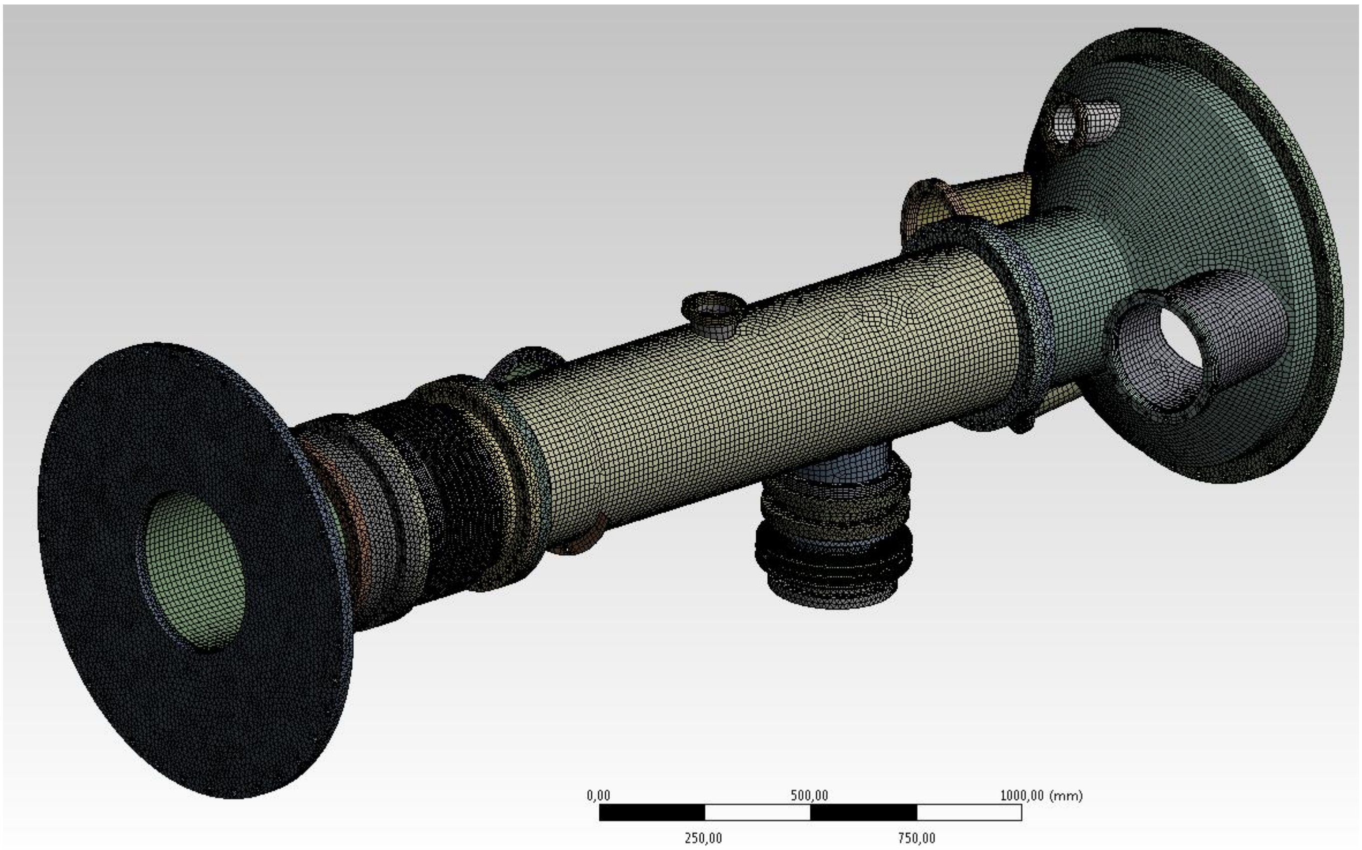
	Customer: European Gravitational Observatory	Job: EG 2559 FLM 12	Page 1 / 36
Tecno s.r.l. Ingegneria e Costruzioni Industriali Via Guido Rossa, 27 - 57013 Rosignano Solvay (LI) Italy Tel. 39 0586 764852 - Fax 39 0586 766894	Document N°	S 2 5 5 9 0 0 3	Rev: 1

BS-PR SYSTEM PIPING CONNECTING ASSEMBLY

TECHNICAL REPORT



1	24/04/2013	*First issue*	*F. Lamperti*	*A. Barbini*	*M. Ciolli*
Rev.	***Date***	***Description***	**Originator**	***Check***	***Approval***

1 Summary

Scope of the work is to design the connection pipes for BS – PR system. In this report stresses are calculated using FEA software. These stresses are checked for compliance with UNI EN 13445-3 (external pressure).

Operating conditions:

- $P_{operating}$ = -1 barg (Full Vacuum)
- $T_{operating}$ = 20°C

Design limits operating:

- $P_{operating}$ = -1 barg (Full Vacuum)
- $T_{operating}$ = 20°C

Weight of components:

- Weight of piping connection (770 kg)

No nozzle loads are defined.

The computed stresses are compared with the maximum allowable stresses according to EN 13445-3

2 Conclusion

The piping connection complies with the requirements of:

UNI EN 13445-3 – Unfired pressure vessel – Part 3: Design

3 Reference documents

The reference documents are the following:

- UNI EN 13445-3 – Unfired pressure vessel – Part 3: Design
- 3D model in "step" format given by EGO
- pdf drawing: EGO-DWG-VAC-LNK-701-2 - GENERAL ASSEMBLY - LINK BS-PR-Gr.7

4 Units

All dimensions are in mm

5 Material

Material of the shell, flanges and bellows is AISI304 with the following properties:

- Elastic modulus: 193000 MPa
- Yield stress: 190 MPa
- Tensile stress: 500 MPa
- Poisson coefficient: 0,3

6 Piping connection system

6.1 Components

The material of the components is AISI304. The components are identified (with their dimensions) in the below layout.

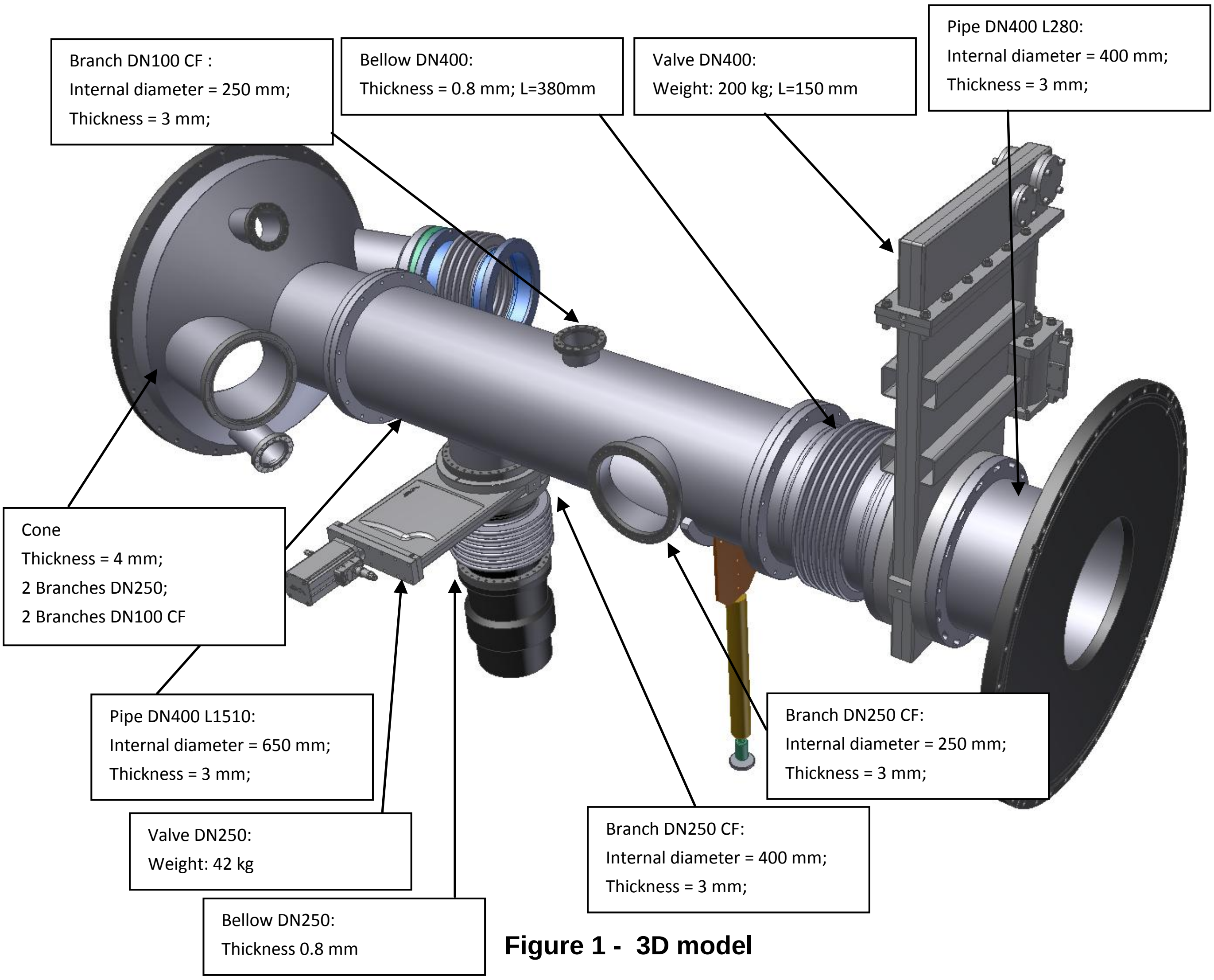


Figure 1 - 3D model

6.2 Corrosion allowances

Corrosion allowance is 0 mm.

6.3 FEA check

With Ansys, stresses and displacement are computed. The stresses in the various figures is the Von Mises stress.

6.3.1 Load case 1 (Design)

Primary load:
- P_{design} = -1 barg (Full vacuum)
- T_{design} =+20°C
  - Weight of components

According to UNI EN 13445-3, the admissible stress is checked:

- $\sigma_{adm} \leq$ yield stress/S = 190/1.5 = 127 MPa with S=1,5 (safety factor) according to UNI EN 13445-3

6.3.2 Load case 2 (Design)

Valve DN 400 closed, vacuum between valve and cone.
Primary load:
- P_{design} = -1 barg (Full vacuum)
- T_{design} =+20°C
  - Weight of components

According to UNI EN 13445-3, the admissible stress is checked:

- $\sigma_{adm} \leq$ yield stress/S = 190/1.5 = 127 MPa with S=1,5 (safety factor) according to UNI EN 13445-3

6.4 Buckling check

According to UNI EN 13445-3, the buckling of the system due to external pressure is checked

6.5 Modal analysis

A modal analysis is carried out to find the natural frequencies of the system.

6.6 Linear Buckling analysis

A linear buckling analysis is carried out to find the first 4 buckling modes of the system.

7 FEA analysis

The FEA analyses are performed using the software package ANSYS. The analyses are linear elastic, no plastic material behavior is incorporated. Both solid and shell elements are used.

7.1 Load case 1 – Design – Loads and boundary conditions

The applied load are

- the self weight;
- the load due to the vacuum pump

The load due to the vacuum pump is:

$$0{,}1\ MPa \cdot \frac{\pi \cdot 250\ mm^2}{4} = 4909\ N$$

- the load on DN250 CF plug due to the atmospheric pressure acting on the plug. The load is:

$$0{,}1\ MPa \cdot \frac{\pi \cdot 256\ mm^2}{4} = 5150\ N$$

- the load on DN100 CF plugs due to the atmospheric pressure acting on the plug. The load is:

$$0{,}1\ MPa \cdot \frac{\pi \cdot 102\ mm^2}{4} = 817\ N$$

- the load on cone DN250 plugs due to the atmospheric pressure acting on the plug. The load is:

$$0{,}1\ MPa \cdot \frac{\pi \cdot 276\ mm^2}{4} = 5982\ N$$

The boundary condition are zero displacements on the other flanges and no vertical displacements on the support below the pipe.
The images below show this loads and boundary condition.

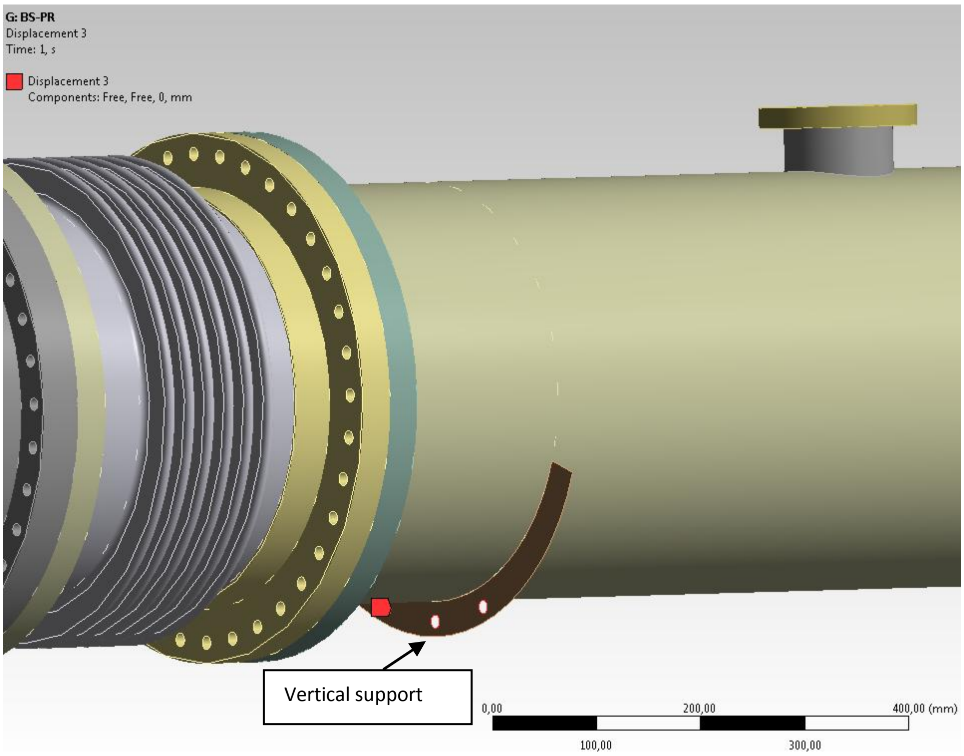


Figure 2 - Vertical support

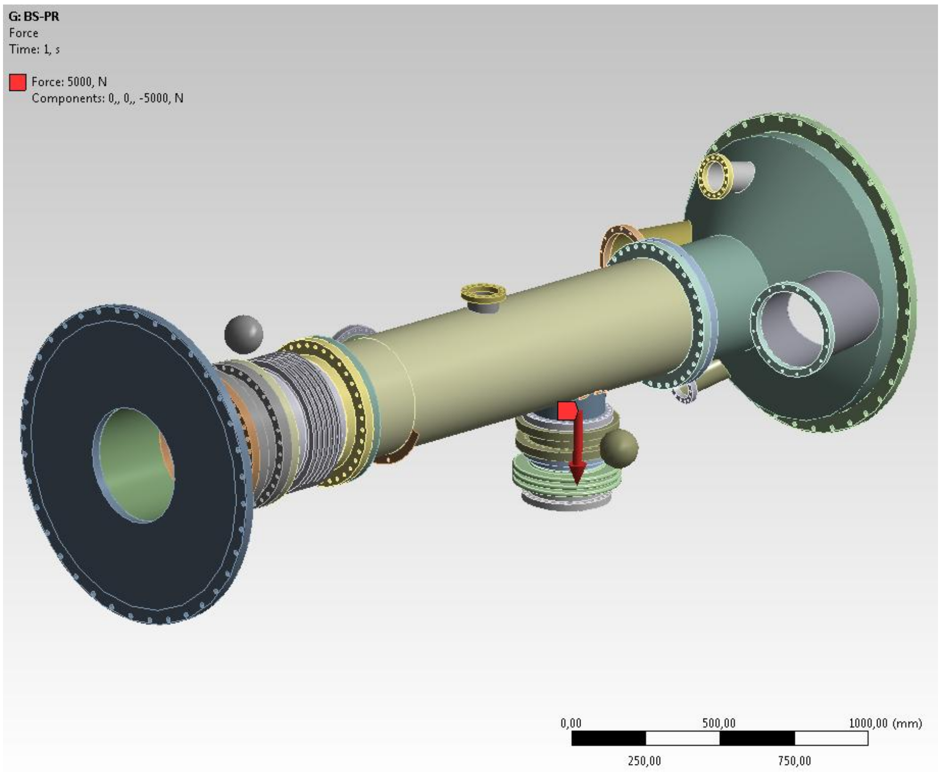


Figure 3 – Force due to vacuum pump

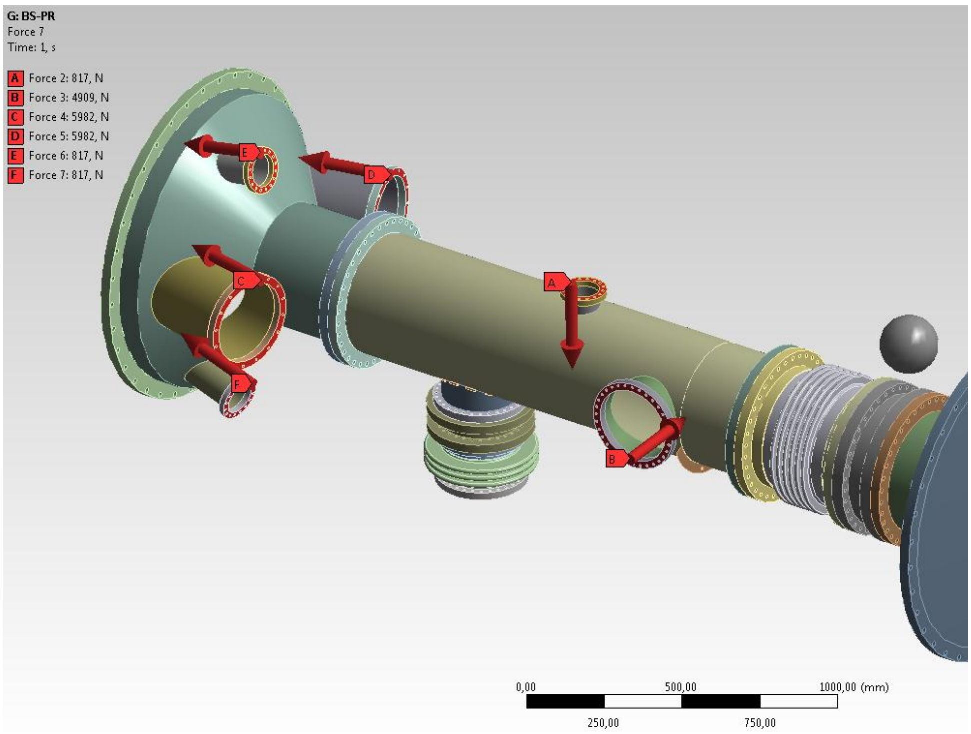


Figure 4 – Force due to atmospheric pressure on plugs of lateral and upper branch

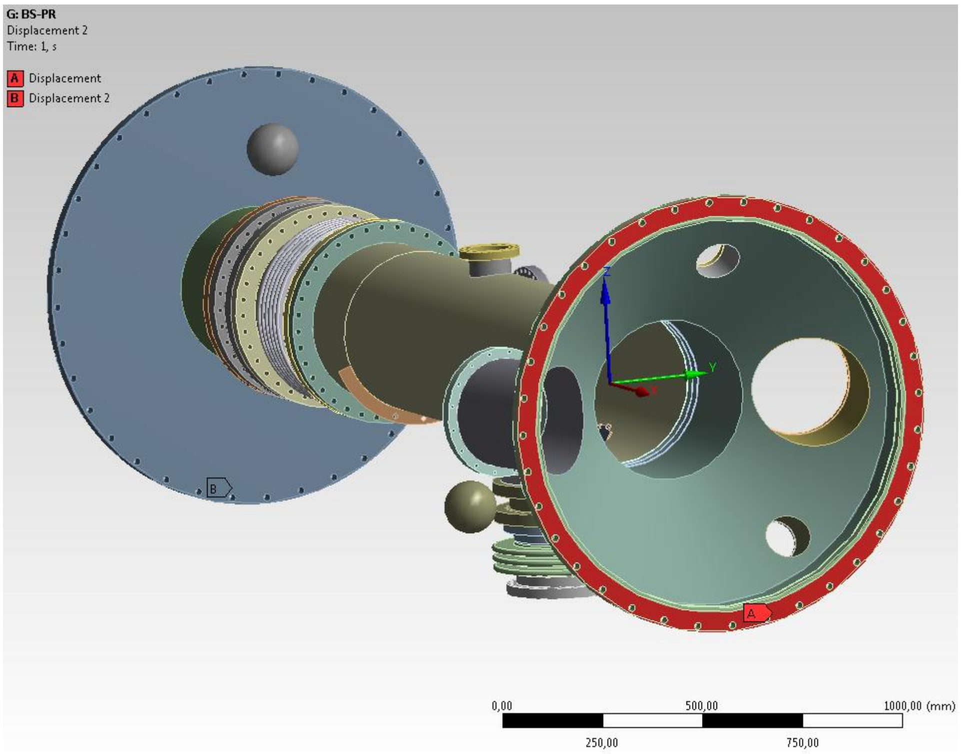


Figure 5 – Constraints on flanges (zero displacements on all directions)

7.2 Load case 1 – Design - Stress results

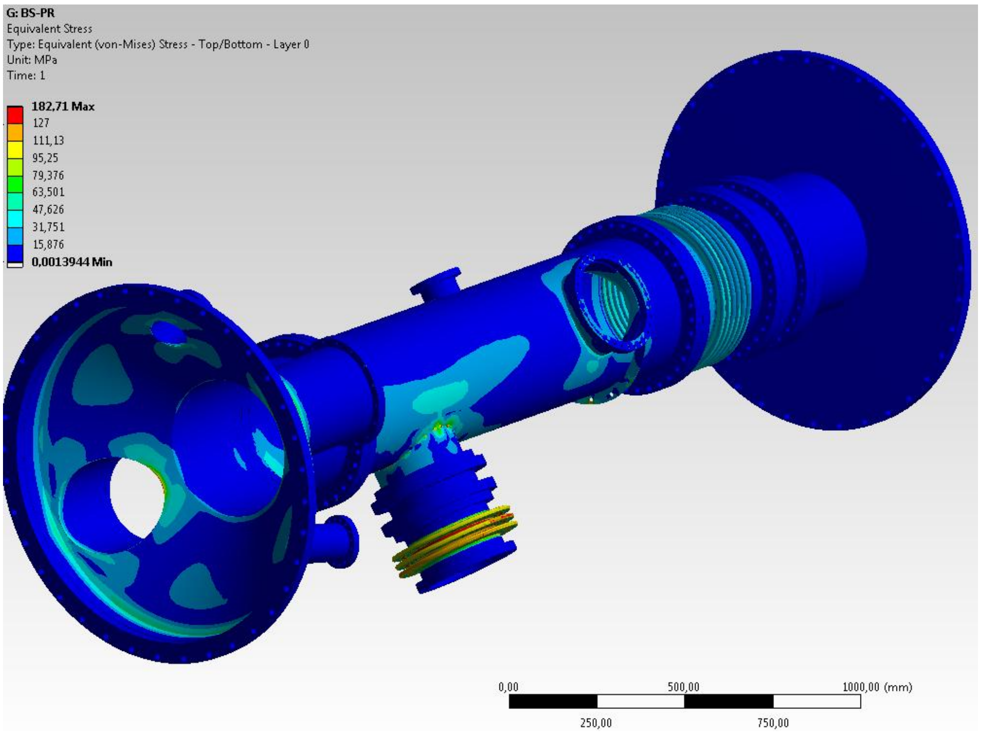


Figure 6 - Von Mises stress

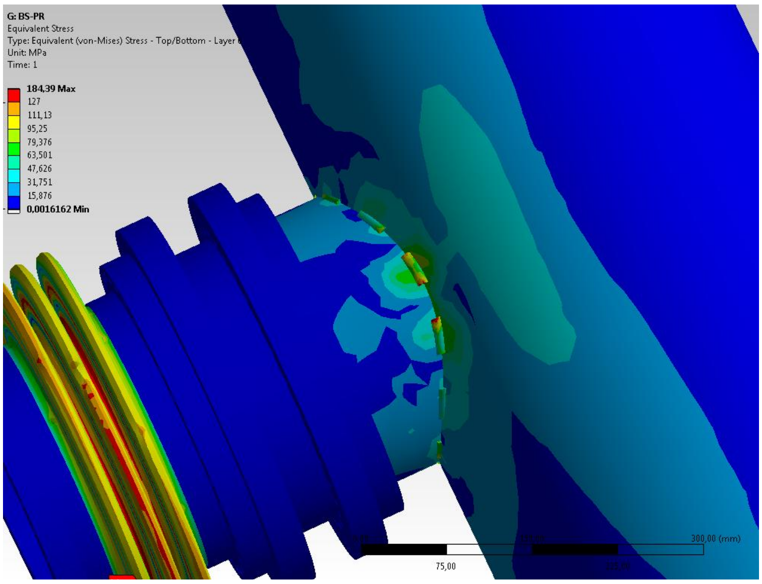
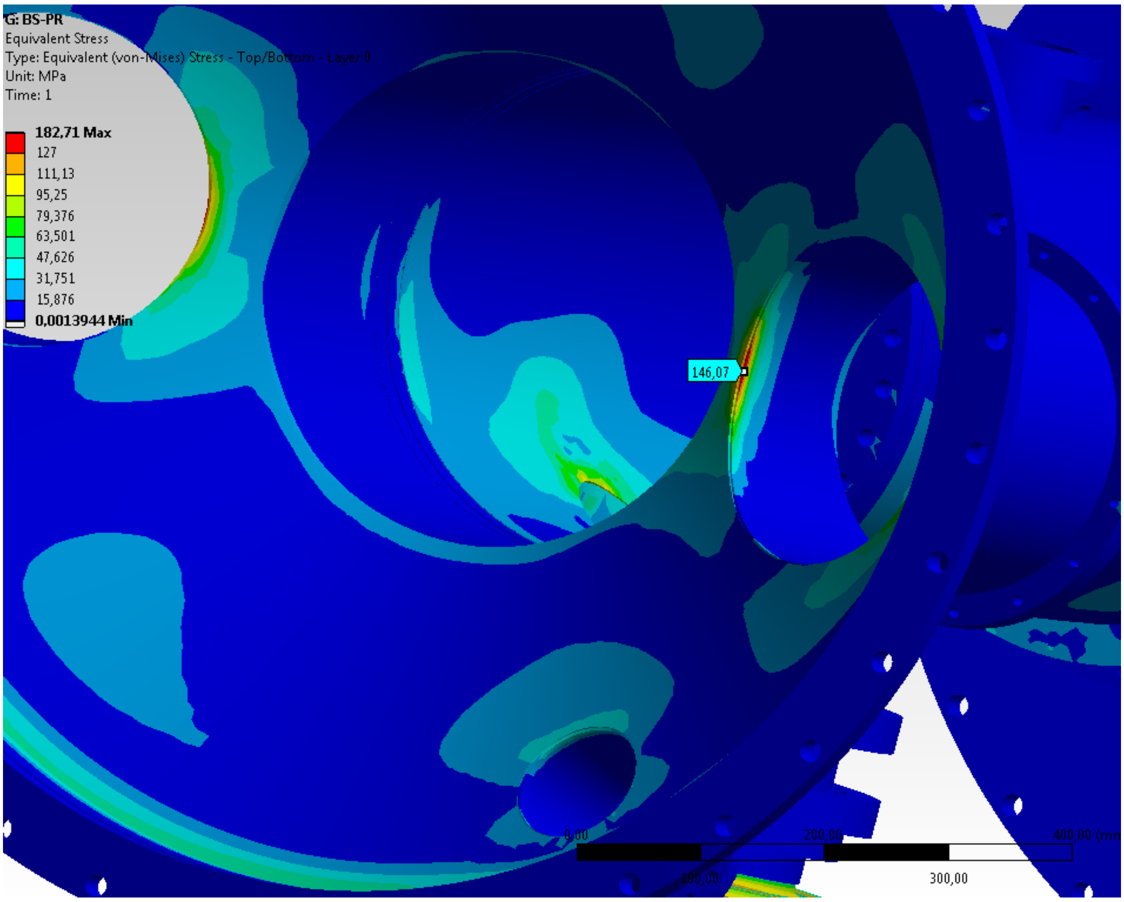


Figure 7 - Von Mises stress - detail



There is a small zone where the stress is slightly above the admissible (146 MPa instead 190/1,5 = 126 MPa). Since the nature of the effect is very local and the zone is very small the effect can be neglected. The stress level of the system is acceptable respect to the admissible stress calculated as stated in EN 13445-3.

7.3 Load case 1 – Design - Displacements results

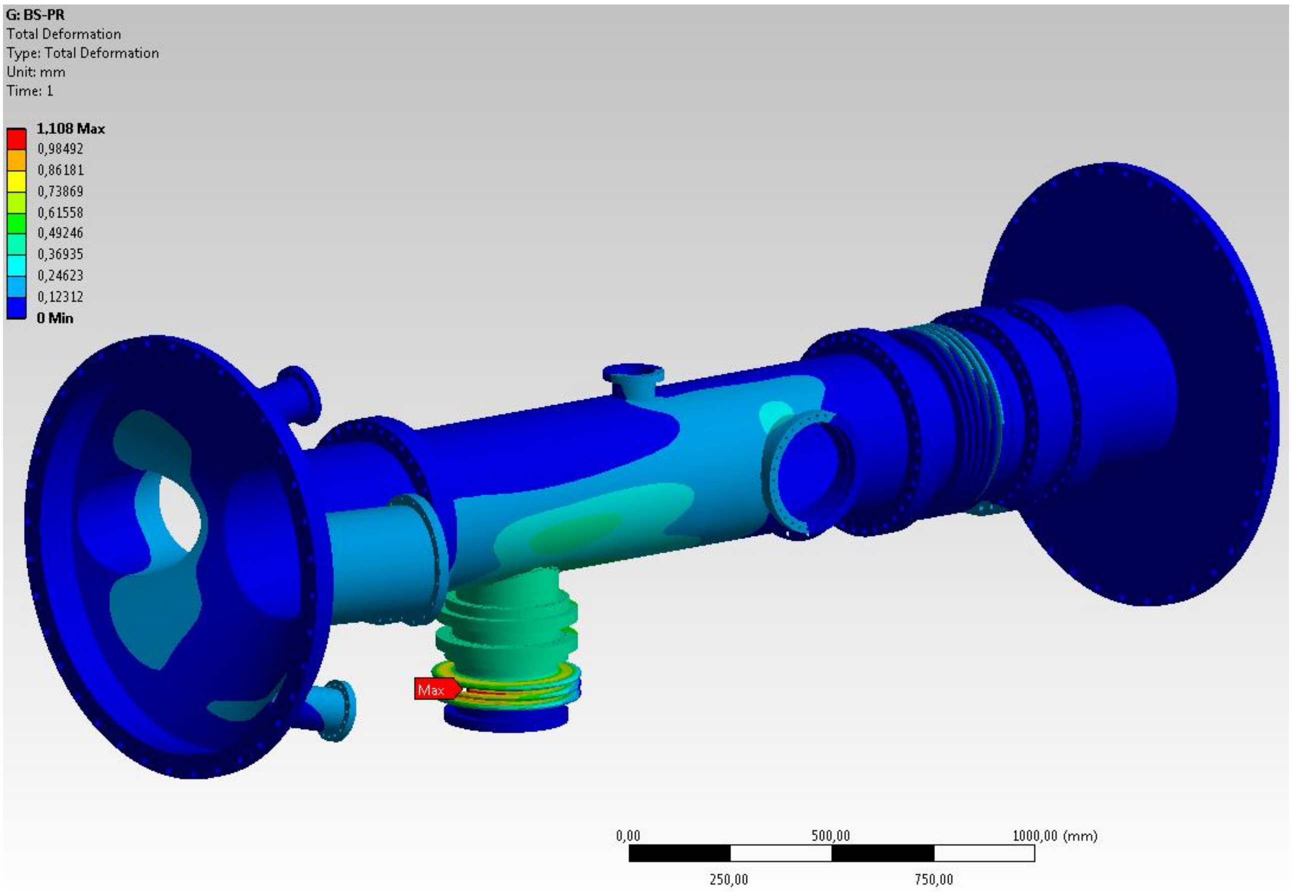


Figure 8 - Displacements

The displacements are very small and can be accepted from a point of view of the functionality of the system.

7.4 Load case 1 – Design - Reaction results

The reactions shown in the below images are in the global coordinate system (depicted in each image).

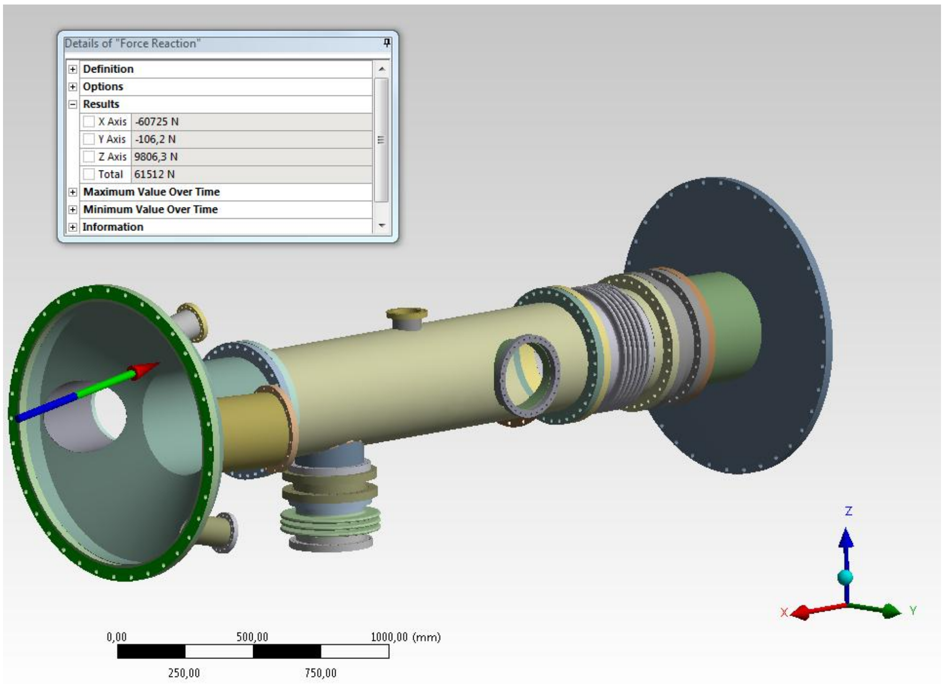


Figure 9 - Flange force reaction

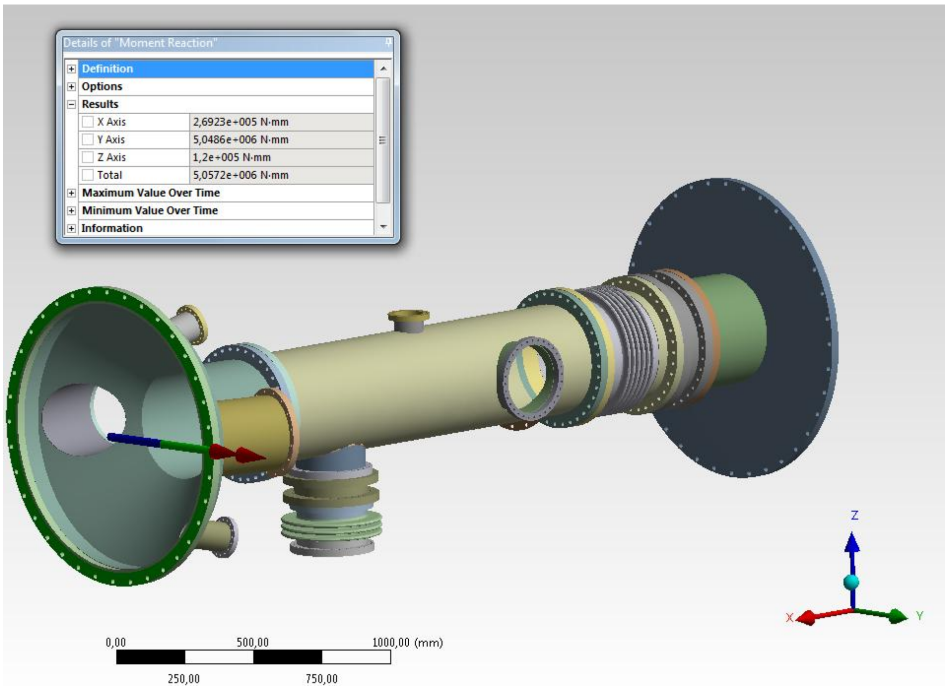


Figure 10 - Flange moment reaction

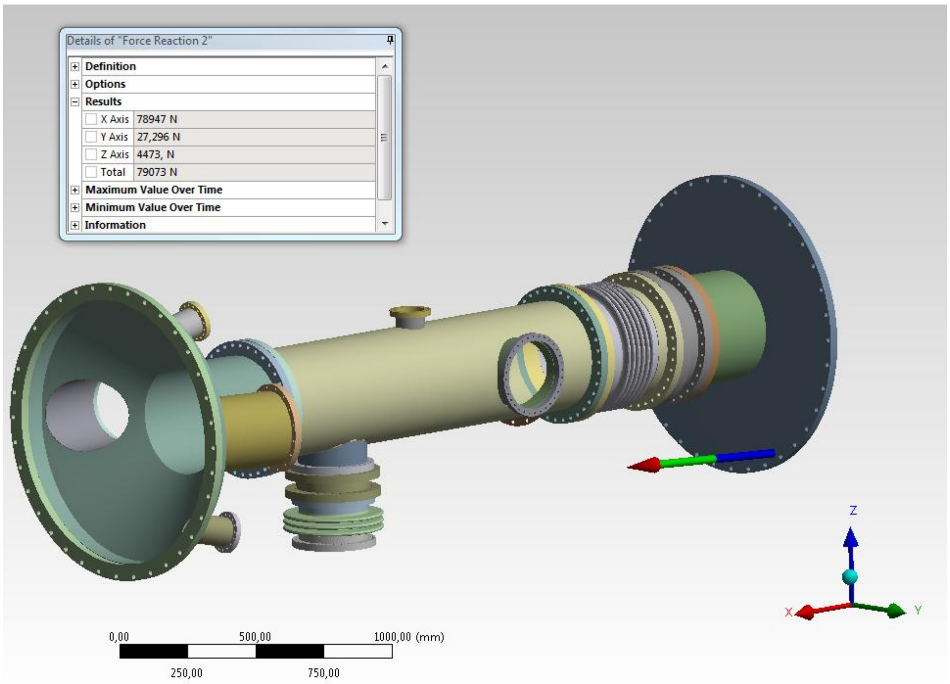


Figure 11 - Flange force reaction

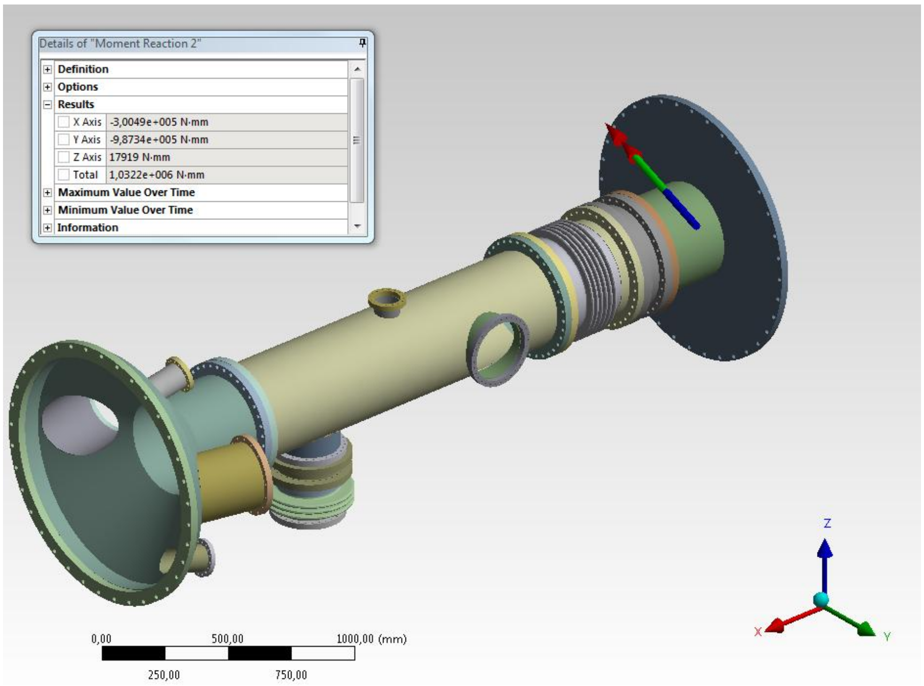


Figure 12 - Flange moment reaction

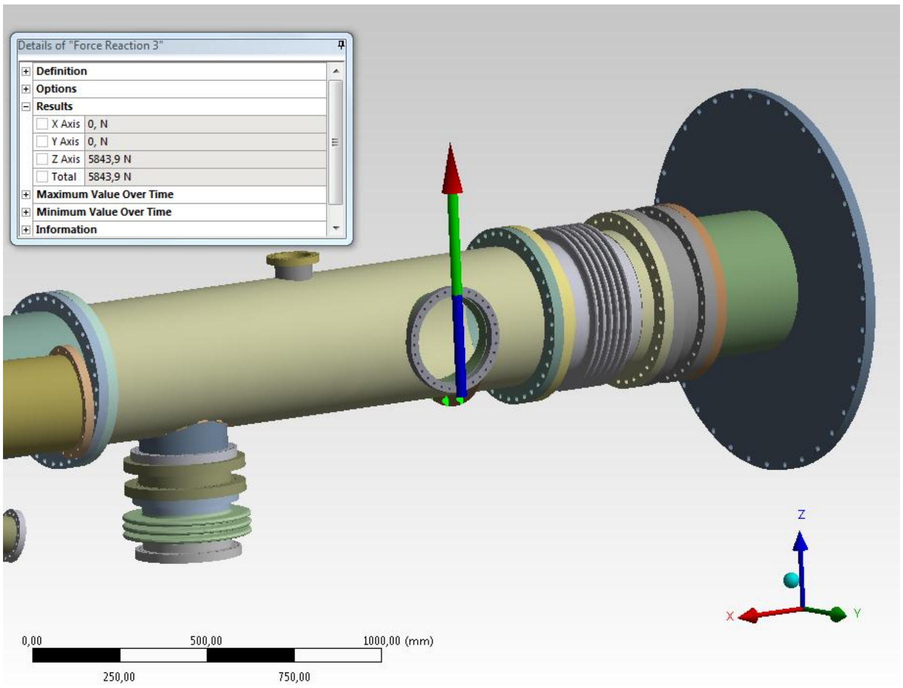


Figure 13 - Vertical support reaction

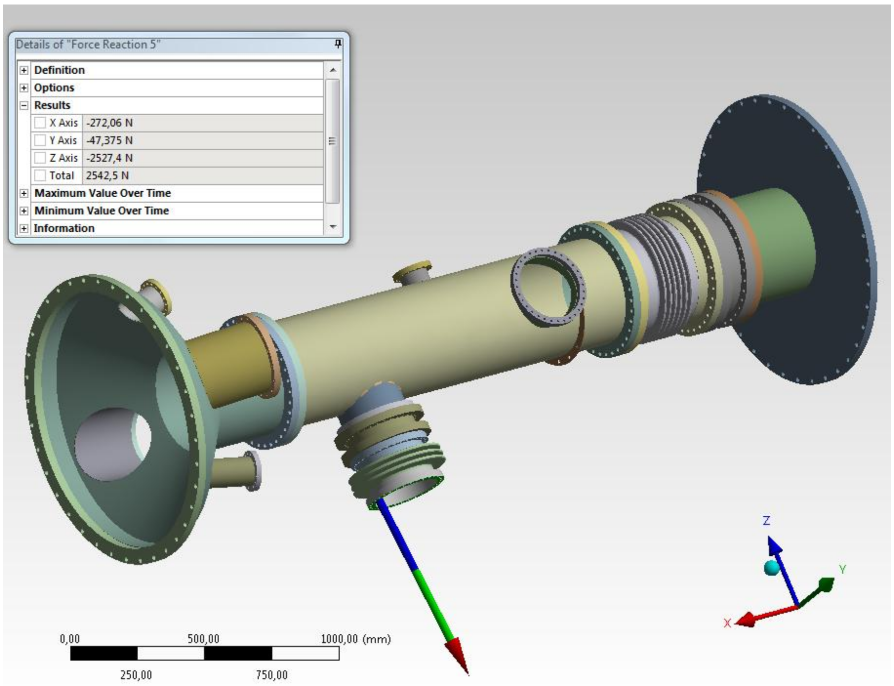


Figure 14 – Pump flange force reaction

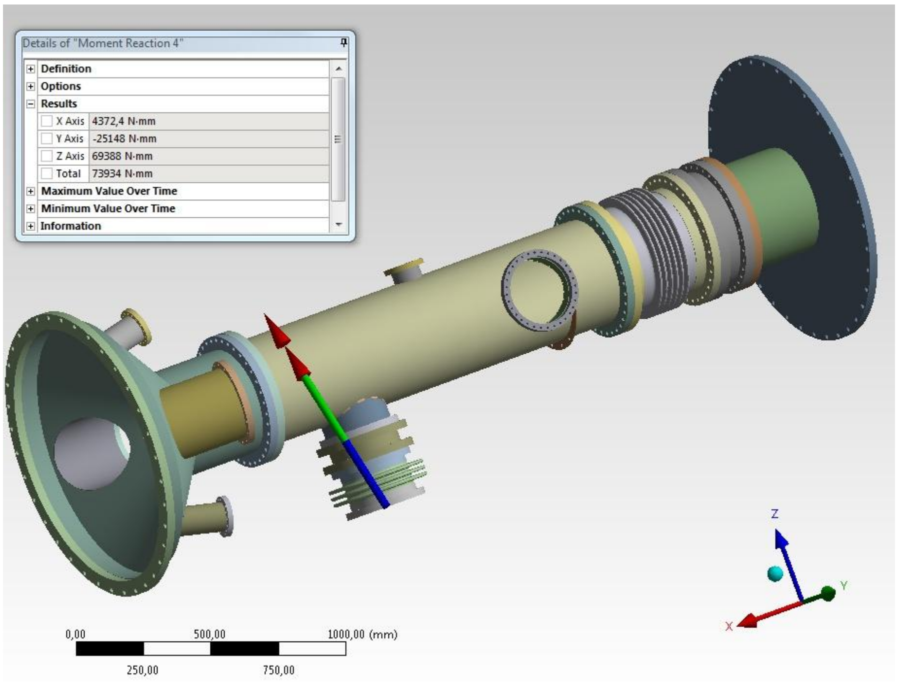


Figure 15 – Pump flange moment reaction

7.5 Load case 2 – Design – Loads and boundary conditions

The applied load are

- the self weight;
- the load due to the vacuum pump

The load due to the vacuum pump is:

$$0,1\ MPa \cdot \frac{\pi \cdot 250\ mm^2}{4} = 4909\ N$$

- the load on DN250 CF plug due to the atmospheric pressure acting on the plug. The load is:

$$0,1\ MPa \cdot \frac{\pi \cdot 256\ mm^2}{4} = 5150\ N$$

- the load on DN100 CF plugs due to the atmospheric pressure acting on the plug. The load is:

$$0,1\ MPa \cdot \frac{\pi \cdot 102\ mm^2}{4} = 817\ N$$

- the load on cone DN250 plugs due to the atmospheric pressure acting on the plug. The load is:

$$0,1\ MPa \cdot \frac{\pi \cdot 276\ mm^2}{4} = 5982\ N$$

- the load on valve DN400 due to the atmospheric pressure. The load is:

$$0,1\ MPa \cdot \frac{\pi \cdot 400\ mm^2}{4} = 12566\ N$$

The boundary condition are zero displacements on the other flanges and no vertical displacements on the support below the pipe.
The images below show this loads and boundary condition.

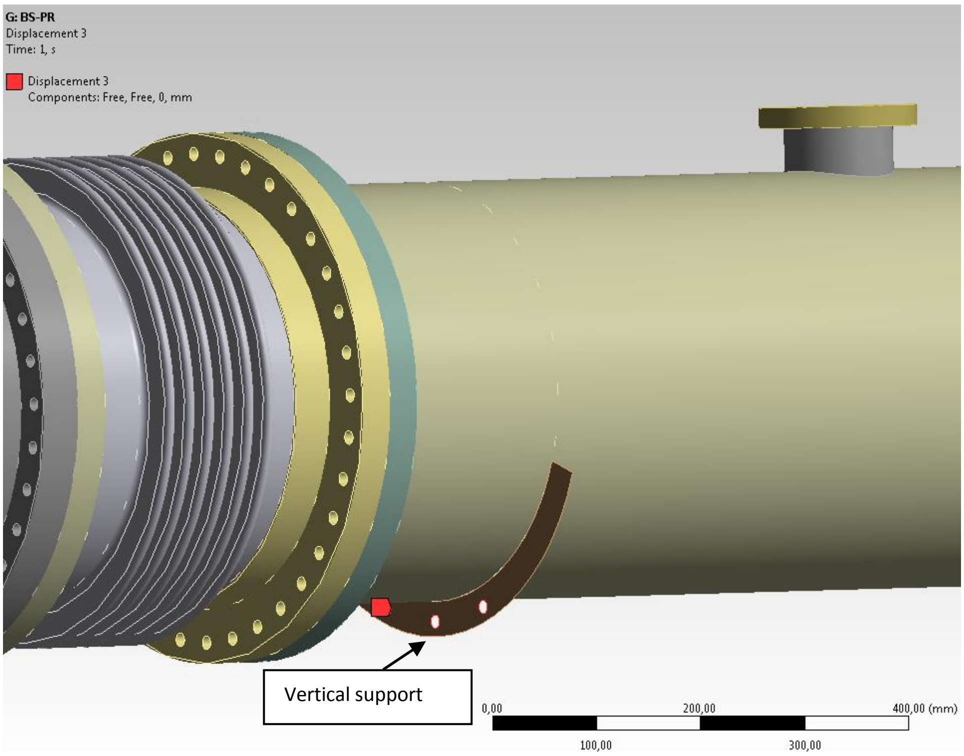


Figure 16 - Vertical support

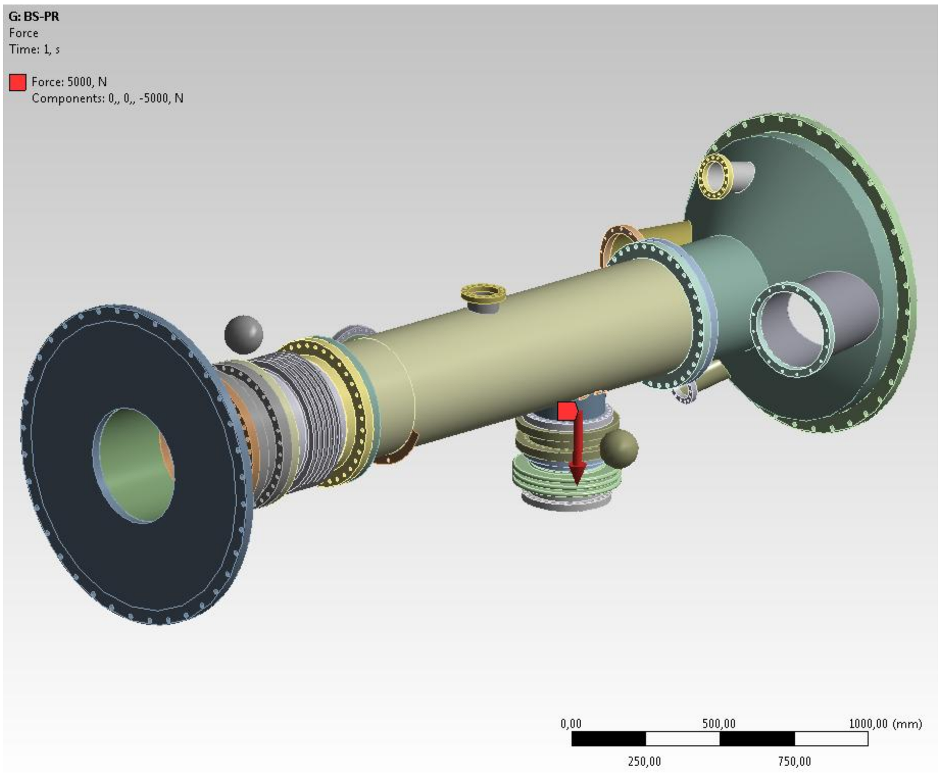


Figure 17 – Force due to vacuum pump

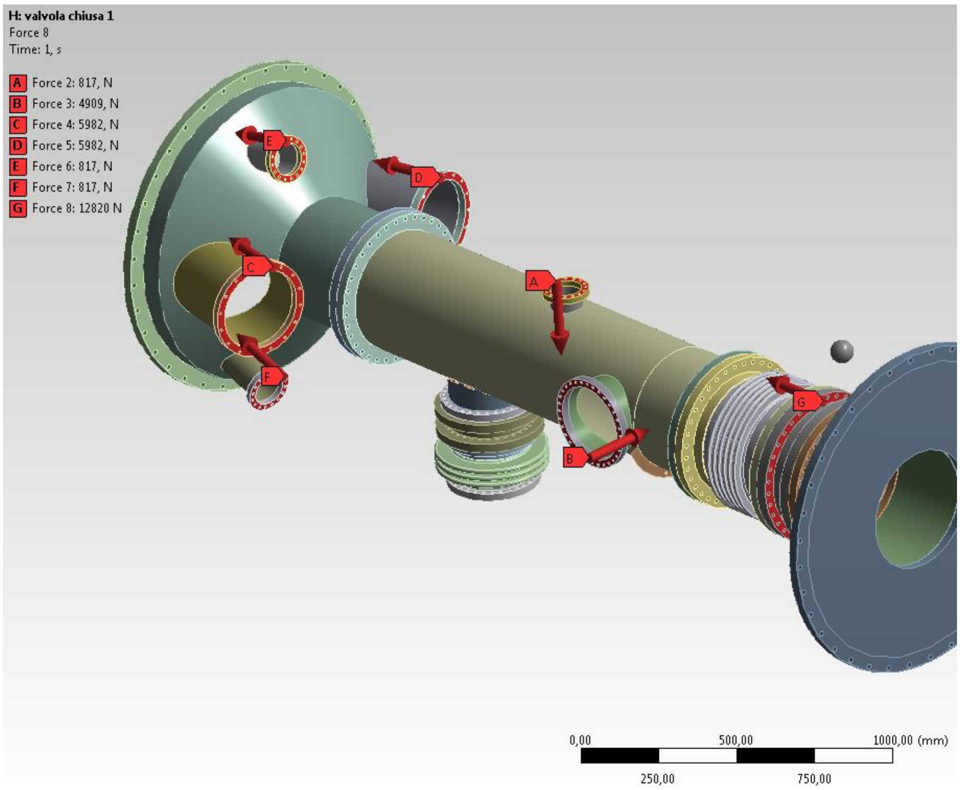


Figure 18 – Force due to atmospheric pressure on plugs of lateral and upper branch

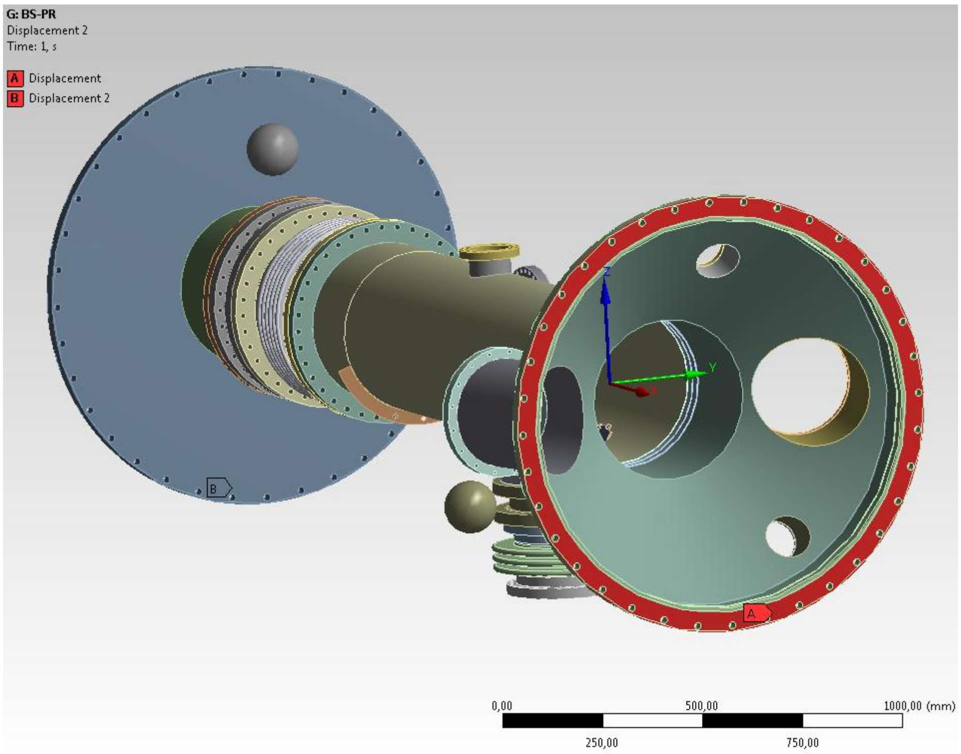


Figure 19 – Constraints on flanges (zero displacements on all directions)

7.6 Load case 2 – Design - Stress results

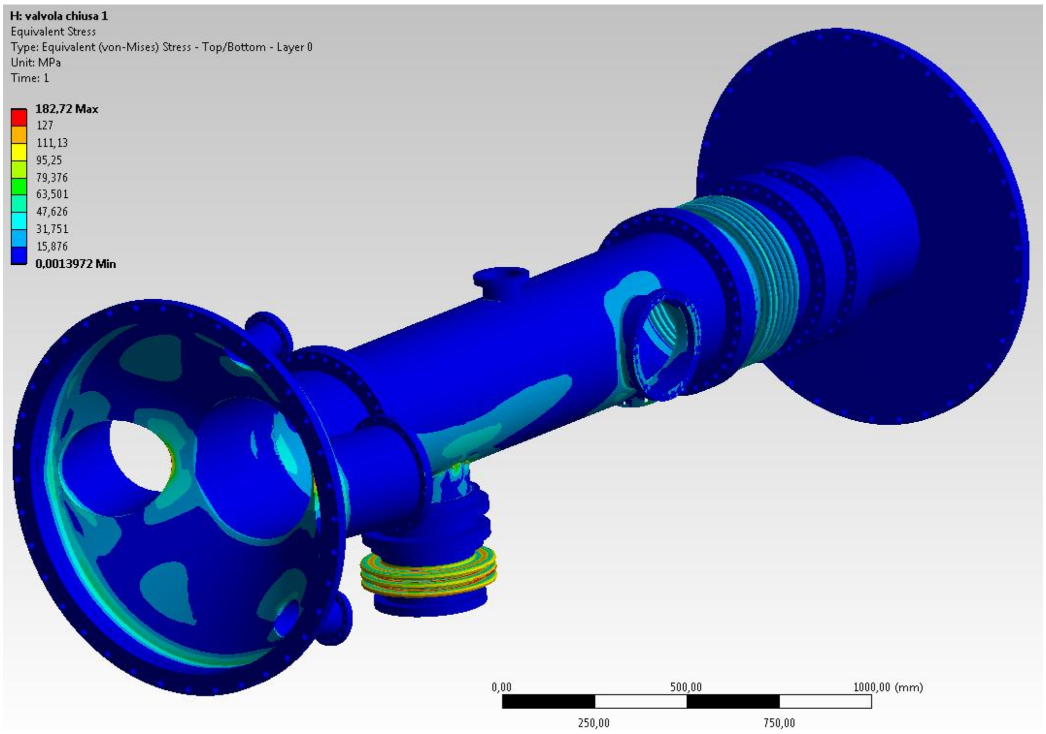


Figure 20 - Von Mises stress

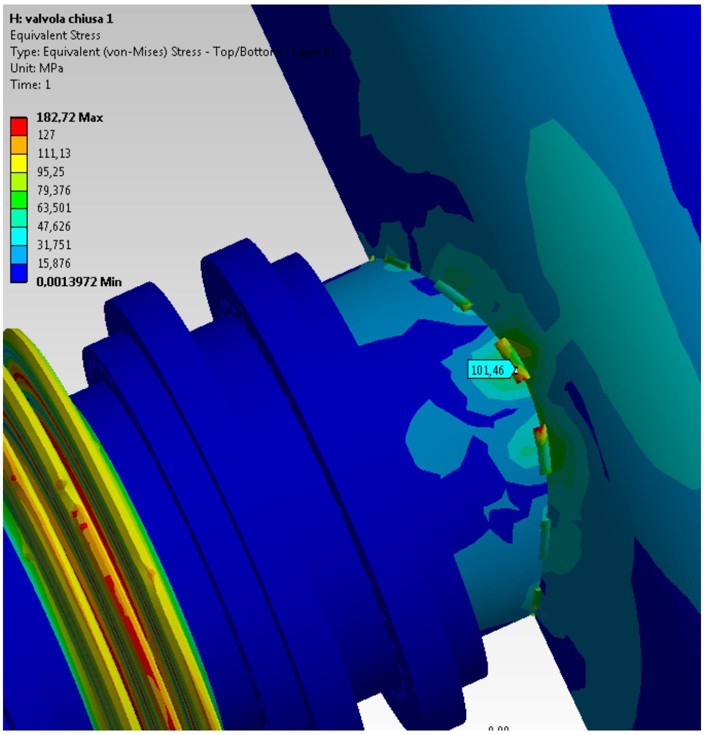
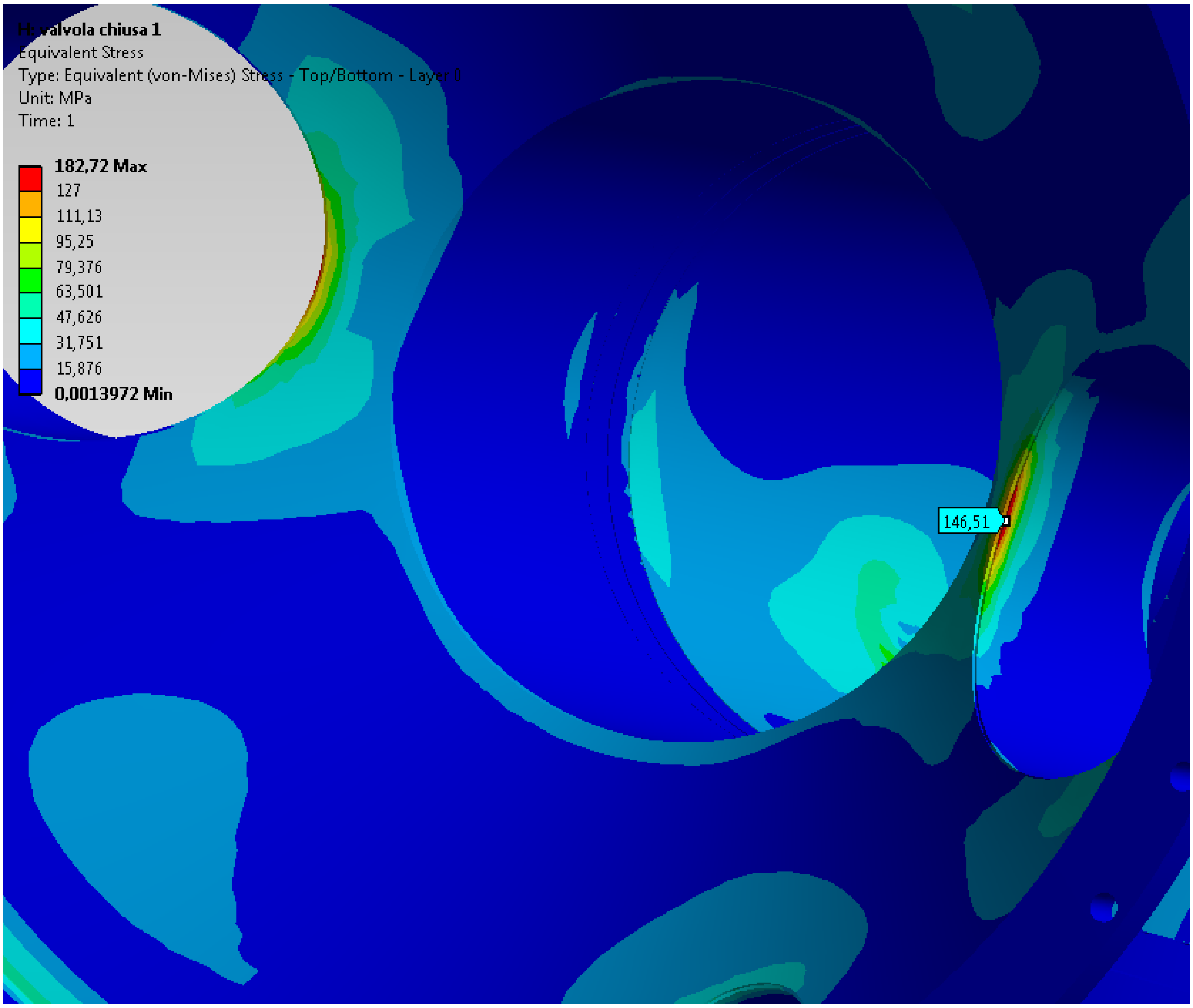


Figure 21 - Von Mises stress - detail



There is a small zone where the stress is slightly above the admissible (146 MPa instead 190/1,5 = 126 MPa). Since the nature of the effect is very local and the zone is very small the effect can be neglected. The stress level of the system is acceptable respect to the admissible stress calculated as stated in EN 13445-3.

7.7 Load case 2 – Design - Displacements results

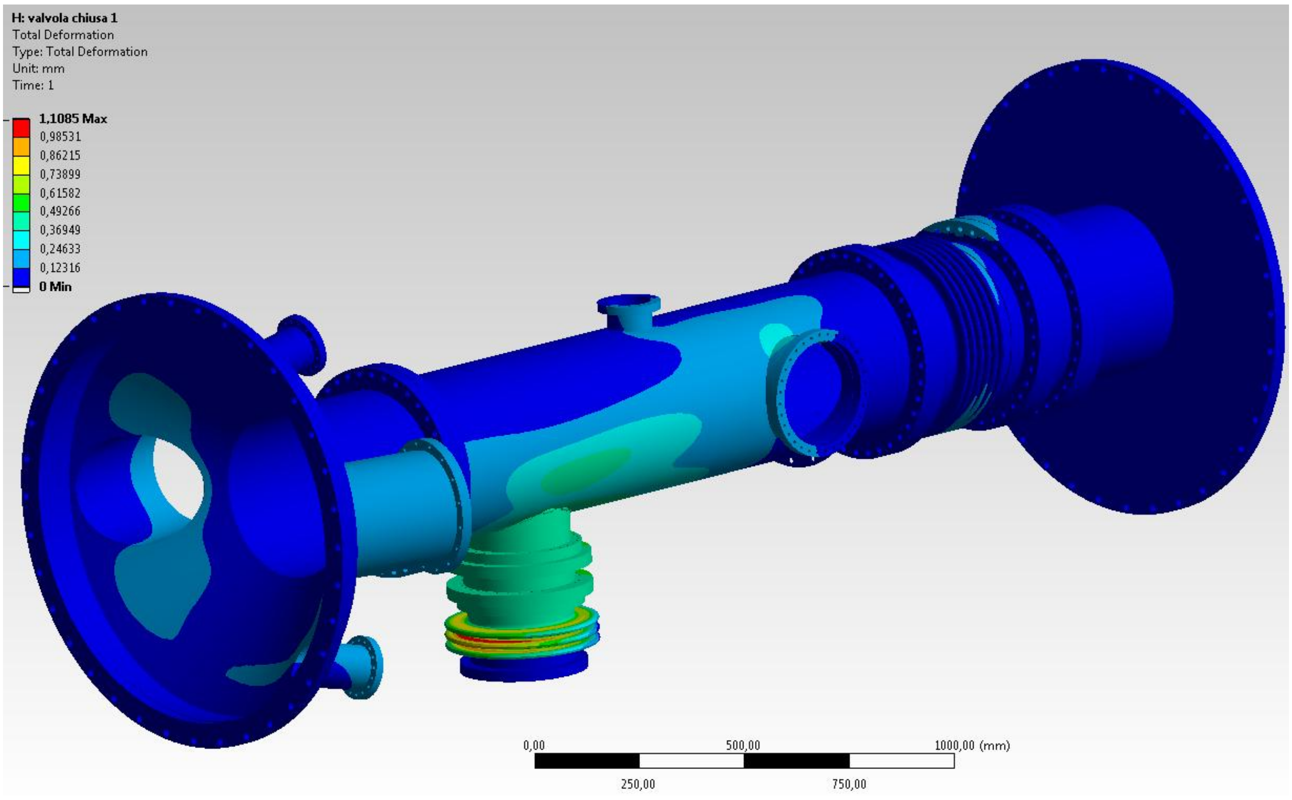


Figure 22 - Displacements

The displacements are very small and can be accepted from a point of view of the functionality of the system.

7.8 Load case 2 – Design - Reaction results

The reactions shown in the below images are in the global coordinate system (depicted in each image).

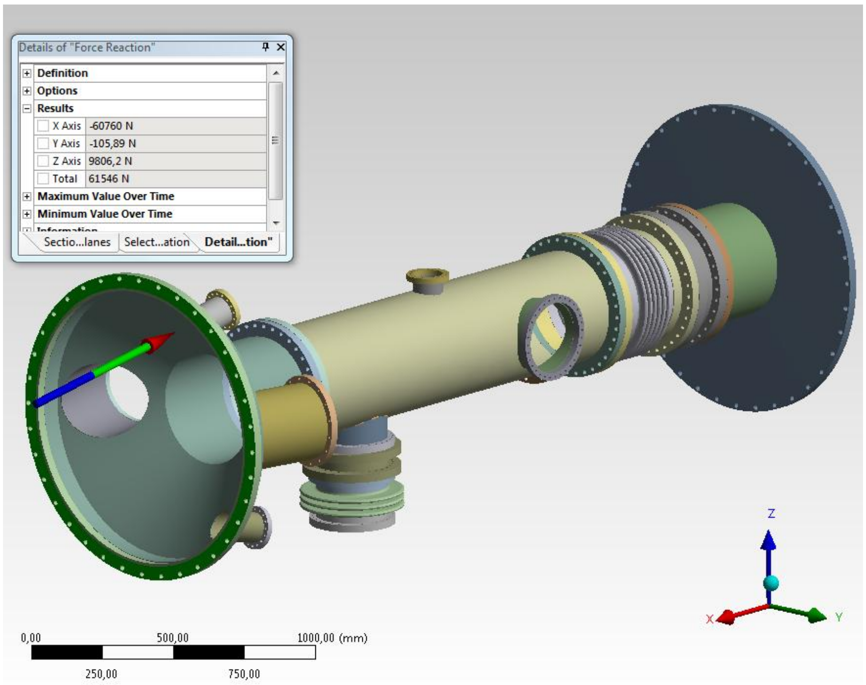


Figure 23 - Flange force reaction

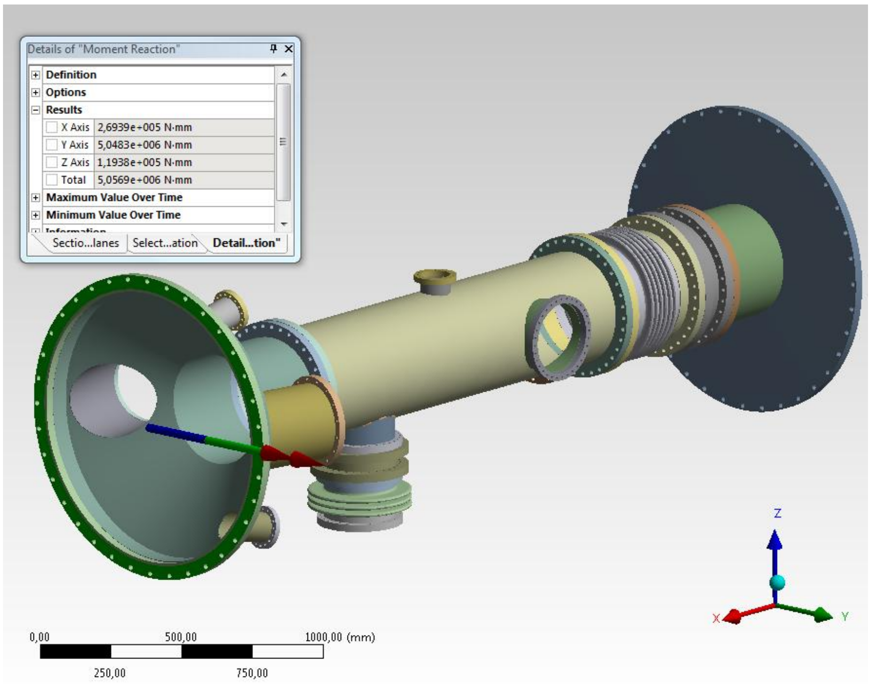


Figure 24 - Flange moment reaction

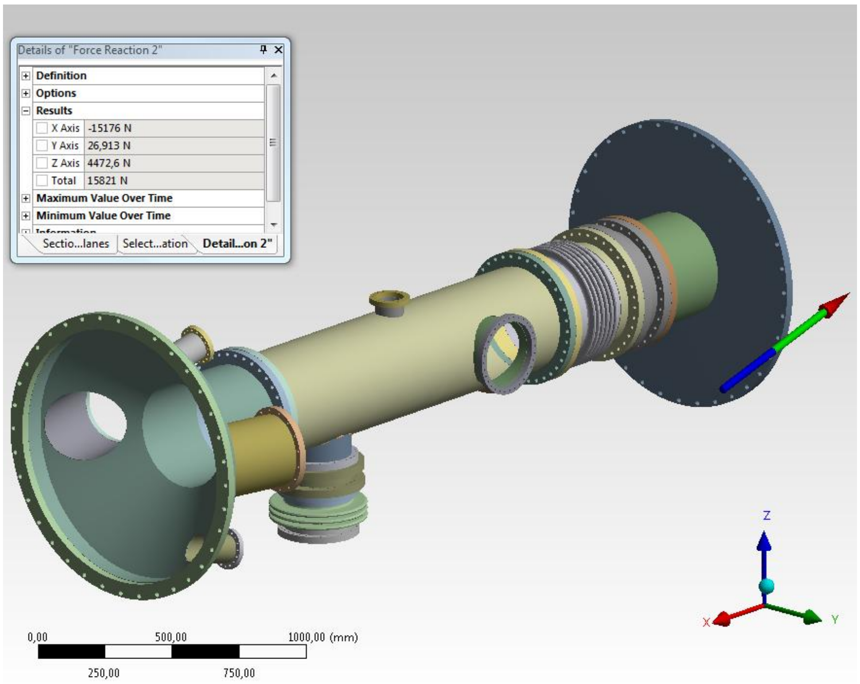


Figure 25 - Flange force reaction

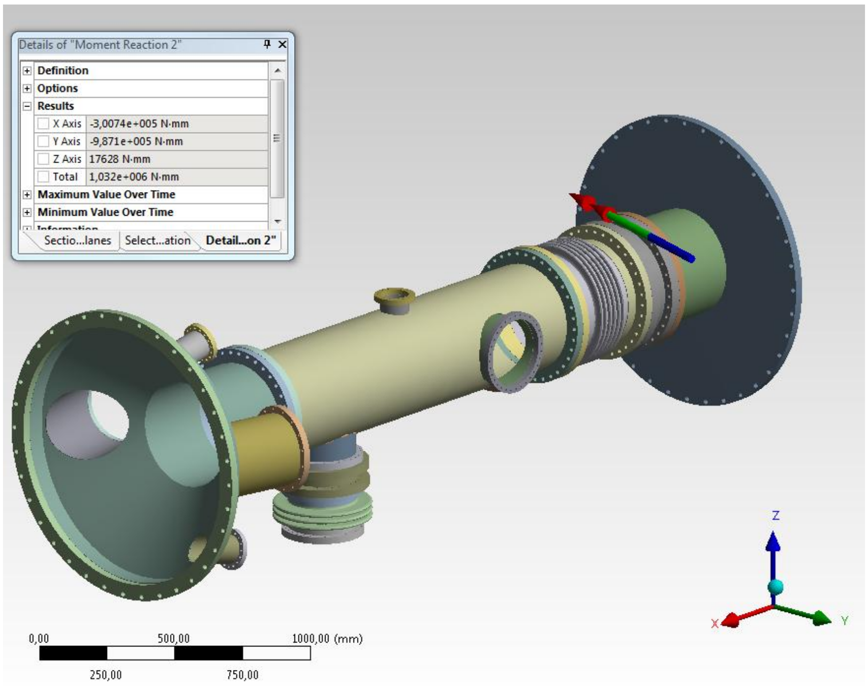


Figure 26 - Flange moment reaction

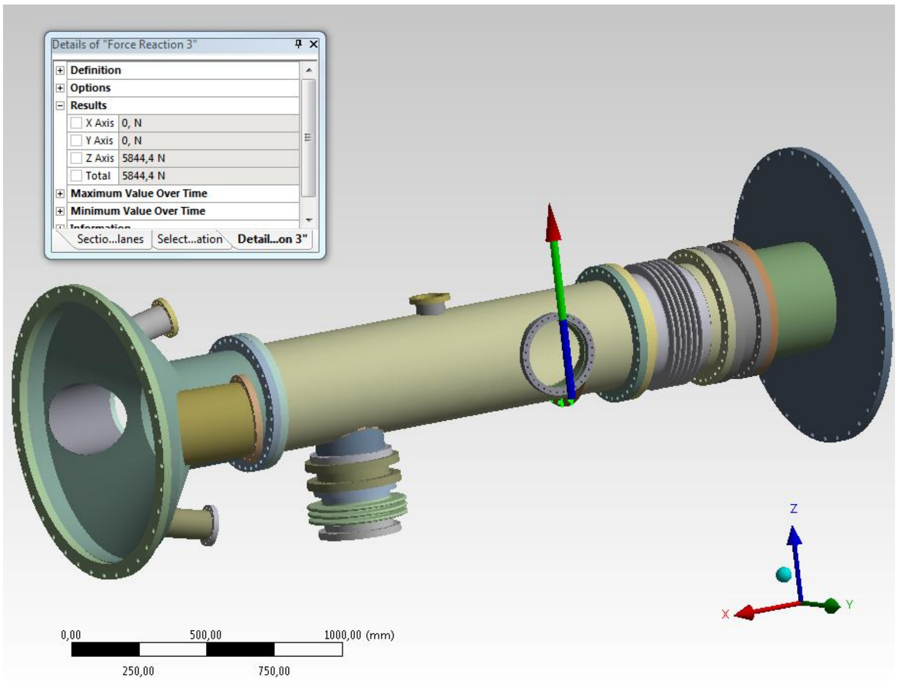


Figure 27 - Vertical support reaction

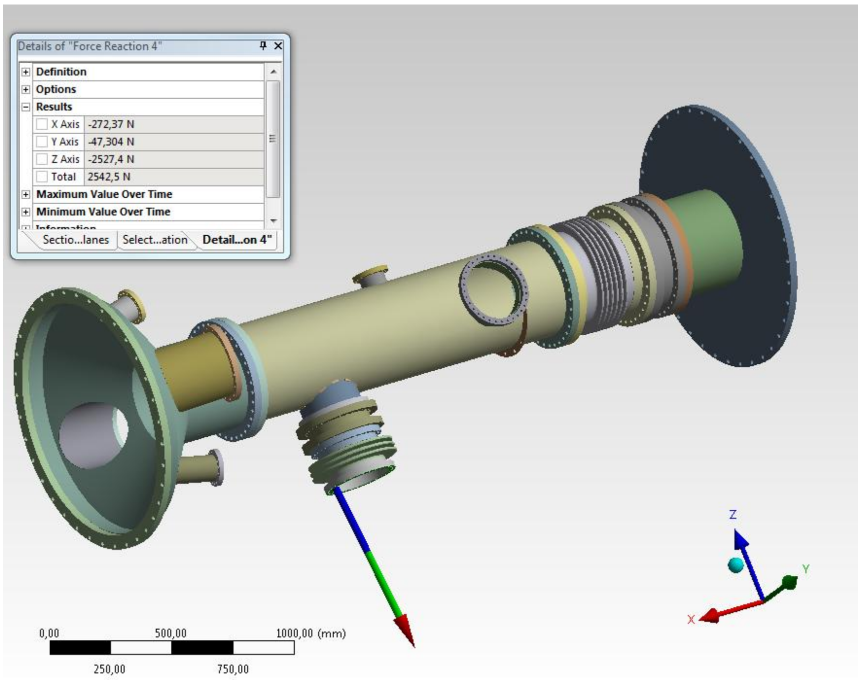


Figure 28 – Pump flange force reaction

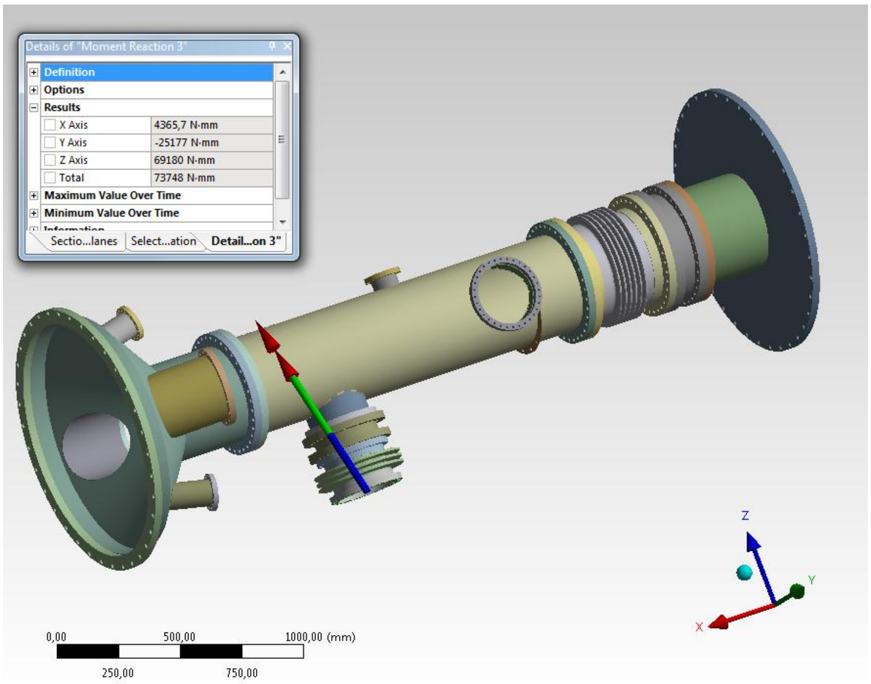


Figure 29 – Pump flange moment reaction

8 Buckling analysis

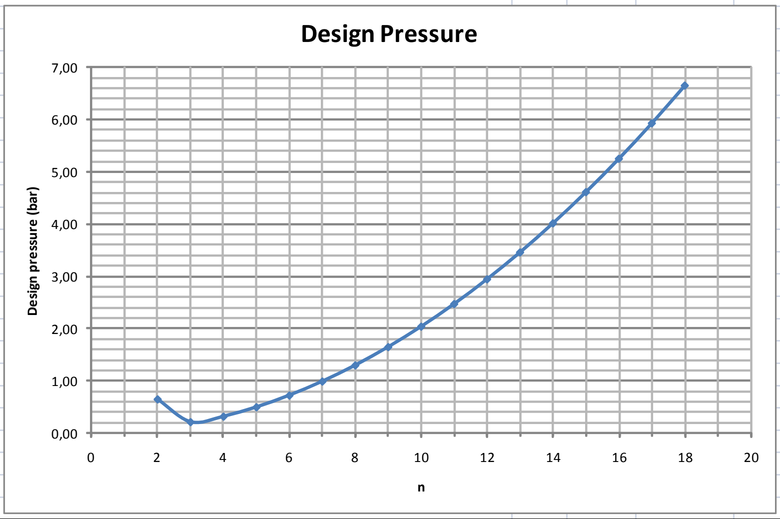
The buckling analysis is made following the EN13445-part 3. The free length of pipe considered is 1510 mm (anyway, the presence of the branches reduces this free length).

The results is shown in the below spreadsheet.

EN13445 - Check external pressure

Material		-	AISI 304
Elastic Modulus	E	*MPa*	193000
Yield stress	$R_{p0,2}$	*MPa*	190
Nominal elastic limit	σ_e	*MPa*	190
Tensile stress (min)	R_t	*MPa*	500
Poisson coefficient	ν	-	0,3
External diameter	D_e	*mm*	406,4
Wall thickness	e_a	*mm*	3
Internal diameter	D_i	*mm*	400,4
Mean radius	R	*mm*	201,7
Length	L	*mm*	1510
Coefficient"Z"	Z	-	0,42
Yield pressure	Py	*MPa*	2,8
Ratio Pr/Py (calculated from below graph)	Pr/Py	*MPa*	0,125
Pressure Pr (calculated lower bound collapse pressure)	Pr	*MPa*	0,35
Safety factor	S	-	1,5
Design pressure	P	*MPa*	0,24

Mode of instability	Theoretical elastic instability pressure for collapse of a perfect cylindrical shell	Ratio between critical pressure and yield pressure
n	P_m	P_m/P_y
-	*Mpa*	*Mpa*
2	1,84	0,65
3	**0,61**	**0,22**
4	0,91	0,32
5	1,42	0,50
6	2,05	0,73
7	2,81	0,99
8	3,68	1,30
9	4,67	1,65
10	5,77	2,04
11	6,99	2,47
12	8,33	2,95
13	9,79	3,46
14	11,36	4,02
15	13,04	4,62
16	14,84	5,25
17	16,76	5,93
18	18,80	6,65



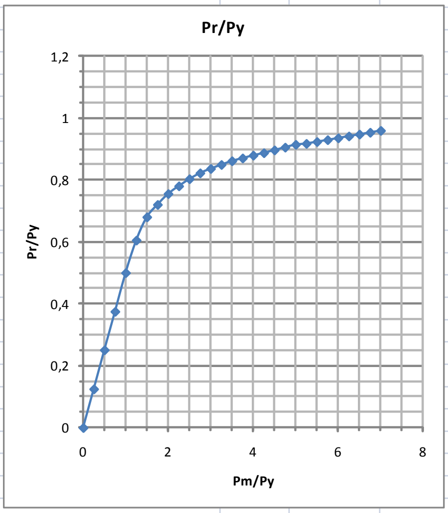


Table 1 - Buckling check

Design pressure (2,4 bar) is greater than design limit (1 bar).

9 Modal analysis

The number of natural frequencies calculated is 6. The min frequency is 41.37 Hz, the max is 107.56 Hz.

9.1 Main modes

The natural frequencies are determined mainly by the bellows that are the components with the lowest stiffness. In the next images showing the main modes, in order to highlight the deformed shape of the most important components (i.e. the pipes), the bellows are hided.

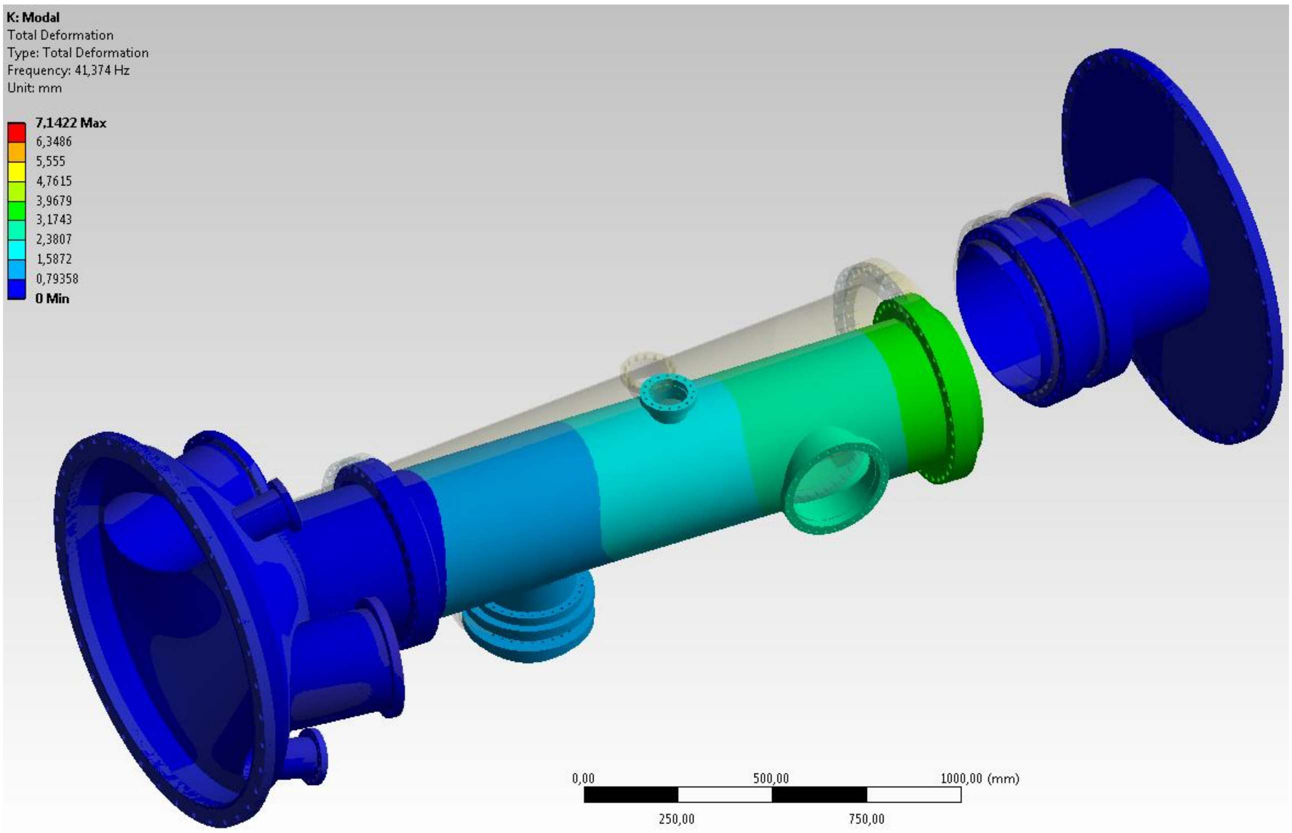


Figure 30 – Mode 1

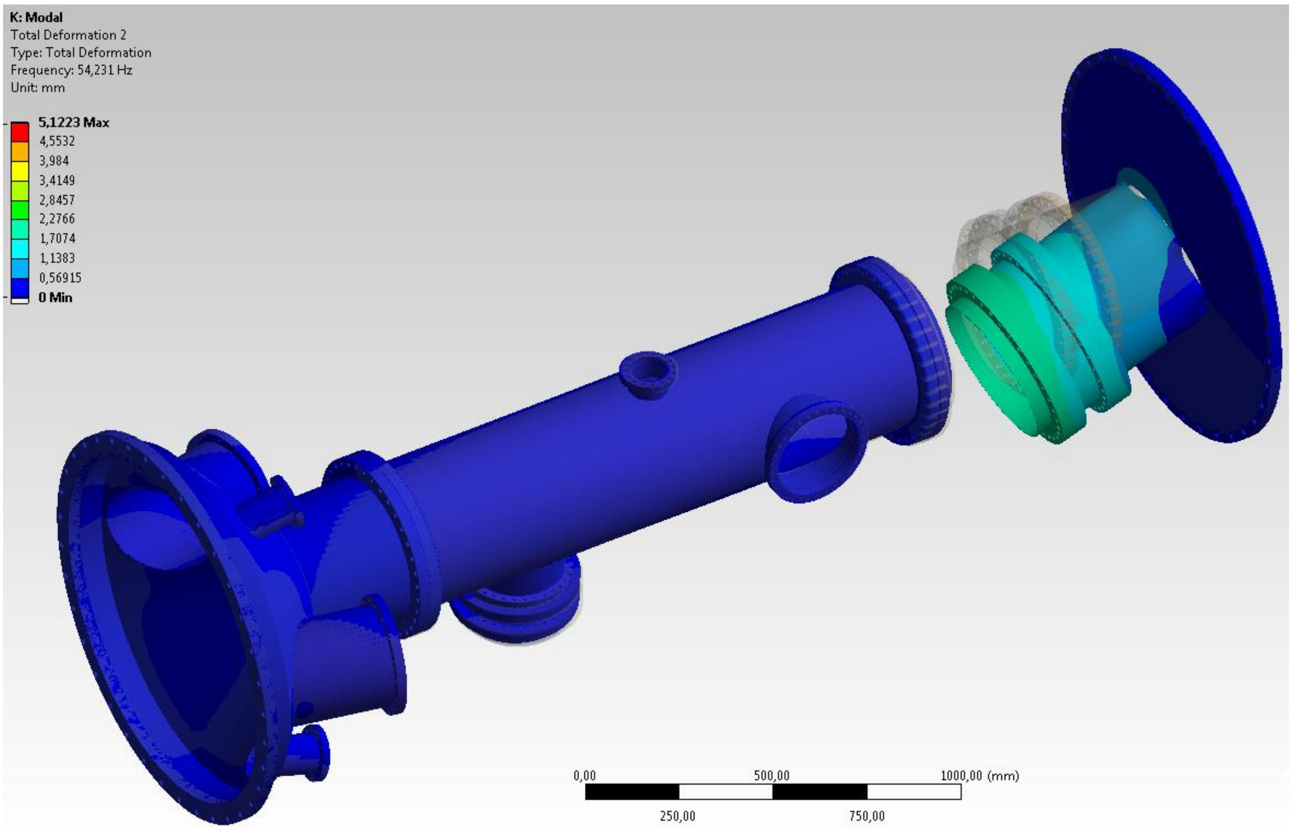


Figure 31 – Mode 2

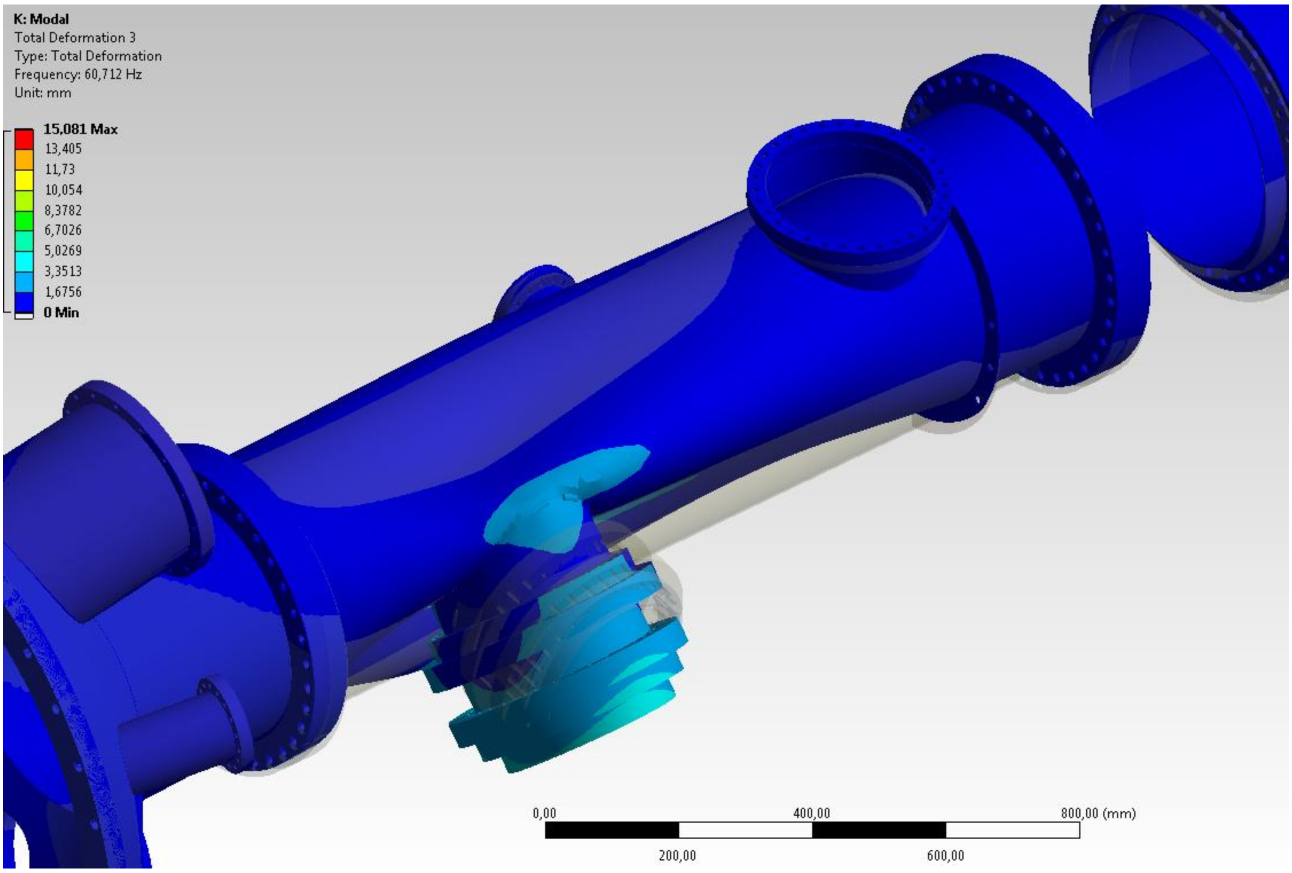


Figure 32 – Mode 3

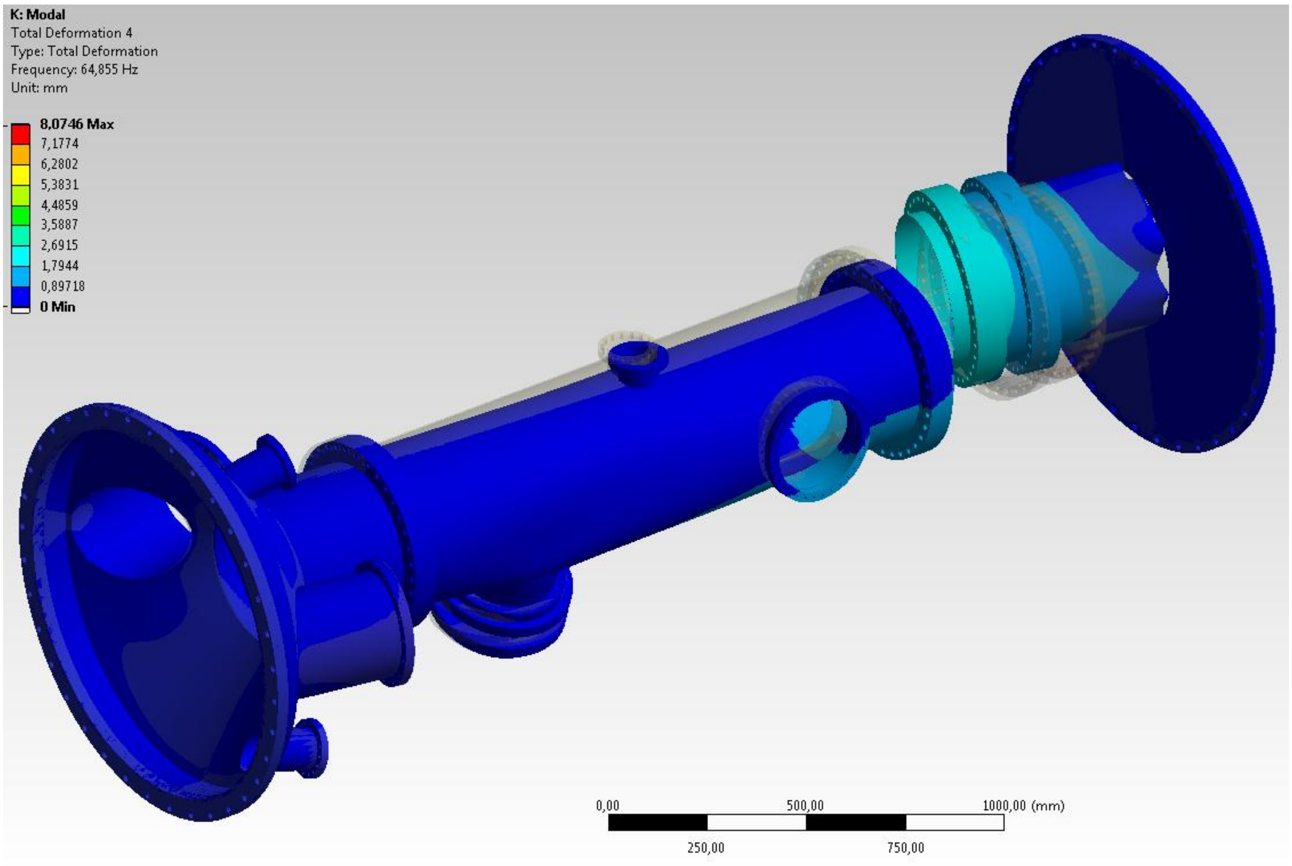


Figure 33 – Mode 4

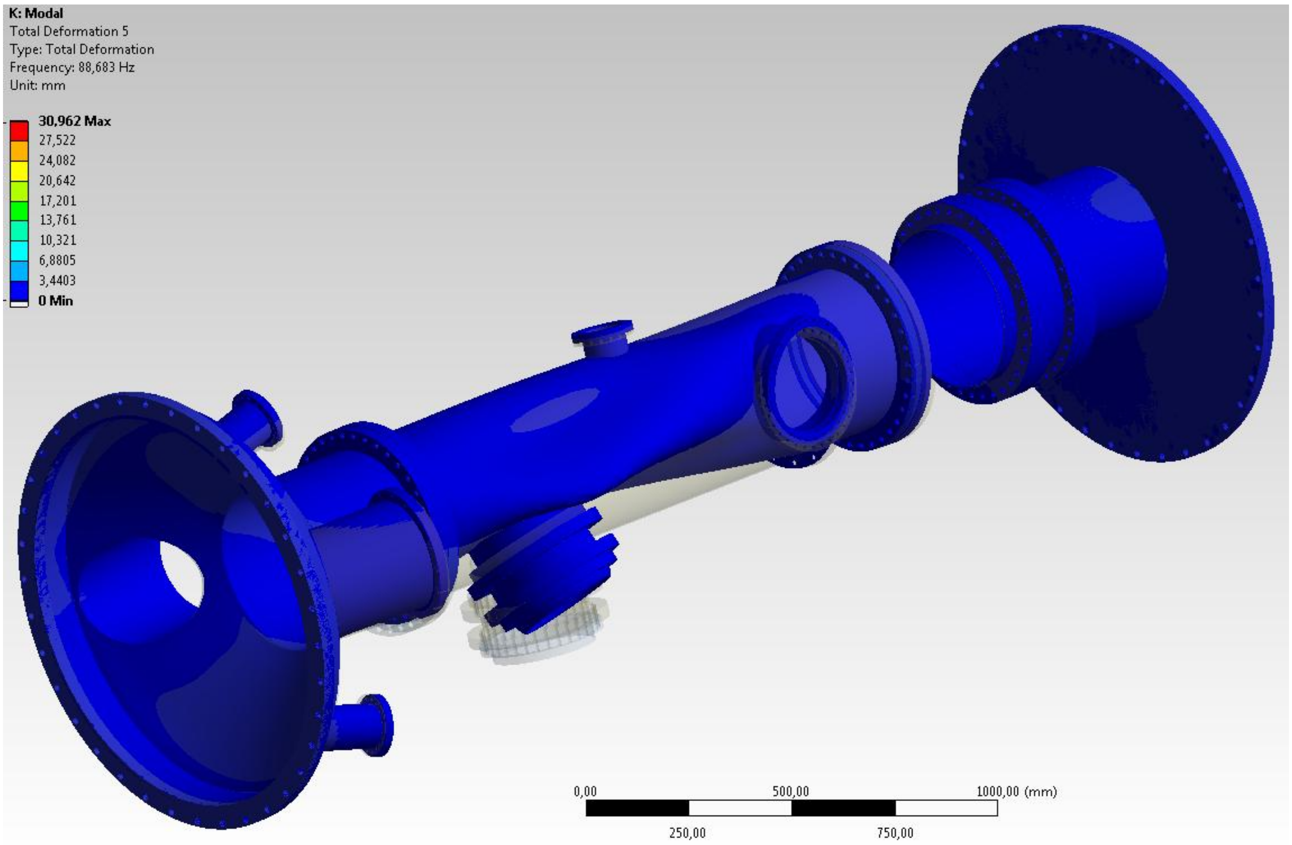


Figure 34 – Mode 5

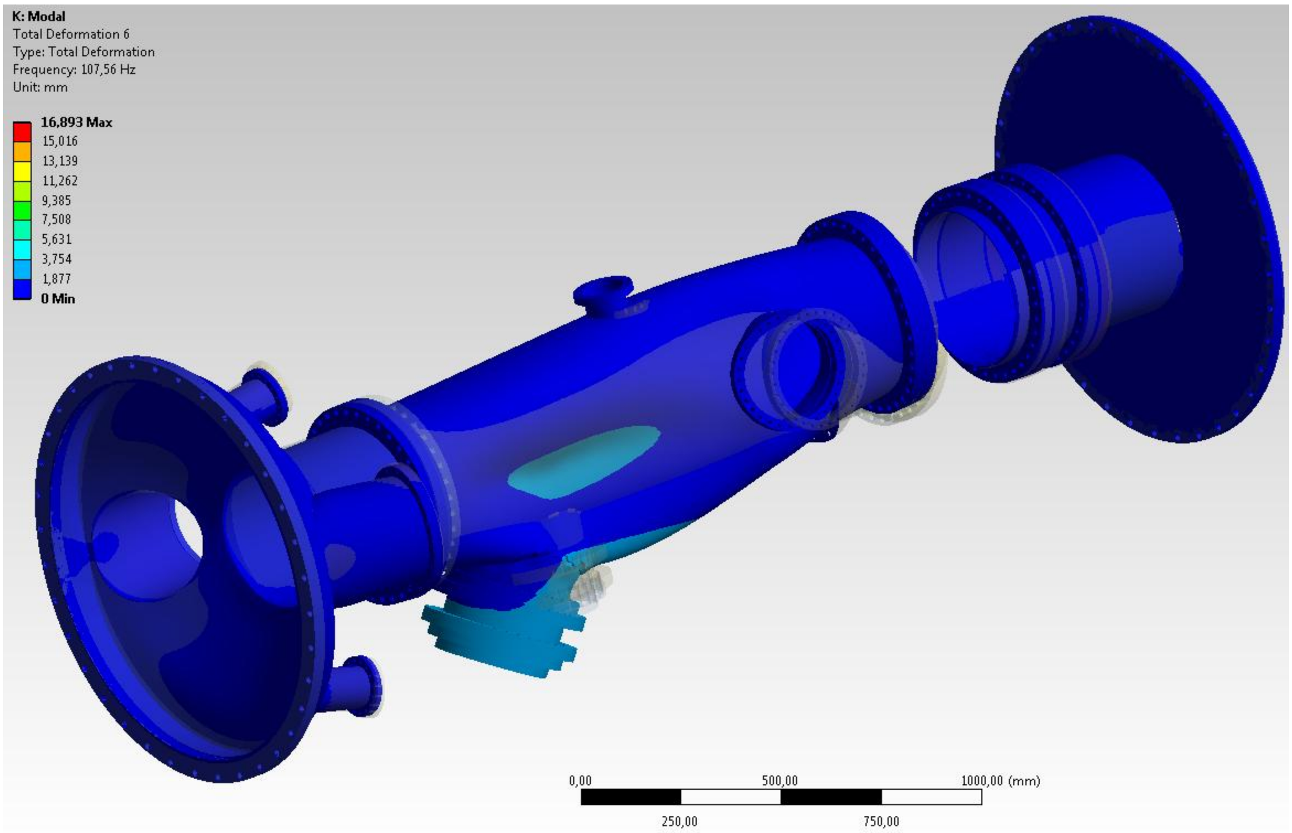


Figure 35 – Mode 6

10 Linear Buckling

Here below linear buckling analysis results are reported. Buckling mode 3 and 4 affect vacuum pump bellow.

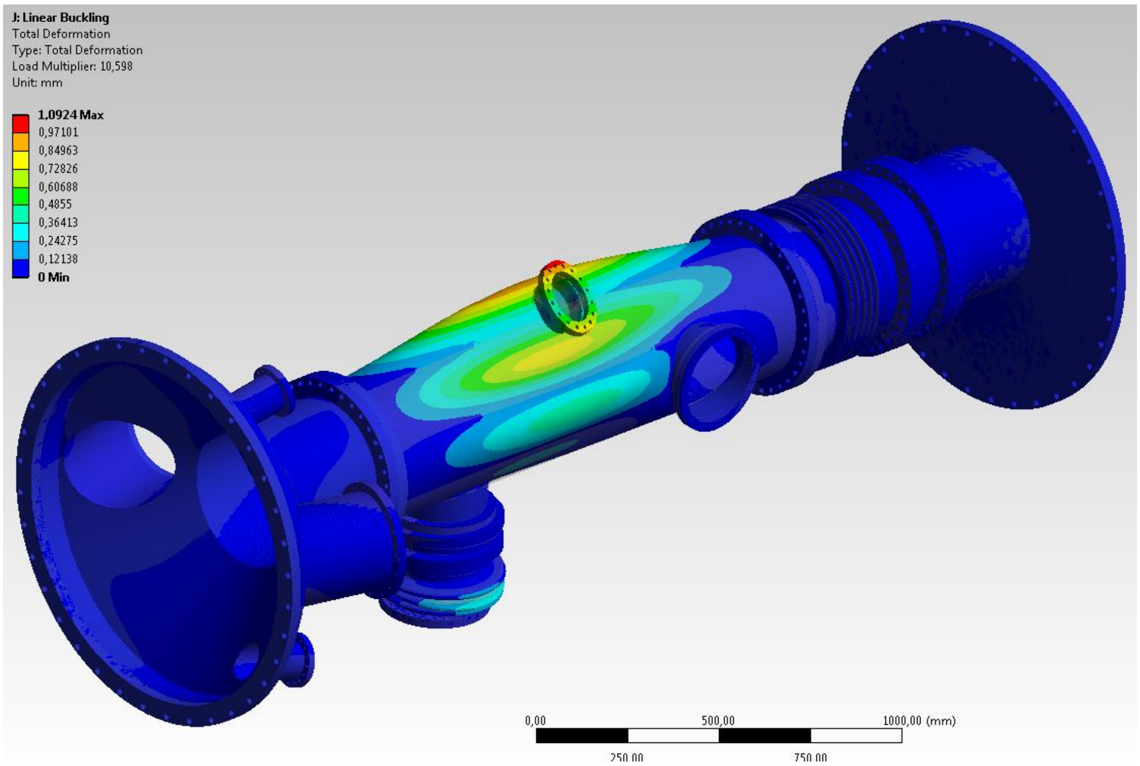


Figure 36 – Buckling Mode 1 - Load Multiplier: 10.6

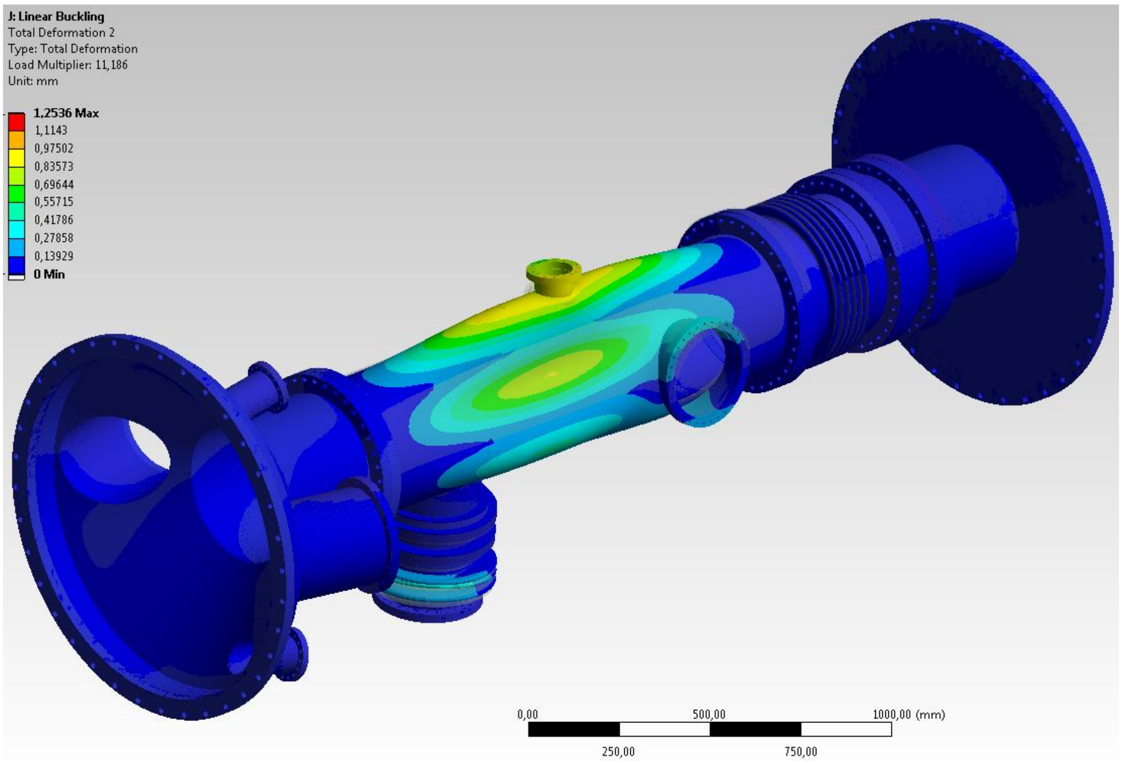


Figure 37 – Buckling Mode 2 - Load Multiplier: 11.2

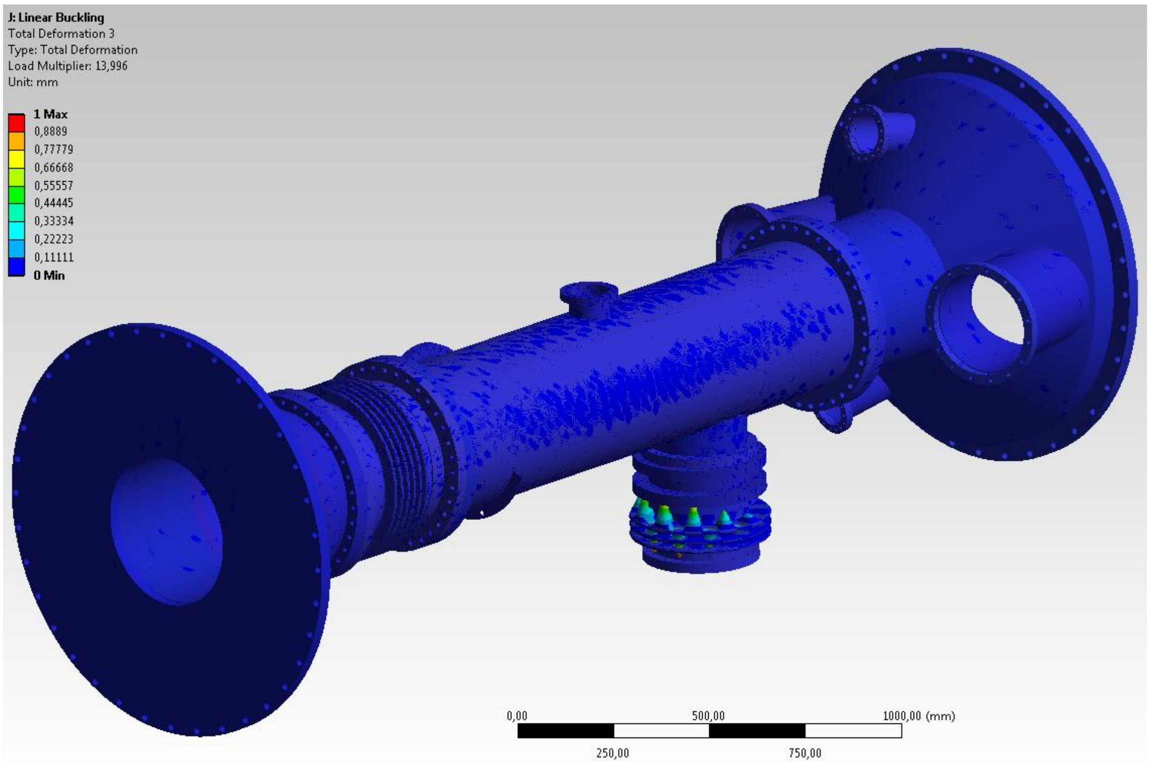


Figure 38 – Buckling Mode 3 - Load Multiplier: 14 (Bellow)

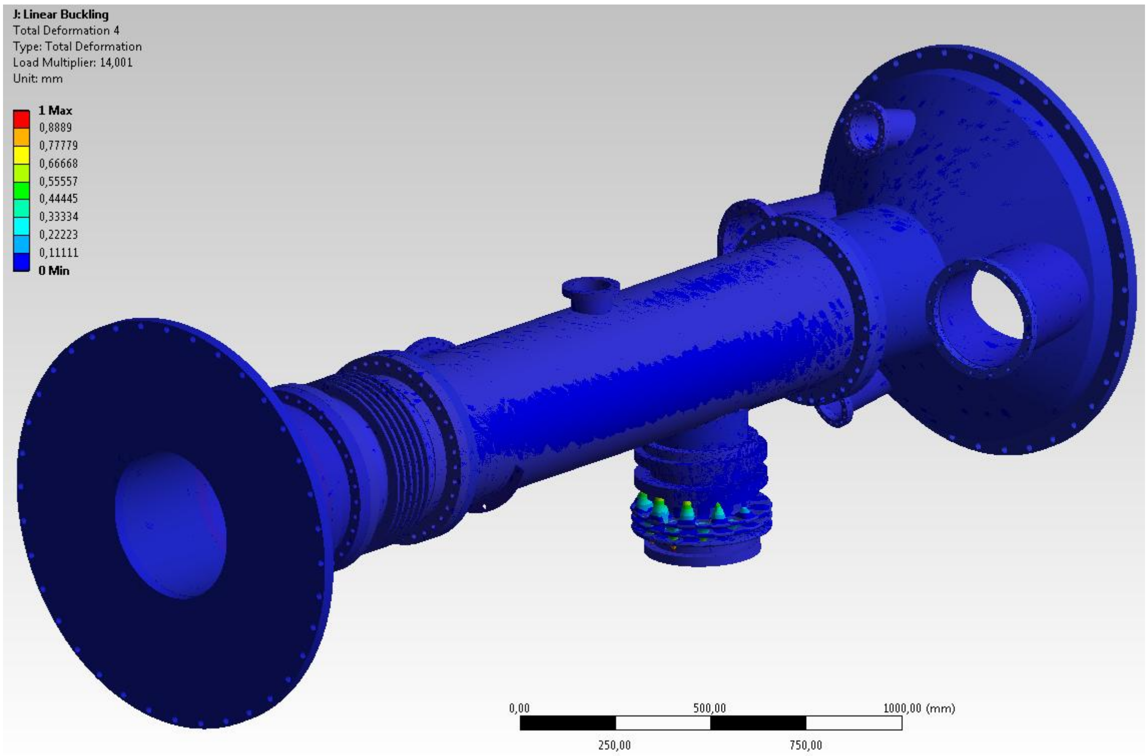


Figure 39 – Buckling Mode 4 - Load Multiplier: 14 (Bellow)