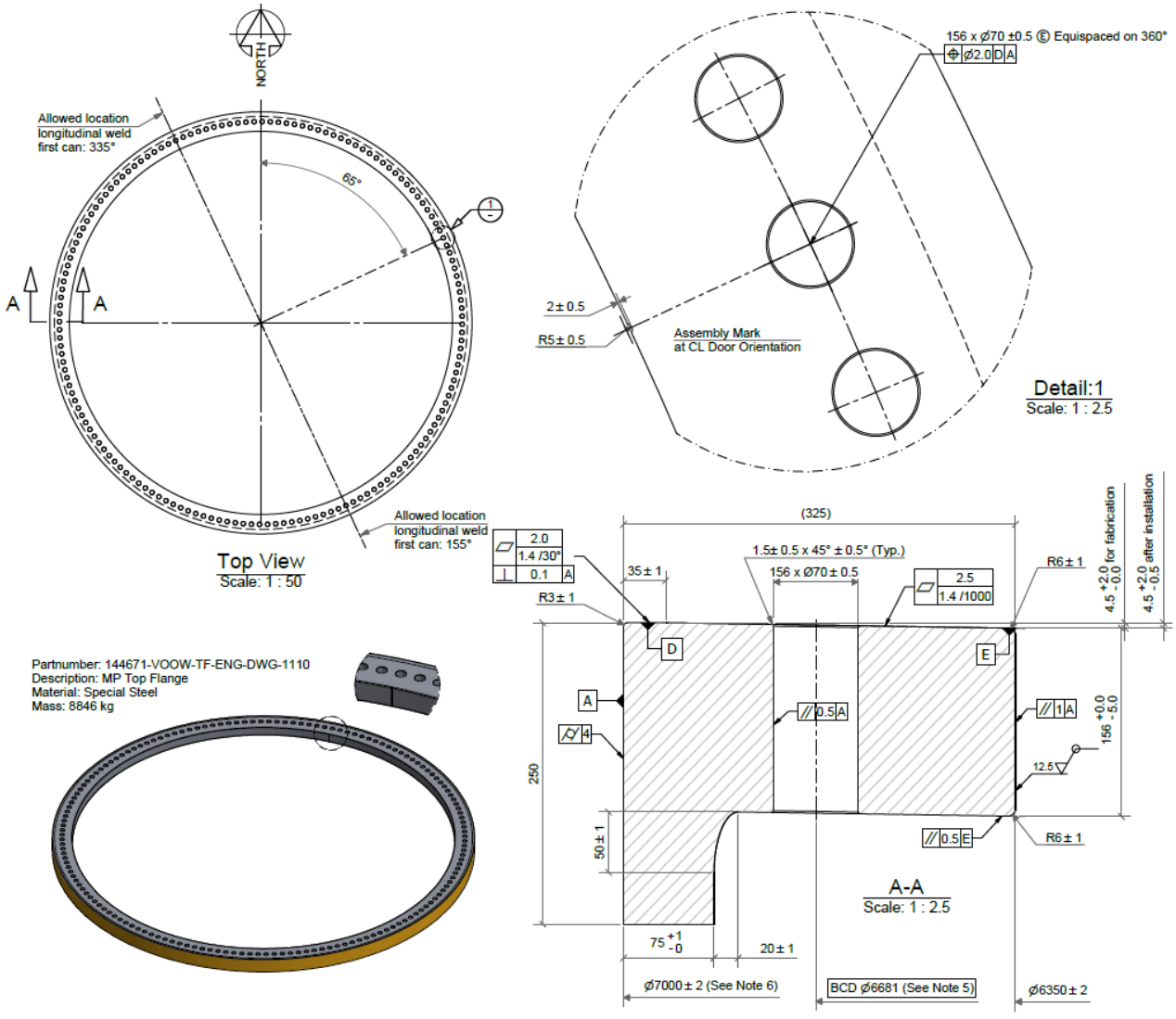


Figure 7.2 – Monopile Flange geometry

NOTE: bottom flange is tapered for hammering purpose.

7.2 DESIGN LOADS

Based on the results of the In-Service Analysis Report, Ref./28/, the maximum loads acting on the TP flange correspond to the reactions at SACS global model joint TMIJ as shown in the figures below.

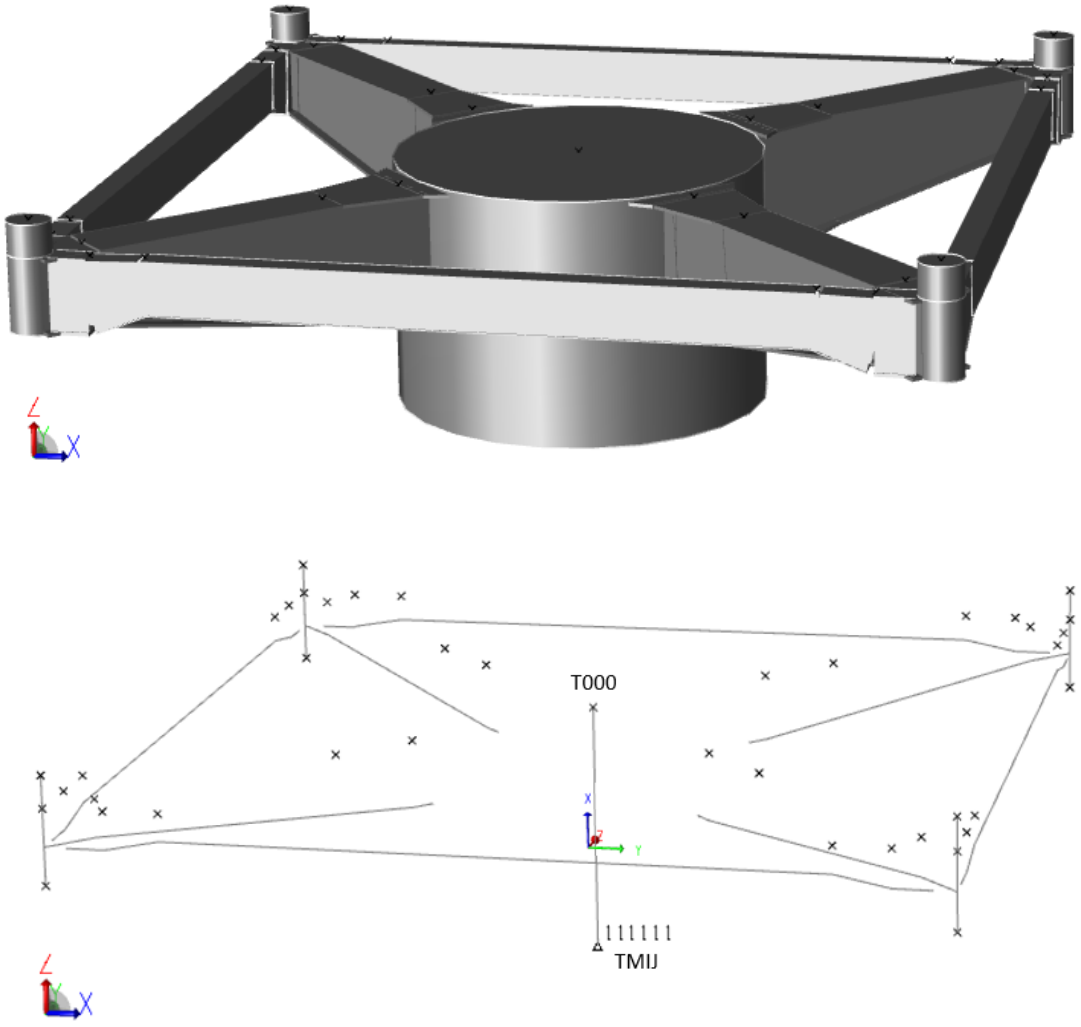


Figure 7.3 – TP SACS model

The following table summarizes the selected maximum forces and moments on TP flange.

In-Service *Load Case (Ref./28/)*	*Note*	*Loads*							
		Fx [kN]	*Fy [kN]*	*Fxy [kN]*	*Mz* (vertical) *[kN]*	*Mx [kNm]*	*My [kNm]*	*Mxy [kNm]*	*Mz* (torsional) *[kNm]*
ON2A	*Max Vertical Force*	*-2749*	*-*	*2749*	*31116*	*24085*	*-43227*	*49484*	*1057*
E13A	*Max Shear Force and Torsional*	*-6819*	*-*	*6819*	*23548*	*31312*	*-90005*	*95296*	*3127*
E13B	*Max Moments*	*-4821*	*-4483*	*6339*	*23548*	*80051*	*-67980*	*105021*	*659*

Table 7.1- Design Loads

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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 8.1 and specified in Refs. /26/ and /27/. 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.

			STEEL NAME						DNV-ST-0145, 2021			
Design Class	Complexity	SQL	Plates and Welded tubular	Sections	SMLS pipes	THK	CVN inpact test	Material designation	Classification of Structural members (DNV-OS-C101)	Plates and Welded tubular	Sections	SMLS pipes
DC1 Complex lift-nodes and element connection to topside, Lift points, main complex joints, TP to monopile flange connection and TP cans	High	I (Z properties)	EN 10225 S420 QLO / MLO EN 10225 S460 QLO / MLO	NA	NA	t <= 12	-	-	Special cat. "S"	NA	NA	NA
						12 < t <= 25	-	-				
						25 < t <= 50	-40	DC1-I-420-40_Z DC1-I-460-40_Z		NV F420 / NV F460 (3)(4)		
						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	Low	II	EN 10225 S420 QLO / MLO EN 10225 S460 QLO / MLO	NA	NA	t <= 12	-		Primary category members "1"	NV F420 / NV F460 (3)(4)	NA	NA
						12 < t <= 25	-20	DC2-II-420-20 / DC2-II-460-20				
						25 < t <= 50	-40	DC2-II-420-40 DC2-II-460-40				
						t > 50	-40					
		I (Z properties)	NA	NA	NA	t <= 12	-	-	Special cat. "S"	NA	NA	NA
						12 < t <= 25	-	-				
						25 < t <= 50	-	-				
						t > 50	-	-				
DC3 all other columns and diagonals, stiffeners, Secondary deck beams, Grillage and sea fastening	High	II	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	Primary category members "1"	NV F36 (4)	NV F36 (4)	NV F36 (4)
						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, bolts	Low	III	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	Secondary category members "2"	NV A36 / AW 36	NV A36 / AW 36	NV A36 / AW 36
						12 < t <= 25	0					
						25 < t <= 50	-	-				
						t > 50	-	-				
DC5 floor plating, grating, Walkways, stairs, handrails	Any	IV	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 / S275 J0H / S355 J0H	t <= 12	10	DC5-IV-235-10 / DC5-IV-275-10 / DC5-IV-355-10 / DC5-IV-GRB-10	Non structural members (NS)	NV A NV A27S	NV A NV A27S	NV A27S
						12 < t <= 25	10					
						25 < t <= 50	-	-				
						t > 50	-	-				

Table 8.1 - Material Selection, Ref /26/

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/mm^2)	Min. Yield Strength (N/mm2)	Steel Type
t ≤ 20	460	355	III
20 < t ≤ 40	460	345	III
40 < t ≤ 63	460	335	III
63 < t ≤ 80	460	325	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 > 50	460/	355/2	IV
16 < t ≤ 40	460	345	IV

Table 8.4 – Mechanical properties for Structural Sections

8.2 BOLTS

Bolts used at the Monopile-Topside interface are class 10.9. According to Eurocode 3 and Material Specification, Refs./9/ and /27/, the following mechanical characteristic values in design have been adopted:

- Yield Strength: f_{yb}= 900 MPa
- Ultimate Tensile Strength f_{ub}=1000 MPa

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9 FE MODEL

The local FE model of the TP connection flange is built using ANSYS, Ref./41/.

The most critical load conditions from In-Service of the BLPH Platform have been applied to the local FE model of the TP flange. The FE model has been used to perform the local checks of structural details analysing the stress distribution and, if occurred, plastic strains entity.

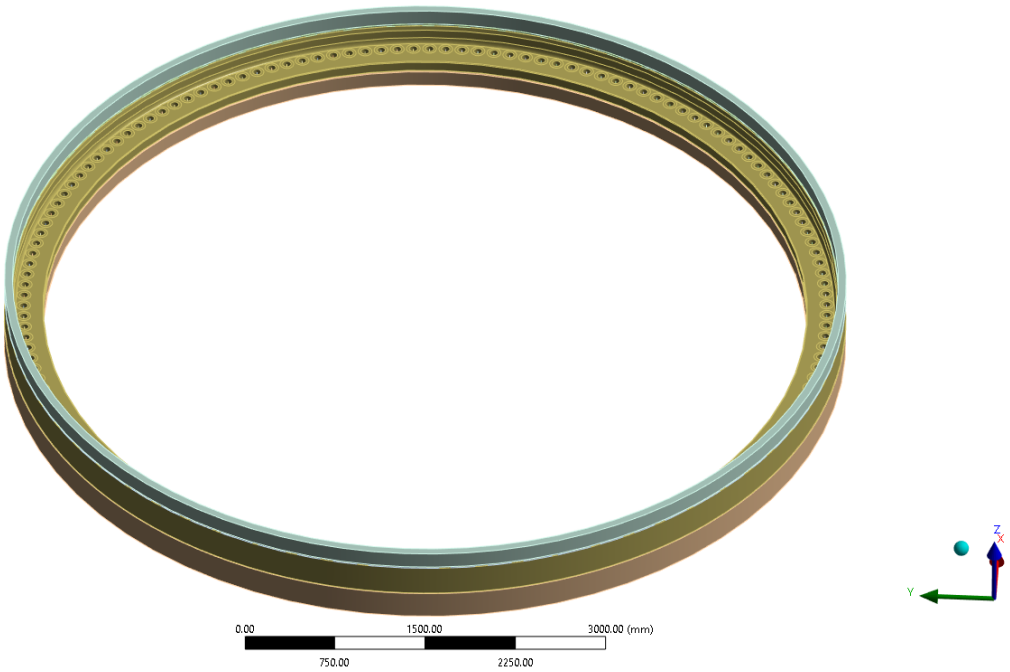
Due the asymmetry of loads and contacts the entire flange has been modelled.

To correctly investigate the stress distribution on the interface connection the FE model includes:

- Portion of TP can (Ø7000x65)
- TP flange
- Monopile Flange

All welds' profiles are included and the geometrical discontinuities as well (fillets, flange gap, etc.). The 156 bolts are modelled using beam elements characterized by proper section properties and connected to the flanges (washer footprint areas) through link elements.

The following figures shows the built model.



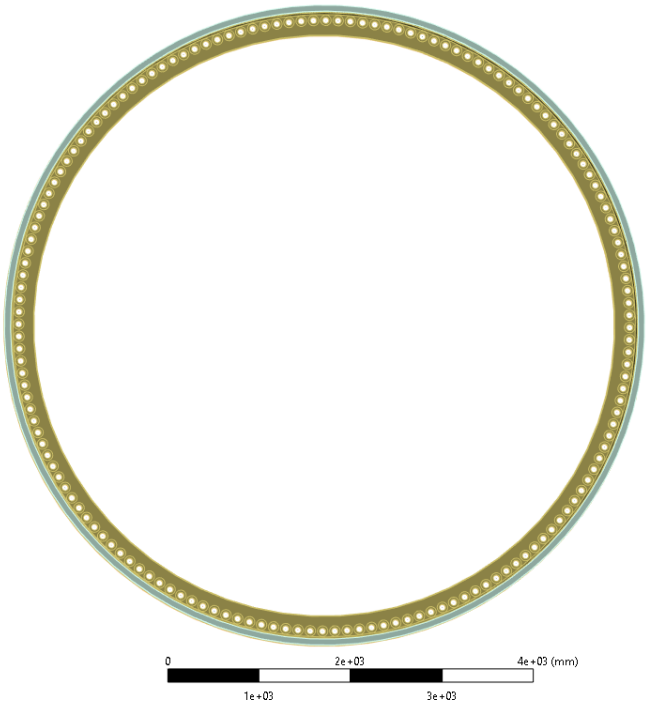


Figure 9.1 – FE Model – Geometry – Global views

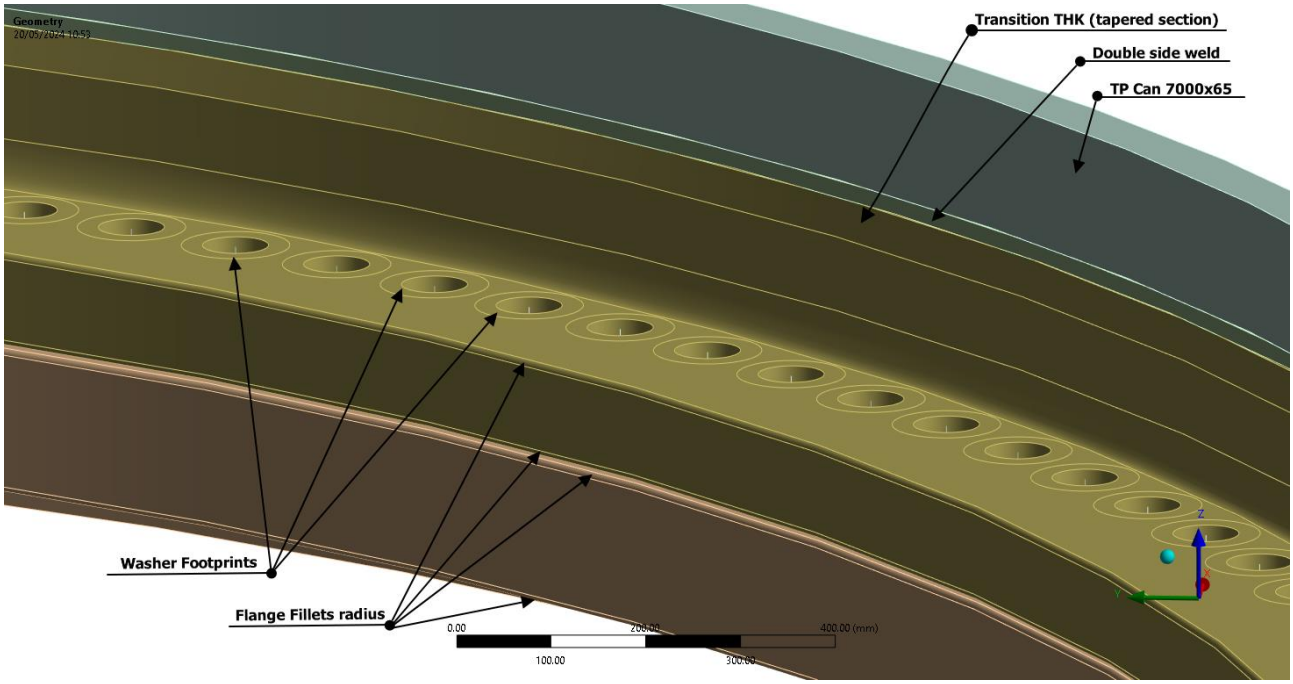


Figure 9.2 – FE Model – Geometry – Detail View

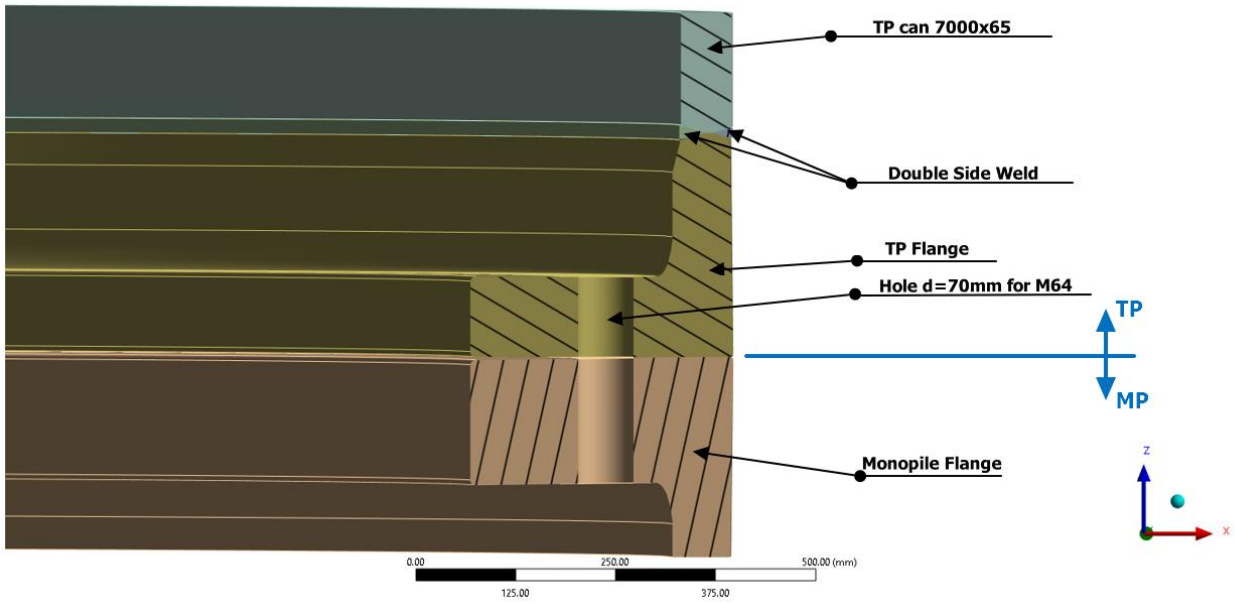


Figure 9.3 – FE Model – Geometry – Transversal Section

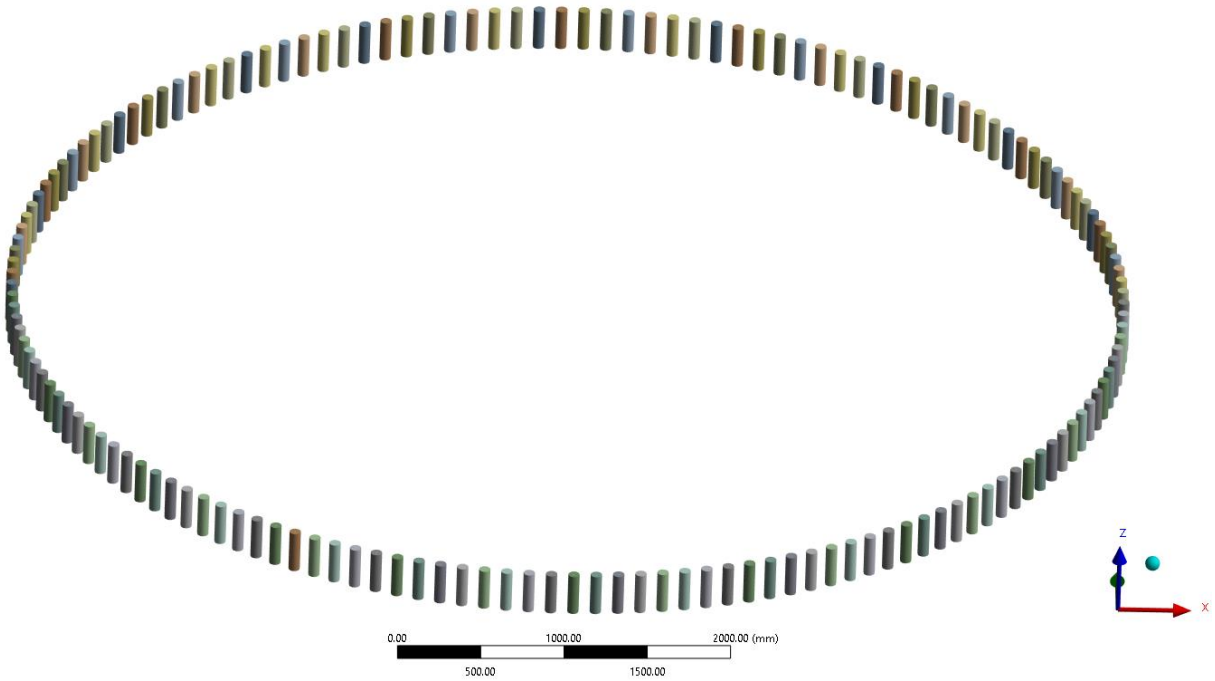


Figure 9.4 – FE Model – Geometry – N.156 M64 Bolts

9.1 MATERIAL MODELLING

The assumed constitutive law for the material is the one proposed by DNV-RP-C208 (Ref./18/) 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 Table 9.1. The curve associated to the previous equation is represented in Figure 9.5.

A Multilinear Kinematic Hardening constitutive law having these features is assigned to the FE model in Ansys Environment.

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 9.1 – S420 steel constitutive law parameters

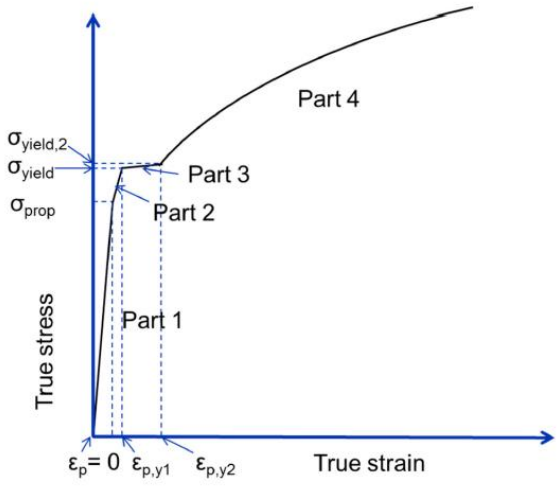


Figure 9.5 – Steel constitutive law according to DNV-RP-C208

10 MODEL MESH

The FE model is made of 3D solids. It is meshed with tetrahedrons and hexahedron elements for solid models. All the elements composing the joint FE model are meshed.

10.1 MESH ELEMENTS

The following mesh elements are used for the developed models:

- SOLID186 (Homogeneous Structural Solid Geometry): is a higher order 3-D 20-node solid element that exhibits quadratic displacement behaviour. The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions. The element supports plasticity, hyperelasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyperelastic materials.

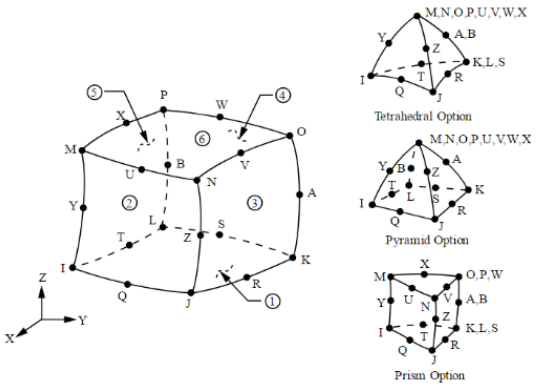


Figure 10.1 – Mesh elements – SOLID186

- SOLID187 (3-D 10-Node Tetrahedral Structural Solid): is a higher order 3-D 10-node element that exhibits quadratic displacement behavior. It is well suited to modelling irregular meshes (such as those produced from various CAD/CAM systems). The element is defined by 10 nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, hyperelasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyperelastic materials.

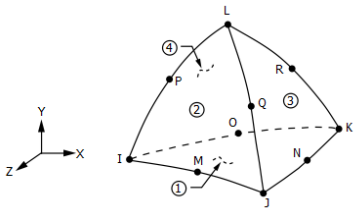


Figure 10.2 – Mesh elements – SOLID187

- 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.

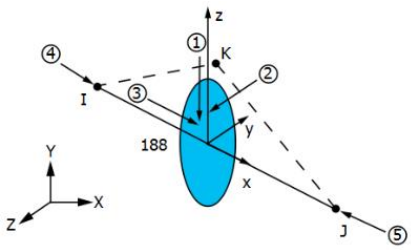


Figure 10.3 – Mesh elements – BEAM188

- 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.

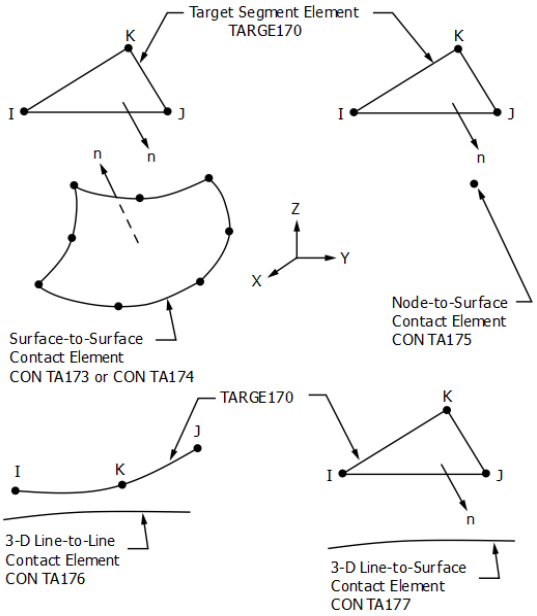


Figure 10.4 – Mesh elements – TARGE170

- 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.

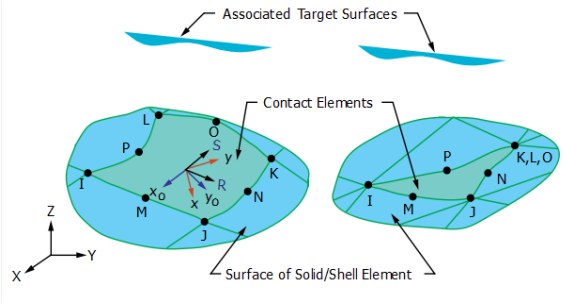


Figure 10.5 – Mesh elements – CONTA174

- MPC184 (rigid link): it represents a general class of multipoint constraint elements that apply kinematic constraints between nodes. The elements are loosely classified here as "constraint elements" (rigid link, rigid beam, etc.) and "joint elements" (revolute, universal, etc).

- PRETS179 (Pretension): it is used to define a 2-D or 3-D pretension section within a meshed structure. The structure can be built from any 2-D or 3-D structural elements (solid, beam, shell, pipe, or link). The PRETS179 element has one translation degree of freedom, UX. (UX represents the defined pretension direction. Only tension loads can be applied; bending or torsion loads are ignored.

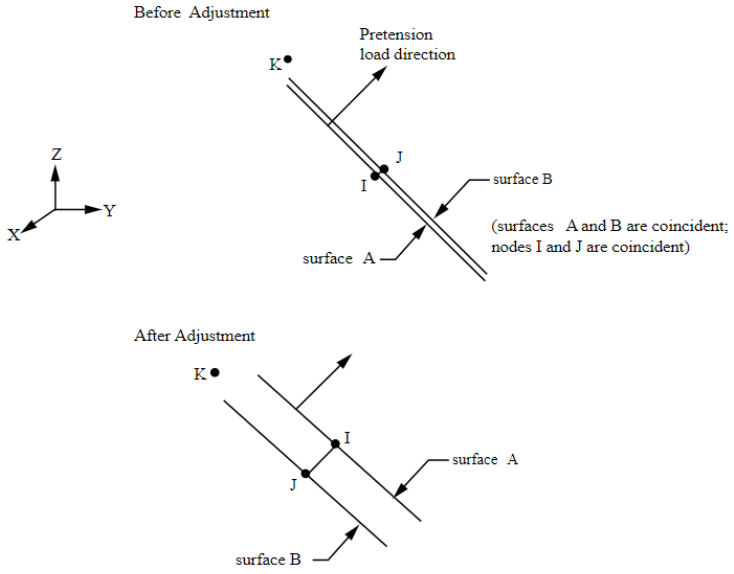


Figure 10.6 – Mesh elements – PRETS179

10.2 MODEL MESH

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

MESH STATISTICS	NUMBER
Nodes	1861838
Elements	1100413

Table 10.1 – TP Flange FE model – Mesh Statistics

The resulting mesh is shown in the following figures.



Figure 10.7: – Model Mesh – Global View

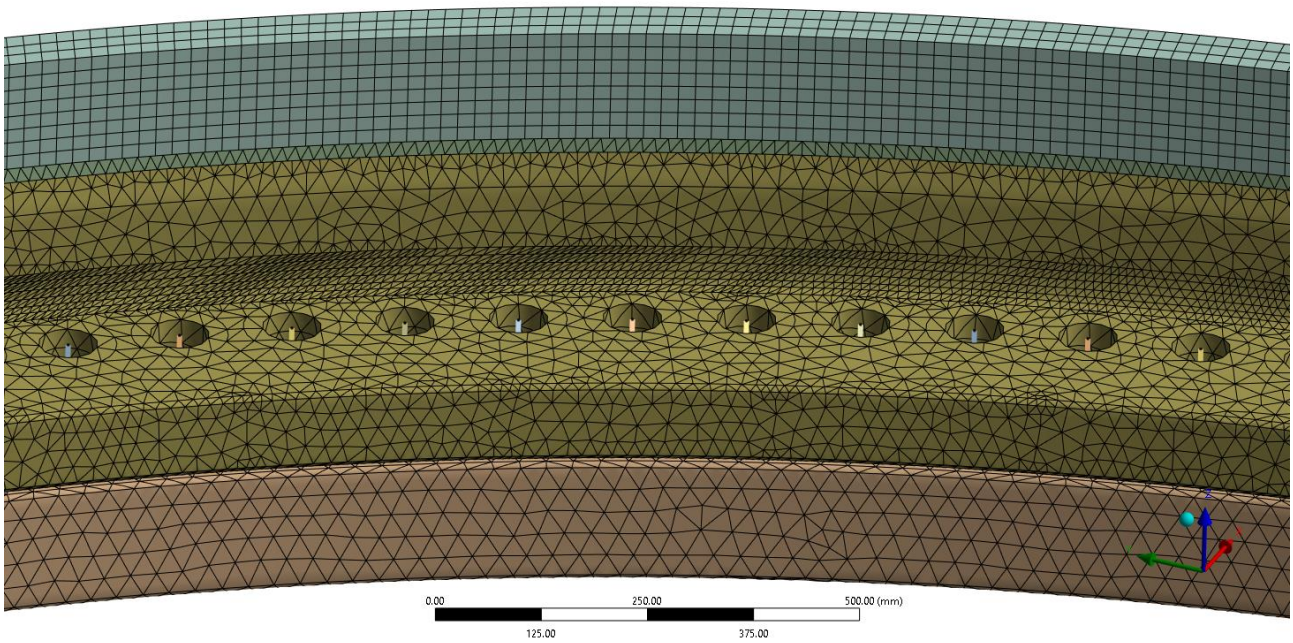


Figure 10.8: – Model Mesh – Detail View

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11 MODEL LOADS

Loads are taken from the In-Service analysis report, Ref./28/, considering all the load combinations coefficients.

The TP flange is checked applying at the same time the maximum design loads. Loads are applied on remote points properly defined at the barycentre of the upper surface.

Design loads are properly amplified by 1.25 corresponding to the Joint Resistance Factor (γ_{M2})

No resistance factor (γ_{M7}) is instead applied on bolt preloads.

11.1 BASIC LOAD CASES AND LOAD COMBINATIONS

The general basic load cases of BLPH Platform are defined in the In-Service, Ref./28/.

The same sets of loads and combinations are maintained. Joints local stress states are computed for the most critical load combinations for the In-Service as per relative report, Ref./28/.

11.2 BOLT PRELOADS

The high strength bolt nominal minimum preload is calculated according to the DNV-ST-0126, Ref./19/ as follow:

$$F_{pC*} = 0.7 f_{yb} A_s = 1686kN$$

Where: $f_{yb} = 900MPa$ is the nominal value of characteristic yield resistance of bolt material

A_s is the net area in the threaded part of the bolt calculated using the following formulation

$$A_s = 0.7854[d - (0.9382P)]^2 = 2676mm^2$$

With: d=64mm is the nominal shank bolt diameter

P=6 is the pitch, axial distance between two adjacent threads

The preload is applied in ANSYS on load STEP 1 and then locks in the STEP 2. The following figure shows the applied preloads ($156F_{pC*}$).

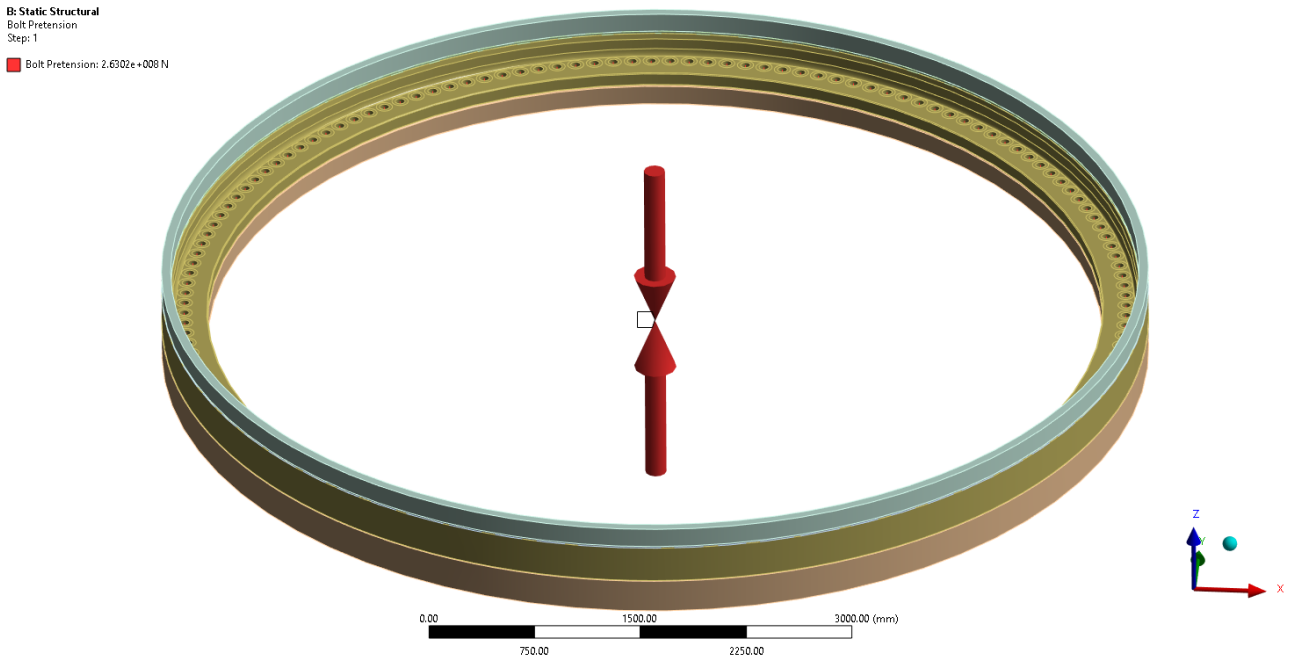


Figure 11.1: – TP Flange FE model – Bolts Preloads

11.3 IN-SERVICE LOADS

The following table summarizes the applied forces and moments applied on proper remote points defined at the barycentre of the modelled surface.

In-Service *Load Case (Ref./28/)*	*ANSYS Load Step*	*Design Loads*					
		Fx [kN]	*Fy [kN]*	*Mz* (vertical) *[kN]*	*Mx [kNm]*	*My [kNm]*	*Mz* (torsional) *[kNm]*
ON2A	*3*	*-3436*		*38895*	*30106*	*-54034*	*1321*
E13A	*4*	*-8524*		*29435*	*39140*	*-112506*	*3909*
E13B	*5*	*-6026*	*-5604*	*29435*	*100064*	*-84975*	*824*

Table 11.1 – TP Flange FE model – In-Service Design Loads

The following figures show the applied forces and moments.

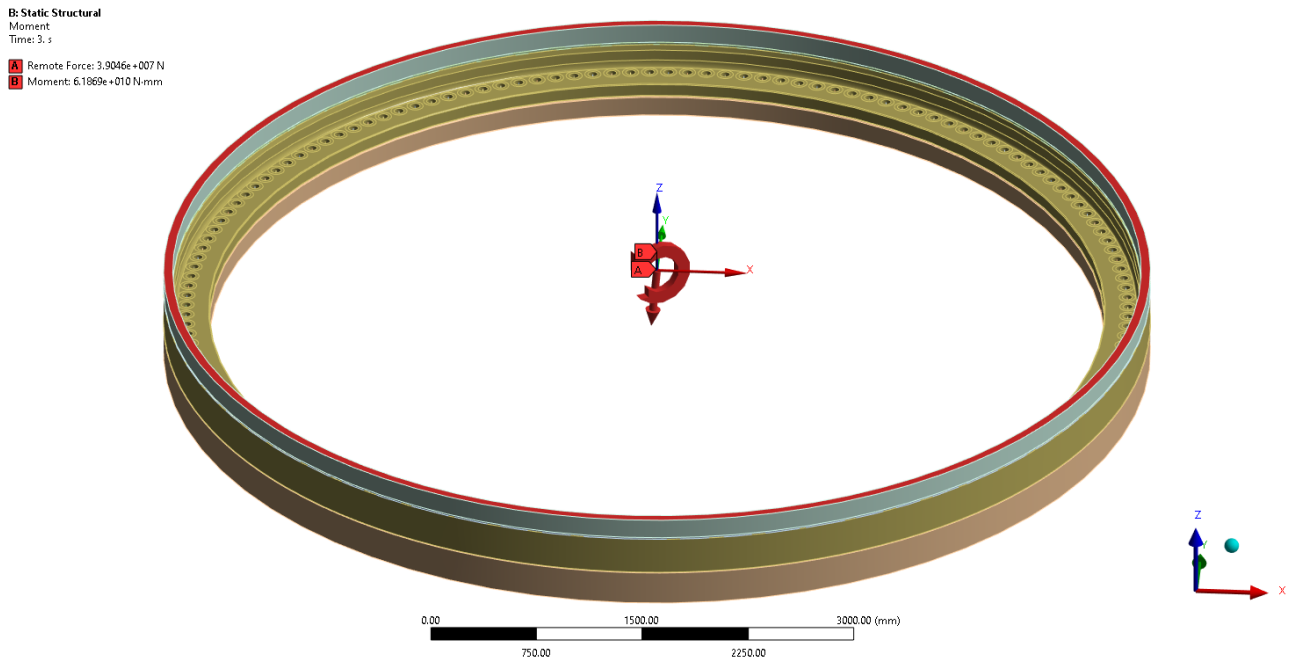


Figure 11.2: – TP Flange FE model – In-Service Design Loads – LC: ON2A (STEP 3)

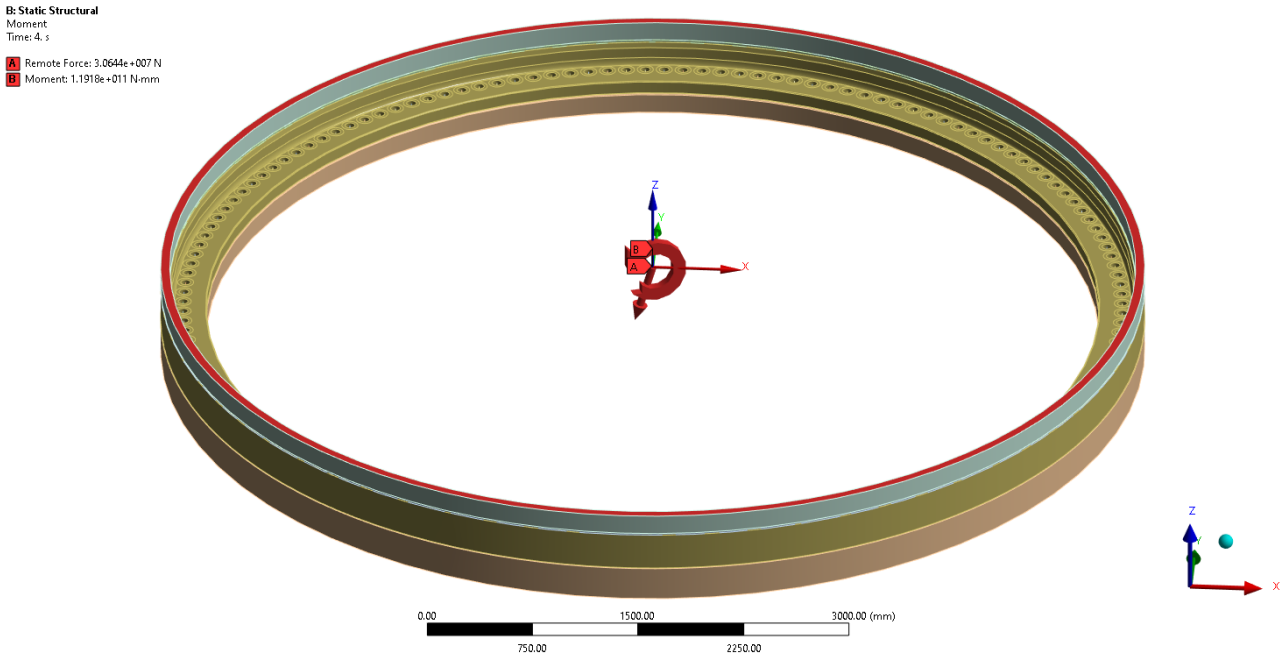


Figure 11.3: – TP Flange FE model – In-Service Design Loads – LC: E13A (STEP 4)

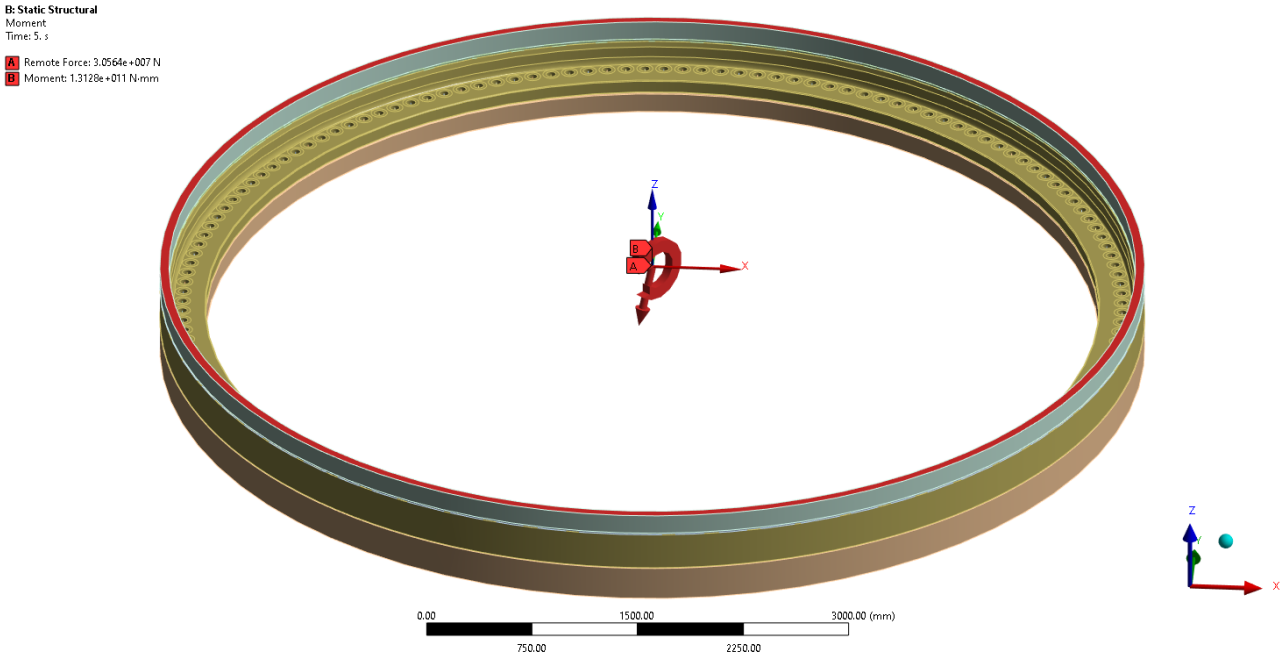


Figure 11.4: – TP Flange FE model – In-Service Design Loads – LC: E13B (STEP 5)

12 RESTRAINTS

The same boundary conditions defined in the original SACS model were recreated in the joint local FE model.

The bottom of the modelled monopile surface has been fully restrained (all translations and rotations are fixed).

The following figure shows the applied restraint.

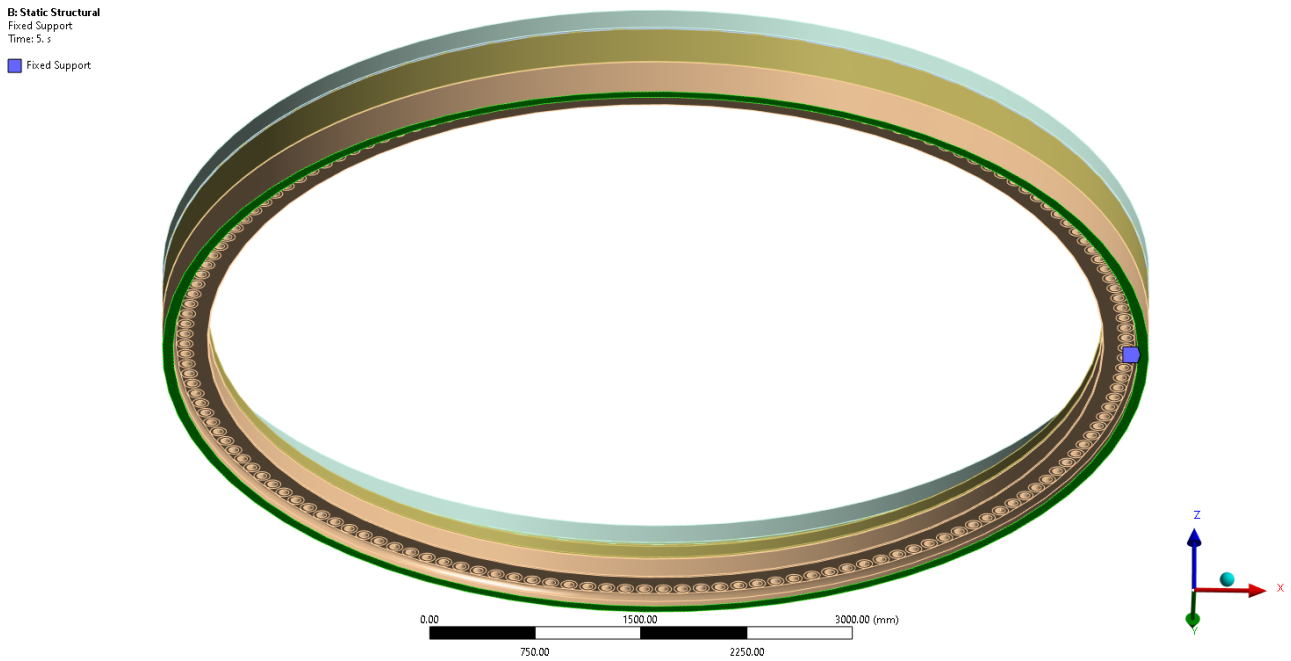


Figure 12.1: – TP Flange FE model – Restraints

13 CONTACTS

The TP flange is connected to the corresponding Monopile flange 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. Used to simulate the connection between the two opposite flange surfaces.



Figure 13.1: – FE model – Flanges contact

- *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.

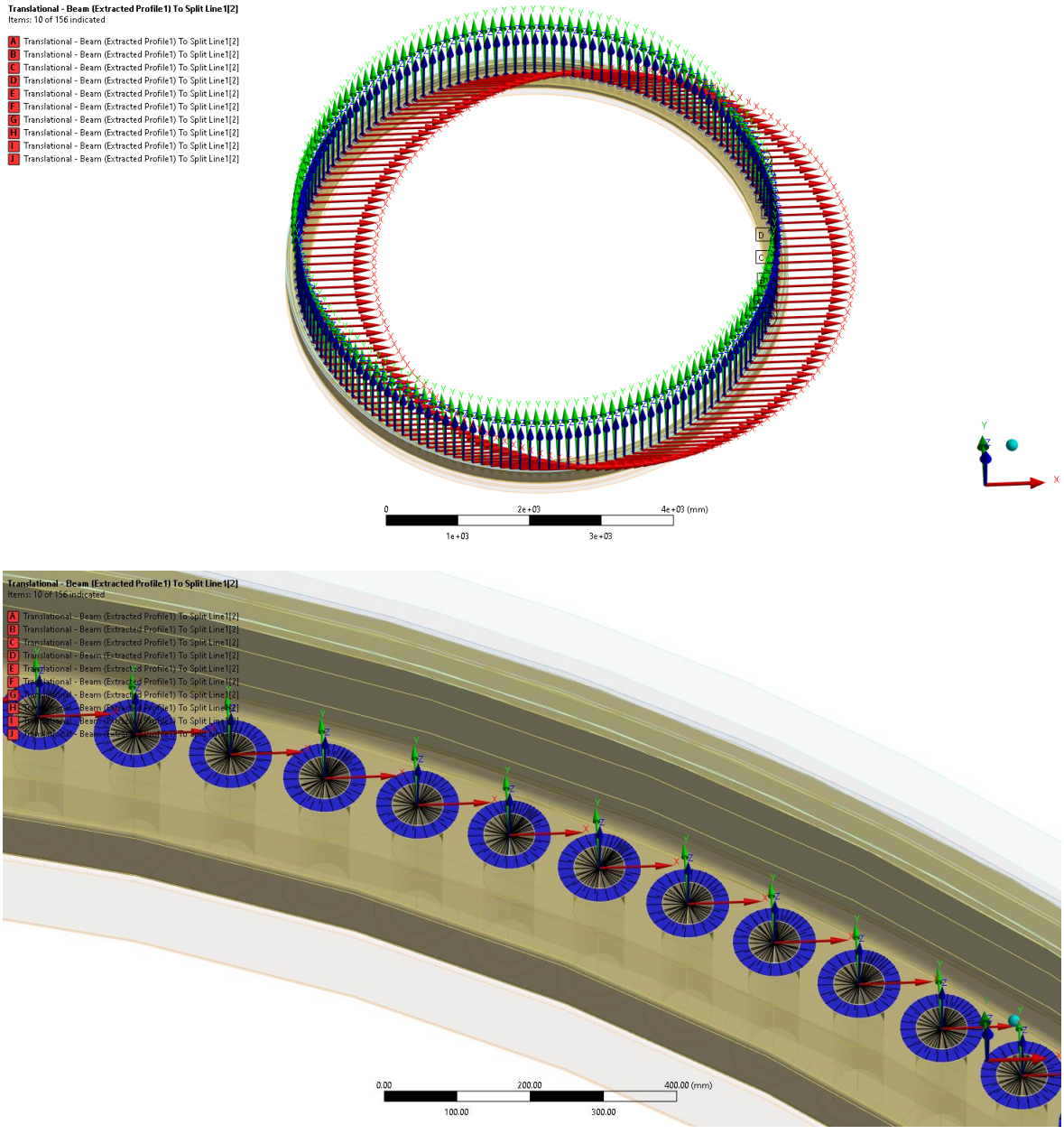


Figure 13.2: – FE model – Connection between Bolts Ends – Washer Footprints on Flanges

14 DESIGN CRITERIA AND REQUIREMENTS

14.1 GENERAL

Structures in SOW is designed in accordance with limit states approach of ISO codes 19901 and 19902, Refs./2/, /4/and /7/. For non-tubular sections, Eurocode, Ref./9/, 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 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 0;
- F_d is the design value of action;
- F_r is the characteristic value of action;
- γ_F is the partial action factor reported in Sec.14.2.

Design according to the provisions for load and resistance factor design (LRFD) of EC3, ref. /9/, 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.14.2
- ϕ Rn = design strength.

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14.2 PARTIAL RESISTANCE FACTORS

14.2.1 Partial Resistance Factors for Tubular Sections:

The partial resistance factors for tubular sections from ISO 19902, Ref./7/, 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 14.1- Resistance Factors for Tubular Sections

14.2.2 Partial Resistance Factors for Non-tubular Sections

The partial resistance factors for non-tubular sections from Eurocode 3, Ref./9/, 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 14.2- Resistance for Non Tubular Section

14.3 ACCEPTANCE CRITERIA

FE checks are performed comparing the resulting Von Mises stresses for each analysis with the allowable stresses defined as per Eurocode, Ref./9/, and ISO 19902, Ref./7/. Allowable stresses in terms of ultimate strength (LRFD) are defined using the material strengths listed in Sec.9.1 and the partial resistance factors listed in Sec.14.2:

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

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./5/) 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.

The bolts are checked according to the requirements of DNV-ST-0126, Ref./19/. The Design Tension Resistance $F_{t,Rd}$ of the individual bolt is:

$$F_{t,Rd} = \frac{0.9 f_{ubA_s}}{\gamma_{M2}}$$

Where:

- f_{ub} = Ultimate Tensile Stress
- A_s = Bolt tensile stress
- γ_{M2} = Partial resisting factor for bolts

15 RESULTS

The TP Flange is checked for the most critical in-service loads acting on each support as reported in previous Section 11.

The FE results are evaluated in terms of:

- Von-Mises stress
- Pressure on contact surface between flanges
- Internal loads on Bolts

15.1 VON-MISES STRESS

15.1.1 Load STEP 1 (Bolts Preload)

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

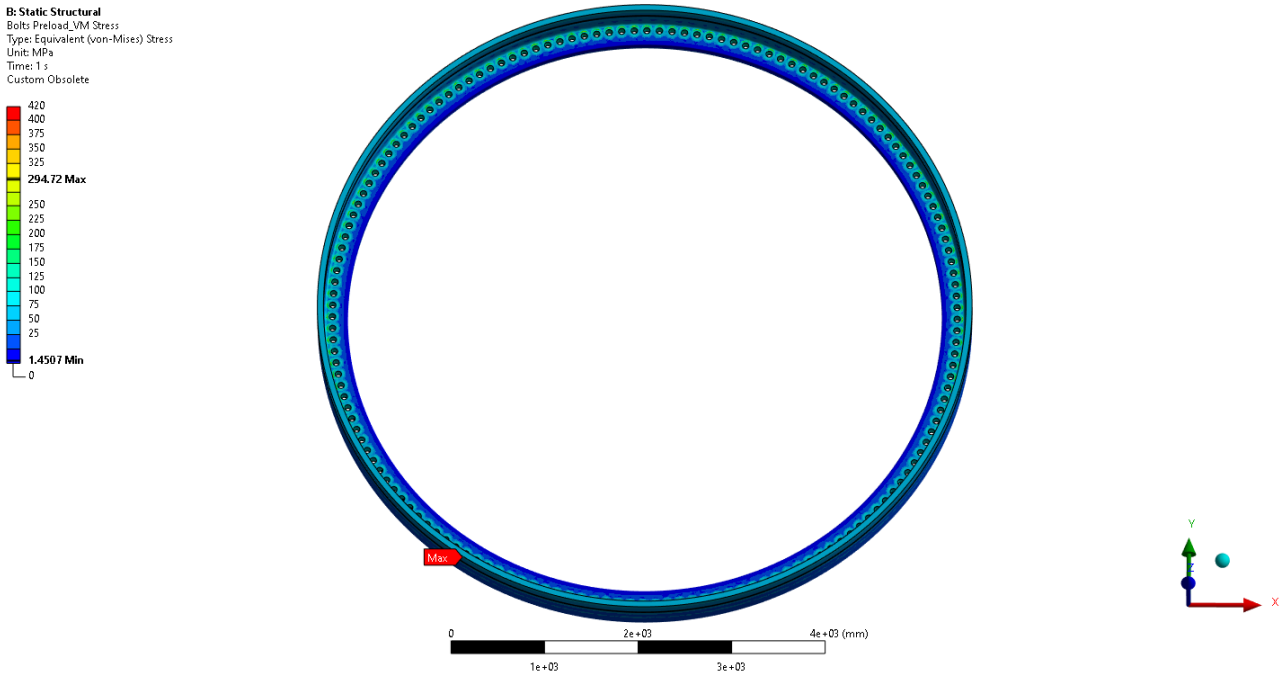


Figure 15.1 – STEP 1 (bolt preloads) – VM Stresses

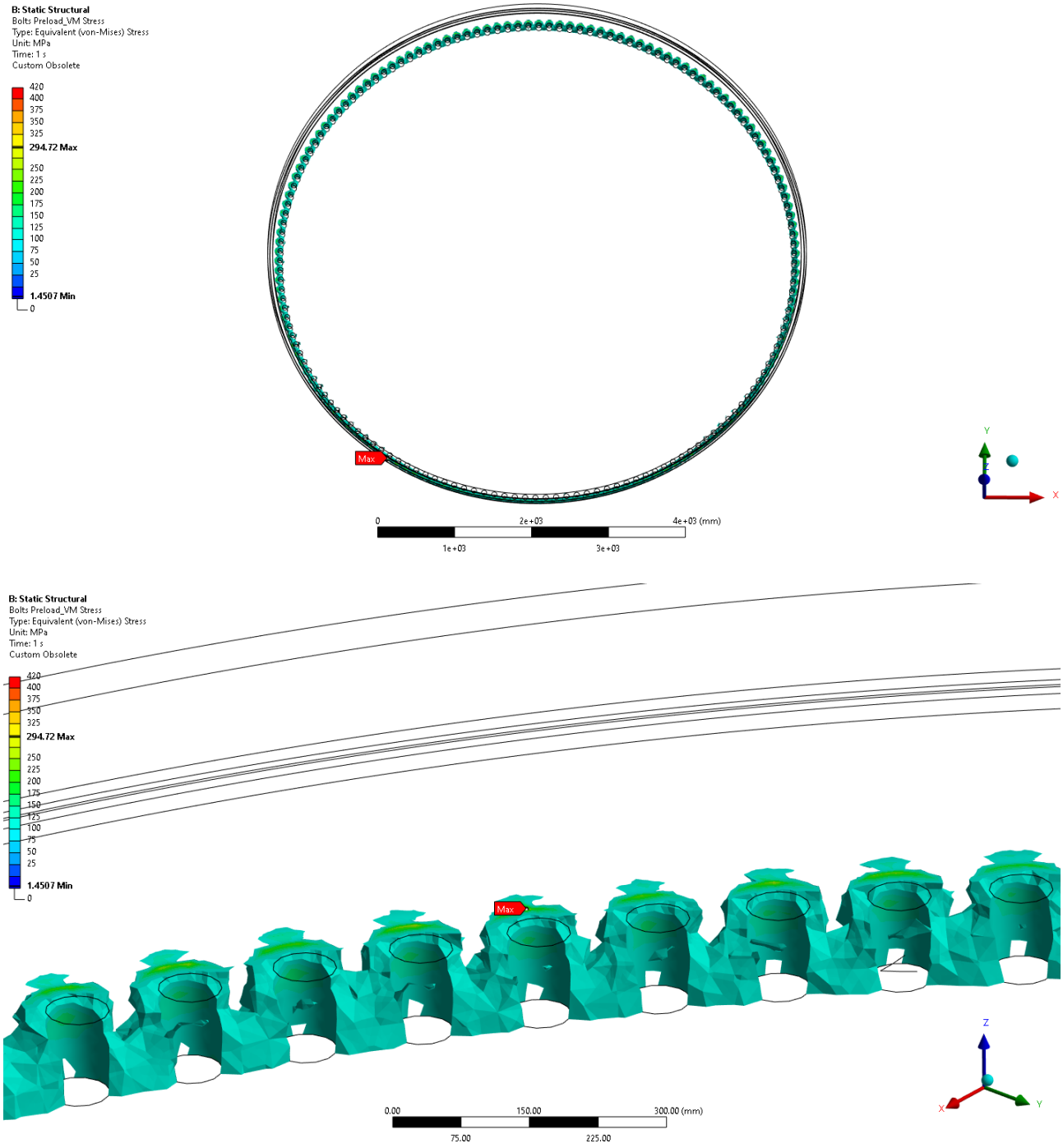


Figure 15.2 – STEP 1 (bolt preloads) – VM Stresses > 100 MPa

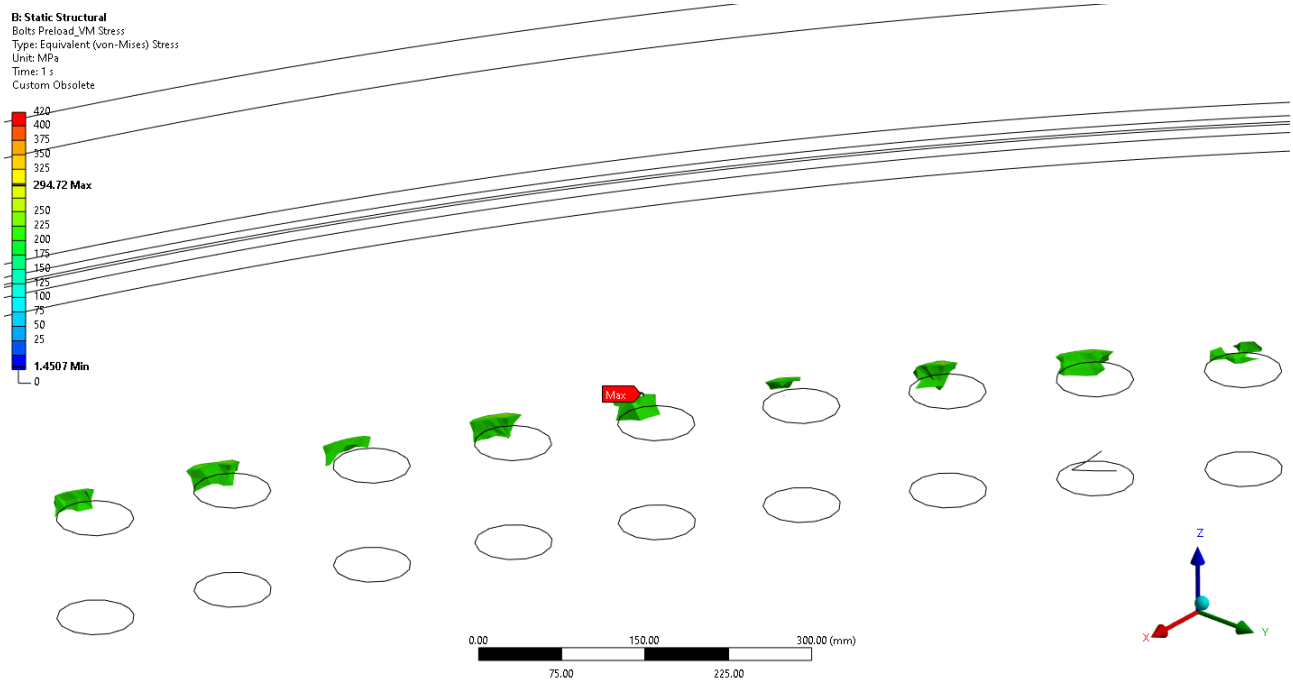


Figure 15.3 – STEP 1 (bolt preloads) – VM Stresses > 200 MPa

As expected, the bolt preloads lead to a concentration of stress in correspondence of the washer footprints (connected areas) in the proximity of the elliptical radius connecting the horizontal flange and the vertical pipe.

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15.1.2 Load STEP 3 (LC: ON2A)

As anticipated STEP 2 is the phase where the preload of bolts is locked.

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

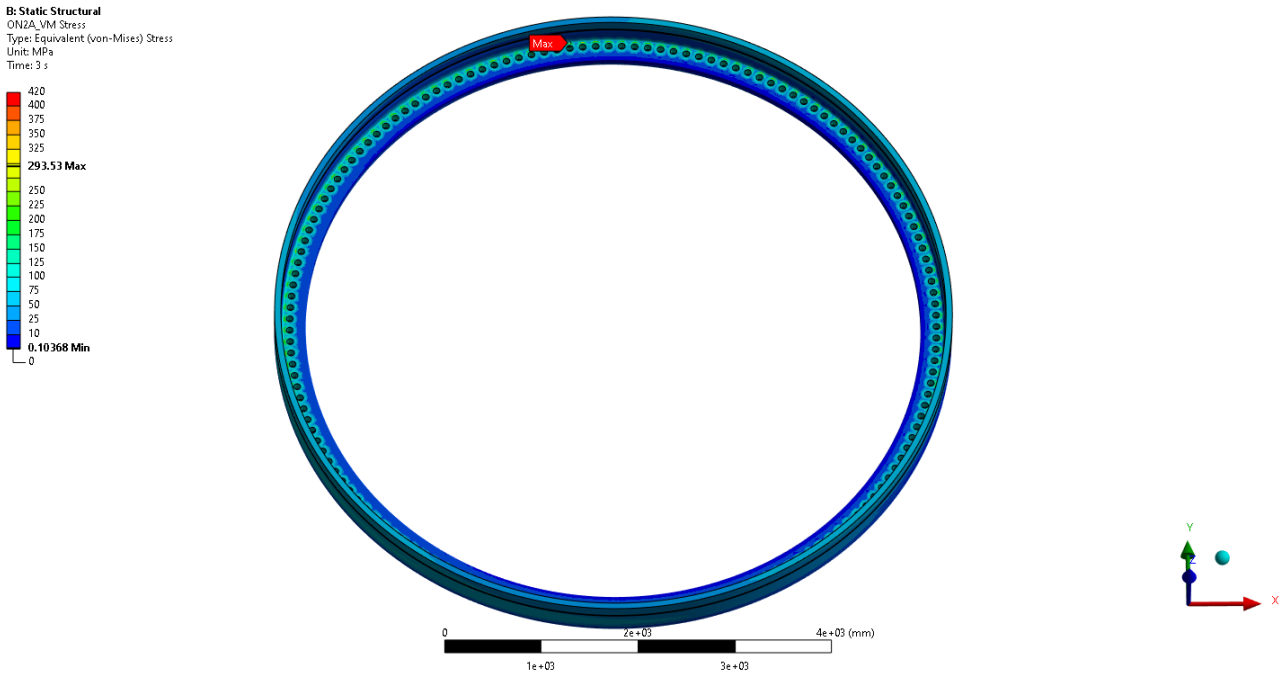


Figure 15.4 – STEP 3 (LC:ON2A) – VM Stresses

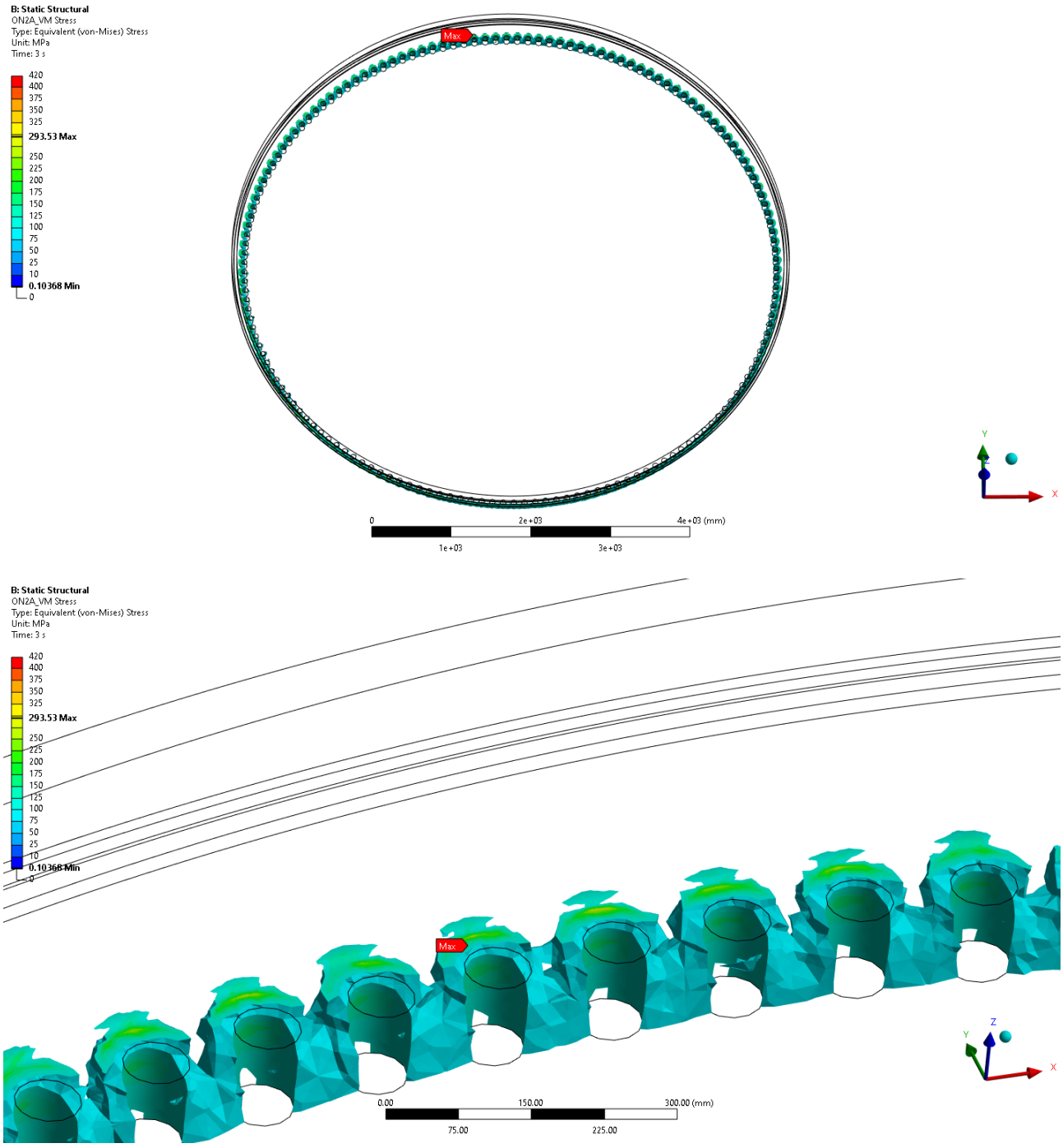


Figure 15.5 – STEP 3 (LC:ON2A) – VM Stresses > 100 MPa

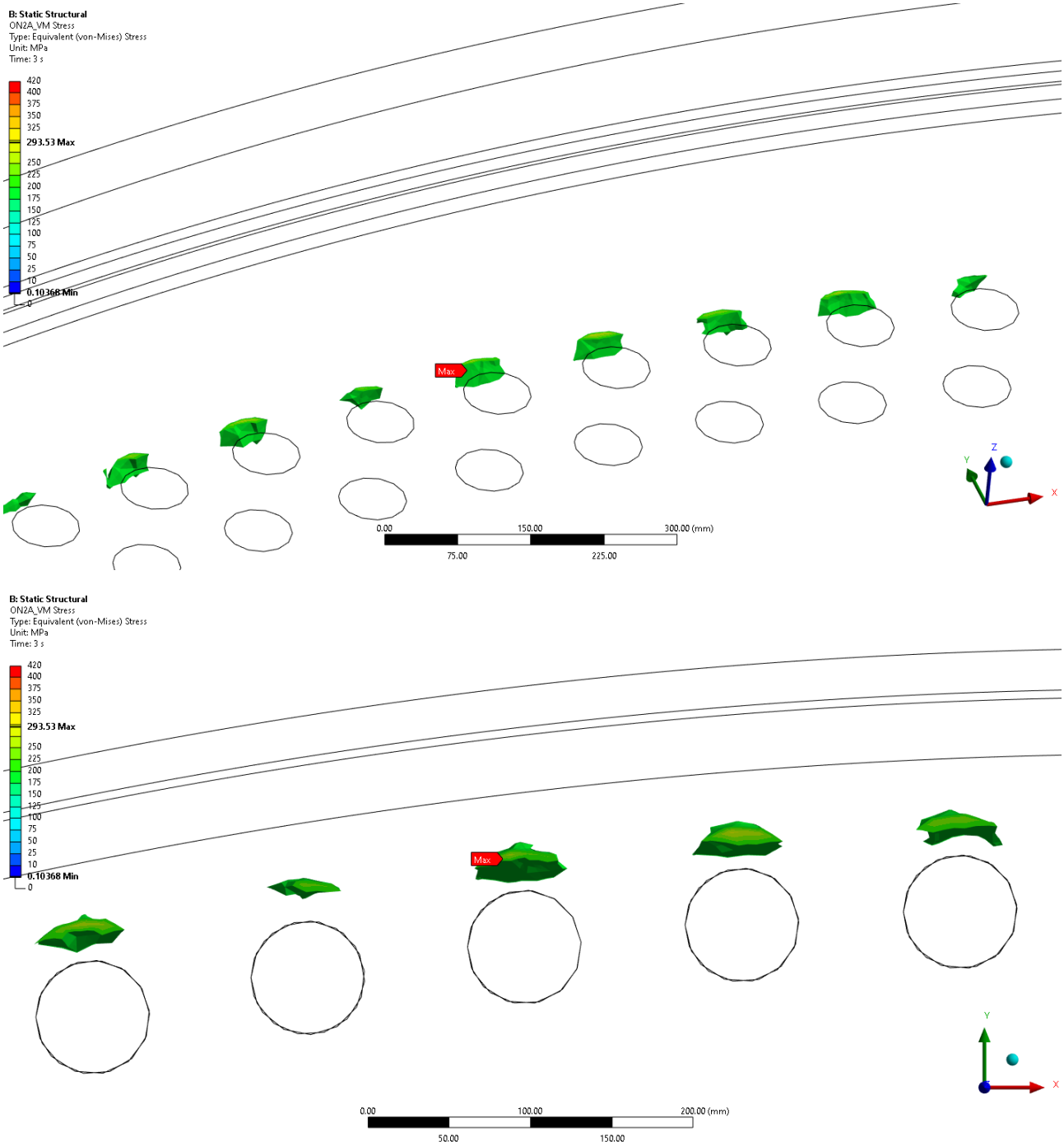


Figure 15.6 – STEP 3 (LC:ON2A) – VM Stresses > 200 MPa

Structural checks are performed comparing the resulting VM sess with the Yield stress due the application of the Partial Resistance Factor at loads.

It can be observed that the max VM stresses is 294MPa, lower than the Yield stress for t>63 mm, F_y = 340 MPa. It occurs in proximity of the bolt holes, and it largely depends on their pretension.

The following figure shows the VM stress on double side weld connecting the TP can to the flange.

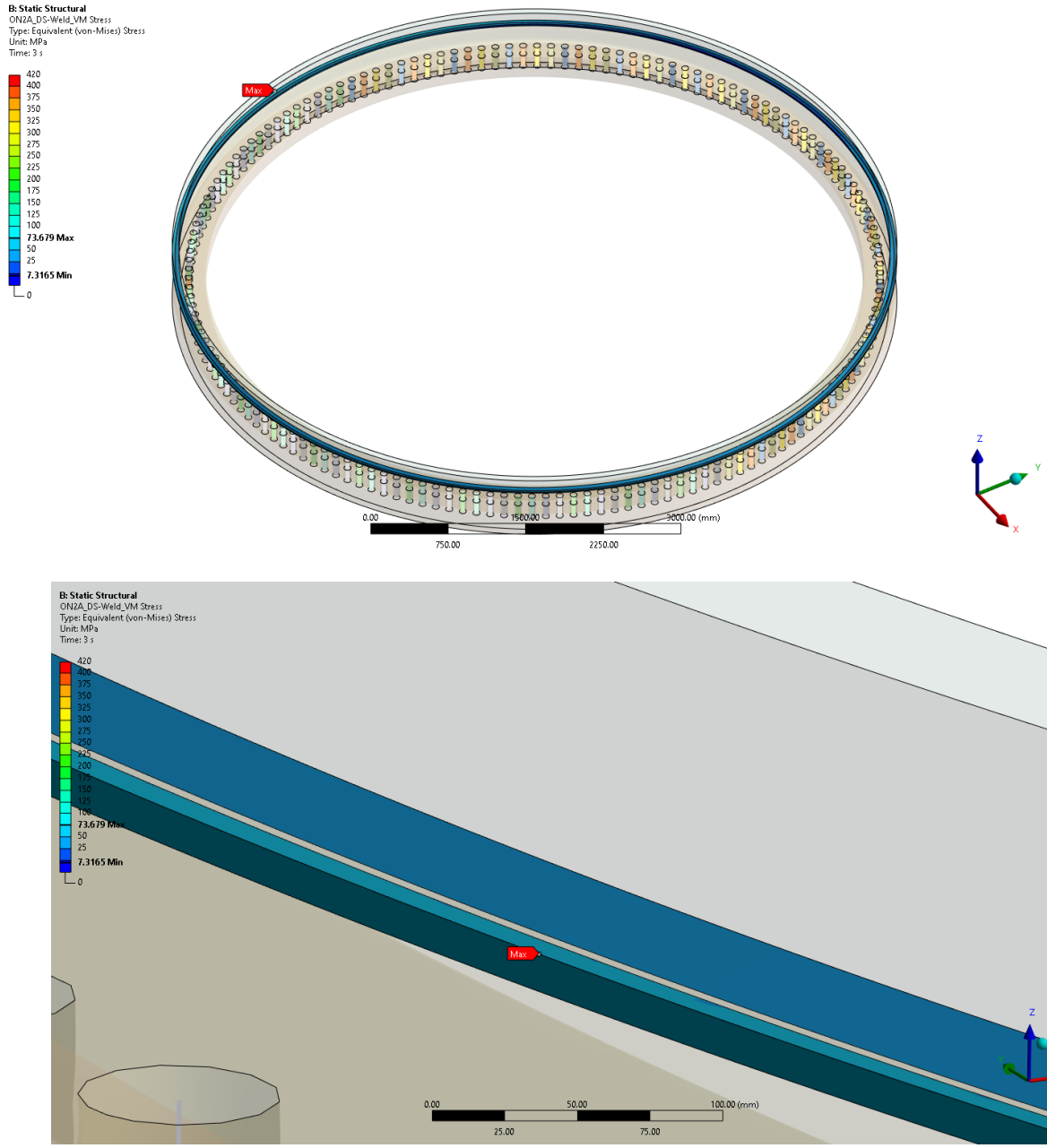


Figure 15.7 – STEP 3 (LC:ON2A) – VM Stresses on Double Side Weld

The maximum VM stress on double side weld for the operative load case ON2A is 74MPa.

15.1.3 Load STEP 4 (LC: E13A)

In the following figures, the Von Mises stresses for the TP flange are shown.

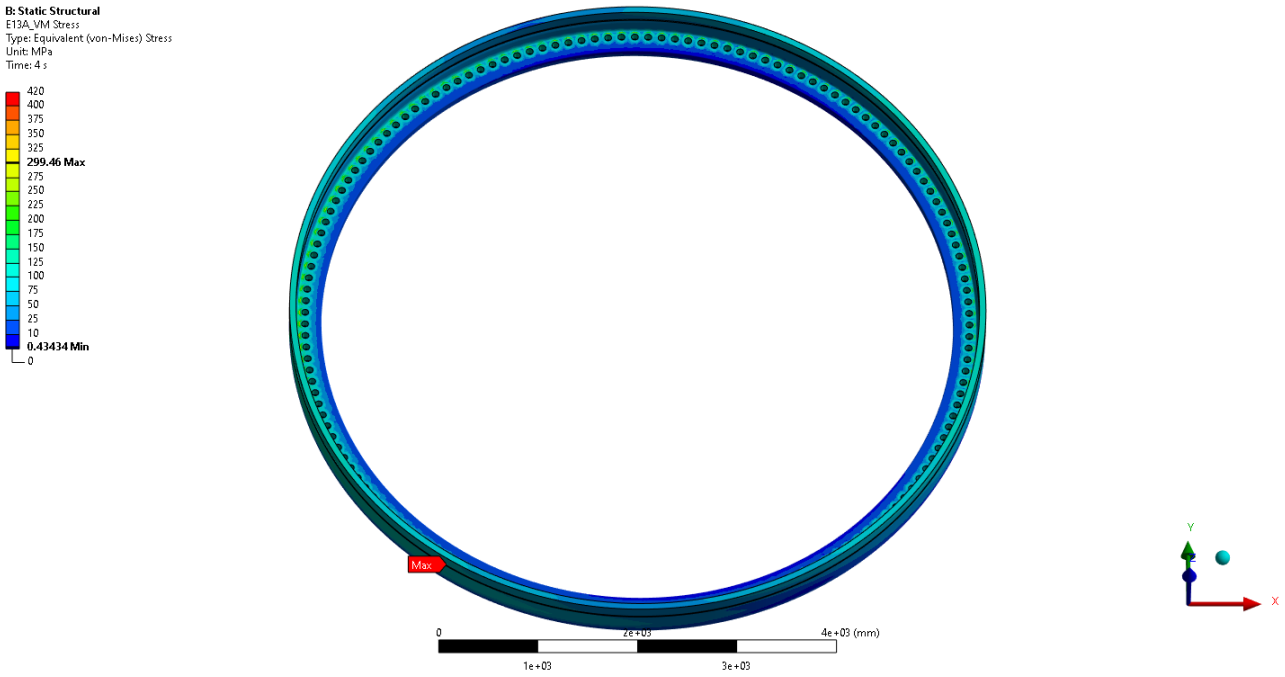


Figure 15.8 – STEP 4 (LC:E13A) – VM Stresses

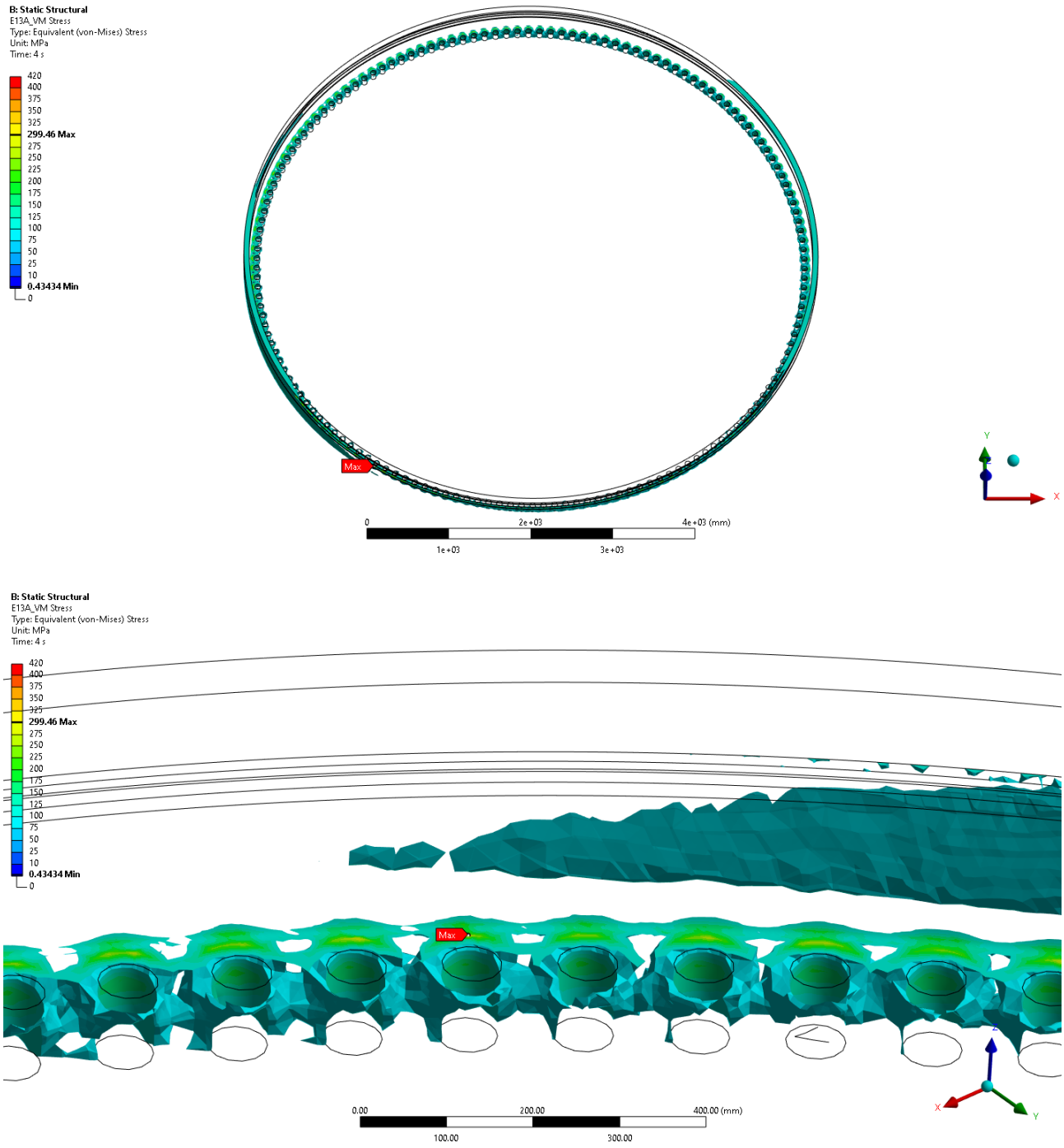


Figure 15.9 – STEP 4 (LC:E13A) – VM Stresses > 100 MPa

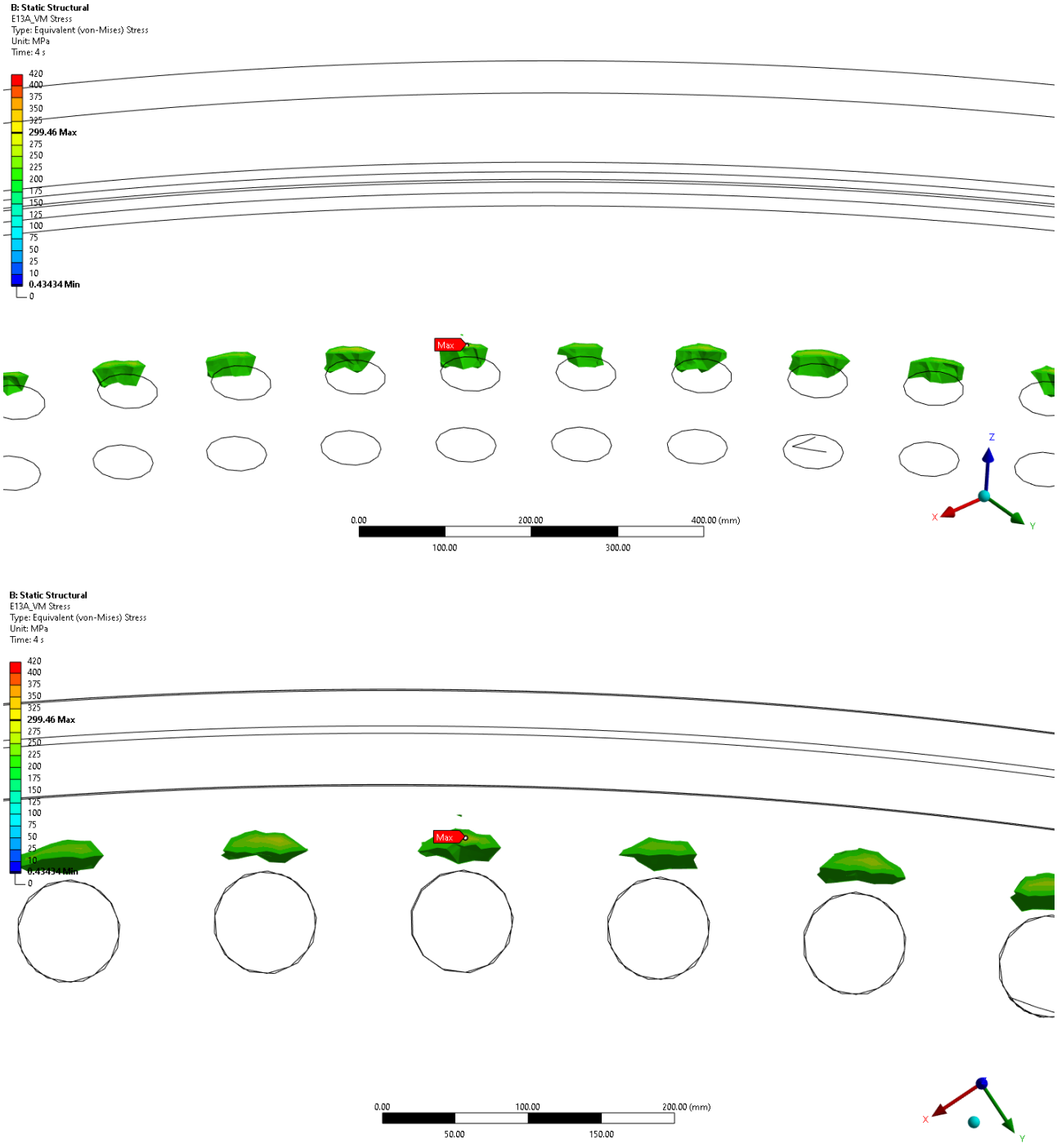


Figure 15.10 – STEP 4 (LC:E13A) – VM Stresses > 200 MPa

It can be observed that for the load case E13A the max VM stresses value is 299MPa, far from the Yield stress for t>63 mm, F_y = 340 MPa. It occurs in proximity of the bolt holes, at the base of the elliptical fillet.

The following figure shows the VM stress on double side weld connecting the TP can to the flange.

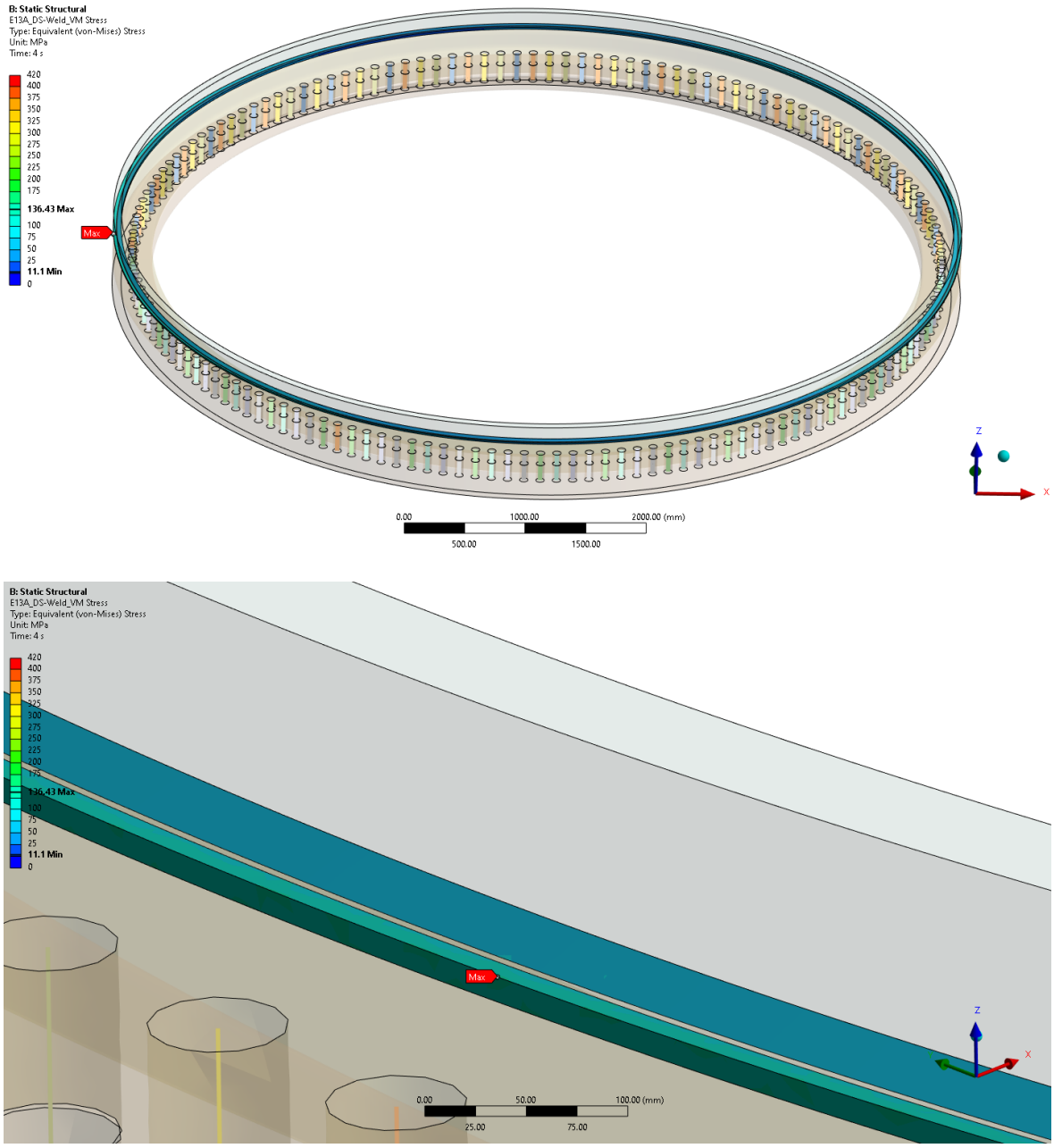


Figure 15.11 – STEP 4 (LC:E13A) – VM Stresses on Double Side Weld

The maximum VM stress on welds for the extreme load case E13A is 137MPa.

15.1.4 Load STEP 5 (LC: E13B)

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

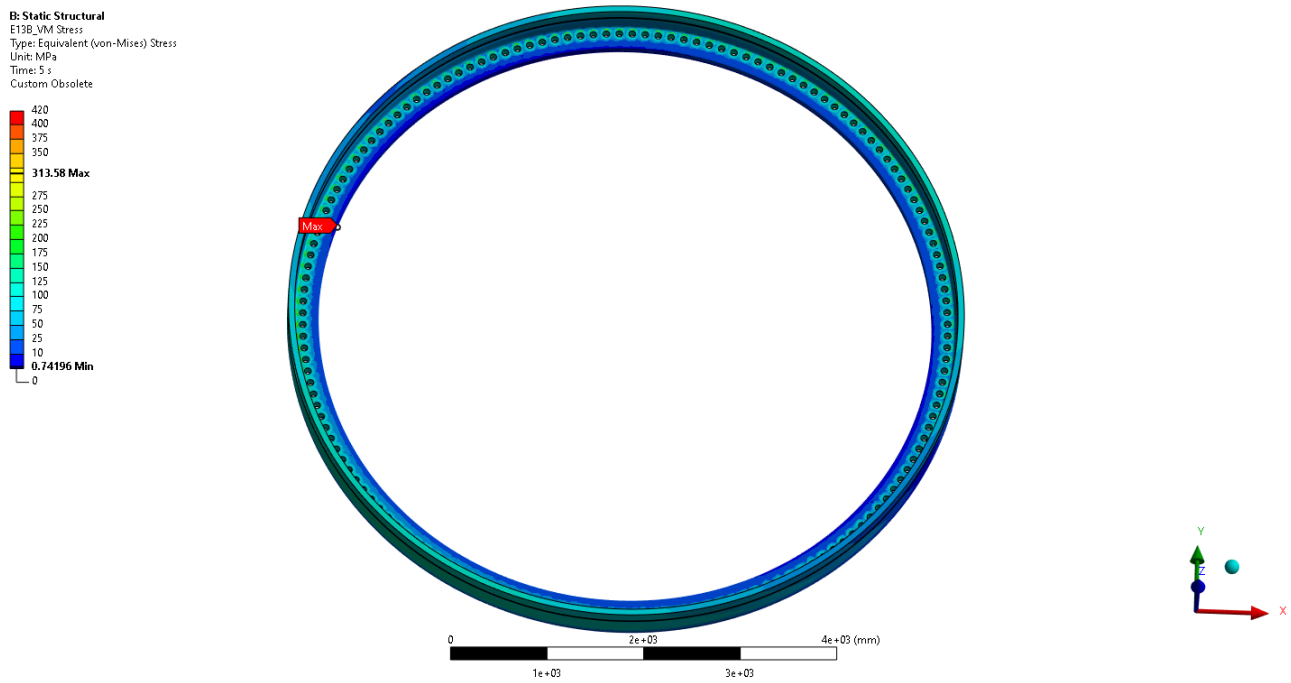


Figure 15.12 – STEP 4 (LC:E13A) – VM Stresses

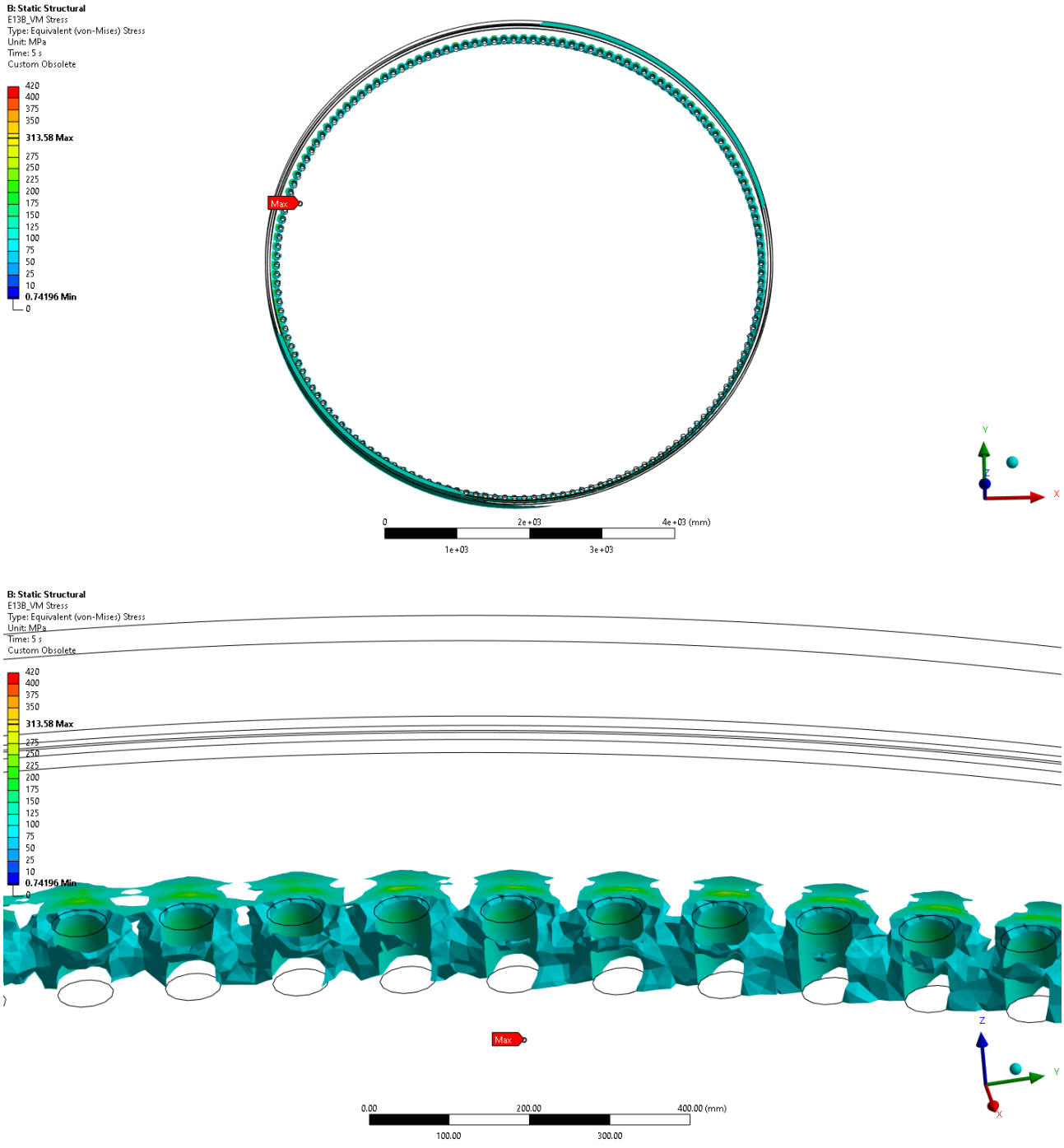


Figure 15.13 – STEP 4 (LC:E13A) – VM Stresses > 100 MPa

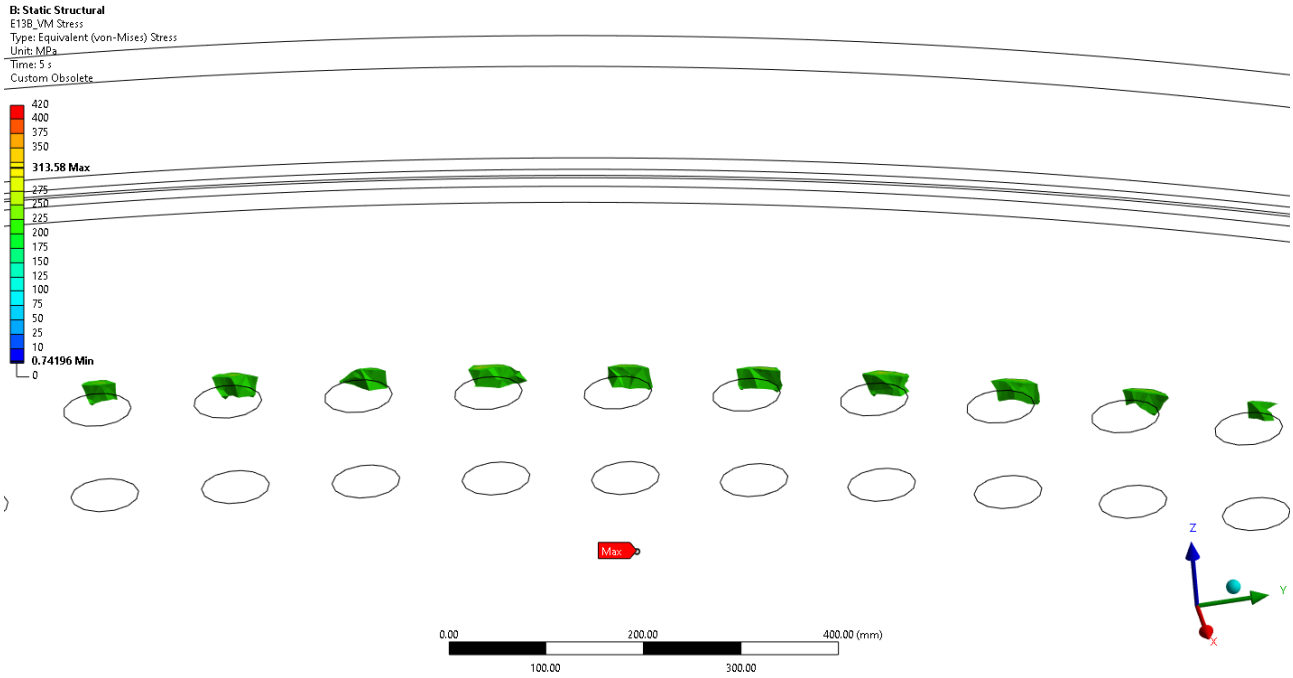


Figure 15.14 – STEP 4 (LC:E13A) – VM Stresses > 200 MPa

It can be observed that for the load case E13A the max VM stresses value is 313MPa, lower than Yield stress for t>63 mm, F_y = 340 MPa. It is a singularity in correspondence of the contact between flanges.

The following figure shows the VM stress on double side weld connecting the TP can to the flange.

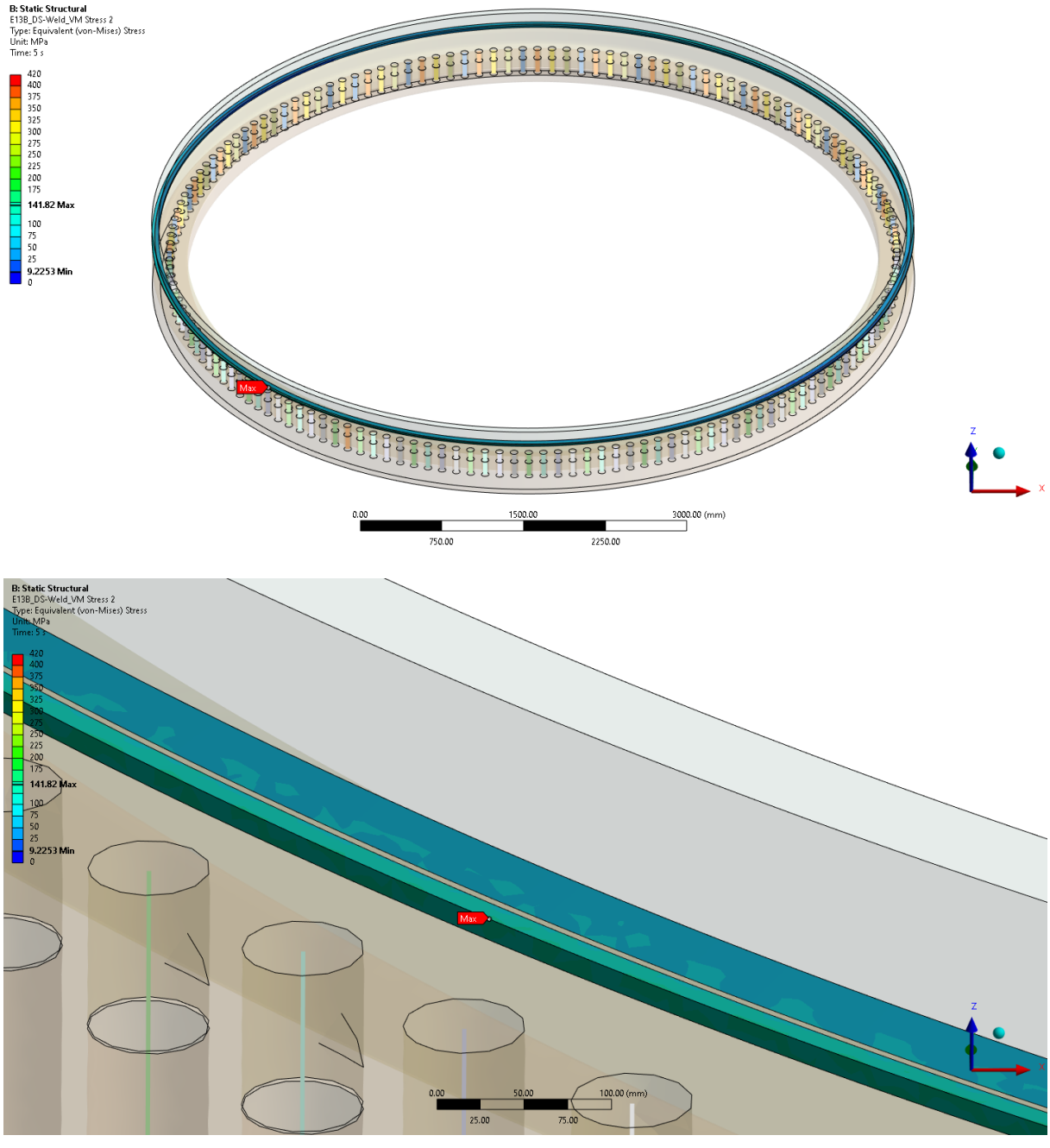


Figure 15.15 – STEP 5 (LC:E13B) – VM Stresses on Double Side Weld

The maximum VM stress on welds for the extreme load case E13B is 142MPa.

15.1.5 Conclusions

The following tables summarize the maximum VM stress on the TP flange and Double Side Weld respectively resulting from the analyzed load conditions. The allowable stress corresponds to the Yield stress because the Partial Resistance Factor has been applied on loads.

In-Service *Load Case (Ref./28/)*	*ANSYS STEP*	*Max Pressure on Contact* [MPa]	σ_{adm} *(Fy) [MPa]*	*UC*
Bolt Preload	*1*	*294*	*340*	*0.86*
ON2A	*3*	*294*	*340*	*0.86*
E13A	*4*	*299*	*340*	*0.88*
E13B	*5*	*314*	*340*	*0.92*

Table 15.1- TP Flange Structural Checks

In-Service *Load Case (Ref./28/)*	*ANSYS STEP*	*Max Pressure on Contact* [MPa]	σ_{adm} *(Fy) [MPa]*	*UC*
ON2A	*3*	*74*	*380*	*0.19*
E13A	*4*	*137*	*380*	*0.36*
E13B	*5*	*142*	*380*	*0.37*

Table 15.2- Double Side Structural Checks

As shown above the TP flange and the relevant connecting double side weld remain on the elastic field of the material curve. Therefore, no plastic strain occurs on the analysed components.

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15.2 PRESSURE ON FLANGE CONTACT

15.2.1 Load STEP 1 (Bolts Preload)

The following figure plots the pressure resulting on the contact between the TP and Monopile flanges in the STEP 1 corresponding to the Bolt Preload.

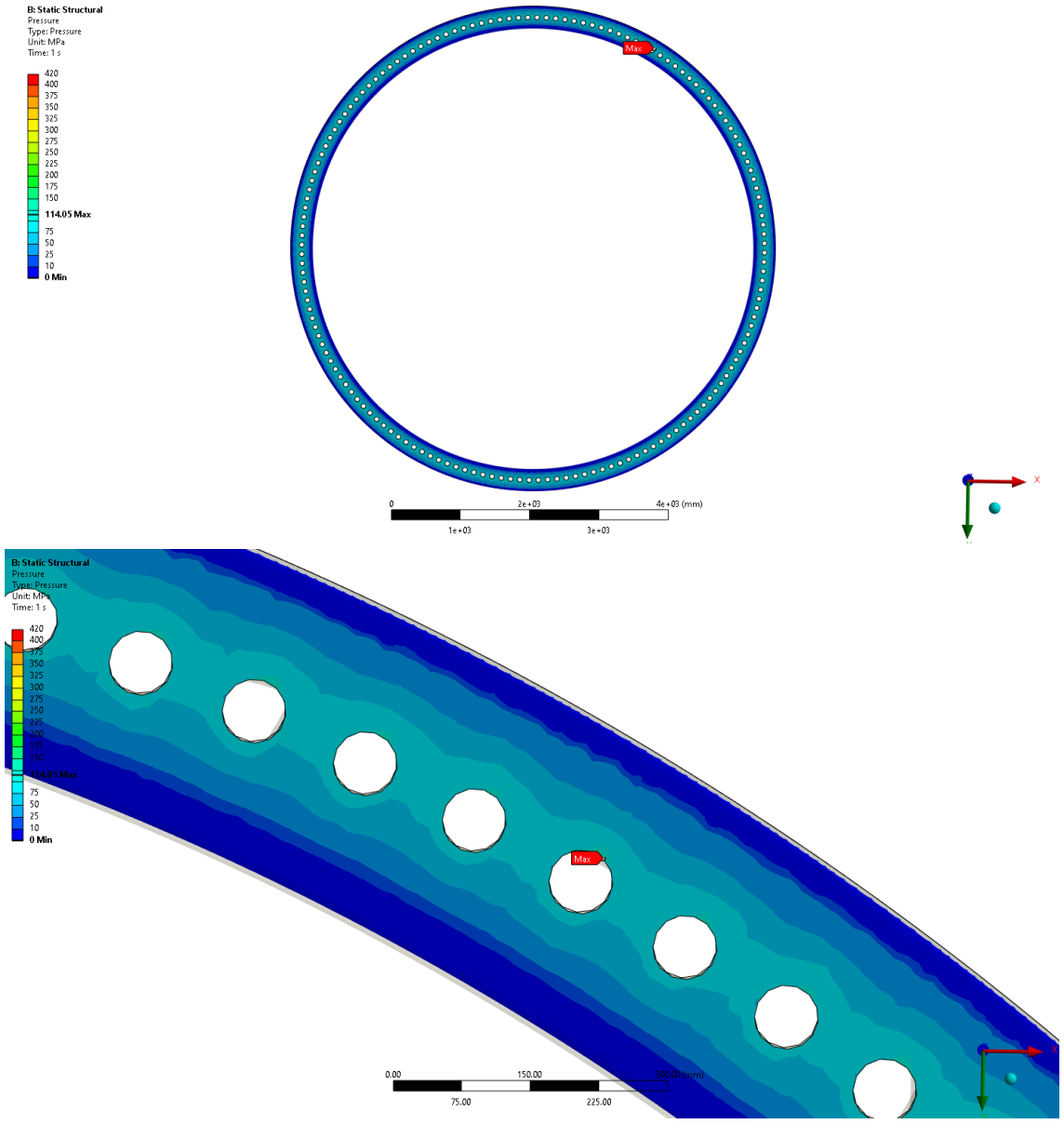


Figure 15.16 – STEP 1 (bolt preloads) – Flanges contact pressure

The maximum pressure on contact between TP and Monopile flanges for the STEP 1 (Bolt Preload) is 114 MPa.

15.2.2 Load STEP 3 (LC: ON2A)

The following figure plots the pressure resulting on the contact between the TP and Monopile flanges in the STEP 3 corresponding to the operative Load Case ON2A.

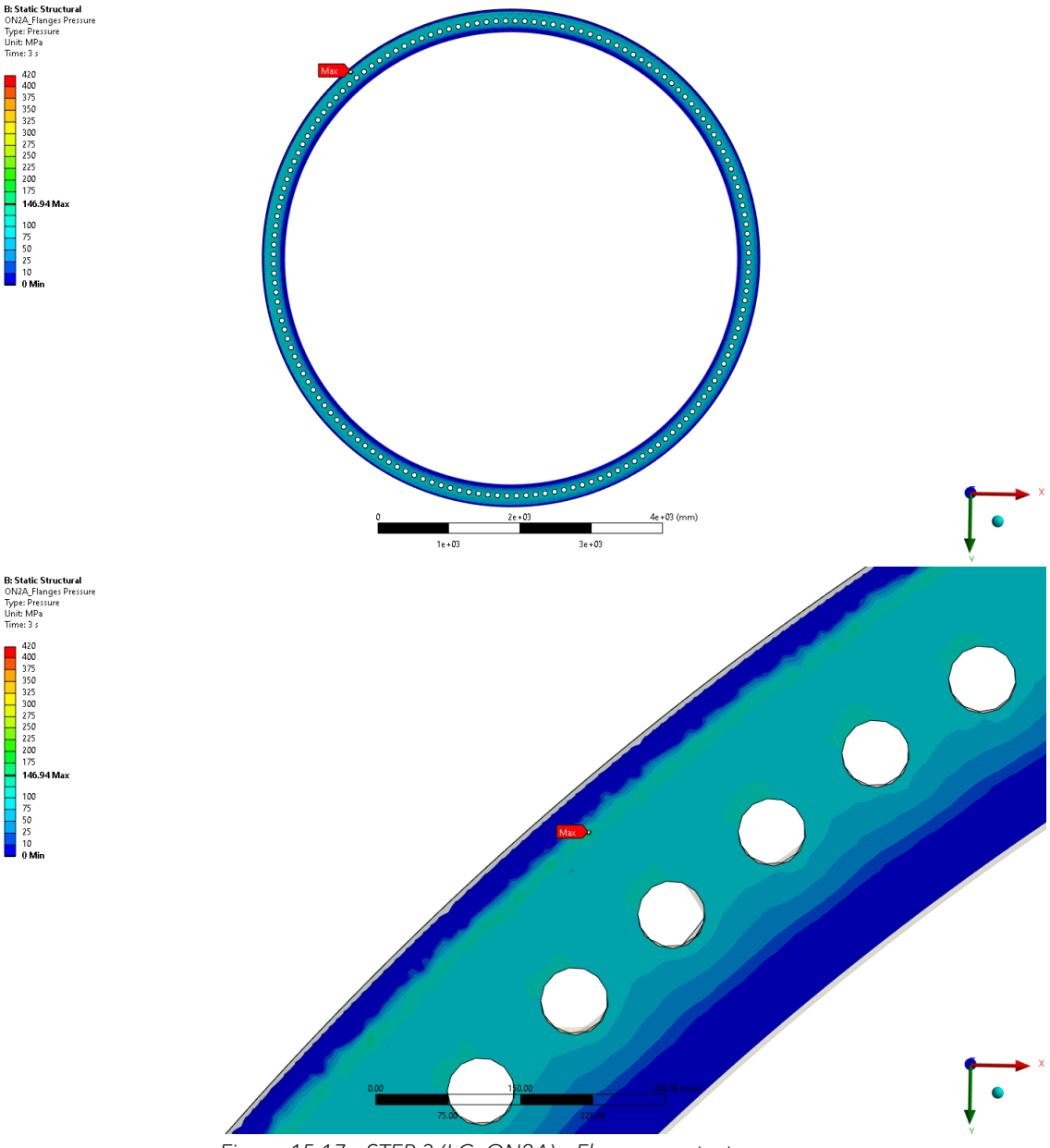


Figure 15.17 – STEP 3 (LC: ON2A) – Flanges contact pressure

The maximum pressure on contact between TP and Monopile flanges for the STEP 3 is 147 MPa.

15.2.3 Load STEP 4 (LC: E13A)

The following figure plots the pressure resulting on the contact between the TP and Monopile flanges in the STEP 4 corresponding to the extreme Load Case E13A.

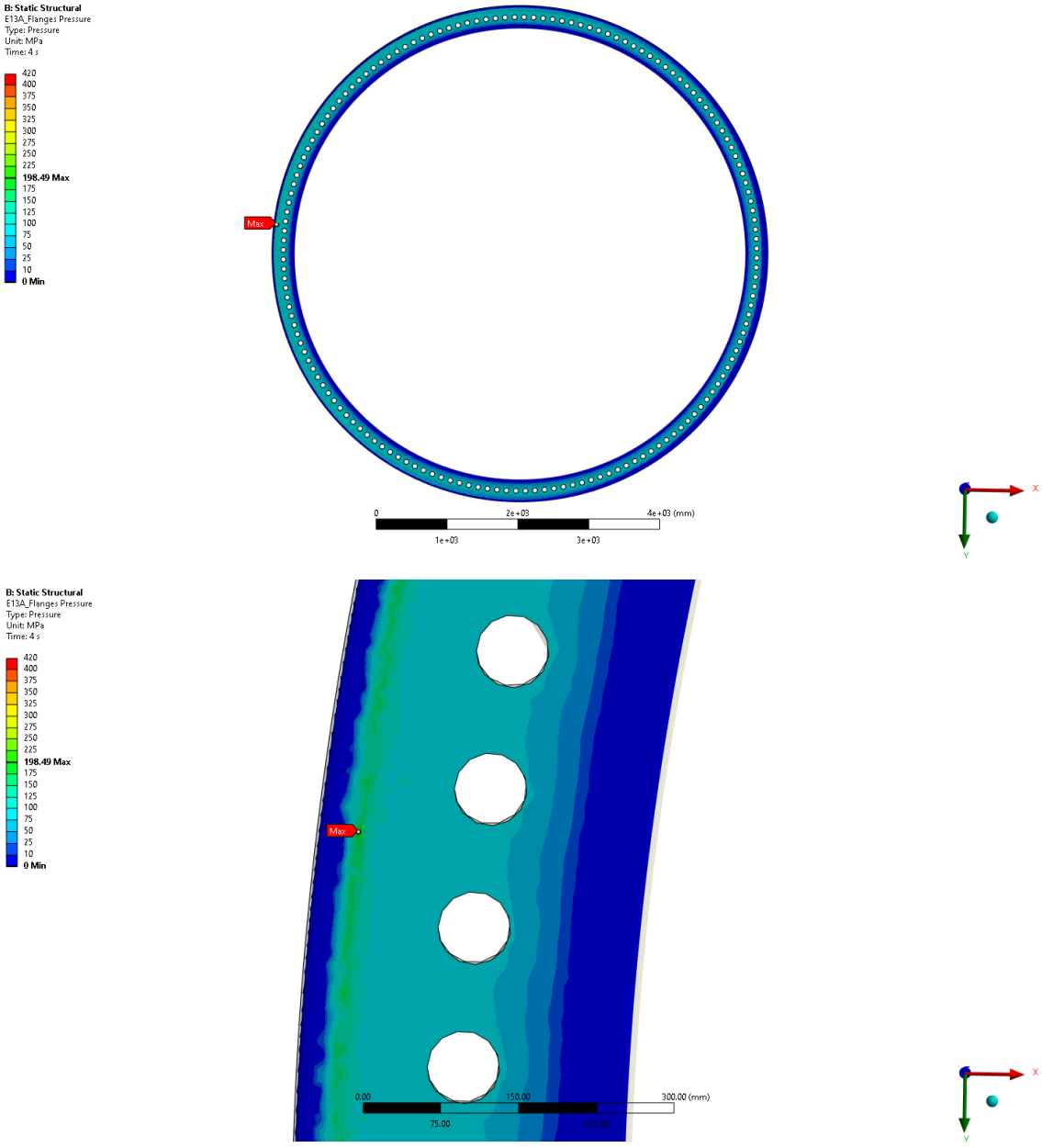


Figure 15.18 – STEP 4 (LC: E13A) – Flanges contact pressure

The maximum pressure on contact between TP and Monopile flanges for the STEP 4 is 199 MPa.

15.2.4 Load STEP 5 (LC: E13B)

The following figure plots the pressure resulting on the contact between the TP and Monopile flanges in the STEP 4 corresponding to the extreme Load Case E13B.

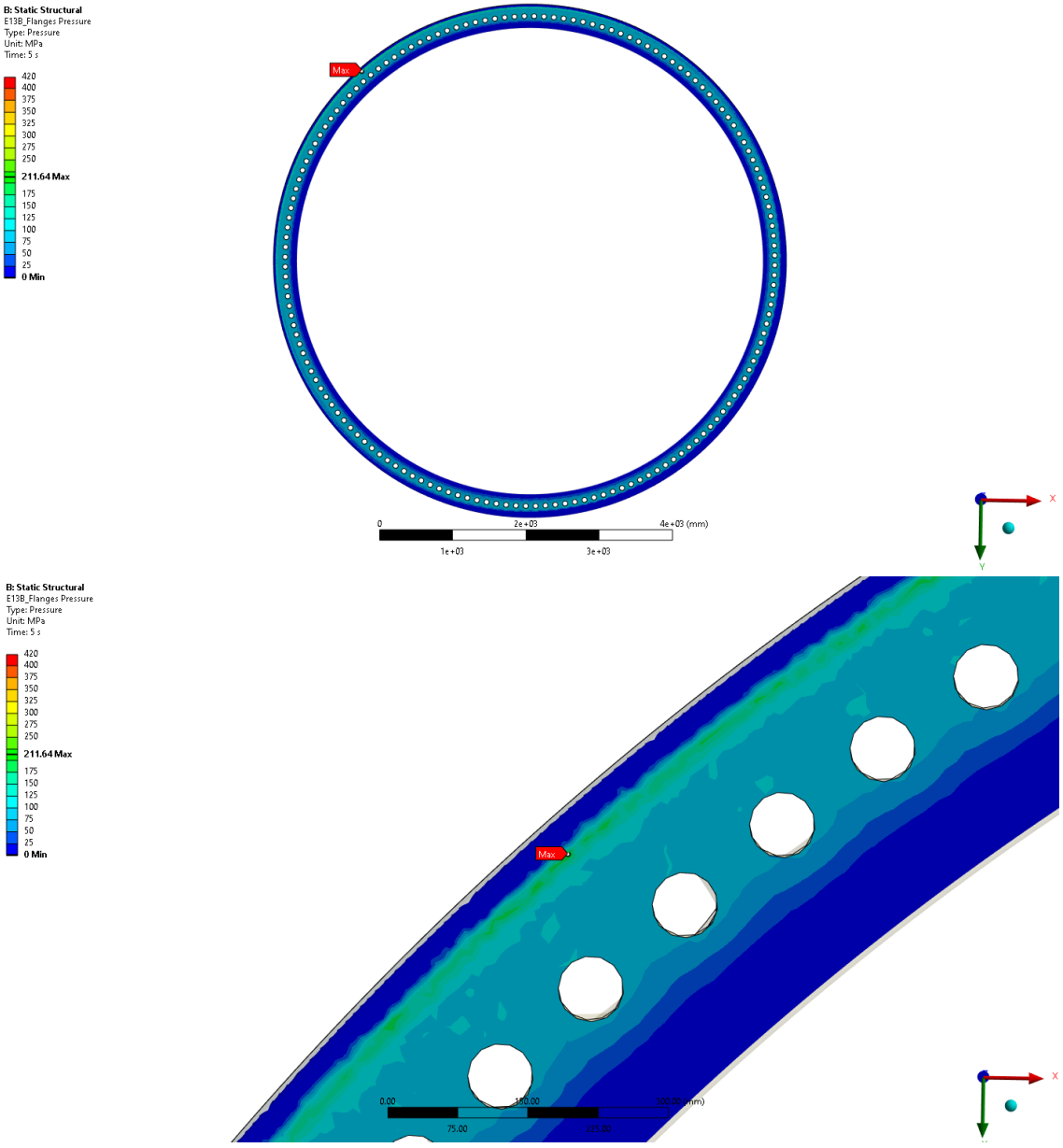


Figure 15.19 – STEP 5 (LC: E13B) – Flanges contact pressure

The maximum pressure on contact between TP and Monopile flanges for the STEP 5 is 212 MPa.

15.2.5 Conclusions

The following table summarizes the pressure on contact between TP and Monopile flanges resulting from the analyzed load conditions.

In-Service *Load Case (Ref./28/)*	*ANSYS STEP*	*Max Pressure on Contact* [MPa]	σ_{adm} *(Fy) [MPa]*	*UC*
Bolt Preload	*1*	*114*	*340*	*0.34*
ON2A	*3*	*147*	*340*	*0.43*
E13A	*4*	*199*	*340*	*0.59*
E13B	*5*	*212*	*340*	*0.62*

Table 15.3- Contact flanges bearing checks

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15.3 LOADS ON BOLTS

15.3.1 Load STEP 1 (Bolts Preload)

The following figure shows the internal loads on M64 bolts for the STEP 1 corresponding to the Bolts Preload.

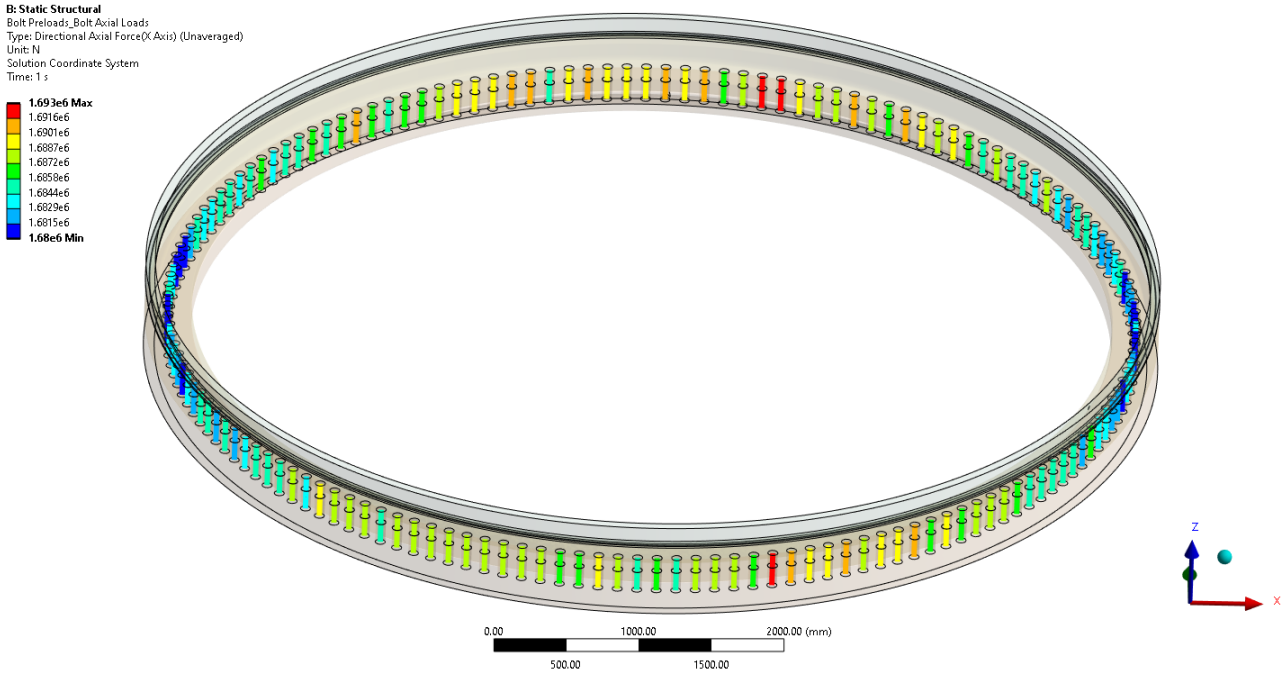


Figure 15.20 – STEP 1 (bolt preloads) – Bolts Internal Loads

15.3.2 Load STEP 3 (LC: ON2A)

The following figure shows the internal loads on M64 bolts for the STEP 3 corresponding to the operative Load Case ON2A.

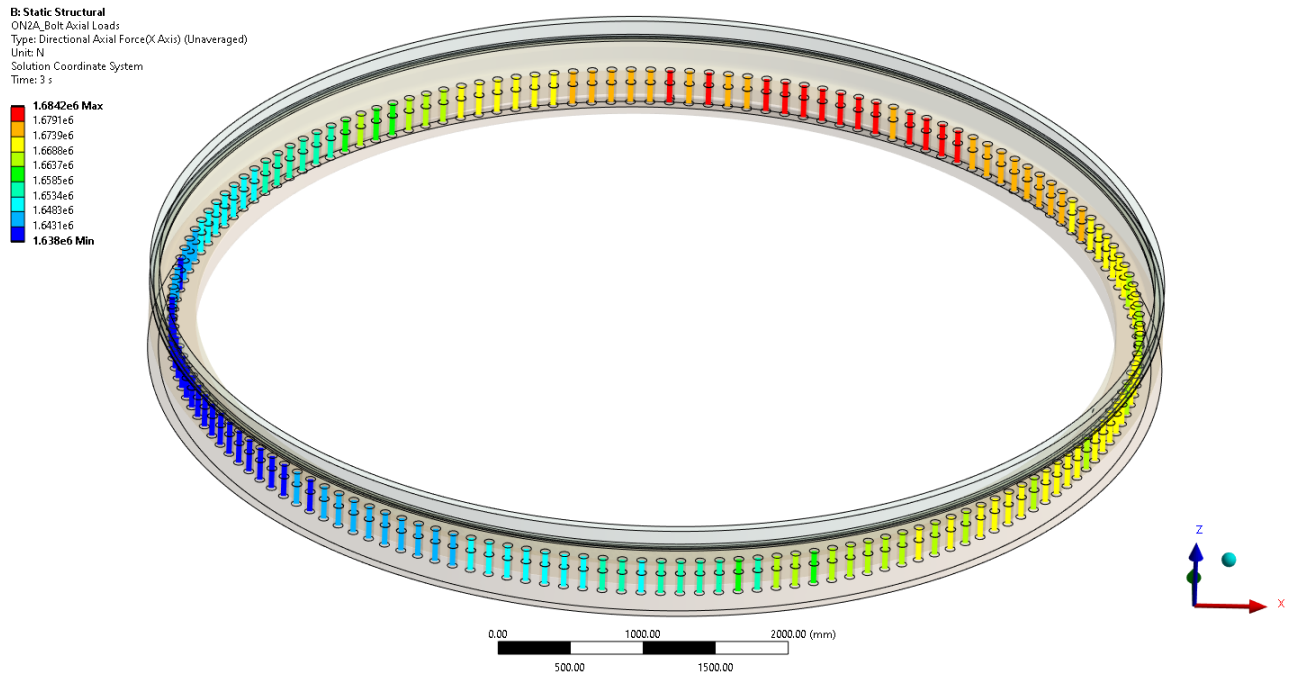


Figure 15.21 – STEP 3 (LC: ON2A) – Bolts Internal Loads

15.3.3 Load STEP 4 (LC: E13A)

The following figure shows the internal loads on M64 bolts for the STEP 4 corresponding to the extreme Load Case E13A.

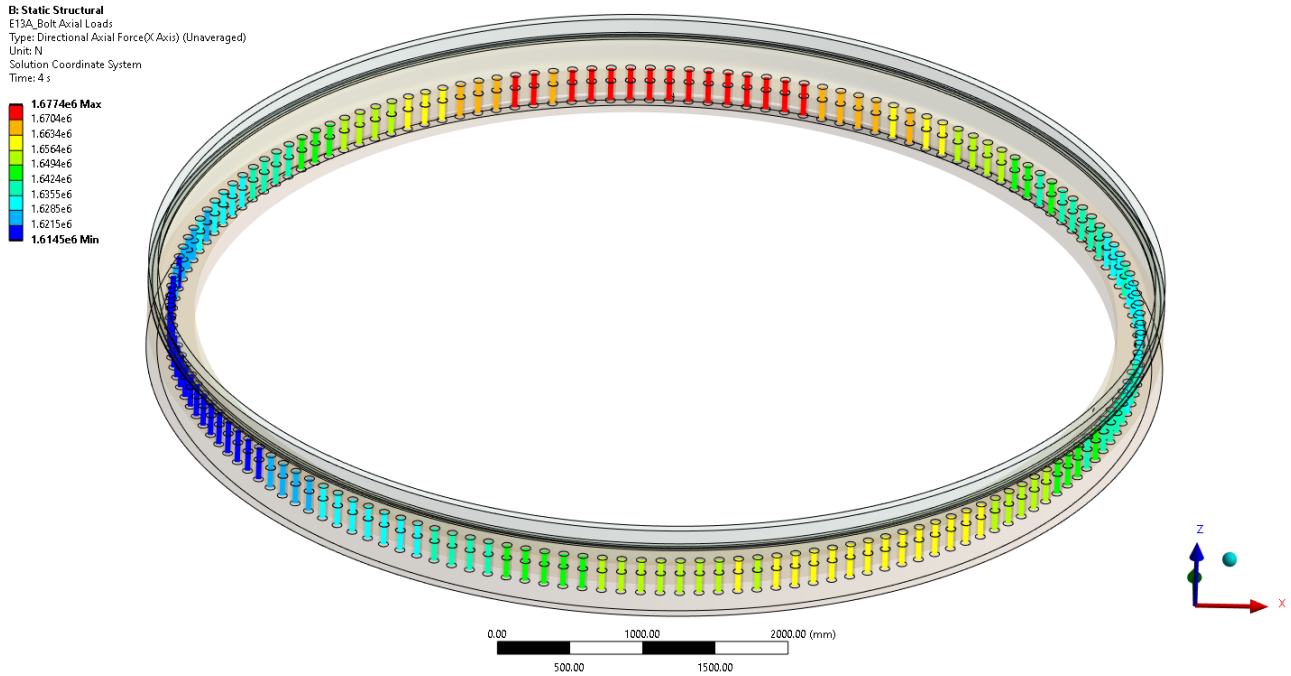


Figure 15.22 – STEP 4 (LC: E13A) – Bolts Internal Loads

15.3.4 Load STEP 5 (LC: E13B)

The following figure shows the internal loads on M64 bolts for the STEP 4 corresponding to the extreme Load Case E13B.

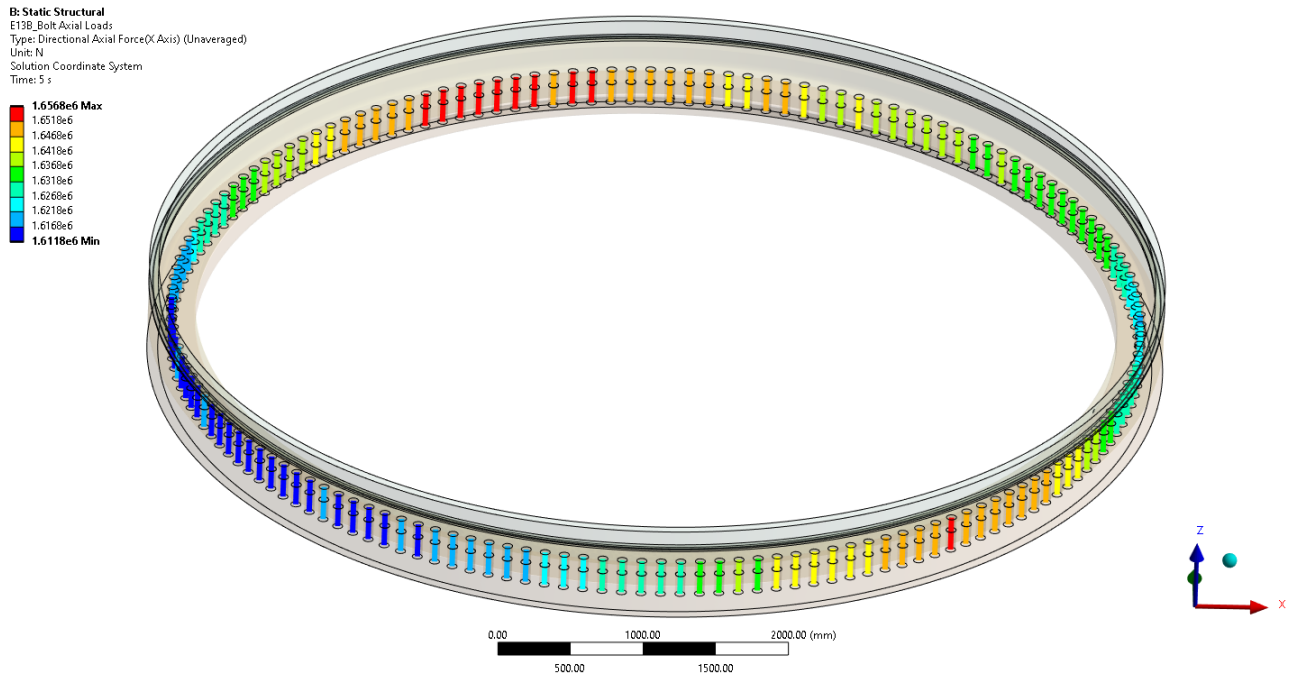


Figure 15.23 – STEP 5 (LC: E13B) – Bolts Internal Loads

15.3.5 Conclusions

As shown in the previous sections the internal loads on bolts remain constant for all the analyzed load cases and equal to the preload (1693kN).

According to the Acceptance Criteria defined in Sec.14.3 the bolt tension resistance results equal to 2490kN. Please note that bolt resistance is defined without the partial resistance factor γ_{M2} because applied on design loads.

The resultant UC is then 0.68.