Mechanical analysis for the Monolith Vessel

Consorcio ESS-BILBAO & Instituto de Fusión Nuclear

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Introduction

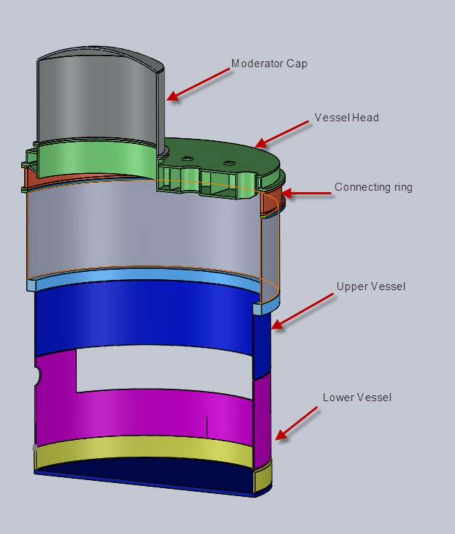
ESS-BILBAO Consortium

Role and functions

- The Spanish Government has taken the decision that ESS-BILBAO will be the only contractor from Spain to ESS project.
- ESS-BILBAO has no independent research activities neither teaching responsabilities outside ESS project.
- Staff of 60 scientific & engineers and the possibility to hire extra staff.
- On January 2015, ESS-Bilbao was chosen as ESS partner for the Monolith Vessel.
- On September 2015, ESS-Bilbao and ESS-ERIC organized the KO meeting in Madrid.
- On November 2015, ESS-ERIC completed the PDR and ESS-Bilbao started the design phase.

Introduction

Monolith Vessel components



Planing and Schedule

Planing and Schedule

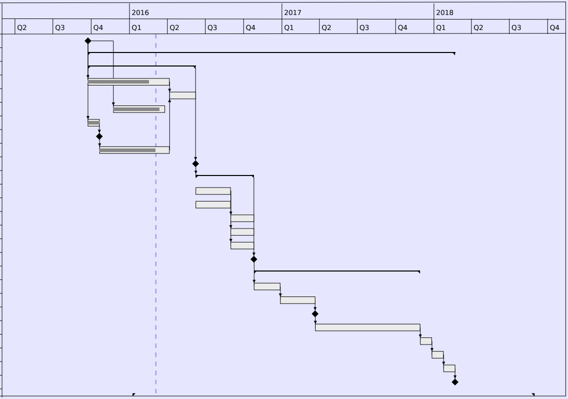
Modifications based on the actual scenario

- We have divided the project in two sub projects with different schedule and SAT: "Lower & Medium Vessel" and "Head of the Vessel & Connection Rings".
- The information required for the design process for the "Lower & Medium Vessel" is mainly on place so the design is progressing on schedule.
- Regarding "Head of the Vessel & Connection Rings" additional clarifications about the number, size and position of the different penetrations have to be provided by the end of the month.
- A clear definition of the vacuum requirements is critical to continue the manufacturing review and the definition of the flanges and joints.

Planing and Schedule

Schedule

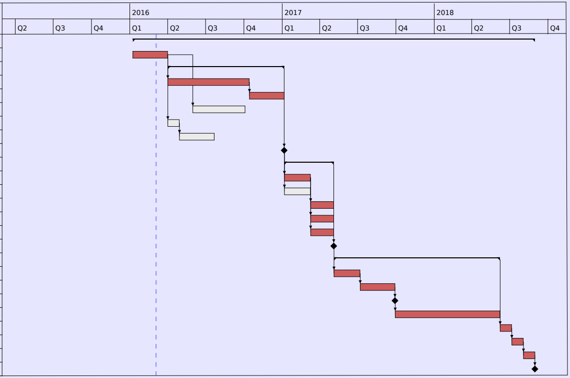
Nombre	Trab...
KO meeting	
Lower & medium Monolith Vessel	**1000d**
Design phase	**415d**
MEC:Mecanical analysis of the vessel	140d
MEC: Sysmic analysis	45d
MC: Damage and activation	90d
Preparation of PCT: Support on manufacturing and transportation	20d
PCT: Contract Award	
PA: manufacturing, welding and transportation analysis	120d
MS: Design review	
Final CAD modeling	**240d**
Final Mechanical and RCC-MRx	60d
Final Neutronic analysis	60d
Final Sysmic analisys	40d
Final Quality specifications & manufacturing requirements	40d
Final Transport analysis	40d
CDR: Critical desing review for Monolith Vessel	
Manufacturing Phase	**285d**
Prepration PCT: Manufacturing vessel	45d
Public advertising: Manufacturing Vessel	60d
MS: Contract award for vessel	
Monolith Vessel Production	180d
Transport to Lund	20d
Instalation	20d
Site testing	20d
MS: SAT by ESS	



Planing and Schedule

Schedule

Nombre	
Conection Ring & Head of the vessel & Covers	**985d**
Carification of the requirements and penetrations	60d
Design phase	**370d**
MEC:Mecanical analysis of the vessel	140d
MEC: Sysmic analysis	60d
MC: Damage and activation	90d
Preparation of PCT: Support on manufacturing and transportation	20d
PA: Support on manufacturing and transportation	60d
MS: Design review	
Final CAD modeling	**210d**
Final Mechanical and RCC-MRx	45d
Final Neutronic analysis	45d
Final Sysmic analisys	40d
Final Quality specifications & manufacturing requirements	40d
Final Transport analysis	40d
CDR: Critical desing review for Monolith Vessel	
Manufacturing Phase	**285d**
Prepration PCT: Manufacturing covers and penetrations	45d
Public advertising: Manufacturing covers and penetrations	60d
MS: Contract award for covers and penetrations	
Manufacturing covers and penetrations production	180d
Transport to Lund	20d
Instalation	20d
Site testing	20d
MS: SAT by ESS	



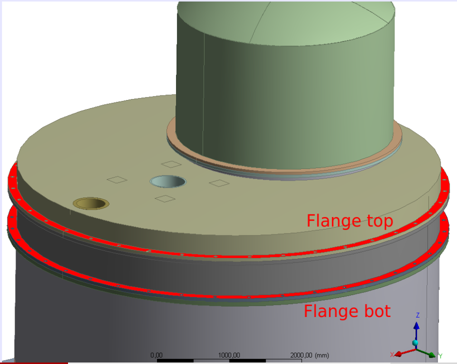
Radiation Damage Analysis

Radiation Damage Analysis

Flanges and seals

The proposed solution for the joint between Connection ring, Head of the Vessel and Medium vessel is based on a bolted flange. An evaluation of the radiation level is need to clarify the type of seal (elastomer or metal) . If a metallic seal is needed the radiation level can be consider negligible ($<<$ 1E-3 dpa).

MCNPX model



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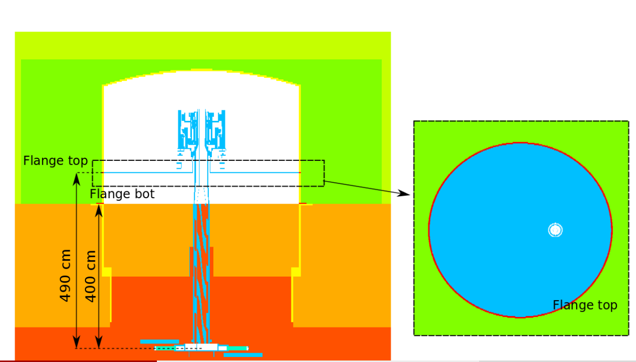


Radiation Damage Analysis

Flanges and seals

The proposed solution for the joint between Connection ring, Head of the Vessel and Medium vessel is based on a bolted flange. An evaluation of the radiation level is need to clarify the type of seal (elastomer or metal) . Considering 40 years of operation, the damage levels are in the range of standard vacuum elastomer ($<$800 Sv).

Dose rate for 5000 h of operation per year (neutrons & photons).

Element	**Gy/year (Steel)**	**Sv/year**	**DPA/year**
Top Flange	2.5	24.3	$6.2 \cdot 10^{-10}$
Bottom Flange	0.8	9.6	$1.8 \cdot 10^{-10}$

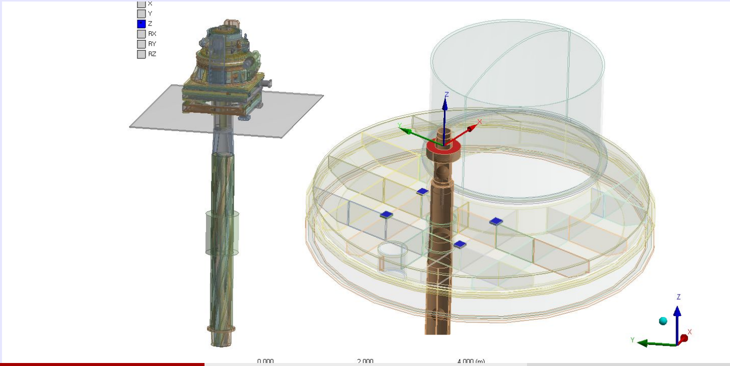
Mechanical analysis

Mechanical analysis

Main loads and boundary conditions

A FEM model has been configured for the mechanical analysis. The Target has been considered as a shaft with point masses (mass and inertia for internal shielding and Target wheel) connected to the vessel by springs (1E9 $N \cdot m^{-1}$) and a joint connection. This simplifications keeps the main resonance modes for the shaft.

Geometrical model for the monolith vessel



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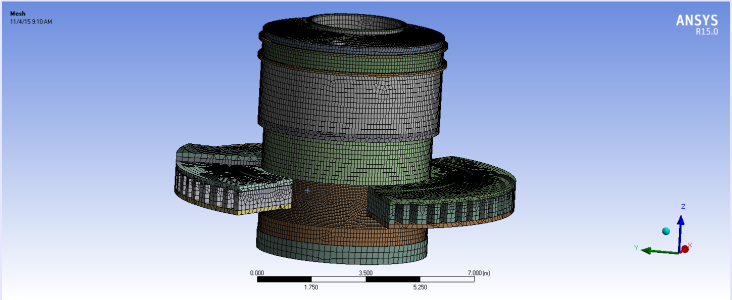


Material selection

Main loads and analysis

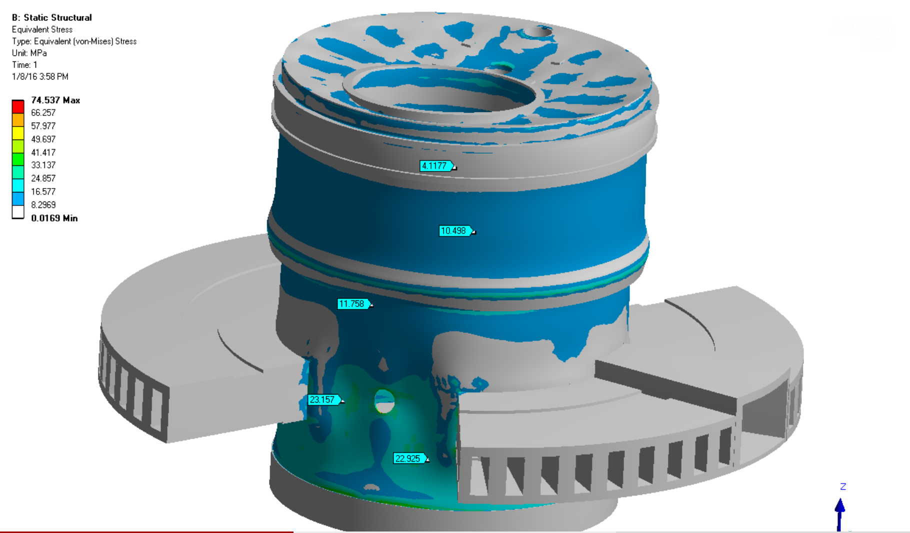
- Dead weight (Target and vessel)
- Vacuum (P-loads & buckling)
- 2.O bars Over pressure (P- loads & bolted union analysis)
- Seismic analysis

Based on vacuum requirements two stainless steels could be considered

- SS-316L: Better corrosion resistance properties (Base line)
- SS-304: Better manufacturing and welding properties.

Mechanical analysis: Vacuum

Stress and deformations relative low compared with acceptable levels (∼ 20-30 MPa)

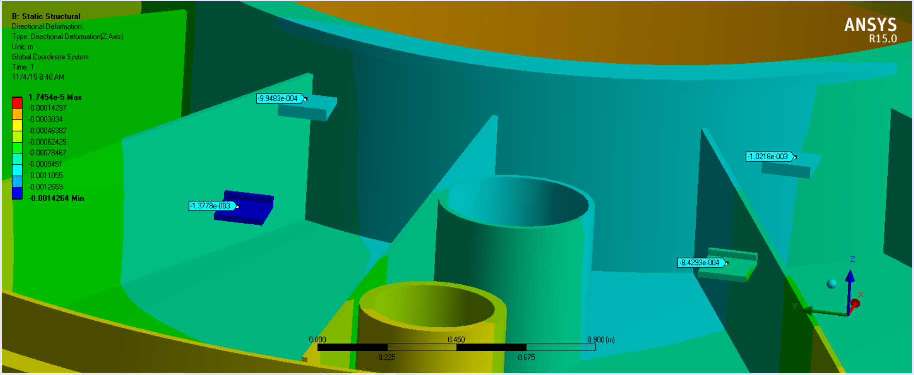


Mechanical analysis: Vacuum

New configuration for the vessel head stiffness

One of the most demanding design criteria is the requirement to minimize the vertical displacement of the target vessel supports. Also it is convenient to have an homogeneous displacement of the supports to keep the target balanced.

The displacement of the drive unit supports



Mechanical analysis: Vacuum

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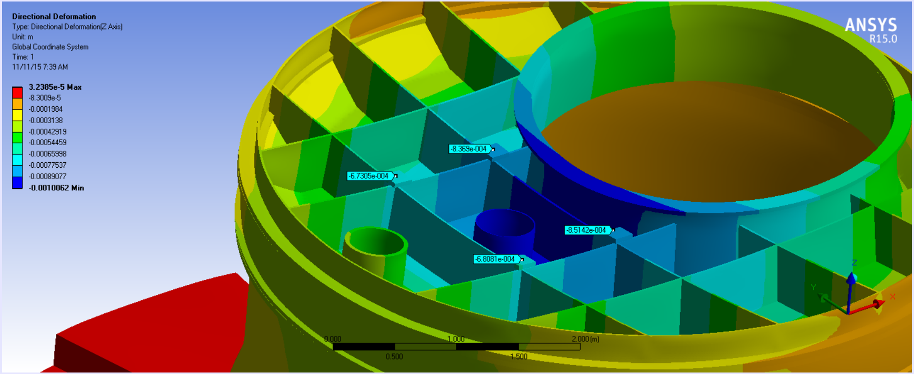
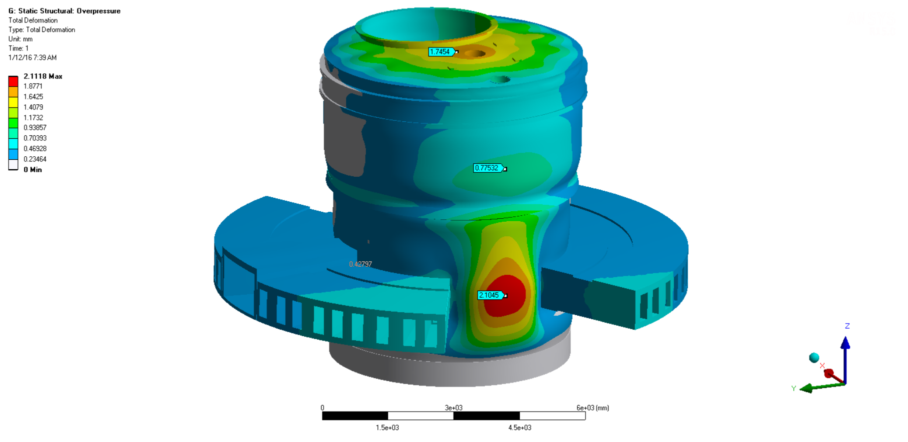


Nominal conditions: Over pressure 2 bar

The displacement of the drive unit supports



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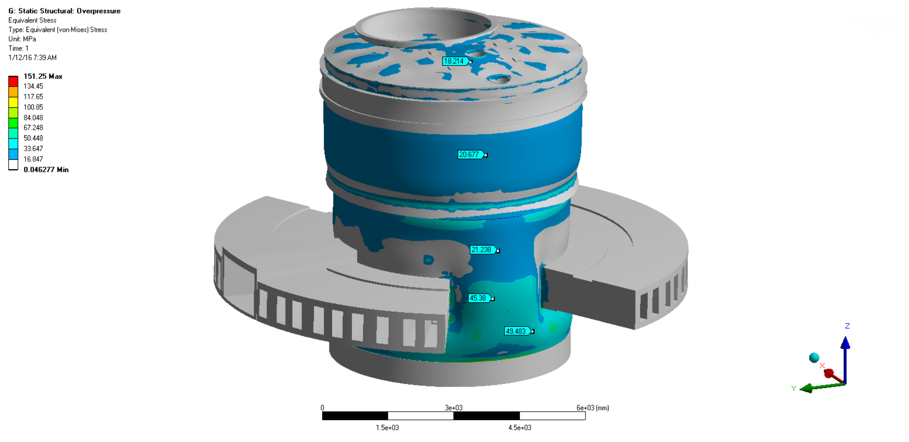
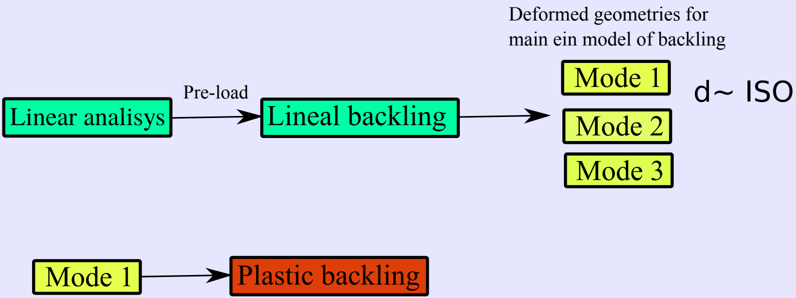
The displacement of the drive unit supports



Mechanical analysis: Buckling

Methodology based on RCC-MRx



Mechanical analysis: Linear buckling

Linear backing “safety factors” for SS-316L

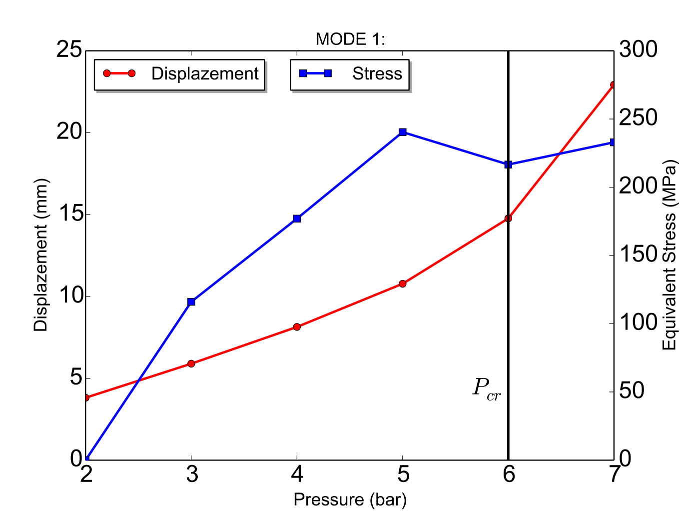
Mode	λ_c
1.	22.916
2.	24.221
3.	24.974
4.	25.995
5.	26.029
6.	26.141
7.	26.743
8.	26.75
9.	26.884
10.	26.896

Linear buckling

The linear buckling analysis can produce a significant error and it is not covered for all materials at RCC-MRx. We have complete the analysis for the first 30 modes.

Mechanical analysis: Plastic Buckling for SS-304

Modes 1 and 3



Mechanical analysis: Plastic Buckling for SS-304

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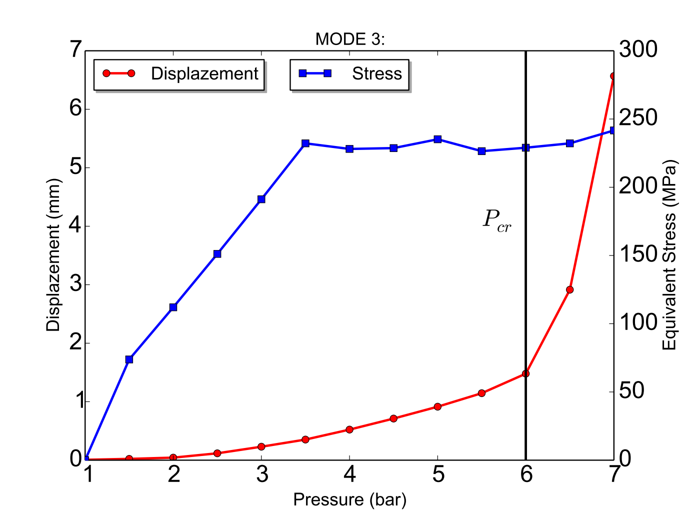

Mechanical analysis: Plastic Buckling for SS-304

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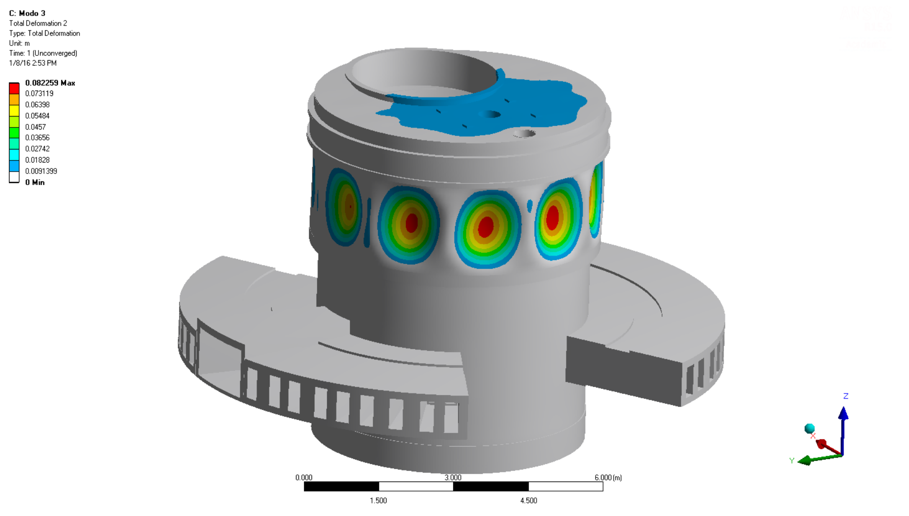
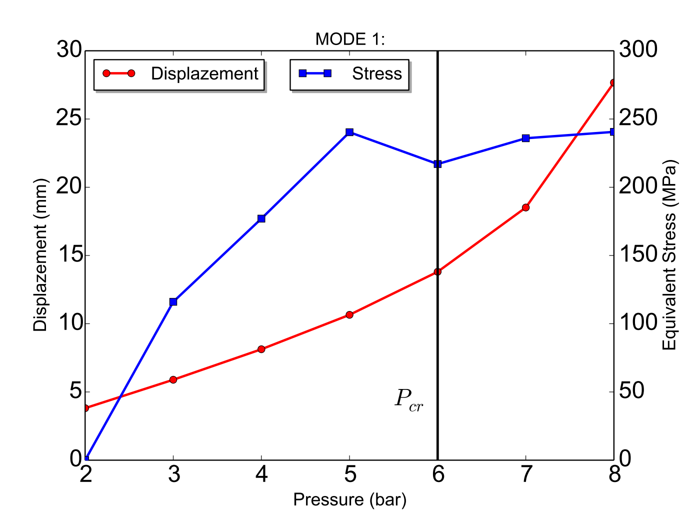


Mechanical analysis: Plastic Buckling for SS-316L

Modes 1 and 3



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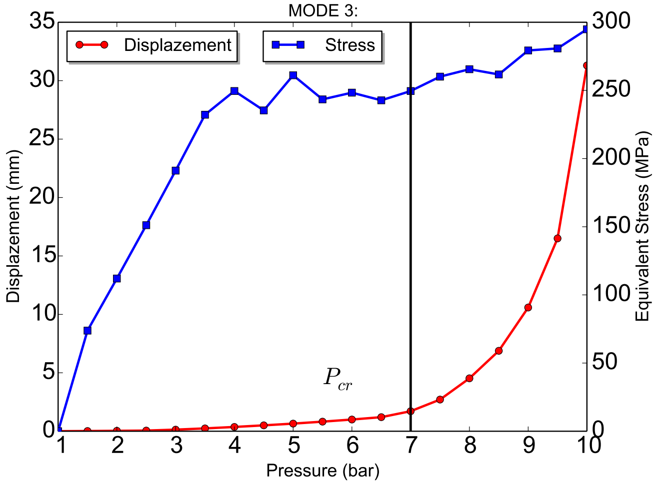
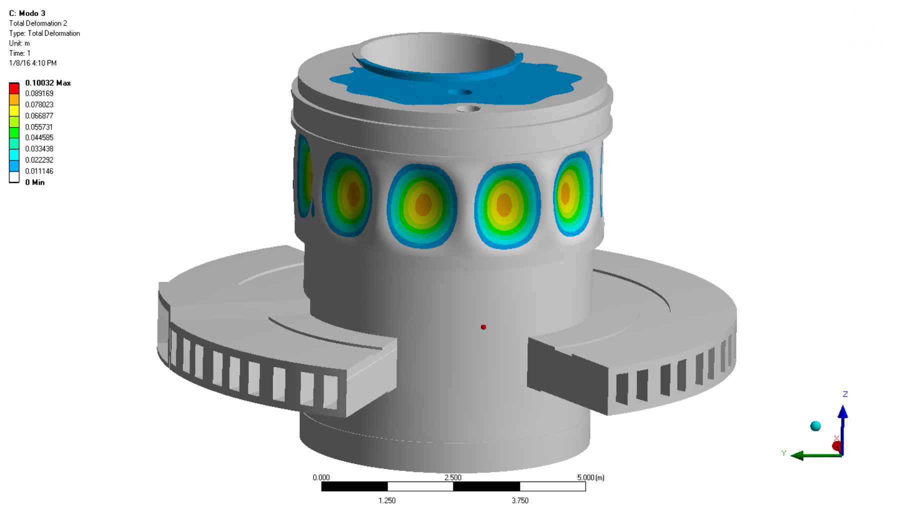


Mechanical analysis: Plastic Buckling for SS-316L

Modes 1 and 3



Mechanical analysis: Conclusions

Remarks from mechanical analysis

- The Stress values are relatively far below the RCC-MRx limits so there is room for thicknesses optimization, specially on lower and medium vessel.
- The displacement in the Target supports can be limited to 2 mm
- Seismic analysis are on going.

Manufacturing Analysis

Review of manufacturing procedure

On December 2015, ESS-BILBAO awarded a contract to ENWESA to review the manufacturing process for the lower and medium vessel (manufacturing, testing, transportation and installation in Lund). The work should be completed in a in a couple of weeks.

ENWESA

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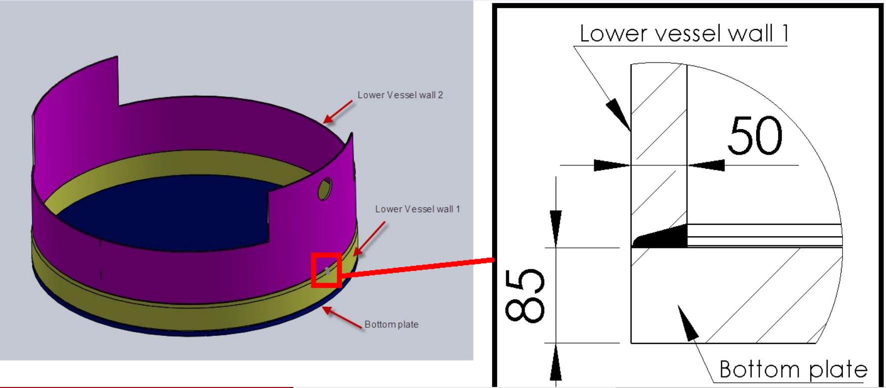
Welding analysis



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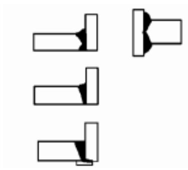

III.1	fillet or T	full penetration	two sides accessible	back weld or back machining
III.2	fillet or T	full penetration	back side inaccessible	gaseous back protection
III.3	fillet or T	full penetration	back side inaccessible	permanent backing strip

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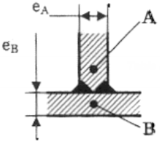
Welding analysis

Table RS 7720 — ***a : class $N2_{Rx}$ shell- vessel welds***
1 : examination of surface to be welded (before welding)

Type		Zirconium X	Aluminium X	Ferritic X	Austenitic X	Non destructive examination	Criteria
1. Butt welded joint (Types I.1, I.2, I.3)	ROLLED FORGED (e ≥ 10 mm)			X		RES or MAG	**RS 7363**
					X	RES	**RS 7363**
	(e ≥ 5 mm)	X	X			RES	**RS 7363**
	CAST			X		RES or MAG	**RS 7363**
	(all thicknesses)		X		X	RES	**RS 7363**
3. Full penetration angle joint (Types III.1, III.2)	PART A (e_A ≥ 10 mm)			X		RES or MAG	**RS 7363**
					X	RES	**RS 7363**
	(e_A ≥ 5 mm)	X	X			RES	**RS 7363**
	PART B all thicknesses			X		RES or MAG	**RS 7363**
			X		X	RES	**RS 7363**
	In addition e_B ≥ 10 mm			X	X	US (2)	**Tome 2**



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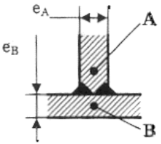
Welding analysis

Table RS 7720 ***a : class $N2_{Rx}$ shell- vessel welds***
2 : examination during weld operations

Type		Zirconium	Aluminium	Ferritic	Austenitic	Non destructive examination	Criteria
1. Butt welded joint (Types I.1, I.2, I.3)	Backing run			X		RES or MAG (1)	**RS 7363**
	Each change of process (RS 7722.11)				X	RES	**RS 7363**
3. Full penetration angle joint (Types III.1, III.2)				X		RES or MAG (1)	**RS 7724.1** **RS 7724.2**
	If neither RAD nor US can be performed on completed weld, examination of root pass and examination every 3 layers during filling up of the weld (RS 7723.1)		X		X	RES	**RS 7724.1**



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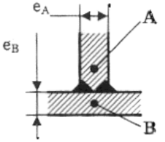
Welding analysis

Table RS 7720 — *a : class $N2_{Rx}$ shell- vessel welds* / *3 : examination after weld operation*

Type		Zirconium	Aluminium	Ferritic	Austenitic	Non destructive examination	Criteria
1. Butt welded joint (Types I.1, I.2, I.3)	All thicknesses :	X	X		X	RES	**RS 7724.1**
	(outer face and inner face when			X		MAG	**RS 7724.2**
	accessible)	X	X	X	X	RAD	**RS 7724.3**
	Additional where e > 50mm			X		US	**RS 7724.4**
	Additional where e > 50mm	X				US(*)	**(*)**
	(*) as per provisions in RS 7721.2						
3. Full penetration angle joint (Types III.1, III.2)	All thicknesses	X	X		X	RES	**RS 7724.1**
				X		MAG	**RS 7724.2**
			X	X	X	RAD (*)	**RS 7724.3**
	(*) If RAD cannot be performed, carry out a US examination (see **RMC 2610** for austenitic steels) If neither RAD nor US can be performed and more particularly for assemblies of flanges and nozzles of internal diameter not exceeding 60 mm see examination during weld operation.						



Conclusions

Main remarks

- The on going activities for the monolith vessel are on schedule for Lower and Medium vessel
- Mechanical analysis shows room for optimization of thicknesses.
- The simplified model for the target has been accepted by ESS for seismic analysis.
- Manufacturing review on going without considering vacuum manufacturing procedures.