AALBORG UNIVERSITY

Department of Civil Engineering

Wavestar C5 prototype

Structural analysis of the UHPFRC FLOAT

Rev. 10-06-2013

AALBORG UNIVERSITY

Resume

The report proves that the new design of the WSE Float structure has a satisfactory load transferring system. The internal loads are primarily hoop stresses in the shell structure, and as membrane forces in the cap. The internal bracing, both in the cap and the shell structure seems to increase the overall stiffness of the structure. The increased stiffness locally means that the stresses concentrations are seen here. The structure cannot be accomplished without any conventional reinforcement, accordingly to these stress concentration. Further analysis must be carried out to find the necessary amount reinforcement to prevent initiation of cracks.

Doc number: AAUCIV - 1.3
Version: 2.0
Made by: MISJ – LD
Date: 10-06-2013

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1. Introduction

In relation to the Wave Star Energy development project, a new design has been initiated to lower the expenses and increase the durability of the arm and float structure significantly. The overall stiffness, weight and durability of the float are the main issues treated in this structural analysis.

Currently the float is designed as a shell structure, made of glass fiber composites. In the new design proposal the shell structure will be redesigned and the glass fiber material will be substituted with ultra-high performance fiber reinforced concrete (UHPFRC). The design should then obviate the need for high rigidity, durability and low weight.

Following topics will be treated within this report.

General design principles – weight and stiffness considerations.

FEM model – Workbench solid model for linear elastic analysis.

Load cases – illustration of the considered load cases.

Weight of structure – weight calculation of the float.

Design limit state – the stress state where micro cracking is initiated.

Global deformations – Study of the stiffness of the structure.

Stress state – Evaluation of the principle stresses.

2. Scope of work

The primary aim of this report is to investigate the new design of the WSE arm structure. Following issues will be treated:

- Material properties of the UHPFRC
- Establish FEM model of C5 float.
- Load cases.
- Principle stress state
- Direction of principle stresses.
- Deformations.
- Weight calculation.

The analysis finally results in a set of design recommendations, which will create the basis for further design considerations regarding how the structure is assembled. The detailed design is not within the present scope.

3. Current WSE arm structure

The current arm structure on the WSE machine can be seen in Figure 3-1. The arm structure translates the movement of the float structure to a hydraulic cylinder. The energy transferred to the hydraulic system runs a generator and electricity can be produced.

Figure 3-1: Current arm design.

The wave machine manufactored for the Roshage site, is overall a steel structure. Design consideration of the machine was primary based on the exstensive knowledge of marine steel structures, known from the offshore oil and gas industry. The idea was to design a wave energy machine based on existing codes and guidelines of marine structures, and thereby let the design relie on conventional offshore design solutions. The report concerns the design of a new arm structure for the wave energy machine. The current design of the arm, float and attachment to the main structure is sketched in Figure 3-2.

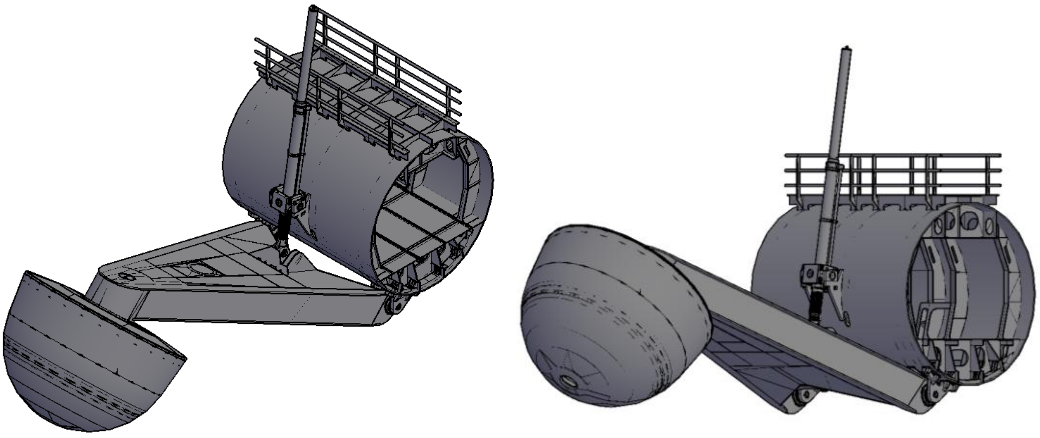
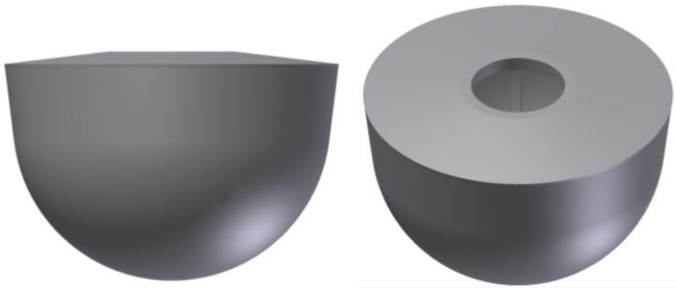


Figure 3-2: Sketch of arm structure and attachment to the hull.

4. Principles of new design

The float structure is designed as a double-curved shell structure, see Figure 4-2. The cap and double curved shell structure will be casted as two separate parts and later assembled.



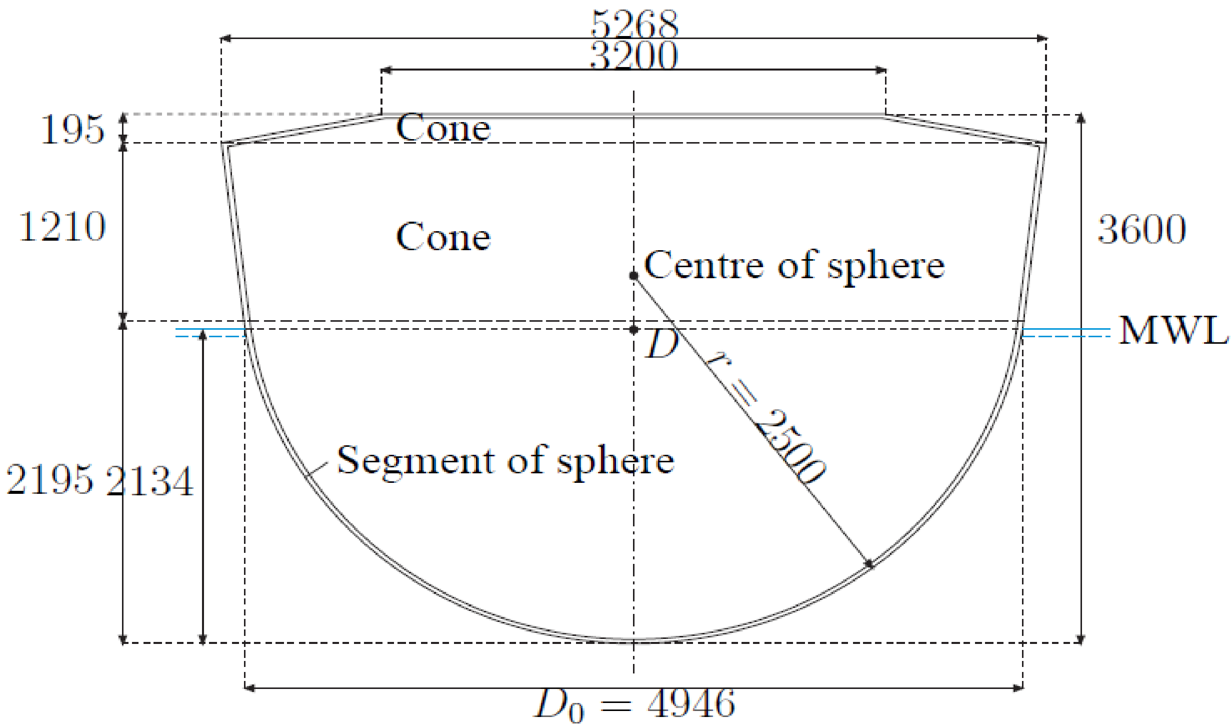


Figure 4-1: Geometry of Wavestar Float used for the prototype at Hanstholm [mm].

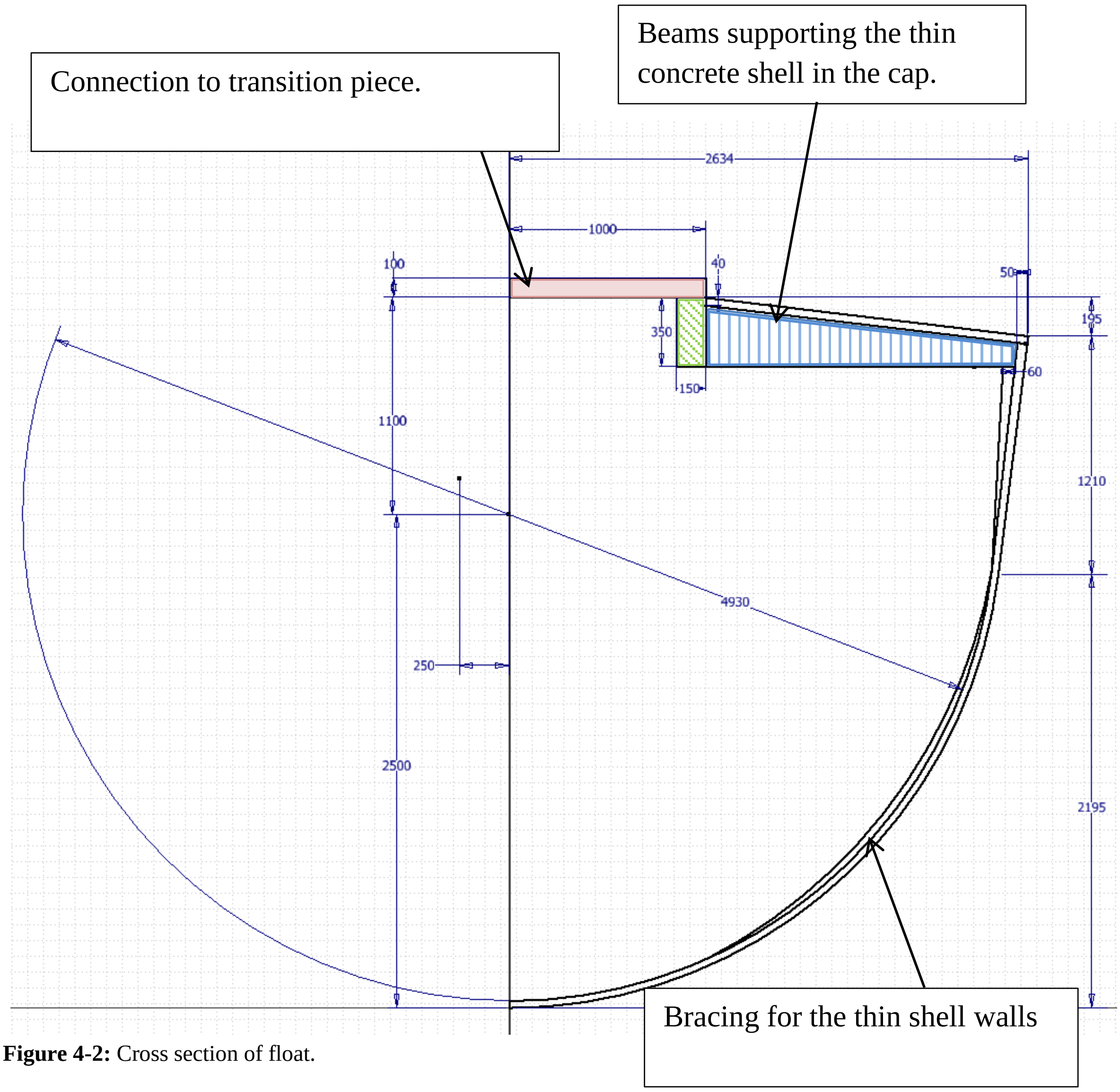


Figure 4-2: Cross section of float.

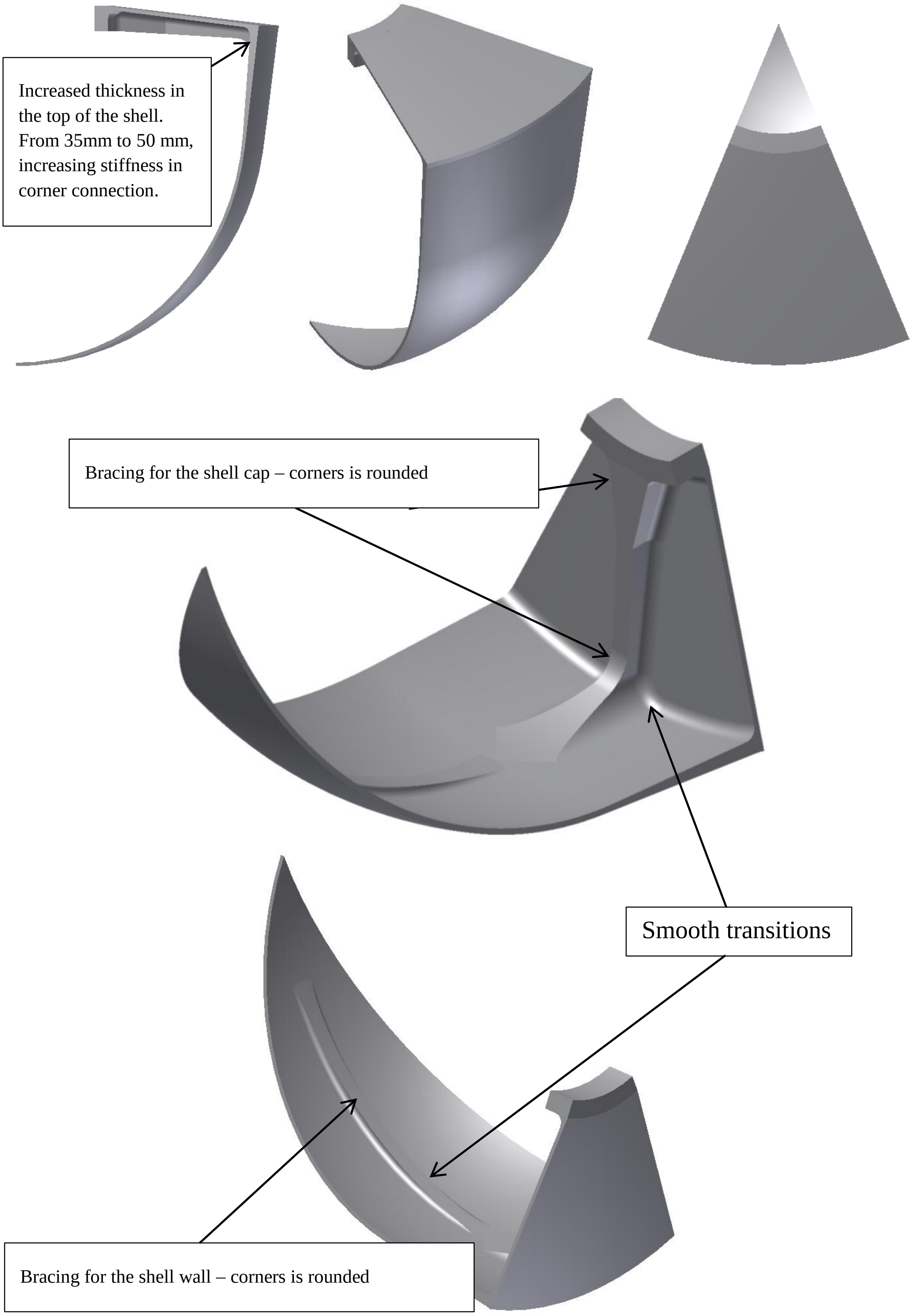


Figure 4-3: The shell structure of the float – sketch.

To reduce stress concentration and achieve a smooth load transfer, all parts of the internal geometry has smooth transitions.

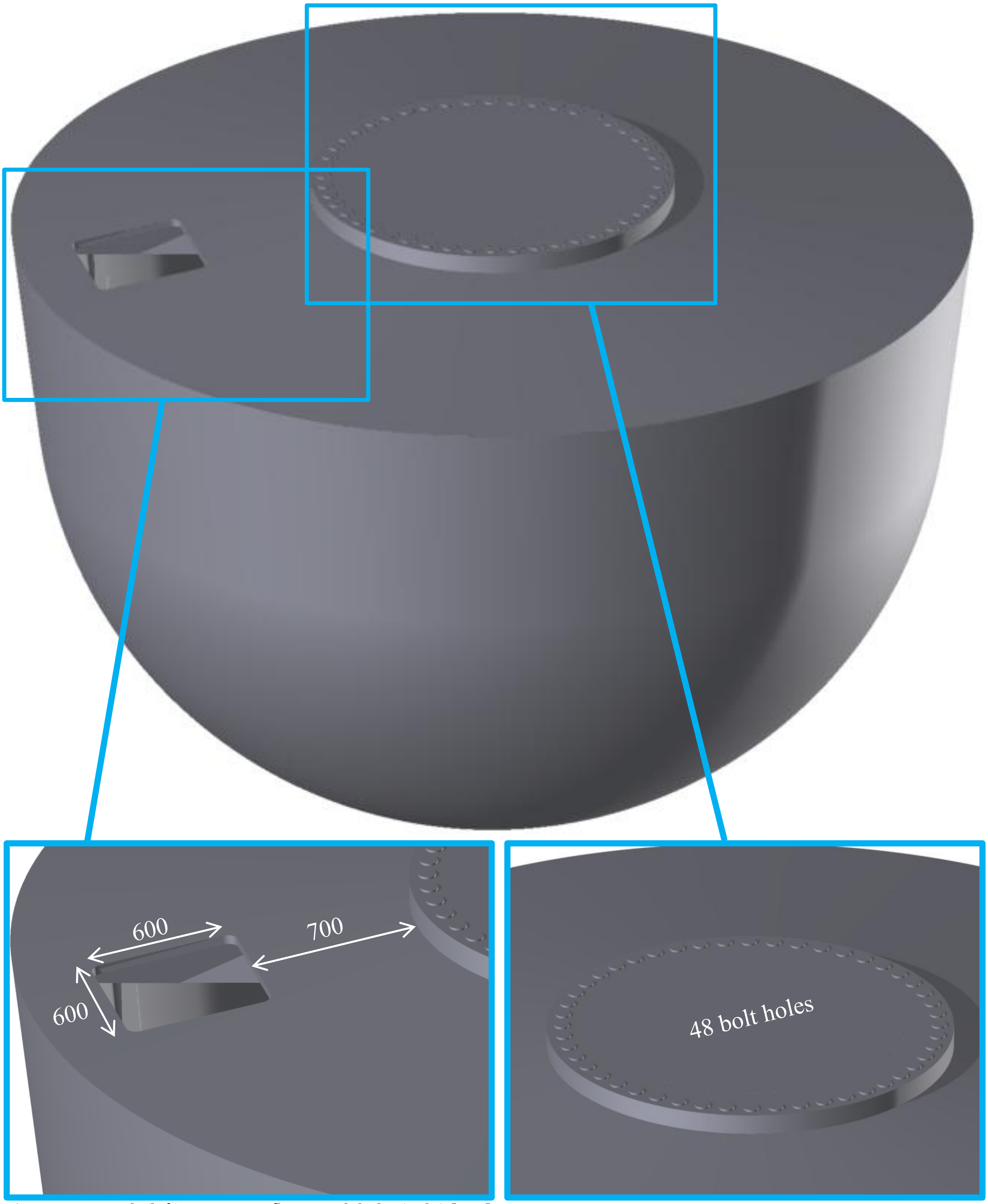


Figure 4-4: Hatch (left), Transition flange with bolts (right) [mm].

5. Material properties

In the new design of the float structure a UHPFRC[1] material is used as primary material of the shell structure. The current material is a product from Hi-con A/S, and is named CRC[2].

Table 5-1: Material parameters of the CRC.

Fiber vol. 2 %		Characteristic	Design
		[MPa]	[MPa]
Compressive strength	f_c	105	63,6
Bending strength	f_{cm}	14,5	8,8
Tensile strength	f_{ct}	5	5
Youngs modulus	E_{c0}	45000	-

The UHPFRC contains 2 volume percent of steel fibers, which increases the ductility and the tensile strength of the material.

The density of the material is estimated to 2700 kg/m^3. The material itself has a density of approximately 2550 kg/m^3, but at present time the arrangement of the reinforcement is not known. Thus the material density is set to 2700 kg/m^3 which take a smeared conventional steel reinforcement into account.

[1] Ultra High Performance Fiber Reinforced Concrete
[2] Compact Reinforced Composites

6. FEM model

The model of the Float has been developed in Inventor, and creates the basis for a 3d FEM model in ANSYS workbench. The geometry is modeled according to the Inventor drawings [XX], see Figure 6-1.

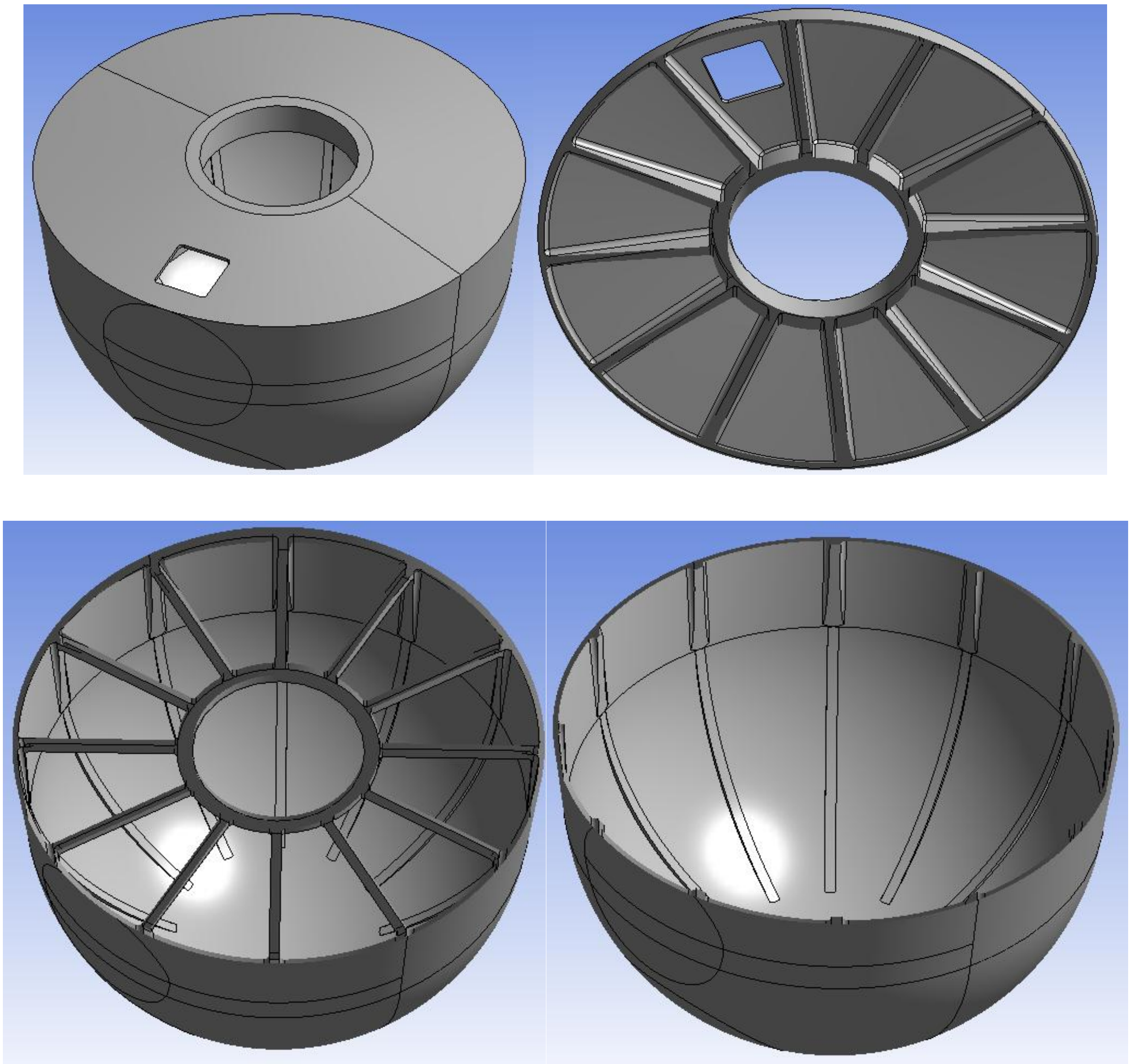


Figure 6-1: Model of float structure in ANSYS Workbench.

The structure will be analyzed as a linear elastic structure, although this is only true when no cracks have been initiated. The linear elastic analysis is carried out to investigate the state of principal stresses and their direction. This gives an indication of the stress flow in the structure and accordingly how the loads are transferred to the support.

7. Load cases

The float structure will be subjected to two types of wave loads, static slamming loads and static wave loading, modeling a difference pressure on the shell surface.
The slamming loads should be treated as the full wave load, and it shall not be combined with any other loads. The loads are calculated in [2]. Results are given in the table below where the characteristic slamming pressure $p_{s,k}$ is without safety factor, whereas the design slamming pressure $p_{s,d}$ includes the partial safety factor $\gamma_{f,E}$ = 1.35.

Parameter			**Roshage float**	**C5 float**	**C6 float**
Slamming pressure, characteristic	$p_{s,k}$	kN/m^2	263	263	266
Slamming pressure, design	$p_{s,d}$	kN/m^2	355	355	359
Diameter of circular area of impact	k	m	1.76	1.76	1.76

Three load cases must be checked; slamming on float bottom (Case A), lower part of float shell (Case B), and upper part of float shell (Case C).

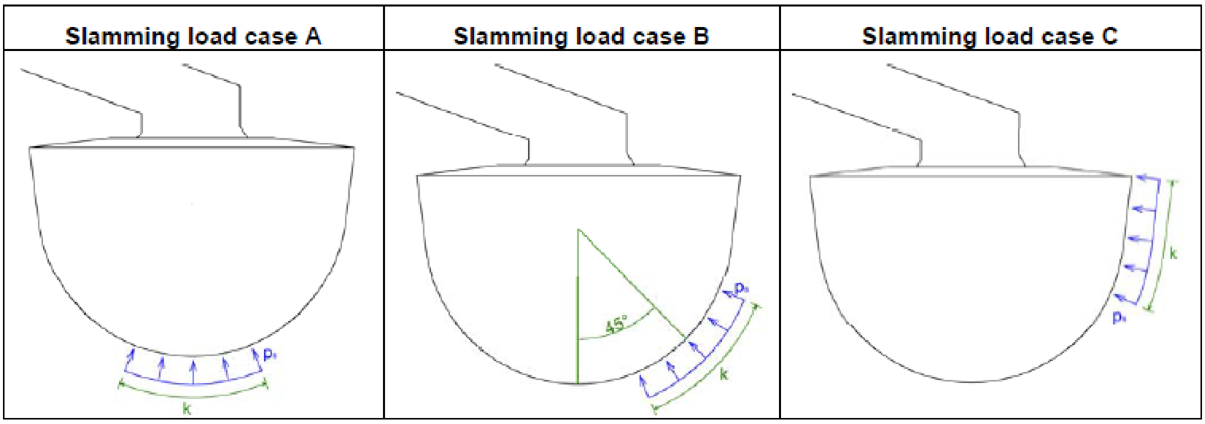


Figure 7-1: Position of Slamming forces.

WSE Material – Received at FLOAT meeting 6th june 2012 at AAU.

7.1. FEM modeling of loads

The structure will currently be designed for 7 load cases. Each load case represents a slamming force location or a differential pressure on the outer surface of the float. The slamming force is furthermore located in the section between two internal bracings, see Figure 7-2 and Figure 7-3.

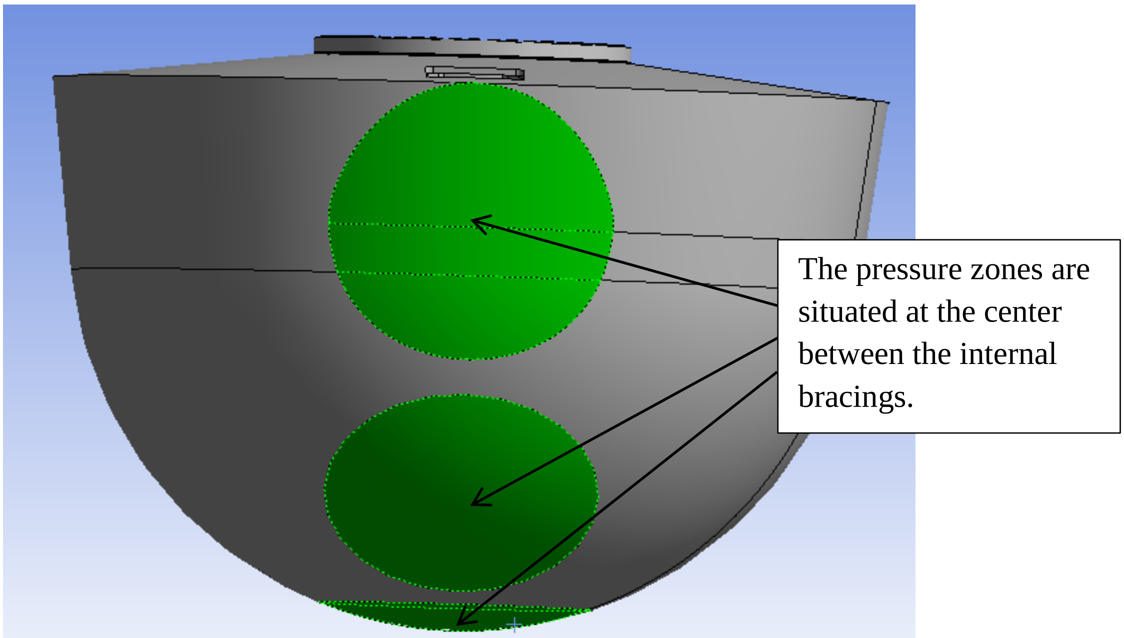


Figure 7-2: Slamming forces located between bracings.

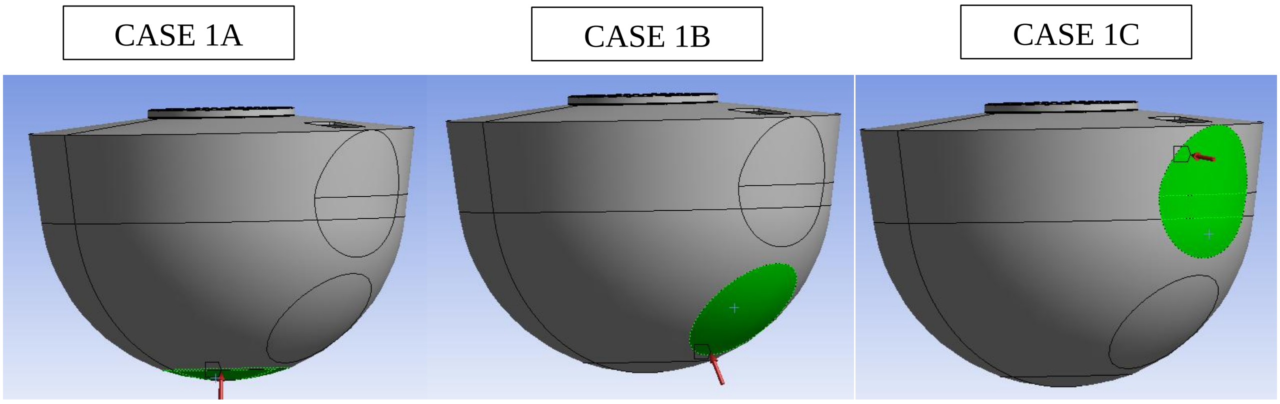


Figure 7-3: Location of slamming loads for Load Case 1A – 1C.

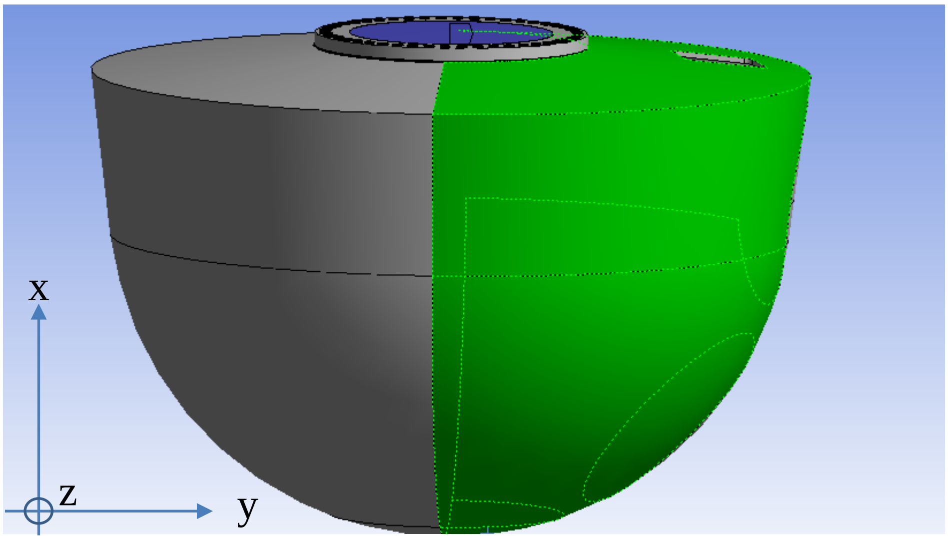
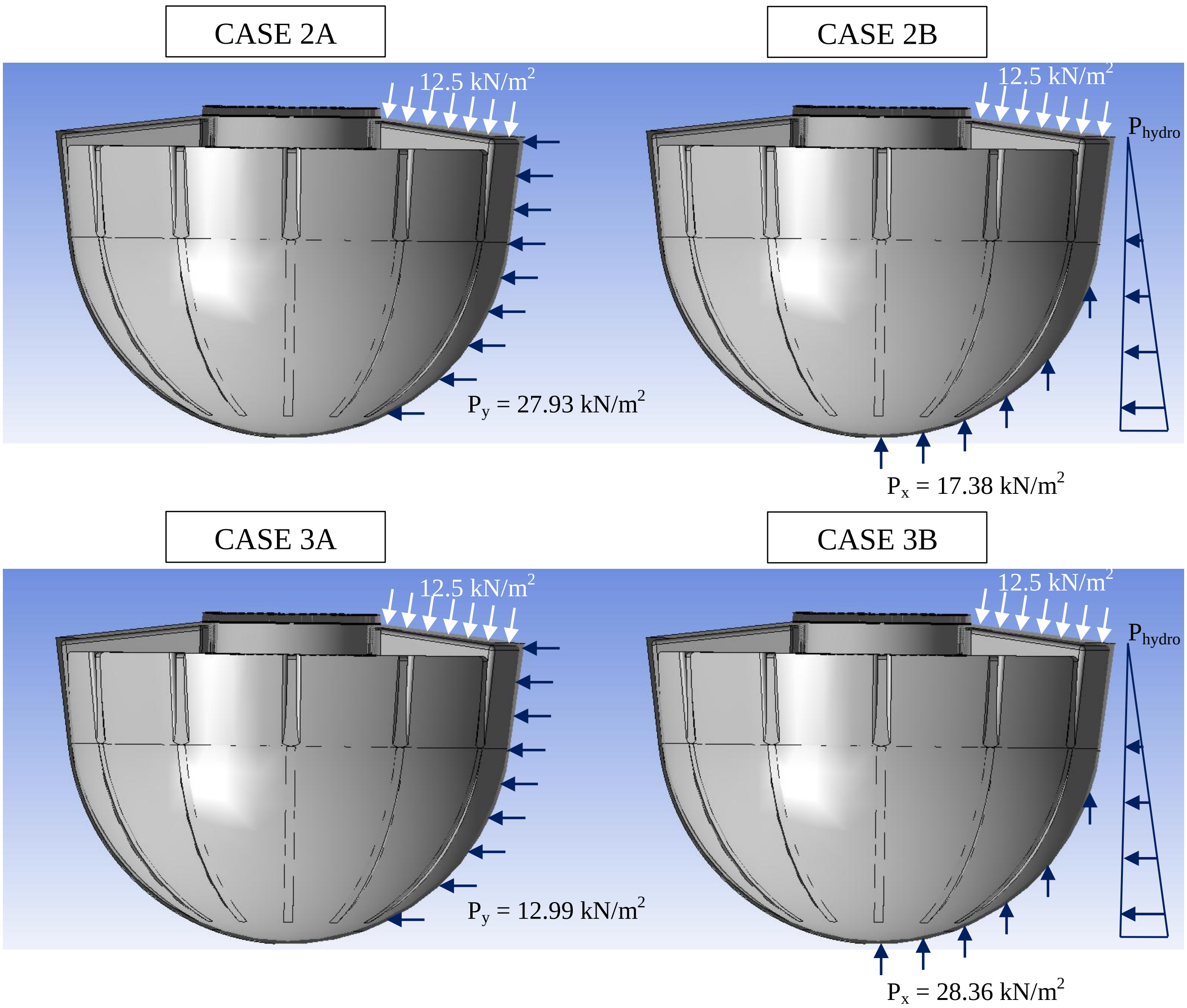


Figure 7-4: Pressure surfaces.



8. Boundary conditions

Fixed support, in the area where the float is attached to the transition piece.

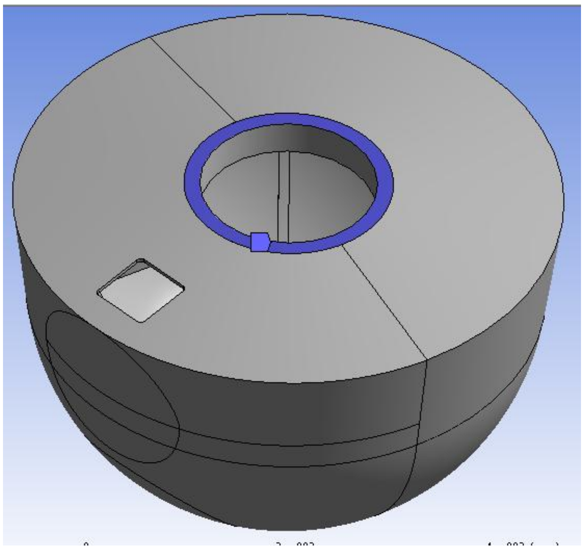


Figure 8-1: Boundary condition, connection to transition piece.

9. Mesh and convergence

The structure has been discretized with 12272 solid elements, controlled by the hex dominant method. The midside nodes are all kept. Mesh generated, see Figure 9-1.

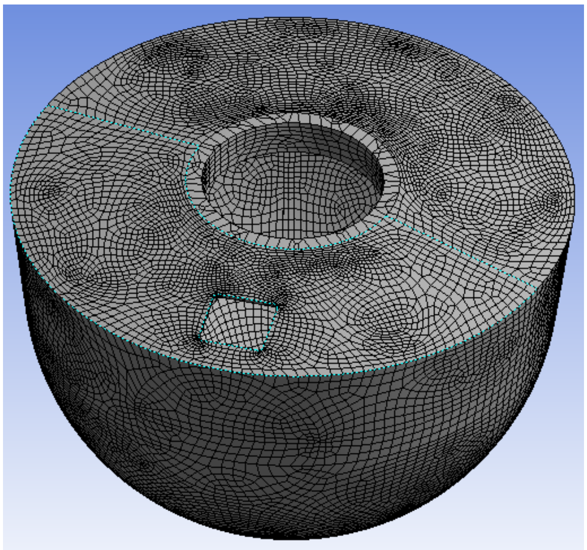


Figure 9-1: Mesh generation.

10. Principal stress state

The Service Limit State will be investigated, to give an indication of the stiffness of the structure and how the structural behave at different load situations. The analysis is carried out to investigate if it is necessary to use passive reinforcement.

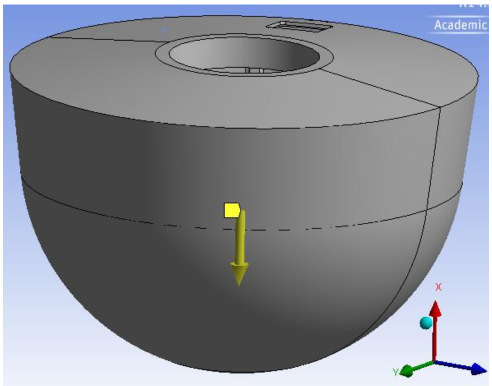
Each analysis is divided into a two section. First section contains the result output from the ANSYS workbench and the following section comments on the results.

10.1. Service limit state – SLS

In this section the results are illustrated of a linear elastic analysis of the service limit state.

10.1.1. Gravity

The Float is subjected to its gravity load only, both in neutral and storm safety position. See below.



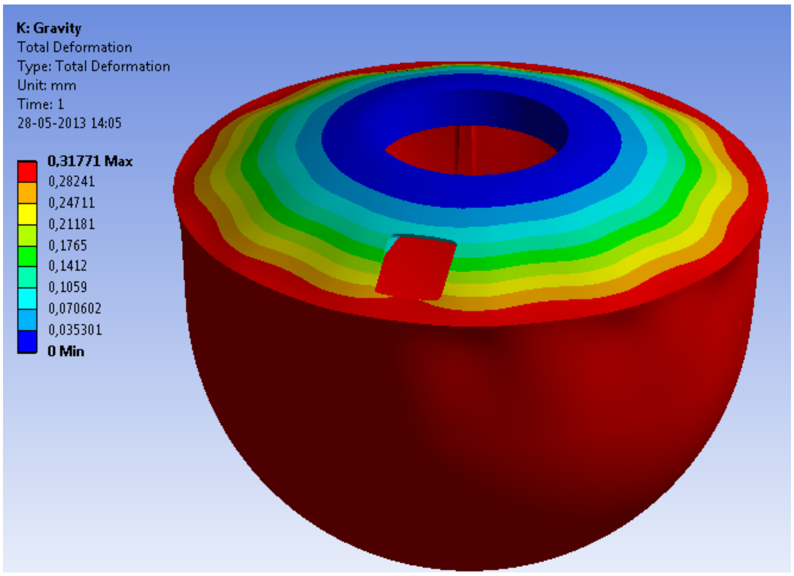


Figure 10-1: Total deformations for gravity load – Gravity neutral position [mm].

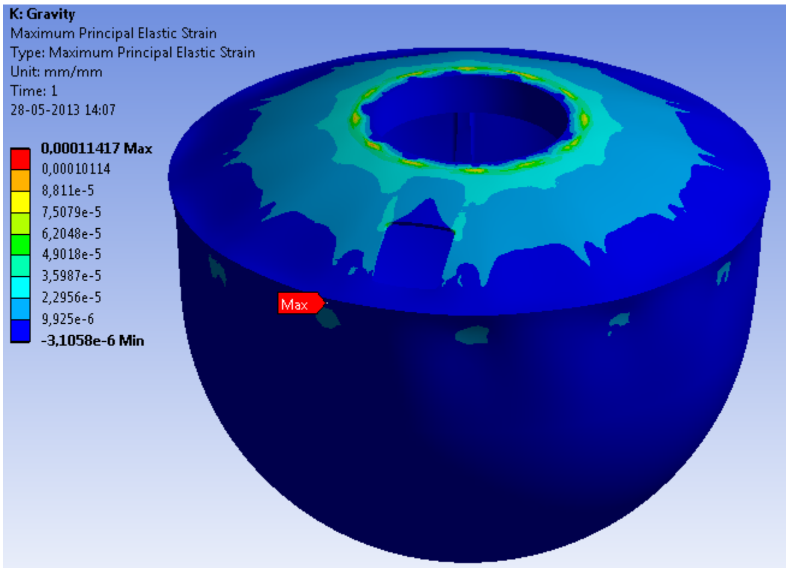


Figure 10-2: Maximum principal elastic strain for gravity load – Gravity neutral position.

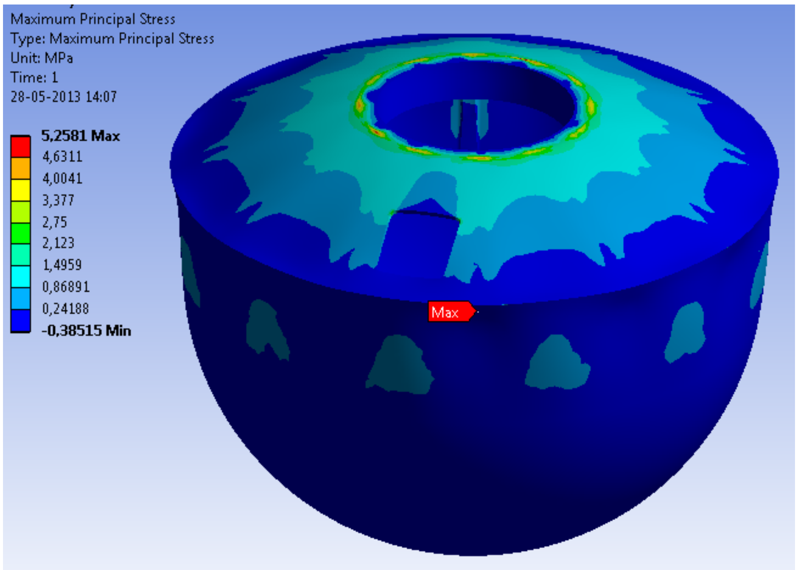


Figure 10-3: 1st principal stress for gravity load – Gravity neutral position [MPa].

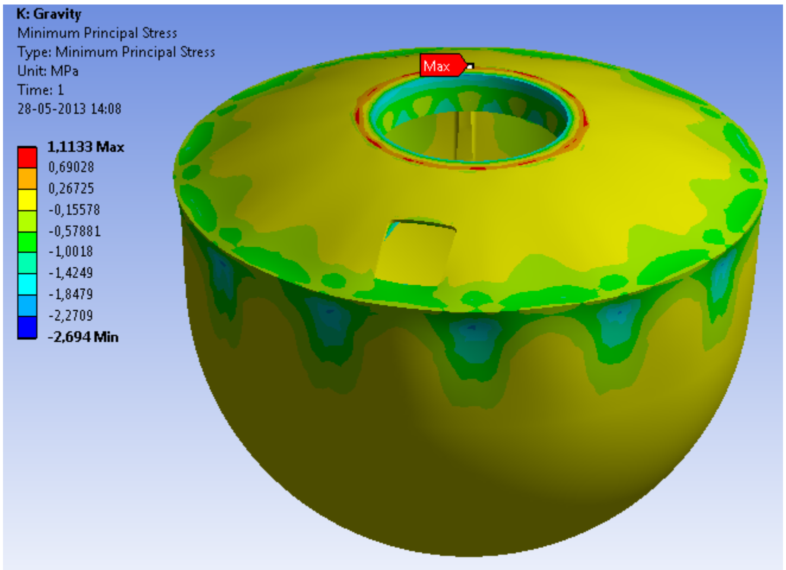


Figure 10-4: 3rd principal stress for gravity only – Gravity neutral position [MPa].

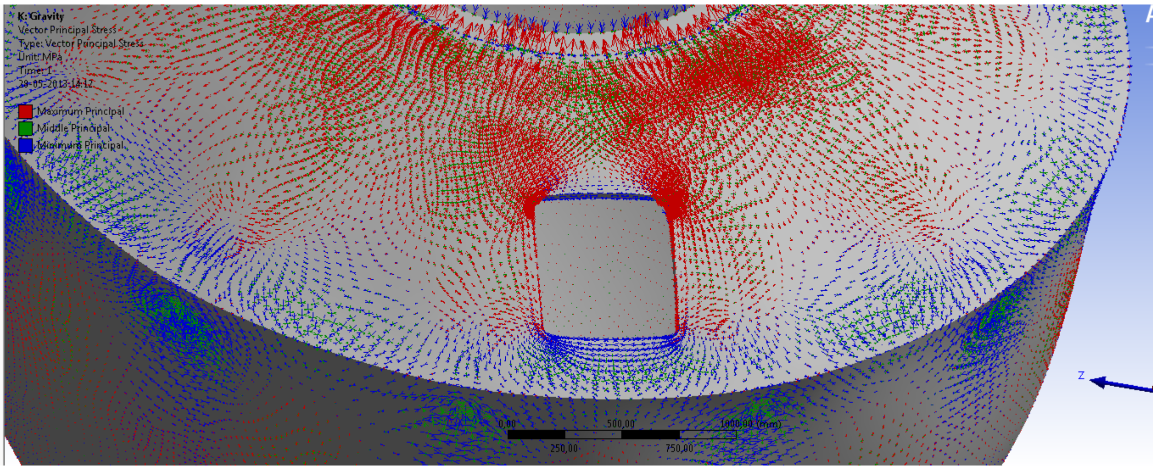
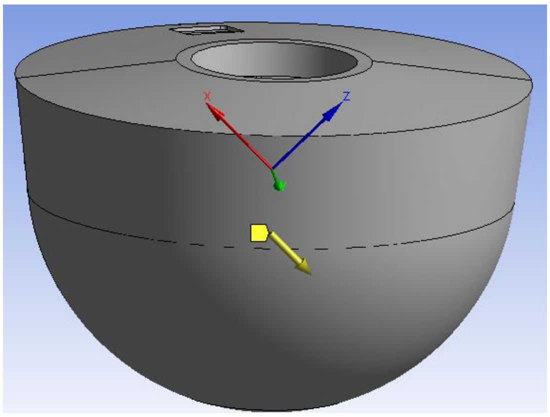


Figure 10-5: Principal stress vector directions.

Table 10-1: Force reaction, global CS.

F_x	F_y	F_z	F_{total}	M_x	M_y	M_z	M_{total}
[kN]	[kN]	[kN]	[kN]	[kNm]	[kNm]	[kNm]	[kNm]
95.083	0	0	95.083	0	0	0	0

The Float is subjected to its gravity load only, both in neutral and storm safety position. See below.



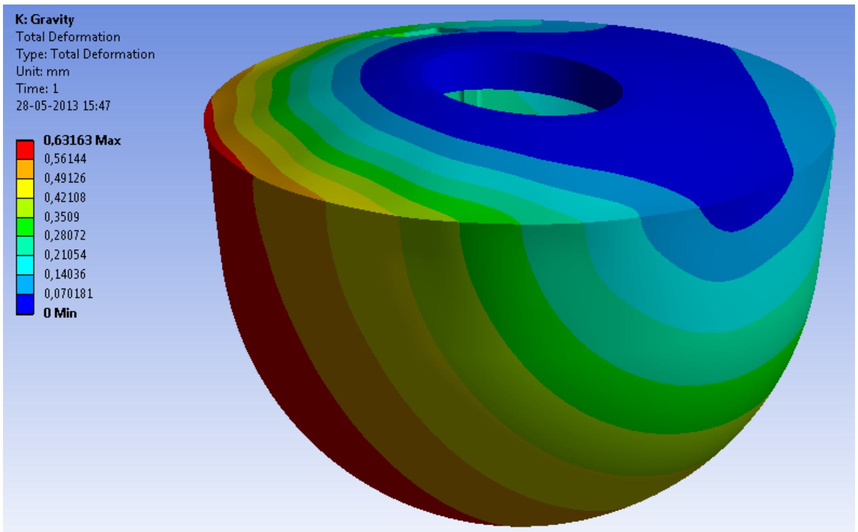


Figure 10-6: Total deformations for gravity load – Gravity storm safety position [mm].

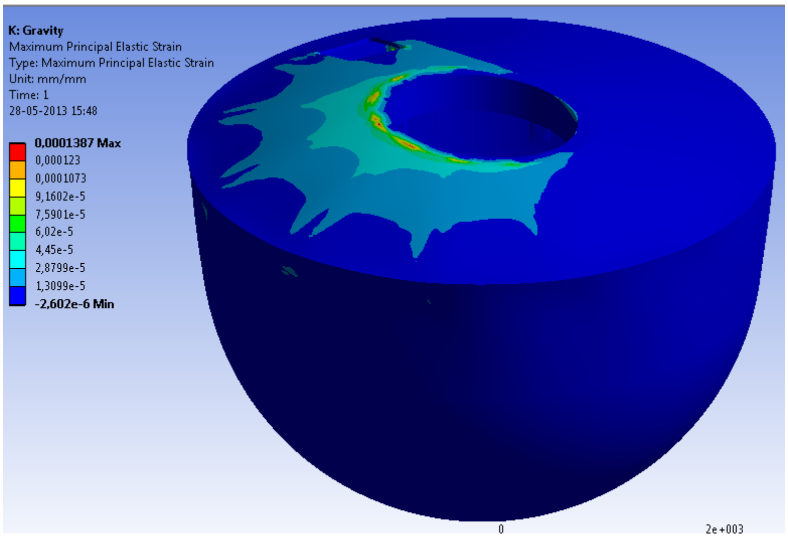


Figure 10-7: Maximum principal elastic strain for gravity load – Gravity storm safety position.

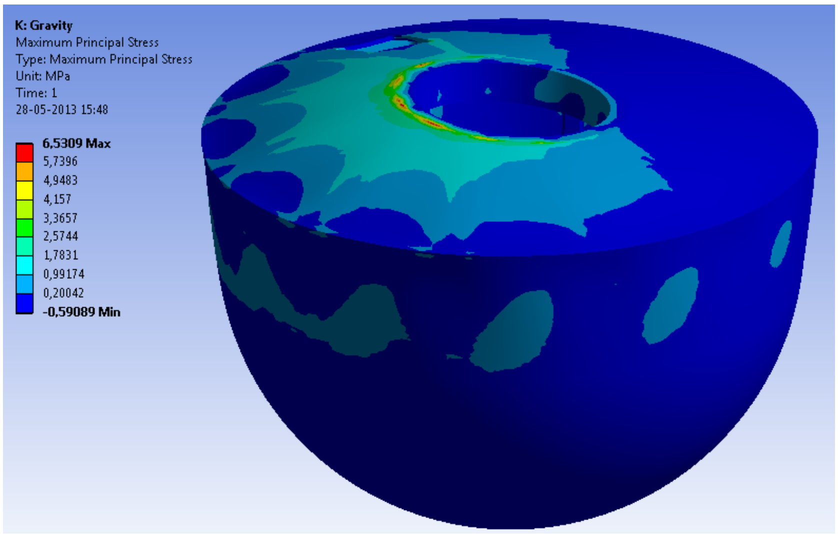


Figure 10-8: 1st principal stress for gravity load – Gravity storm safety position [MPa].

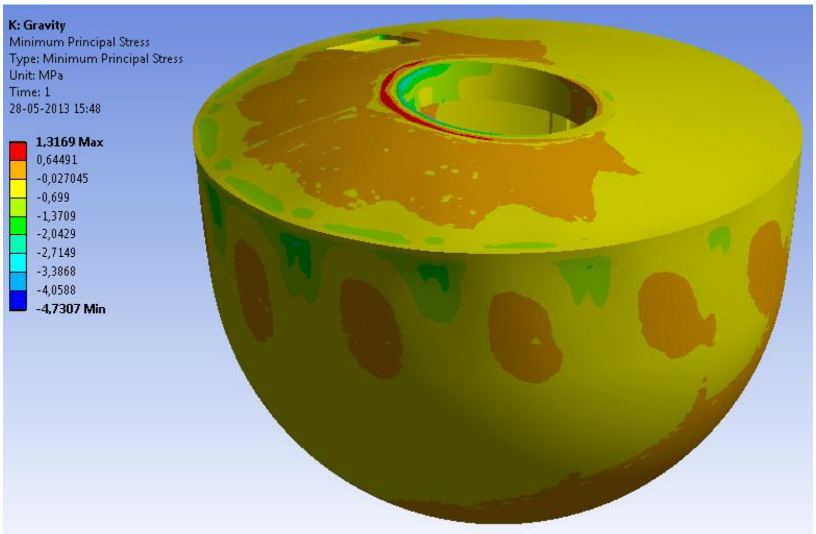


Figure 10-9: 3rd principal stress for gravity only – Gravity storm safety position [MPa].

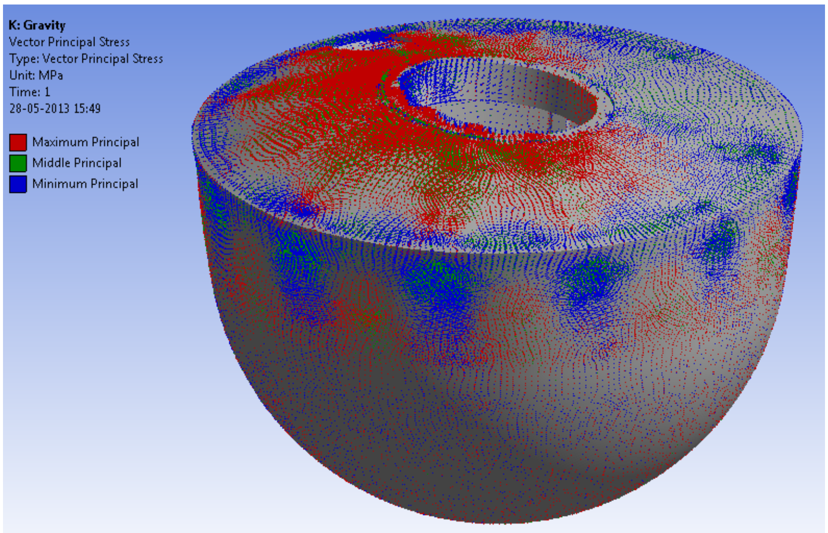


Figure 10-10: Principal stress vector directions.

10.1.1.1. Comments

The combination of internal bracing and the membrane in the cap seems to give a satisfactory load transferring system. The gravity loads, at neutral position has local principal stresses at 5 MPa. These peaks are located at the support ring, and it clearly shows the need for passive reinforcement.

10.1.1.2. Recommendation

Further analyses of the stress distribution in the connection between the shell and the cap have to be carried out.

10.1.2. Temperature

The Float is subjected to a temperature load, corresponding to temperature differential from -40 to 30 ^{0}C.

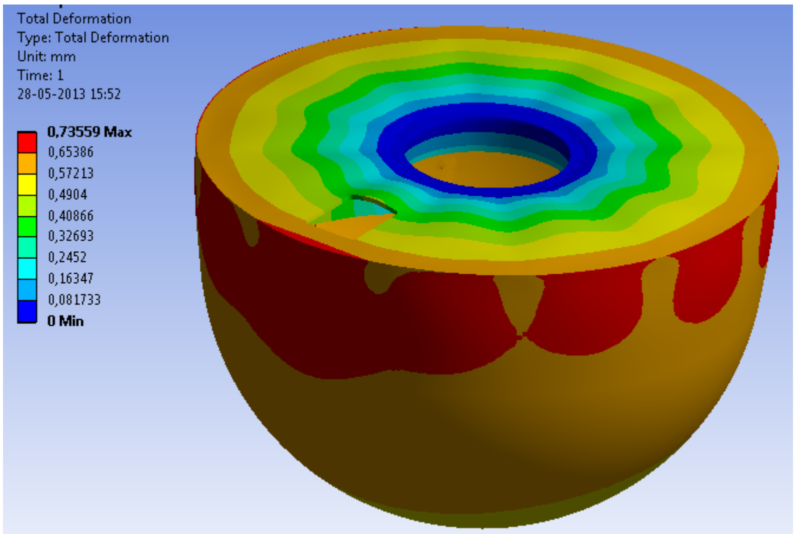


Figure 10-11: Total deformations for gravity load – Gravity storm safety position [mm].

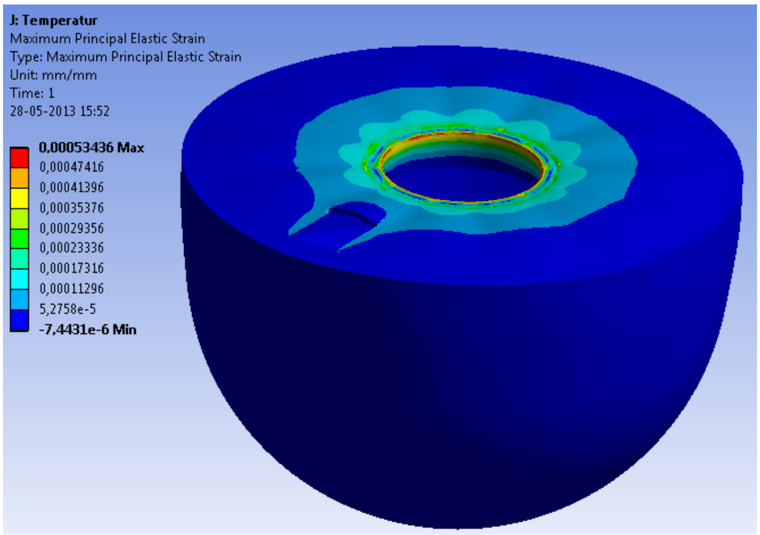


Figure 10-12: Maximum principal elastic strain for gravity load – Gravity storm safety position.

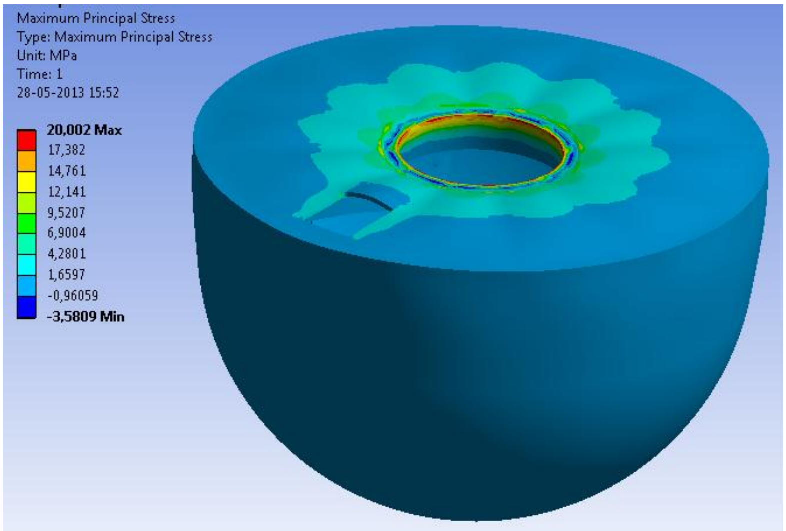


Figure 10-13: 1st principal stress for gravity load – Gravity storm safety position [MPa].

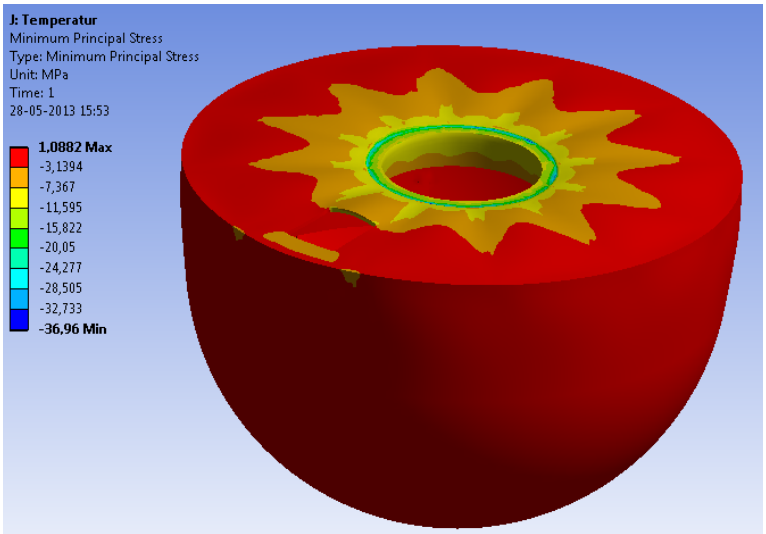


Figure 10-14: 3rd principal stress for gravity only – Gravity storm safety position [MPa].

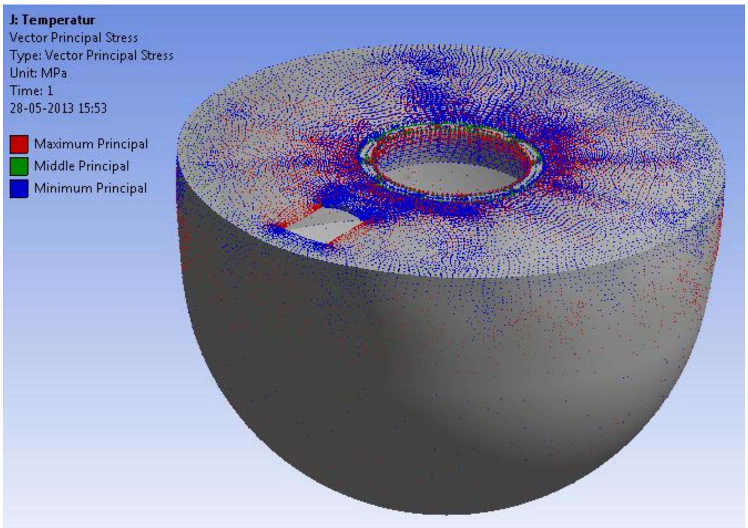


Figure 10-15: Principal stress vector directions.

Table 10-2: Force reaction, global CS.

F_x	F_y	F_z	F_{total}	M_x	M_y	M_z	M_{total}
[kN]	[kN]	[kN]	[kN]	[kNm]	[kNm]	[kNm]	[kNm]
95.083	0	0	95.083	0	0	0	0

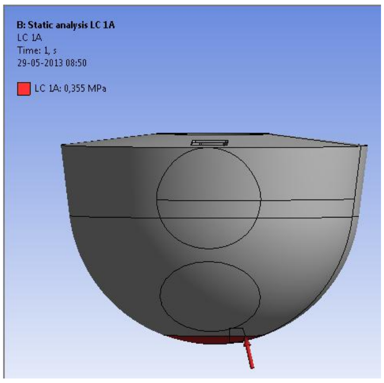
10.1.2.1. Comments

The combination of internal bracing and the membrane in the cap seems to give a satisfactory load transferring system. The highest tensile stresses are recorded at the supporting ring. Passive reinforcement is needed.

10.1.2.2. Recommendation

Further analyses of the stress distribution in the connection between the shell and the cap have to be carried out.

10.1.3. Load case 1A



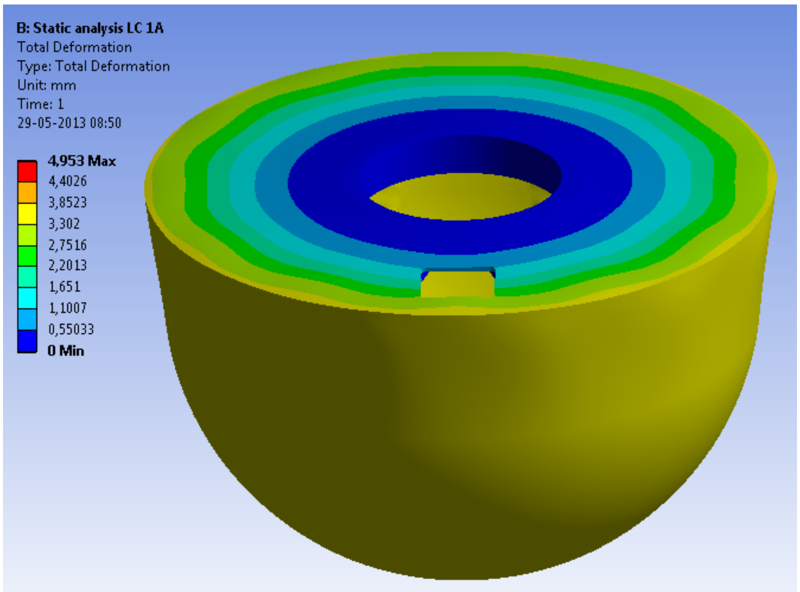


Figure 10-16: Total deformations– LC 1A [mm].

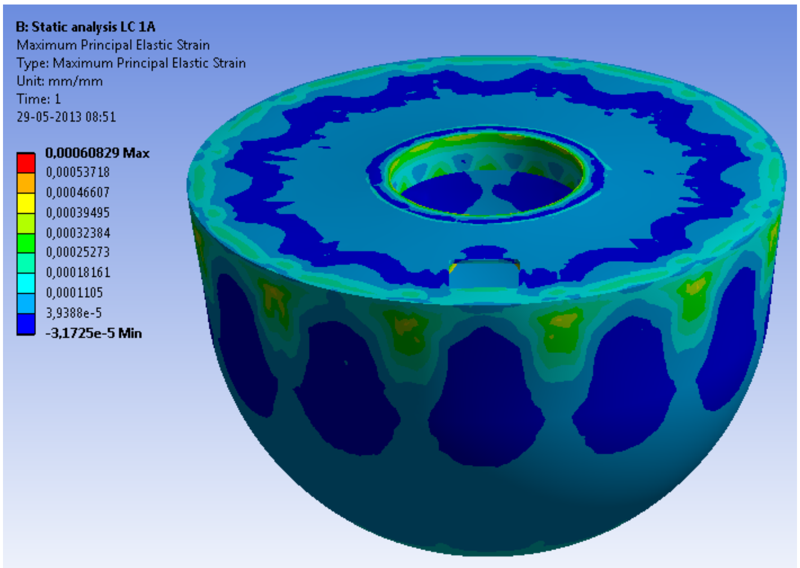


Figure 10-17: Maximum principal elastic strain – LC 1A [mm].

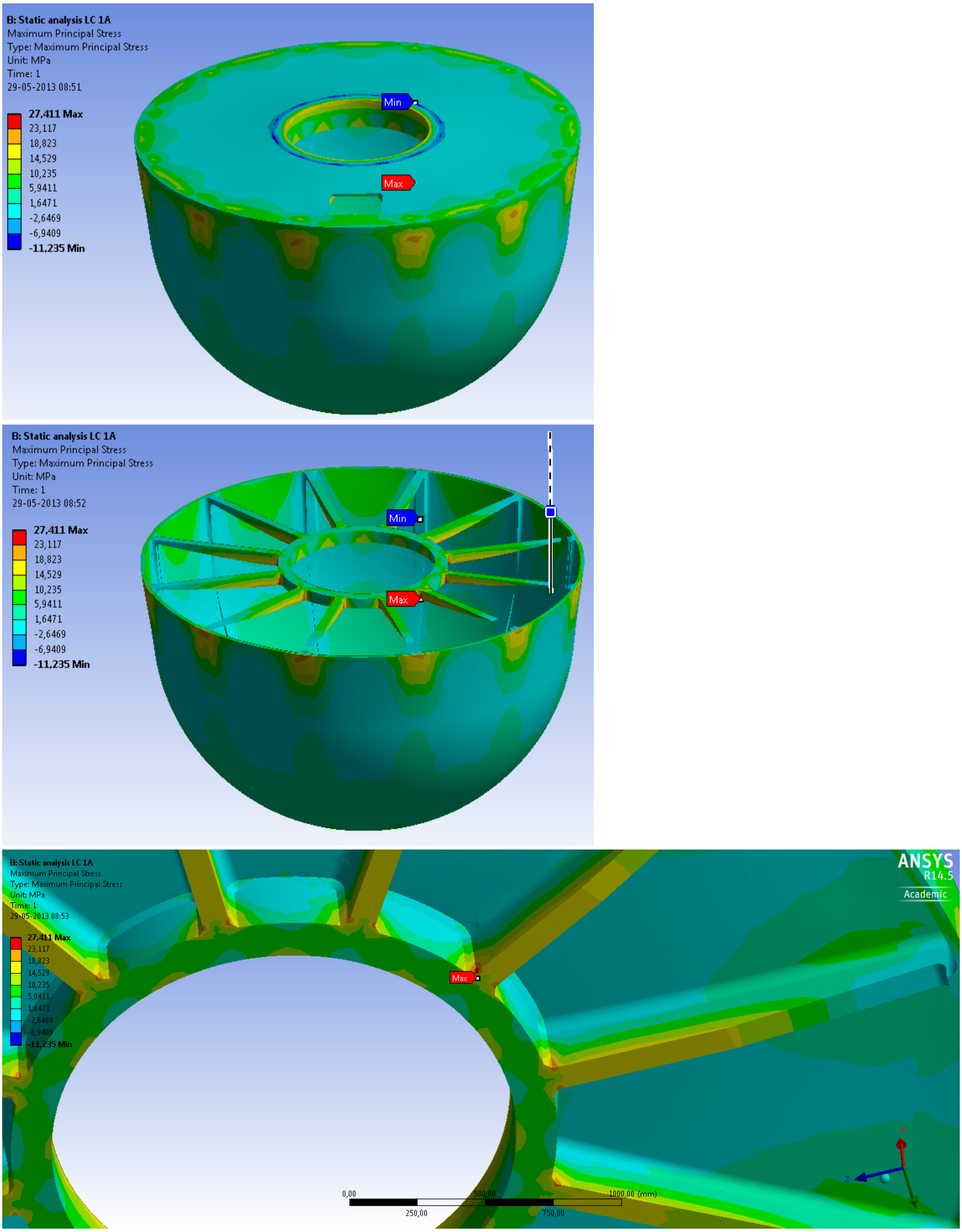


Figure 10-18: 1st principal stress – LC 1A [MPa].

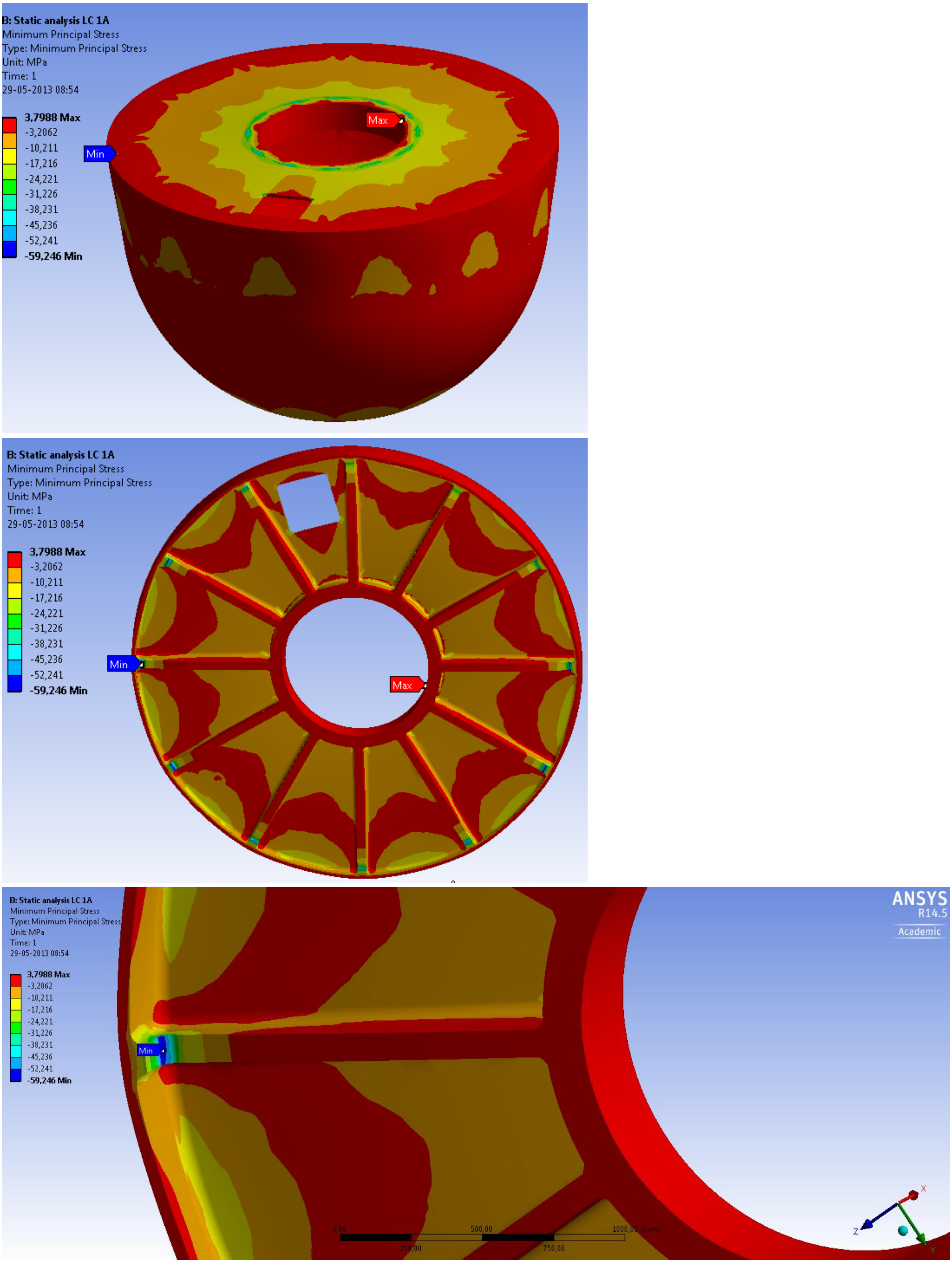
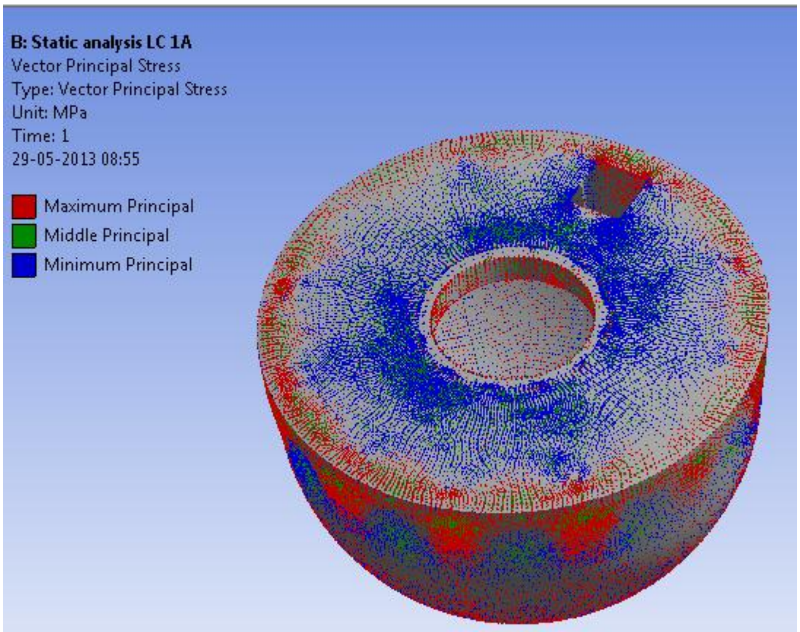
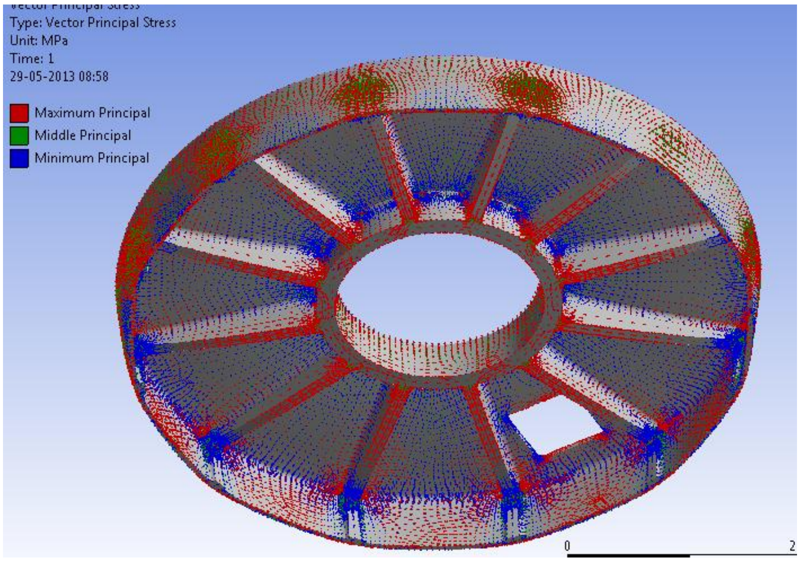


Figure 10-19: 3rd principal stress – LC 1A [MPa].


B: Static analysis LC 1A
Vector Principal Stress
Type: Vector Principal Stress
Unit: MPa
Time: 1
29-05-2013 08:55
Maximum Principal
Middle Principal
Minimum Principal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Unit: MPa
Time: 1
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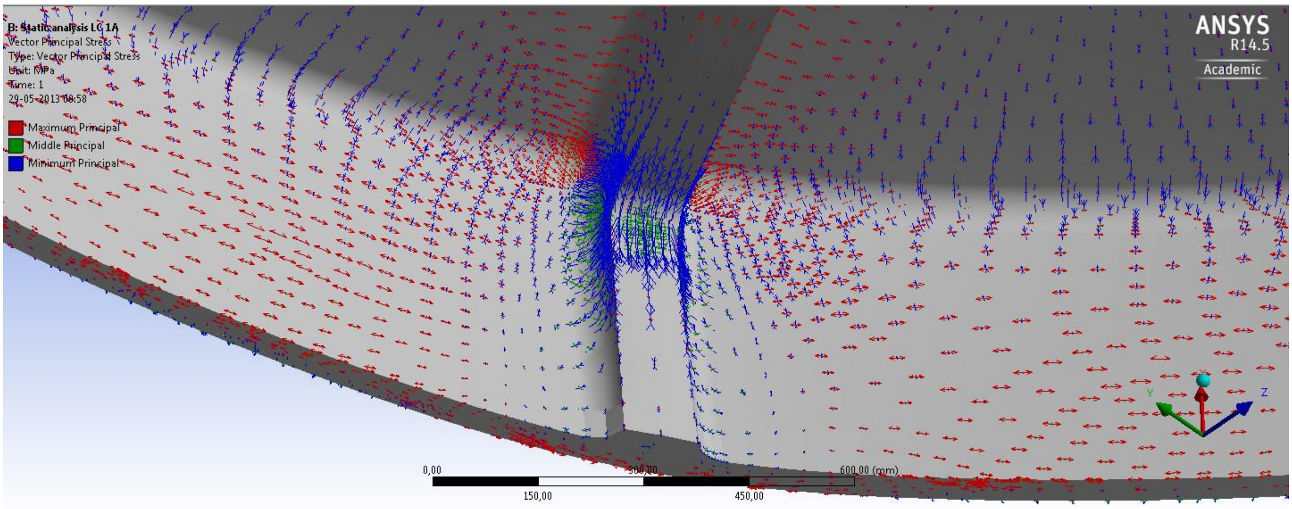
Maximum Principal
Middle Principal
Minimum Principal
0
2


ANSYS
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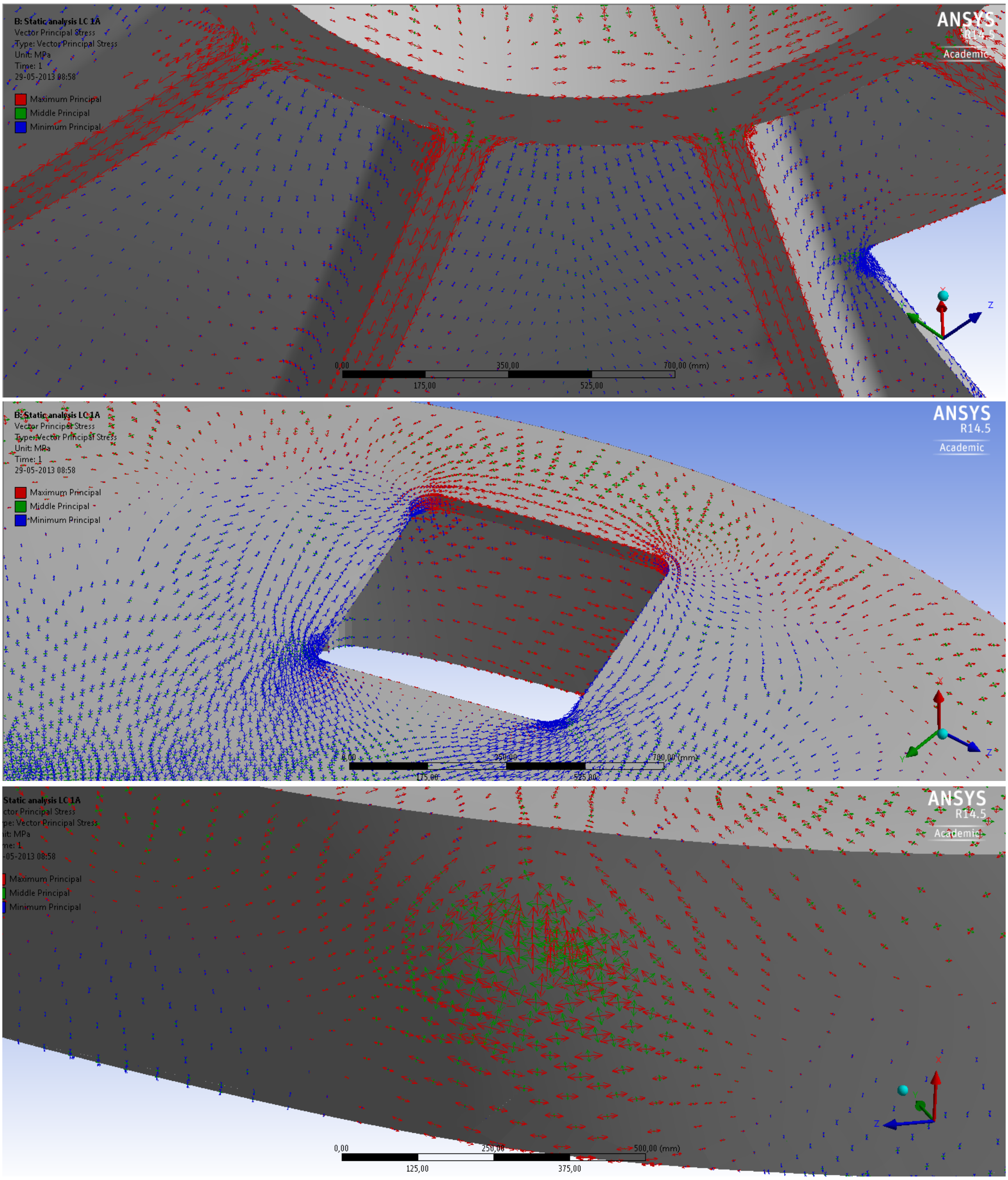


Figure 10-20: Principal stress vector directions.

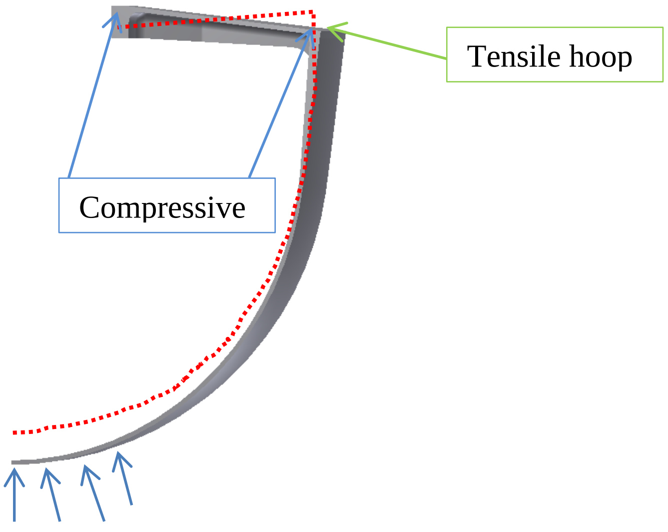


Figure 10-21: Sketch of global deformations – LC2.

The structure is globally deformed as sketched above.

Table 10-3: Reactions, global CS.

F_x [kN]	F_y [kN]	F_z [kN]	F_{total} [kN]	M_x [kNm]	M_y [kNm]	M_z [kNm]	M_{total} [kNm]
-733.48	0	0	733.48	0	0	0	0

Table 10-4: Buckling modes – LC 1A.

Mode	Load factor
1	31.006
2	31.11
3	31.38

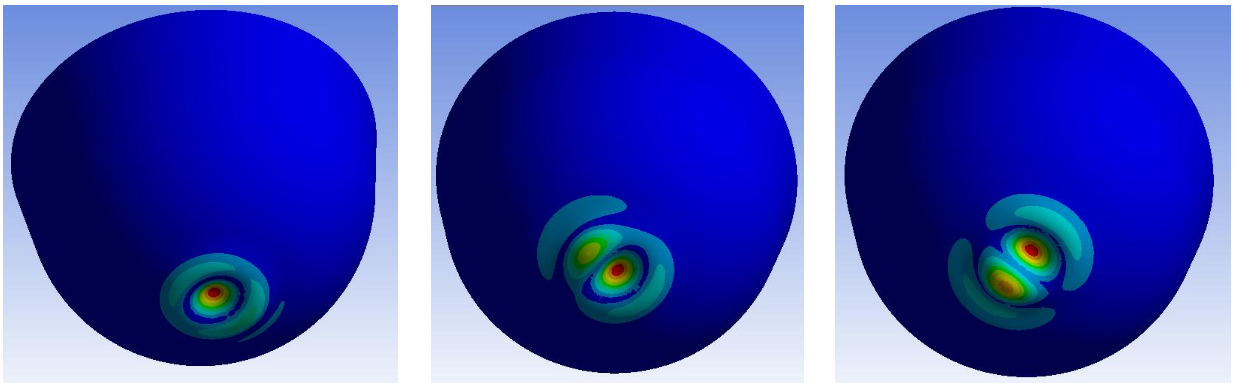


Figure 10-22: Buckling modes – LC 1A.

10.1.3.1. Comments

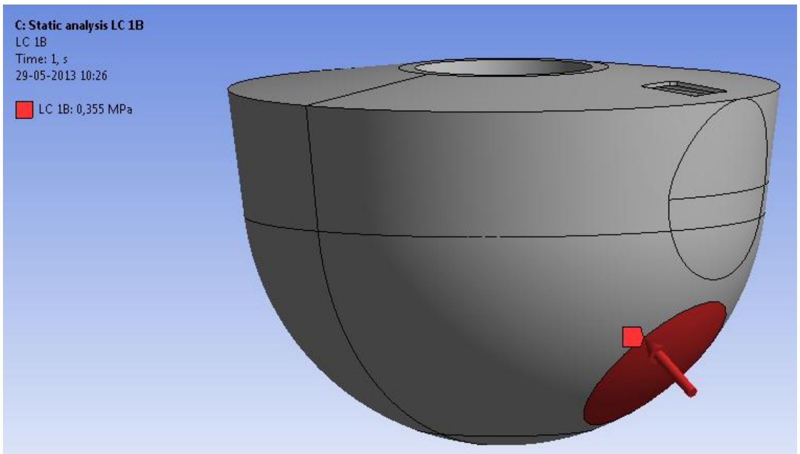
In this section the float has been subjected to slamming load 1A, representing a situation where the wave hits the float at its bottom. It can be seen in Figure 7-3 that the global deformation is about 5 mm and indicates that the load transferring the shell to the beams located in the cap gives a appropriate stiffness to vertical loading. In Figure 10-18 and Figure 10-19 it can be seen that the maximum principal stress is 28 MPa and the minimum principal stress is -59 MPa. It represents local peaks/concentrations near geometrical discontinuities. The discontinuities is located at the connection between the shell and the cap beams, see Figure 10-19 and at the connection between the cap beams and the attachment ring, see Figure 10-18. The load is transferred through the shell to the cap beams, creating bending in the beams. The direction of the principal vector at the boundaries, Figure 10-20, shows that hoop stresses occur near the connection between the outer shell and the cap. The design of the shell secures sufficient buckling rigidity.

10.1.3.2. Recommendation

The tensile stresses in the hoop direction, indicates that conventional reinforcement has to be provided. In the cap beam, large moments has to be carried transferred to the attachment ring, and conventional reinforcement has to be provided, to get sufficient resistance to tensile stresses.

10.1.4. Load case 1B

The Float is in Load Case 2 subjected to a pressure load at its bottom part, see assumption in Figure 7-1.



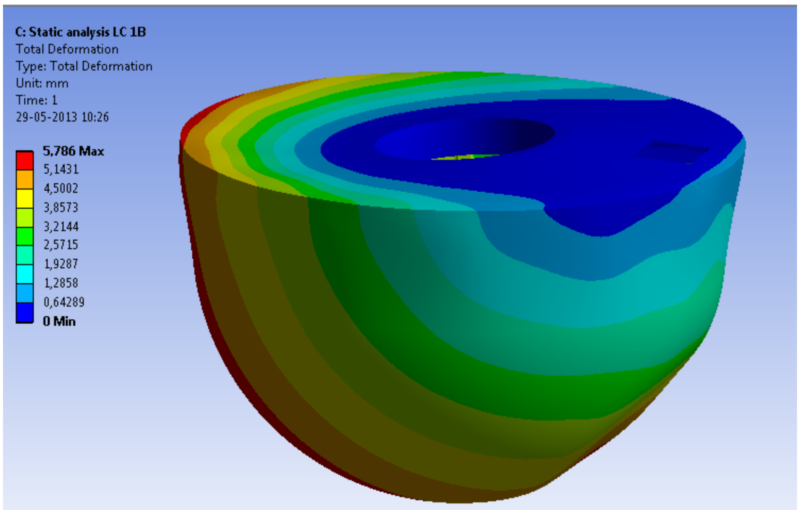


Figure 10-23: Total deformations – LC 1B [mm].

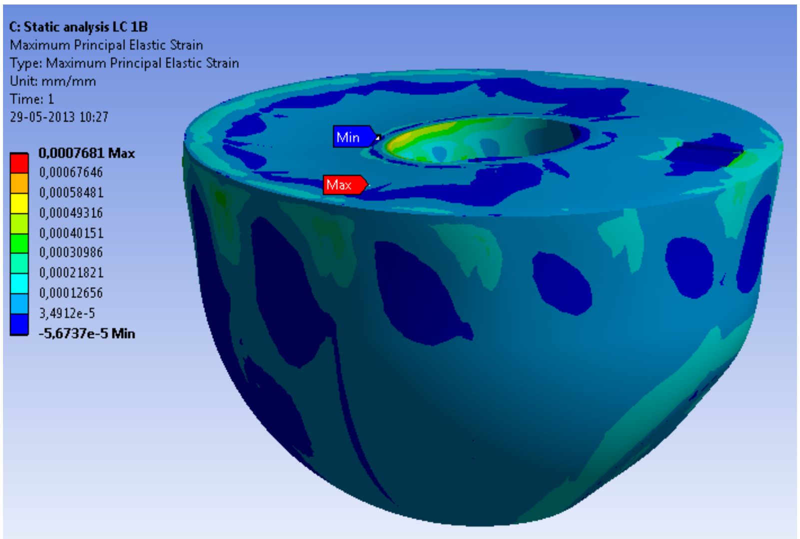
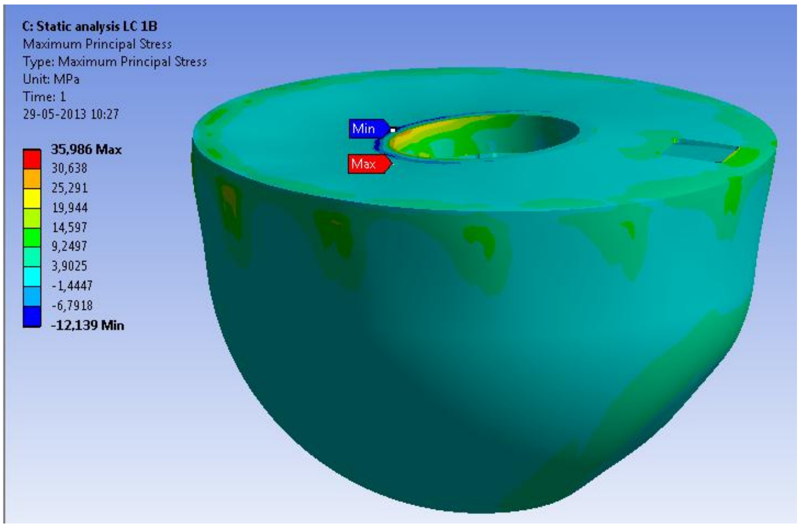
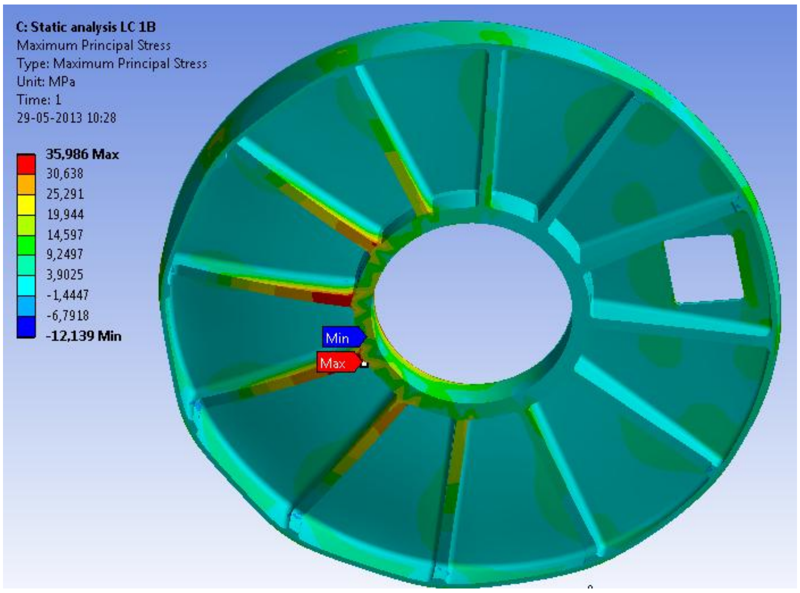


Figure 10-24: Maximum principal strain – LC 1B [MPa].





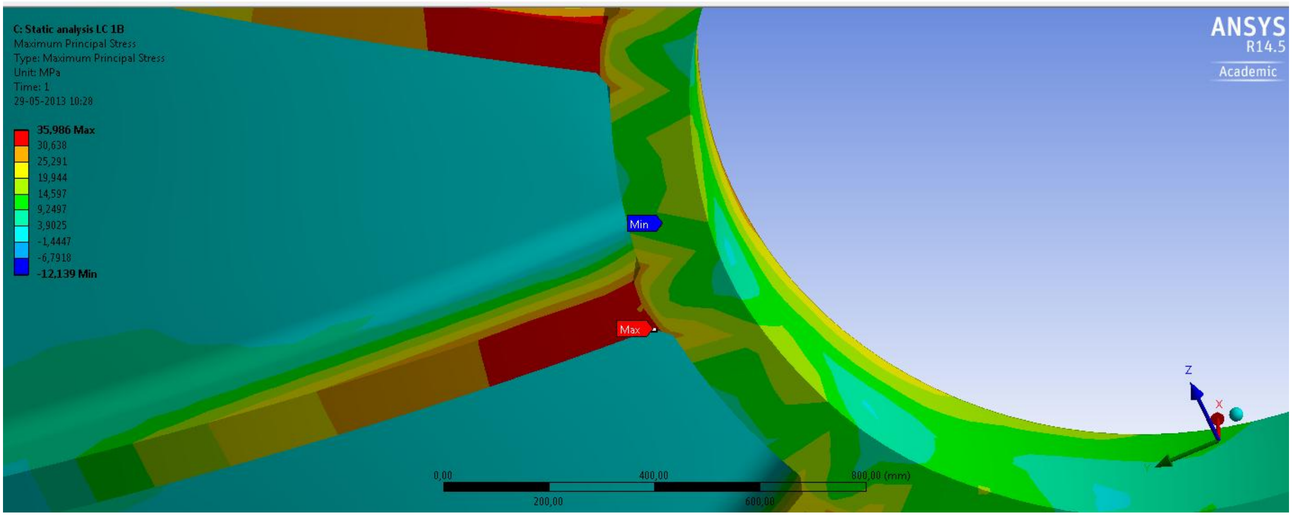


Figure 10-25: 1st principal stress – LC 1B [MPa].

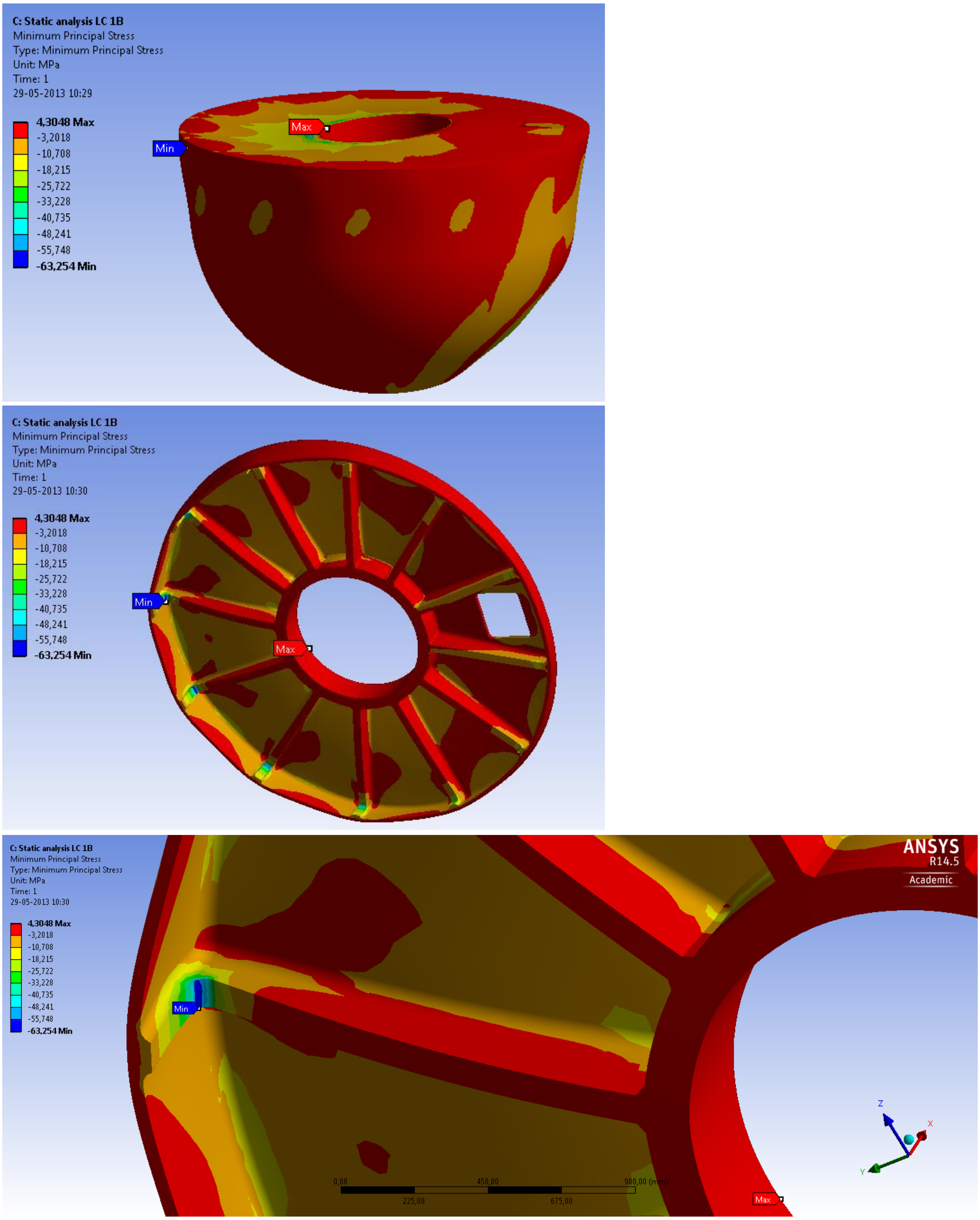


Figure 10-26: 3rd principal stress – LC 1B [MPa].

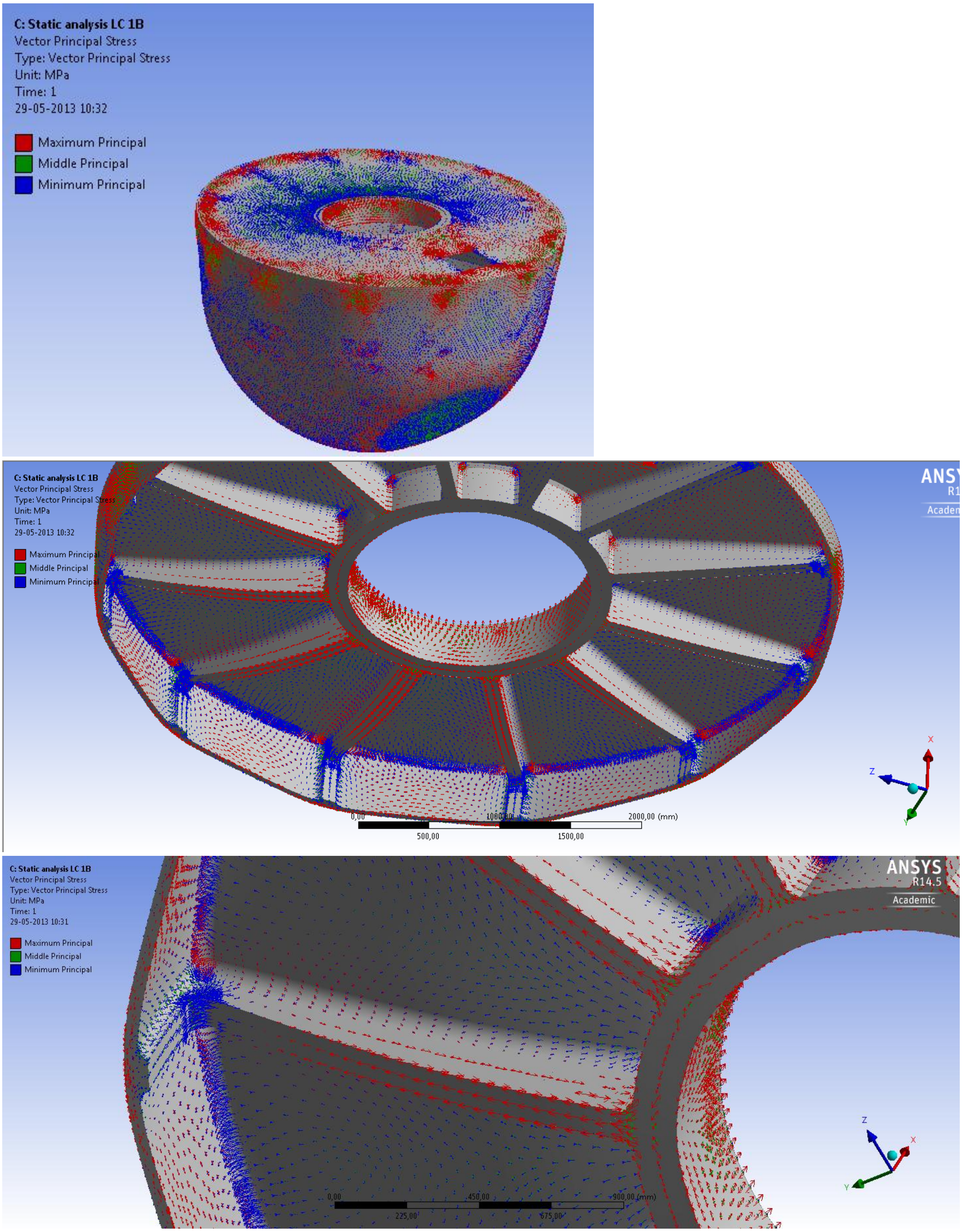


Figure 10-27: Principal stress vector directions.

Table 10-5: Reactions, global CS.

F_x [kN]	F_y [kN]	F_z [kN]	F_{total} [kN]	M_x [kNm]	M_y [kNm]	M_z [kNm]	M_{total} [kNm]
-490.88	-565.96	-151.65	764.38	0	-166.61	621.78	643.72

Table 10-6: Buckling modes – LC 1B.

Mode	Load factor
1	33.56
2	34.21
3	35.65

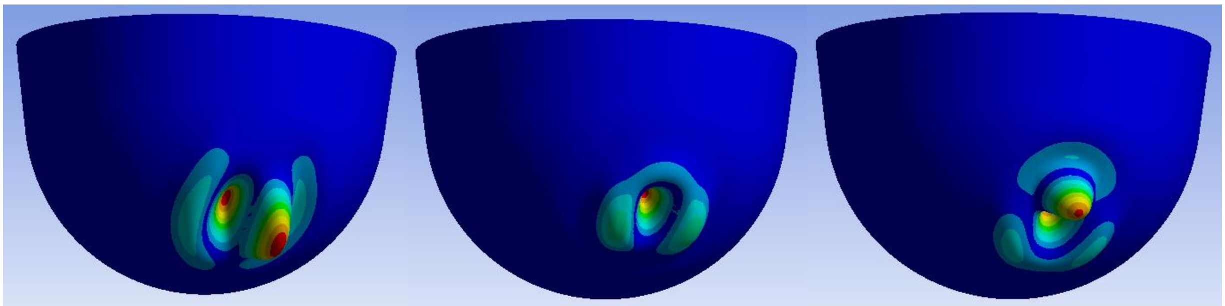


Figure 10-28: Buckling modes – LC 1B.

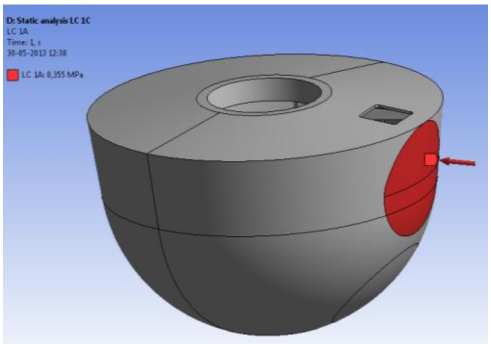
10.1.4.1. Comments

In Load Case 2 the Float structure is subjected to a pressure load at its bottom surface, see Figure 7-1 case B. It can be seen in Figure 10-24 to Figure 10-27 that the pressure load is transferred to the beam arrangement in the cap, causing bending and high tensile stresses in the beams. Taking a closer look at the stresses in the shell structure, it can be seen that the stress state between the internal bracings is dominated by compressive forces, especially near the connection between cap and outer shell. At the bracing in the outer shell the stress state is dominated by tensile stresses in the hoop direction. The linear elastic buckling analysis shows sufficient that the structure has sufficient buckling resistance.

10.1.4.2. Recommendations

Further study of the direction of the principle stresses.

10.1.5. Load case 1C



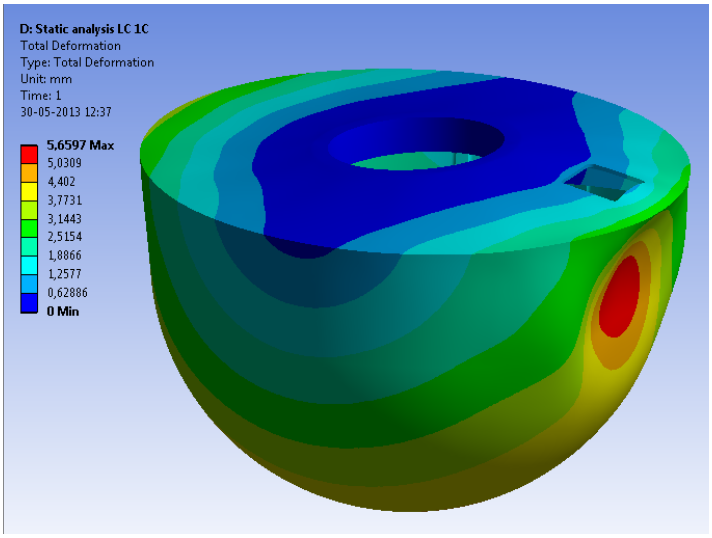


Figure 10-29: Total deformations – LC 1C [mm].

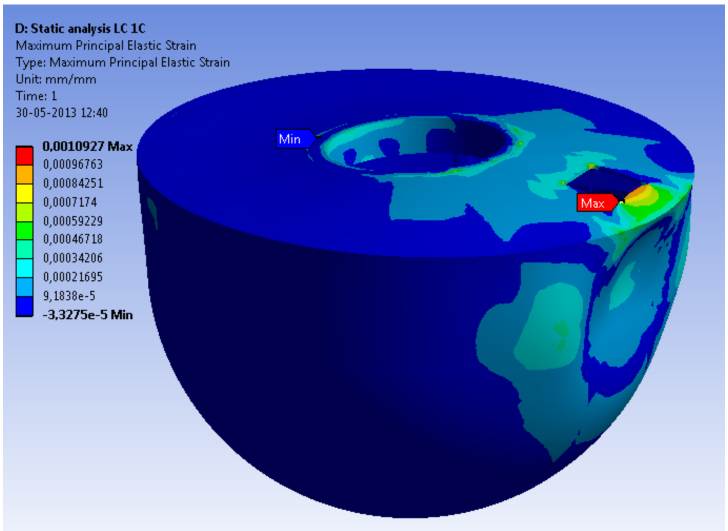


Figure 10-30: Maximum principal elastic strain – LC 1C [MPa].

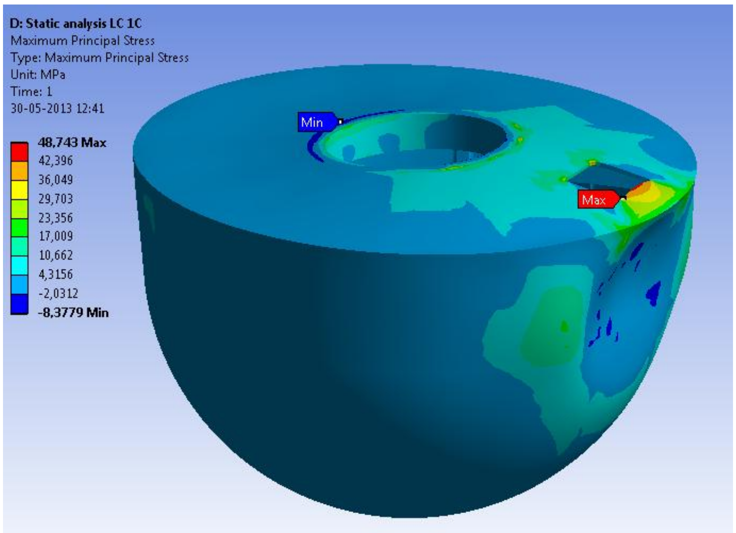


Figure 10-31: 1st principal stress – LC 1C [MPa].

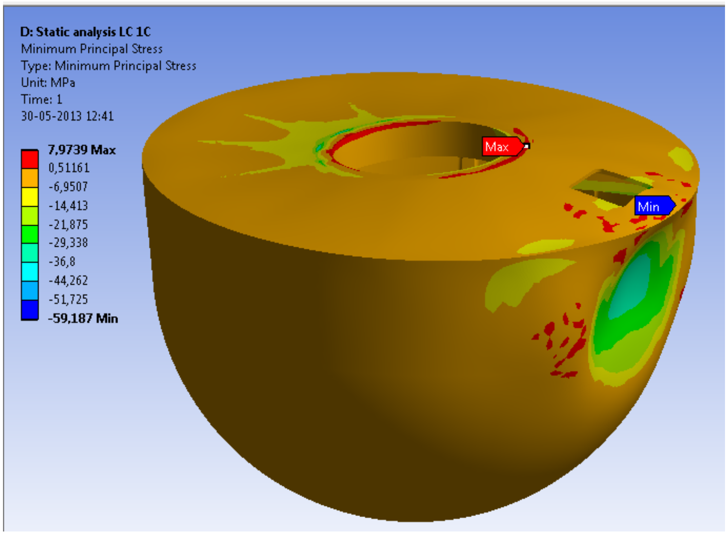
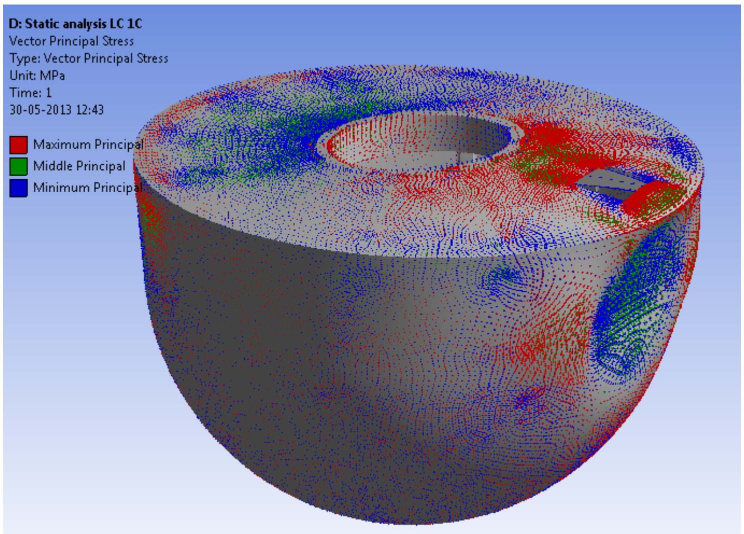


Figure 10-32: 3rd principal stress – LC 1C [MPa].



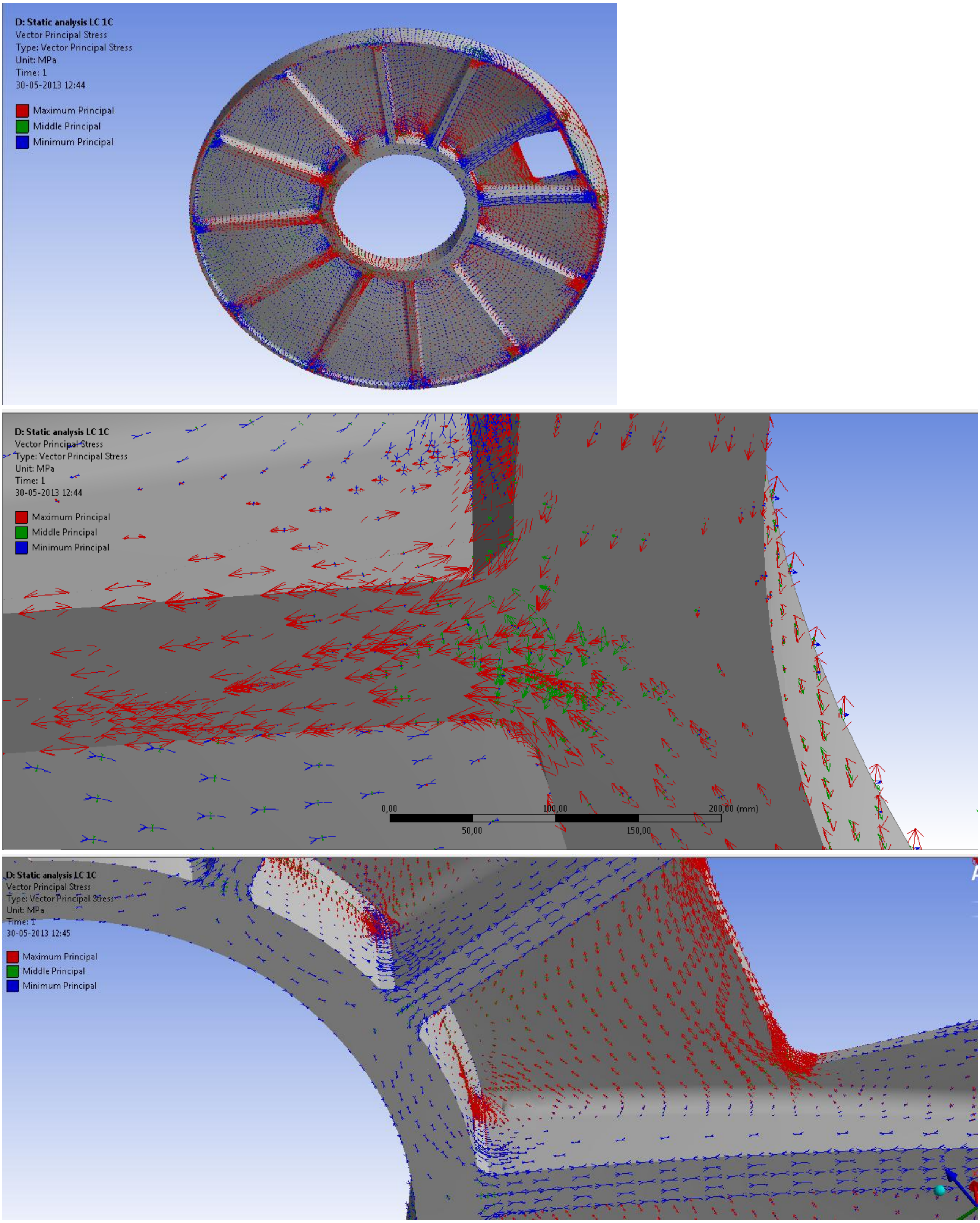


Figure 10-33: Principal stress vector directions.

Table 10-7: Reactions, global CS.

F_x [kN]	F_y [kN]	F_z [kN]	F_{total} [kN]	M_x [kNm]	M_y [kNm]	M_z [kNm]	M_{total} [kNm]
-35.349	-829.47	-222.26	859.46	0	155.1	578.86	599.28

Table 10-8: Buckling modes – LC 1B.

Mode	Load factor
1	13,663
2	13,714
3	23,953

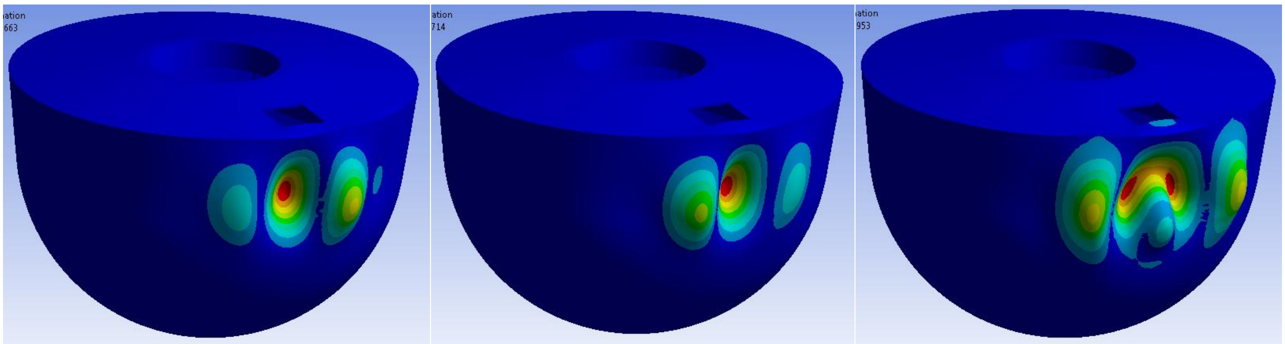


Figure 10-34: Buckling modes – LC 1C.

10.1.5.1. Comments

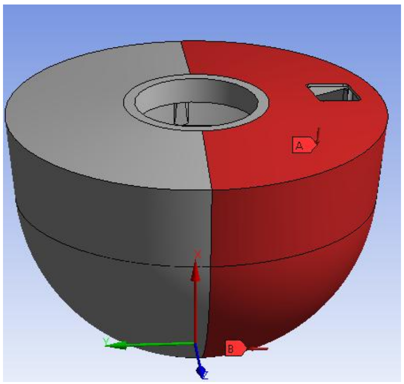
It can be seen in Figure 10-24 to Figure 10-27 that the Float structure has a very desirable way of carry the slamming load located at the top section of the outer shell, illustrated in Figure 10-29. It can be seen that the forces are primarily located in the cap and in the connection between the cap and the shell structure. The forces are furthermore transferred to the internal beams, and are almost translated as normal forces, seen as either 1st or 3rd principle stresses (no variation in the height of the structure). Additionally it seen that the cap has a membrane behavior, and assimilates a great part of the internal forces between the internal bracing.

10.1.5.2. Recommendation

The combined behavior of the membrane effect of the cap and how the forces are transferred to the internal bracing has to be investigated.

10.1.6. Load case 2A

The Float is in Load Case 4 subjected to a pressure load see the position in in Figure 7-1.



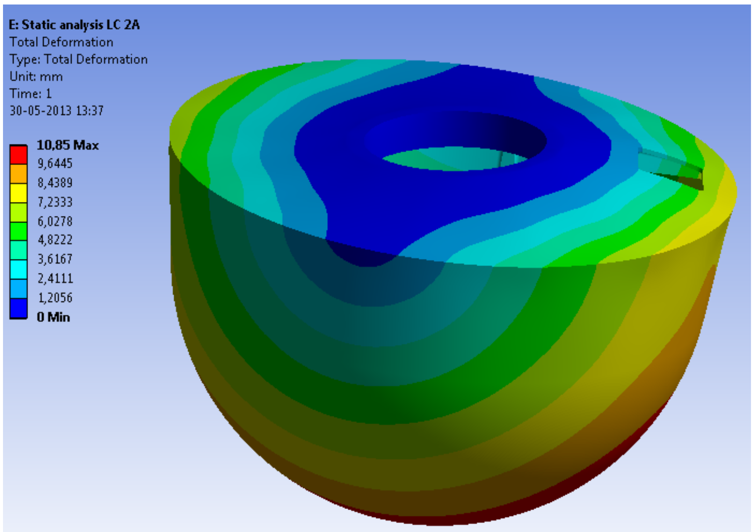


Figure 10-35: Total deformations – LC 2A [mm].

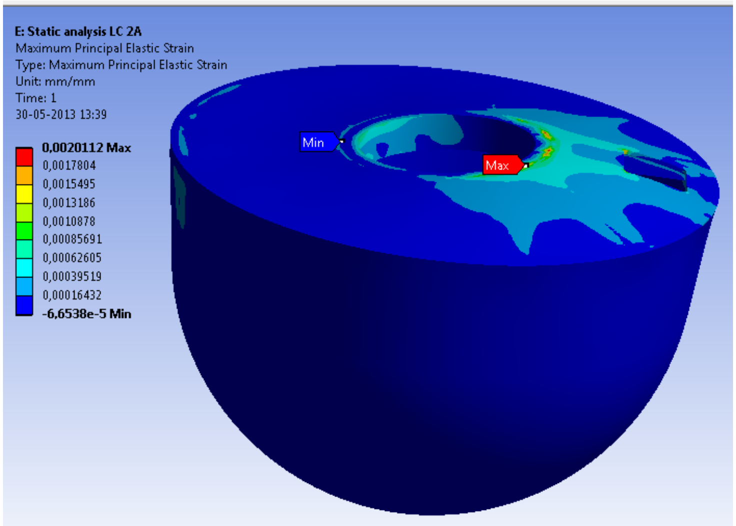


Figure 10-36: Maximum principal elastic strain – LC 2A [mm].

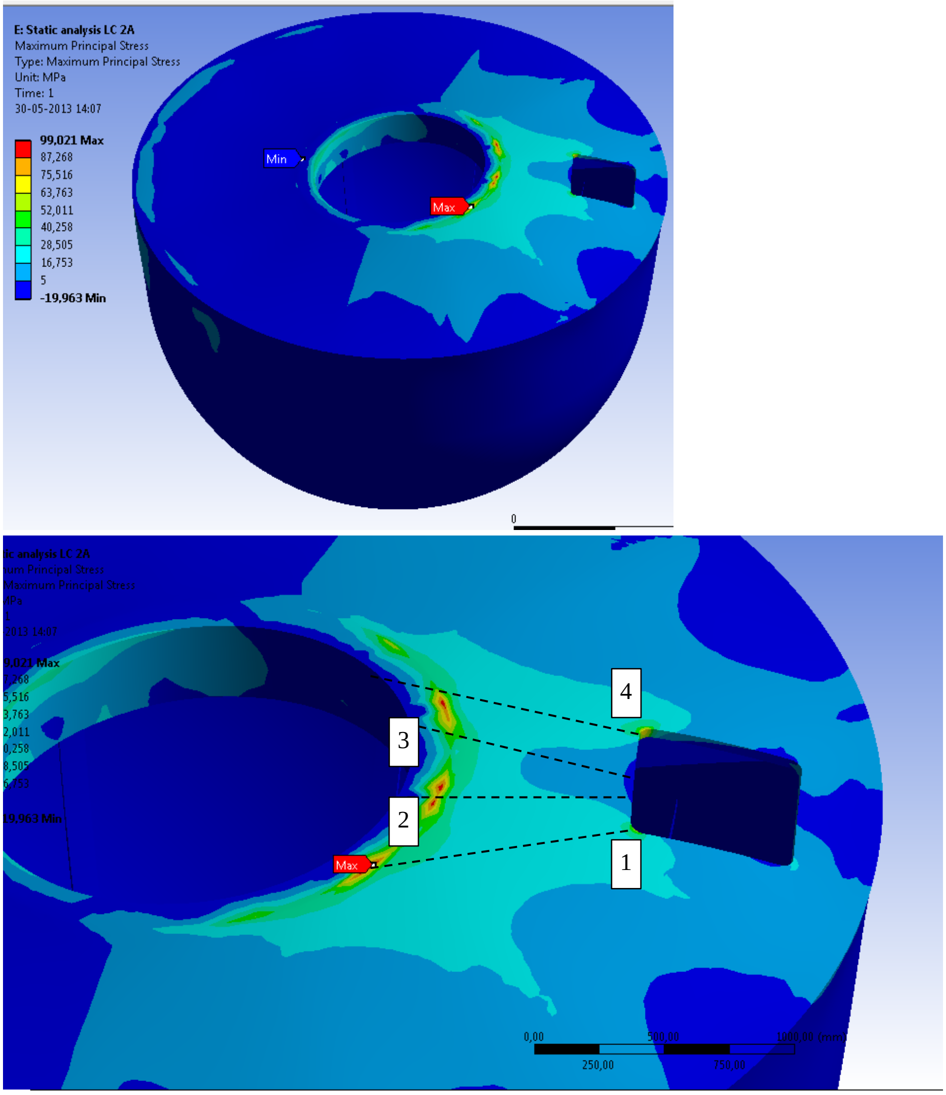
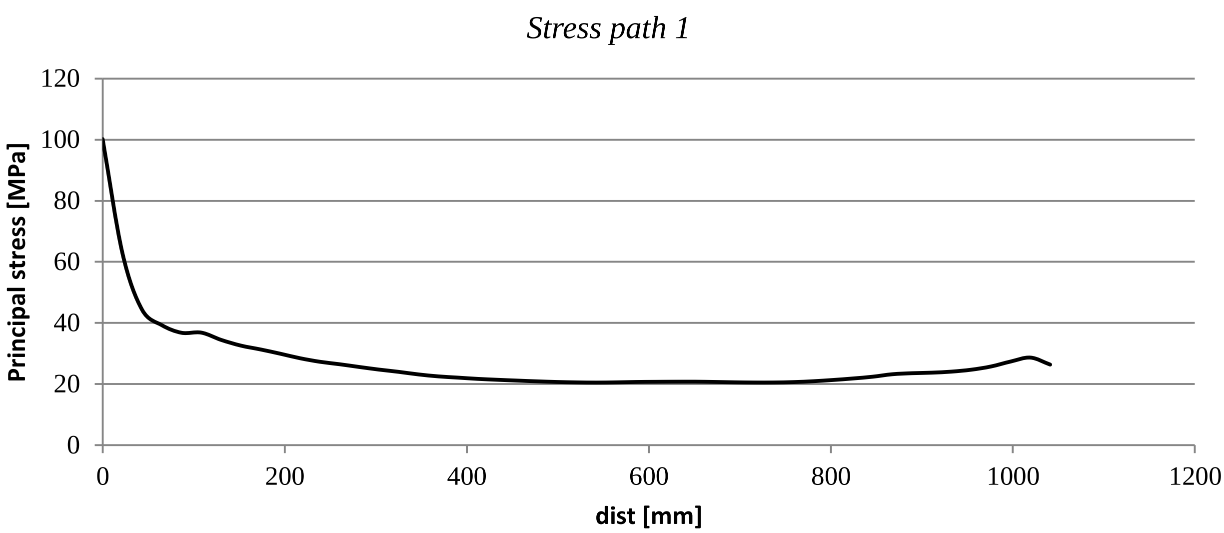
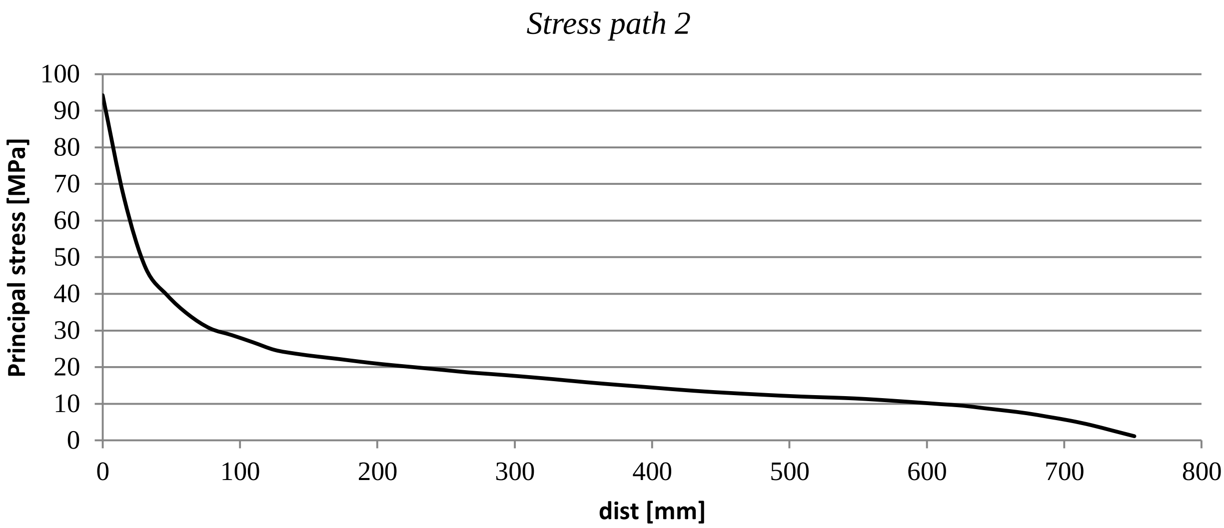
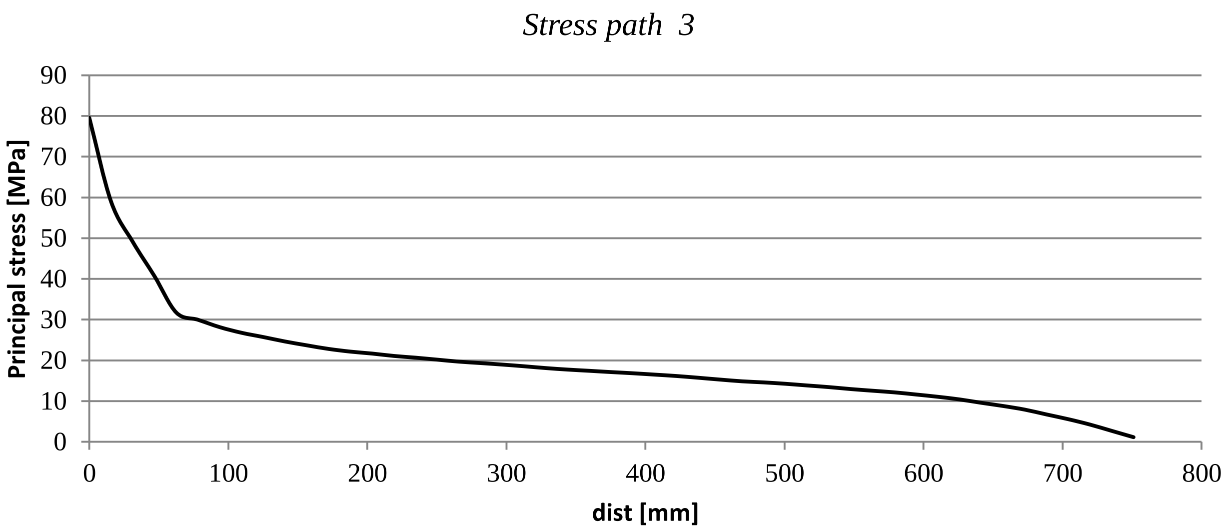


Figure 10-37: 1st principal stress and stress path 1 -4 – LC 2A [MPa].


Stress path 1
Principal stress [MPa]
120
100
80
60
40
20
0
0
200
400
600
800
1000
1200
dist [mm]


Stress path 2
Principal stress [MPa]
100
90
80
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
800
dist [mm]


Stress path 3
Principal stress [MPa]
90
80
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
800
dist [mm]

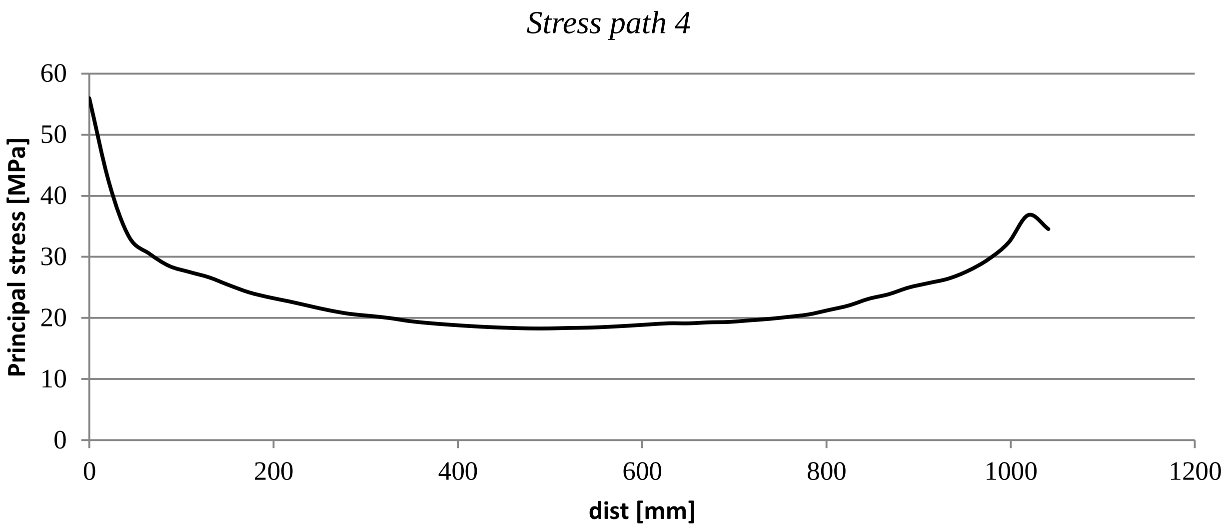


Figure 10-38: Stress path 1 – 4, LC 2A.

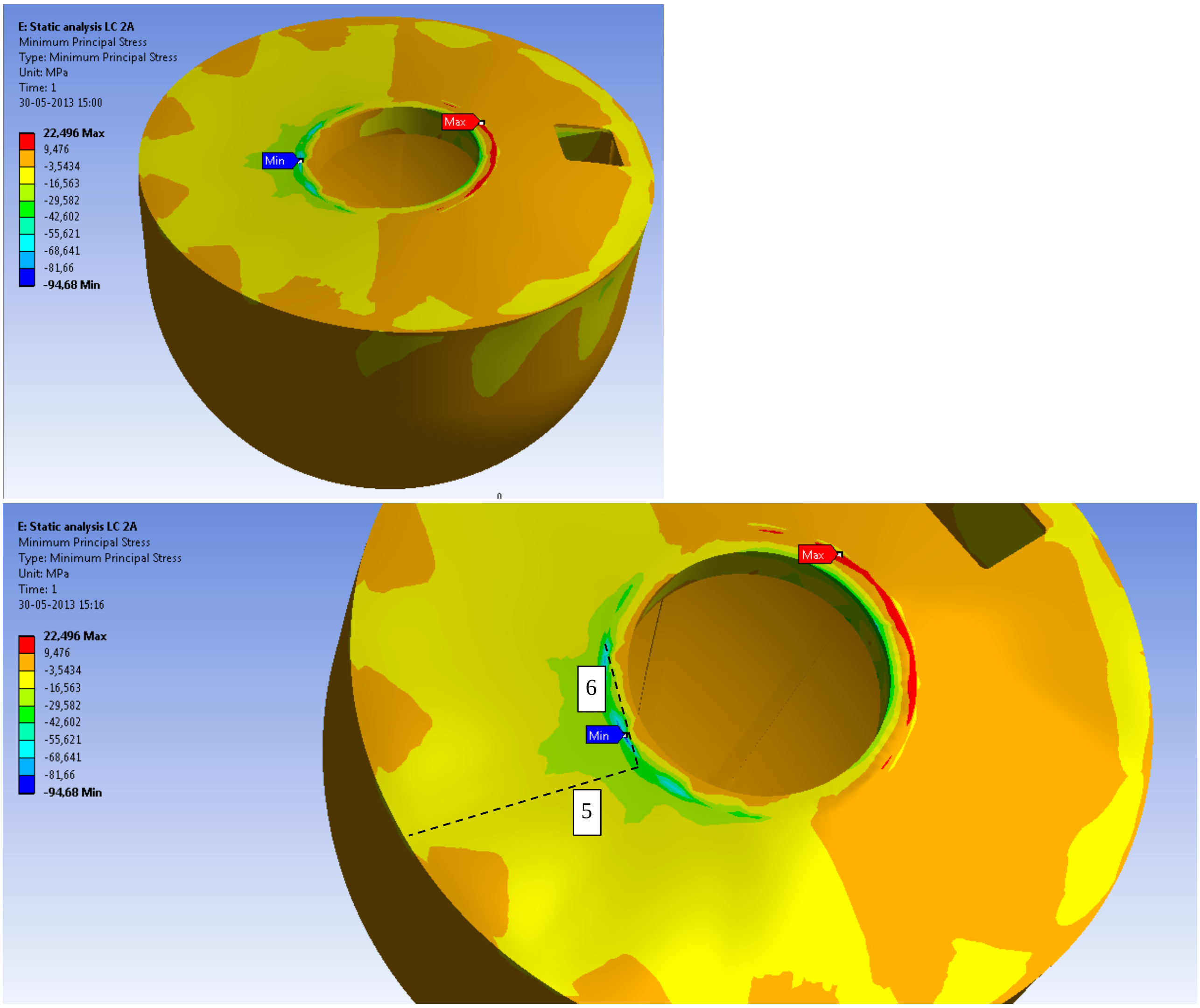
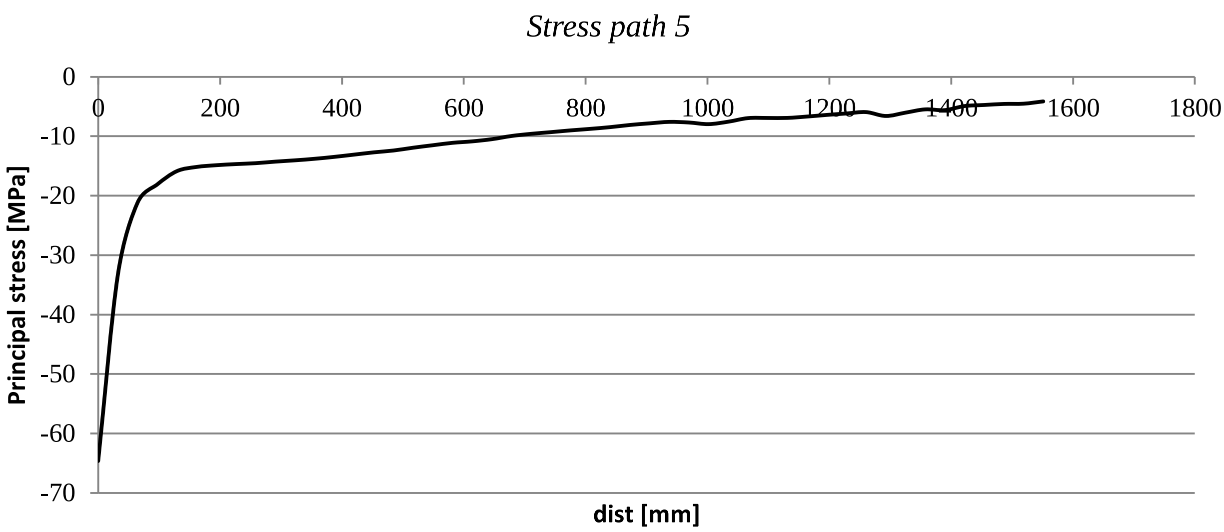


Figure 10-39: 3rd principal stress, stress path 5 and 6 – LC 2A [MPa].



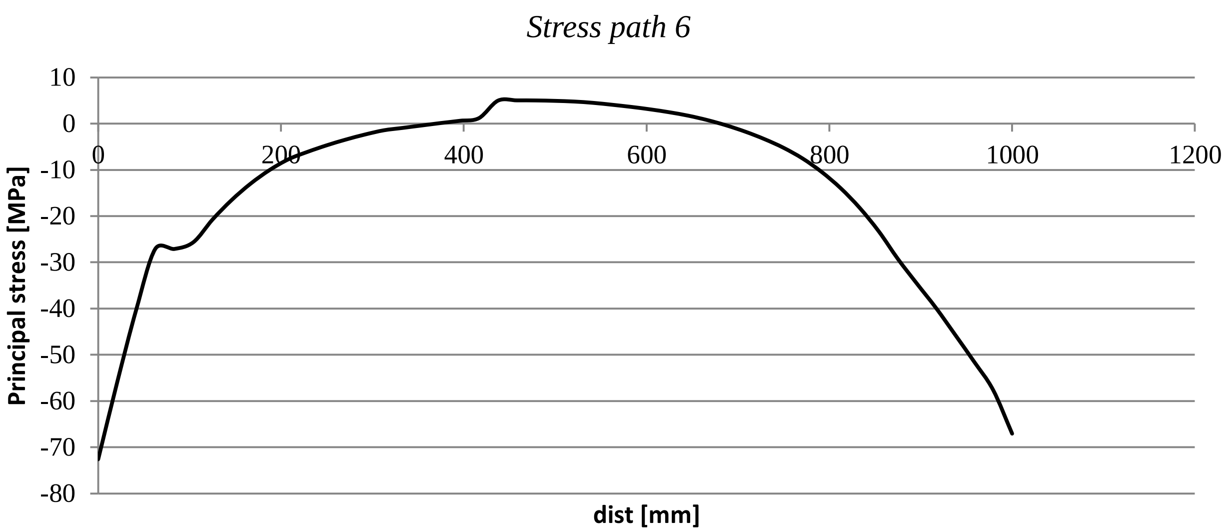
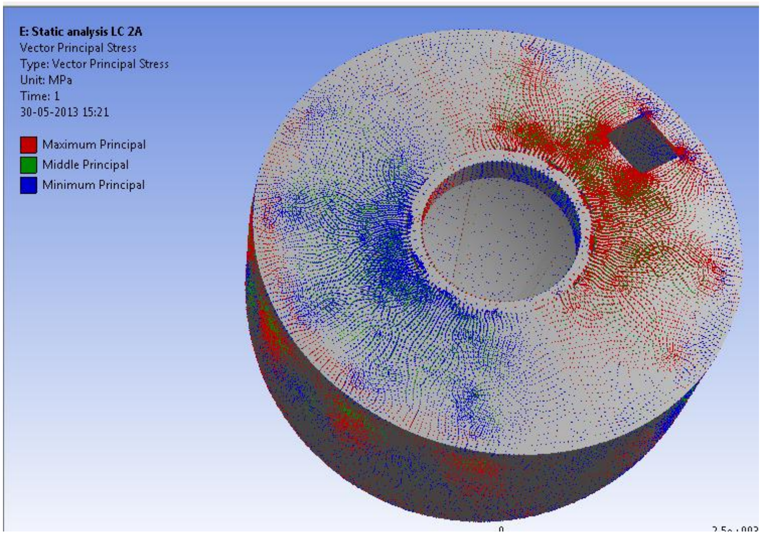
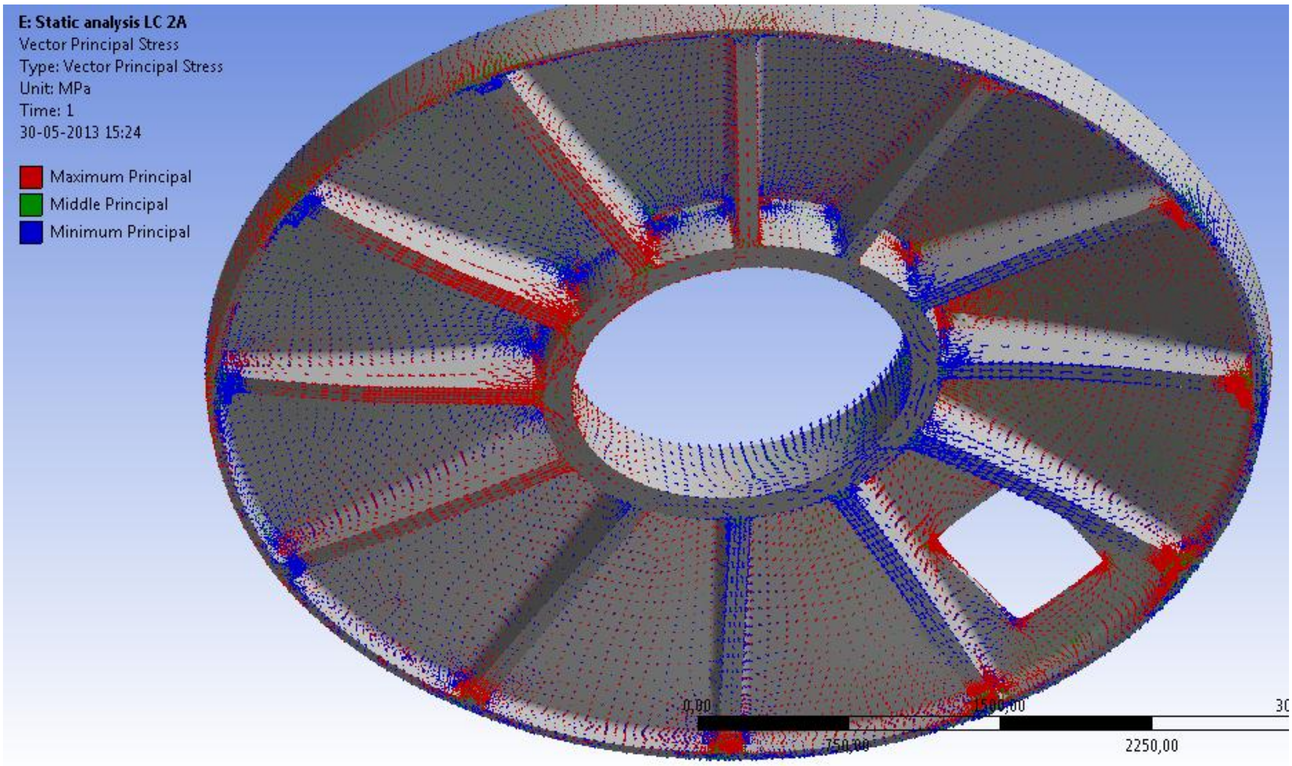
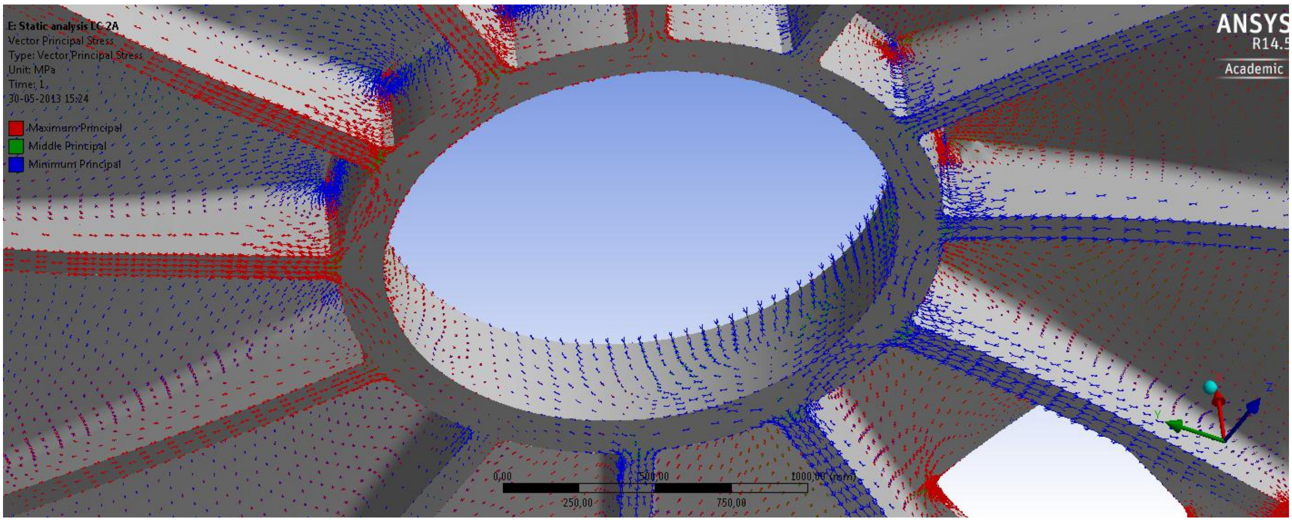


Figure 10-40: Stress path 5 and 6, minimum principal stress.




E: Static analysis LC 2A
Vector Principal Stress
Type: Vector Principal Stress
Unit: MPa
Time: 1
30-05-2013 15:24
Maximum Principal
Middle Principal
Minimum Principal
0,00
1500,00
750,00
2250,00


E: Static analysis LC 2A
Vector Principal Stress
Type: Vector Principal Stress
Unit: MPa
Time: 1
30-05-2013 15:24
Maximum Principal
Middle Principal
Minimum Principal
0,00
500,00
1000,00 (mm)
250,00
750,00

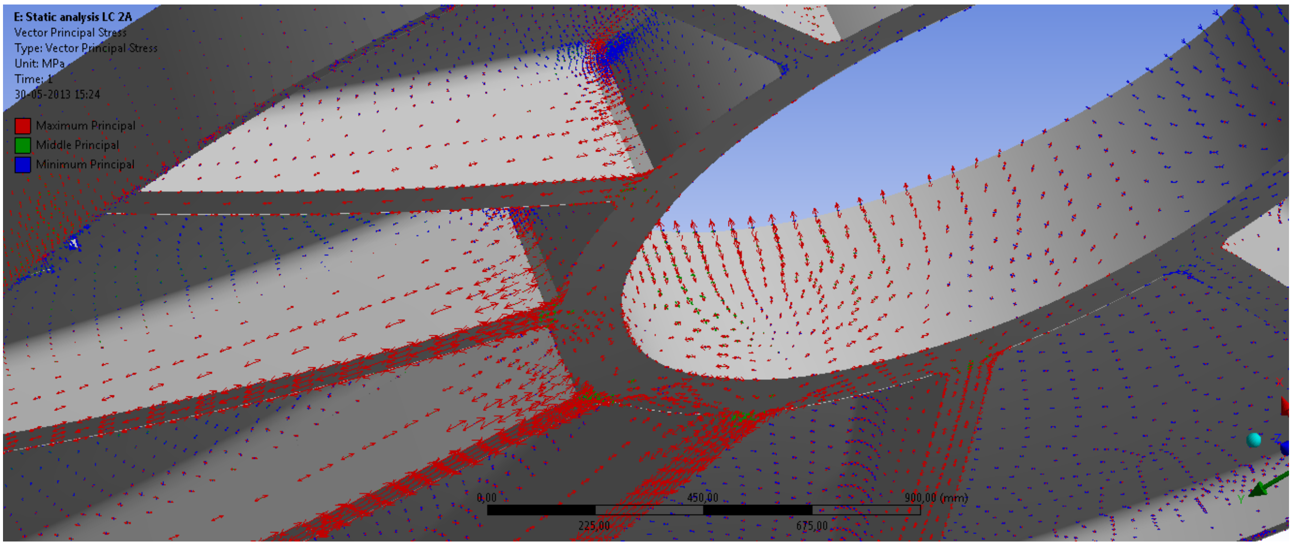


Figure 10-41: Principal stress vector directions.

Table 10-9: Force reaction, global CS.

F_x [kN]	F_y [kN]	F_z [kN]	F_{total} [kN]	M_x [kNm]	M_y [kNm]	M_z [kNm]	M_{total} [kNm]
206.93	-763.52	0.145	791.06	0	2.6911	1557.2	1557.2

Table 10-10: Buckling modes – LC 1B.

Mode	Load factor
1	49,242
2	54,505
3	65,973

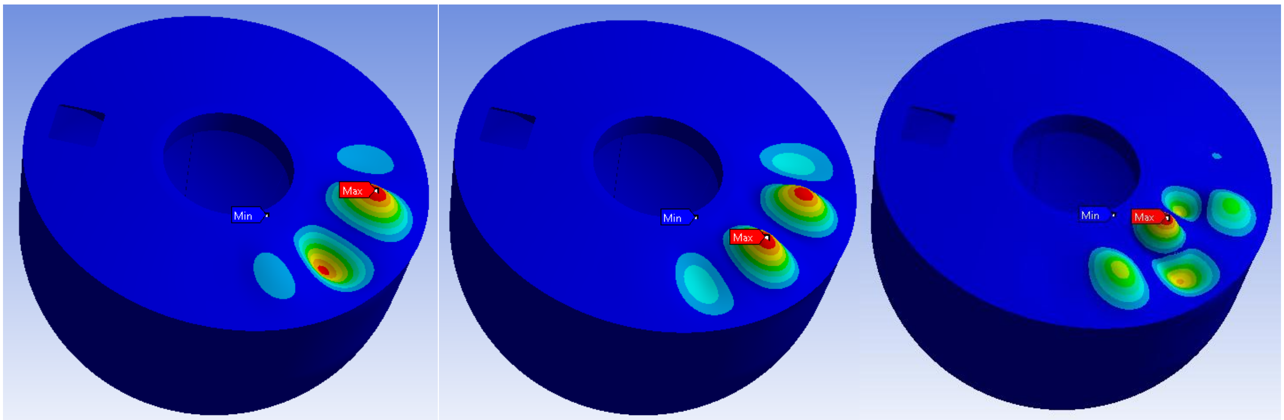


Figure 10-42: Buckling modes – LC 2A.

10.1.6.1. Comments

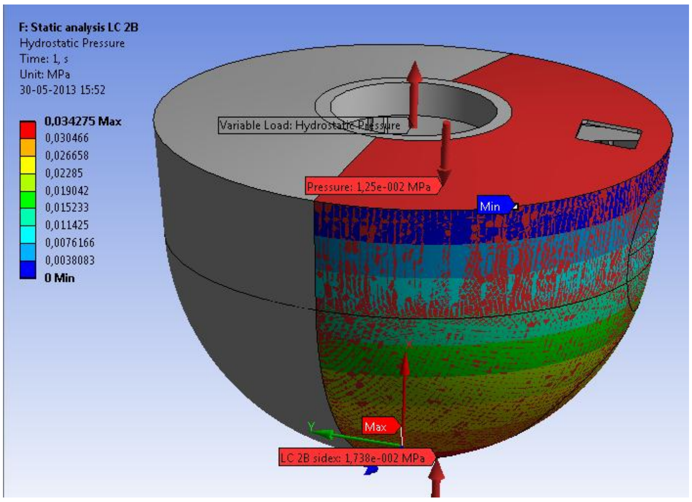
The combination of internal bracing and the membrane in the cap seems to give a satisfactory load transferring system. The stress state at the cap has locally very high peaks, which has to be dealt with by sufficient passive reinforcement. The stress path illustrates the tensile and compressive stress state in the cap, where the highest stress state is recorded. The stress level in the cap is has high peaks near the supporting ring. Passive reinforcement is needed to overcome the stress state near the hatch.

10.1.6.2. Recommendation

Further analyses of the stress distribution in the connection between the shell and the cap have to be carried out.

10.1.7. Load case 2B

The Float is in Load Case 4 subjected to a pressure load see the position in in Figure 7-1.



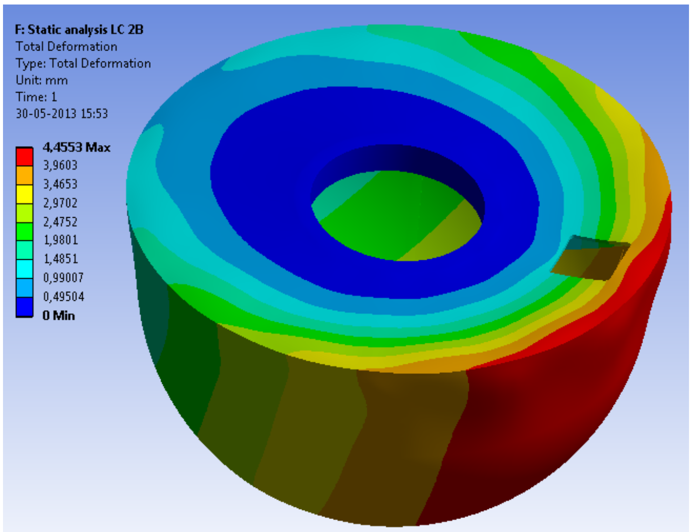


Figure 10-43: Total deformations – LC 2B [mm].

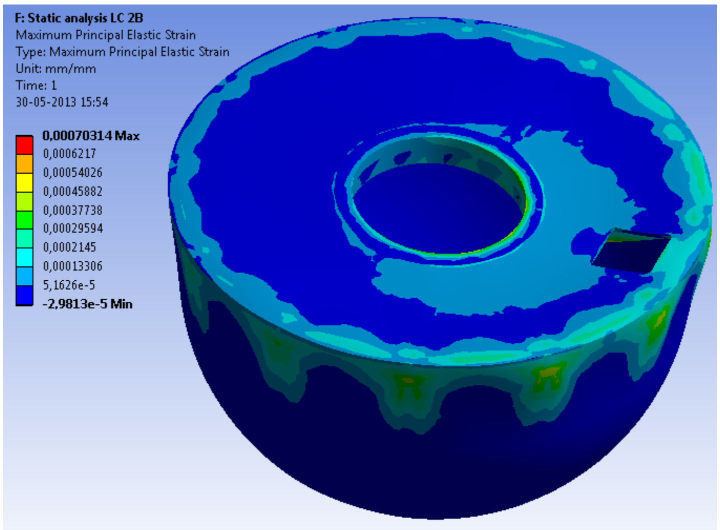


Figure 10-44: Maximum principal elastic strain – LC 2B [MPa].

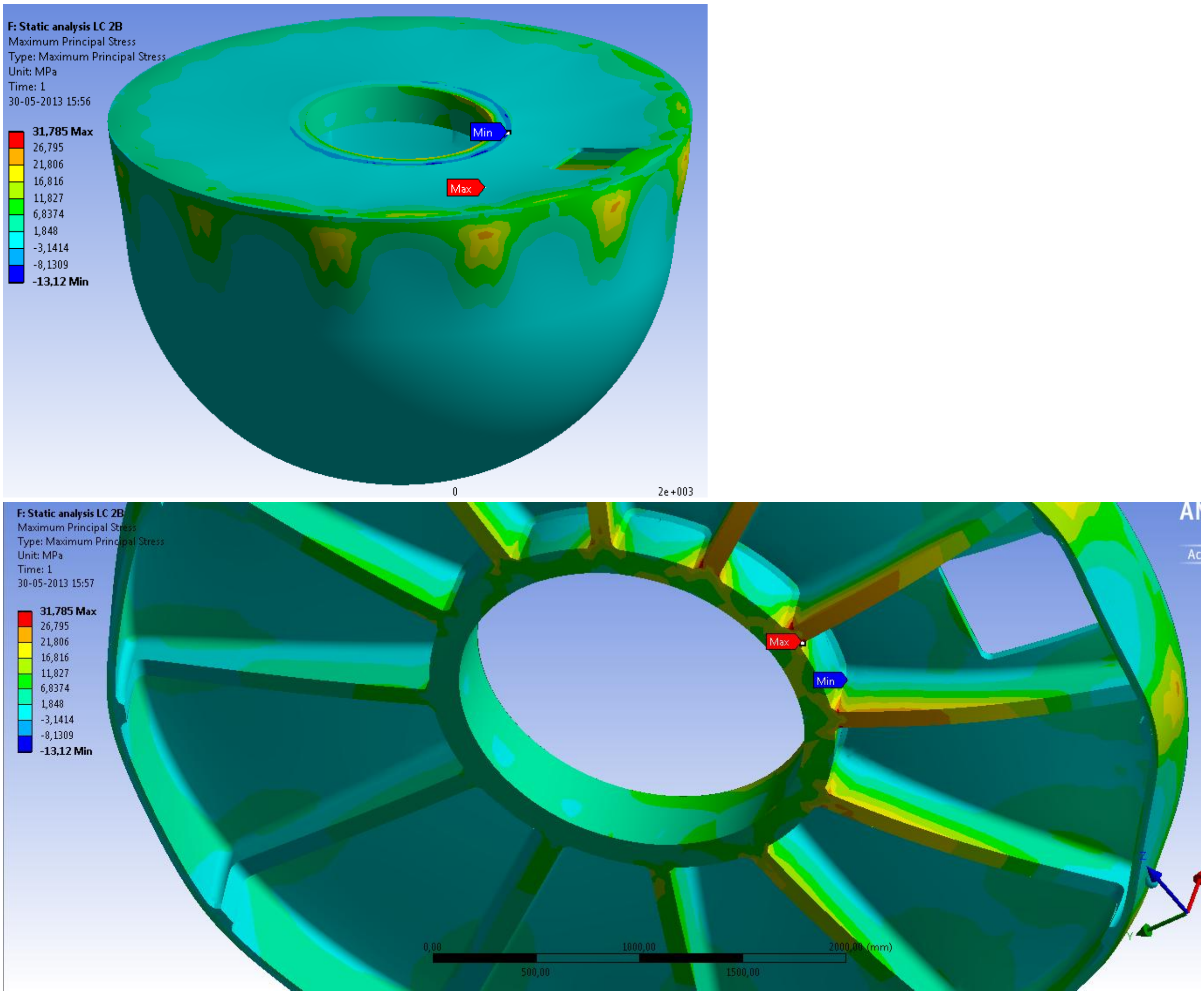
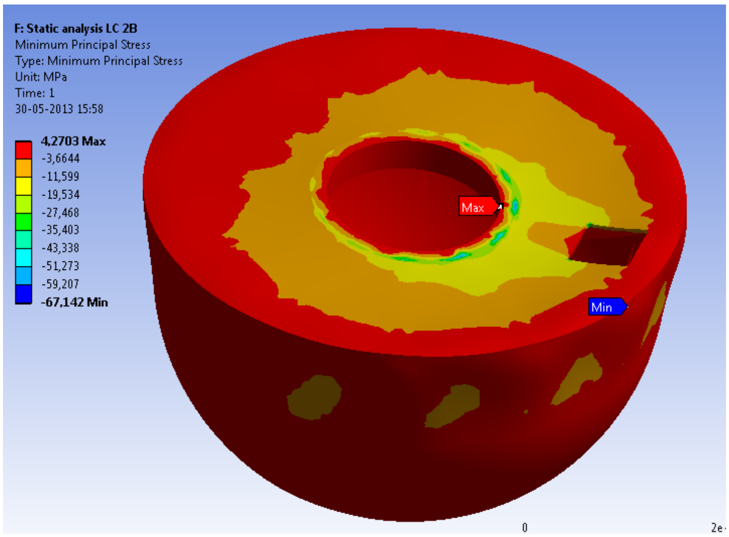


Figure 10-45: 1st principal stress – LC 2B [MPa].



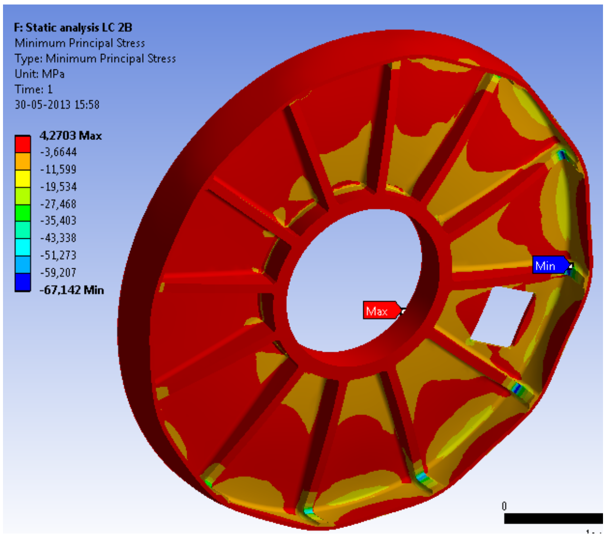


Figure 10-46: 3rd principal stress – LC 1A [MPa].

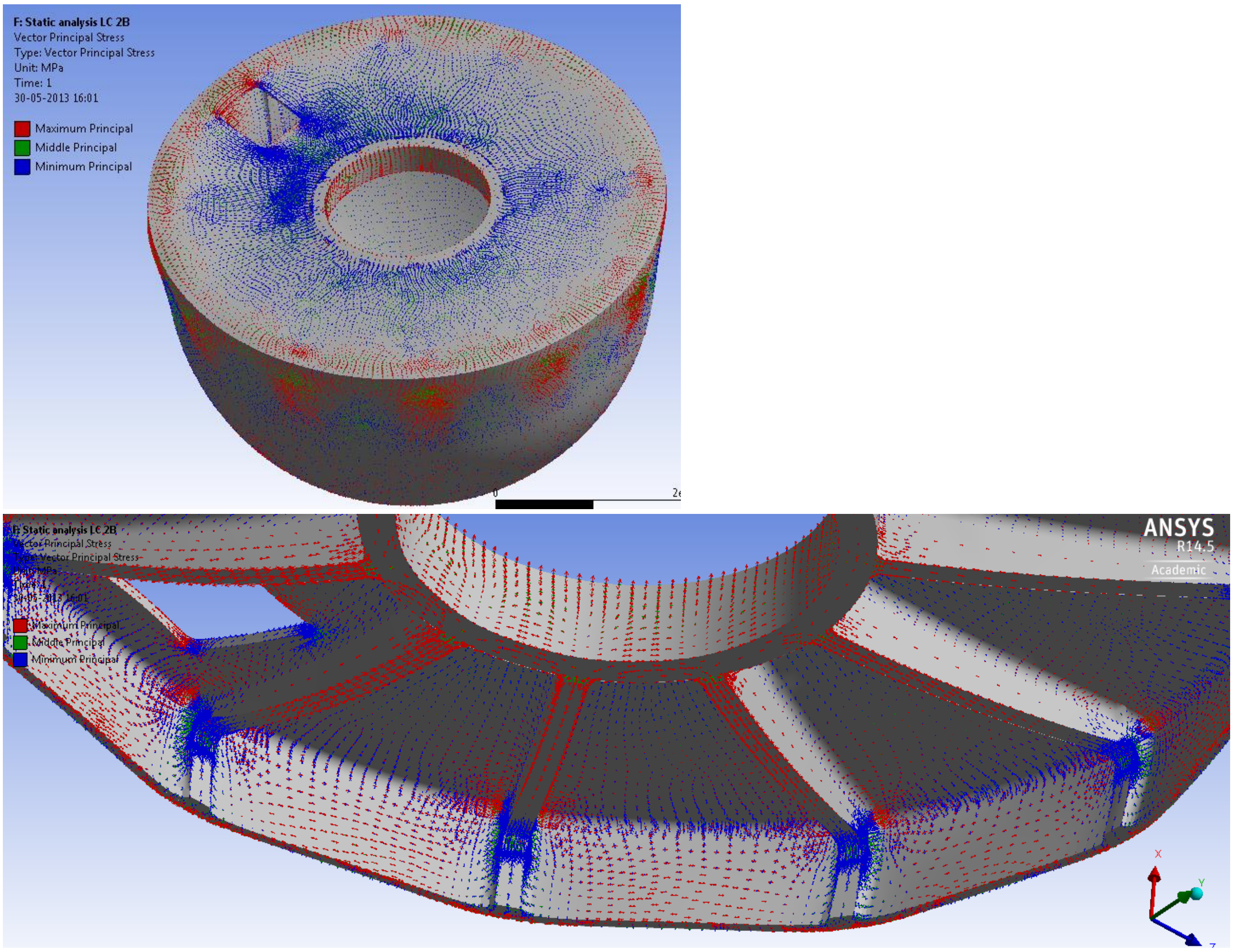


Figure 10-47: Principal stress vector directions.

Table 10-11: Force reaction, global CS.

F_x [kN]	F_y [kN]	F_z [kN]	F_{total} [kN]	M_x [kNm]	M_y [kNm]	M_z [kNm]	M_{total} [kNm]
-522.88	-223.71	0.15	568.73	0	2,6944	-281.76	281.77

Table 10-12: Buckling modes – LC 1B.

Mode	Load factor
1	91,978
2	97,952
3	103,49

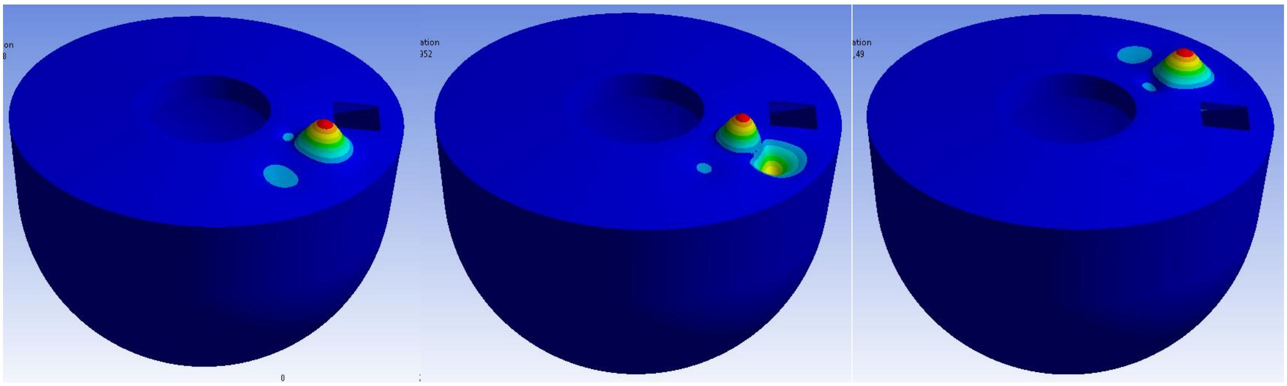


Figure 10-48: Buckling modes – LC 2B.

10.1.7.1. Comments

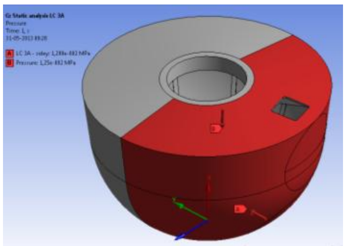
The combination of internal bracing and the membrane in the cap seems to give a satisfactory load transferring system. The bracing secures a sufficient overall stiffness, and the deformation of the unsupported fields in the shell is below 5 mm. The differential pressure at the float surface is transferred by tensile hoop stresses at the bracing. Ring reinforcement is needed near the connection between the cap and the shell.

10.1.7.2. Recommendation

Further analyses of the stress distribution in the connection between the shell and the cap have to be carried out.

10.1.8. Load case 3A

The Float is in Load Case 3A subjected to a pressure load at the cap and one half of the side of the outer shell, secondly the half part of the structure is subjected to hydraulic pressure, representing a pressure where the float is submerged to a level near the cap. See figure below.



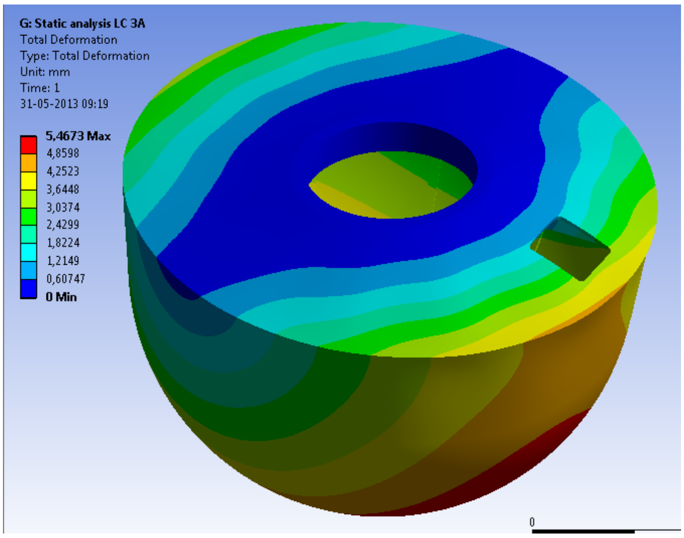


Figure 10-49: Total deformations – LC 3A [mm].

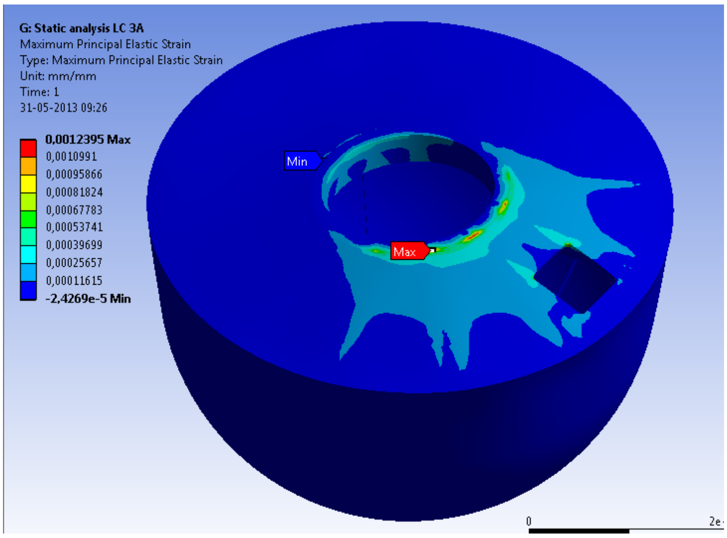


Figure 10-50: Maximum principal stresses – LC 3A [mm].

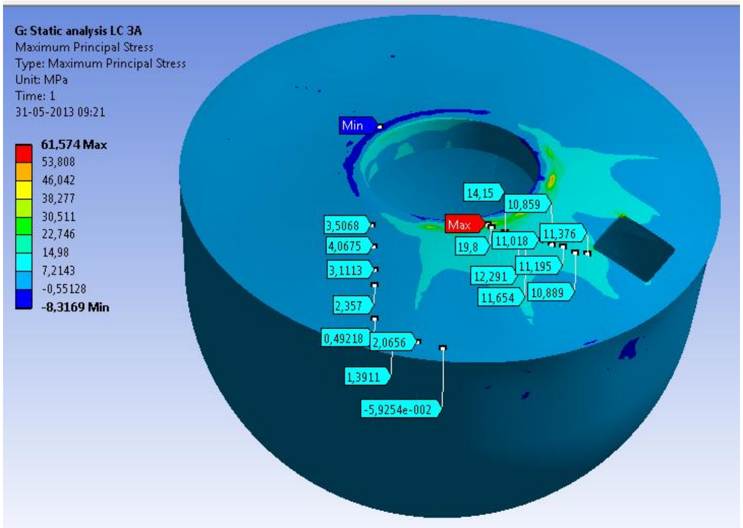


Figure 10-51: 1st principal stress – LC 3A [MPa].

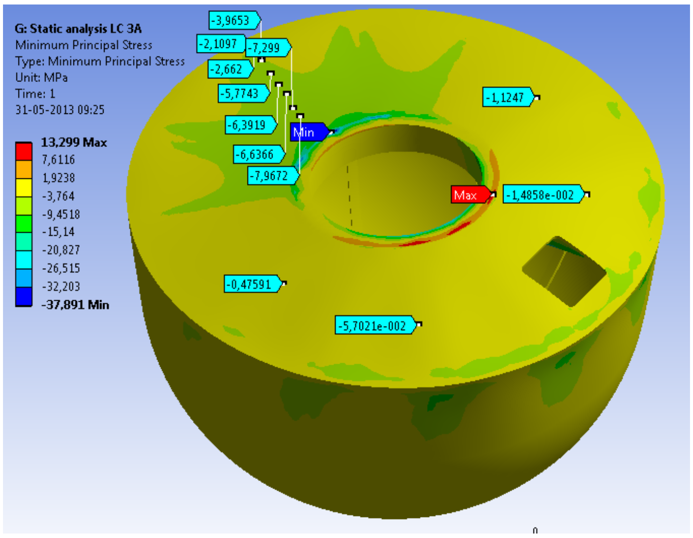
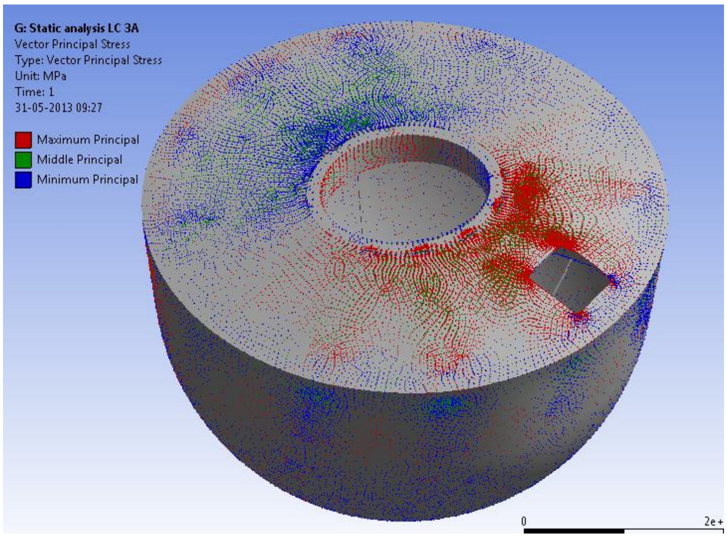


Figure 10-52: 3rd principal stress – LC 3A [MPa].



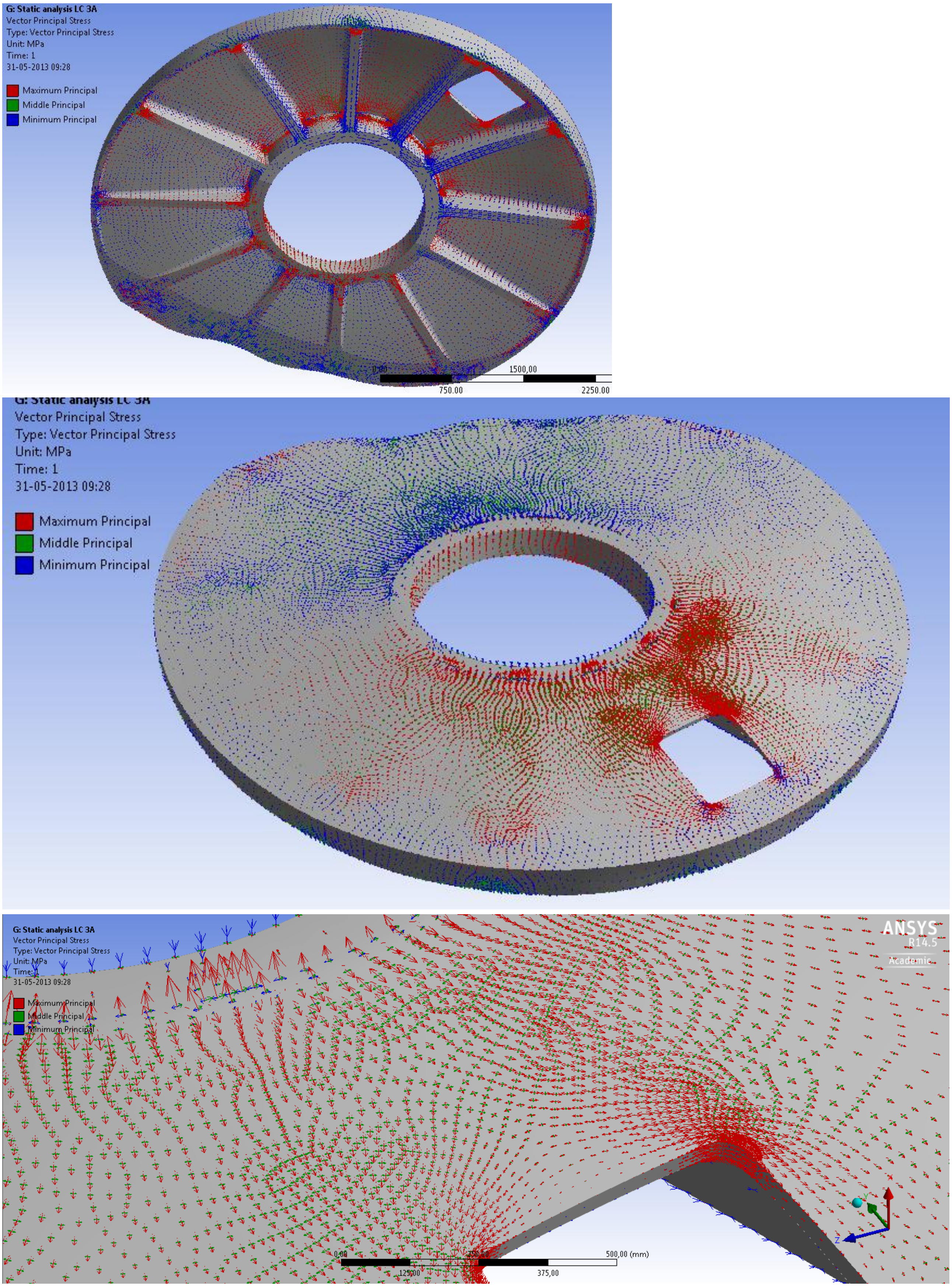


Figure 10-53: Principal stress vector directions.

Table 10-13: Force reaction, global CS.

F_x	F_y	F_z	F_{total}	M_x	M_y	M_z	M_{total}
[kN]	[kN]	[kN]	[kN]	[kNm]	[kNm]	[kNm]	[kNm]
206.93	-359.55	1.45	414.85	0	2.70	796.41	796.42

Table 10-14: Buckling modes – LC 1B.

Mode	Load factor
1	103,79
2	115,16
3	143,43

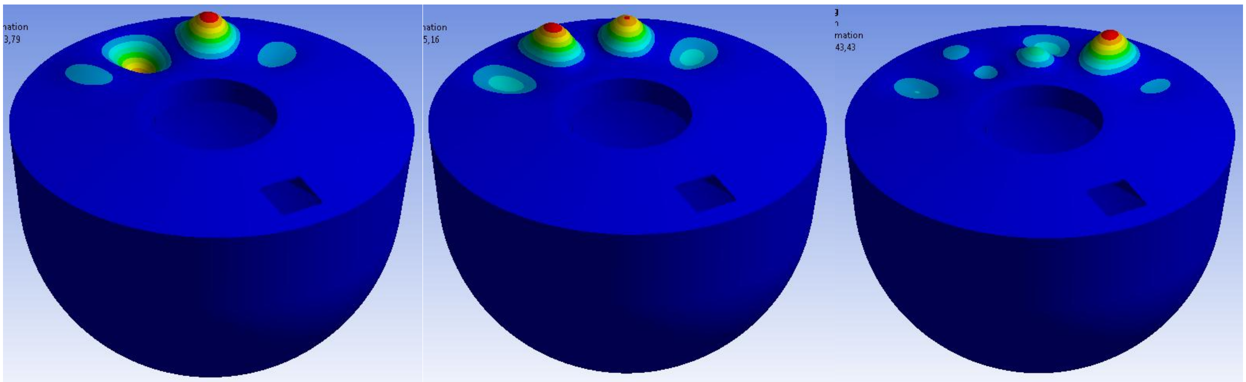


Figure 10-54: Buckling modes – LC 2B.

10.1.8.1. Comments

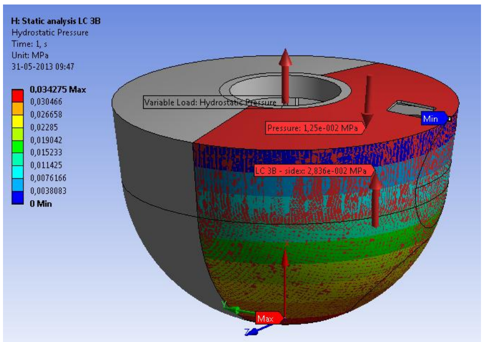
The combination of internal bracing and the membrane in the cap seems to give a satisfactory load transferring system. In this load case, it is clearly seen that special attention has to be directed to the reinforcement of the hatch. The stress flow around the hatch will cause significant cracking.

10.1.8.2. Recommendation

Further analyses of the stress distribution in the connection between the shell and the cap have to be carried out.

10.1.9. Load case 3B

The Float is in Load Case 4 subjected to a pressure load see the position in in Figure 7-1.



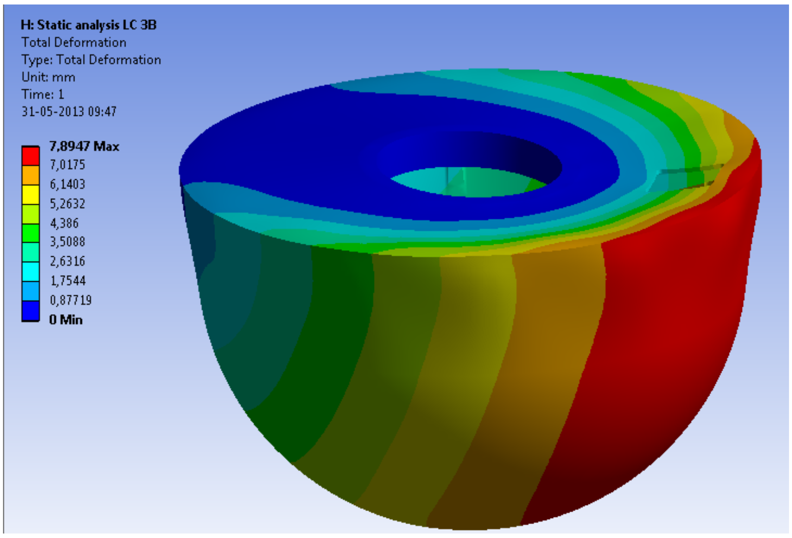


Figure 10-55: Total deformations – 3B [mm].

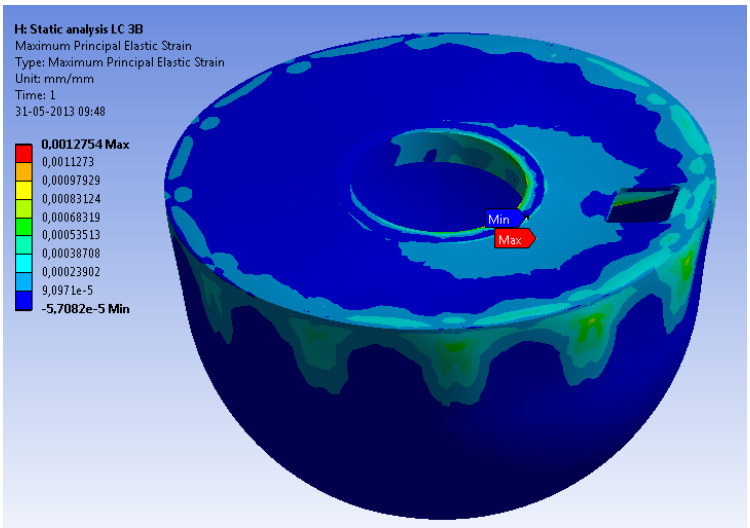


Figure 10-56: Maximum principal strain – LC 3B [mm].

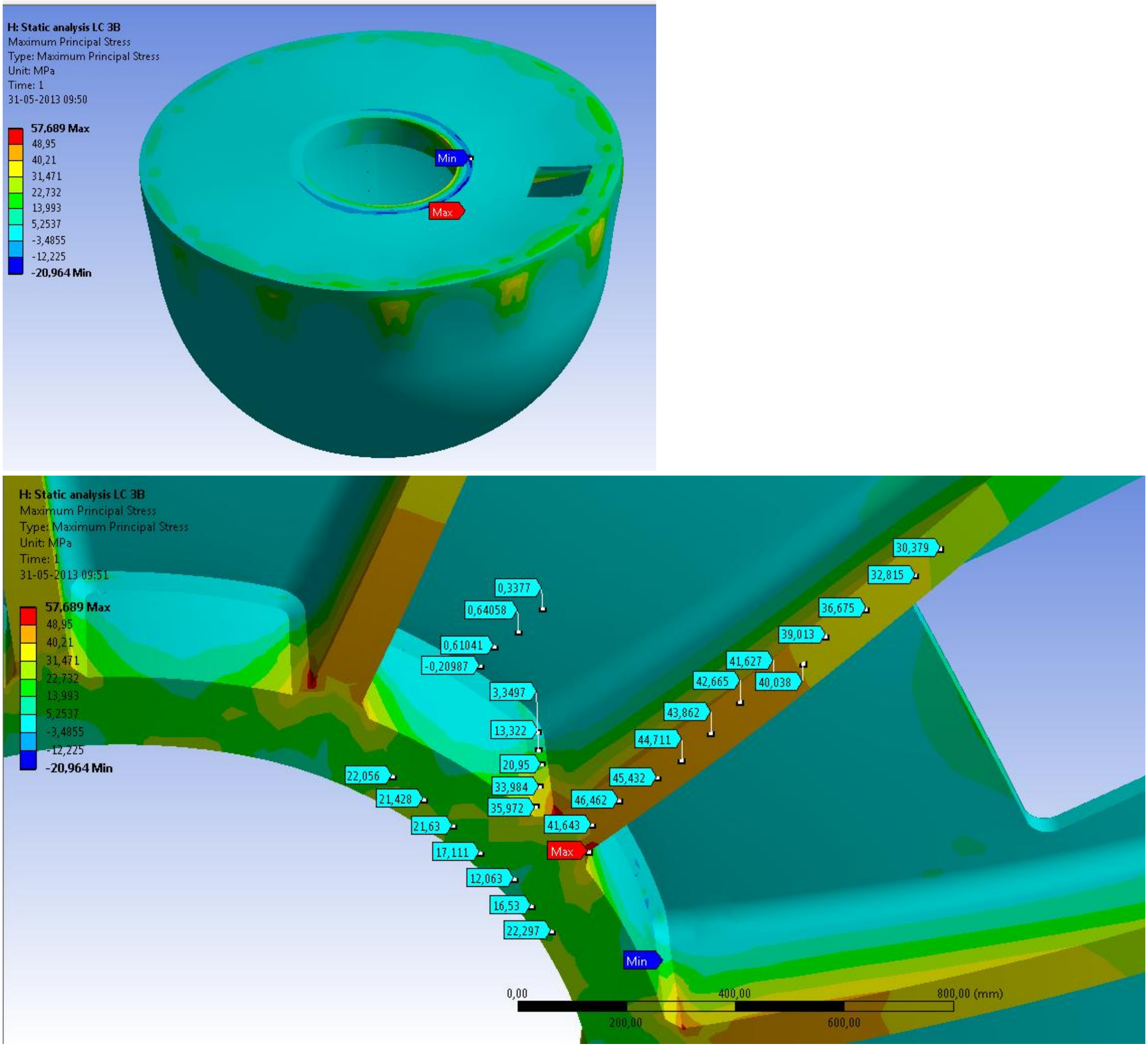
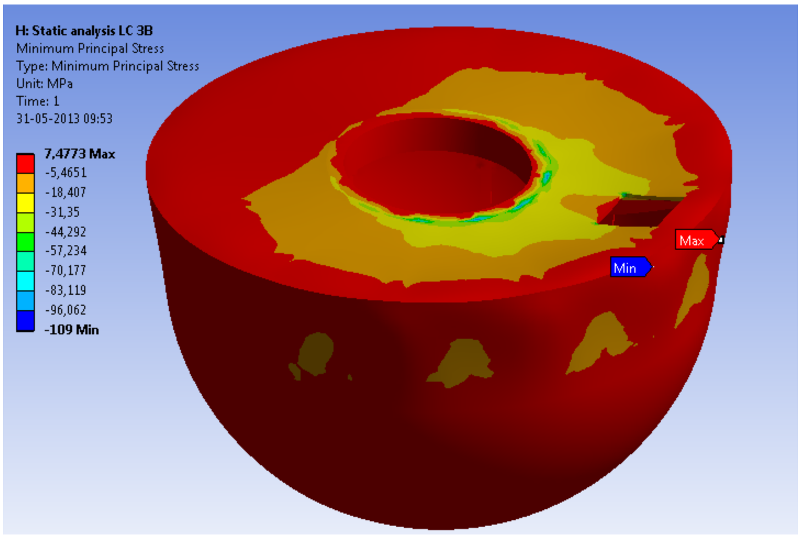


Figure 10-57: 1st principal stress – LC 3B [MPa].



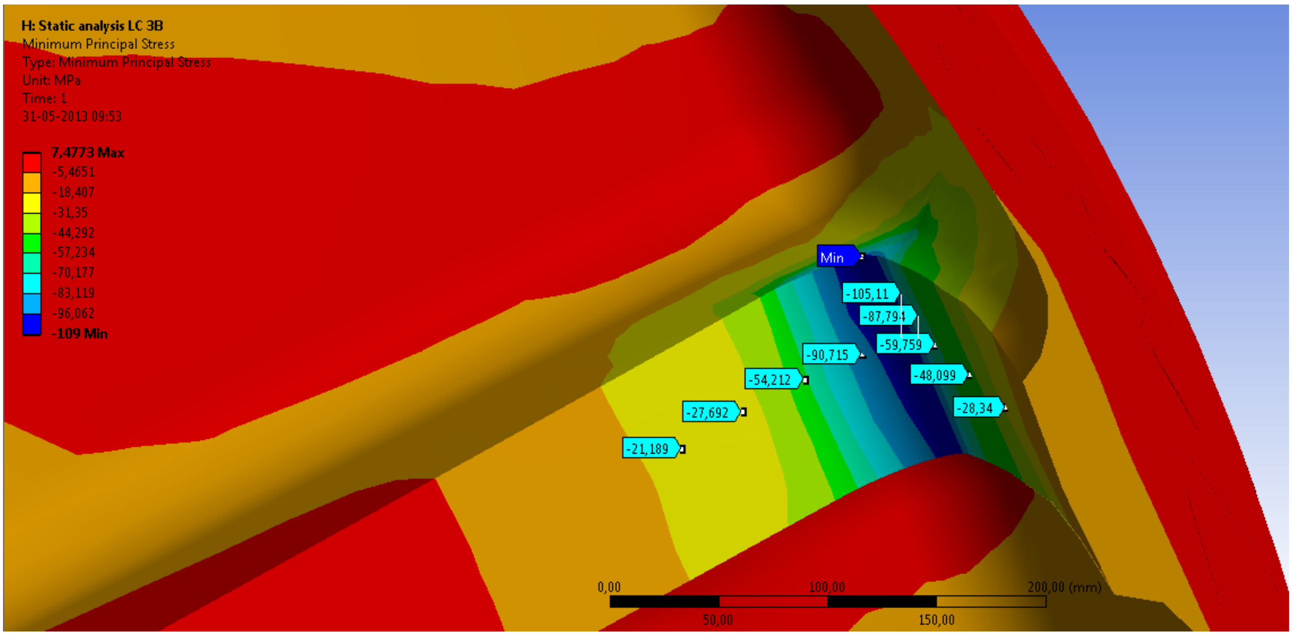
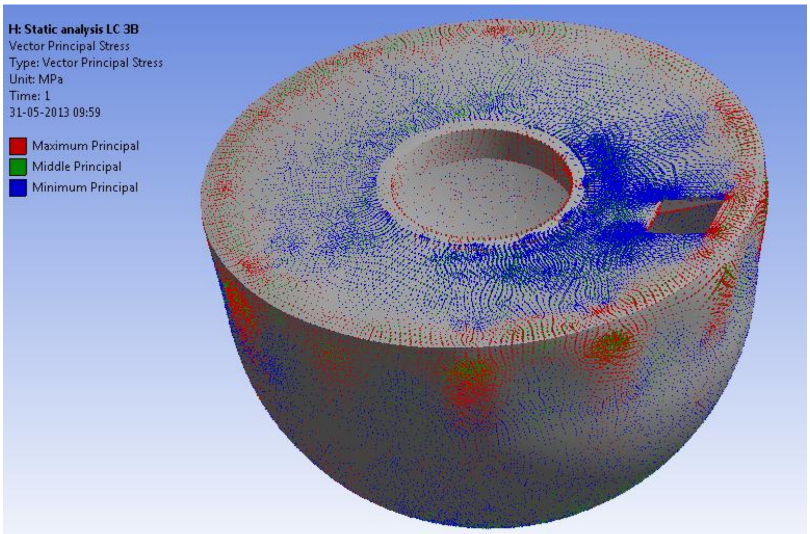
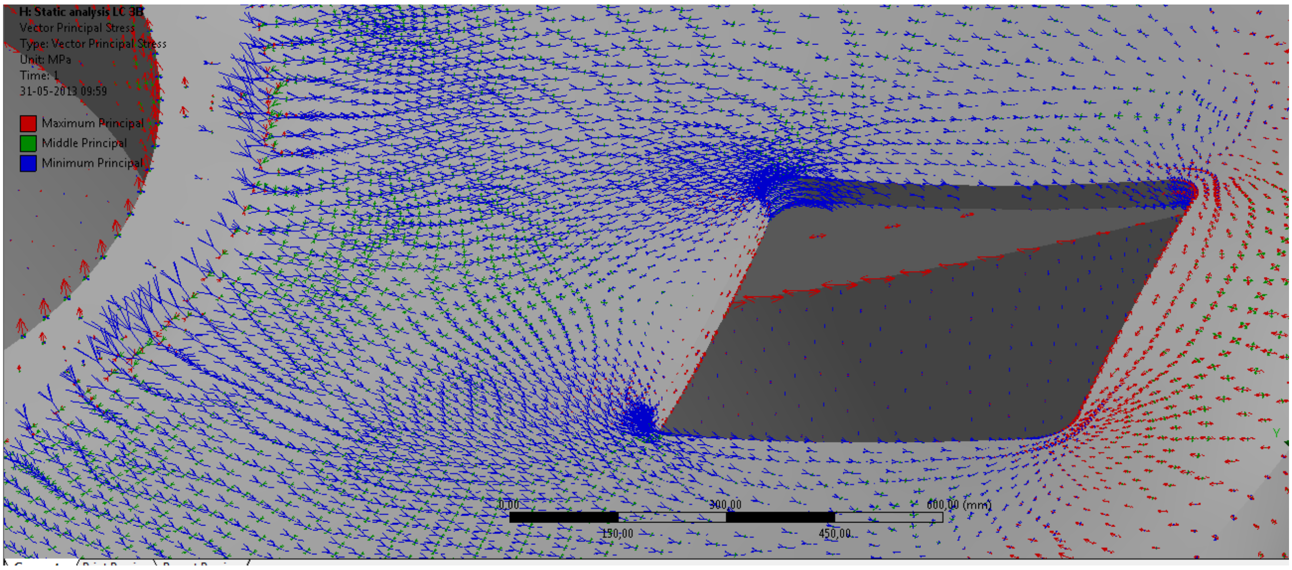


Figure 10-58: 3rd principal stress – LC 3B [MPa].





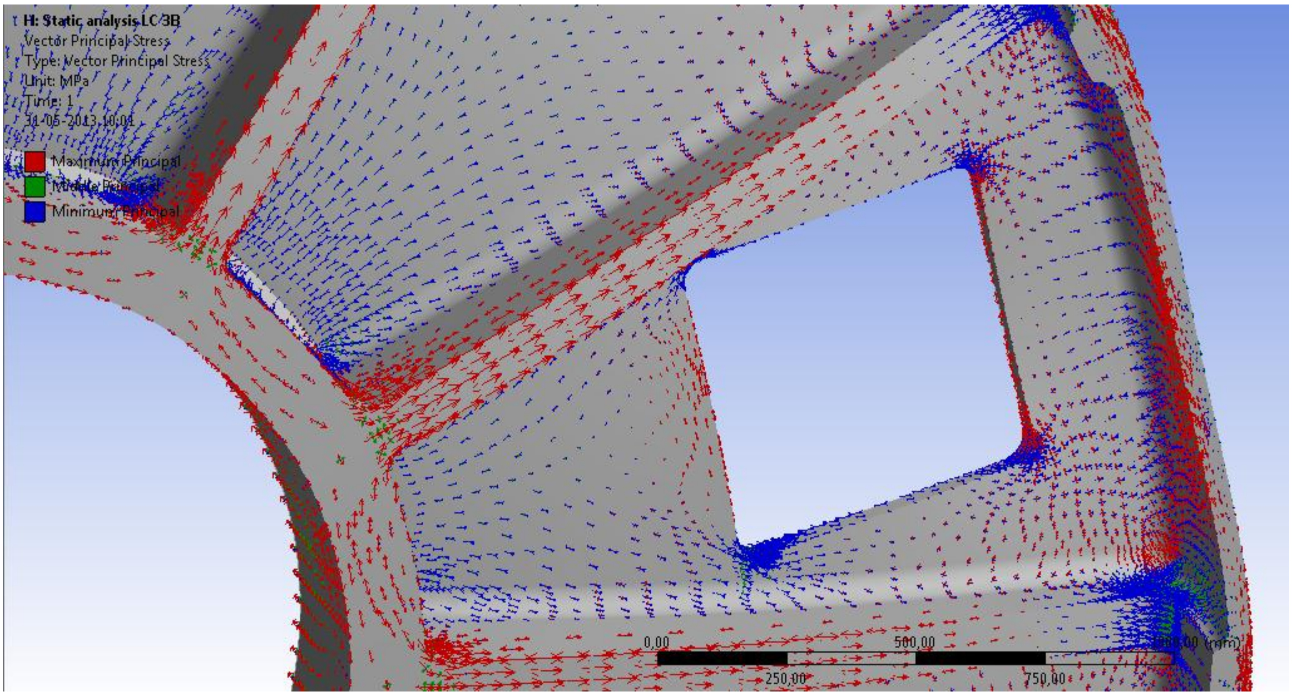


Figure 10-59: Principal stress vector directions.

Table 10-15: Force reaction, global CS.

F_x	F_y	F_z	F_{total}	M_x	M_y	M_z	M_{total}
[kN]	[kN]	[kN]	[kN]	[kNm]	[kNm]	[kNm]	[kNm]
-819.78	-223.71	1.47	849.75	0	2.69	-684.74	684.75

10.1.9.1. Comments

The combination of internal bracing and the membrane in the cap seems to give a satisfactory load transferring system. The loads are primarily carried by bending of the cap beams and membrane effect in the top shell.

10.1.9.2. Recommendation

Further analyses of the stress distribution in the connection between the shell and the cap have to be carried out.

11. Weight

The illustrated design has a weight of 9.6 tons, assuming that the density is 2700 kg/m^3.

12. Conclusion

It is shown that the new design of the WSE Float structure has a satisfactory load transferring system. The internal loads are primarily hoop stresses in the shell structure, and as membrane forces in the cap. The internal bracing, both in the cap and the shell structure seems to increase the overall stiffness of the structure, seen as a high buckling rigidity. The increased stiffness locally means that the stresses concentrations are seen here. The structure cannot be accomplished without any conventional/passive reinforcement, accordingly to these stress concentration (near supporting ring, connection between cap and shell and near the hatch). Further analysis must be carried out to find the necessary amount of reinforcement to prevent initiation of cracks or limitation of cracks.

Appendix

Appendix 1