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STRUCTURAL ANALYSIS OF THE ELLIPTICAL CRYOMODULE SUPPORTS

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1. SCOPE

The elliptical cryomodules connect to the vale box via an axial expansion joint. The valve box will at times experience a vacuum, this creates a net force on the interconnection. The connection will have stiffeners installed that will take some or all of the load. Furthermore, the cryomodules will have clamps installed on the feet. This report aims to structurally verify those clamps and feet. Initially a full differential pressure of 1 atmosphere will be assumed, if the stress is too high in such a scenario a maximum allowed force/pressure for the current design will be calculated.

The nomenclature used in this report is explained in Figure 2.

2. CONTRIBUTORS

Saverio Ardovino contributed all the designs used in this report in April of 2020.

3. INTRODUCTION

The full geometry of an elliptical cryomodule with its connection to the valve box can be seen in Figure 1.

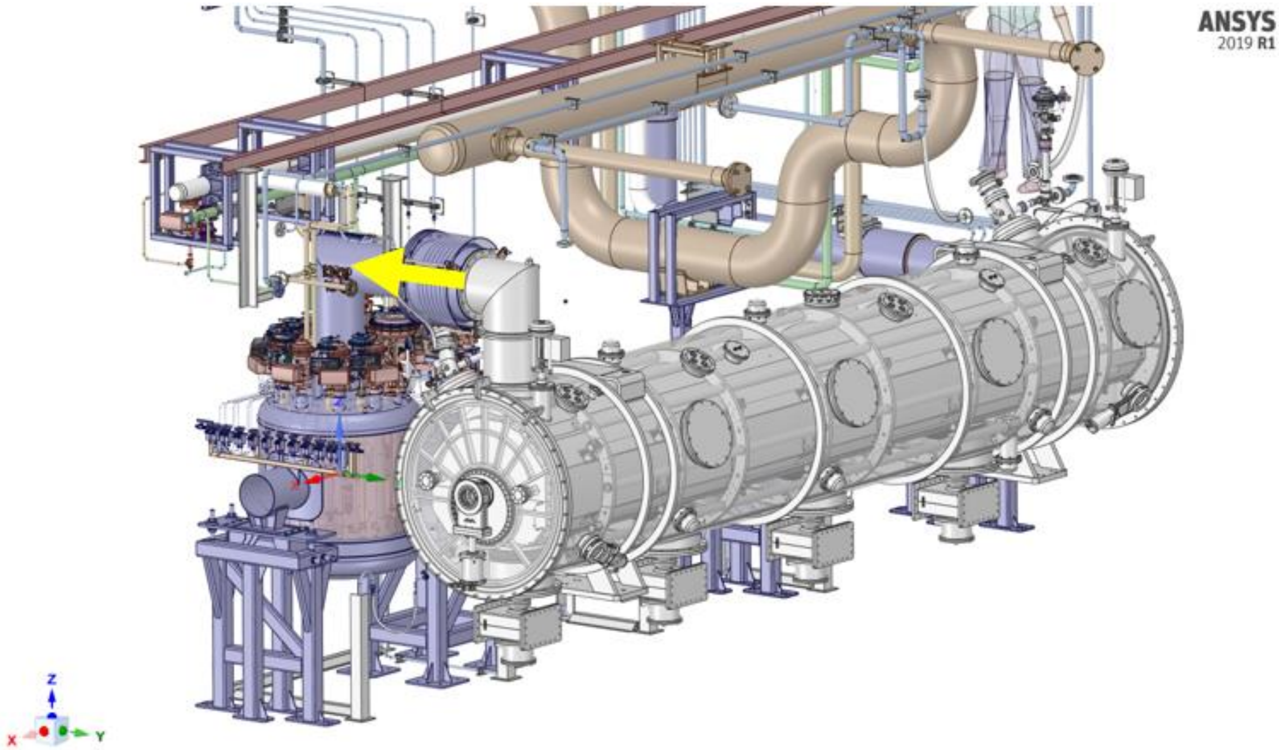

Figure 1 Full geometry including the valve box and surrounding piping

The expansion joint seen in Figure 1 exerts a force on the cryomodule as it contracts, this is represented by the yellow arrow.

4. ASSUMPTIONS

4.1. Naming

Throughout this report the names presented in Figure 2 will be used.

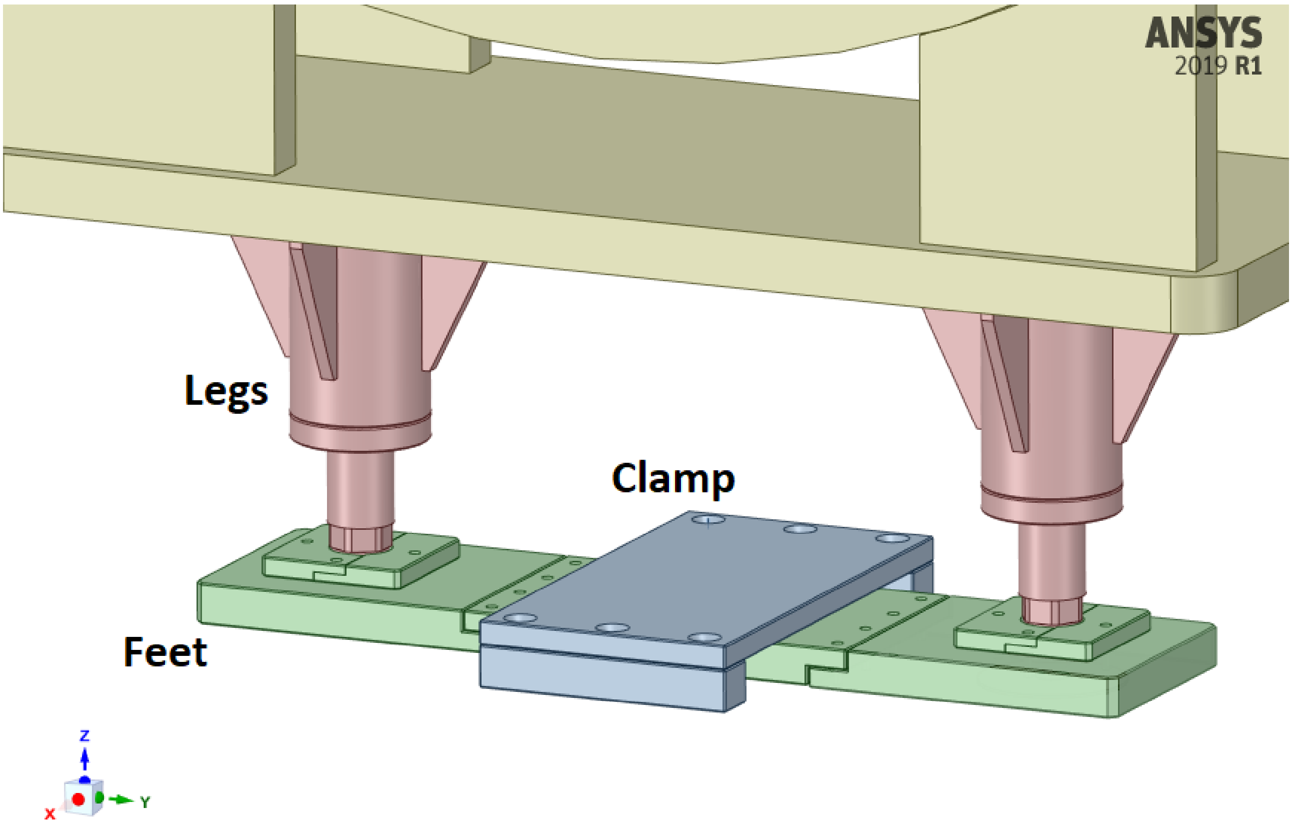

Figure 2 Red = Legs, Green = feet, Blue = clamp, everything in the picture = support

4.2. Material

The majority of the design consists of stainless steel 1.4301 (a part of the legs of the CM are made of A2-70). The material properties that are used for 1.4301 are:

- Density = 8000 kg/m^3
- Young's Modulus = 193 GPa
- Poisson's Ratio = 0.3
- Calculation Yield Strength = 187 MPa
- Ultimate Tensile Strength = 500-700 MPa

The calculation yield strength is based on the stated 1% proof strength of the material in [1] multiplied with the material safety factor presented in [2] and conversion between Von Mises and Trescas stress criterion. This results in the calculation yield strength 187 MPa presented above.

The part made of A2-70 can be seen in Figure 3.

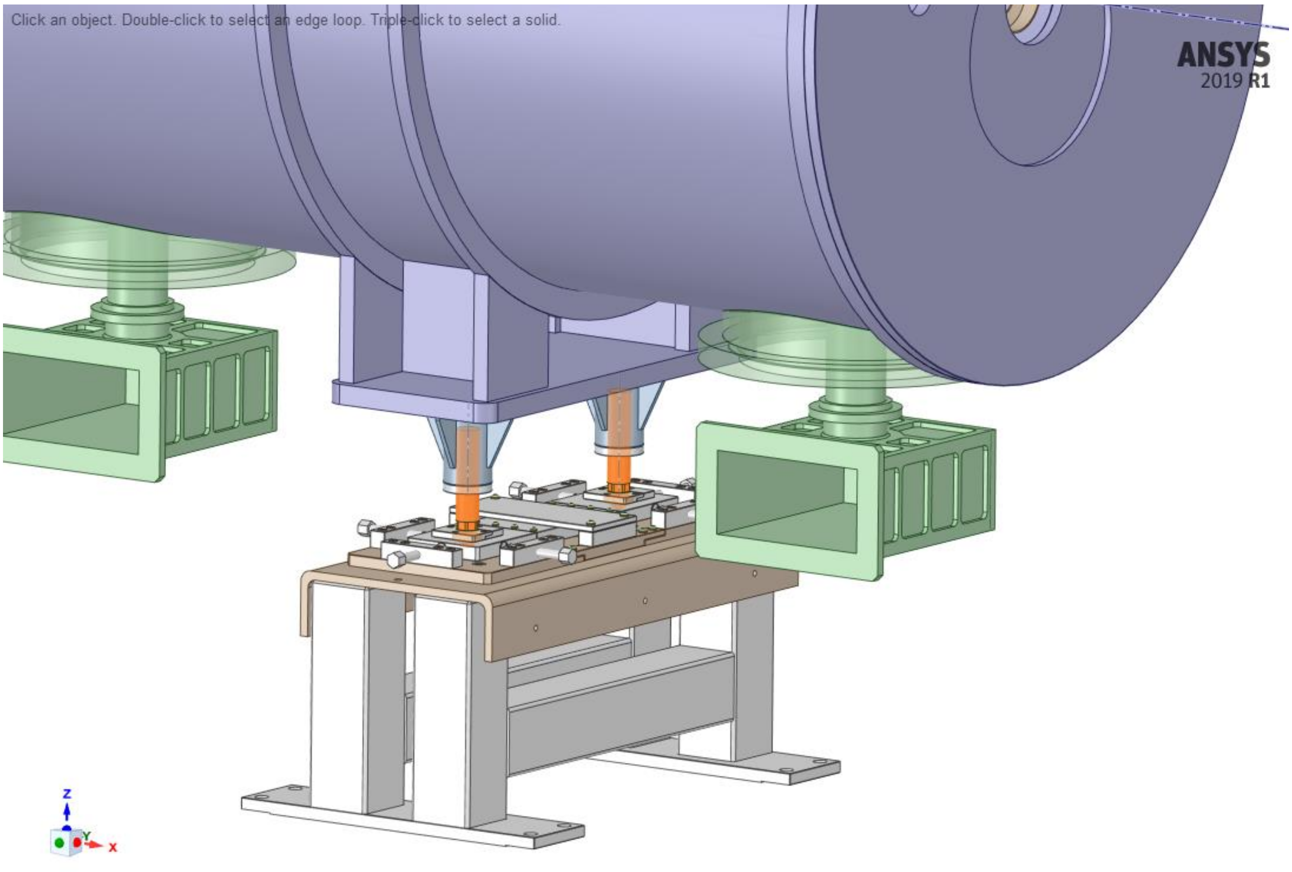

Figure 3 A2-70 steel part shown in orange

A2-70 has a tensile strength of at least 700 MPa and a yield strength (0.2%) of 450 MPa, [3]. With a material safety factor of 1.25, [2], this results in a calculation yield strength of 311 MPa.

5. MODEL

The geometry was simplified in order to focus on the parts relevant for this report. The majority of the cryomodule was replaced with a mass that was placed upon the legs, as can be seen in Figure 4.

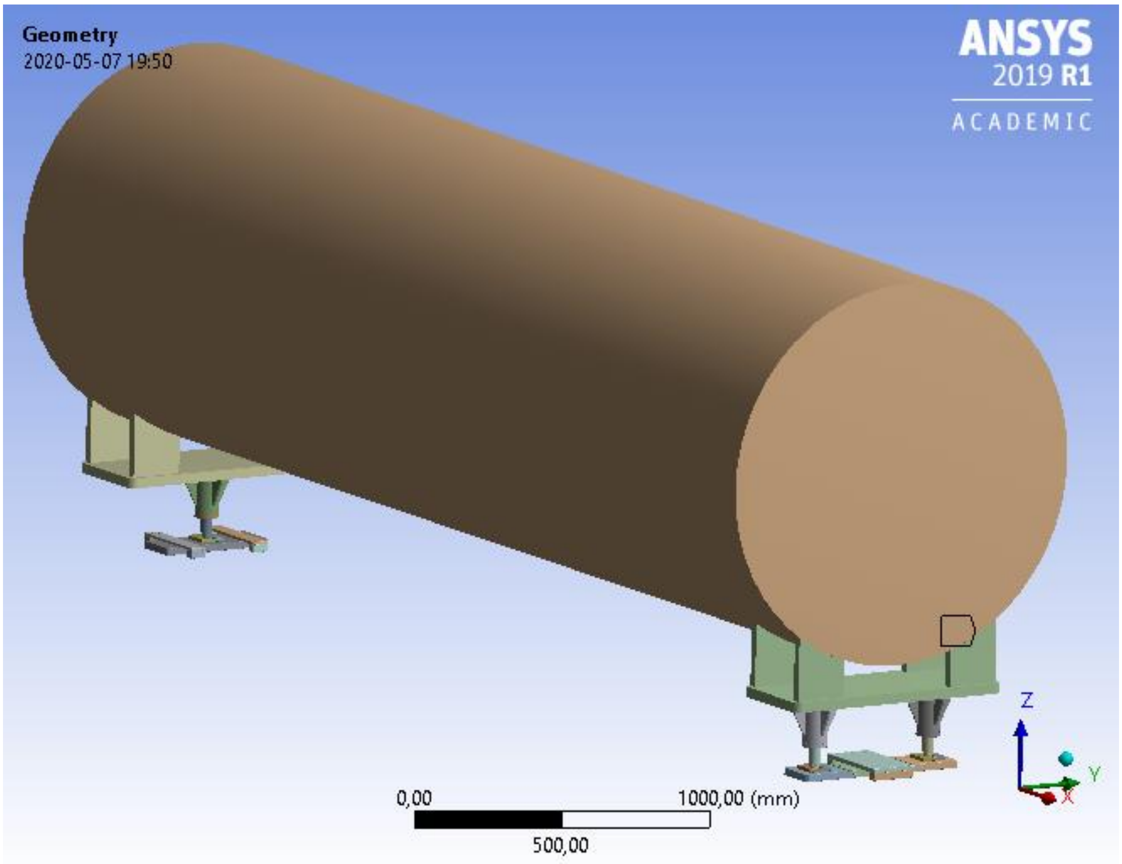

Figure 4 Simplified geometry

The critical bolts around the legs were modelled as rigid beam elements which enables extraction of reaction forces. This was done in a separate model focusing on the bolts.

The mesh of the support with two legs can be seen in Figure 5.

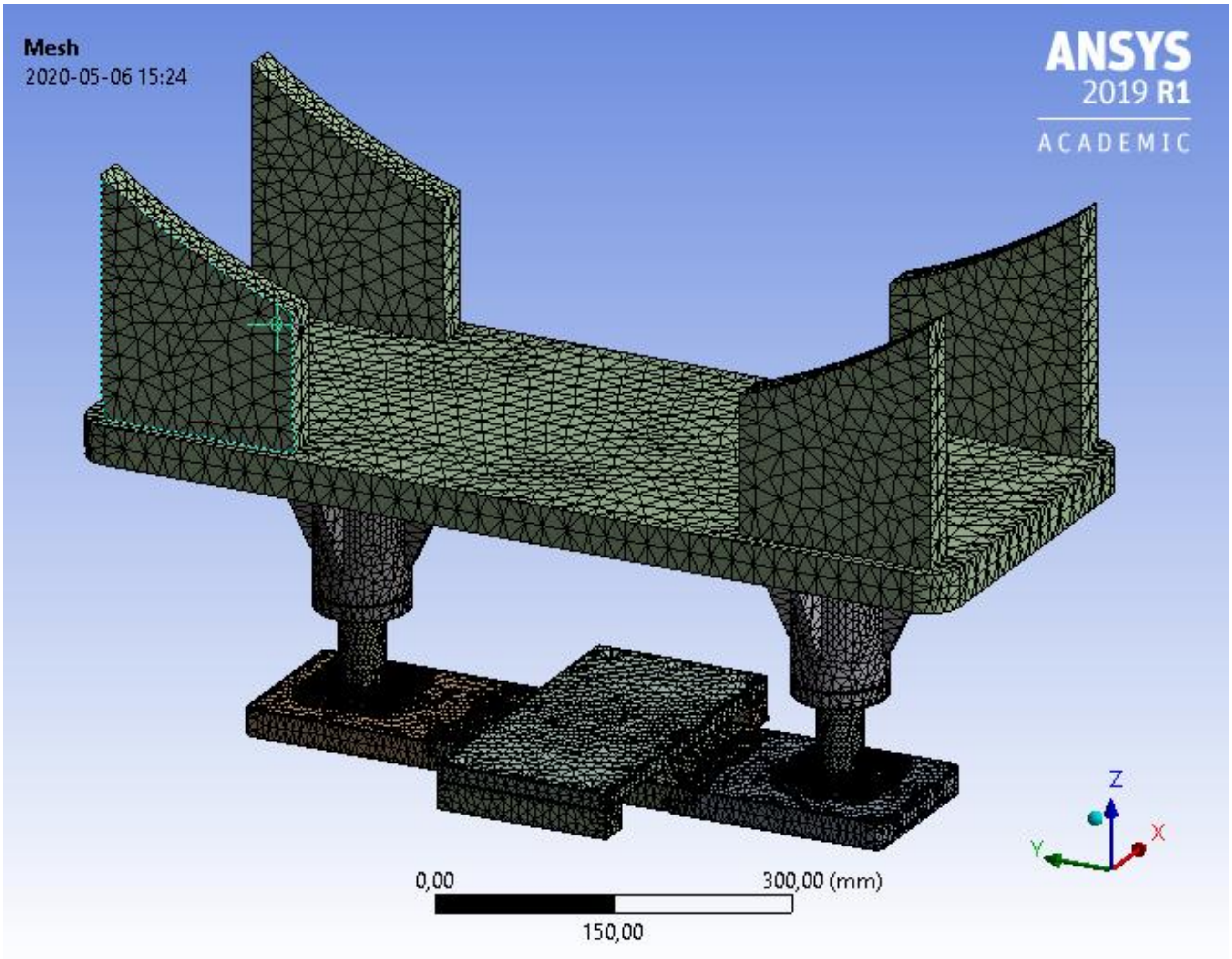

Figure 5 Mesh of a cryomodule support

Another zoomed in picture of the mesh of a single leg can be seen in Figure 6.

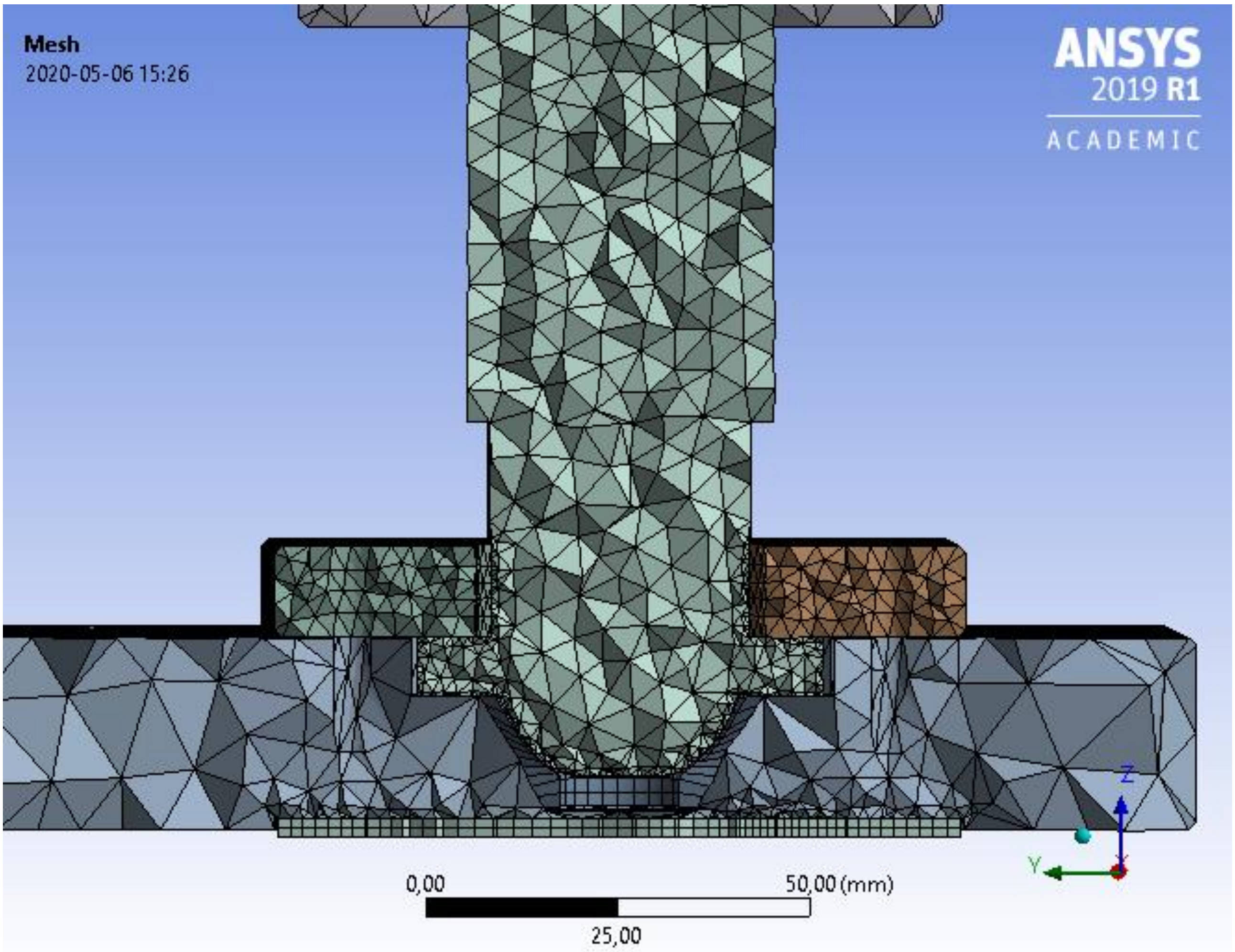

Figure 6 Detailed view of the mesh

As can be seen in Figure 7 the force on the interconnection was applied to the model via a remote force. The force applied is based on the assumption that an axial expansion joint with an effective area of 1830 cm^2 is used at the interconnection. At 1 atm pressure difference this results in a force of 18540 N.

Furthermore, the feet of the cryomodule were kept in place by compression only boundary conditions and the clamps were fixed, these boundary conditions can be seen in Figure 7 and Figure 8.

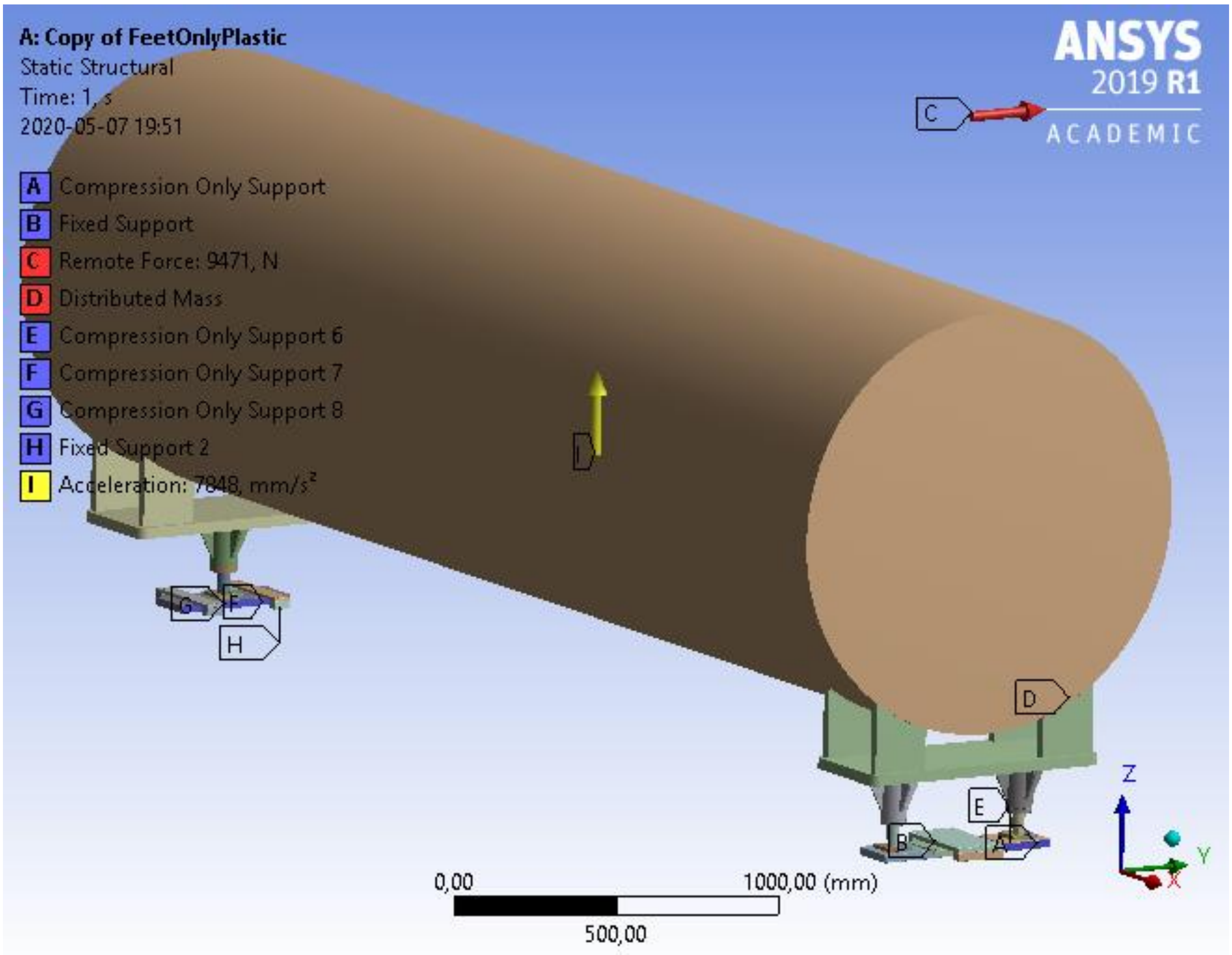

Figure 7 Boundary conditions

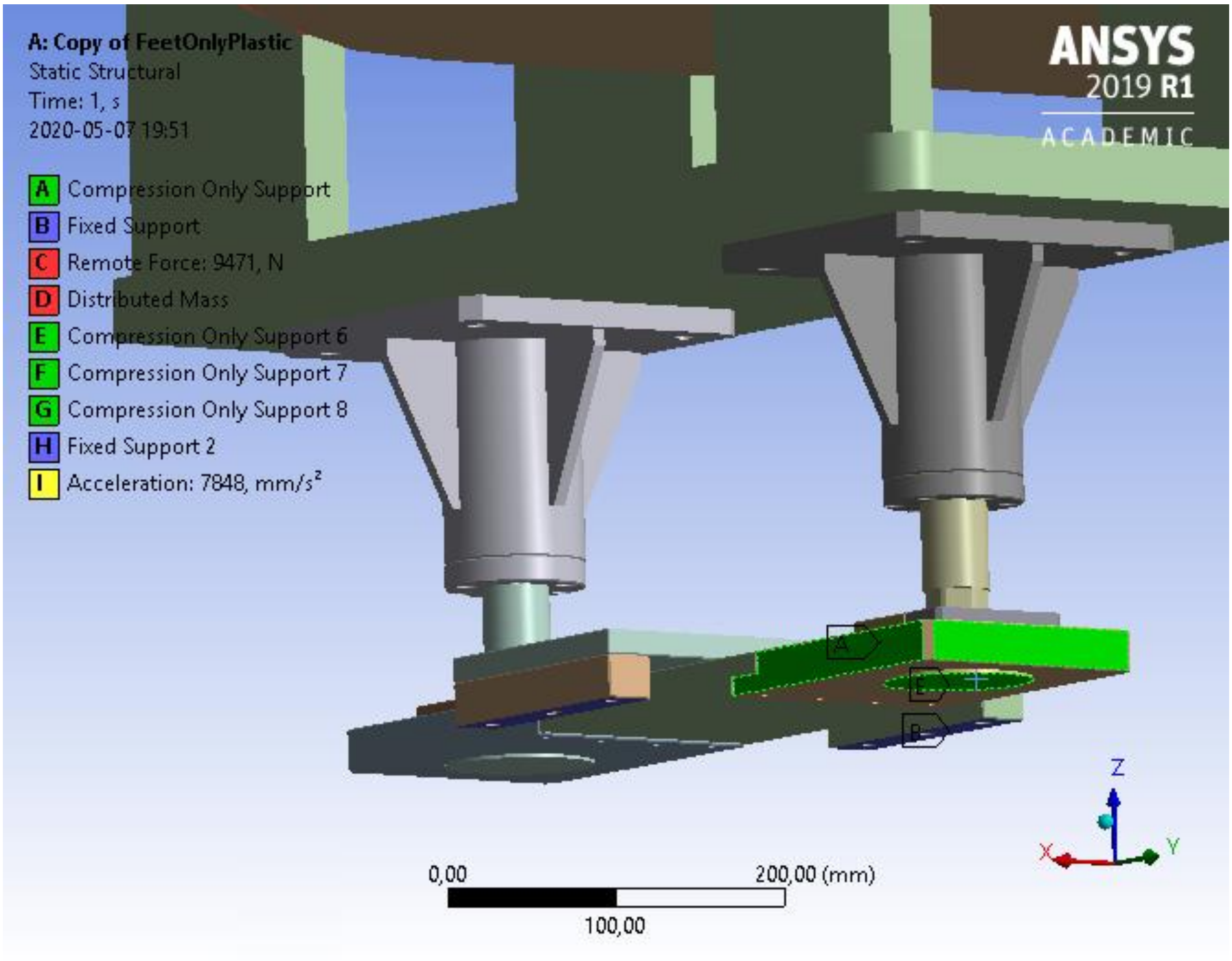

Figure 8 Zoomed in picture of the boundary conditions on the feet of the cryomodule

Note that since the dead weight is beneficial it was multiplied by a factor of 0.8 in accordance with [2] (in fact the gravitational acceleration was multiplied by 0.8 which produces the same result).

5.1. Submodel bolts

The bolts were analysed in a submodel that can be seen in Figure 9.

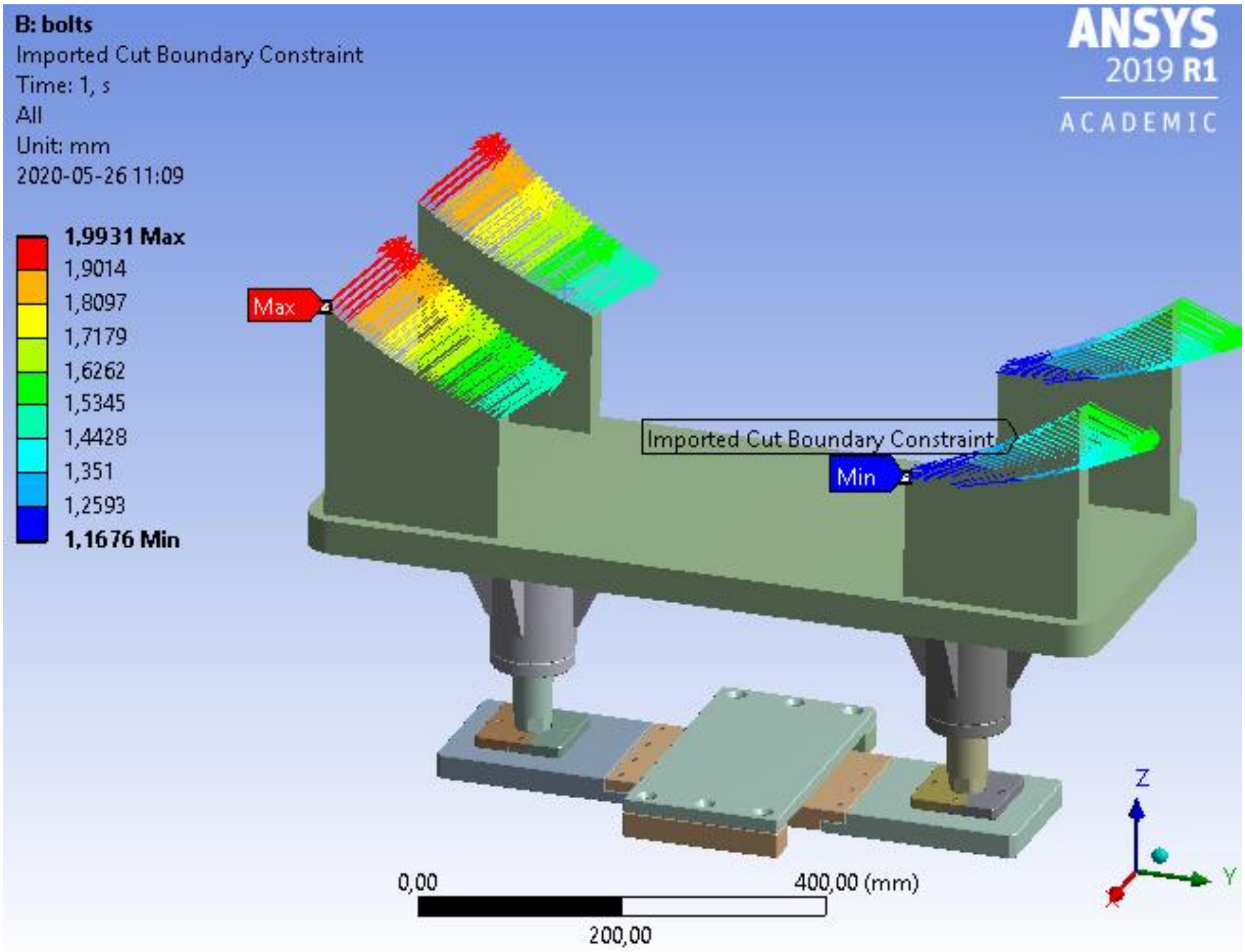

Figure 9 Submodel interface for bolt calculation

The boundary conditions of the feet were the same as for the full model, see Figure 8. The bolts however were modelled as beam elements as can be seen in Figure 10.

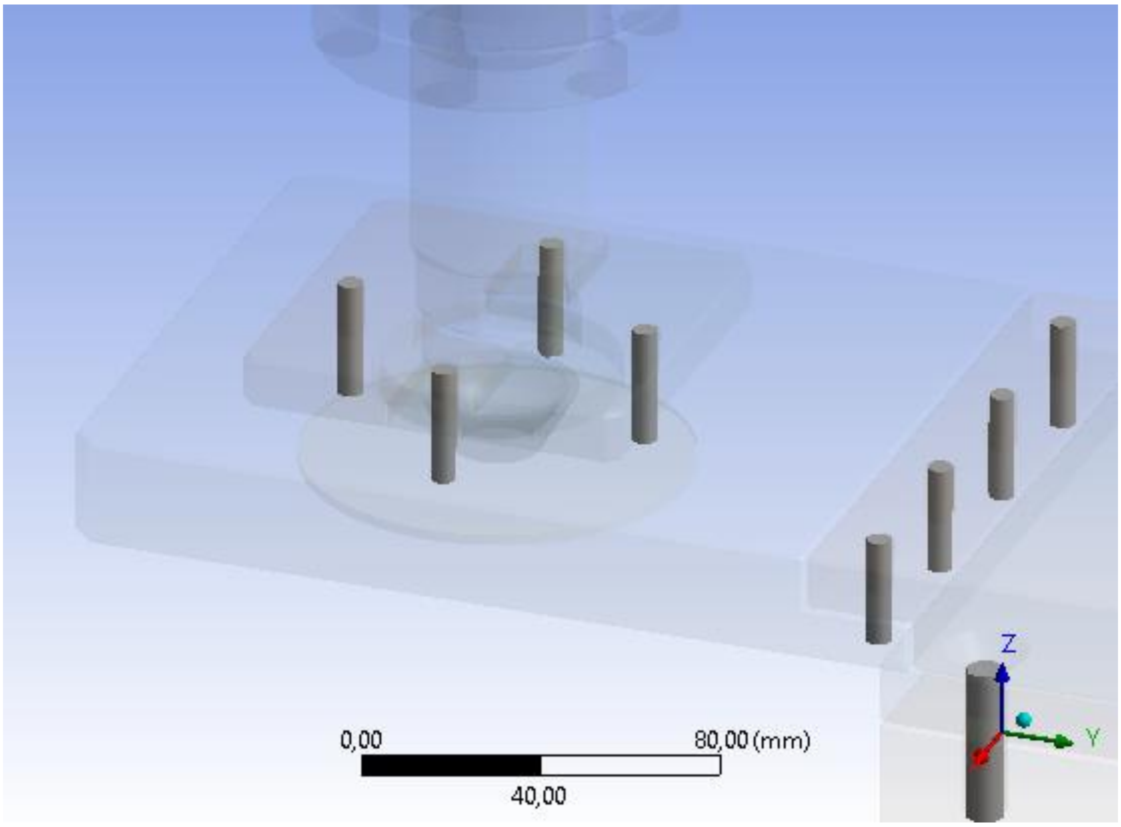

Figure 10 Beam elements modelling the bolts

5.2. Legs

The legs were investigated in more detail in its own model. In this model the feet were excluded and instead compression only boundary conditions were used for this interface. The boundary conditions in question can be seen in Figure 11 and Figure 12.

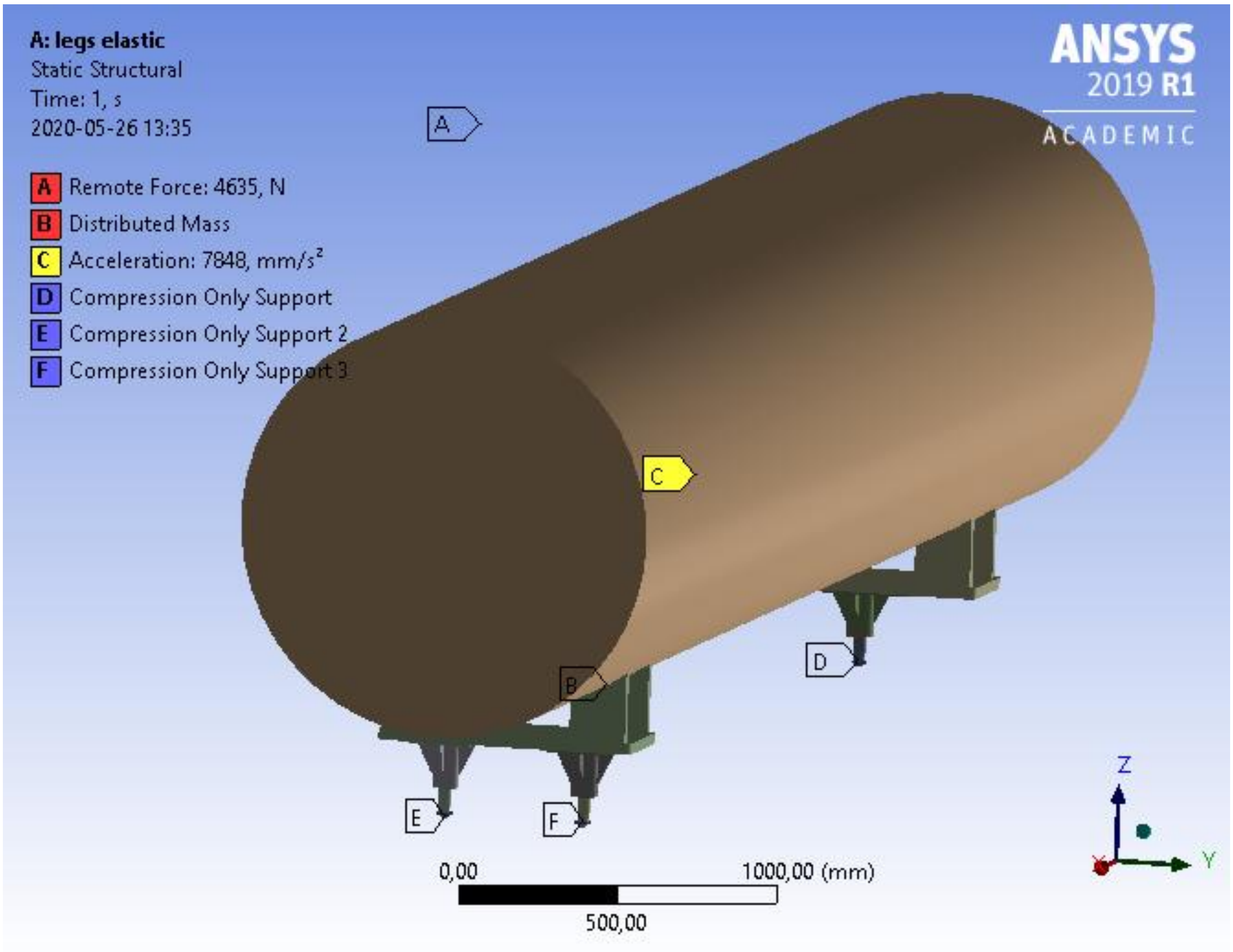

Figure 11 Model investigating the legs

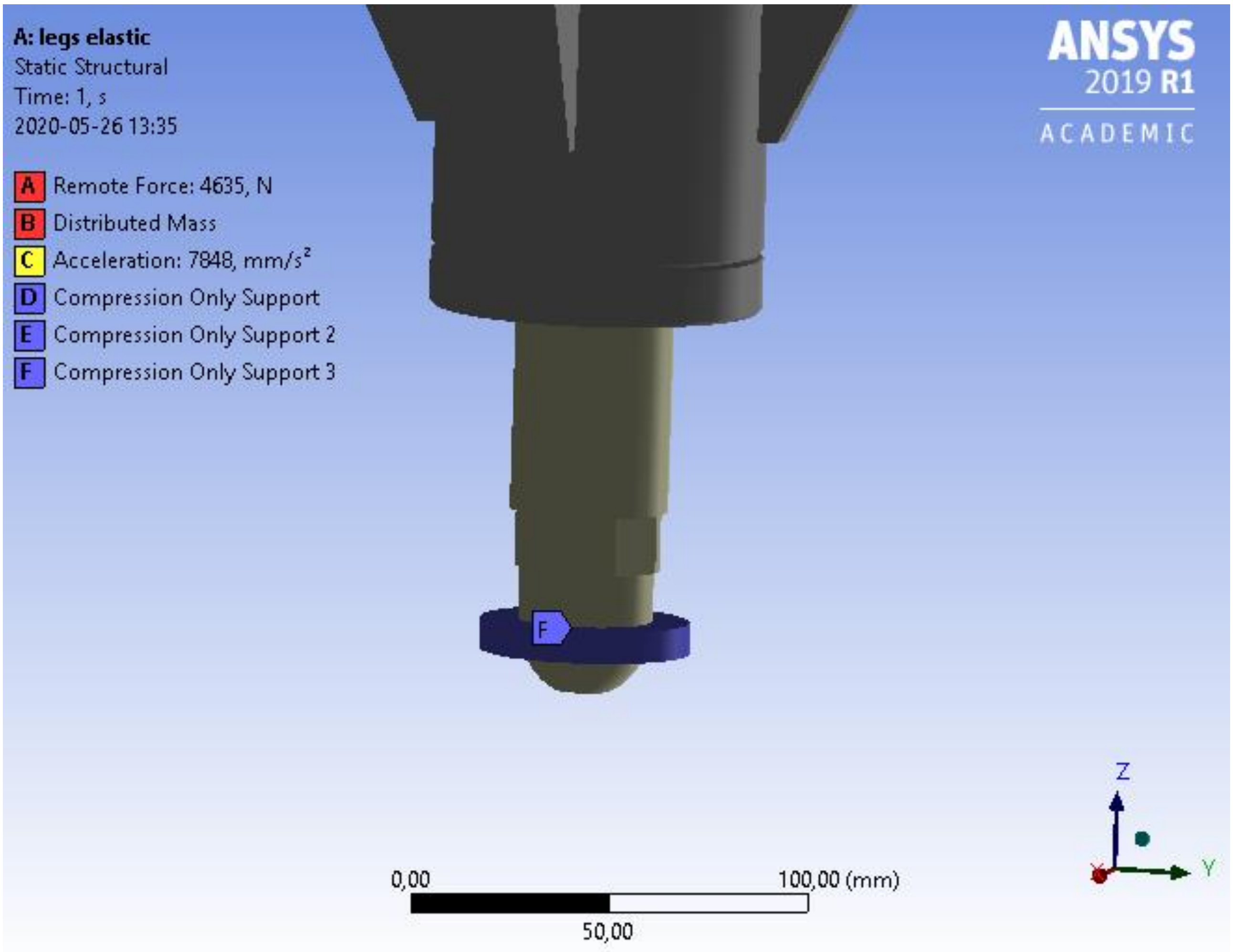

Figure 12 Zoomed in picture of the compression only boundary conditions on the legs

6. RESULTS

6.1. Full atmosphere

When applying the equivalent force of one atmosphere differential pressure on the cryomodule interconnection large parts of the feet experience high stress. This can be seen in Figure 13.

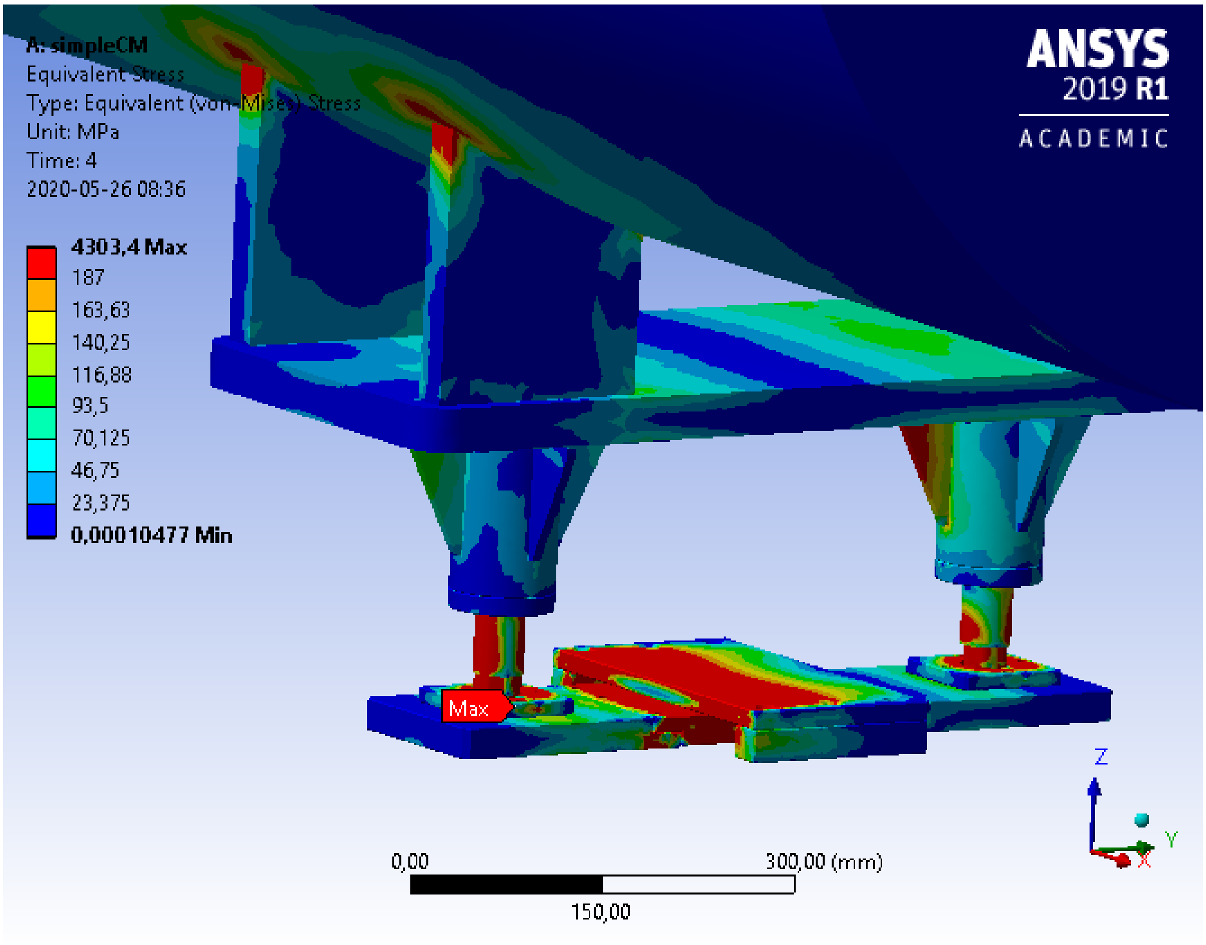

Figure 13 Stress when the full load is applied

6.2. Variable load

The remote force applied to the model was increased in increments and the maximum stress extracted for each application. The resultant plot can be seen in Figure 14.

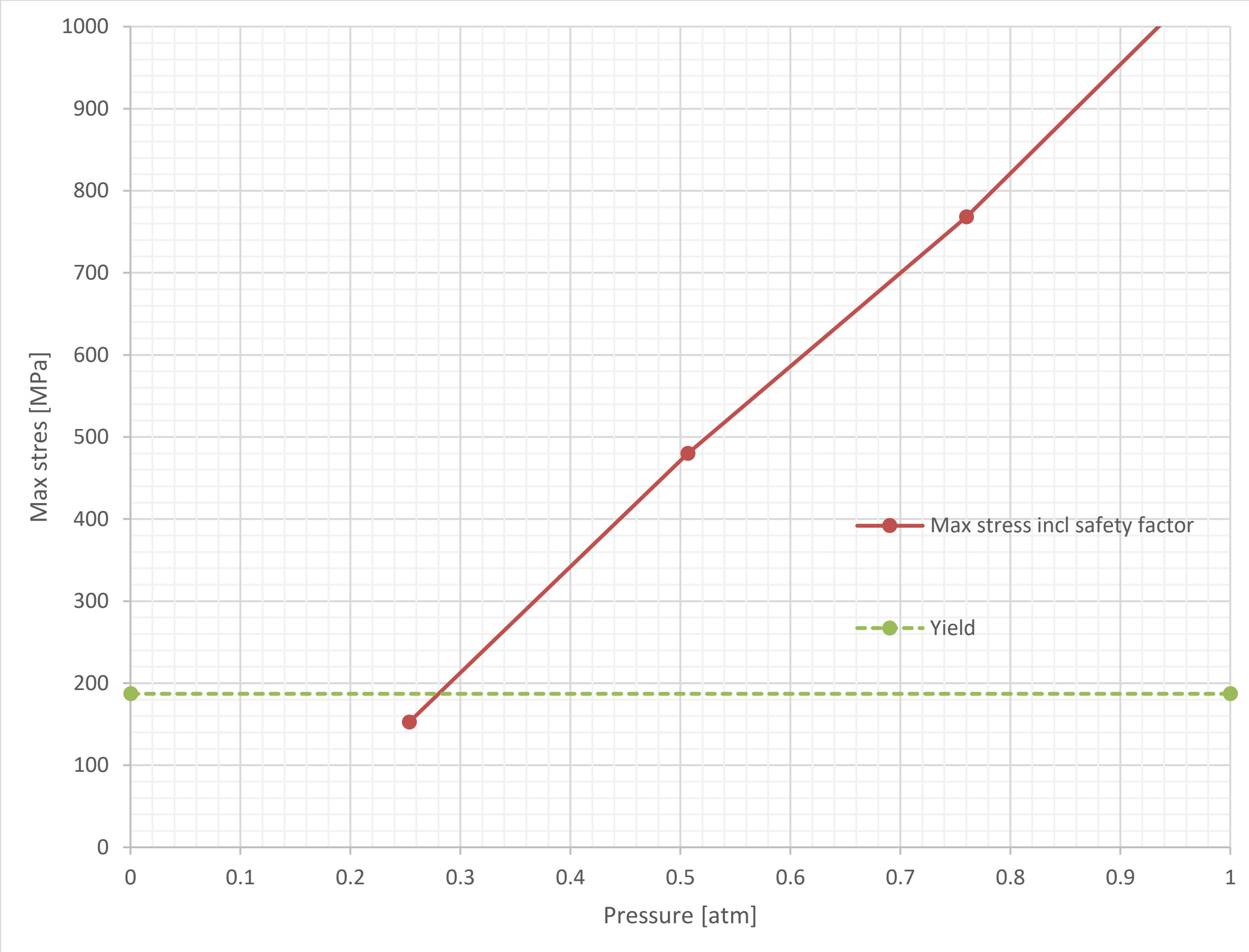

Figure 14 Maximum allowed load

The feet reach yield stress at a load equivalent to about 0.27 atm on the connection, including a load factor of 1.2 according to [2].

The stress distribution when 0.25 atm is applied to the interconnection can be seen in Figure 15. Note that the load factor has not yet been applied.

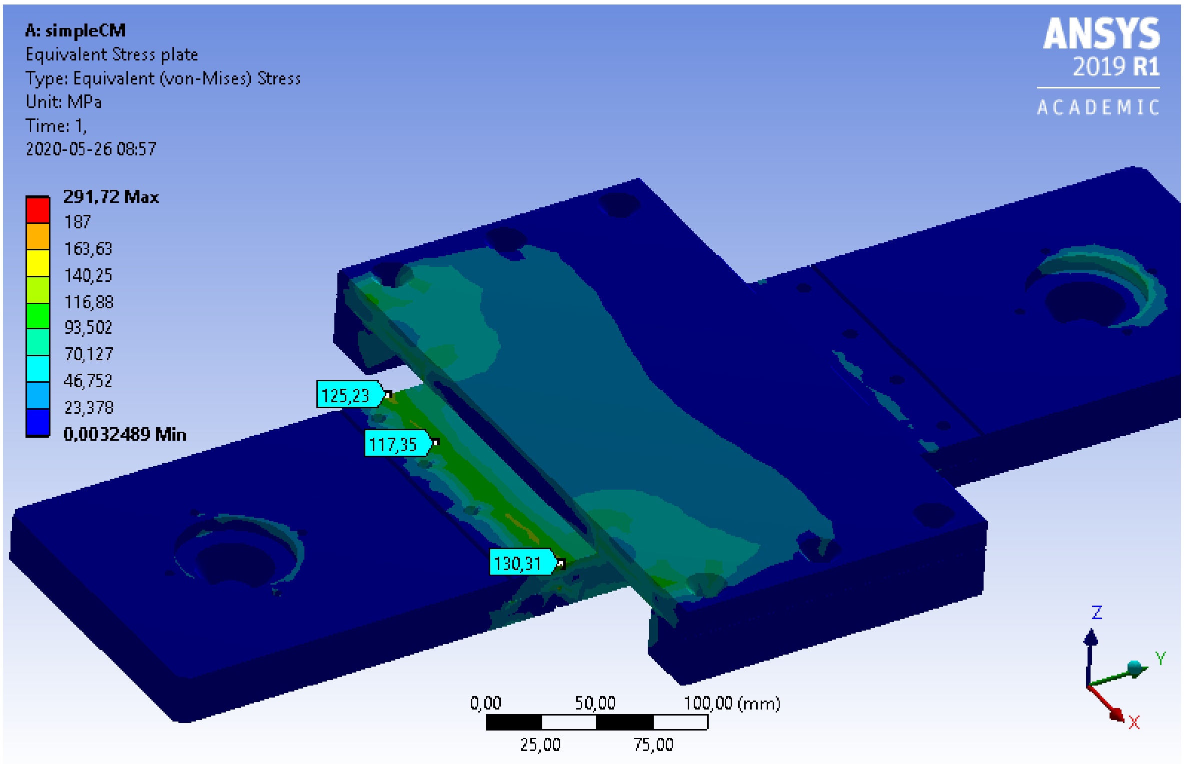

Figure 15 Stress in the base plate when 0.25 atm is applied to the interconnection

As can be observed in Figure 15 the maximum stress is about 291 MPa this stress is however highly localized and is ignored in Figure 14.

6.3. Bolts

The reaction forces in the most heavily loaded bolt can be seen in Table 1.

Table 1 Reaction forces in the most heavily loaded bolt

Load [atm]	Axial Force [N]	Torque [Nmm]	Shear Force 1[N]	Shear Force 2[N]	Moment 1[Nmm]	Moment 2[Nmm]
0.21	5711	-18	116	115	1705	1425
0.42	18882	-26	464	440	6673	5524
0.63	32210	-35	878	813	12337	10501
0.83	45645	-43	1337	1215	18443	16003

Linear interpolation between the values reveal that the max load for the bolts is 0.21 atm assuming an effective area of the bolts of 21.1 mm^2.

6.4. Legs

The legs are below yield (see Figure 16) at 0.25 atm and is therefore not the weakest component.

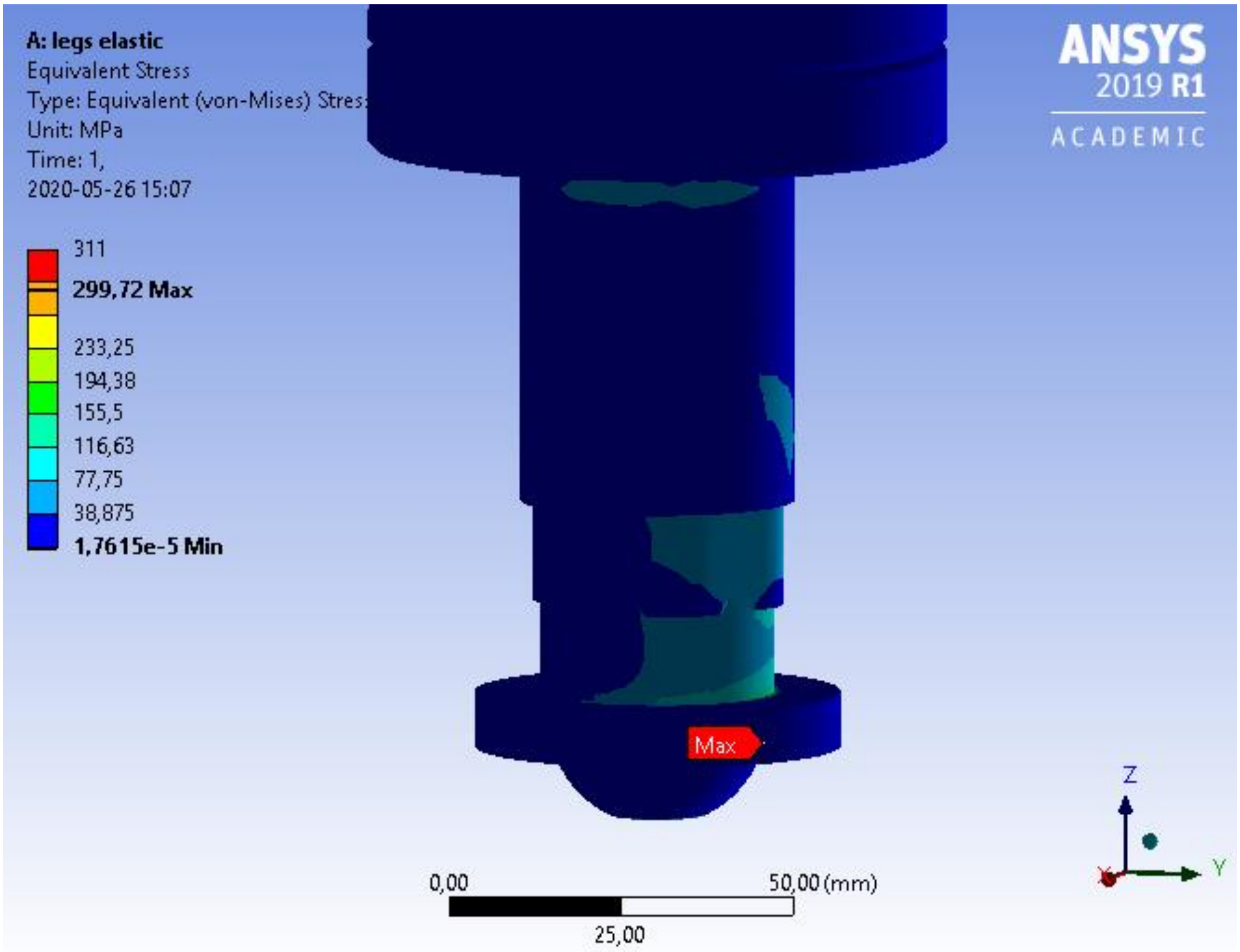

Figure 16 Equivalent stress in the legs at 0.25 atm

7. CONCLUSIONS AND RECOMMENDATIONS

The current design cannot withstand a full atmosphere on the connection. It can however withstand about 0.21 atm. The bolts are the weakest part of the construction closely followed by the feet.

8. REFERENCES

[1] European committee for standardization, SS-EN_10028-7_2016 Stainless steels, 2016-08-09

[2] European committee for standardization, SS-EN_13445-3_2014+C5_2018 Unfired pressure vessels Design, 2018-09-14

[3] European committee for standardization, SS-EN_ISO 3506-1:2020, Fasteners – Mechanical properties of corrosion-resistant stainless steel fasteners – Part 1: Bolts, screws and studs with specified grades and property classes, 2020-04-21

DOCUMENT REVISION HISTORY

Revision	Reason for and description of change	Author	Date
1	First issue	Jonathan Moberg	2020-05-07