SUMMARY

1. REVISION RECORD

DESCRIPTION	REVISION	DATE and AUTHOR
Creation	A	21/11/2014-SA-AP
Update	C	31/03/2015-SA-AP

2. ABSTRACT

The Dipole SHMS outer vessel mechanical stress is calculated by finite element analysis (FEA). The calculation considers the worst case scenario which includes the combination of maximum reaction forces exerted by the suspension links, the dead weight and the horizontal acceleration provided by the magnet moving girder.

The outer vessel is Designed by Analysis (DBA). As the pressure is limited to 1 bar outside and vacuum inside the vessel the ASME Boiler and Pressure Vessel Code (ASME BPVC) is not required. For convenience we will use the maximum allowable stress criteria as defined by the ASME BPVC to validate the design.
This report presents the FEA analysis made by Sigmaphi. The shells thicknesses are optimized wherever it is possible to reduce the weight and ease the welding. The main modifications are the outer shell thickness 25 mm (JLAB Reference design) which becomes 15 mm and the inner shell thickness 10 mm (JLAB reference design) which becomes 8 mm. The details of the suspension links attachment are also modified compared to the JLAB reference design in order to reduce the peak stresses.

The vacuum vessel mechanical design as proposed by this report complies with the ASME BPVC maximum allowable stress requirement and is validated.

We conducted a surface model and a solid model on areas where constraints are strongest.

3. FEA Software

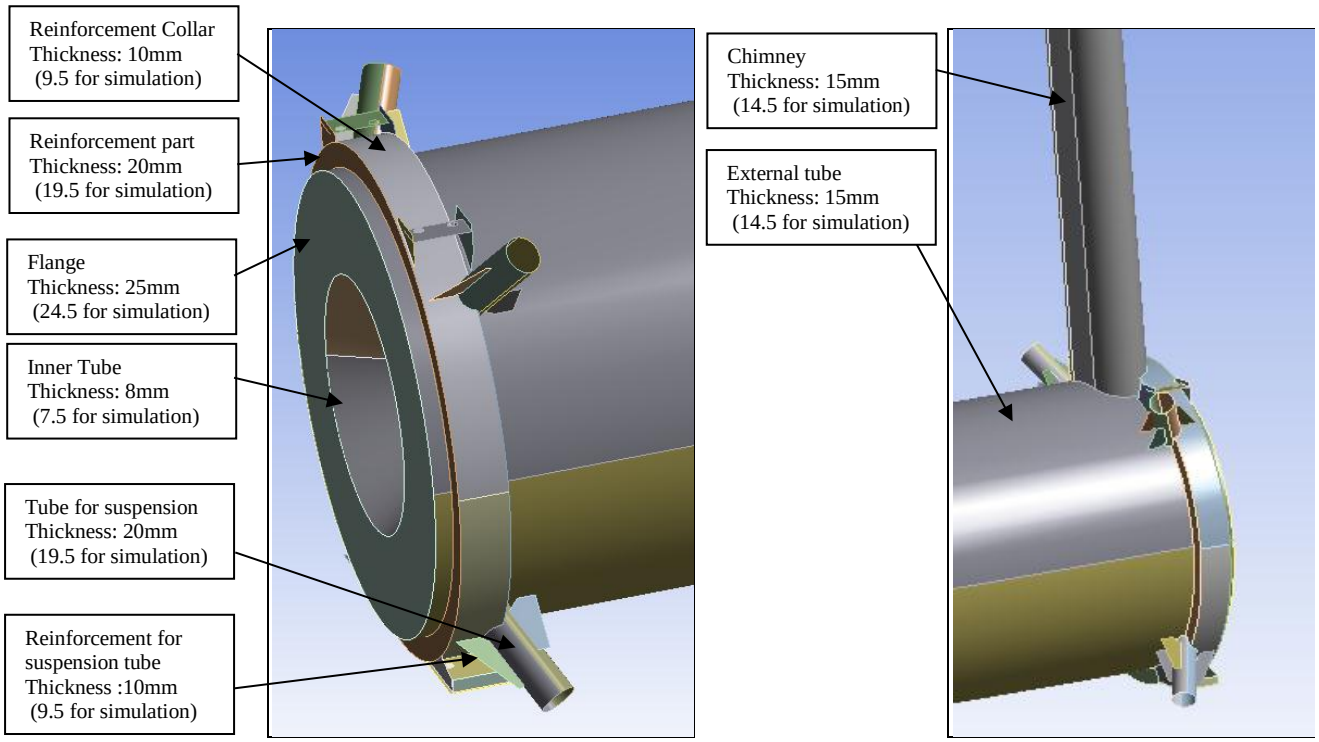
The FEA software used is ANSYS 15.0 Mechanical (Ansys Professional NLS)

4. USER'S DESIGN SPECIFICATION

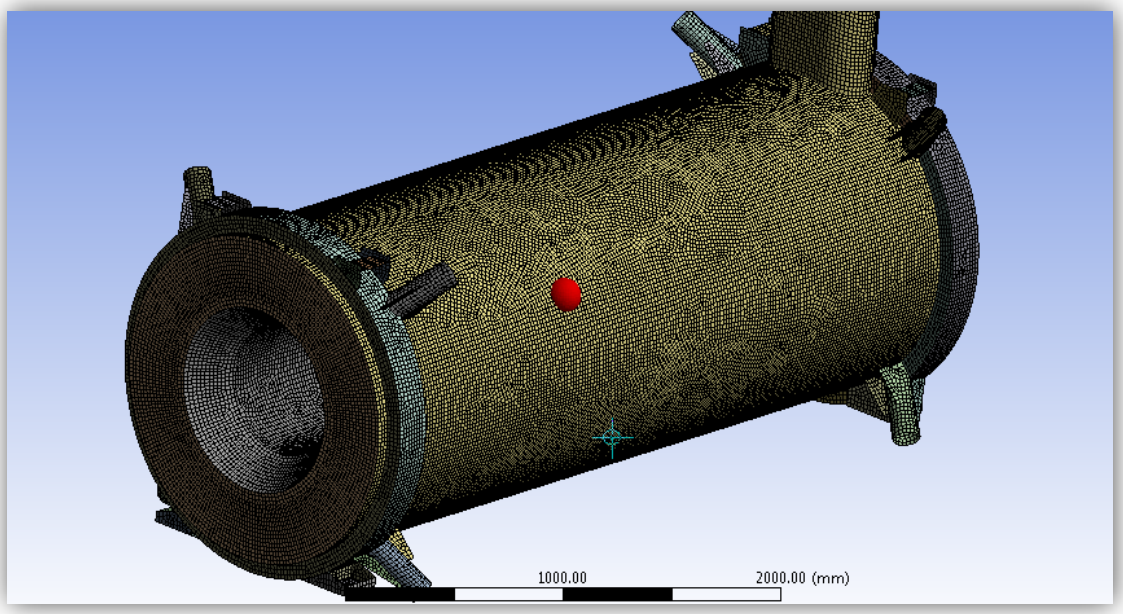
The user's specification is given below.

- Fluid: Vacuum
- Drawings : 317111-JLA-701-001-revD.PDF and 317111-jlab-outer V12-membrane.PDF
- Operating temperature: 20°C
- Thermal stress : none
- Design pressure: vacuum inner (≤ 10-4 mbar), 1 atm outer (0,1 MPa)
- Lateral Acceleration 1G (9806.6mm/s²)
- Gravity (9806.6 mm/s²)
- External forces:
  - Suspension Links maximum reaction: 1,68.E5 N (16800daN " Reaction force of the He Vessel simulation (the coil weight and acceleration and gravity, temperature, pressure)")

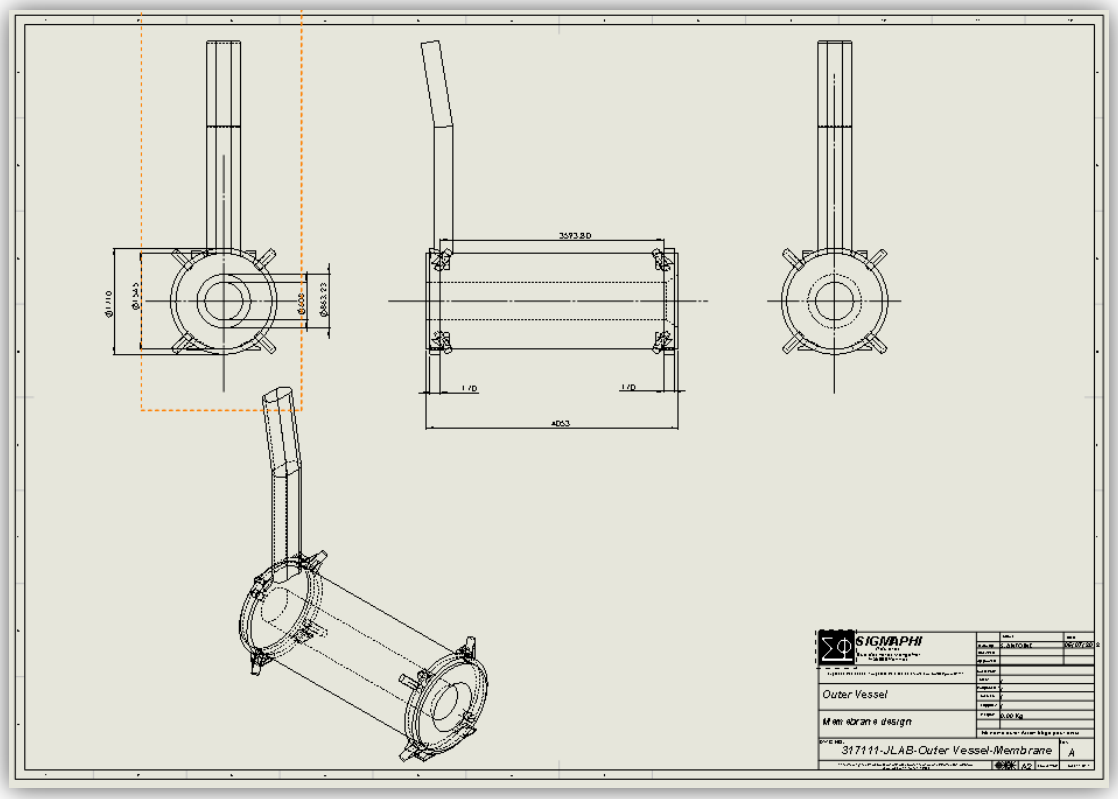
5. FEA MODEL GEOMETRY AND MESHING



All shell thicknesses for Ansys model were reduced by 0.5mm in order to take into account the material tolerances (figures in bracket).
The chimney of the vacuum vessel is studied in details in another report: this chimney has been reinforced in order to decrease its deformation.

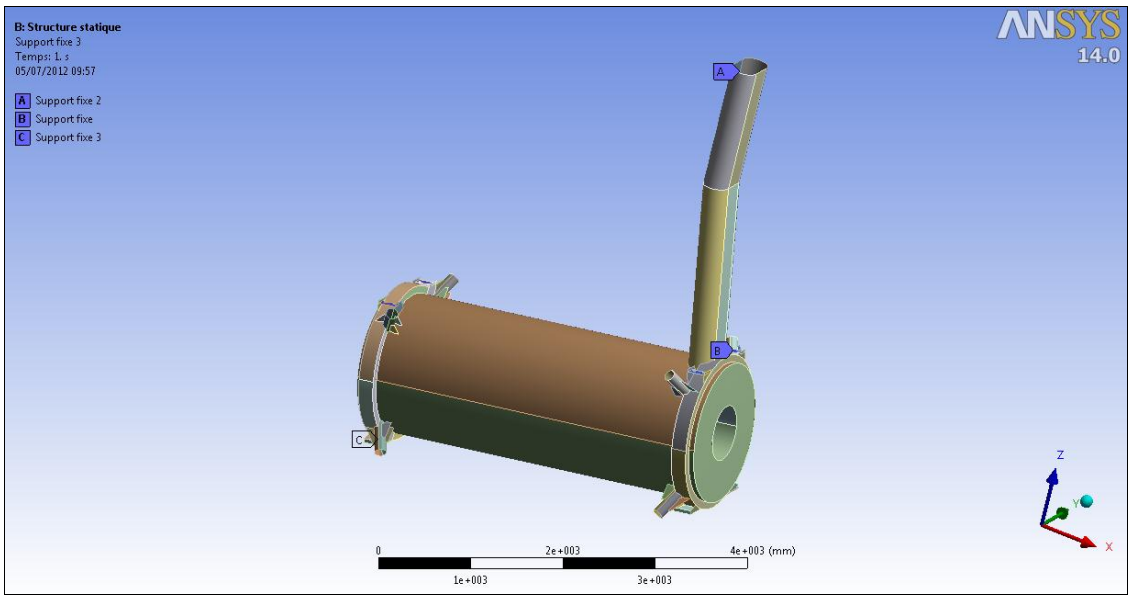


Mesh



Cad View (Membrane dimensions)

6. FEA MODEL CONTACT AND BOUNDARIES CONDITIONS



We apply a fixed support to the 8 feet and a fixed support to the top of the chimney.

7. FEA MODEL MATERIALS

The maximum allowable stress S is based on ASME Section VIII UG23 , UHA 23 and Section II Part D for the parts in stainless steel in contact with the pressure .

The properties used for each material are given hereafter. The outer vessel operates only at room temperature therefore the properties at low temperature are given only for completeness but are not required for the model solving.

- *Vessel 304L*

Material: 304L - UNS No. S30403 - Nominal composition: 18Cr-8Ni
According to ASME Section VIII Division I, UG23, High Alloy Steel UHA 23, Materials Section II Part D
Allowable Specifications:

- Plates: SA-240
- Welded tube: SA-249, SA-688,
- Seamless pipe: SA-312
- Welded pipe: SA-312, SA-358,SA-409, SA-813, SA-814
- Bar: SA-479
- Note: Forging product form is not used for this vessel

Max Allowable Stress S at 20°C: **S=115 MPa** (16,7 ksi)

Expansion coefficient and young modulus as a function of temperature:

Stainless steel 304 L

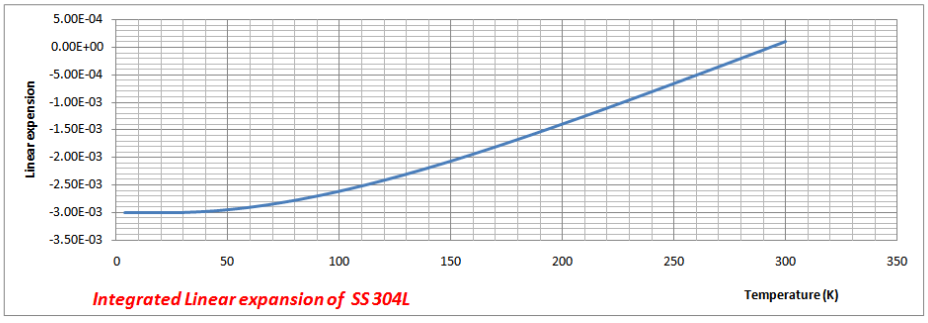
		SS 304	SS 304
	DL/L*10^5	units: GPa	units: GPa
a	-2.96E+02	2.10E+02	2.10E+02
b	-3.98E-01	1.22E-01	1.53E-01
c	9.27E-03	-1.15E-02	-1.62E-03
d	-2.03E-05	3.61E-04	5.12E-06
e	1.71E-08	-3.02E-06	-6.15E-09
T	23	5-57	57-300

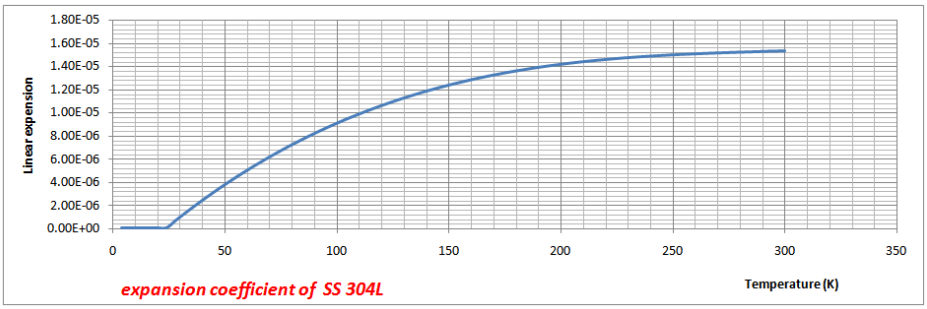
Density	7900 Kg/m3

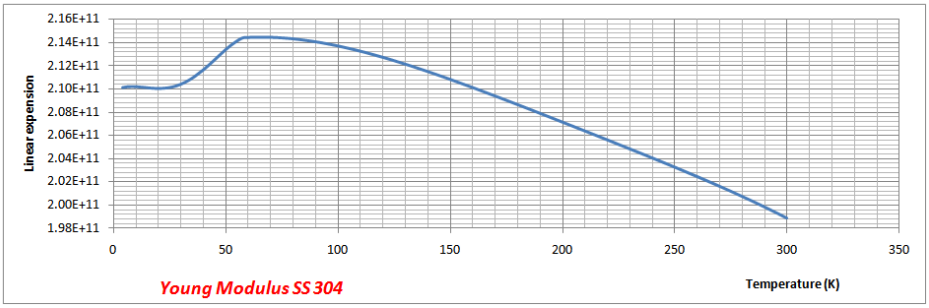
Equation of the form	
$y = a + bT + cT^2 + dT^3 + eT^4$	T≥Tlow(23°K)
y=f	T<Tlow(23°K)

**References for this material: http://cryogenics.nist.gov*

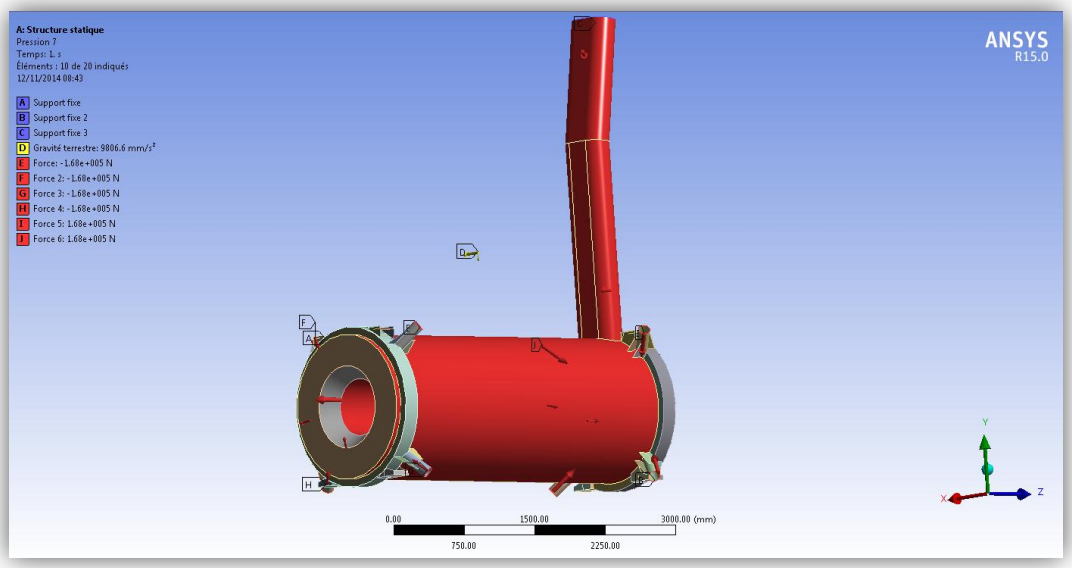
Equation of the form - Integrated coefficient	
$dy/dT = b + 2.cT + 3.dT^2 + 4.eT^3$	T≥Tlow(23°K)
dy/dT=0	T<Tlow(23°K)







8. FEA MODEL LOADING



Loading cases

Loading forces:
Outer pressure: 0.1MPA (1Bar)
Suspension links: 168000 N (1.68e5N)
Gravity: 9806.6mm/s²
Acceleration 1G (9806.6mm/s²)
Calculation temperature: 20°C

9. FEA MODEL SOLVING

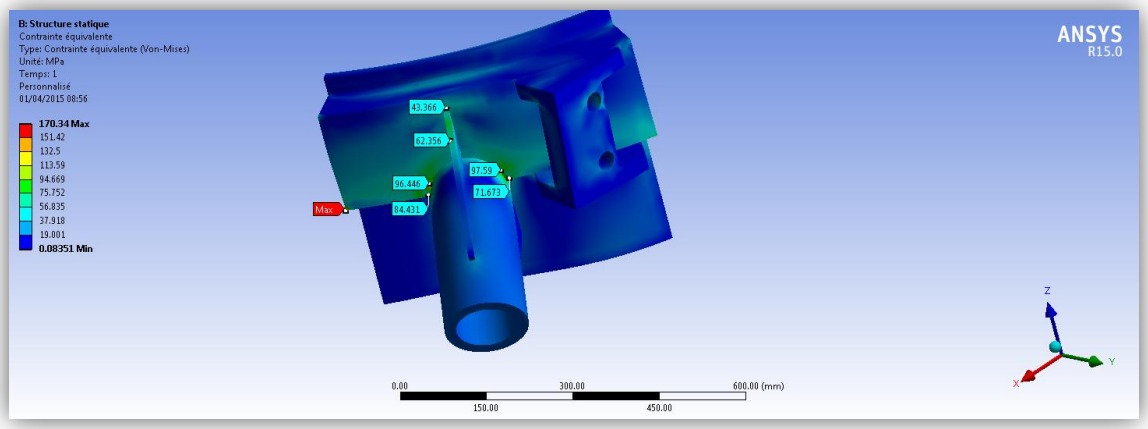
The model is solved directly at a fixed temperature of 20°C insofar as temperature dependant material properties are not required.

10. STRESS ANALYSIS

The Von Mises stress is inferior to S = 115 MPa in the surface model except for the welding between the outer tube and the chimneys of suspension links. A sub model is built in order to study this area. The Von Mises stress is inferior to S in this sub model.
We consider all stresses as primary and general stress which disregards the need to classify and linearize the stresses. The stress analysis is based on the Von Mises criteria and considers S as the maximum allowable stress for all locations.

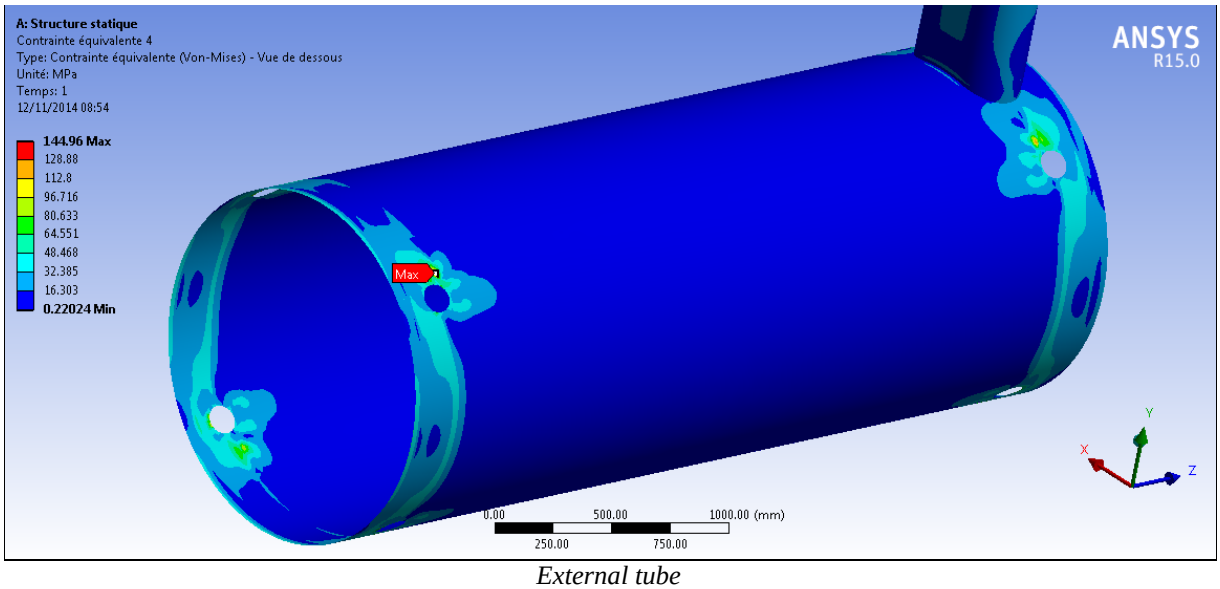
Material	Von Mises Peak stress	Max Allowable stress S
Stainless steel 304L	Inferior to 100 MPa for the solid sub model	115 MPa

Screenshots are provided hereafter.

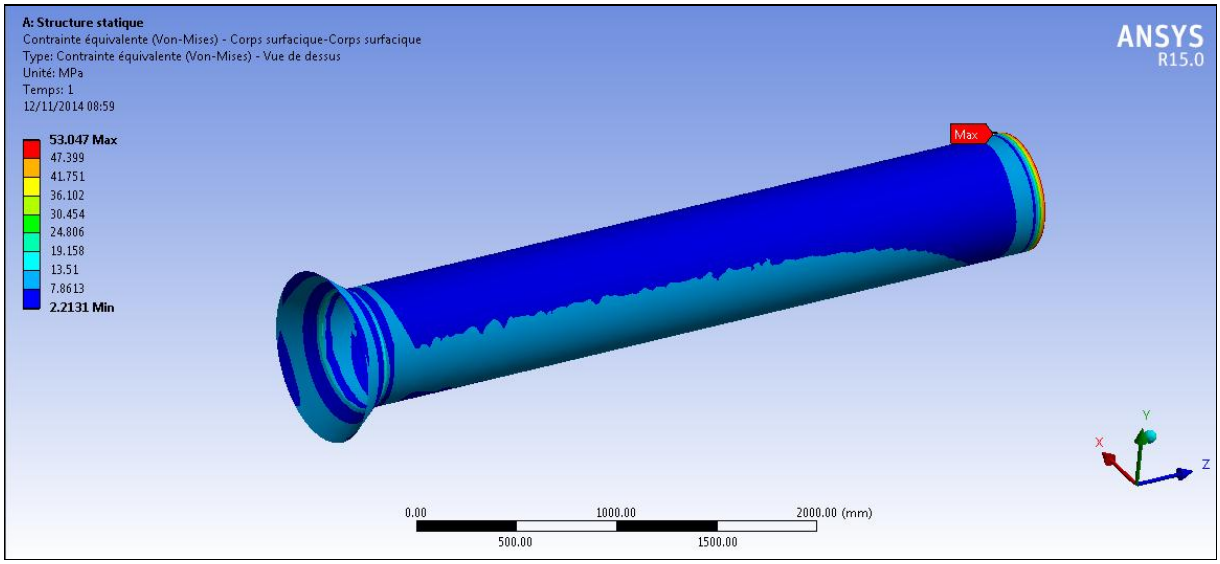


Von Mises stress in Sub Model

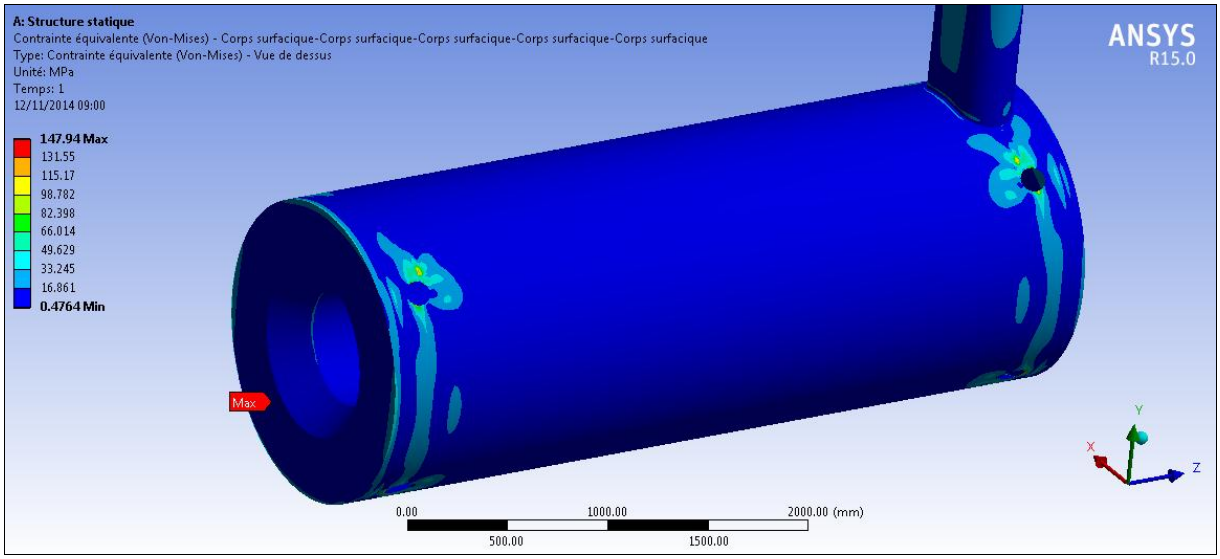
Equivalent (Von Mises) Upper membrane Stress



External tube

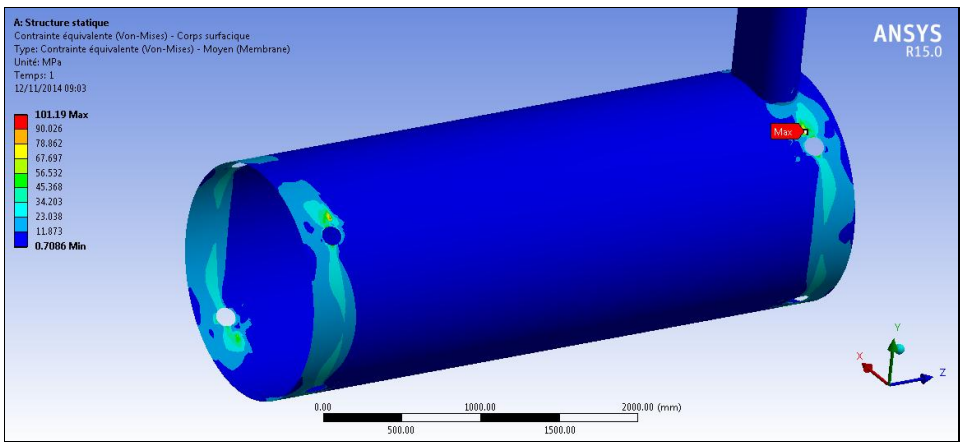


Internal tube

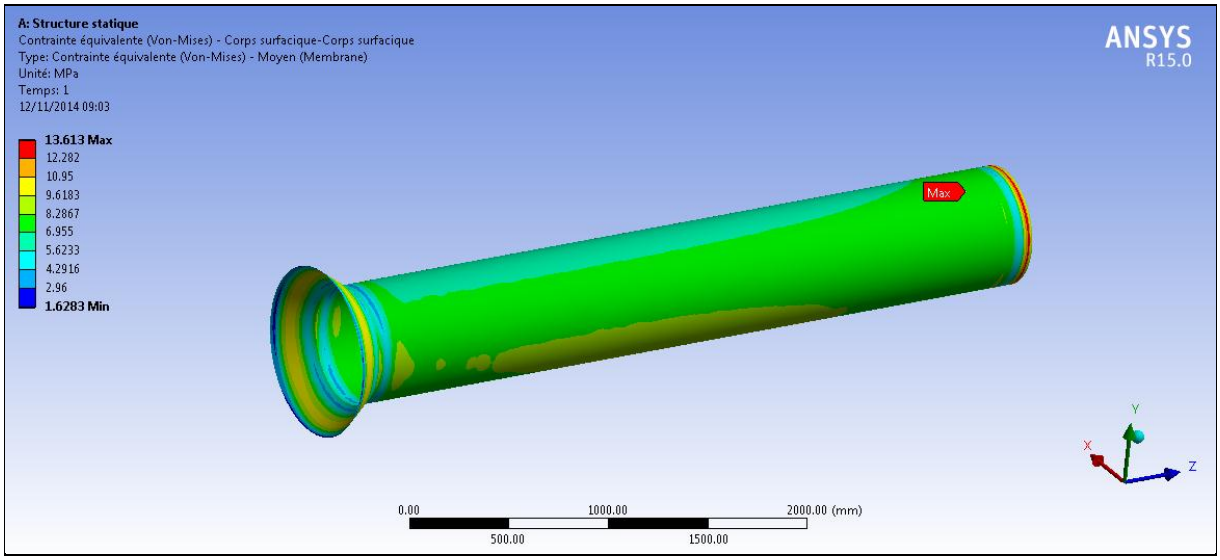


External Tube + Internal tube+ Flange

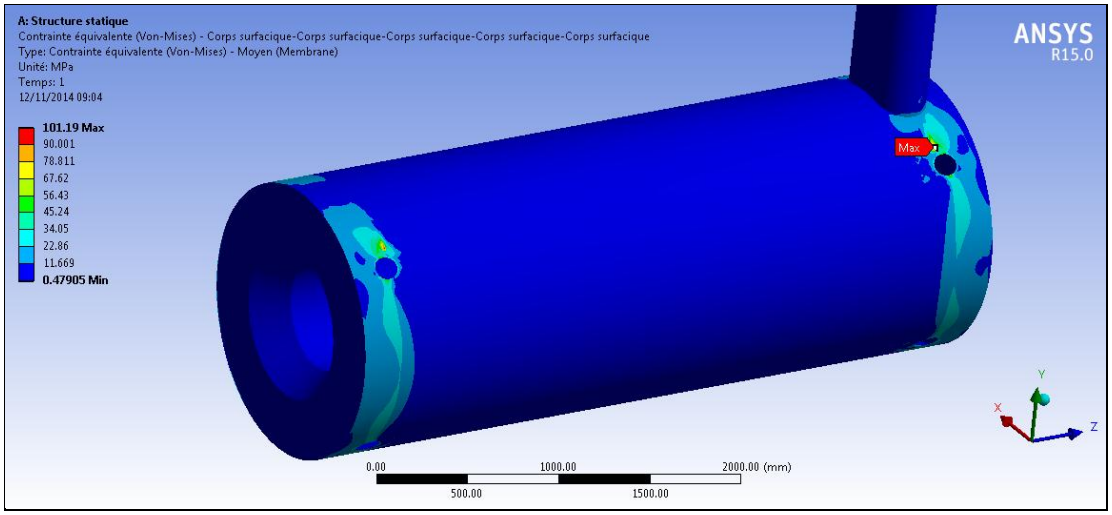
Middle Membrane Stress



External tube

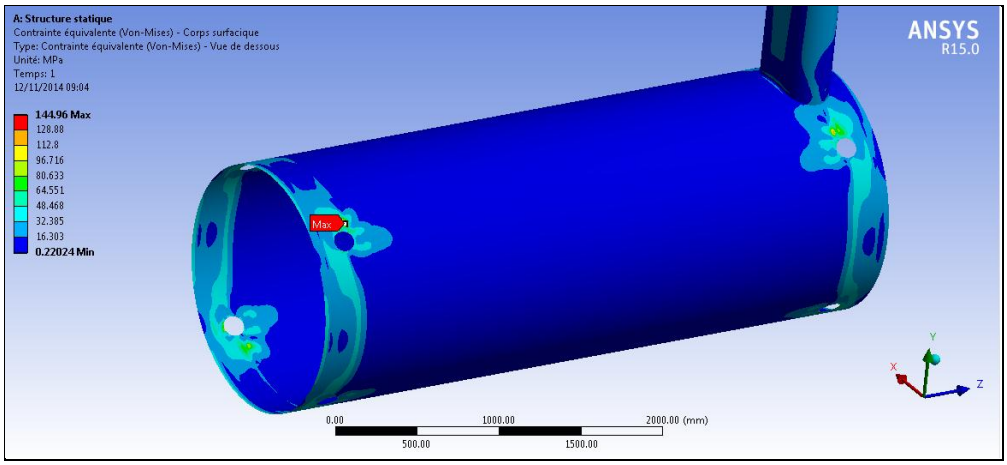


Internal tube

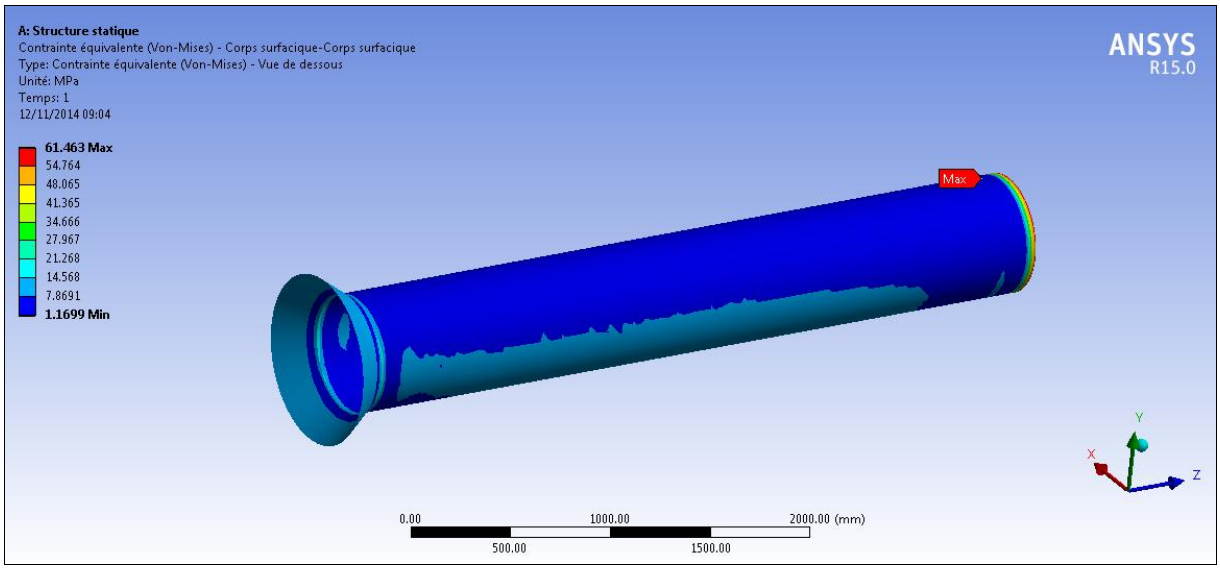


External Tube + Internal tube+ Flange

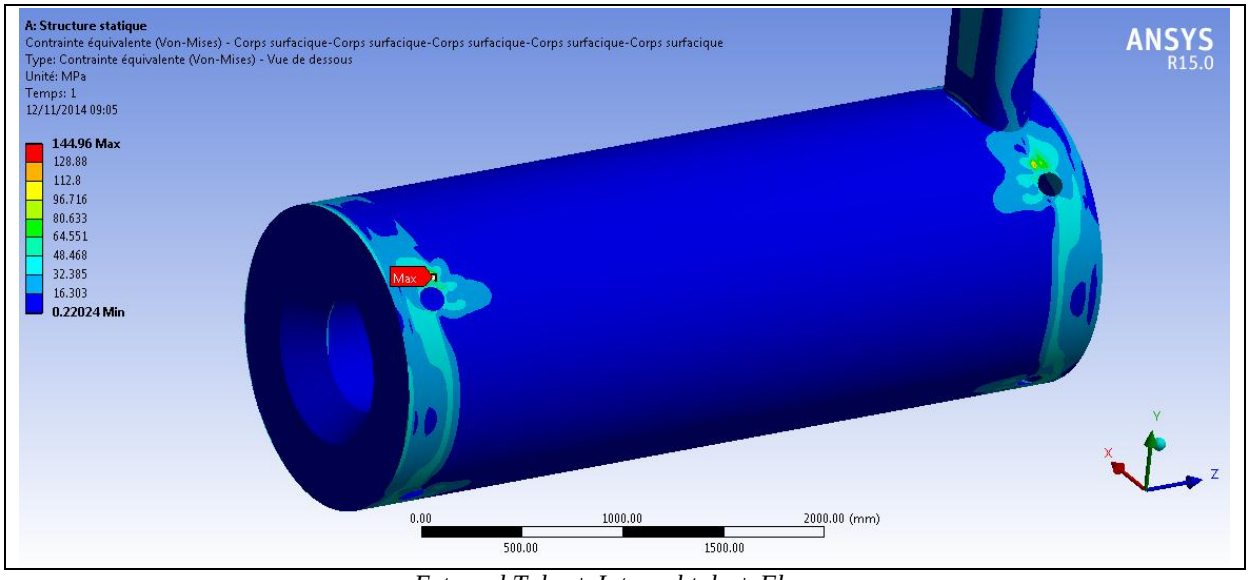
Lower Membrane Stress



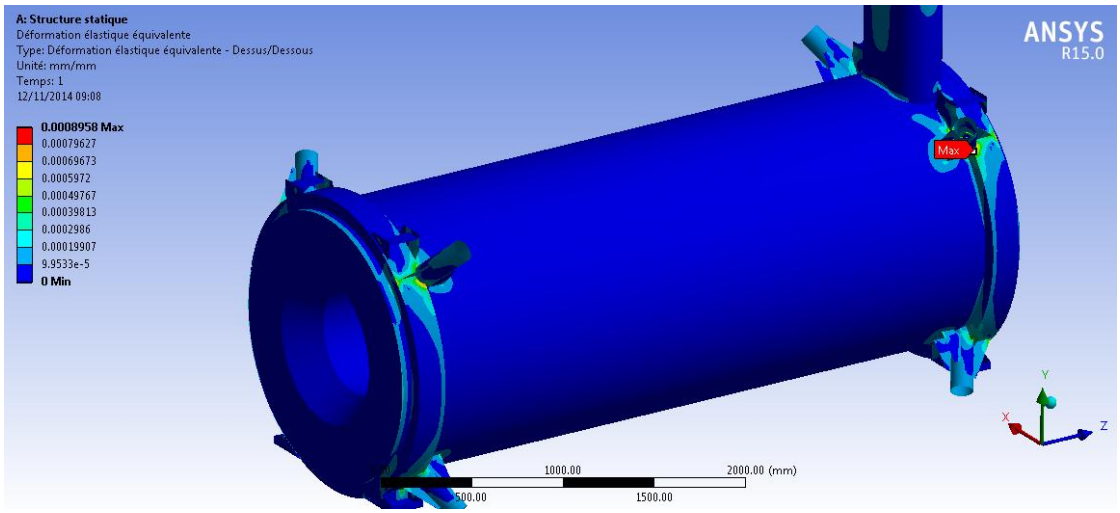
External tube

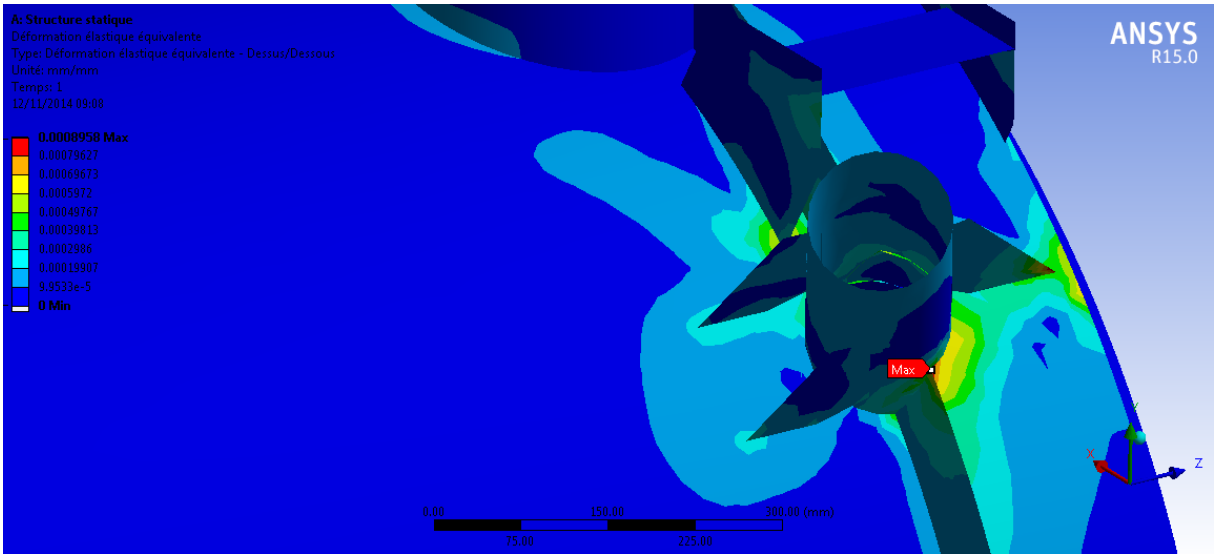


Internal tube



External Tube + Internal tube+ Flange





Distorted model, scale magnified

11. THICKNESS OF SHELLS AND TUBES UNDER EXTERNAL PRESSURE

Calculated allowable maximum pressure by the external tube (outside diameter: 1725mm, thickness 15 mm, length of tube 4053mm) knowing that the pressure that the tube is 0.1MPa.

This calculation was performed following the 2010 ASME Section VIII Division I .

Do= Outer diameter	1725	mm
L=Length between support	4053	mm
t=minimum thickness of tube	15	mm

L/Do	2.34956522
Do/t	115

Factor A	4.50E-04
Factor B	42.5

Max Pa=	0.49275362	Mpa

The maximum pressure permissible is 0.49Mpa

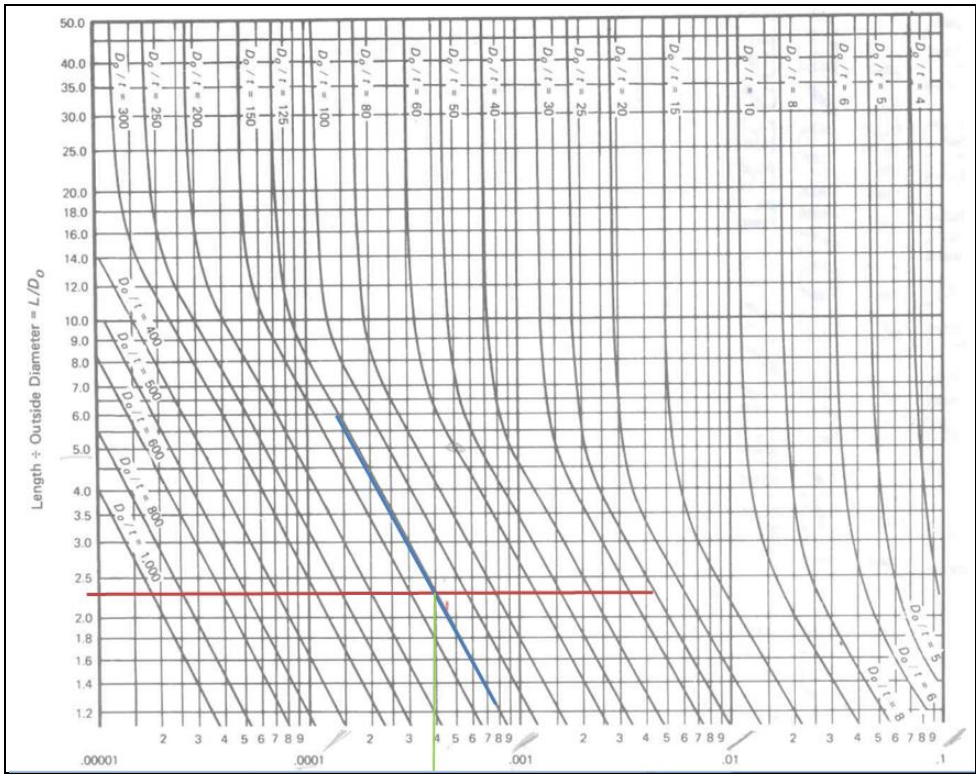


Table Fig.G

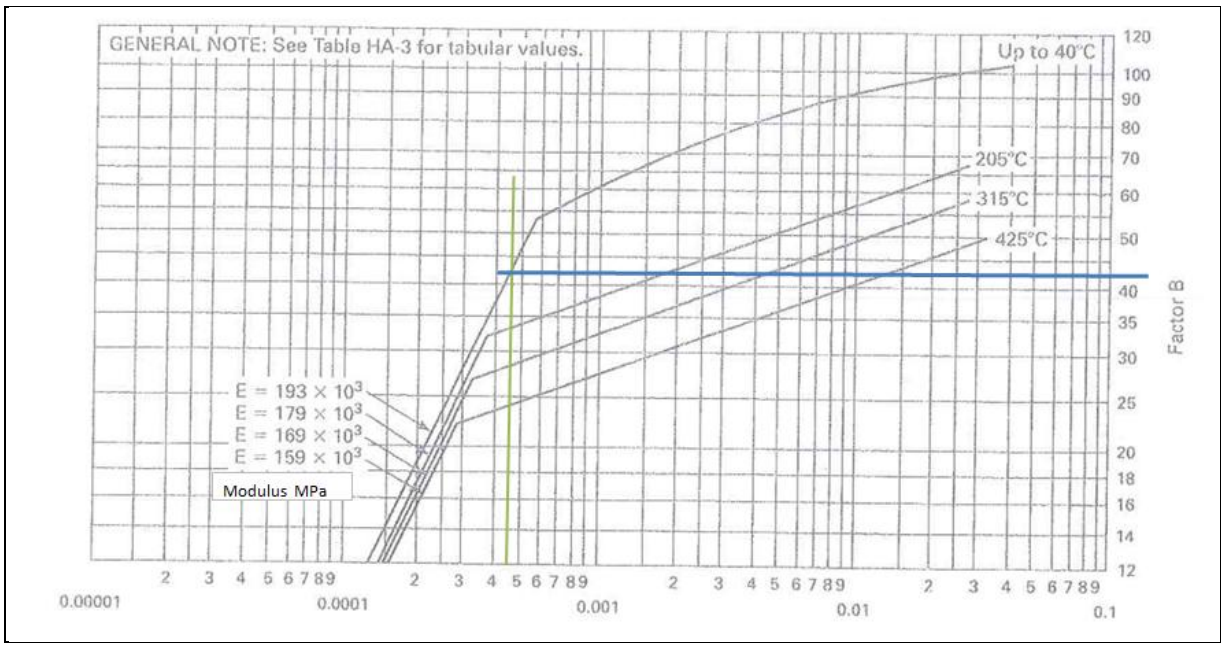


Table Fig.HA-3 (Metric)