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Memorandum / Note

Complementary analyses for TCPH to justify the integrity after design change

This memo is linked to the report ITER_D_TF7JJV - Structural Analysis of Torus Cryo Pump Housing(TCPH) v2.2 . it present additional analyses in order to justify the integrity of TCPH with regards to design changes:- A Reduce of Gussets height- The removal of welds between the inner cylinder and the vertical platesFinally Results provided in this memo are showing : - 20% margin for the plastic collapse of the load combination NO(100KREGEN) + LOCA PC III based on an elasto-plastic analysis. Furthermore the behavior of TCPH become non linear after the load factor 1.2 due to the buckling of vertical shell. At LF=1.2 the maximum radial and toroidal displacement for the vertical shell is 25mm.- A fatigue usage fraction of 0.516 for ribs including an amplification factor of 2.8

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Tailhardat O.**	**25 Jan 2017:signed**	**IO/DG/COO/TED/VSD**
Co-Authors			
Reviewers	**Bhardwaj A.** **Vitupier G.**	**25 Jan 2017:recommended** **26 Jan 2017:recommended**	**IO/DG/COO/TED/VSD** **IO/DG/COO/TED/VSD**
Approver	**Choi C.- H.**	**15 Feb 2017:approved**	**IO/DG/COO/TED/VSD**
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Memorandum

Route de Vinon sur Verdon 13115 Saint Paul lez Durance France www.iter.org

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Ref. Number: ITER_D_U7DB2R
Subject: Complementary analyses for TCPH to justify the integrity after design change

From: Olivier Tailhardat
Department: IO/DG/COO/TED/VSD
Phone: 04 42 17 89 21
E-mail: Olivier.Tailhardat@iter.org

To: Anil Bhardwaj, Guillaume Vitupier

Abstract

The structural integrity for Torus Cryo Pump Housing (TCPH) has been checked in the scope of the Final Design Review and analyses results are included in the reference [1].
In order to improve the design and to ease the manufacturability, the following design changes were implemented:

- A Reduce of Gussets height
- The removal of welds between the inner cylinder and the vertical plates

More details on geometry can be found in Figure 1 to Figure 3.

The integrity of TCPH including these modifications has been assessed and results are documented in the structural analysis report [2] . The conclusion of this report is showing 2.6% margin on the membrane plus bending stress for one load combination in the evaluation of plastic collapse and a Fatigue Usage Fraction (FUF) of 0.8 on ribs for load combination of category I/II.
Given the uncertainty on mesh and the conservatism used for the calculation of peak stress, the purpose of this memo is to cut the conservatism used in the analyses and to re-evaluate the margins against plastic collapse and to calculate the peak stress using sub-modelling techniques including 10mm fillet welds in order to demonstrate that additional margin can be achieved.

Table 1 Summary results extracted from conclusion of reference [2]

Type of damage	Type of analysis	Load combination	Category	Results	Margin
Plastic Collapse	Elastic	NO (100K REGEN) + LOCA_PC III	III	Pm=40.3MPa Pm+Pb=189.3MPa	68.9% 2.62%
Fatigue	Elastic	-	I-II	FUF=0.808	20%

Warning

Due to time constraints, this memo covers the evaluation of margin for one particular load combination for the plastic collapse and the calculation of fatigue usage fraction for the rib. The evaluation for all load combination an all other damages except these two particular case can be found in reference [2] .

Purpose

The purpose of this memo is to benchmark the TCPH model provided with the report given in reference [2] and more particularly to check the result for plastic collapse of situation NO (100K REGEN) + LOCA_PC III and fatigue. This memo includes the verification of:

- The mesh with mesh sensitivity analysis;
- Axisymmetric boundary conditions used for the calculation of seismic loads

Description of the FE model/analysis

The geometry used for these analyses is similar to the one detailed in reference [2] . It includes:

- half geometry of TCPH and Cryostat (Sector of 10°)
- half geometry for Torus Cryo Pump, VV port duct bellow and surface of port duct extension facing TCPH represented in a simplified manner with shell to account for radiation heat transfer with TCPH.
- half geometry of Cryostat Wall flange
- half geometry of inner cylinder
- half geometry of interface flange
- The removal of stiffener included in reference [2]

The FE model is completely re meshed for the purpose of analyses with solid element for TCPH and Cryostat.

Note: The mass of TCP 8tons is included in the structural analysis with one mass element. The mass element is connected to the interface flange and located at 2.022m from the Cryostat Wall Flange.

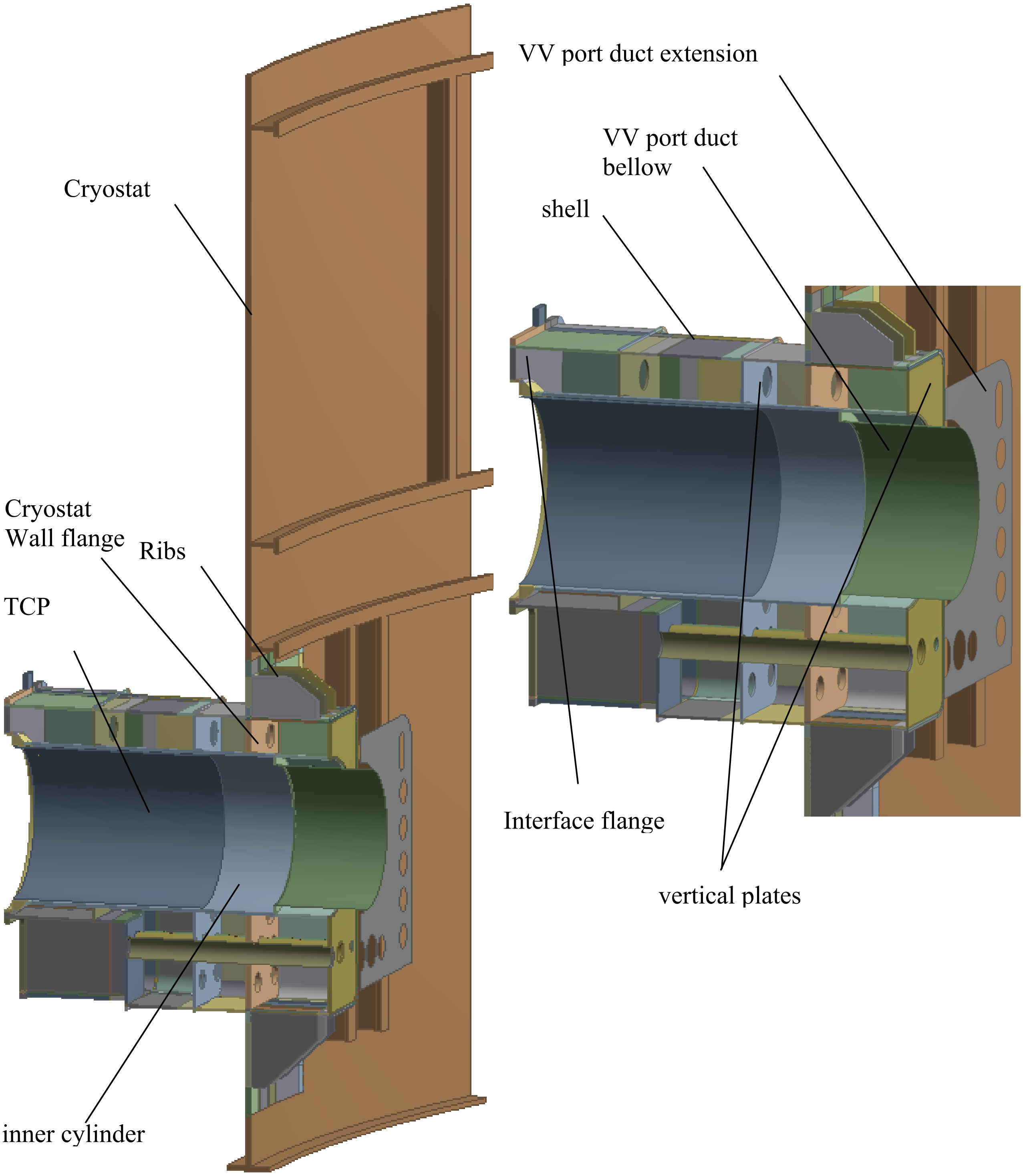
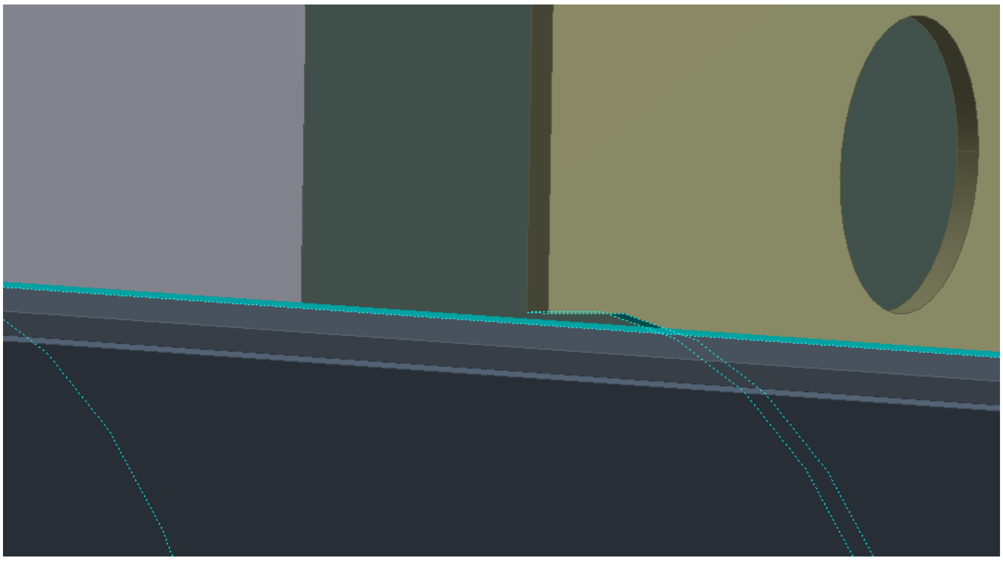
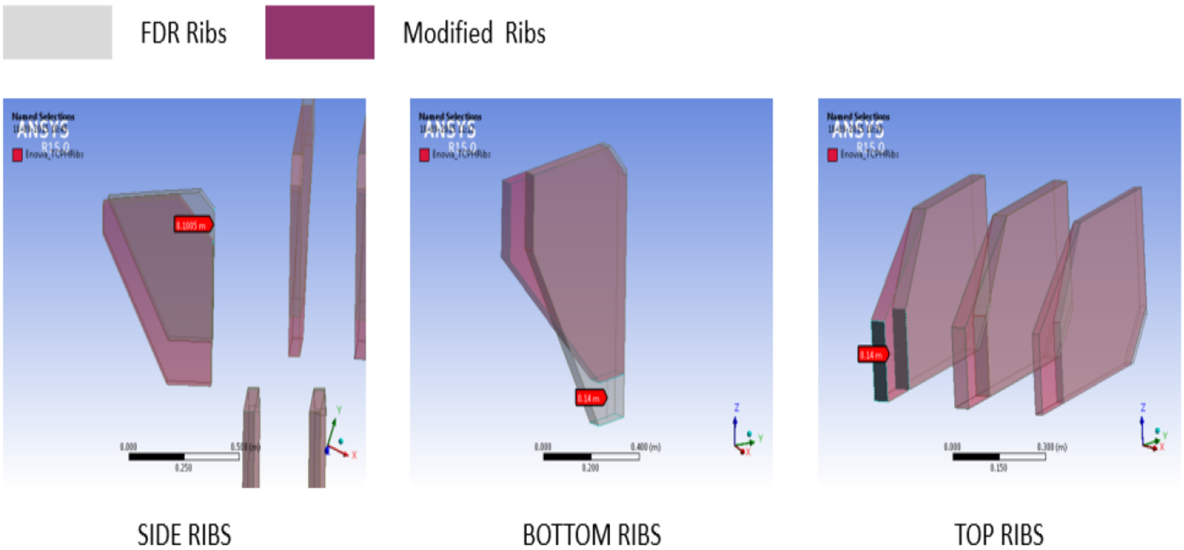


Figure 1 Geometry used for FE analyses



a) removal of welds between vertical plates and inner cylinder (10mm gap between light blue surfaces)



b) Modification of ribs

Figure 2 Details of modification provided to the geometry after TCPH FDR

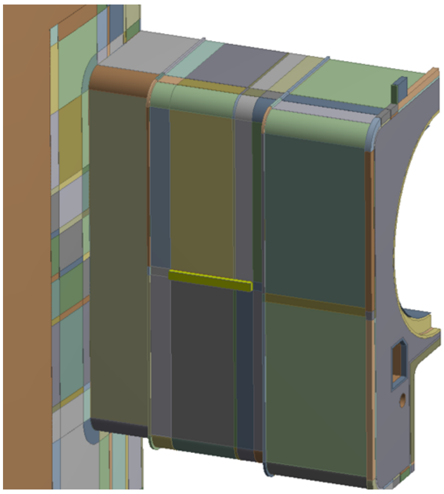


Figure 3 Ribs highlighted in yellow, not included in the geometry

Symmetric boundary conditions (Uy=Rotx=Rotz=0) are applied for DW, thermal loads pressure load and vertical seismic loads whereas antisymmetric boundary conditions (Ux=Uz=Roty=0) are applied for seismic horizontal loads acting along the toroidal direction Y. The surfaces where these boundary conditions are applied are highlighted in blue on Figure 4.

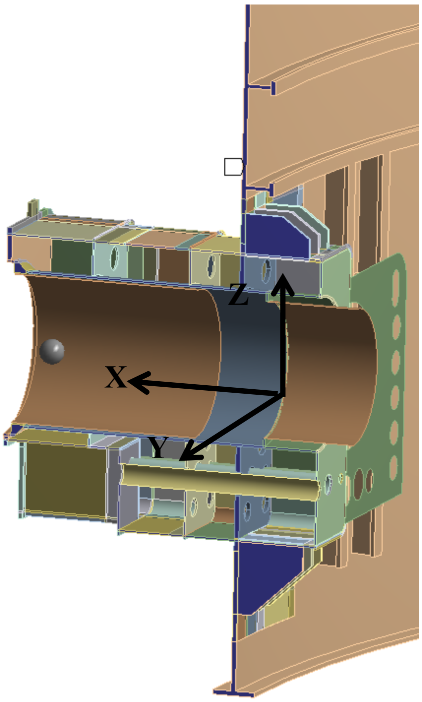


Figure 4 Symmetric or Antisymmetric Boundary conditions

Vertical displacement is fixed (Uz=0) on the top and bottom surface of cryostat, respectively A (on VSS) and B on Figure 5. Toroidal displacement is fixed on surface C

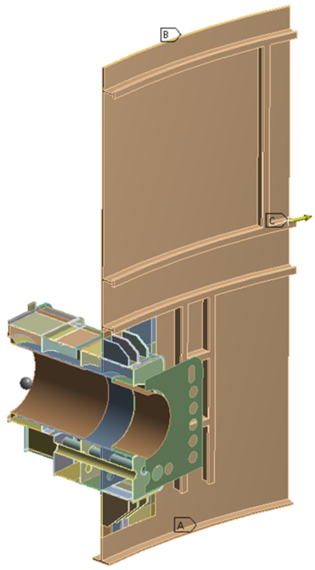


Figure 5 Boundary conditions applied on the model

Loads

The loads summarized from Table 2 to Table 4 are extracted from reference [1] these tables are reminded for information.

Table 2 Thermal loads

<table>
<tr><th rowspan="2"></th><th rowspan="2">Cat</th><th rowspan="2">Port duct Wall temperature [°C]</th><th rowspan="2">TCP casing temperature [°C]</th><th rowspan="2">TCP flange temperature[°C]</th><th colspan="3">Environment temperature [°C]</th></tr>
<tr><th>VV</th><th>Cr</th><th>PC</th></tr>
<tr><td>Maintenance</td><td>I</td><td>25</td><td>25</td><td rowspan="16">12</td><td>25</td><td rowspan="12">25</td><td rowspan="12">25</td></tr>
<tr><td>NO</td><td>I</td><td>110</td><td>-23</td><td>110</td></tr>
<tr><td>NO (100K REGEN)</td><td>I</td><td>110</td><td>-28</td><td>110</td></tr>
<tr><td>VV BK</td><td>I</td><td>200</td><td>-23</td><td>200</td></tr>
<tr><td>VV BK (100K REGEN)</td><td>I</td><td>200</td><td>-28</td><td>200</td></tr>
<tr><td>VV ICEII</td><td>II</td><td>110</td><td>-23</td><td>127</td></tr>
<tr><td>NO (100K REGEN) + VV ICEII</td><td>II</td><td>110</td><td>-23</td><td>127</td></tr>
<tr><td>NO (470K REGEN)</td><td>II</td><td>110</td><td>127</td><td>110</td></tr>
<tr><td>NO + VV ICE III</td><td>III</td><td>200</td><td>-23</td><td>27</td></tr>
<tr><td>NO (100K REGEN) + VV ICEIII</td><td>III</td><td>200</td><td>-28</td><td>27</td></tr>
<tr><td>NO + VV ICEIV</td><td>IV</td><td>200</td><td>-23</td><td>27</td></tr>
<tr><td>NO (100K REGEN) + VV ICEIV</td><td>IV</td><td>200</td><td>-28</td><td>27</td></tr>
<tr><td>NO + LOCA PC III</td><td>III</td><td>200</td><td>-23</td><td>200</td><td>120</td><td>120</td></tr>
<tr><td>NO (100K REGEN) + LOCA PCIII</td><td>III</td><td>200</td><td>-28</td><td>200</td><td>120</td><td>120</td></tr>
<tr><td>NO (100K REGEN) + Cr ICE II</td><td>II</td><td>110</td><td>-28</td><td>110</td><td>-88</td><td rowspan="2">25</td></tr>
<tr><td>NO (100K REGEN) + Cr ICE III</td><td>III</td><td>110</td><td>-28</td><td>110</td><td>-95</td></tr>
</table>

NO (100K REGEN) + Cr ICE IV	IV	110	-28		110	-95	

Table 3 Seismic acceleration multiplied by 1.5

	Estimated Horizontal Acceleration [m.s-2]	Estimated Vertical Acceleration [m.s-2]
SL-2	10.05	6.75
SMHV	7.29	4.39
SL-1	3.42	2.29

Table 4 Pressure loads

	Cat.	**TCP valve head status**	**Internal Pressure [kPa]**			
			VV	**TCP/TCPH**	**PC**	**Cr**
Maintenance	I	NA	100	100	100	100
NO (100K REGEN)	I	close	0	0	100	0
NO (100K REGEN) + VV ICEII	II	close	106	0	100	0
NO (100K REGEN) + VV ICEIII	III	close	150	0	100	0
NO (100K REGEN) + VV ICEIV	IV	close	200	0	100	0
NO (100K REGEN) + LOCA PC III	III	close	150	0	160	0
NO + Cr ICE II	II	open	0	0	100	31
NO + Cr ICE III	III	open	0	0	100	156
NO + Cr ICE IV	IV	open	0	0	100	247

The load combination analysed for the purpose of this memo is summarized in Table 5

Table 5 Relevant Load Combination

Load combination	Load category	Verification against
NO (100K REGEN) + LOCA PCIII	III	Plastic collapse
NO (100K REGEN) + CRICEII	II	Fatigue
NO(100KREGEN)	II	
VV BK(100K REGEN) + CRICEII	II	
BK(100K REGEN)	II	
VV BK(100K REGEN) + VVICEII	II	
VV BK	II	
NO(470K REGEN)	II	
NO	I	
DW	I	

Note: the load combination used for the evaluation of fatigue are extracted from the worst loading history given in reference [2] .

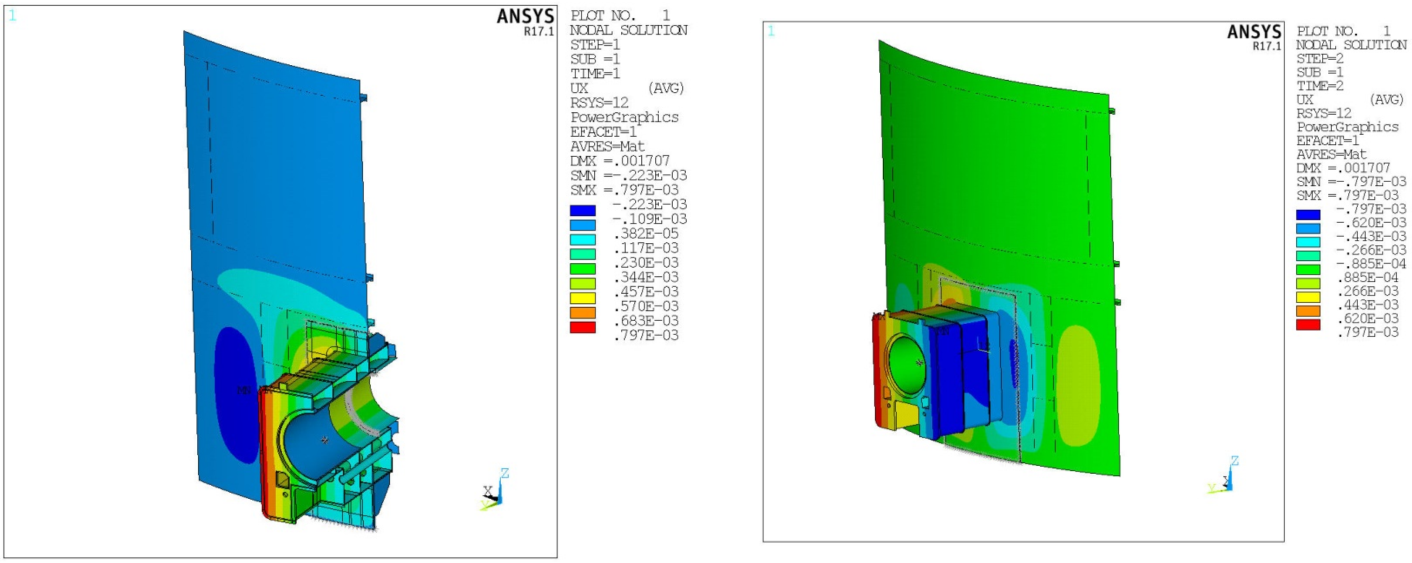
To check the margin against plastic collapse with an elasto-plastic analysis, the load combination extracted from table 5.5 of ASME VIII D2 2010 corrected by factor 1.2 for service level C is used:

- (2.4/1.2)*(P+D)

Discussion on model

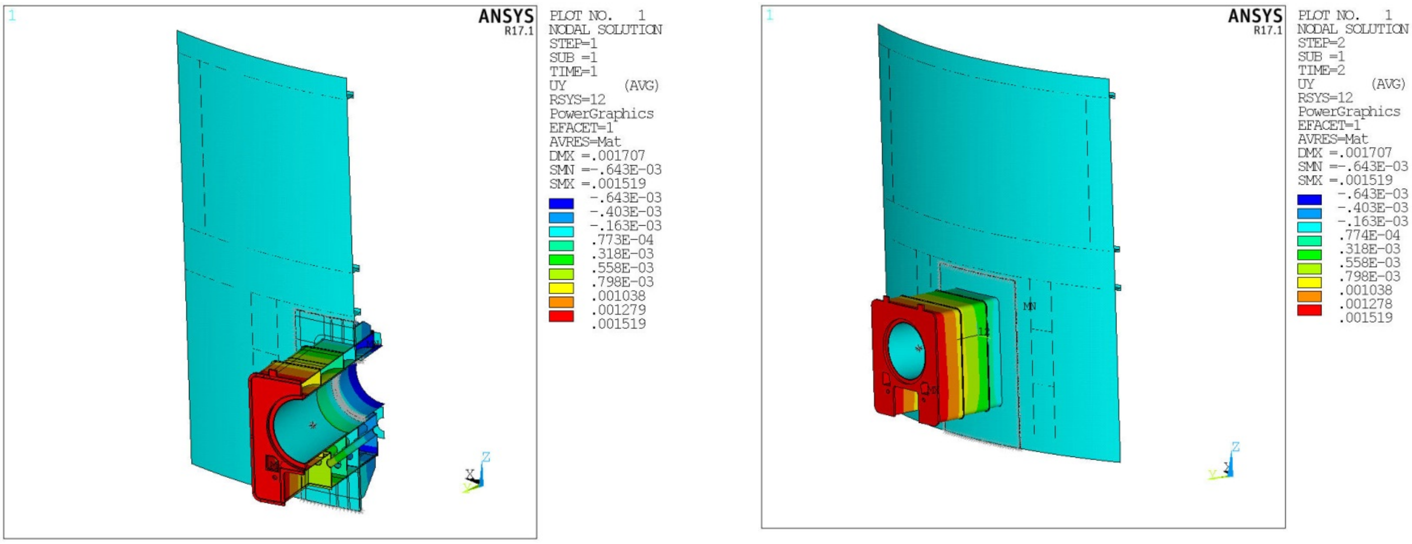
Impact of Boundary Conditions

The full model of TCPH is built with a symmetry of the mesh built for the half model in order to check the validity of using antisymmetric boundary conditions for horizontal seismic loads. Both models are showing similar displacement and stress results on Figure 6 to Figure 9 as a result the validity of using half model for asymmetric loads is verified.



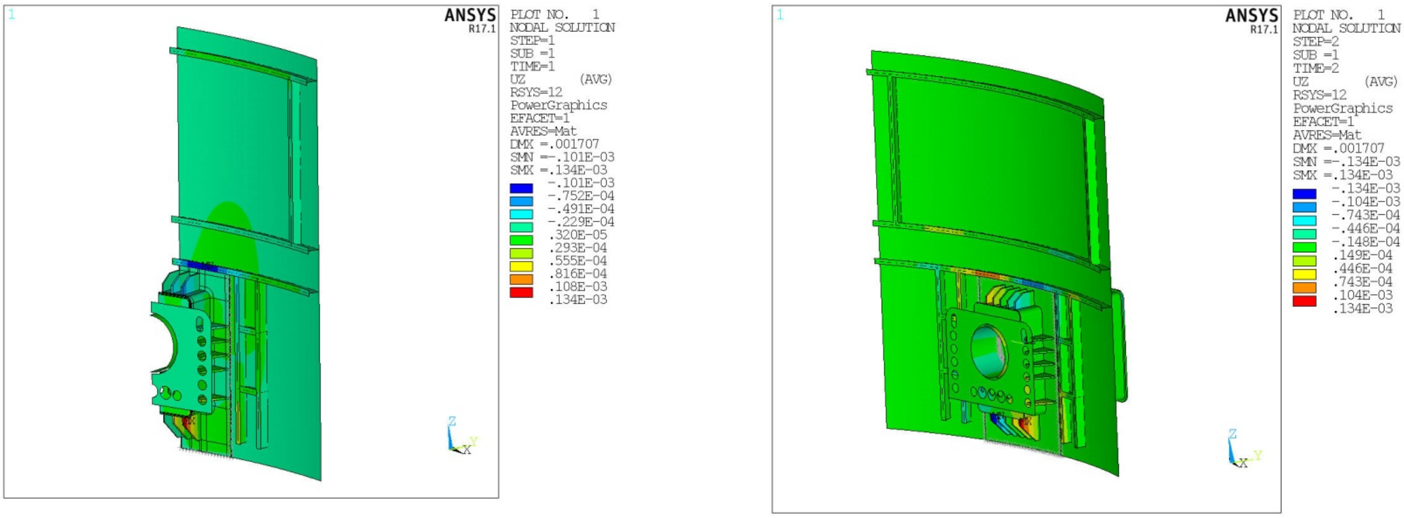
a) half model b) full model

Figure 6 Radial displacement [m]



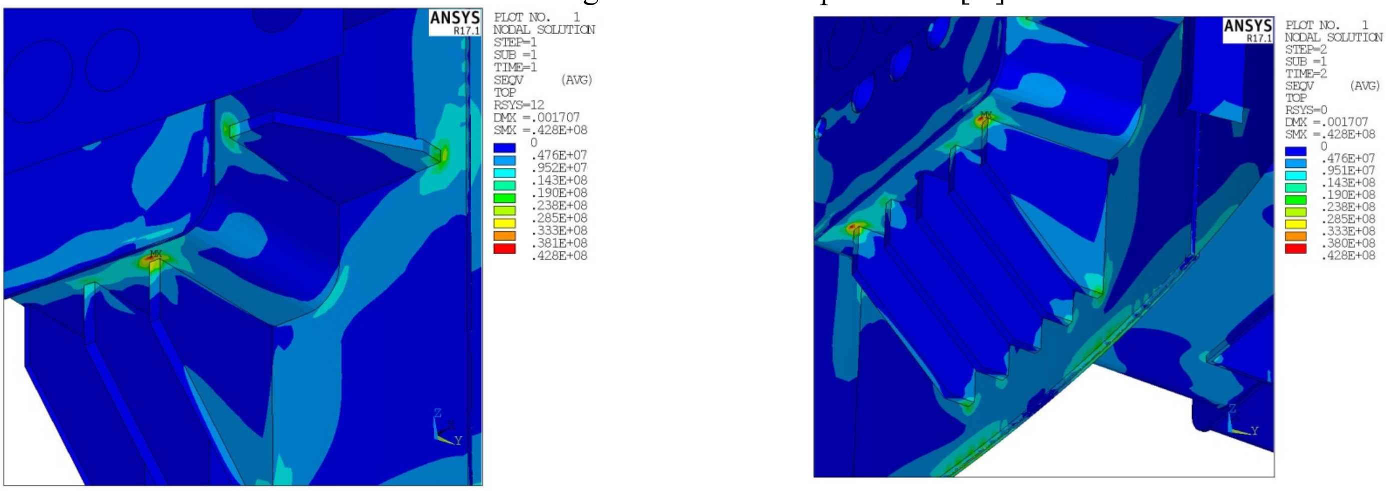
a) half model b) full model

Figure 7 Toroidal displacement [m]



a) half model b) full model

Figure 8 Vertical displacement [m]



a) half model b) full model

Figure 9 Von Mises total stress [Pa] (/GRAPHICS,FULL)

Impact of Mesh sensitivity analysis

A mesh sensitivity analysis has been performed in order to check the validity of the results for the situation NO (100K REGEN) + LOCA PCIII. The driving parameter is the pressure in the Port Cell and the critical area is the shell of TCPH. For the purpose of this study only pressure in the Port Cell has been applied. Figure 10 show a maximum membrane + bending stress of 207MPa whereas the membrane plus bending stress from the table 7 of reference [2] is 187 MPa for the same load combination. A multiplication factor of 1.1 shall be considered on the results given in reference [2] to account for the mesh sensitivity analysis and the margin provided in reference [2] are recalculated in .Results for the plastic collapse of the situation NO (100K REGEN) + LOCA PCIII obtained with an elastic analysis is over the allowable limit.

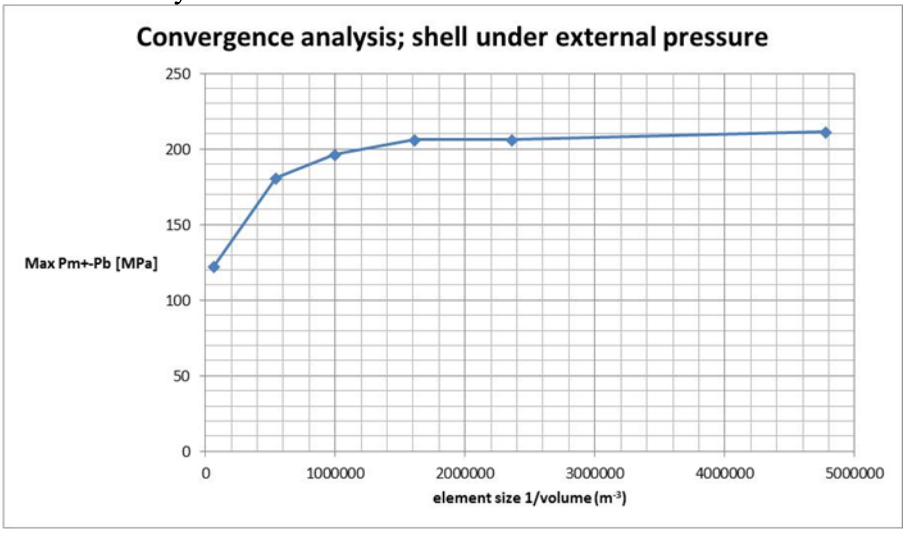


Figure 10 Convergence of Von Mises stress on shell, NO (100K REGEN) + LOCA PCIII

Table 6 Evaluation of margin with an additional multiplication factor 1.1 on result from reference [2]

		Minimum margin [%]	
Damage type	Type of verification	From reference [2]	Including multiplication factor 1.1 on stresses
Plastic collapse	Pm	63	60
	Pm+Pb	2.6	**-7.11**
Local failure	S1+S2+S3	19	11
Ratcheting	P+Q	30	3

Impact of fillet weld on gussets

A submodel of the ribs including 10mm fillet has been built in order to determine the amplification factor due the fillet for the calculation of peak stress in the fatigue evaluation. The ANSYS FE models and set of results files related to NO(100KREGEN) + CRICE II have been uploaded to the analysis database. The ratio between the peak stress and the linearized stress is 1143/416=2.8 this result is consistent with the previous analyses presented in reference [1]. This ratio corresponds to the amplification factor of 10mm fillet. This factor will be applied on the linearized stress further in this report to calculate the peak stress for all the load combination.

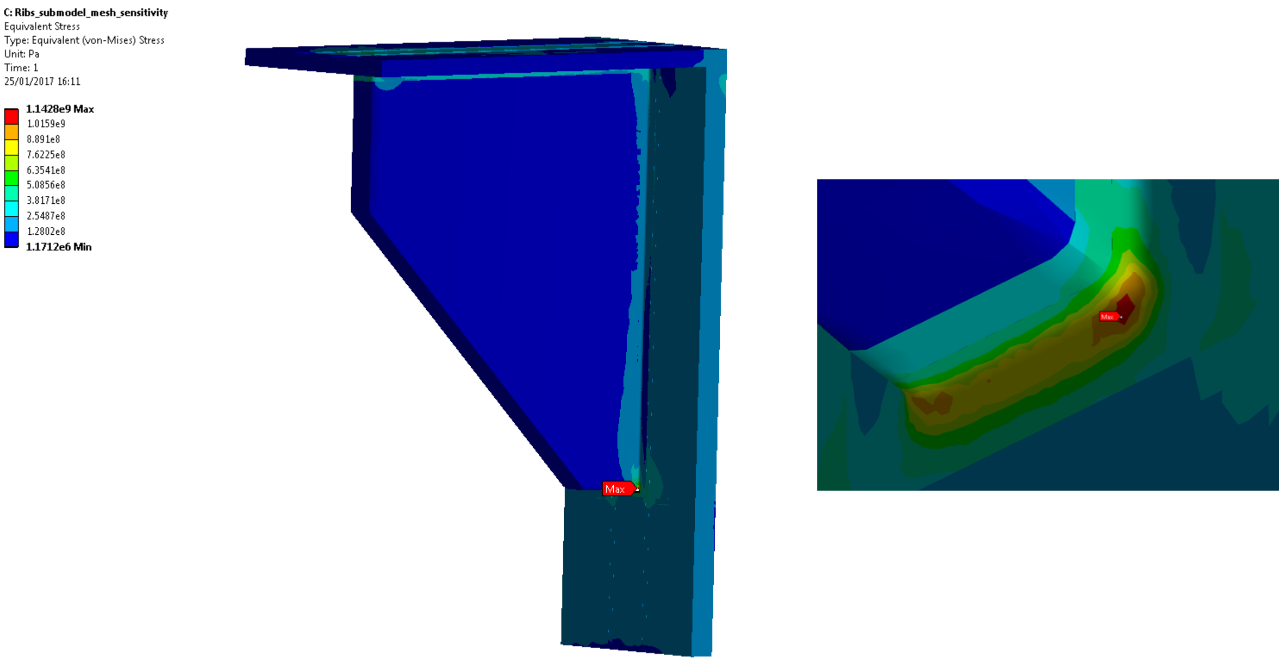


Figure 11 Von Mises peak stress in the rib; 1143MPa

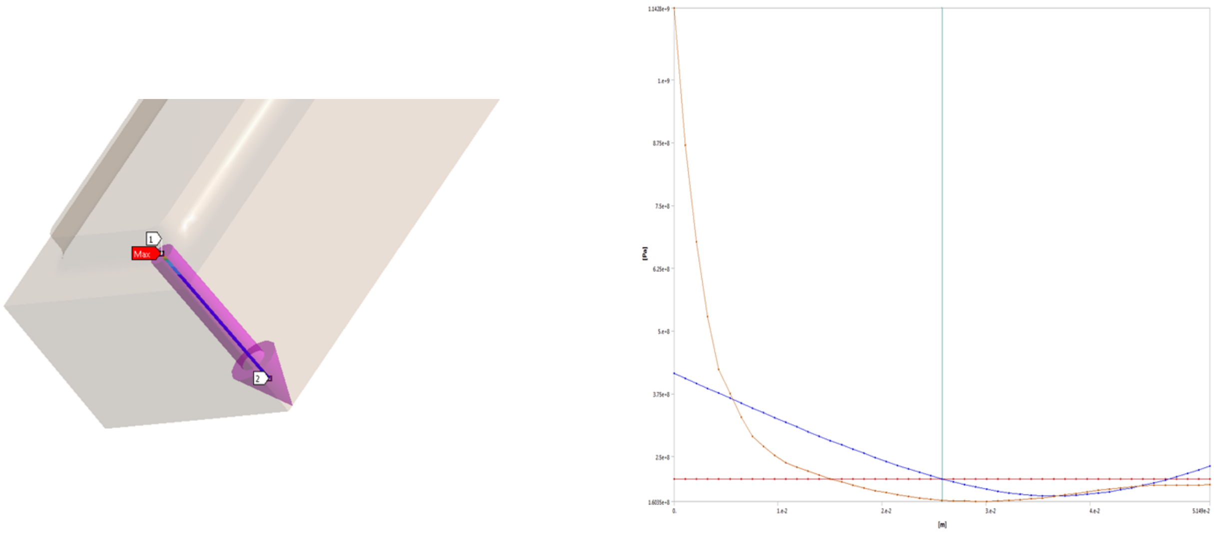


Figure 12 Von Mises linearized stress Pm+Pb+Q=416MPa

Result

Plastic collapse NO (100K REGEN) + LOCA PCIII

The plastic collapse is verified with an elasto-plastic analysis. External pressure and Dead Weight are continuously increased until the collapse of analysis or the first met bisection. The displacements are plotted at two particular areas, one area is relevant for the evolution of the radial displacement, see Figure 13, another area is relevant for the toroidal displacement, see Figure 14. The linear behaviour of TCPH is guaranteed until the load factor 1.2, see Figure 15, therefore the plastic collapse is verified with 20% margin and the maximum Von Mises strain is 1.2%, see Figure 16. The evolution of Von Mises strain is given in Figure 17

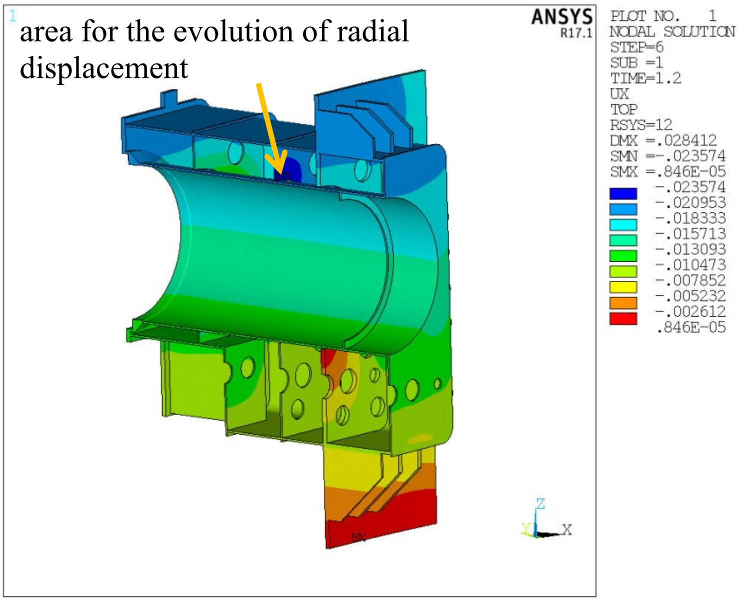


Figure 13 Evolution of the radial displacement

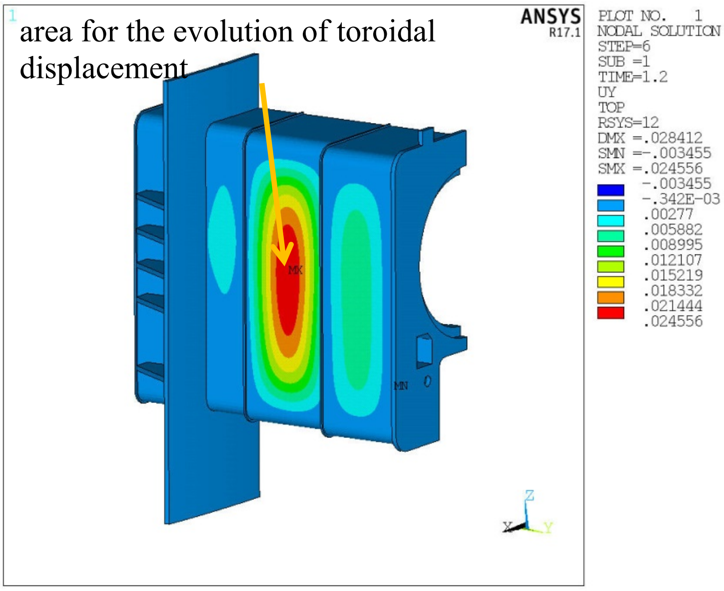


Figure 14 Evolution of the toroidal displacement

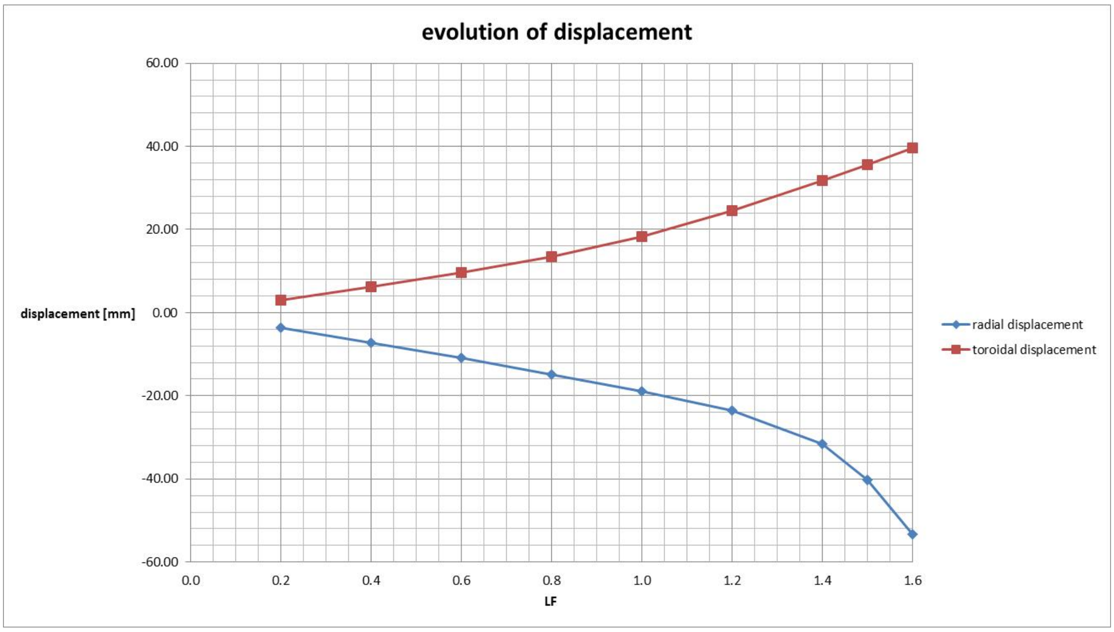


Figure 15 Evolution of the radial and toroidal displacement [mm]

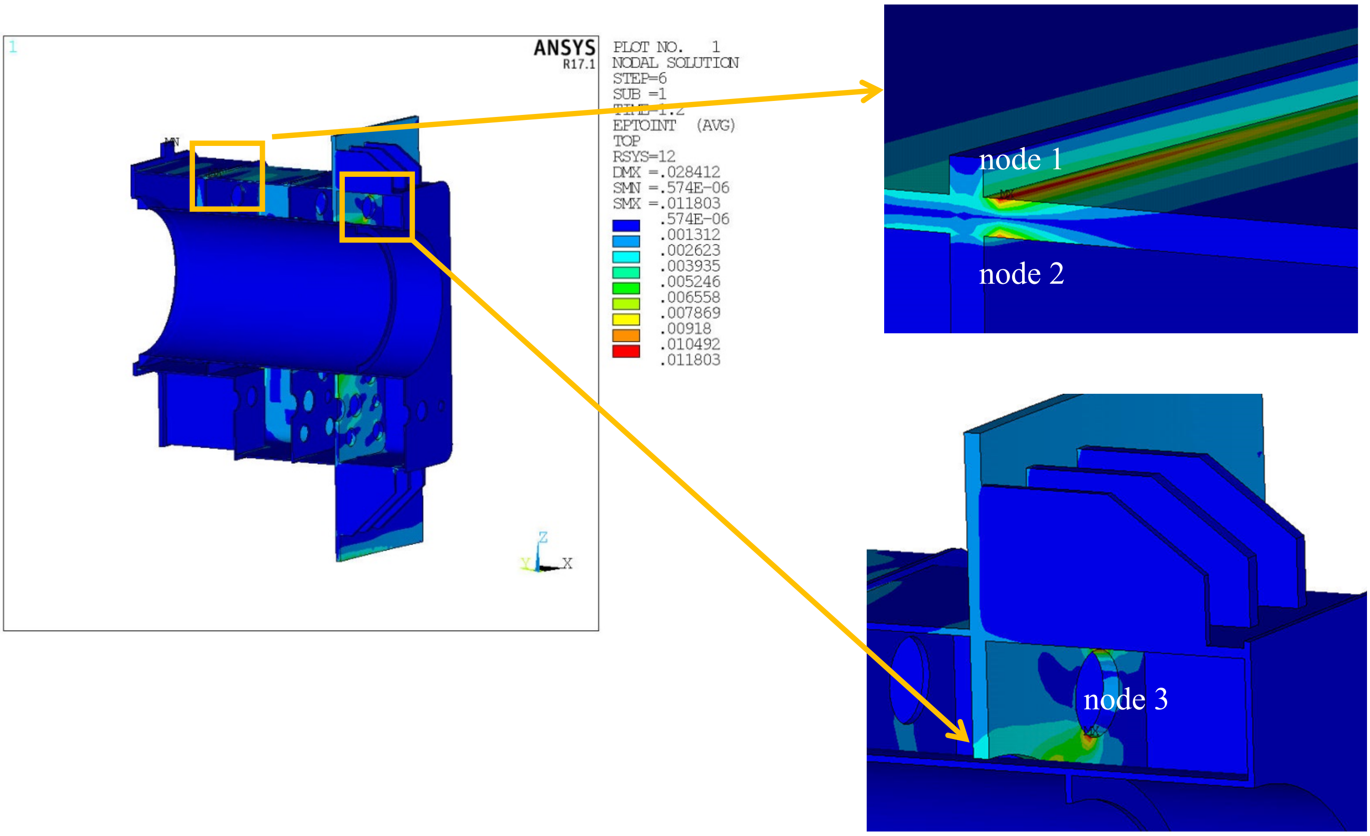


Figure 16 Von Mises strain at load factor 1.2

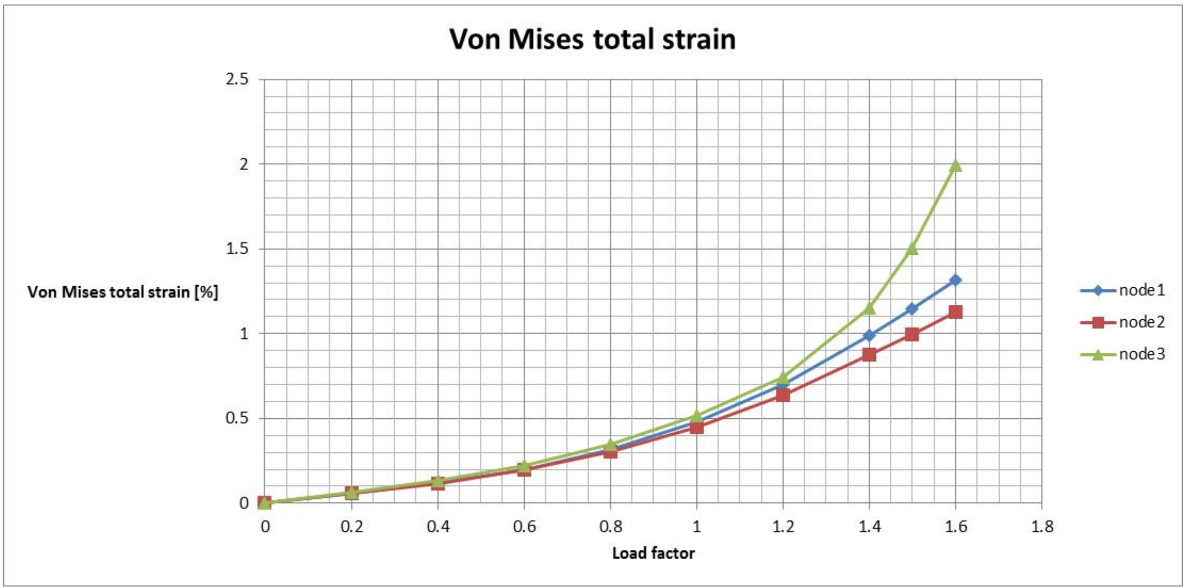


Figure 17 Evolution of Von Mises strain for three particular nodes

Evaluation of fatigue on ribs

The fatigue usage fraction for ribs is calculated from a worst loading history. It corresponds to the combination of cycles which gives the highest stress range. The linearized stress range is multiplied by 2.8 in order to calculate the peak stress ΔSp,k as discussed above. The worst loading history has been extracted from reference [2] and it is reminded in Table 7. The maximum fatigue usage fraction calculated for the ribs is 0.516.

Table 7 Worst loading history from reference [2]

Worst history		ΔSn,k	ΔSp,k	state	Cycles 1	2	3	4	5	6	7	8
DW + QBK+QCRICE+PCRICE	NO(100KREGEN)+CrICE	344	962	8								
DW + QBK+QVVICE+PVVICE	NO(100KREGEN)+SL1	132	368	7								
DW + QNO+Q100KREGEN+ASL1	BK(100KREGEN)+VVICE	98	276	6								
DW + QNO+Q470KREGEN+QVV	BAKING	93	260	5								
DW + QNO	NO(470KREGEN)	93	260	4								
DW + QBK	NO(100KREGEN)	93	260	3								
DW + QNO+Q100KREGEN	BAKING(100KREGEN)	92	259	2								
DW + QBK+Q100KREGEN	NO	92	259	1								
DW	DW	35	97	0								
Cycles					300	500	50000	1000	500	15	50	15

Table 8 Stress range matrix from reference [2]

Stress range tensor											
i/j			0	1	2	3	4	5	6	7	8
	Value		97	259	259	260	260	260	276	368	962
		number of cycles	800	51300	515	50065	1000	1000	15	50	15
0	97	800		163	163	163	163	163	170	133	682
1	259	51300			0	1	1	1	12	143	545
2	259	515				0	1	1	12	143	545
3	260	50065					0	0	12	143	545
4	260	1000						0	11	143	544
5	260	1000							11	143	544
6	276	15								148	533
7	368	50									669
8	962	15									

Table 9 Fatigue Evaluation for ribs

Fictitious cycle	FU fictitious cycle								
	ΔSn,k [MPa]	ΔSp,k [MPa]	$K_{e,k}$	Salt,k [MPa]	Y	X	Nk	nk	FU
1	750	2101	3.33	3501	508	1	30	15	0.492
2	163	456	1.00	228	33	5	49926	15	0.000
3	187	524	1.00	262	38	4	31455	15	0.000
4	179	502	1.00	251	36	5	36198	770	0.021
5	1	3	1.00	2	0	7	30207323	230	0.000
6	1	3	1.00	2	0	7	30207323	1000	0.000
7	1	3	1.00	2	0	7	30207323	49070	0.002
8	0	0	1.00	0	0	8	32929774	515	0.000
								sum	**0.516**

Conclusion

Structural Integrity of TCPH is verified and results are included in reference [2] nevertheless the current stress analysis report gives low margin for the plastic collapse of one load combination and a high fatigue usage fraction on ribs.

The purpose of this memo is to benchmark the FE model of TCPH including boundary conditions, mesh sensitivity analysis and the stress amplification factor due to the fillet weld on ribs
The validity of using the half geometry of TCPH with asymmetric boundary conditions has been proven thanks to the comparison with the full model of TCPH.
The mesh sensitivity analysis showed that a multiplication factor of 1.1 must be applied on the results provided in reference [2] as a results stresses for the plastic collapse of NO(100KREGEN) +LOCA PC III are over the allowable limits with an elastic analysis.
The stress amplification factor has been calculated with a local submodel of ribs. This analyses shown that the peak stress for fatigue evaluation can be calculated with the linearized stress multiplied by a ratio 2.8 instead of 4

Finally Results provided in this memo are showing :

- 20% margin for the plastic collapse of the load combination NO(100KREGEN) + LOCA PC III based on an elasto-plastic analysis. Furthermore the behavior of TCPH become non linear after the load factor 1.2 due to the buckling of vertical shell. At LF=1.2 the maximum radial and toroidal displacement for the vertical shell is 25mm.
- A fatigue usage fraction of 0.516 for ribs including an amplification factor of 2.8

Reference

[1] TCPH structural Analysis report FDR design ITER_D_Q4P42N v2.0
[2] Structural Analysis of the Torus Cryo Pump Housing ITER_D_TF7JJV v2.2