Oak Ridge National Laboratory | SECOND TARGET STATION

Vessel Systems and Target Station Shielding Structural Analysis

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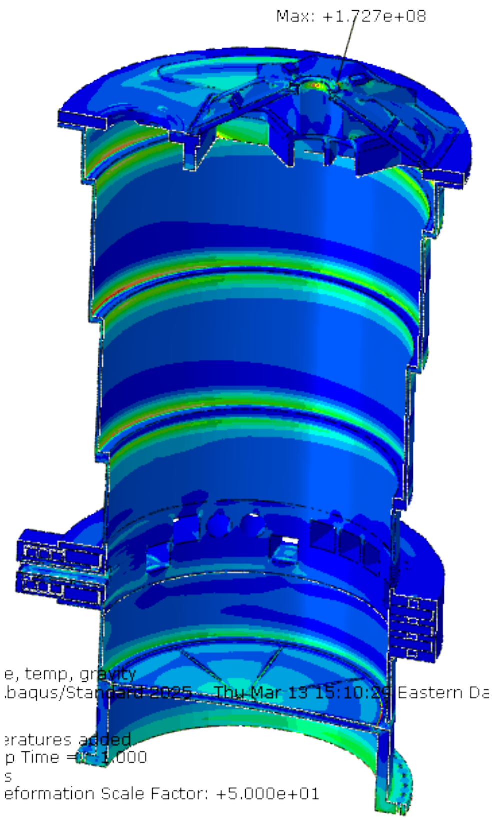
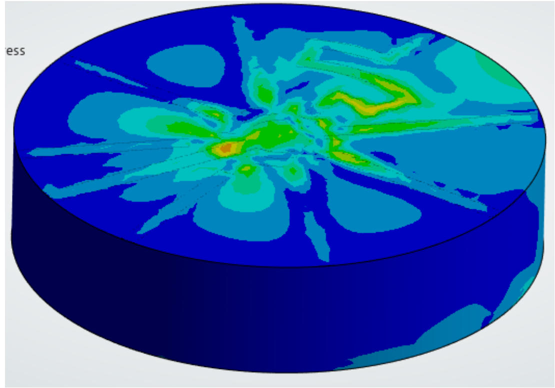
Presentation Outline

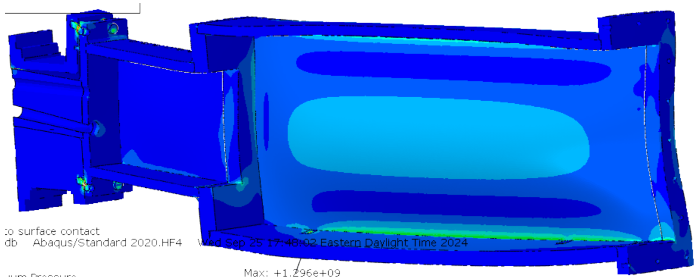
Core Vessel Analysis



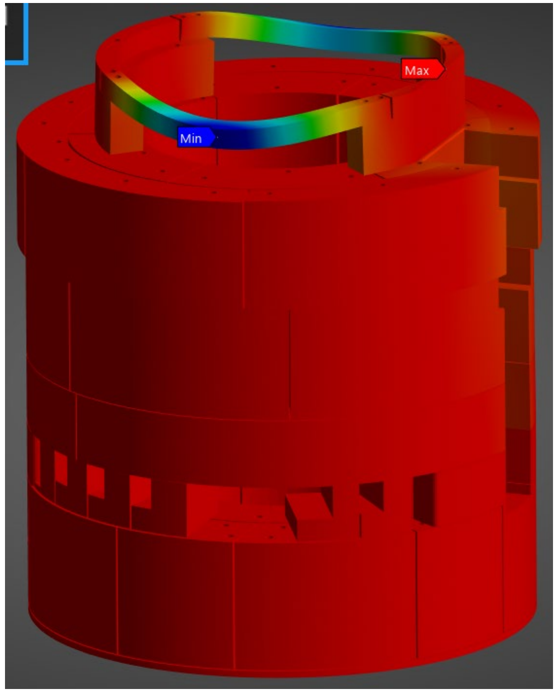
Shield Block #1 Analysis



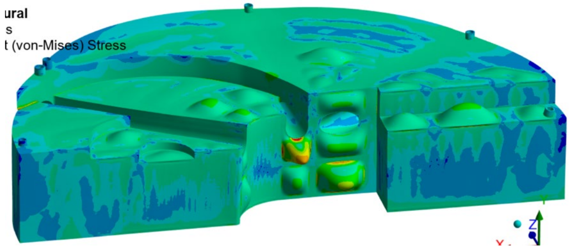
QIKR Nozzle Extension Analysis



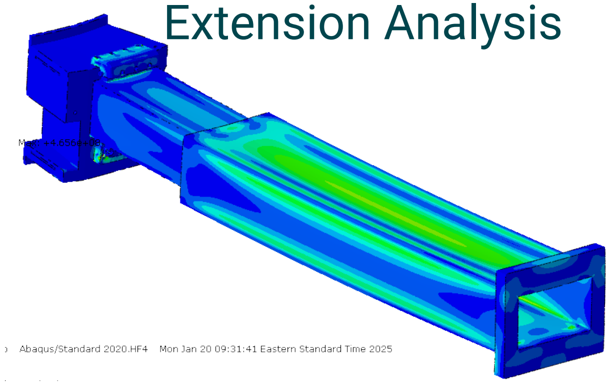
TSS Analysis



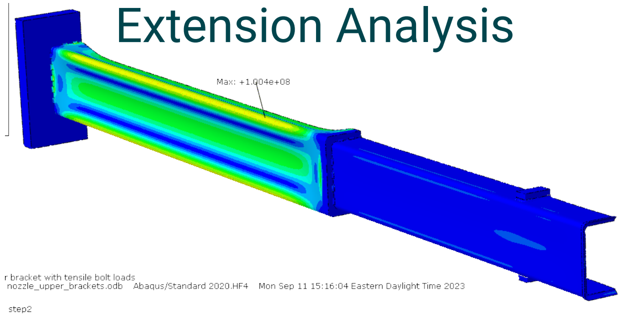
Shield Block #3 Analysis



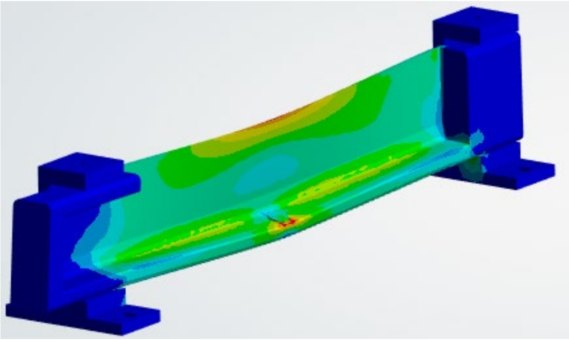
Dual Channel Nozzle Extension Analysis



Standard Nozzle Extension Analysis



Gamma Gate Analysis



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Core Vessel 4/2025 Preliminary Structural Analysis

T. McManamy

4/7/25

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Core Vessel Introduction and Requirements

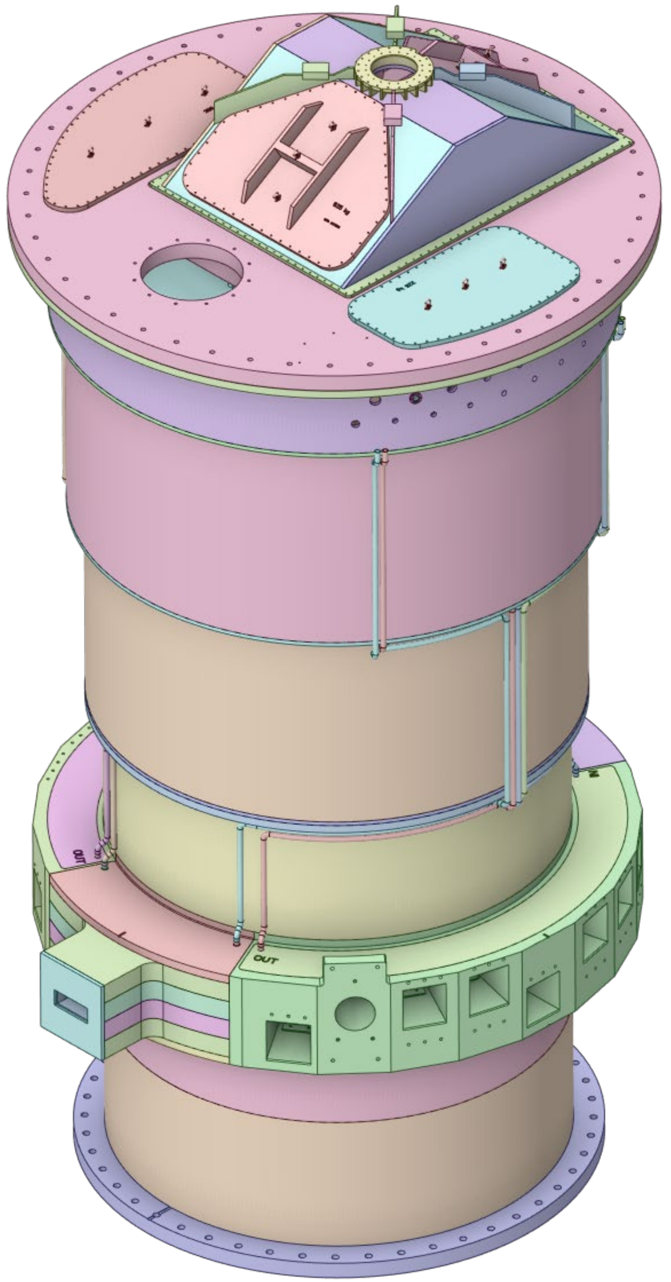
- The following components are directly or indirectly supported by the Core Vessel:
  - Target Assembly
  - Moderator Reflector Assembly
  - Core Vessel Shielding
  - Monolith Inserts (neutron guide optics)
  - Target Viewing Periscope

Relevant mechanical loads:

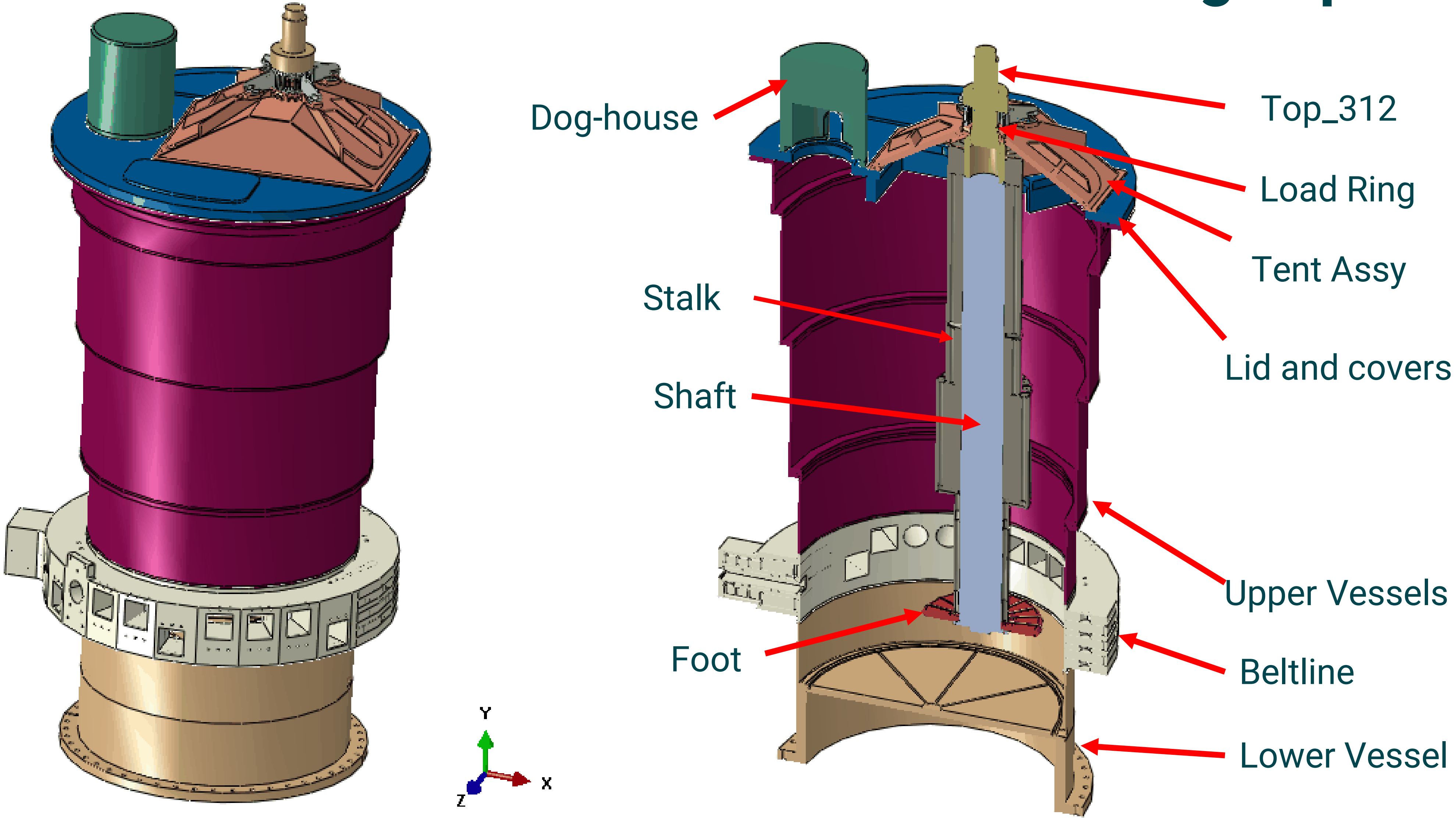
- Gravity
- Internal vacuum
- Cooling water pressure
- Seismic
- Thermal

Core Vessel Structural Requirements:

- Maximum allowable membrane stress = 115 MPa
- Maximum allowable membrane plus bending stress = 172.5 MPa
- Maximum allowable deflections vary based on location



Overall Core Vessel Seismic model with merged parts



Internal Shielding and nozzle extensions not included

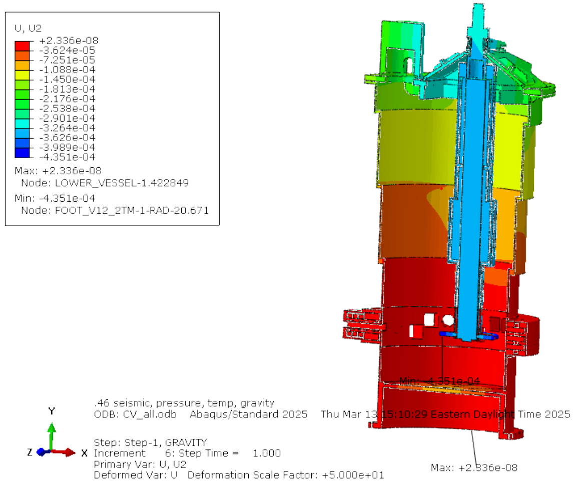
Analysis sequence

- Step 1 – Gravity only with internal shielding weight simulated with a pressure on the core vessel lip
- Step 5 – Added Seismic side load of .072 G to give approximately 5 mm lateral displacement at shaft bottom
- Step 6 – Added Seismic side load of .39 G for a total of .46 G with a 5mm displacement boundary condition applied to nodes at the bottom of the shaft near contact area with snubber ring
- Step 2 – Vacuum pressure loads added
- Step 3 – Internal water pressure load added
- Step 4 – Core vessel CFD temperatures added with all model nodes assumed initially at 36 C stress free and the Core vessel CFD temperature applied to the lower cylinders, beltline, upper cylinders and lid. The results for this step then included all loads

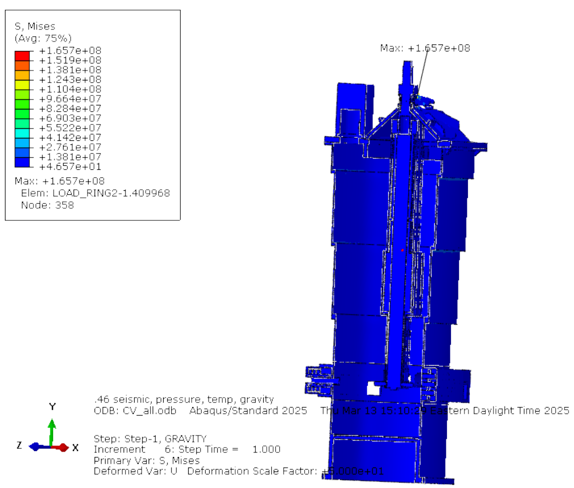
- Seismic analysis assumes the shaft is centered in the snubber ring attached to the core vessel shielding with a 5 mm gap all around
- If the shaft is offset within the ring or if the ring can move under the seismic load, allowing a greater shaft displacement in one direction, the stresses could be significantly increased

Step 1 Gravity loads Results

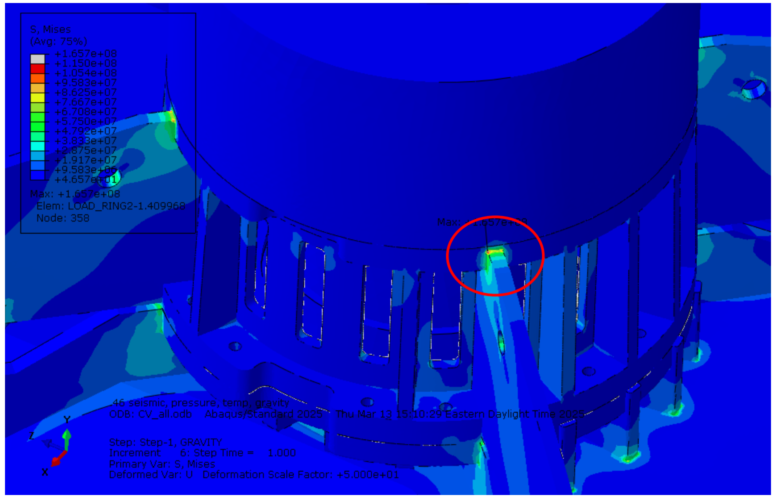
Vertical deflection 0.4 mm max downward



Von Mises Stress



Peak Stress 166 MPa



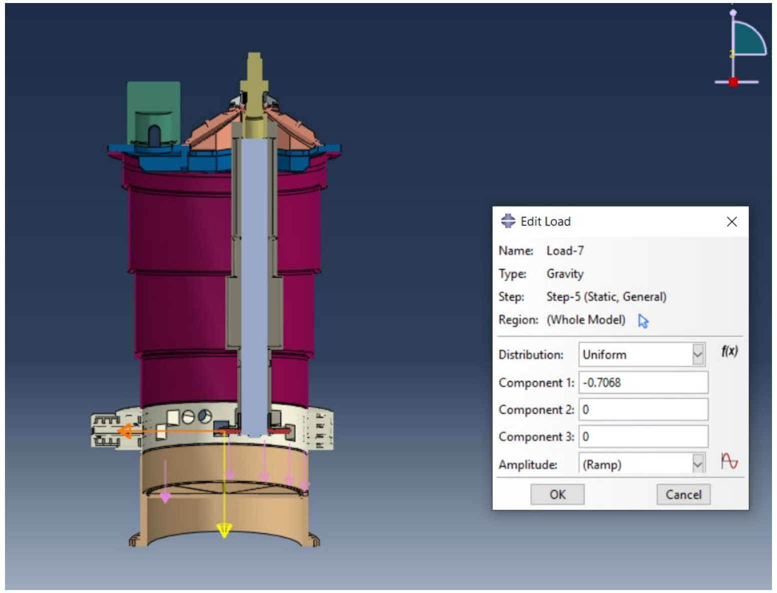
115 MPa scale max

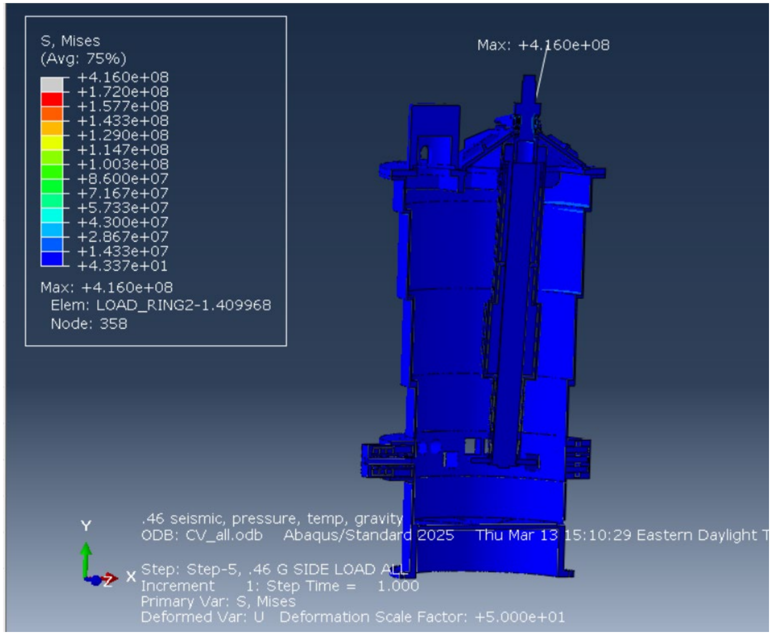
Step 5 Side load to give approximately 5 mm displacement

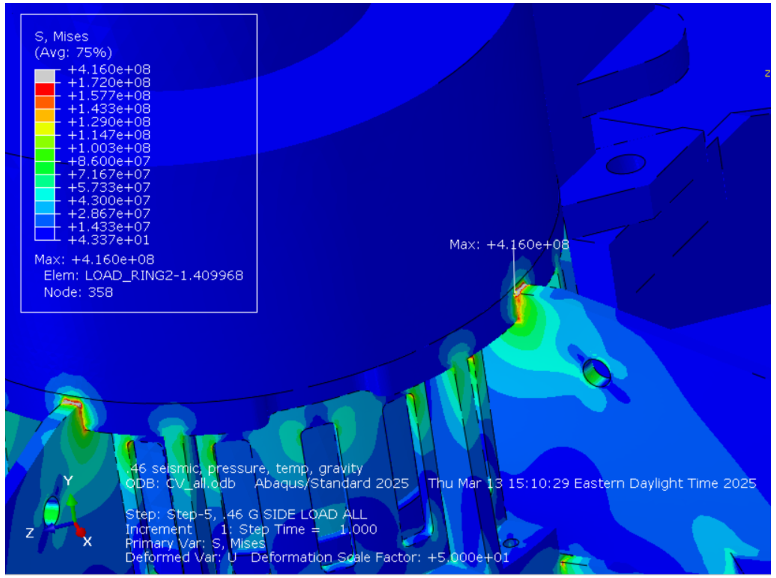
Side load .15 g

Peak stress 416 MPa

Peak at sharp corner and localized



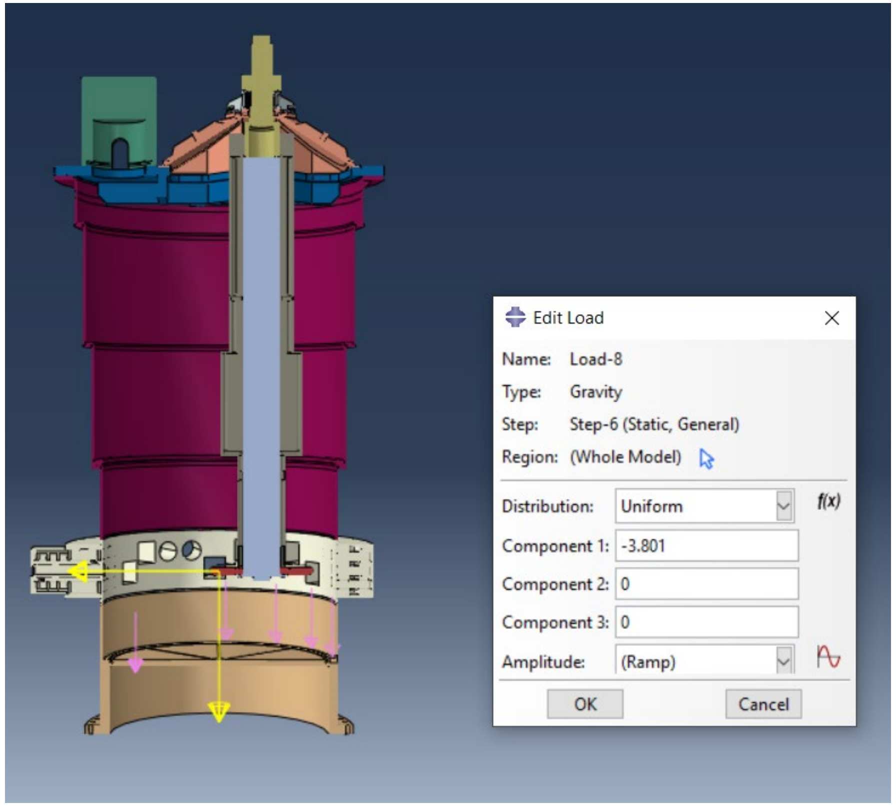




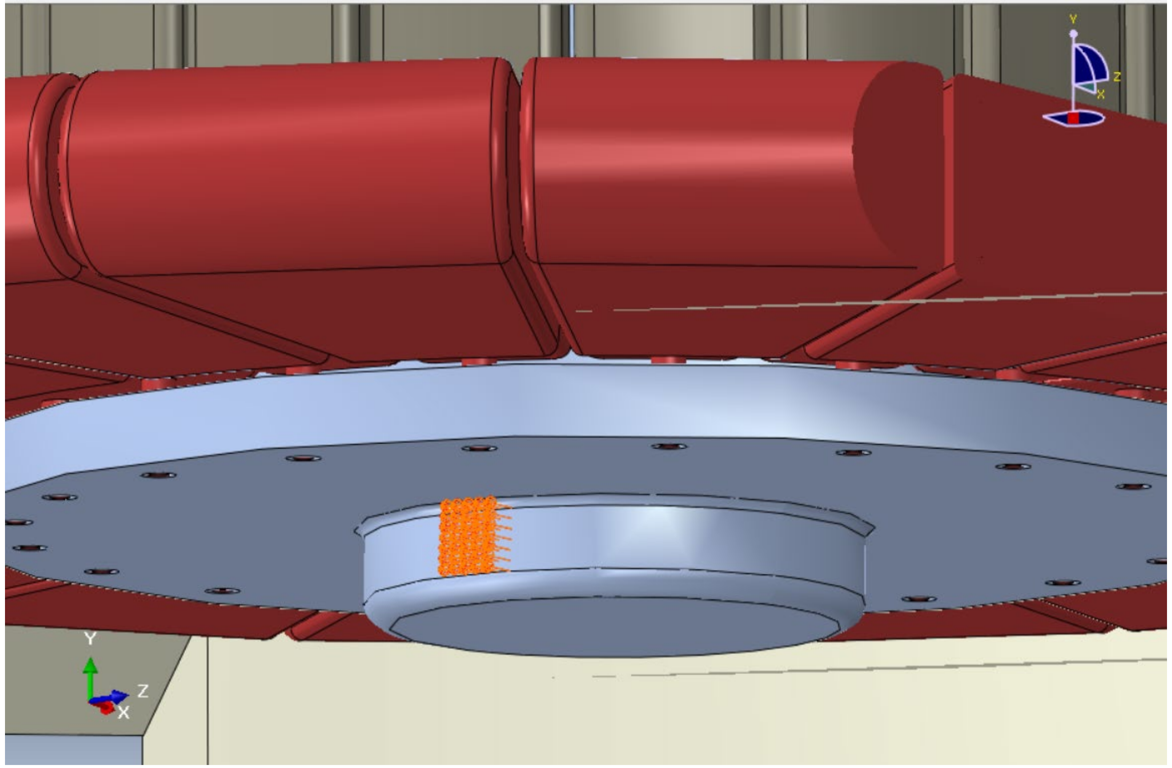
Scale max 1.5 Sm – 172 MPa

This step was included to distinguish stresses incurred from shaft angular deflection from full .46 G side load

Step 6 – side load added to give a total of 0.46 g and 5 mm displacement boundary condition at shaft bottom added

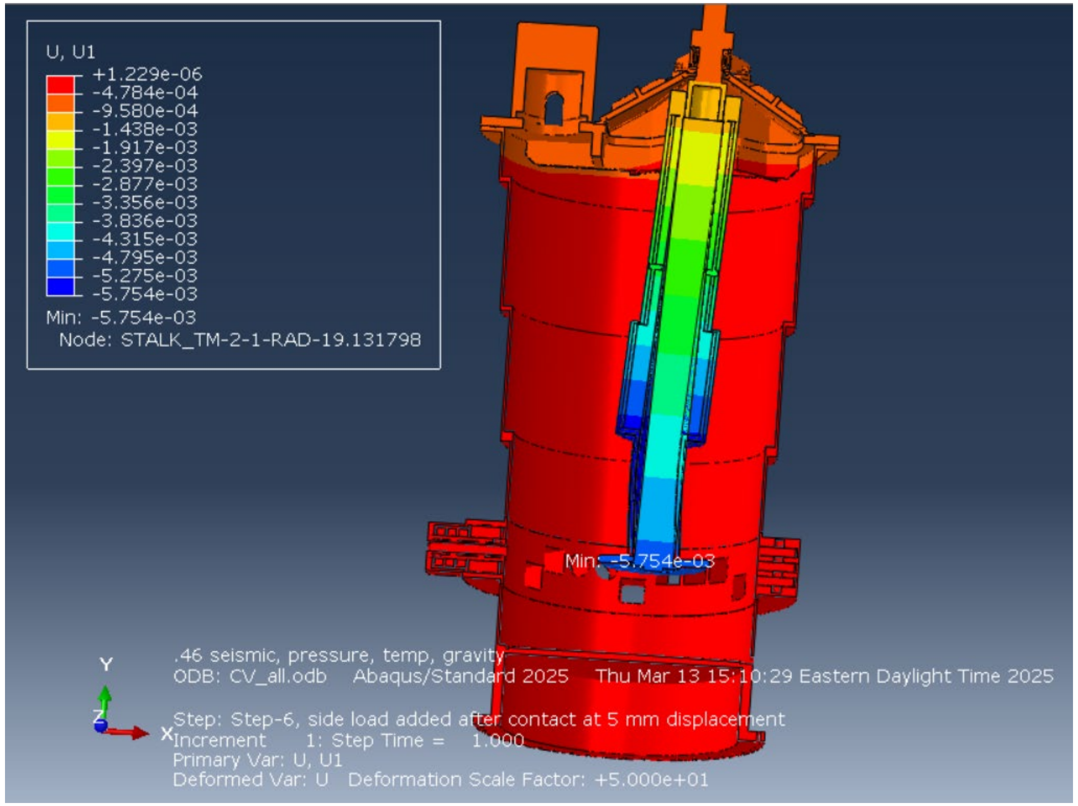


5mm displacement boundary condition

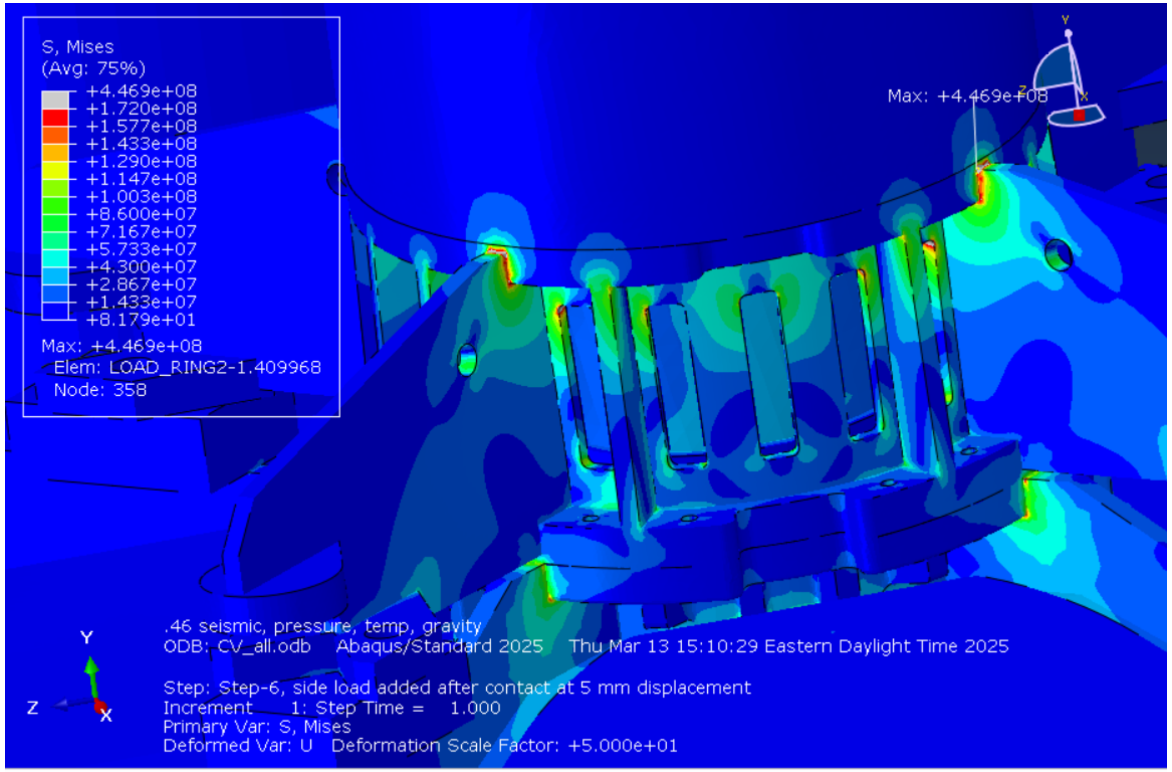


Step 6 gravity plus .46 seismic side load

U1 horizontal displacement peak 5.7 mm

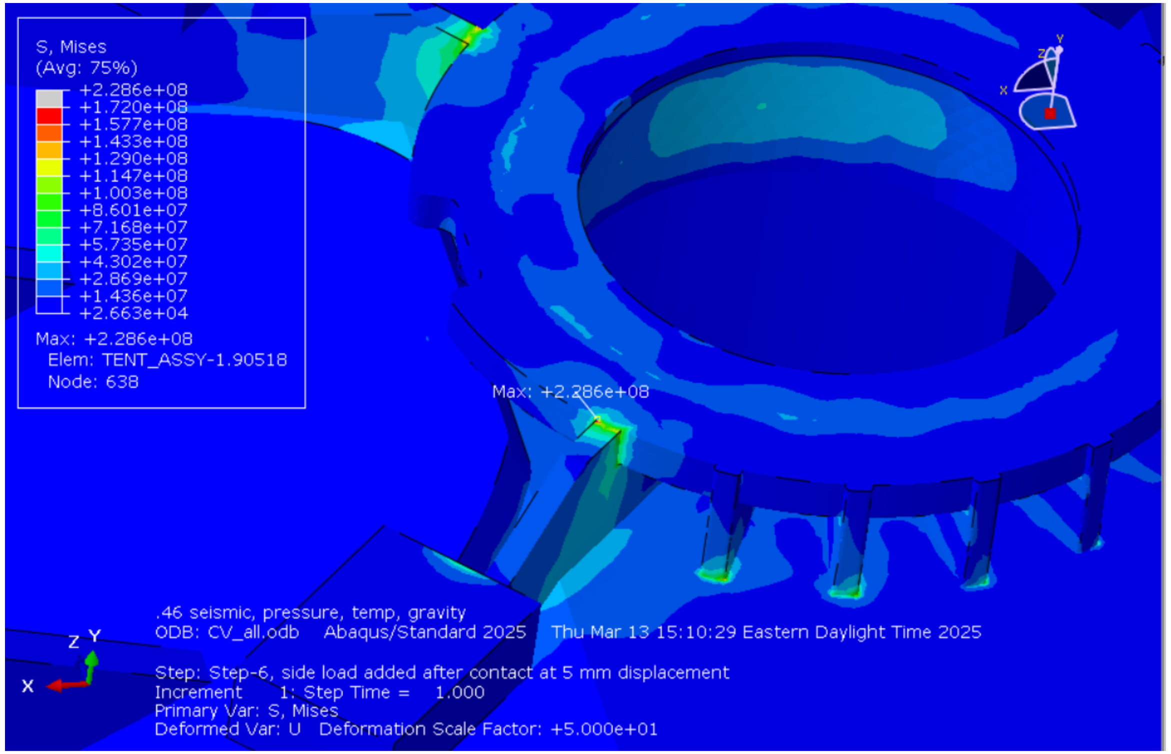


S peak 447 MPa on load ring sharp corner

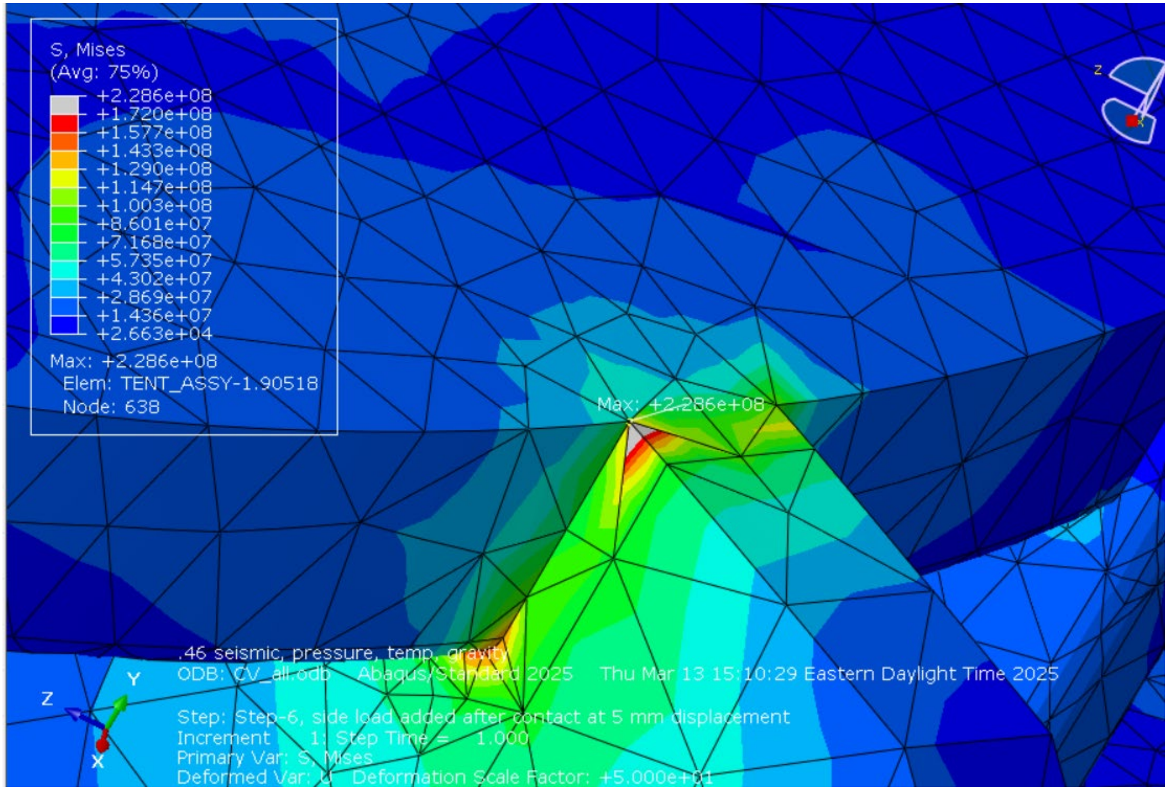


Step 6 Peak stress 226 MPa in core vessel structure by tent

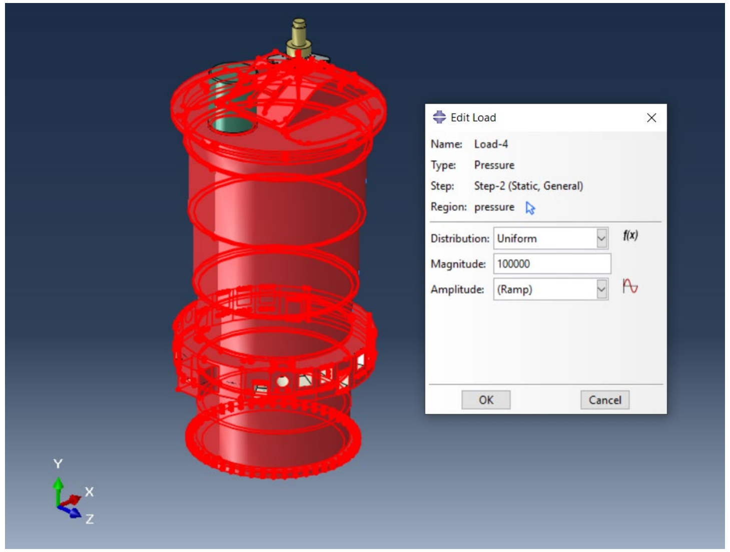
Peak Core Vessel stress 226 MPa

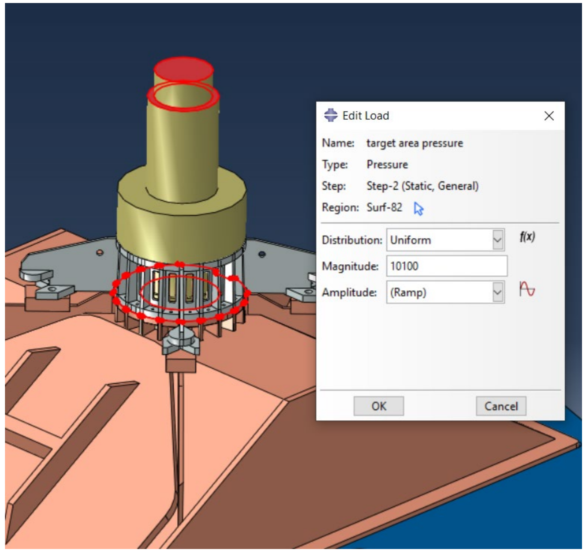


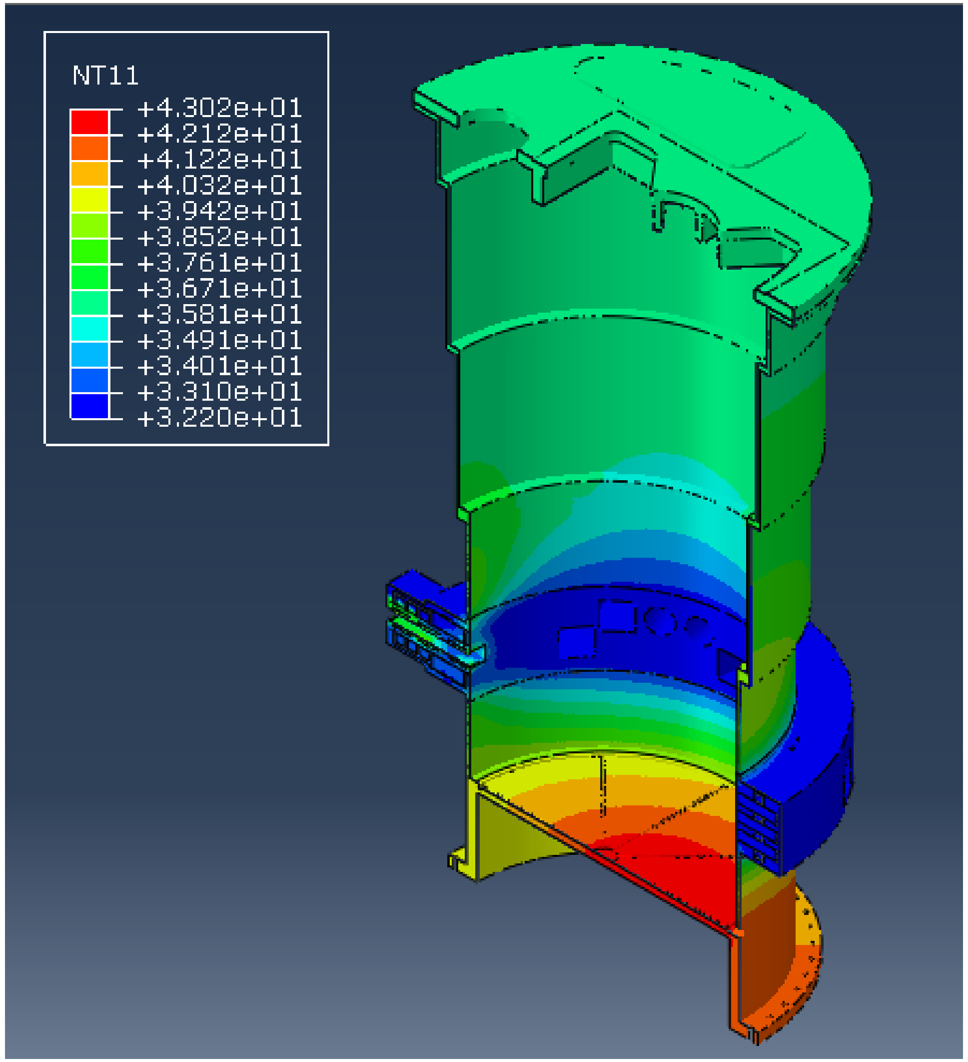
Peak at singularity average below 172 MPa

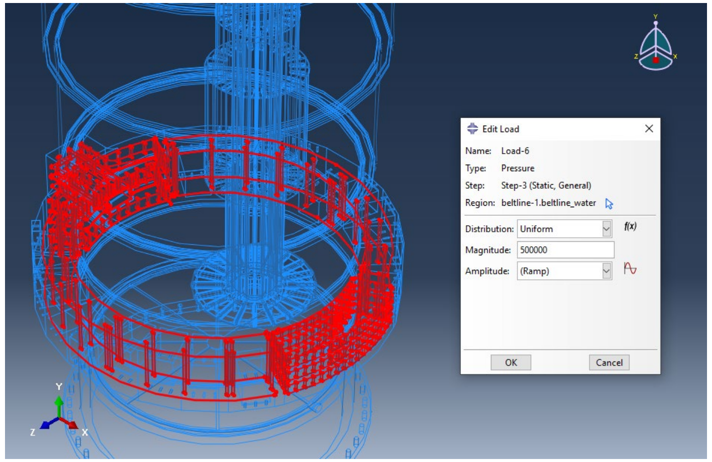


Analysis for Vacuum Pressure, Water Pressure and Thermal loads added to gravity and Seismic loads



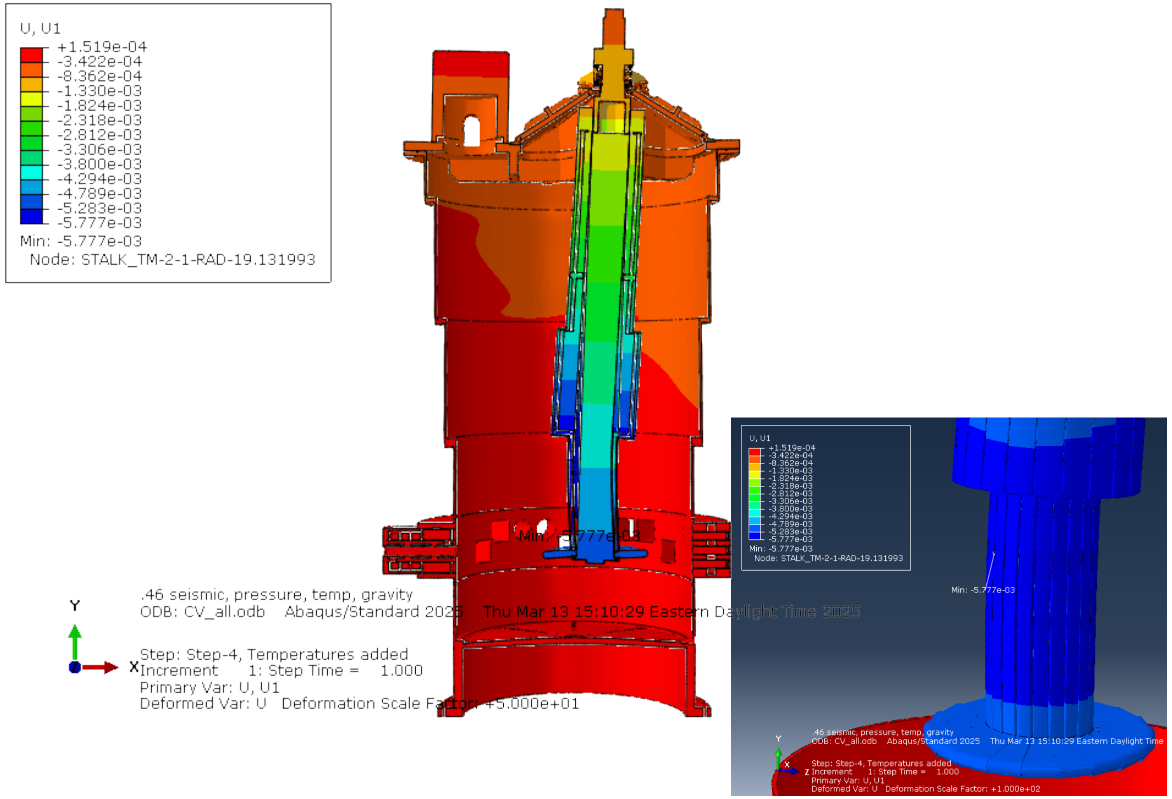




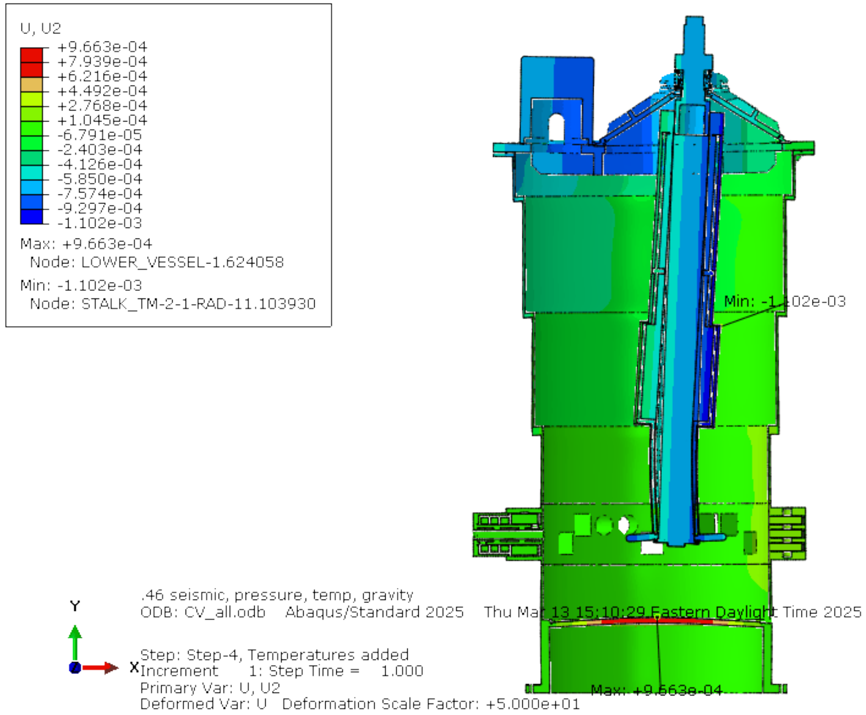


Step 4 Results – Seismic and operational loads

U1 peak 5.8 mm

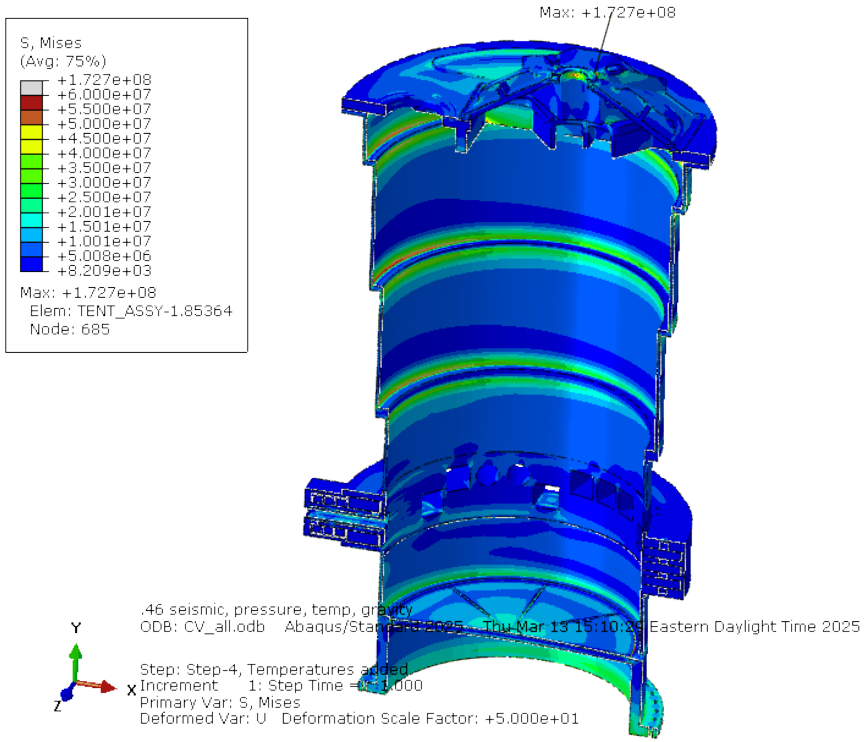


U2 peak 1.1 mm down and 1 mm up at bottom plate

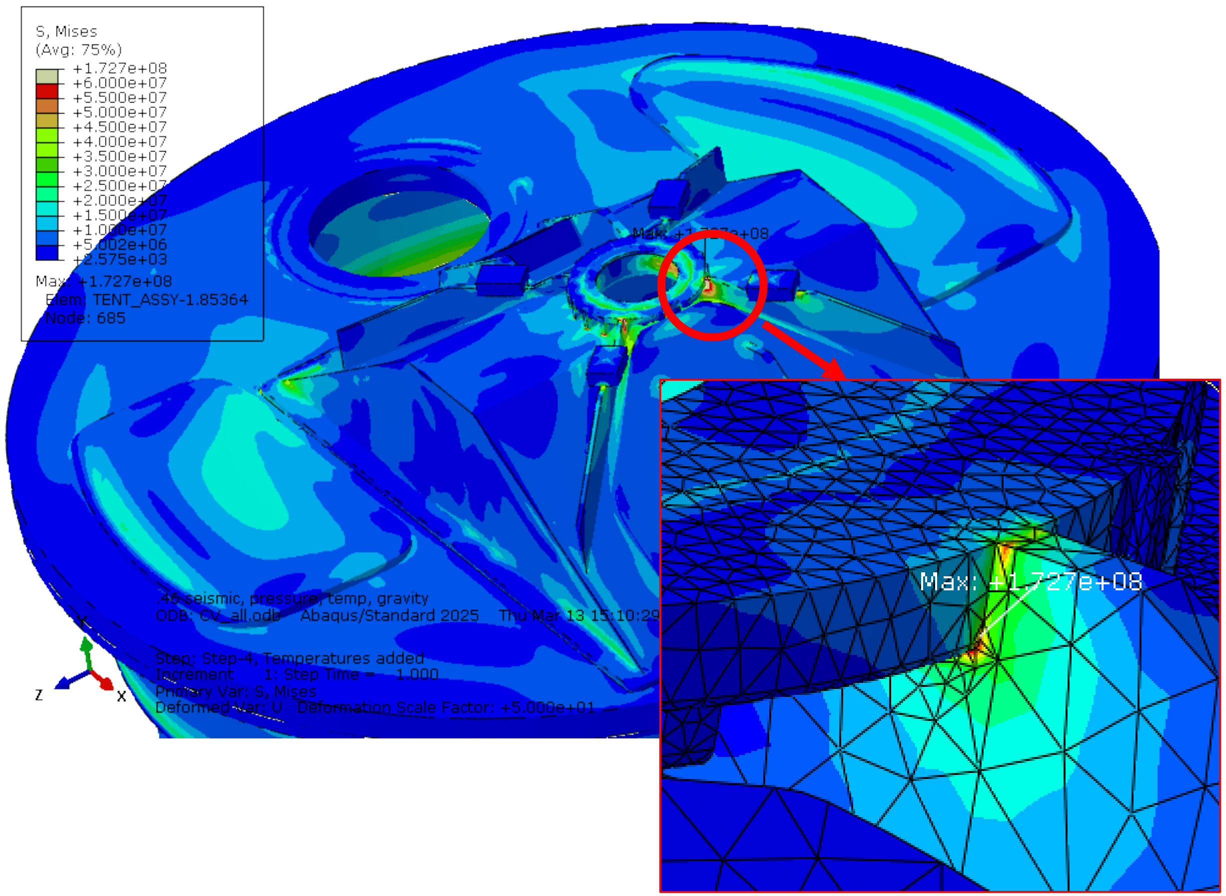


Step 4 Core Vessel Stress Results – Seismic and operational loads

Core Vessel Stress – 172 MPa peak – 60 MPa scale

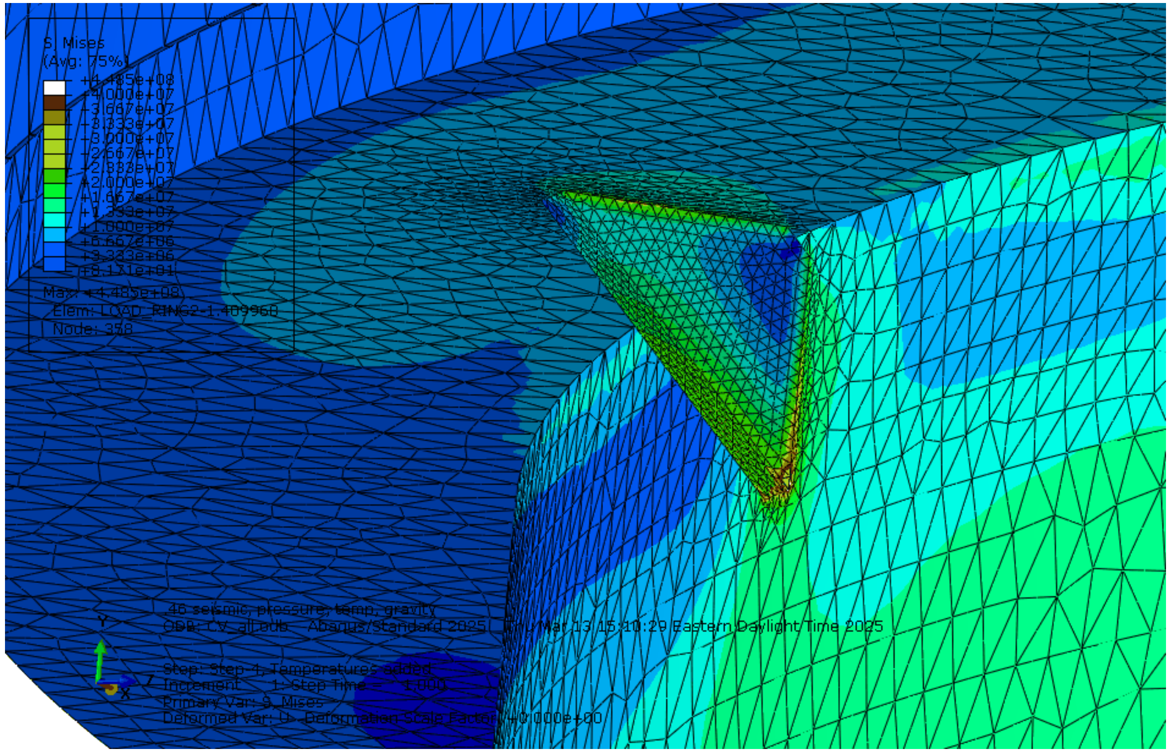


Peak stress 172 MPa by "tent" leg connection

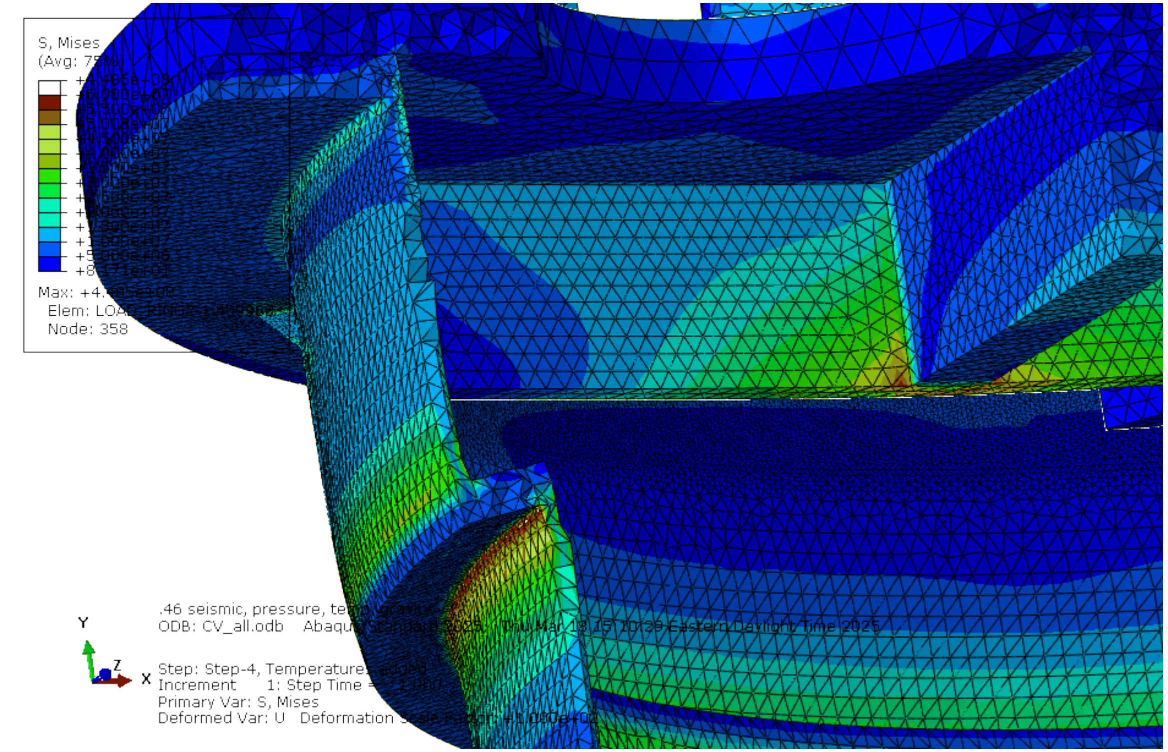


Step 4 Stress Results – Seismic and operational loads

Lid gusset – 40 MPa scale maximum

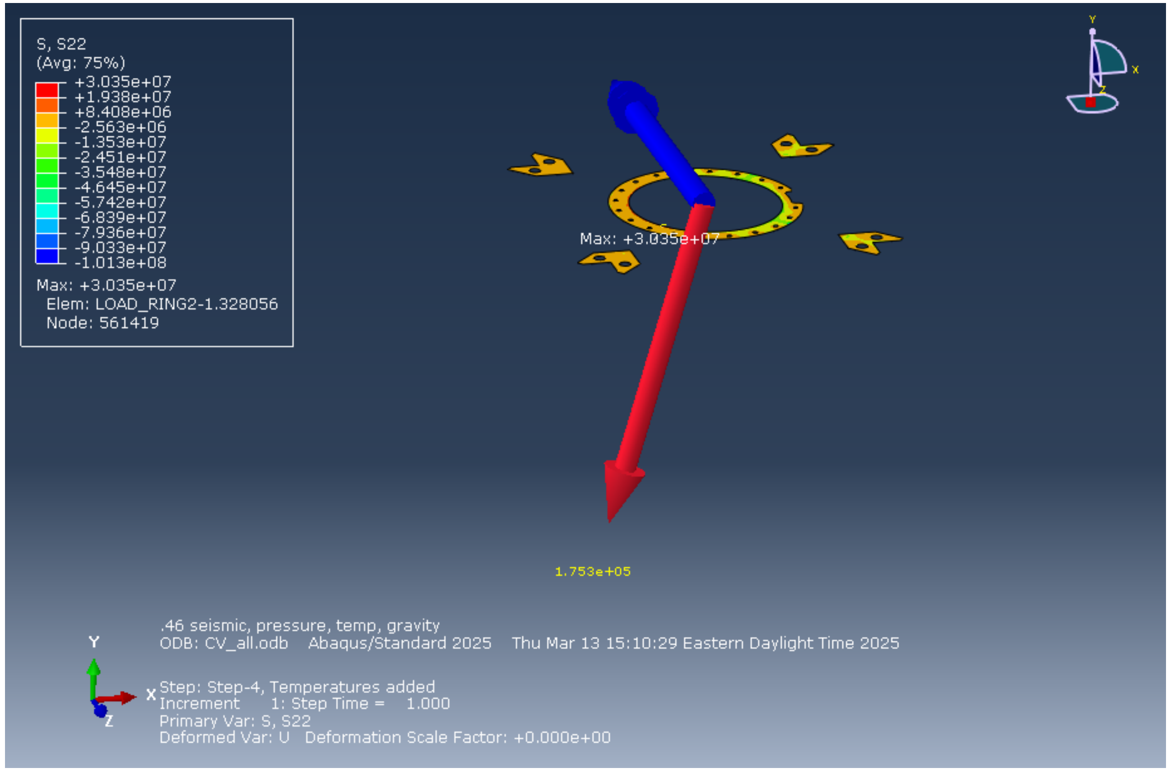


Vessel Stress 60 MPa scale - mesh

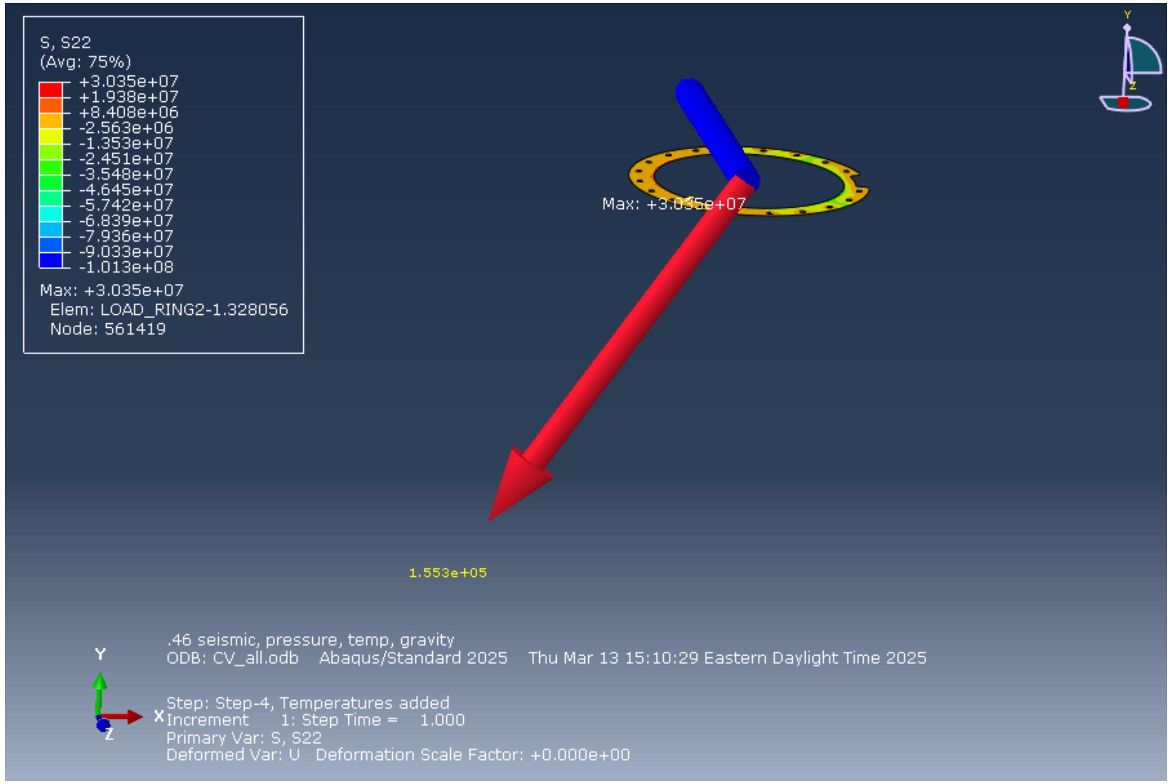


Step 4 results with a cut 1 mm above the load ring tie to the tent assembly

Vertical stress and loads at bottom of load ring and legs



Vertical stress and load in central ring



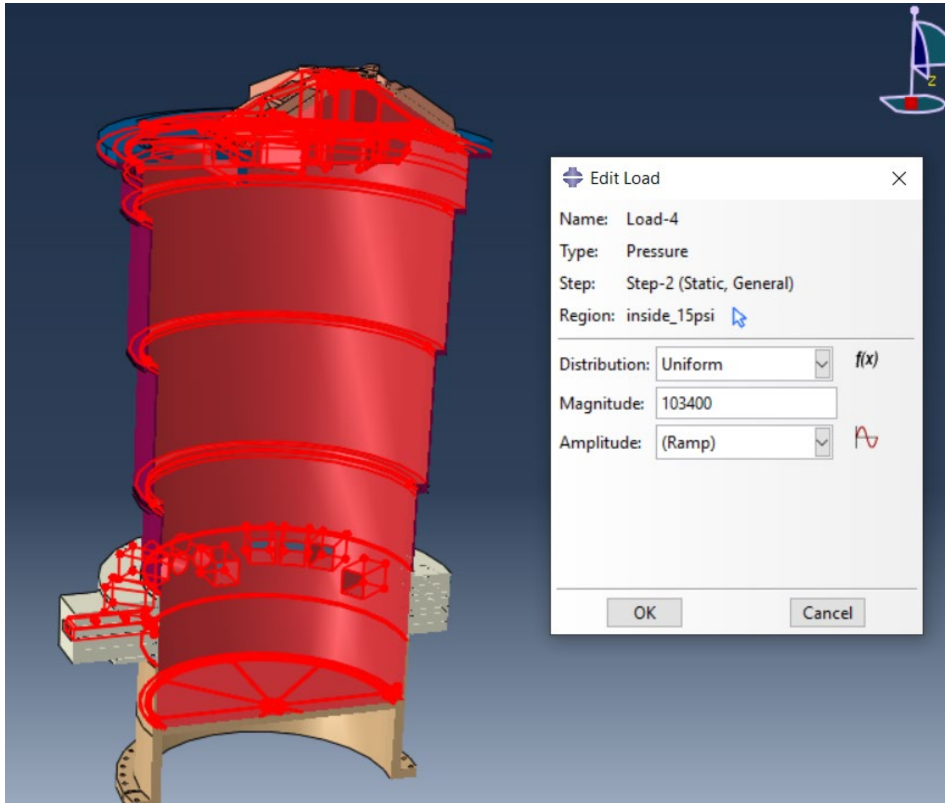
Approximately 88% of the vertical load is transmitted to the central ring

The overpressure case with 15 PSIG internal pressure was evaluated

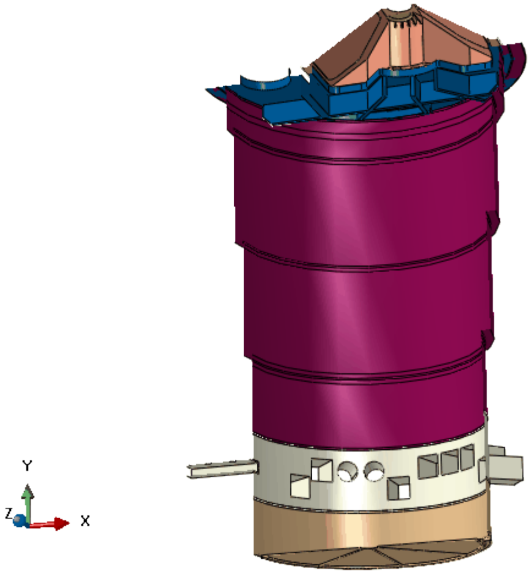
- The external pressure of 1 bar in step 2 was replaced with an internal pressure of 103400 Pa (15 PSIG)
- All other loads were applied as previously done including seismic displacement and imported temperature profile

Internal 15 PSIG case added for Step 2

Internal 15 psig on core vessel

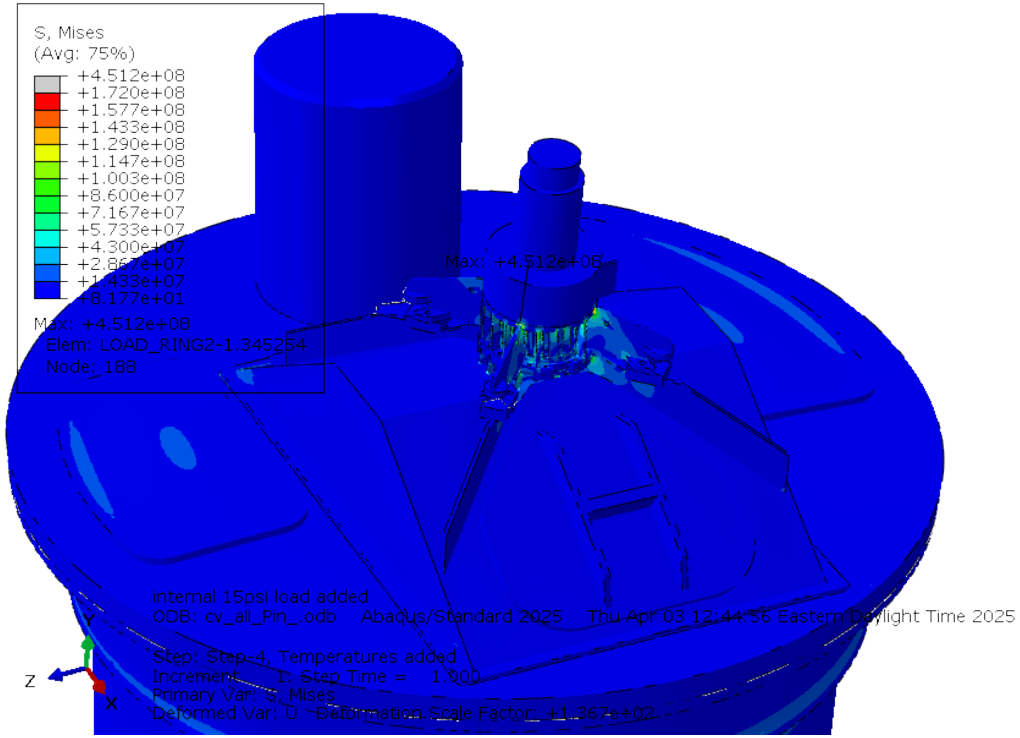


Surfaces with 15 PSIG applied

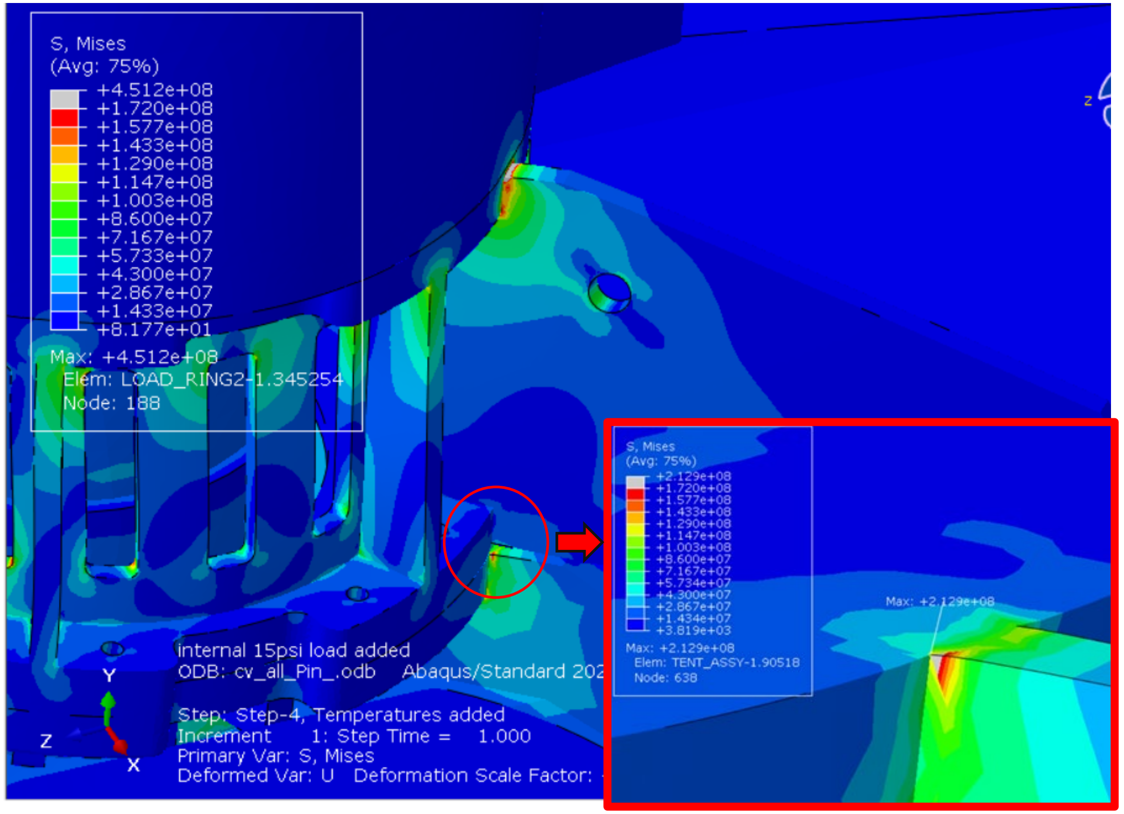


Mises stress with combined loads including internal pressure

S Mises = 172 MPa scale maximum

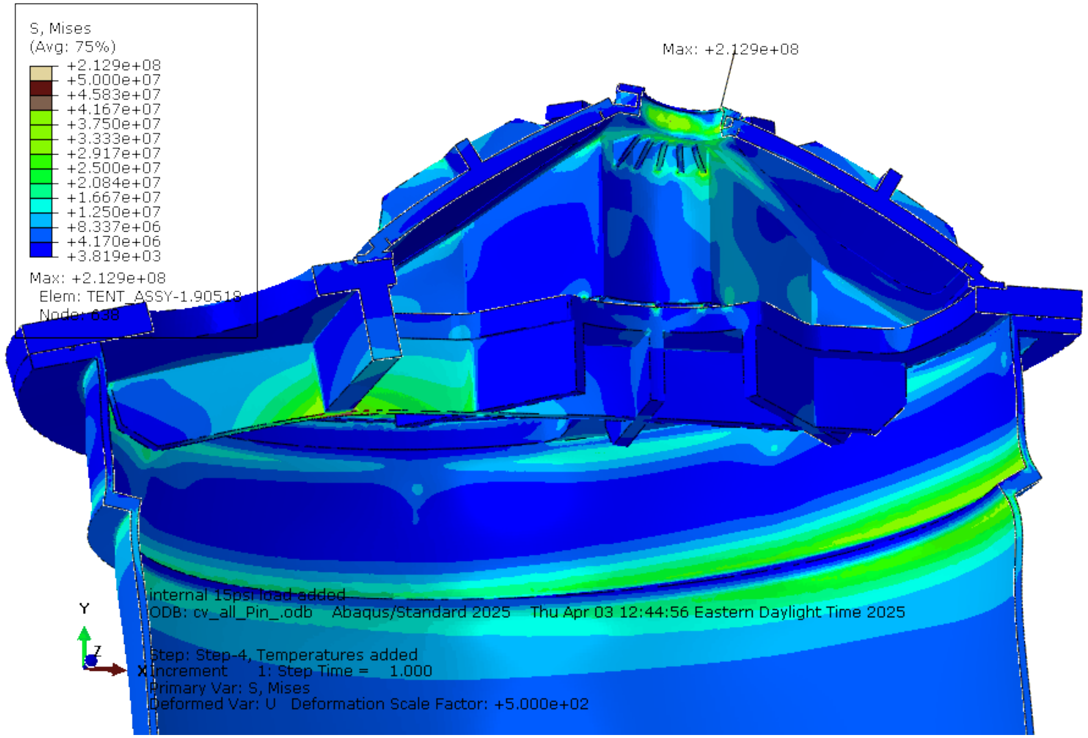


Peal stress 213 MPa in core vessel

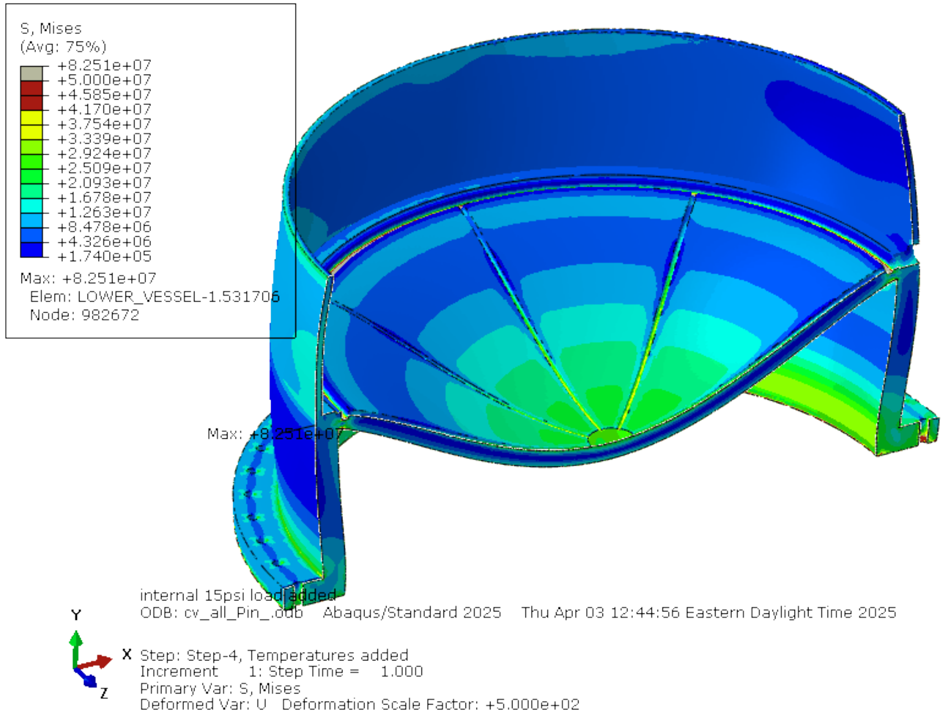


Peak core vessel stresses with all loads still driven by shaft displacement with a peak of 213 MPa at a corner singularity

Von Mises stress with 50 MPa scale maximum



Peak stress in lower cylinder of 82 MPa in drainage groove – 50 MPa scale



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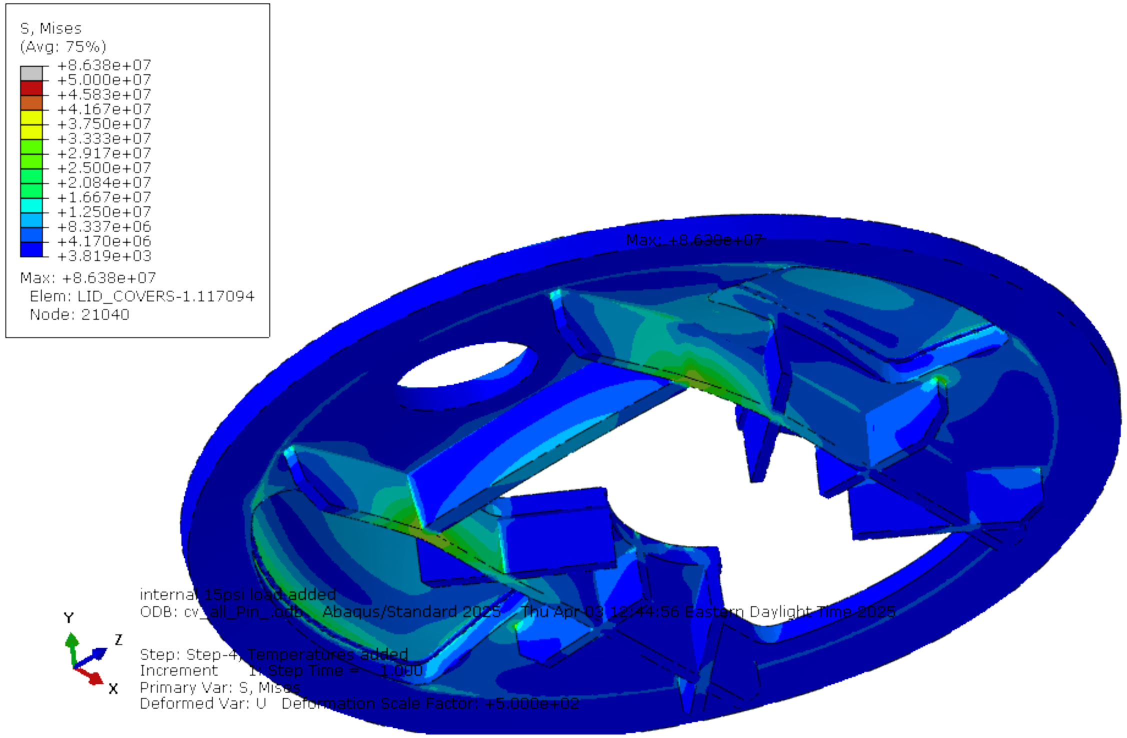
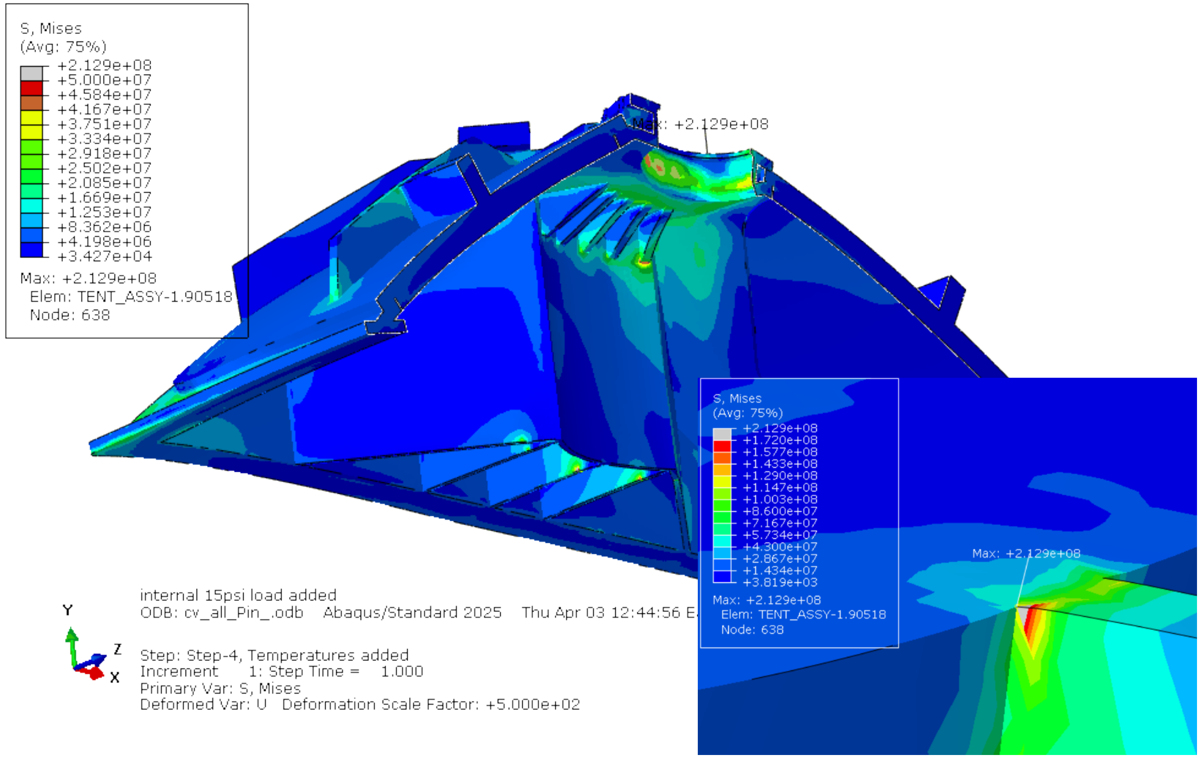
Component Stresses with all loads including internal pressure

Lid and Covers – peak 86 MPa



Tent Assembly 50 MPa scale – peak 213



Summary

- Results are preliminary and do not include any bolt analysis
- Elastic material properties assumed
- Mesh refinement in some high stress locations would be desirable
- Lower Vessel thermal stresses assume a 36 C base plate temperature
- Loads do not include nozzle extensions
- Approximately 88 % of the vertical gravity loads from the target assembly go through the central ring structure and only approximately 12 % is carried by the "legs"
- Calculated Core vessel stresses all are at or below the 172 MPa limit for 1.5 Sm on membrane plus bending including a .46 G seismic load in the beam upstream direction and vacuum operation
- The target shaft load ring and core vessel peak stresses are driven by the angular deflection of the stiff shaft
- The peak stresses are very sensitive to the amount of deflection at the base of the shaft within the nominal 5 mm gap from the restraint ring

Summary (continued)

- An internal pressure of 15 psig instead of vacuum increased the peak stress at the tent leg connection corner singularity from 172 MPa to 213 MPa including a 5 mm seismic displacement at the bottom of the shaft
- Stresses from the internal pressure were generally below 90 MPa except at the singularity by the leg connection
- Cover plate stresses from internal pressure did not consider bolt loads and assumed merged surfaces

Summary (continued)

Relevant mechanical loads:

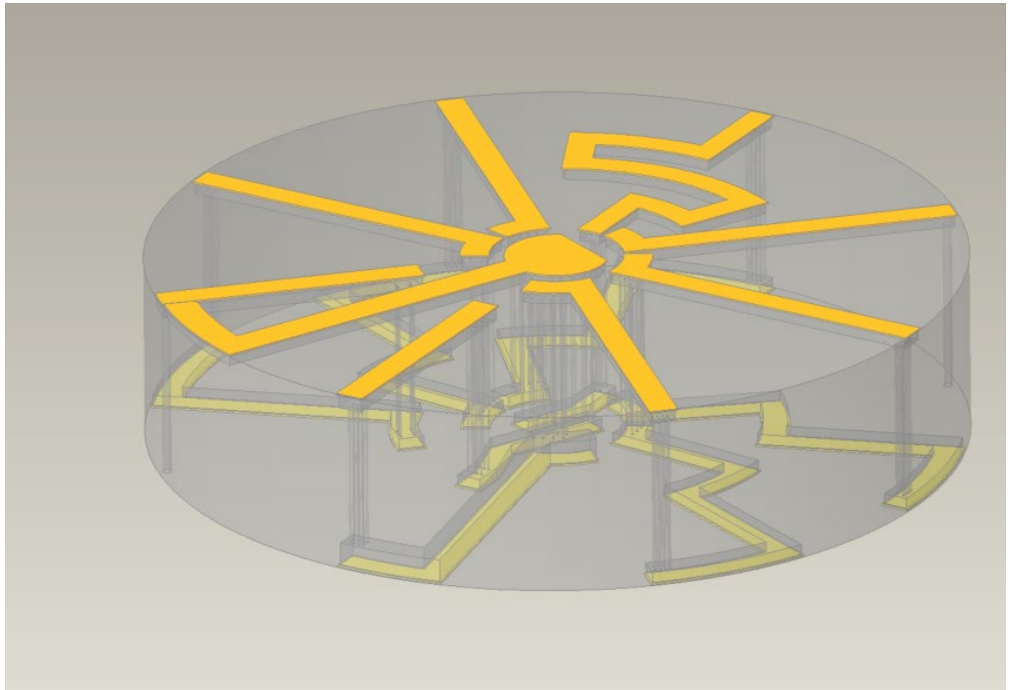
- Gravity → Included
- Internal vacuum → Included
- Cooling water pressure → Included
- Seismic → Included
- Thermal → Included

Core Vessel Structural Requirements:

- Maximum allowable membrane stress = 115 MPa
  - Maximum stress observed in CV shells = ~ 60 MPa → PASS
- Maximum allowable membrane plus bending stress = 172.5 Mpa
  - Maximum bending stress in bottom lid = ~80 MPa → PASS
  - Maximum bending stress in top lid under vacuum loading = 172 MPa → PASS
  - Maximum bending stress in top lid under pressure loading = 213 MPa → FAIL
    - This scenario combines simultaneous seismic and overpressure loads
- A comprehensive deflection analysis will be performed during final design

Shield Block #1 Introduction and Requirements

- The following components are directly or indirectly supported by Shield Block #1:
    - Target Assembly Snubber
    - Moderator Reflector Assembly
    - Core Vessel Shielding
    - Target Viewing Periscope



Relevant mechanical loads:
- Gravity
- Internal vacuum
- Cooling water pressure
- Seismic
- Thermal

Core Vessel Structural Requirements:
- Maximum allowable membrane stress = 115 MPa
- Maximum allowable membrane plus bending stress = 172.5 MPa
- Maximum allowable deflections vary based on location

Cooled Block #1 Structural Analysis

Stainless Steel

Density	7750	kg/m^3

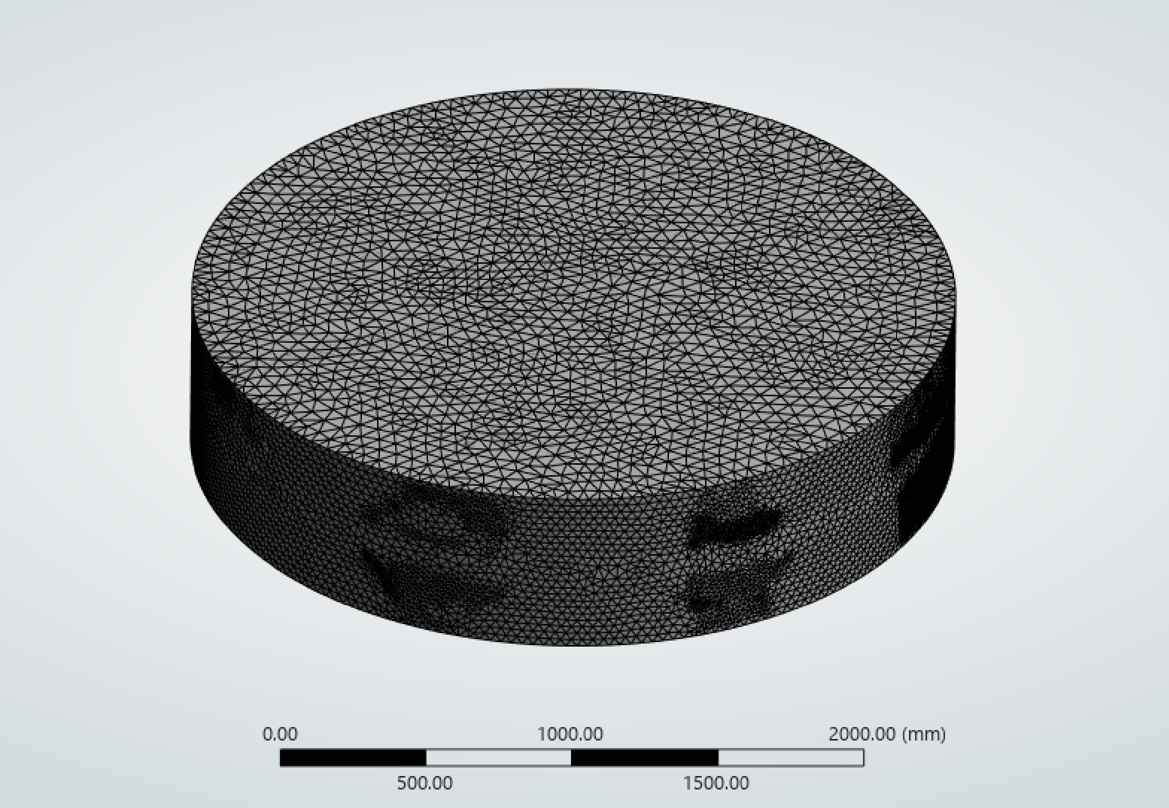
Structural

Isotropic Elasticity		
Derive from	Young's Modulus and Poisson's Ratio	
Young's Modulus	1.93e+11	Pa
Poisson's Ratio	0.31	
Bulk Modulus	1.693e+11	Pa
Shear Modulus	7.3664e+10	Pa
Isotropic Secant Coefficient of Thermal Expansion	1.7e-05	1/°C
Compressive Ultimate Strength	0	Pa
Compressive Yield Strength	2.07e+08	Pa
Tensile Ultimate Strength	5.86e+08	Pa
Tensile Yield Strength	2.07e+08	Pa

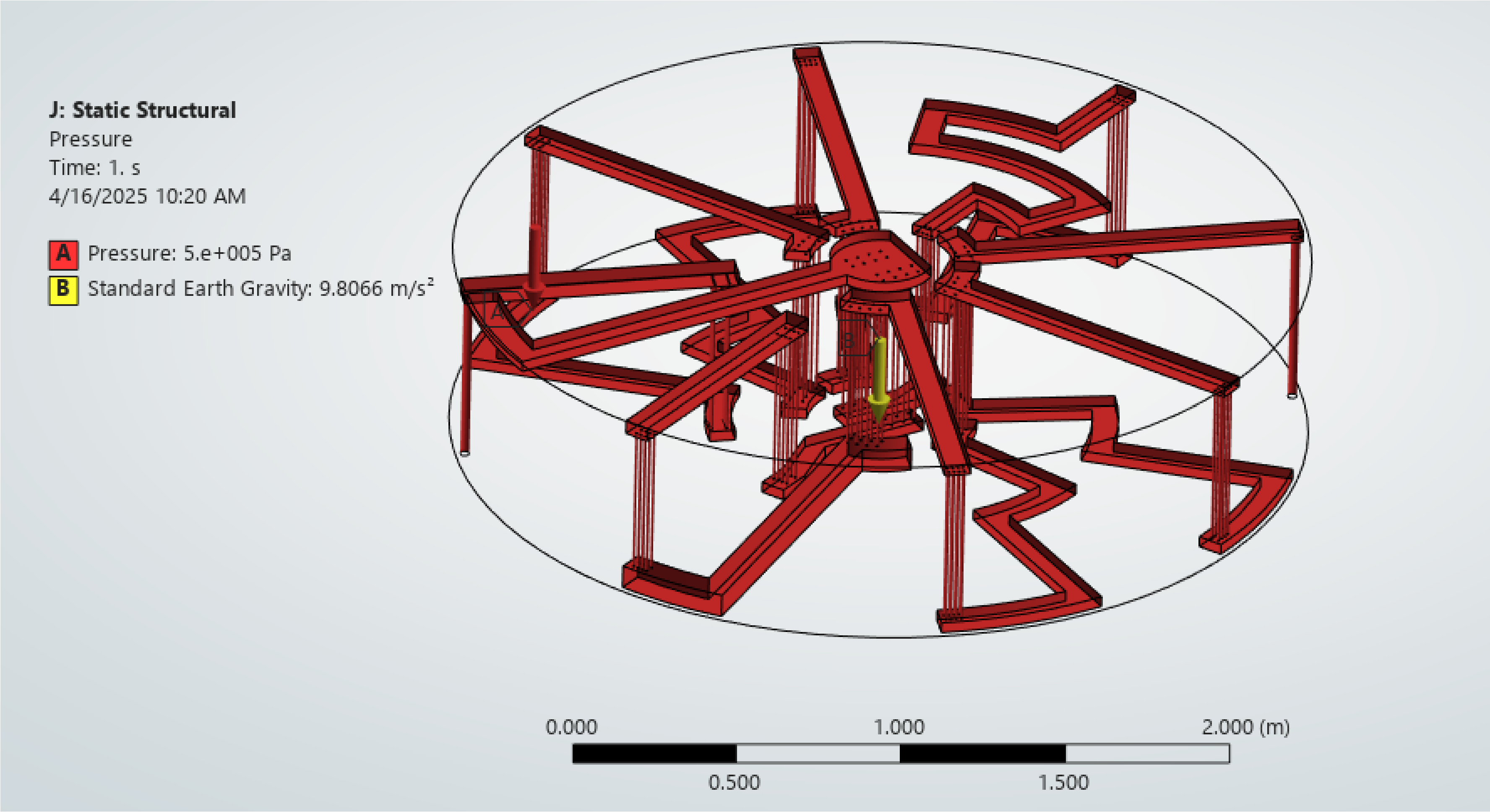
Thermal

Isotropic Thermal Conductivity	15.1	W/m·°C
Specific Heat Constant Pressure	480	J/kg·°C

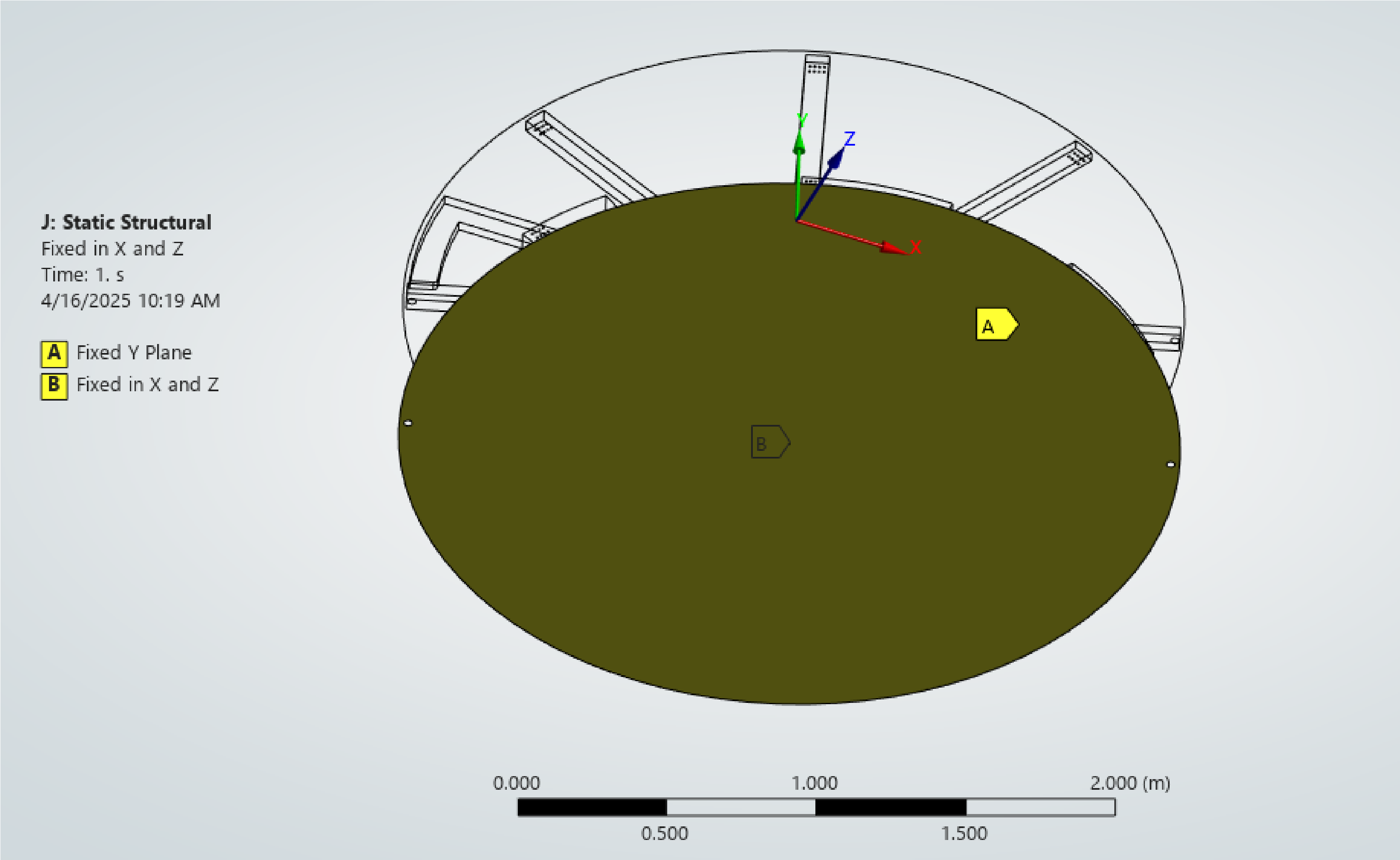
Statistics	
Nodes	1425468
Elements	966921
Show Detailed St...	No



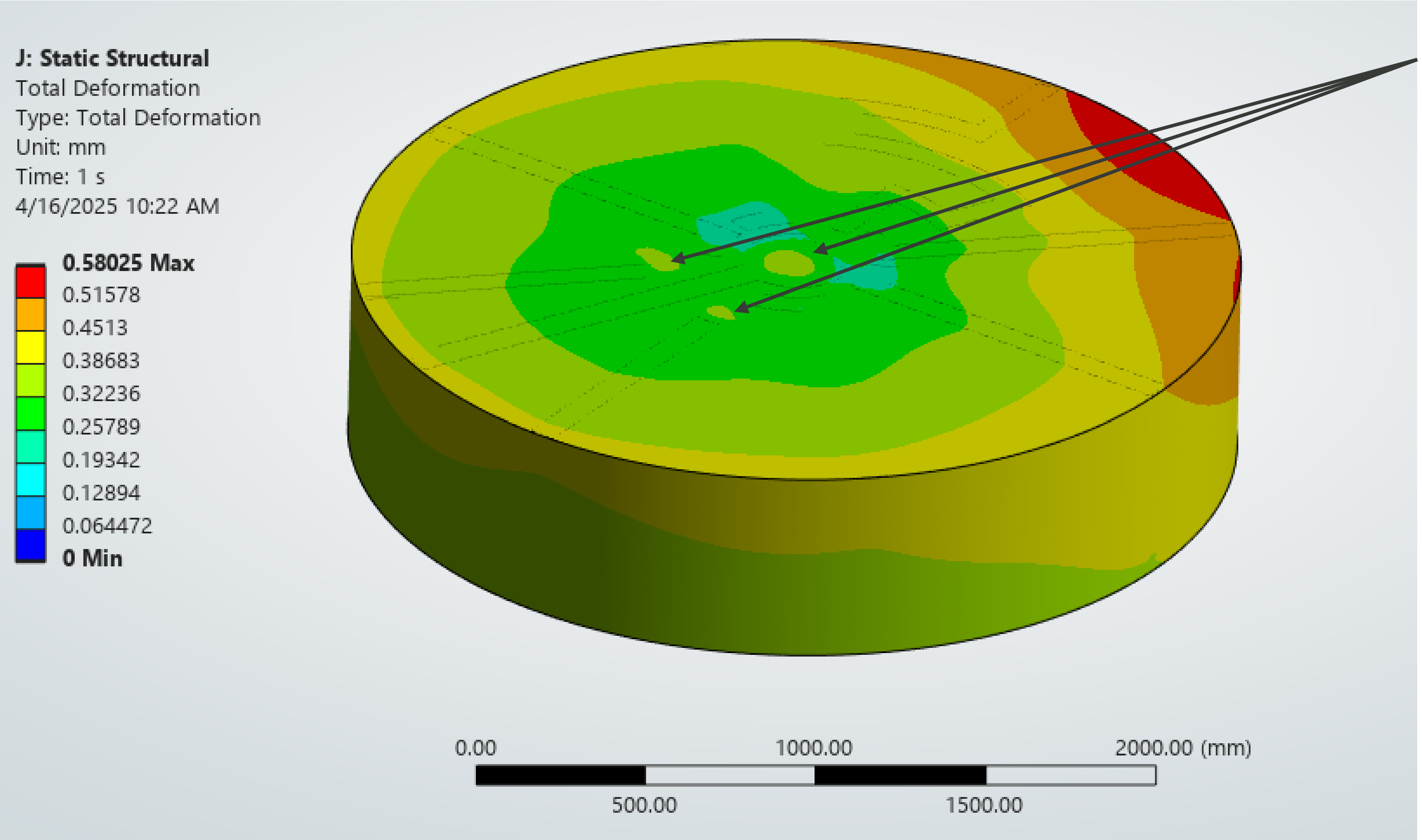
Structural Analysis Applied Loads



Structural Analysis Boundary Conditions

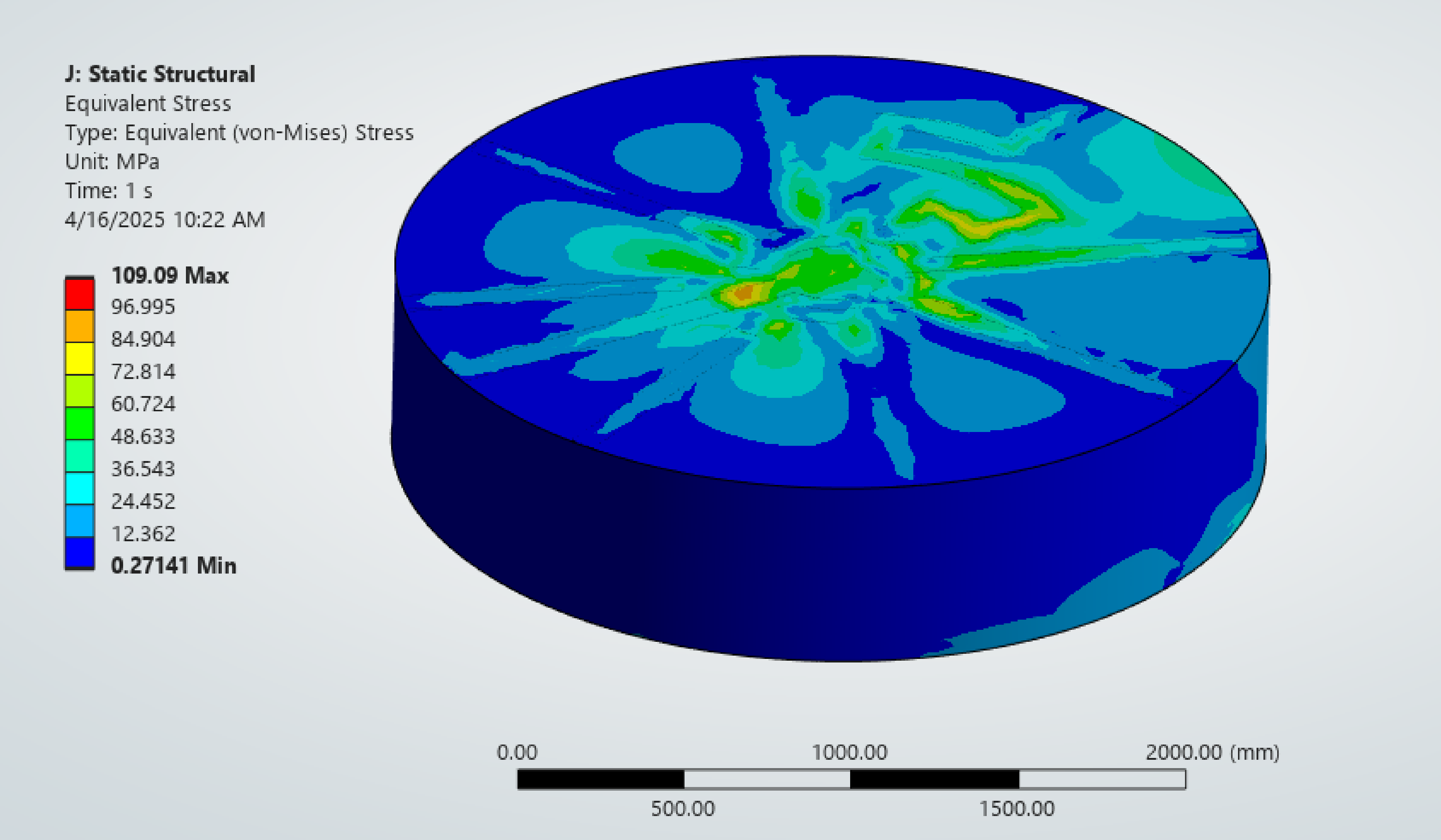


Structural Analysis Deformation Results



MRA Landing Points

Structural Analysis Stress Results



Shield Block #1 Summary of Results

Relevant mechanical loads:

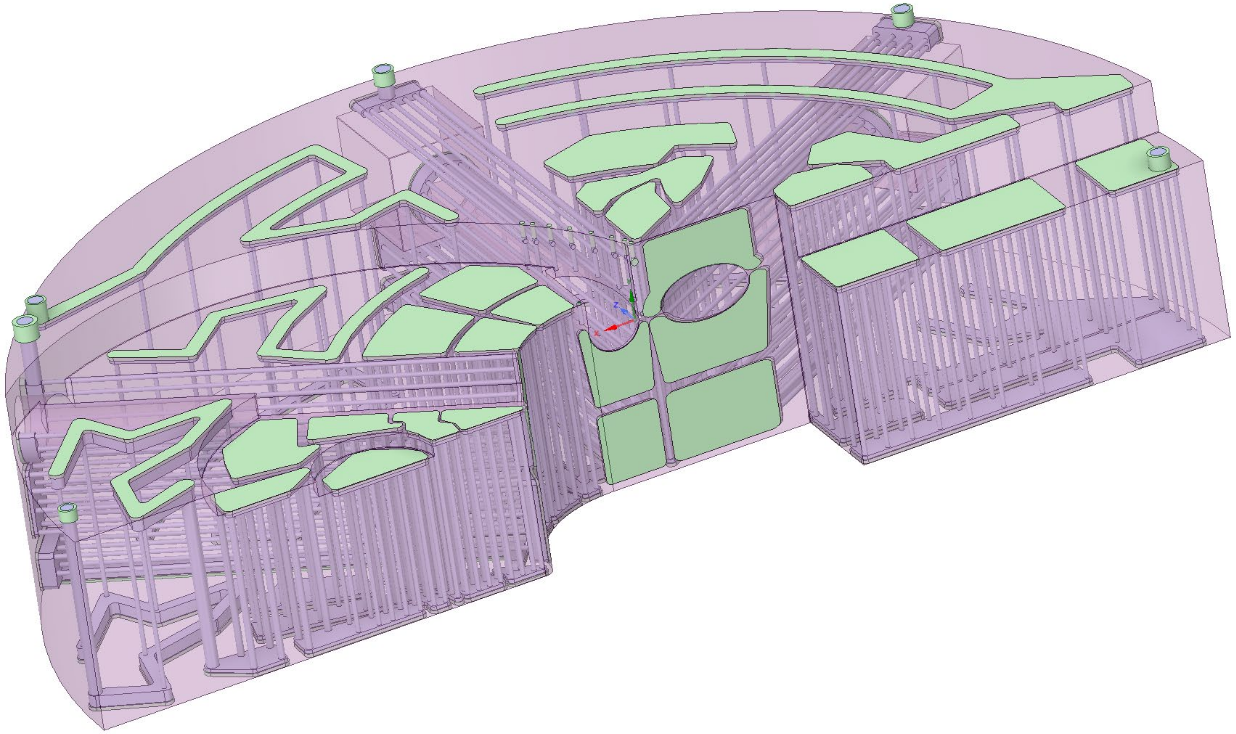
- Gravity → Partially Applied
- Internal vacuum → Applied
- Cooling water pressure → Applied
- Seismic → Not Applied
- Thermal → Applied

Core Vessel Structural Requirements:

- Maximum allowable membrane stress = 115 MPa
  - Maximum stress in shield block body ~ 50 MPa → PASS
- Maximum allowable membrane plus bending stress = 172.5 MPa
  - Maximum stress in cover plates (bending) = 109 MPa → PASS
- Maximum allowable deflections vary based on location
  - Maximum deflection at far edge = 0.58mm
  - Maximum deflection at moderator anchor points = 0.35mm

Shield Block #3 Introduction and Requirements

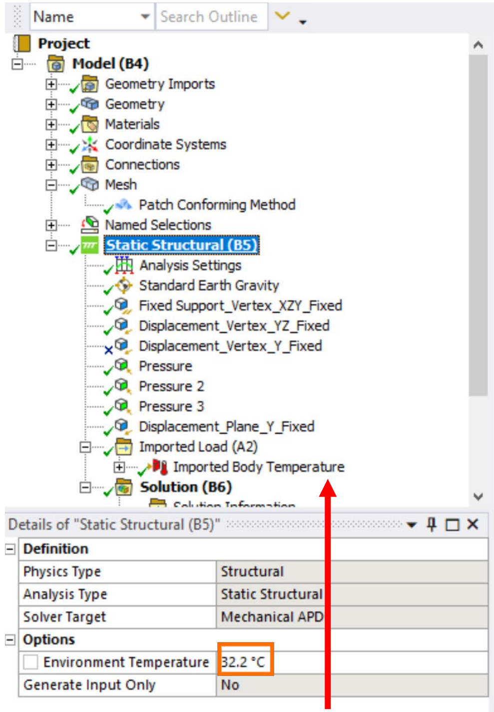
- The following components are directly or indirectly supported by Shield Block #1:
  - Target Assembly Snubber
  - Core Vessel Shielding
  - Target Viewing Periscope

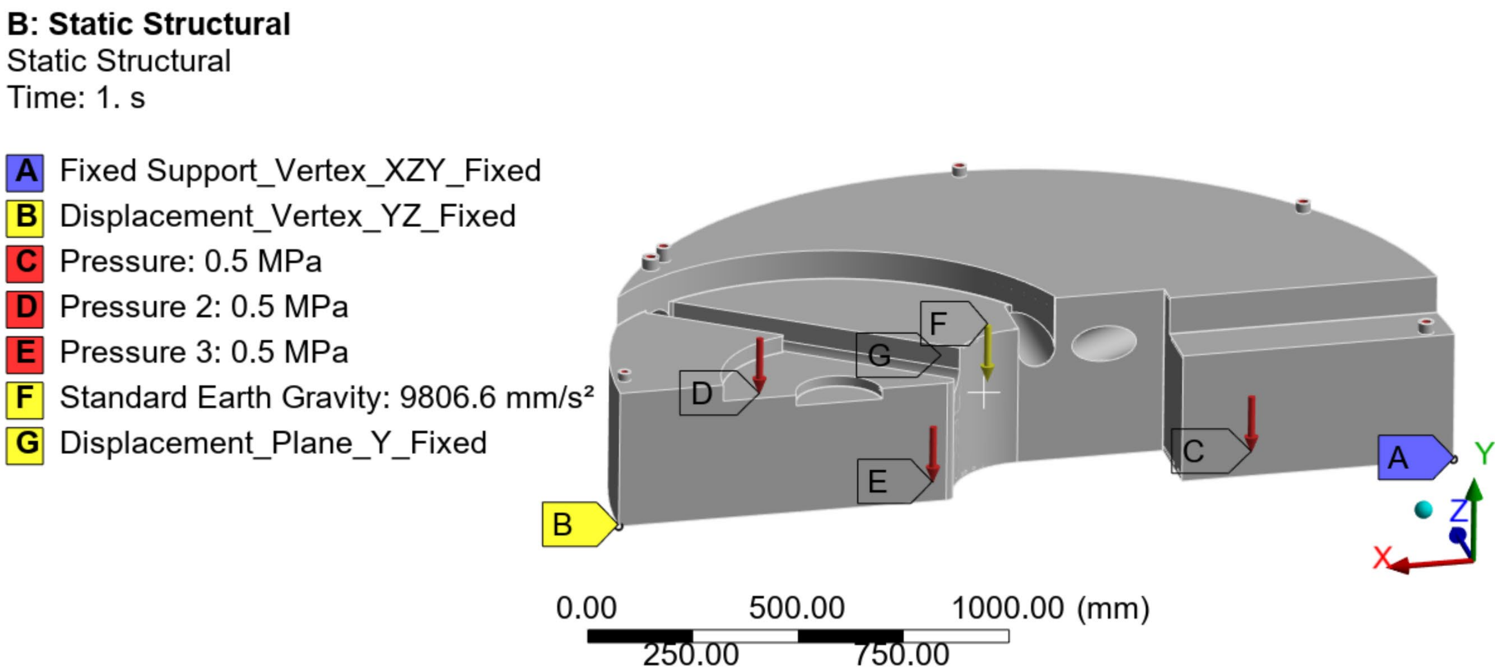


Relevant mechanical loads:
- Gravity
- Internal vacuum
- Cooling water pressure
- Seismic
- Thermal

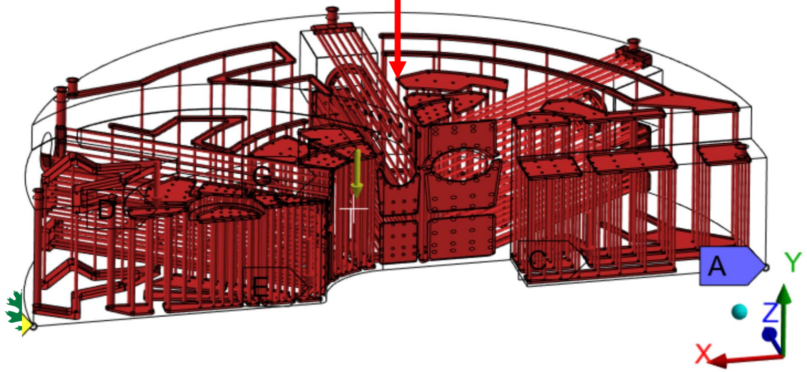
Core Vessel Structural Requirements:
- Maximum allowable membrane stress = 115 MPa
- Maximum allowable membrane plus bending stress = 172.5 MPa
- Maximum allowable peak stress under self-limiting conditions = 345 MPa

Shield Block #3, SS316 (Design_31) Structural BCs





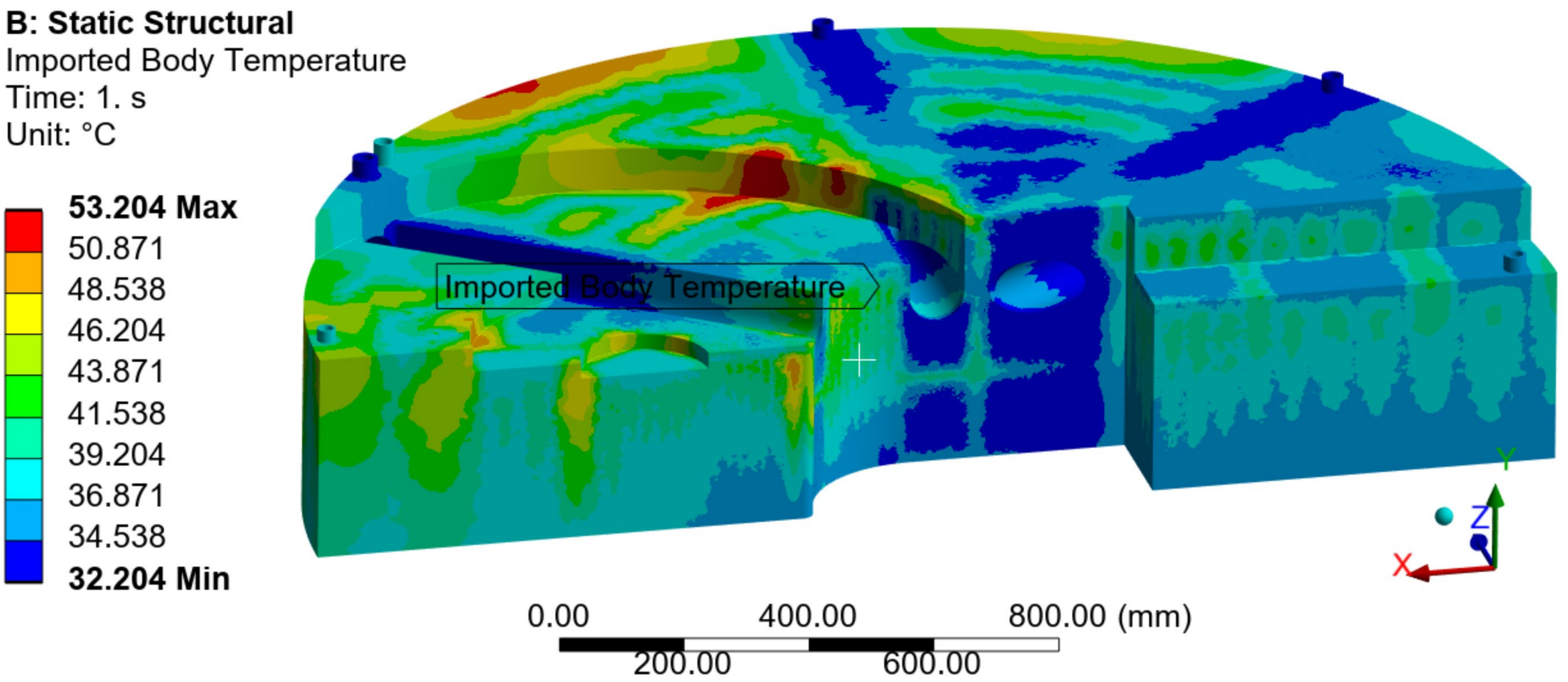
- **Temperature** from CFD (STARCCM+)
- **Constant 5 bar Pressure**



- BC-A: Point fixed in x, y and z directions
  - Reference point
- BC-B: point fixed in y and z directions.
  - Fixed in y and z : prevent rotation
  - This point can only move in x direction (beam direction)
- BC-G: Plane fixed in y
  - Block rests on flat surface
- BC-F: Gravity (-y direction)
- BC-C-E: Constant 5 bar pressure

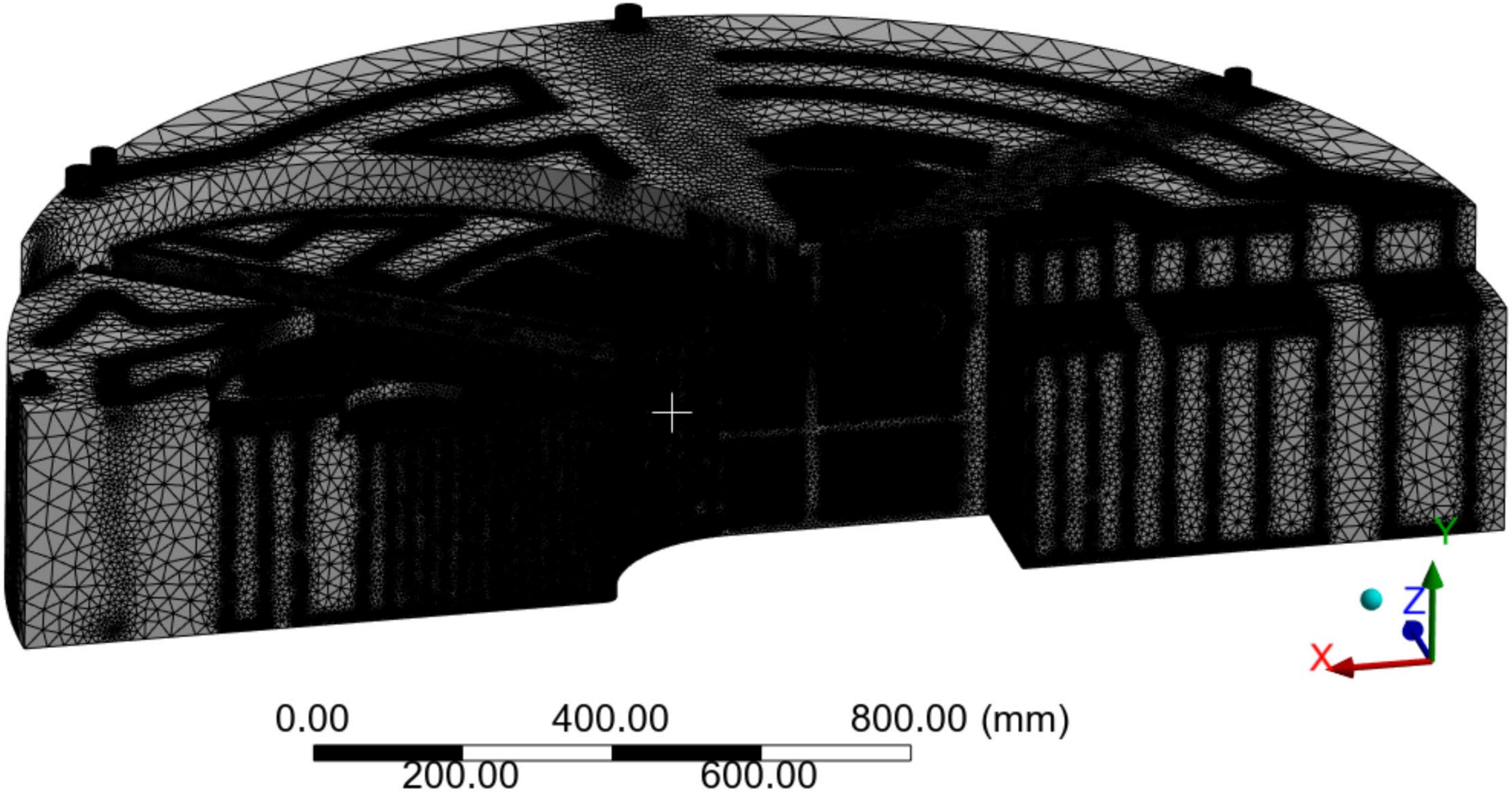
Temperature Profiles from CFD (STARCCM+)

Imported Temperature



Shield Block #5, Mesh Configuration

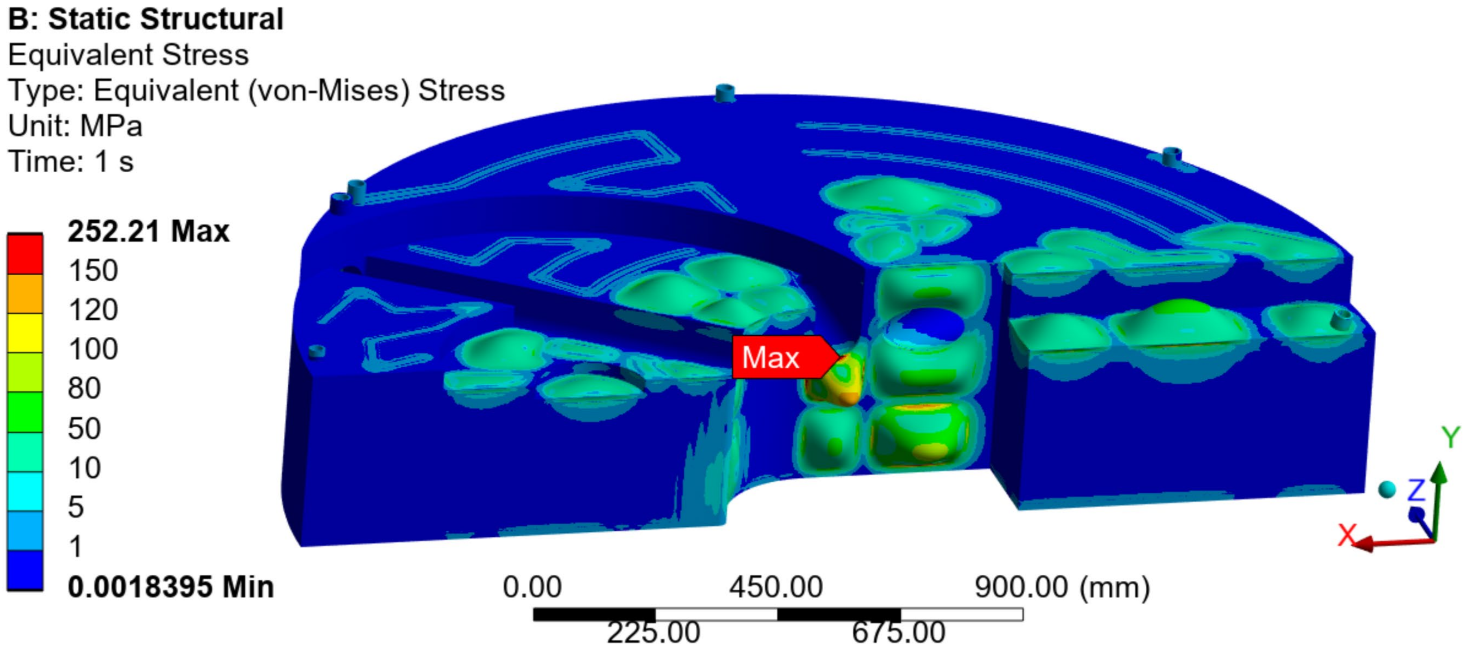
Nodes	12,510,087
Elements	8,303,253

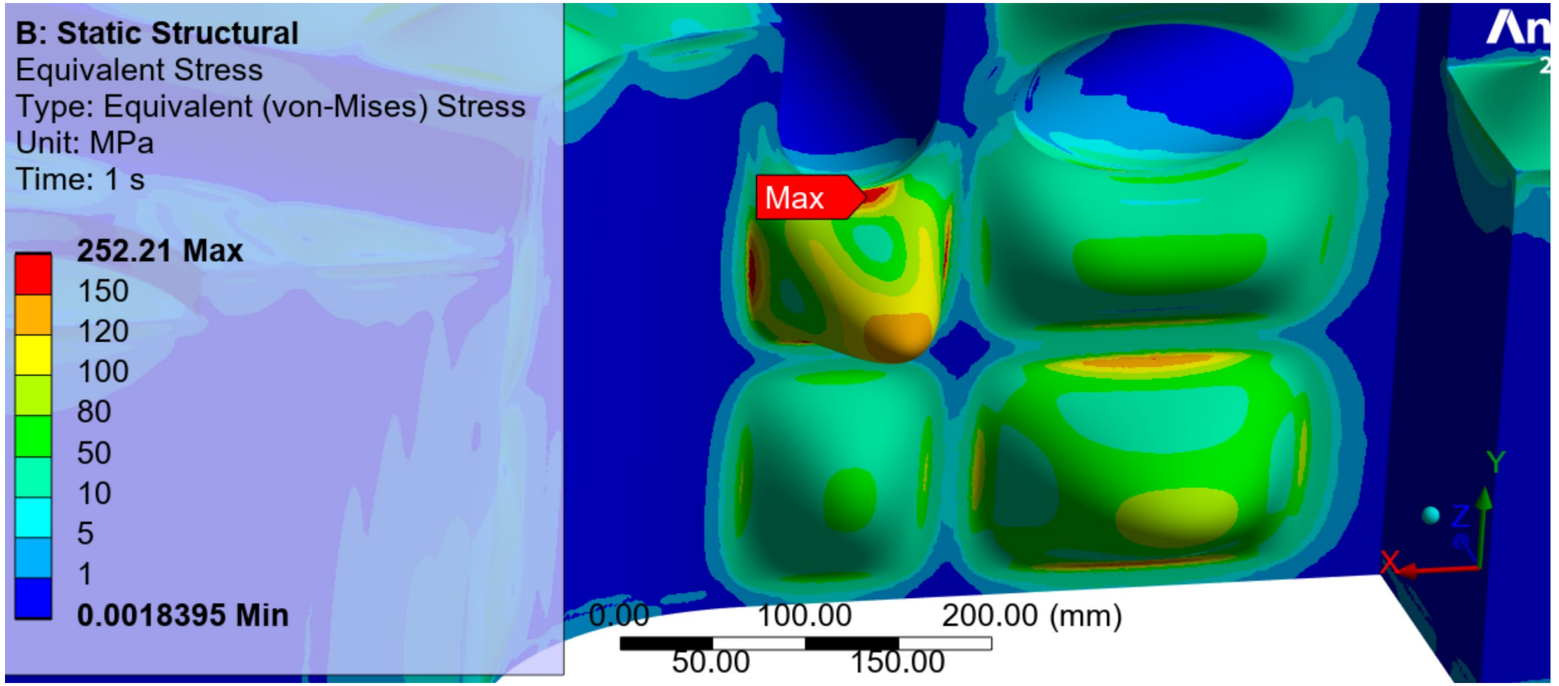


Water Pressure Only (5 bar Constant)

Von-Mises Stress

Peak Stress : 252 MPa
SS316 Yield Strength: 252 MPa

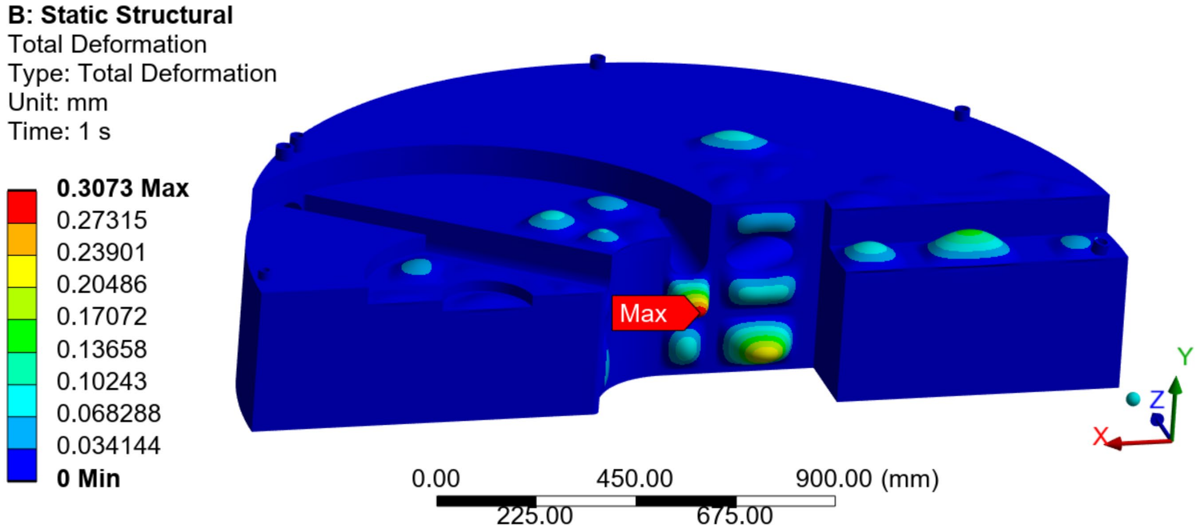




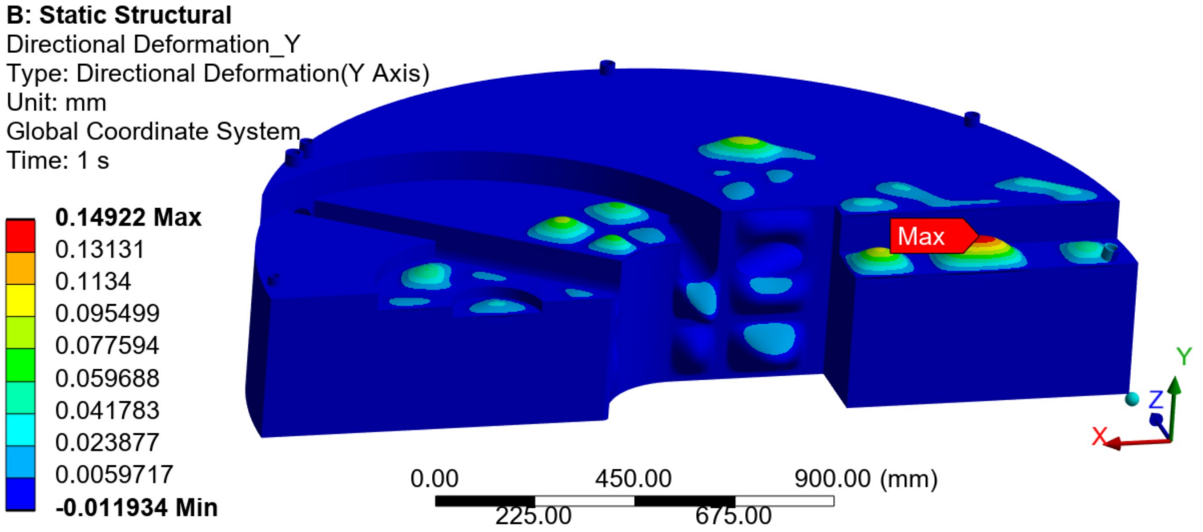
Water Pressure Only (5 bar Constant)

Displacement

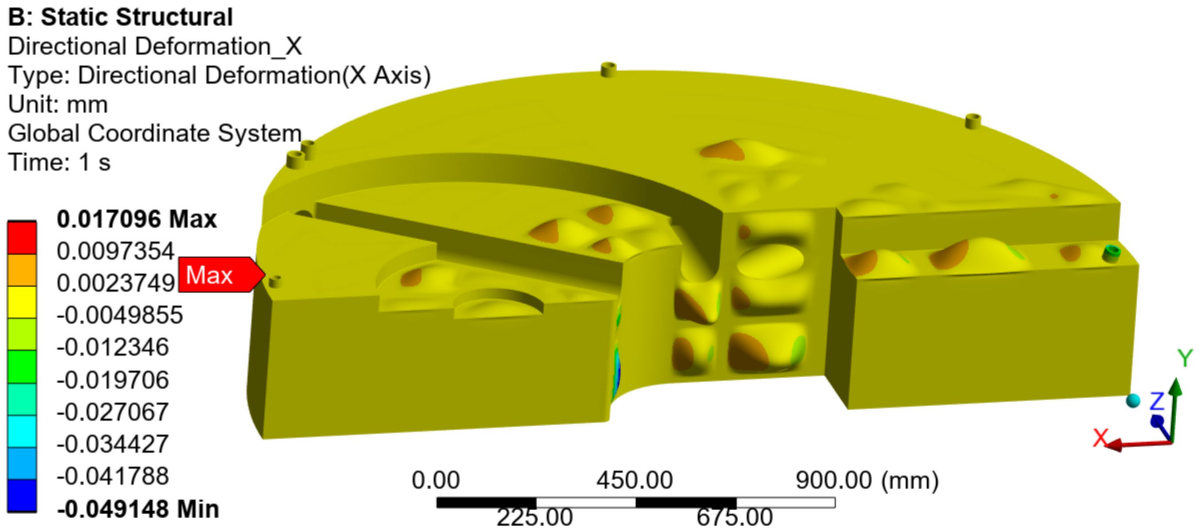
Total Deformation



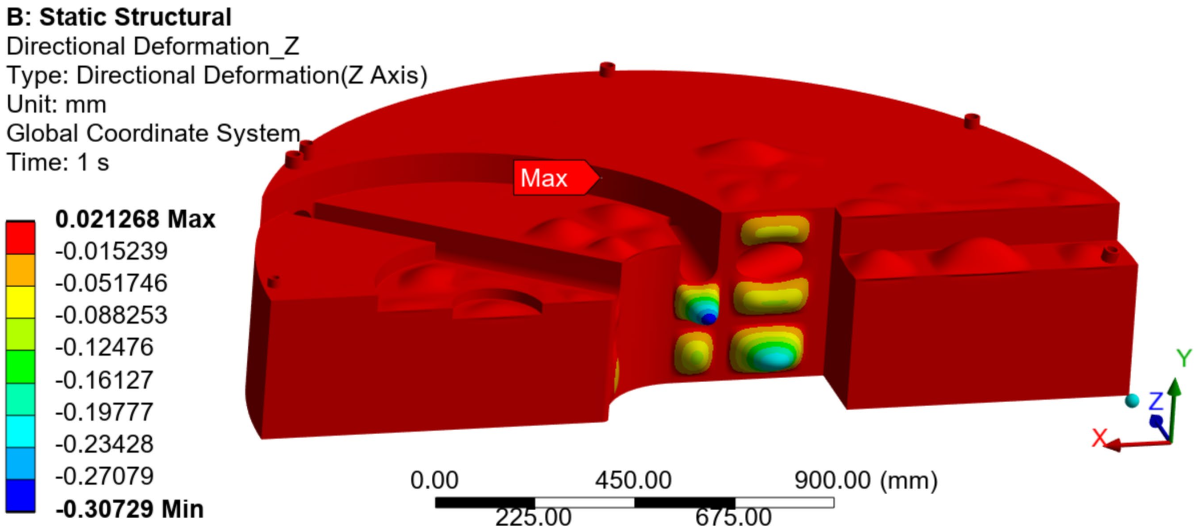
Y - Deformation



X - Deformation



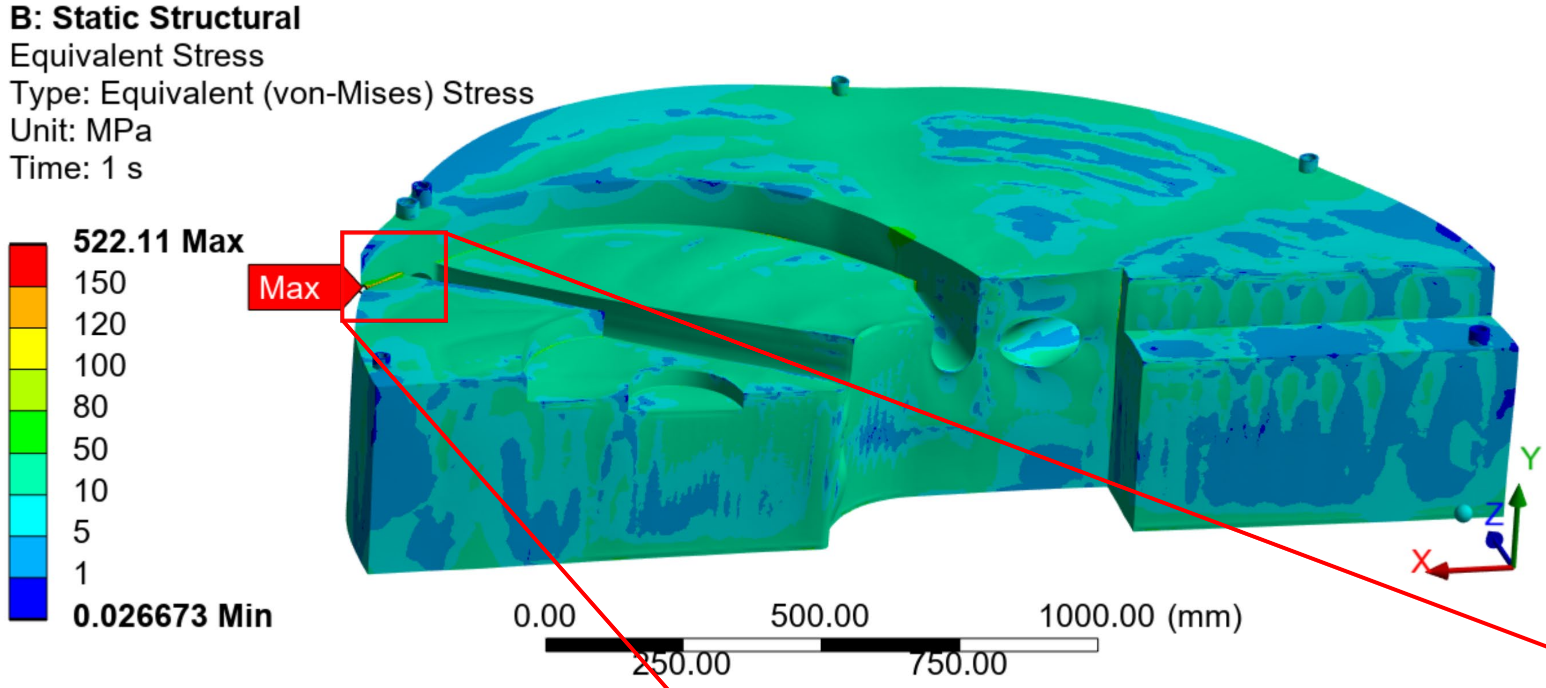
Z - Deformation

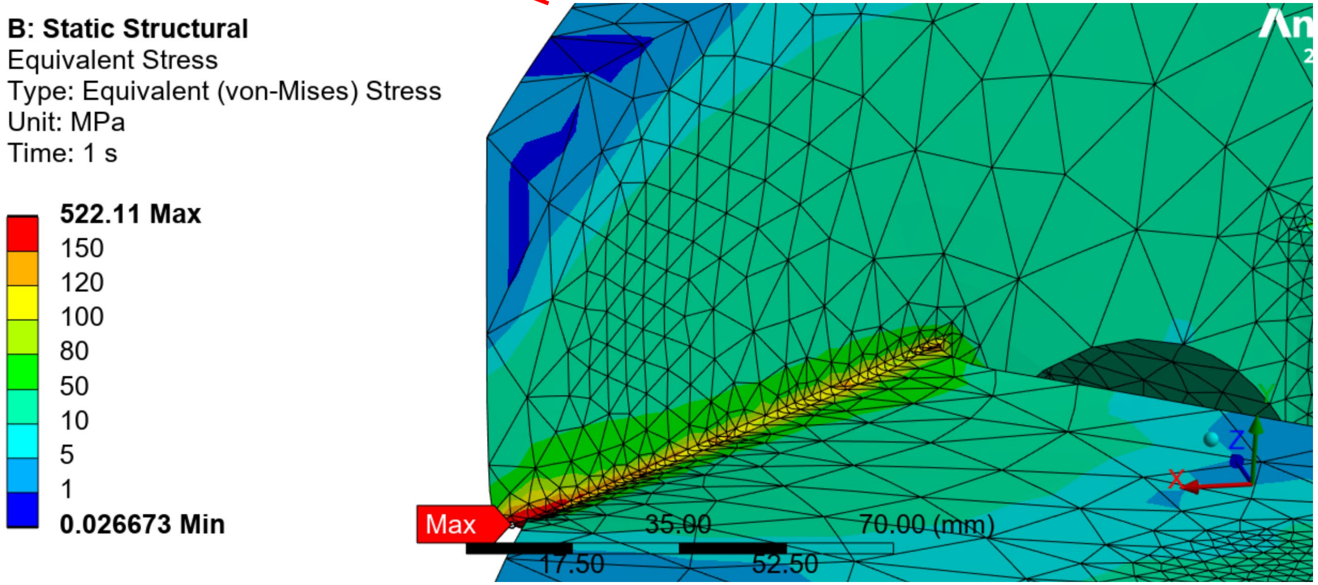


Thermal Only

Von-Mises Stress

Peak Stress : 522 MPa
SS316 Yield Strength: 252 MPa

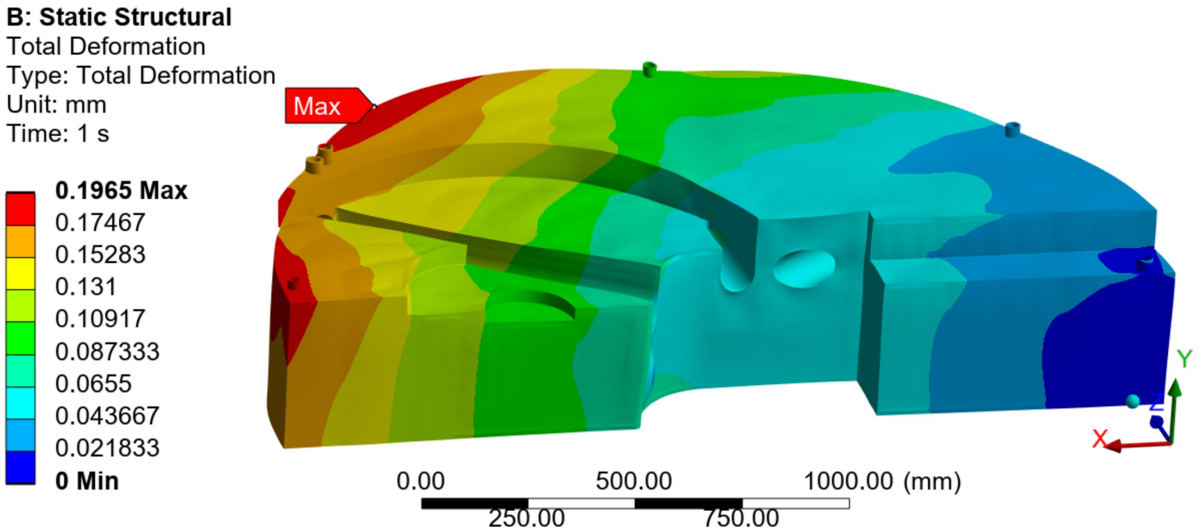




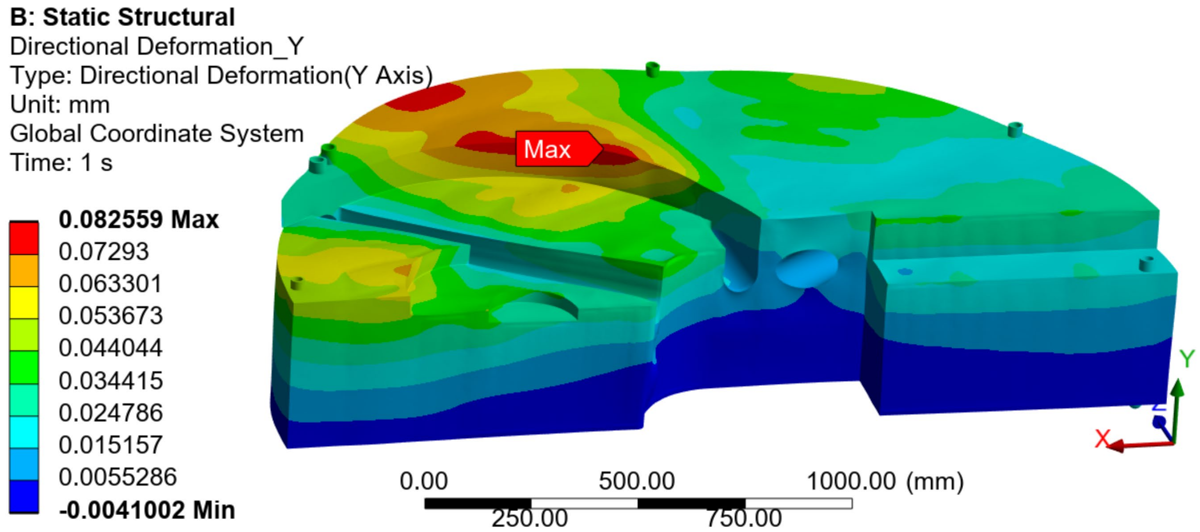
Thermal Only

Displacement

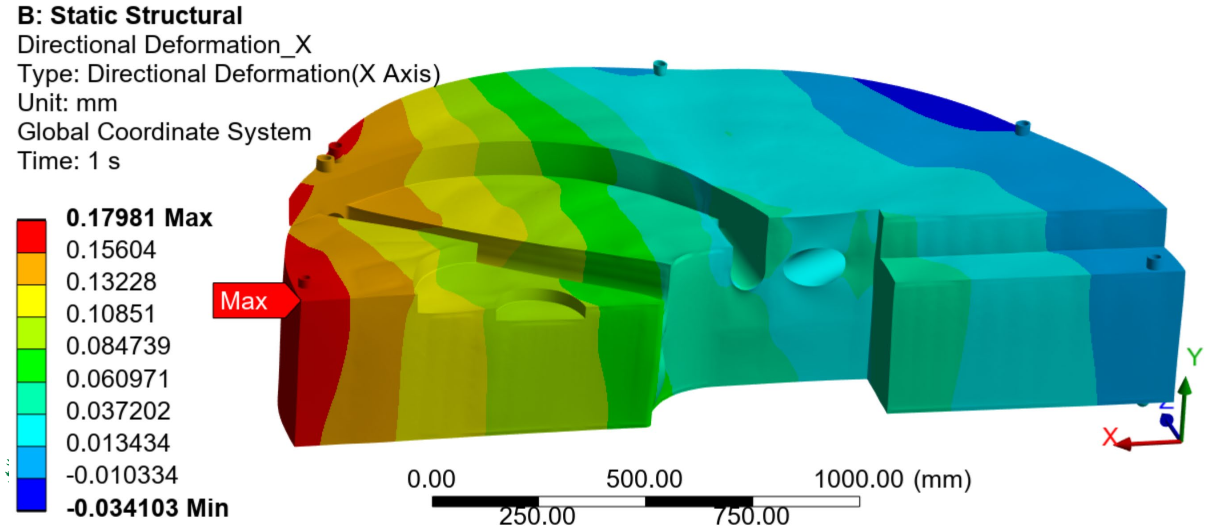
Total Deformation



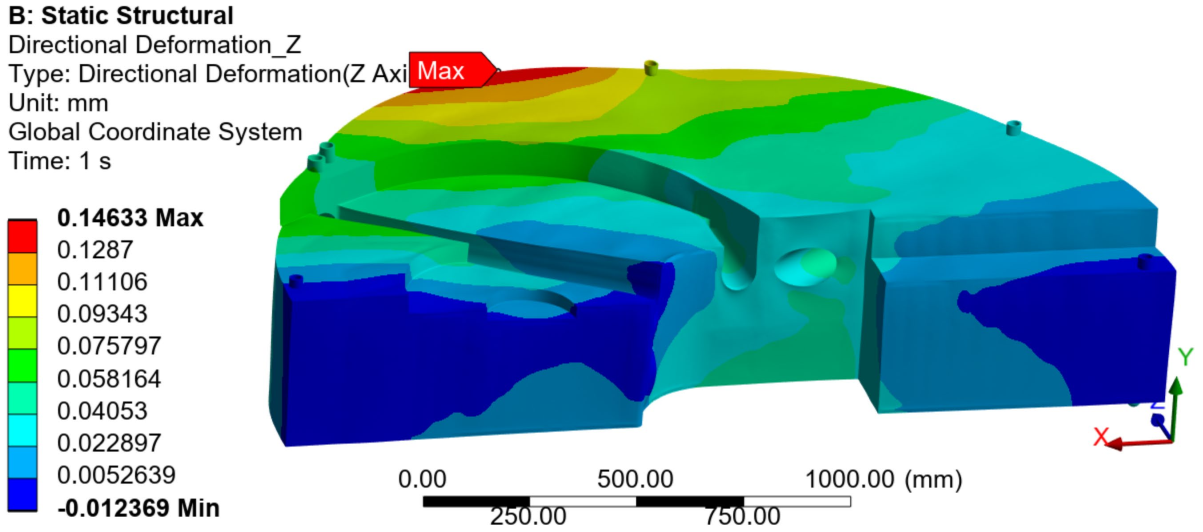
Y - Deformation



X - Deformation



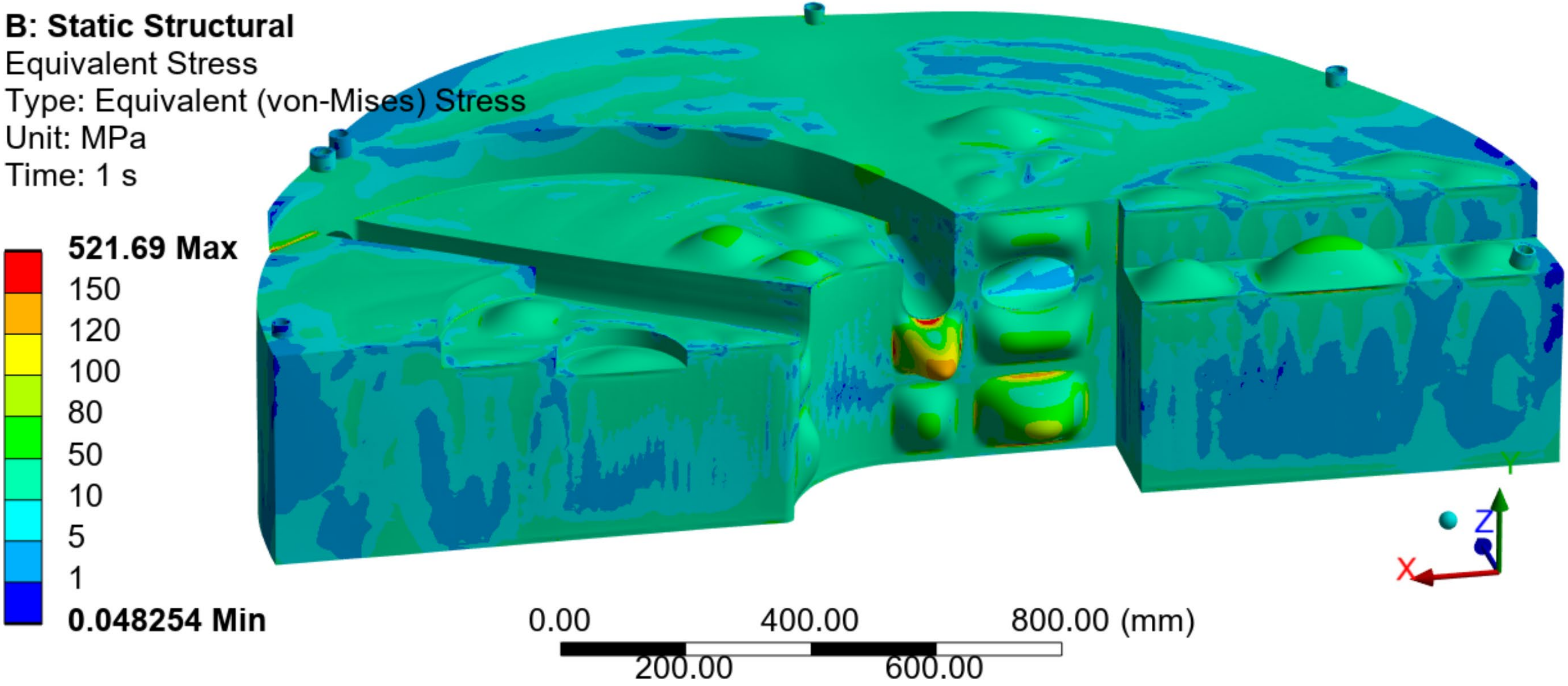
Z - Deformation



5 bar pressure + Thermal + Gravity

Von-Mises Stress

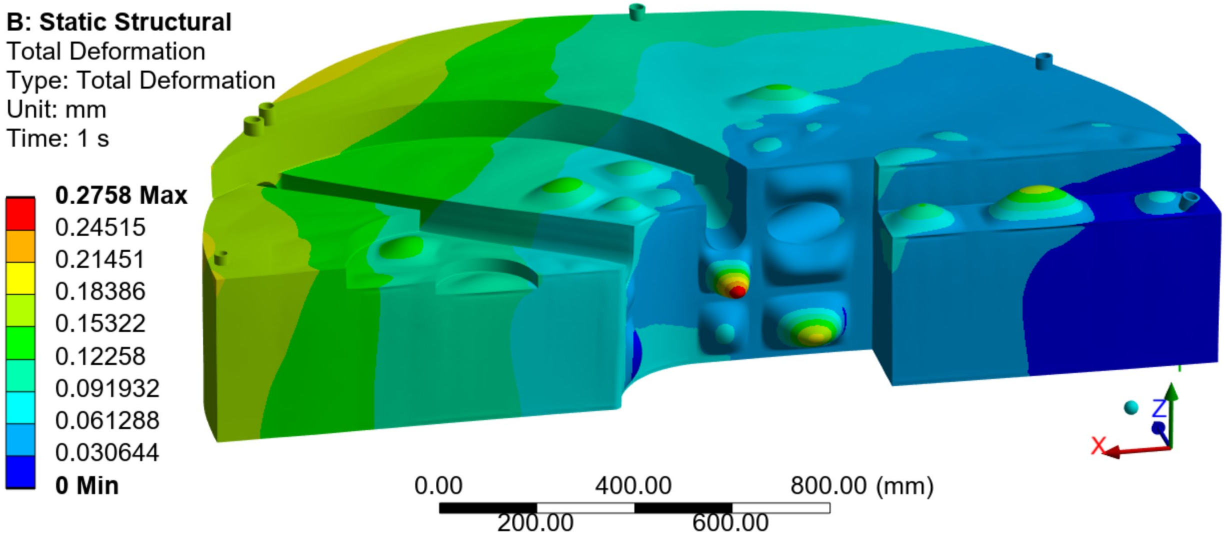
Peak Stress : 521 MPa
SS316 Yield Strength: 252 MPa



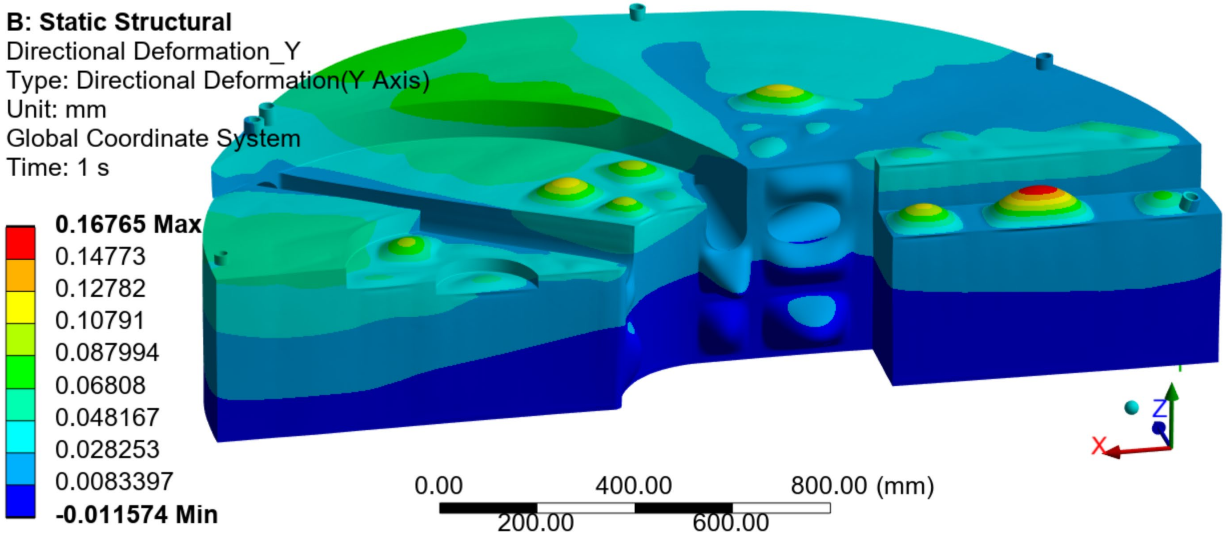
5 bar Pressure + Thermal + Gravity

Displacement

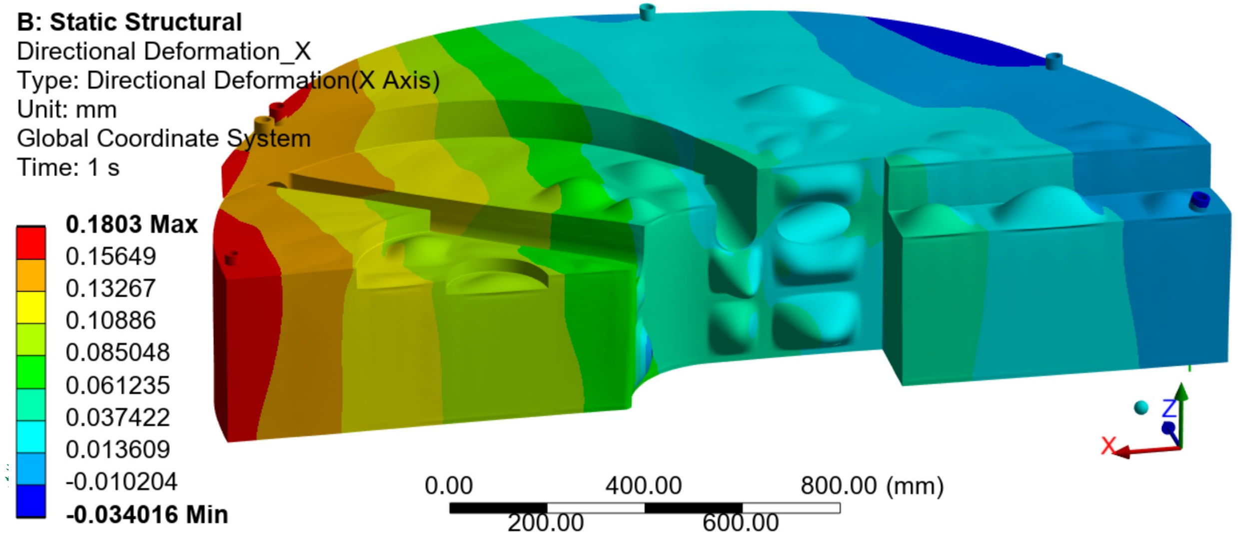
Total Deformation



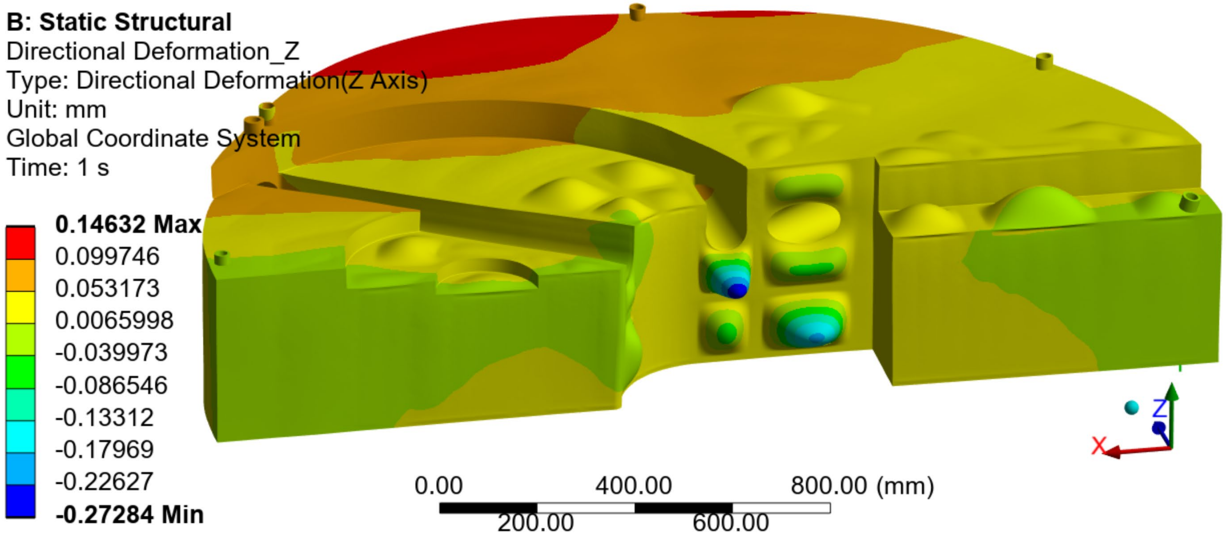
Y - Deformation



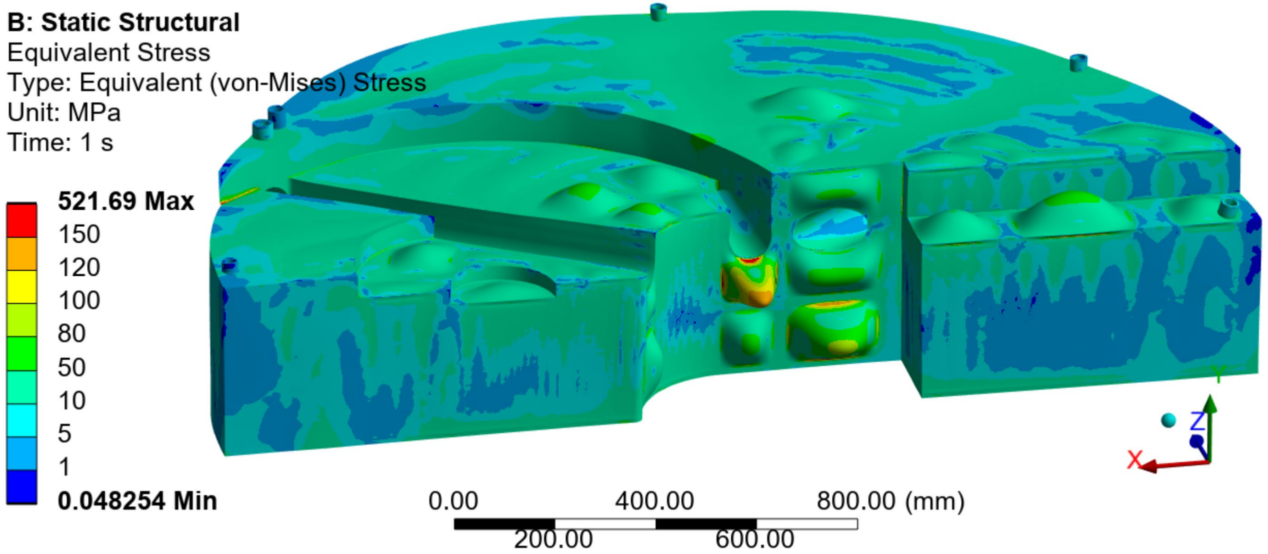
X - Deformation



Z - Deformation



Shield Block #3 Summary of Results



Relevant mechanical loads:

- Gravity → Included
- Internal vacuum → Included
- Cooling water pressure → Included
- Seismic → Not Included
- Thermal → Included

Core Vessel Structural Requirements:

- Maximum allowable membrane stress = 115 MPa
- Maximum allowable membrane plus bending stress = 172.5 Mpa
  - Maximum bending stress in covers = 252 MPa → FAIL
- Maximum allowable peak stress under self-limiting conditions = 345 Mpa
  - Maximum thermal-induced stress = 522 MPa → FAIL

Core Vessel Standard Nozzle Extension Preliminary Analysis

Thomas McManamy

9/19/23

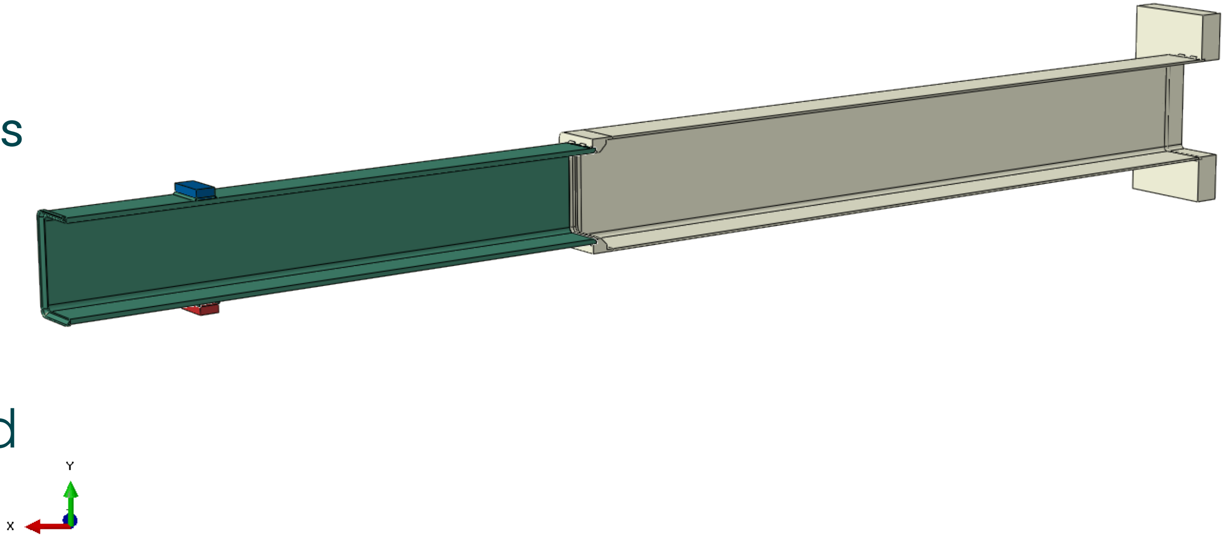
ORNL is managed by UT-Battelle, LLC for the US Department of Energy

Abaqus model of Nozzle Assembly

Assembly with Four Parts Half Symmetry

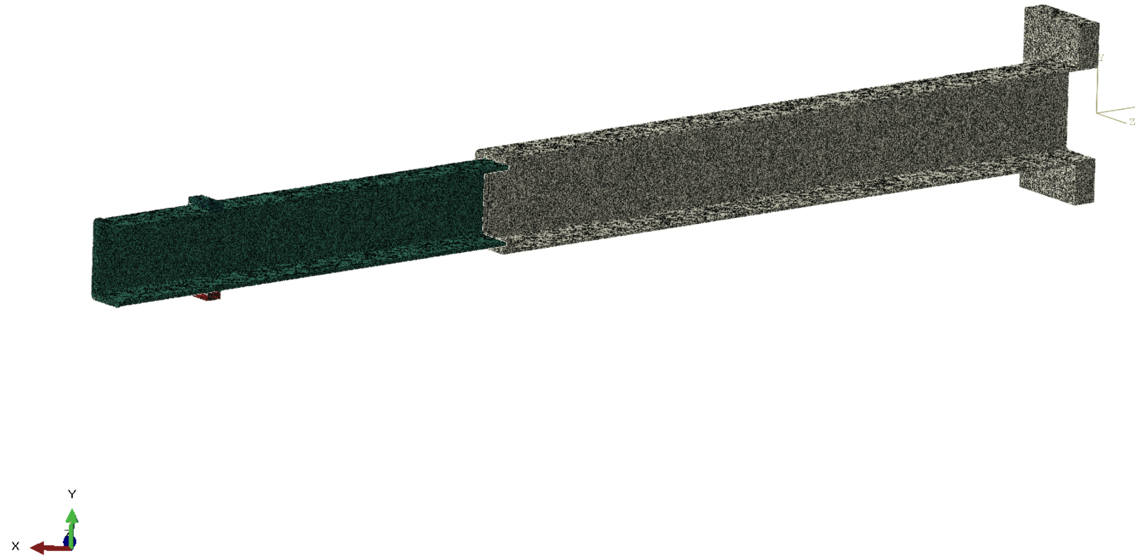
- Most welds and flanges were merged
- Four parts
  - Outer nozzle, flange, most welds
  - Inner nozzle and weld to core vessel and welds to upper and lower support blocks
  - Upper support block
  - Lower support block
- Skip welds on curved edges not modeled
- Outer to inner nozzles connected by tie conditions on the interface weld and skip welds

Merged Assembly

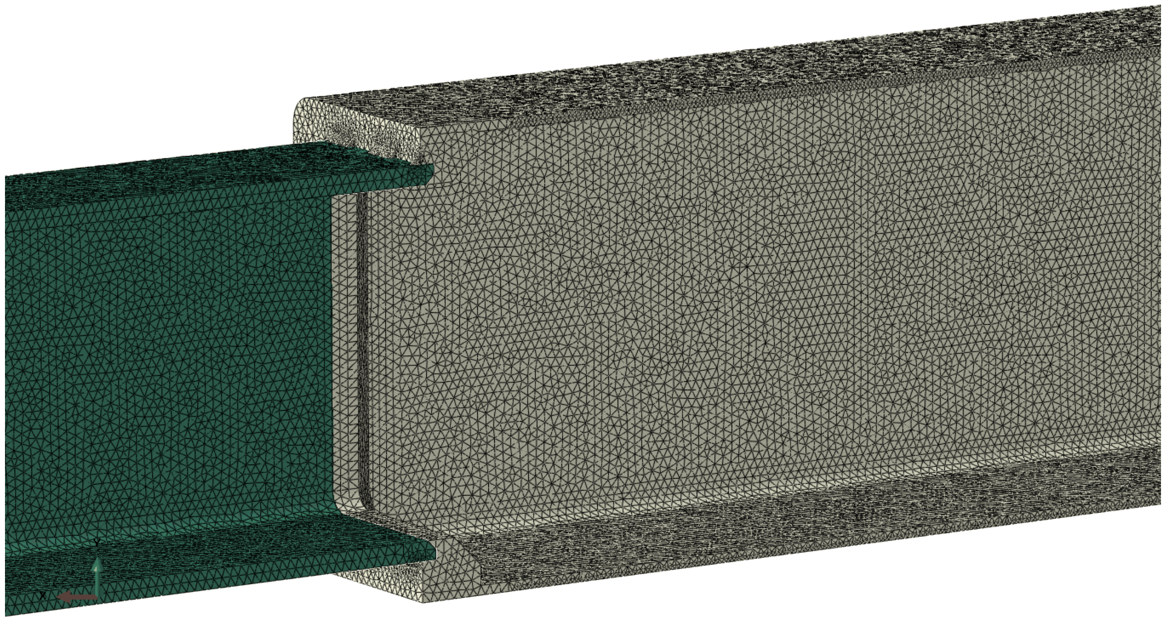


Nozzle Mesh

Overall Mesh with C3D10 elements total 1,682,518 elements for nozzle parts



Mesh around Joint region



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Analysis

- The assembly was evaluated in the following steps

1. Pretension on the bolts and gravity
2. Gravity and the full mass of the insert loaded on a small wheel bearing area near the axial middle
3. Gravity and pressure without the insert mass

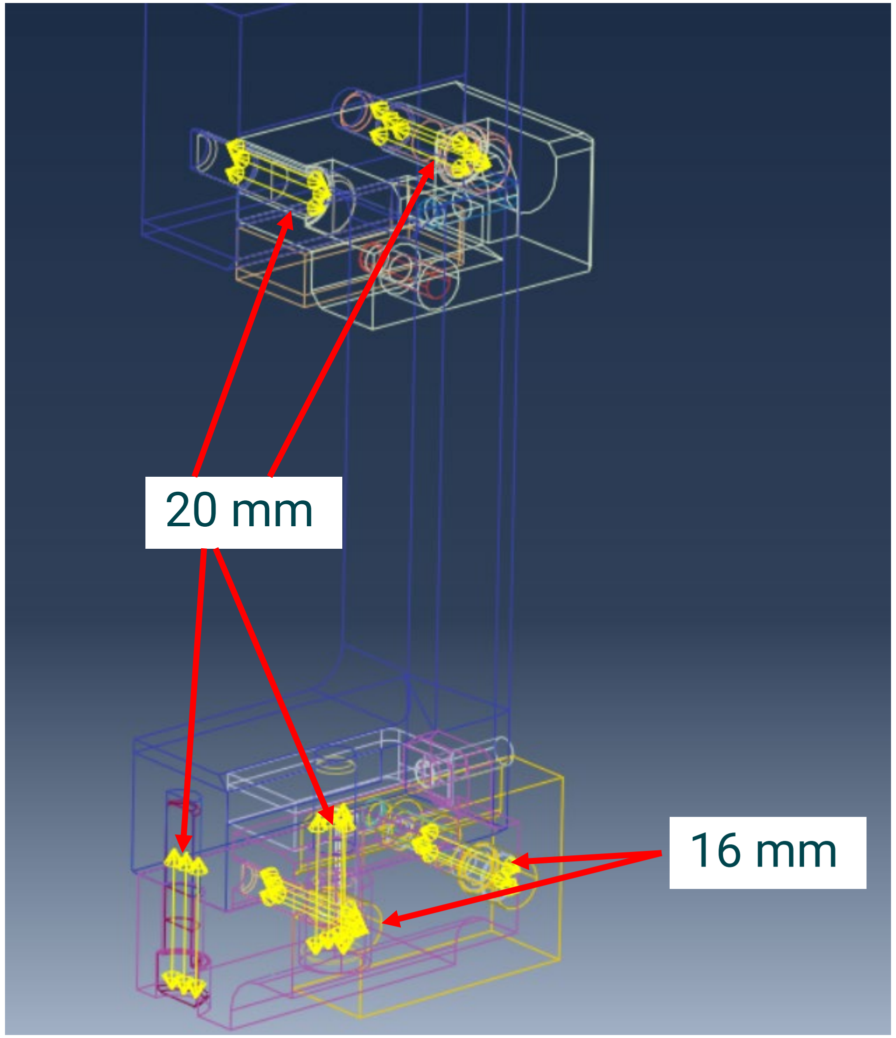
Pretension bolt loads

Preload applied on bolt cross sections

- M16 bolts (Stainless steel class A4-70, Proof strength 450N/mm^2) = 52,987 N
- M20 bolts (Stainless steel class A4-70, Proof strength 450N/mm^2) = 82,616 N

Half bolts on z symmetry plane had half the force applied

6 bolts with preload



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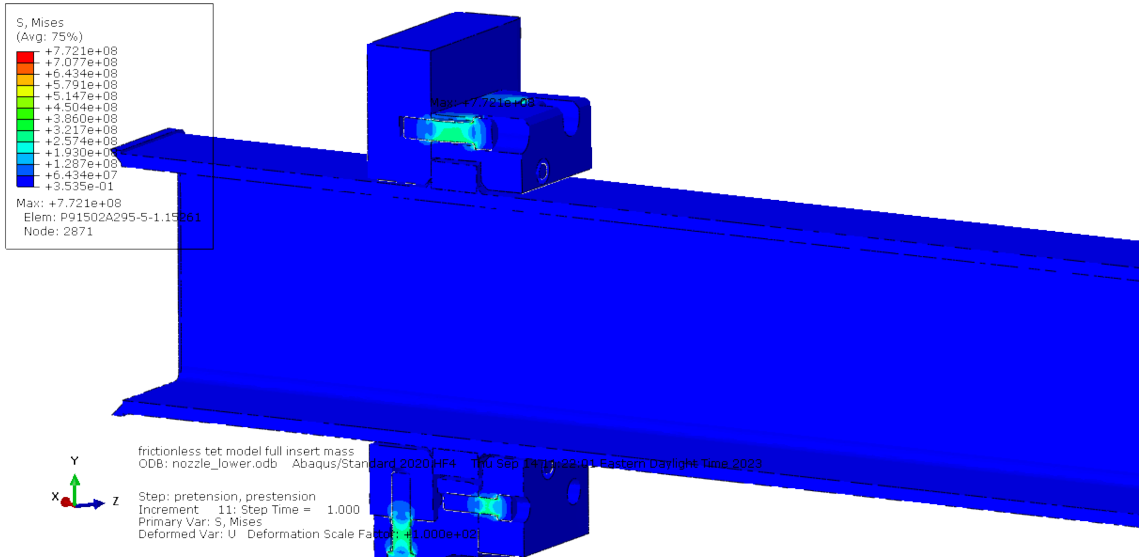
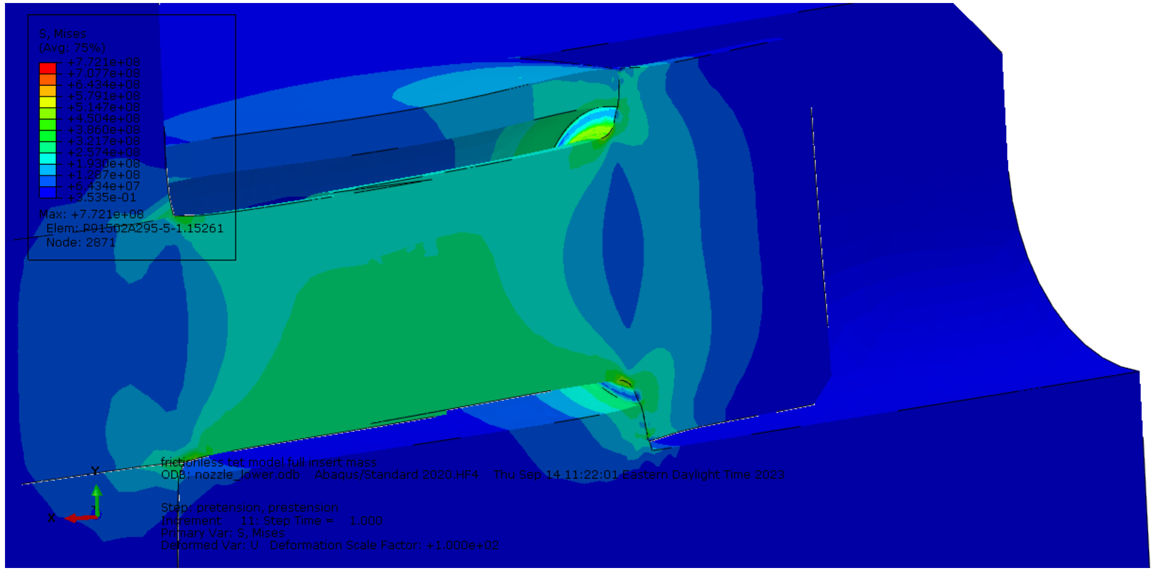
Pretension Step

S Mises



Close view



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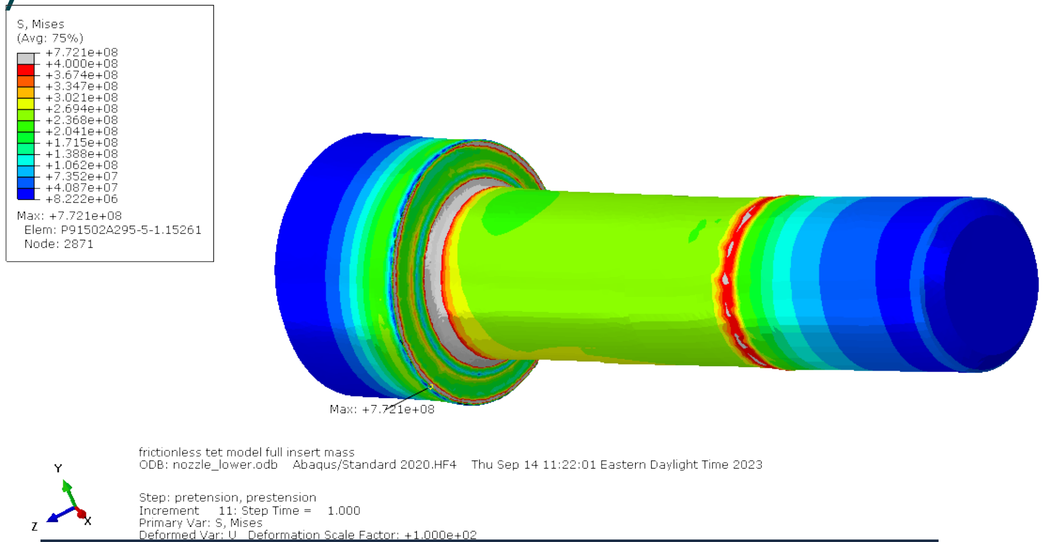
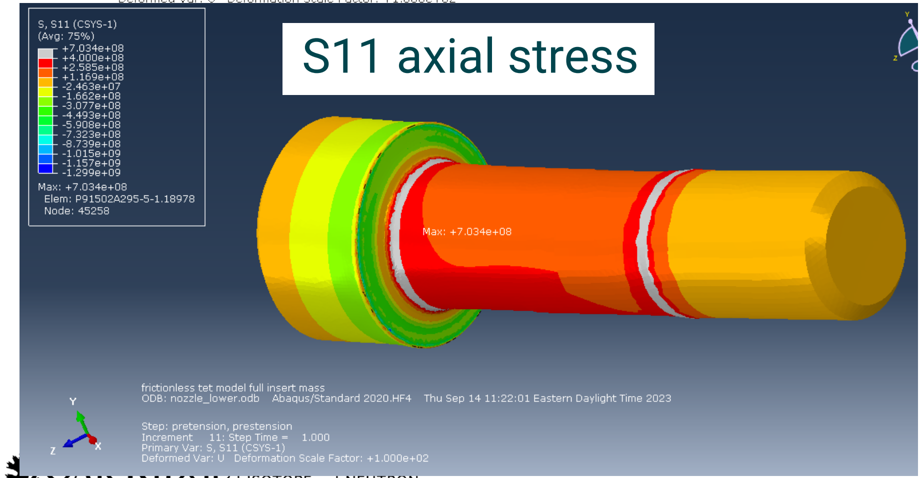
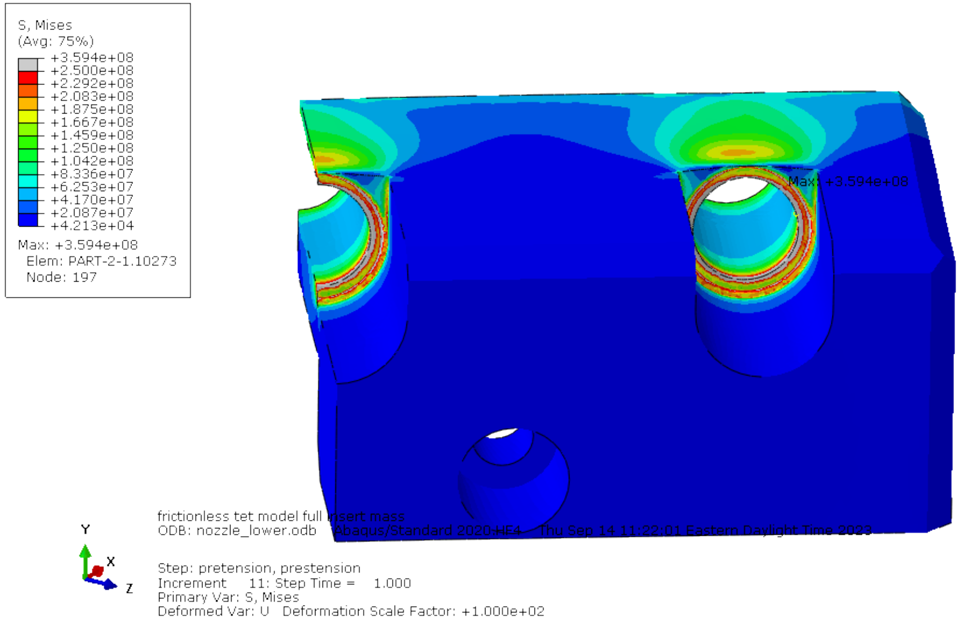
Upper bracket stresses

20 mm bolt Mises – 400 MPa bolt yield maximum scale





Mating upper bracket Mises stress with 250 MPa yield scale maximum

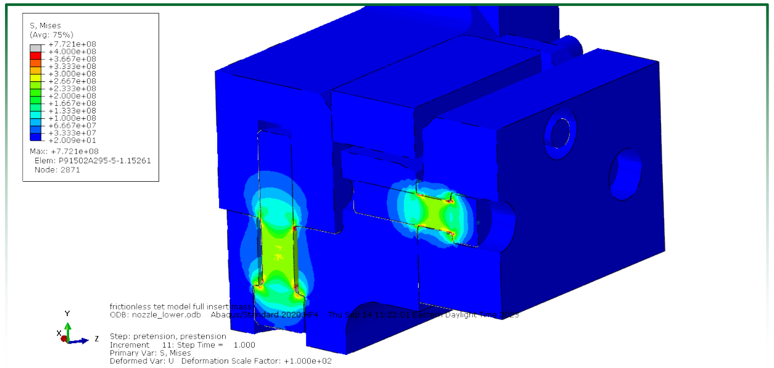


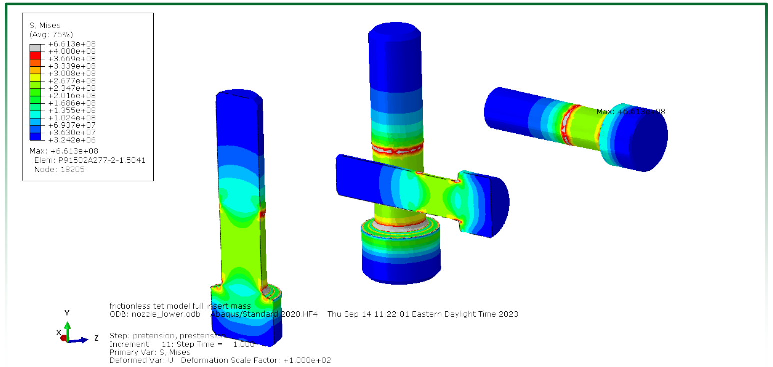
Lower Bracket Pretension Step

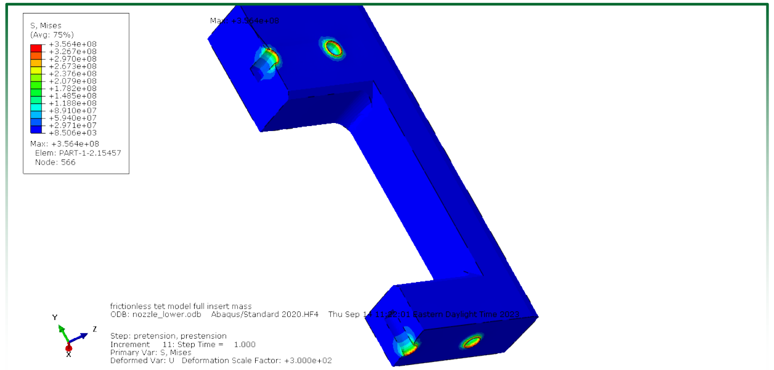
Lower Bracket Mises with 400 MPa scale maximum

Bolt Mises stress – 400 MPa scale

Core Vessel Mises stress







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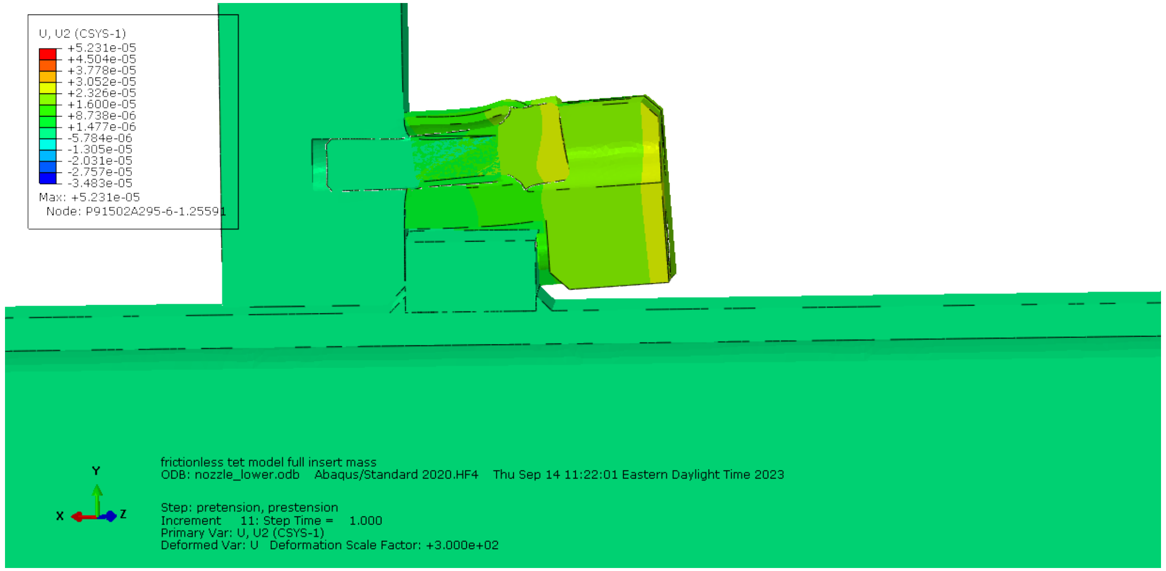
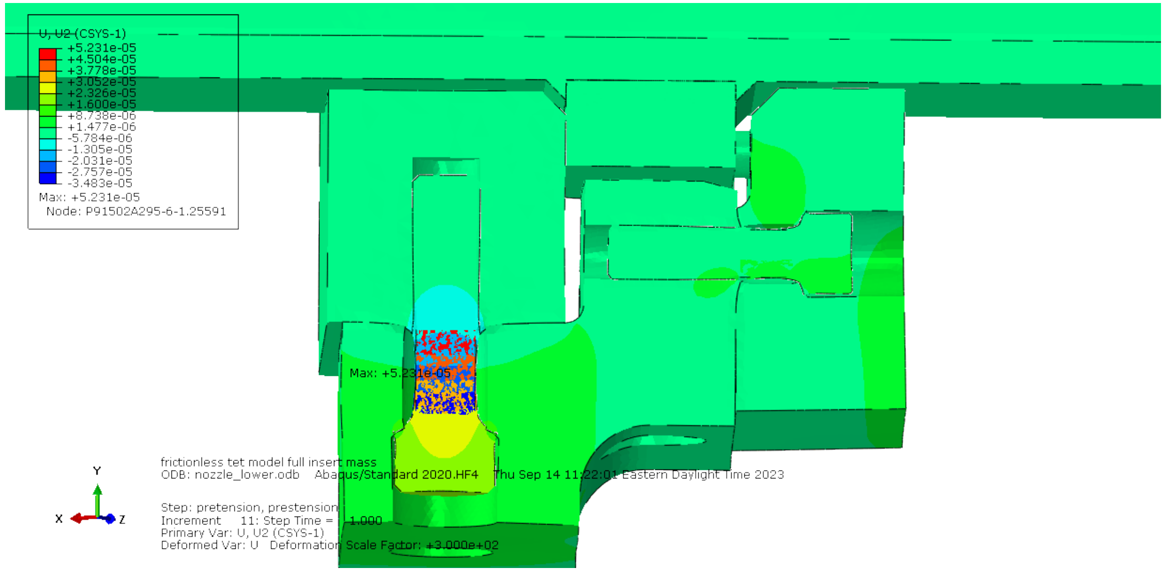
Vertical deflections due to Pretension

Vertical Displacement Upper Bracket

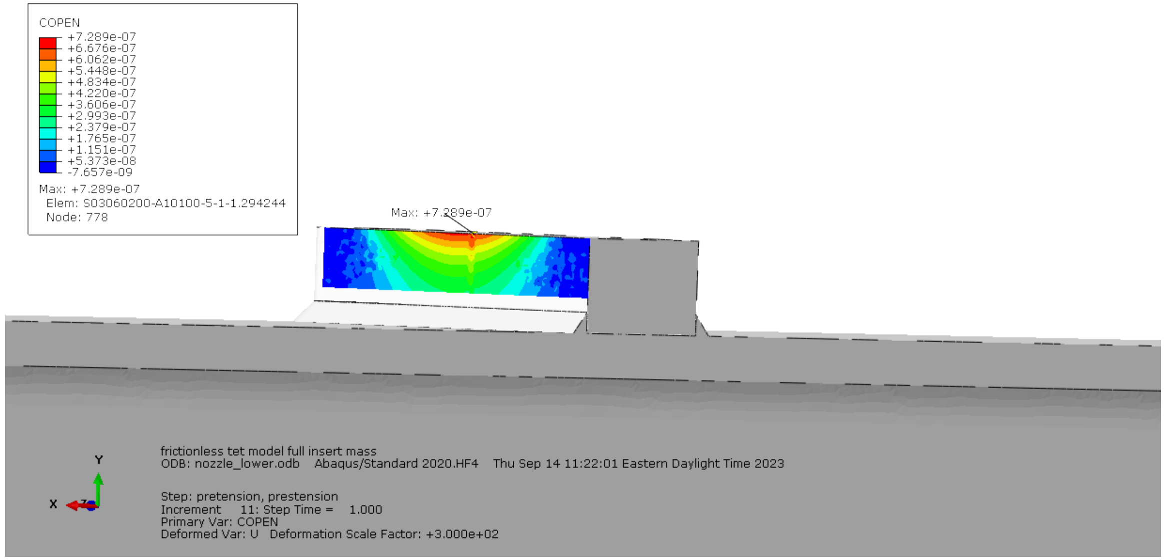


Vertical Displacement Lower Bracket

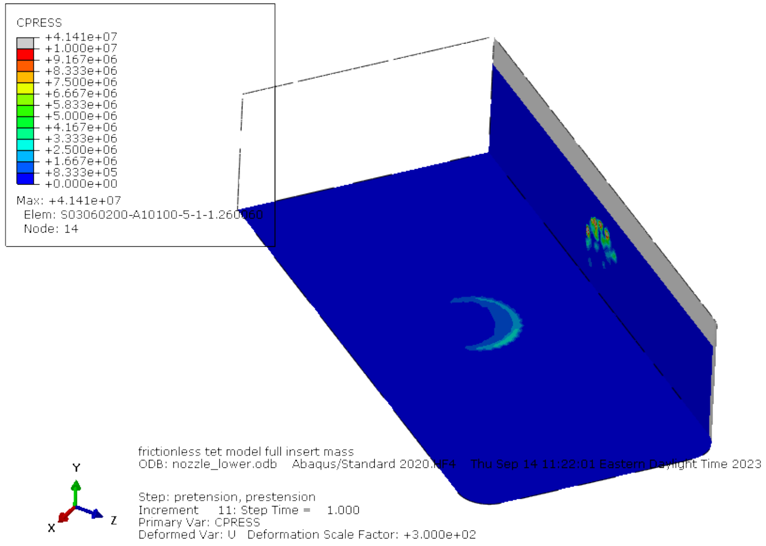


Support Blocks with gravity and pretension

Open Contact – Upper support block



Lower support block- Contact pressure from vertical and axial pins



Upper block pulls away from core vessel and lower block contacts vessel and carries vertical loads

Step 2 – Gravity loads including Insert mass

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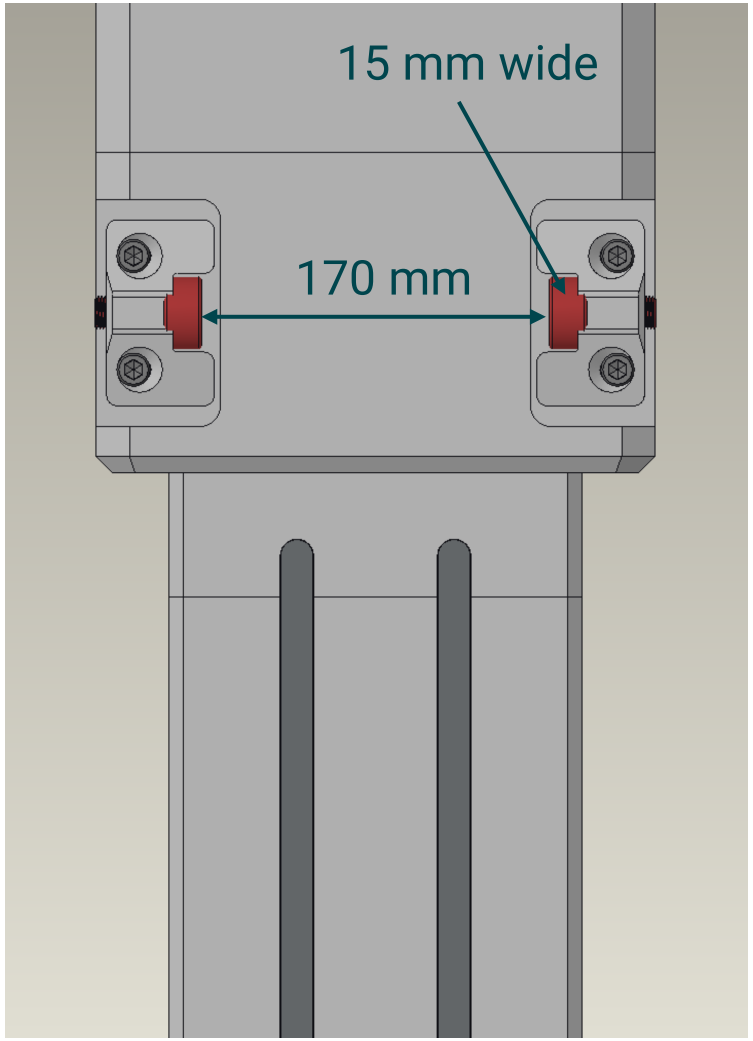
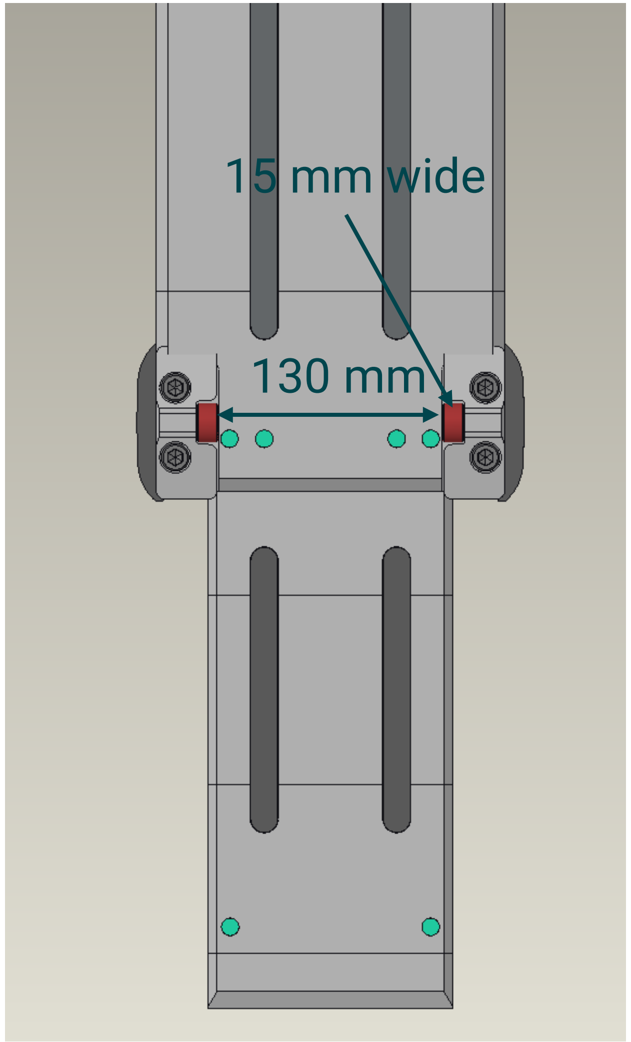
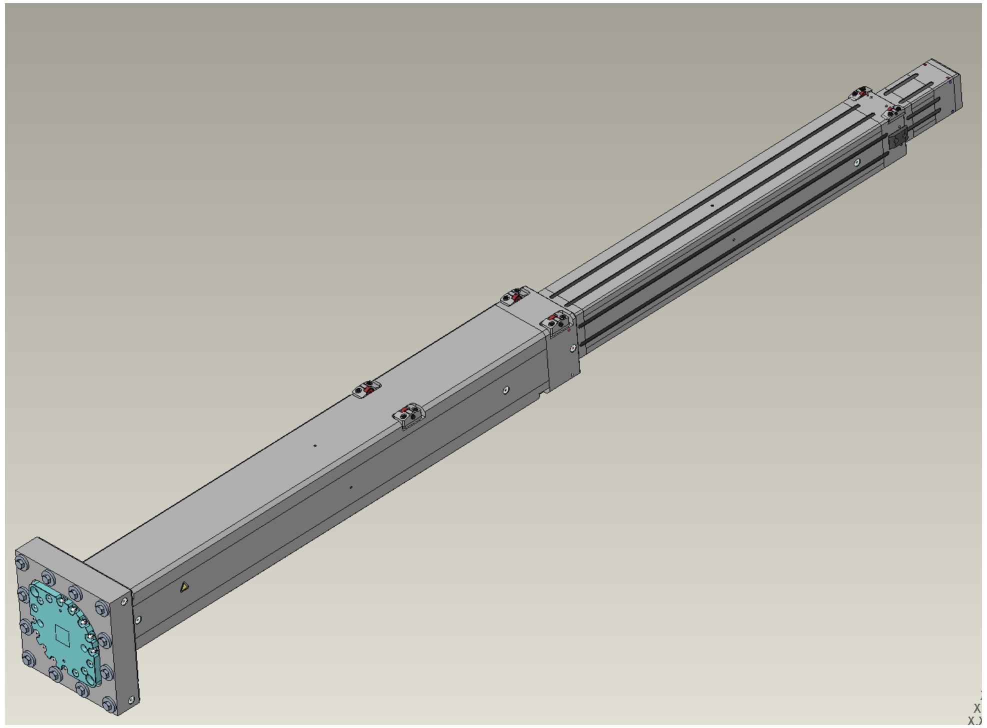
Insert to be installed within nozzle







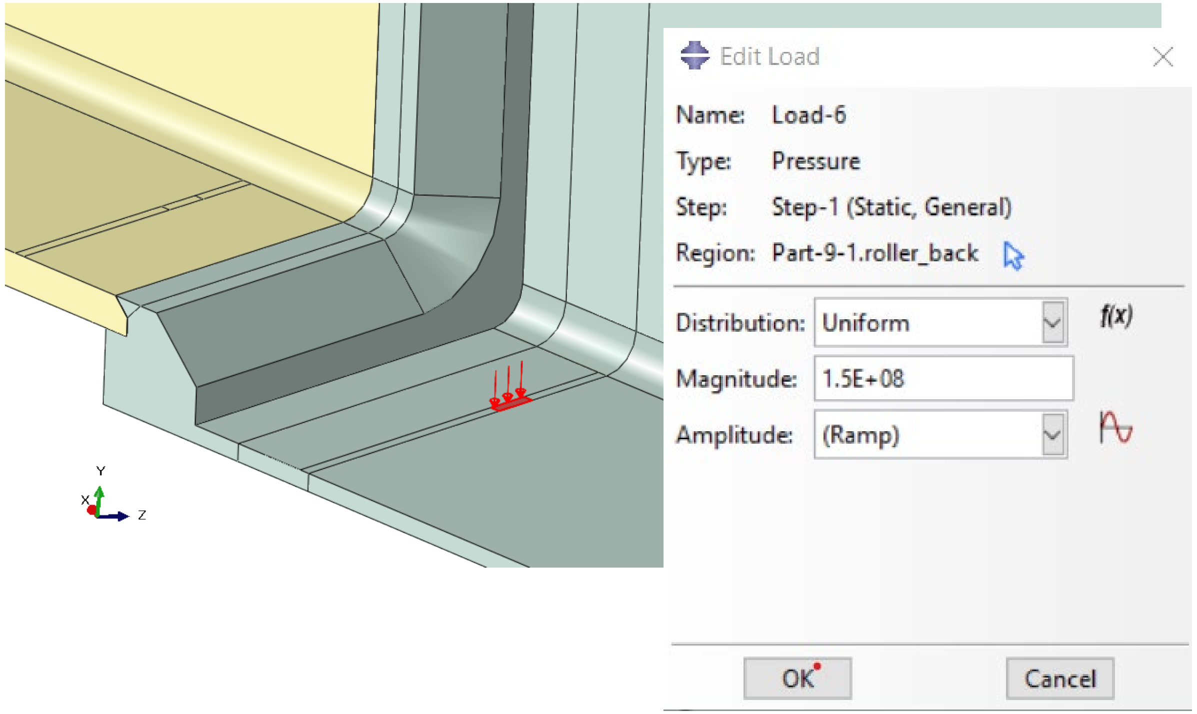
Monolith Insert Mass = 1830 kg
The red parts are wheels, so we can assume a small width contact area

Insert mass loading worst case assumption

Loading Assumption

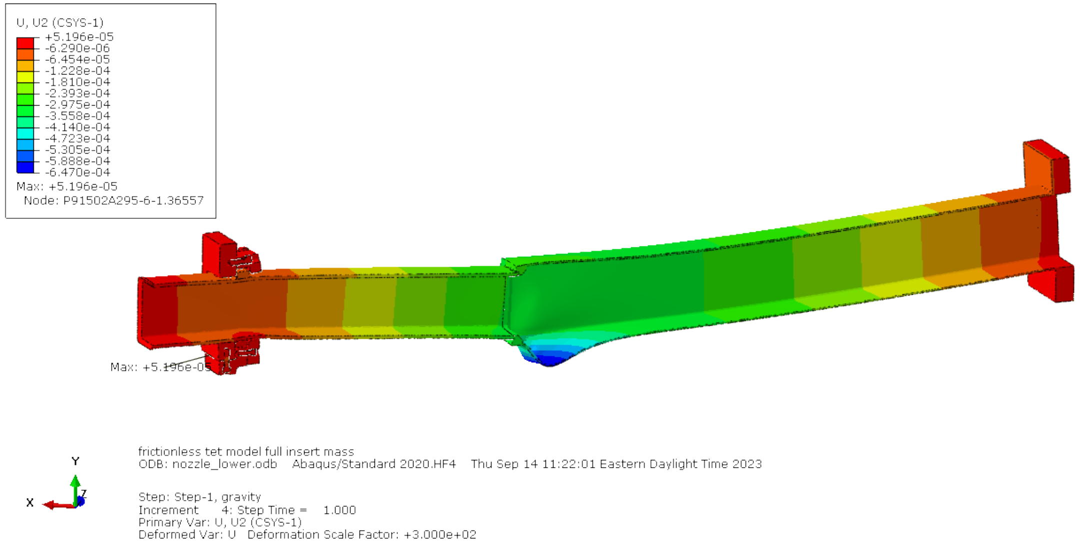
- Total mass 1830 kg
- Worst location on thinner plate
- Assume the whole mass is supported on the two wheels without accounting for an outer support
- Wheel contact area estimated at 4 mm x 15 mm
- Pressure = 1830*9.8/(2*(4e-3*15e-3)) =149.5 MPa

Roller Pressure on back nozzle section

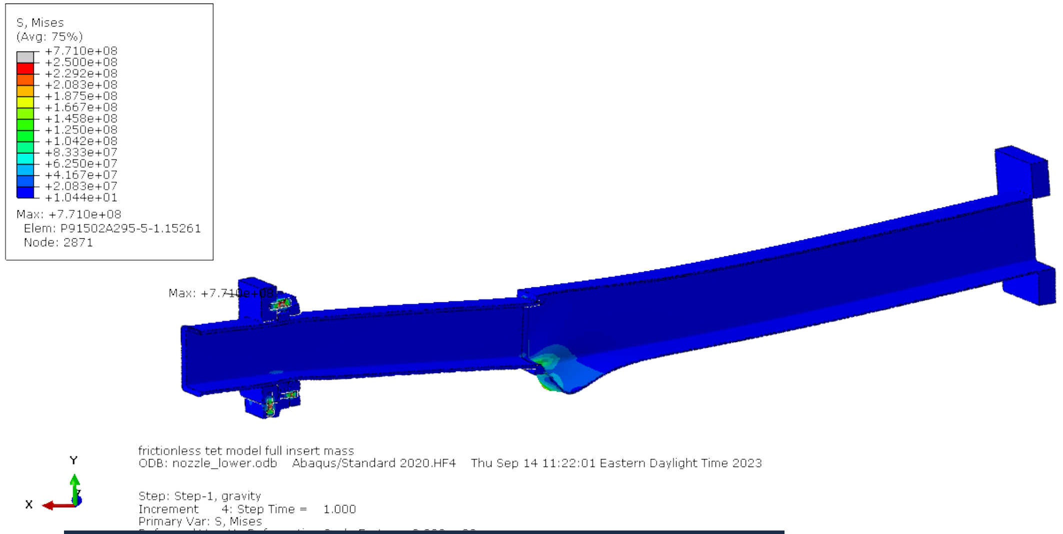


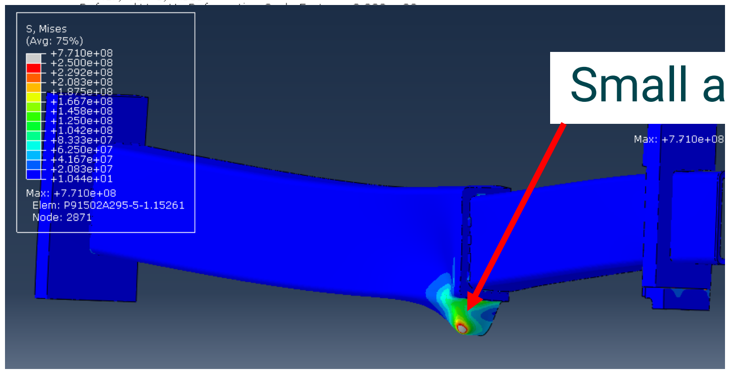
Step 1 Gravity including Insert total mass

Vertical deflection – peak .6 mm under insert support wheel



Mises stress – 250 MPa scale maximum





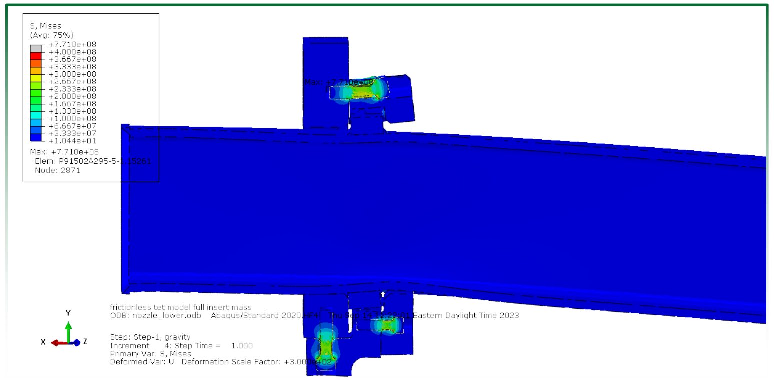
Small area above yield

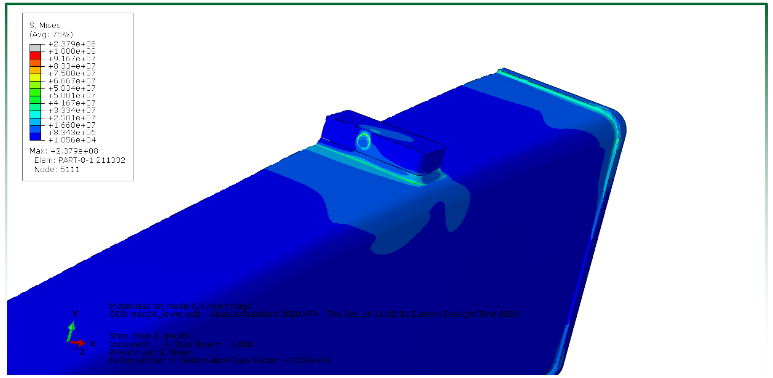
Step 1 stresses

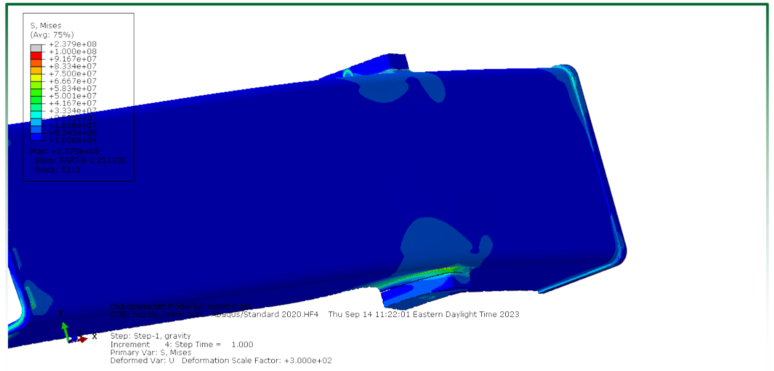
Bolts stresses similar to preloading but bracket vertical deflections increased

S Mises 100 MPa scale showing low weld stresses

Lower support block welds peak ~ 120 MPa

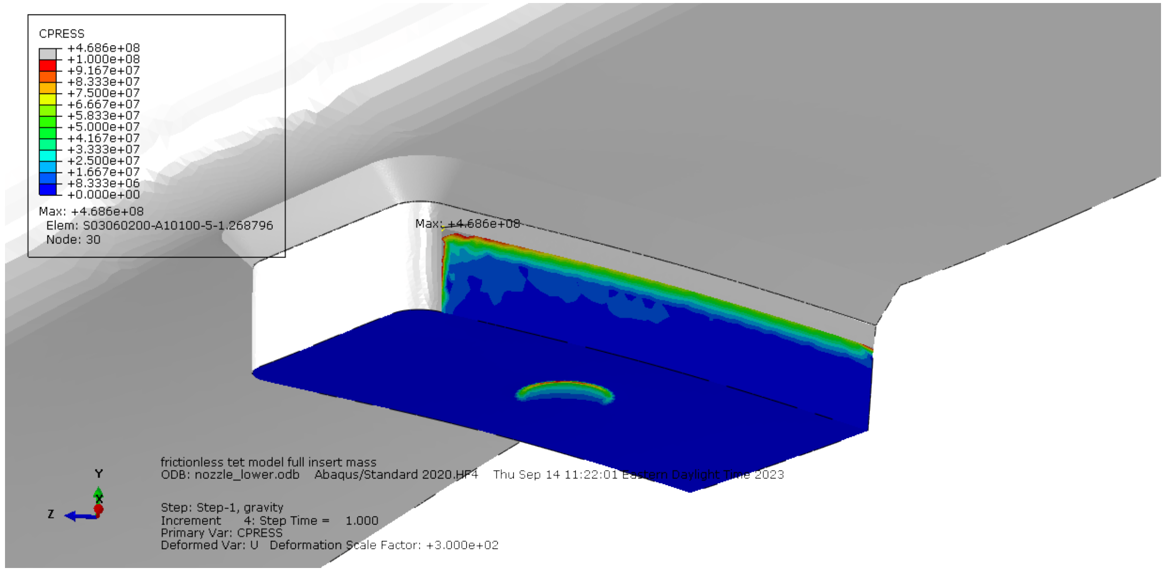




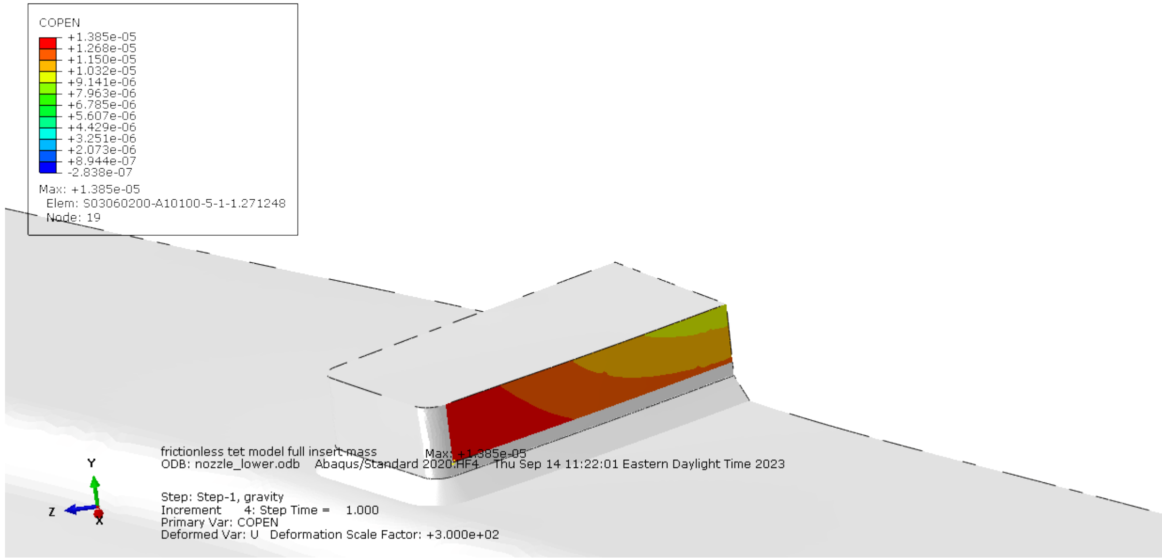


Step 1 Support Blocks

Contact pressure between lower support block and core vessel



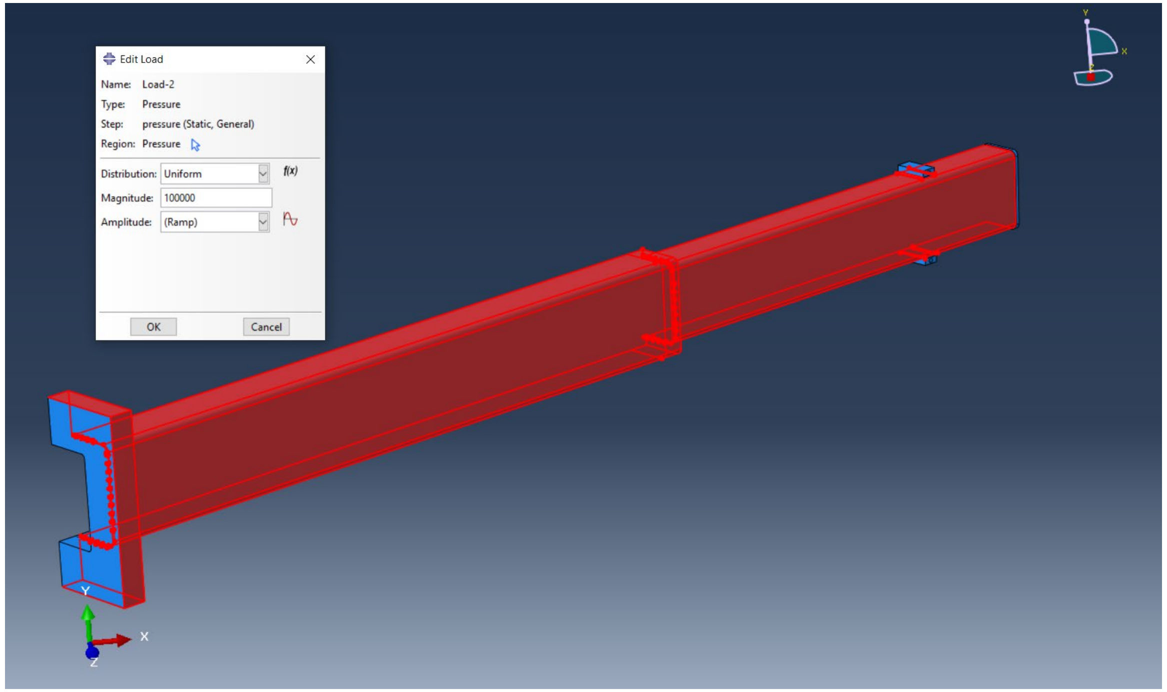
Open Contact area on upper support block – no contact on Core vessel



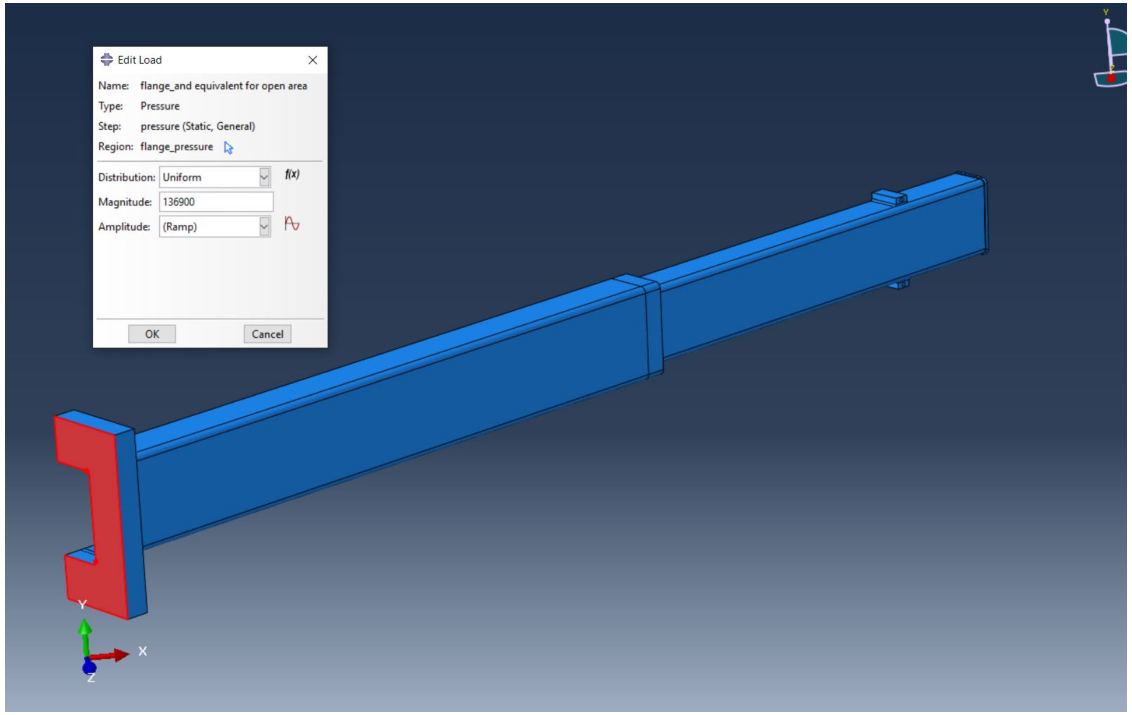
Step 2 – Gravity without insert mass, vacuum pressure and bolt preloads

Pressure Loads

External Pressure



Flange pressure increased to account for 1 bar on open area



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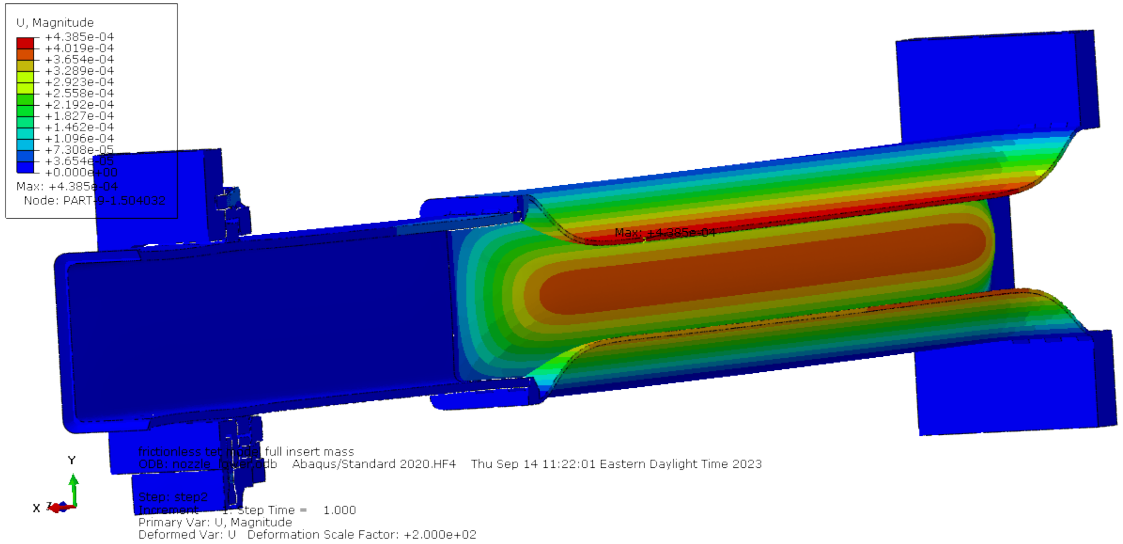
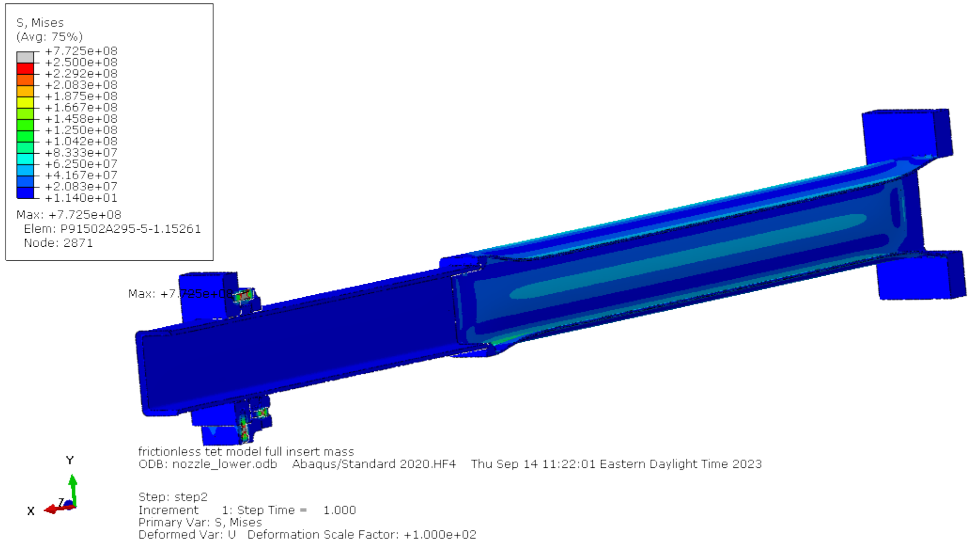
Lower Nozzle Step 2

Displacement magnitude

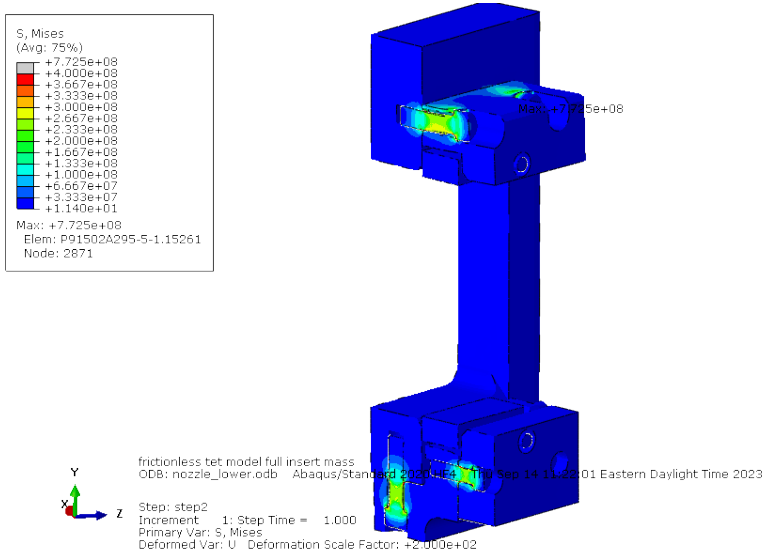


S Mises – 250 MPa Scale

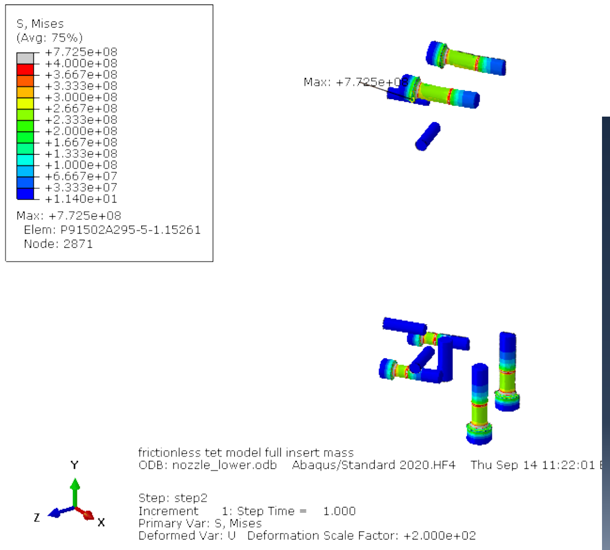


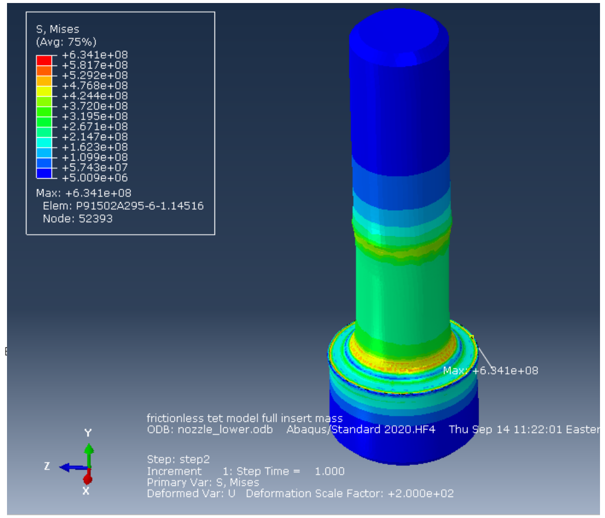
Step 2 stresses

Bolt and brackets S Mises 400 MPa scale



Bolt Mises Stress 400 MPa scale





Lower 20 mm bolt
Peak near head ~ 450 MPa

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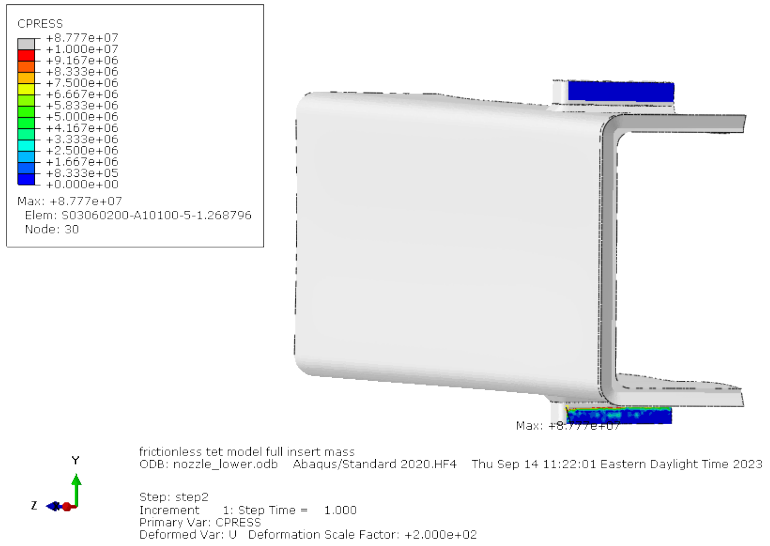
Step 2 Support Blocks contact conditions

Upper block not in contact with core vessel

Contact pressure on lower block

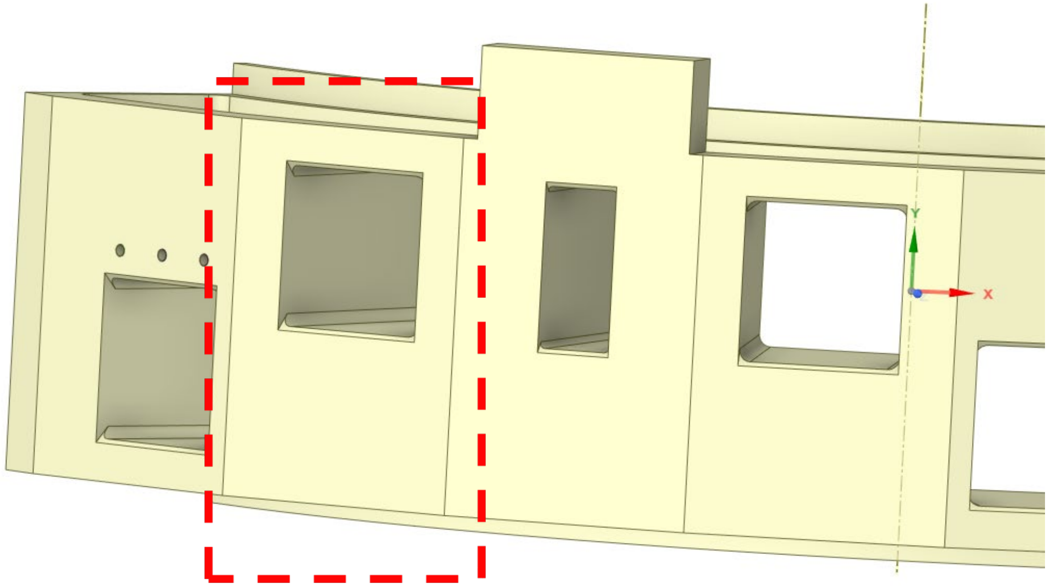


Summary for lower nozzle assembly

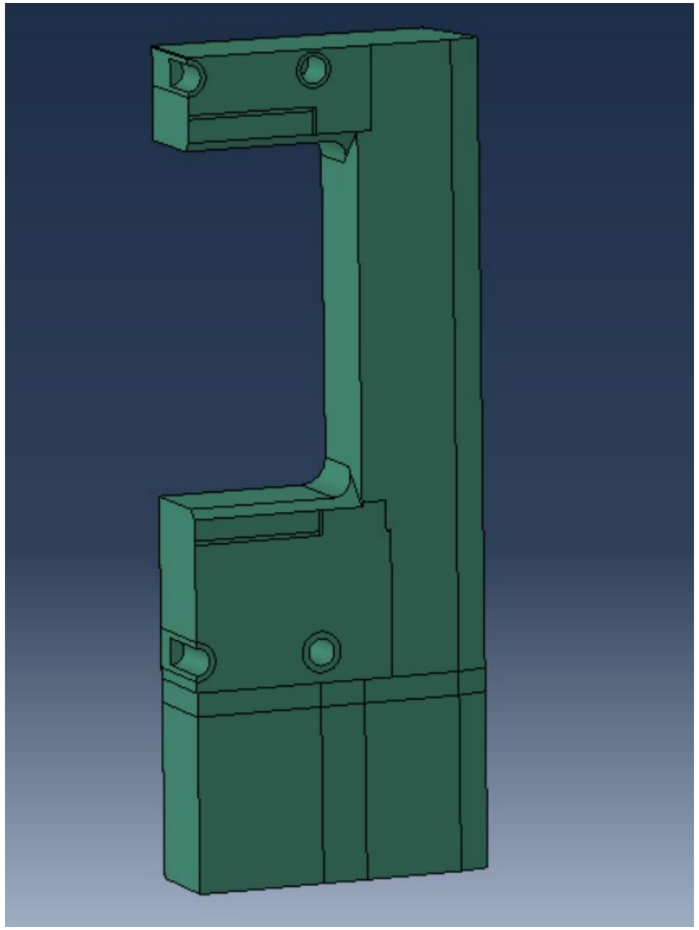
- Preloads on bolts are approximately 60% of proof loads but do show small zones of yielding around base of head and by core vessel tie
- Bracket parts show some local yielding around edges adjacent to bolt bearing areas and at start of ties simulating threads
- Upper support bracket does not contact core vessel after loading
- Nearly all nozzle stresses are well below yield for normal operation

Upper Nozzle and brackets

Section of the core vessel for the next upper port selected, “trimmed” and moved to align with nozzle model



Half symmetry model of upper port



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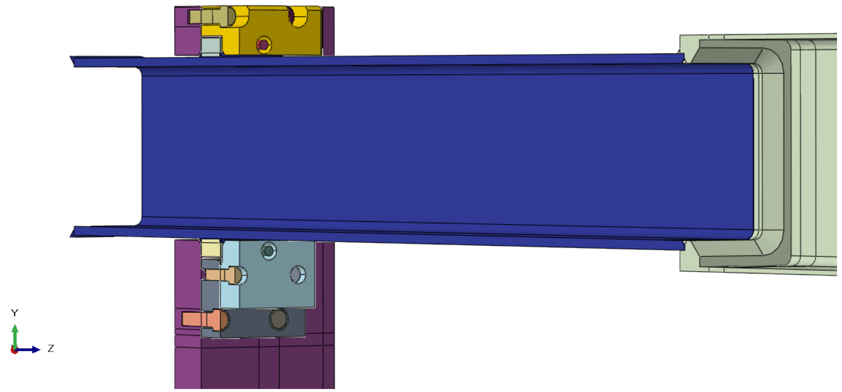
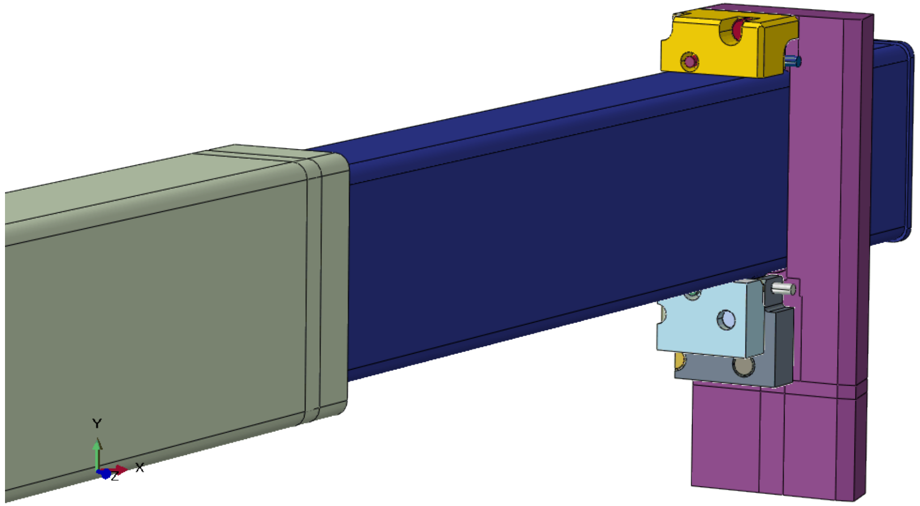
Upper Nozzle Assembly with Brackets

Half Symmetry model

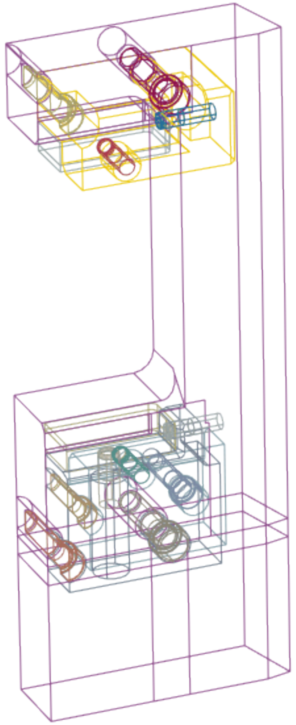


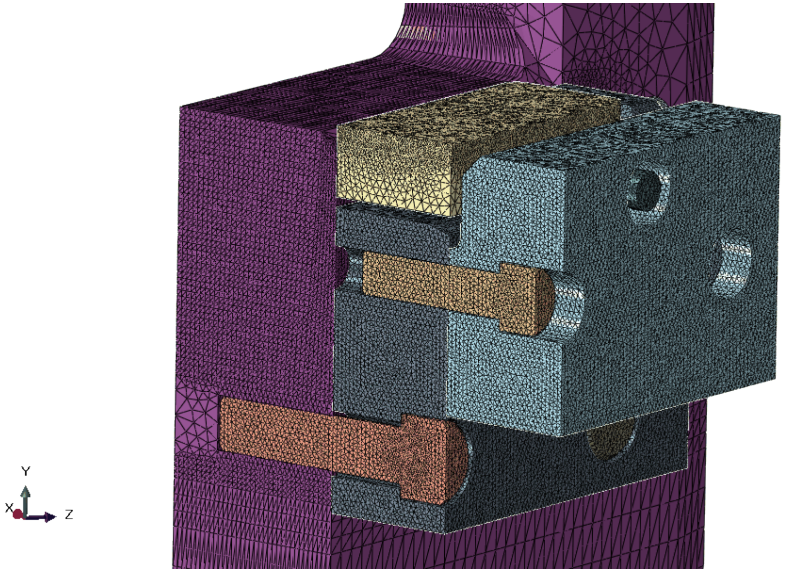
Side view

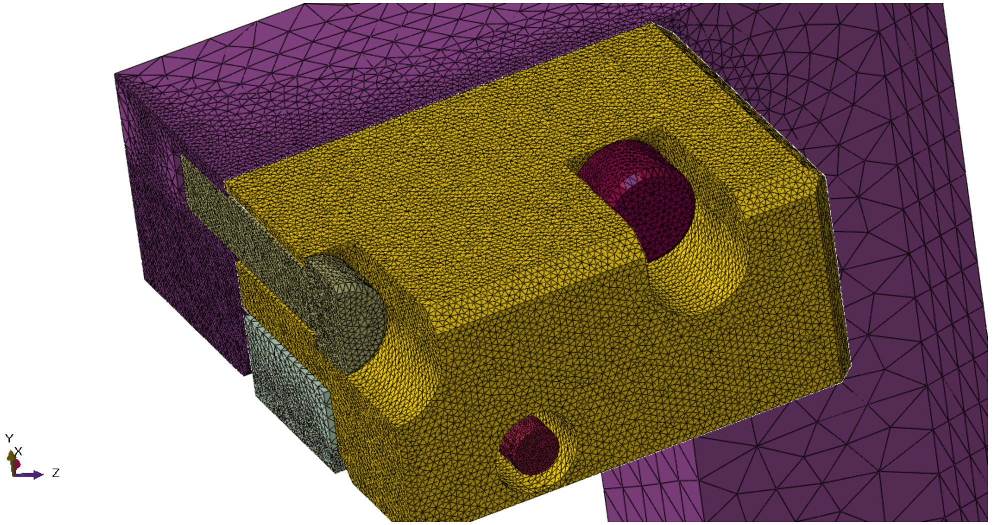


Lower Bracket simplified compared to lower assembly and bolts horizontally into core vessel instead of on bottom otherwise similar constraints and contacts

Upper Nozzle Assembly brackets and mesh examples

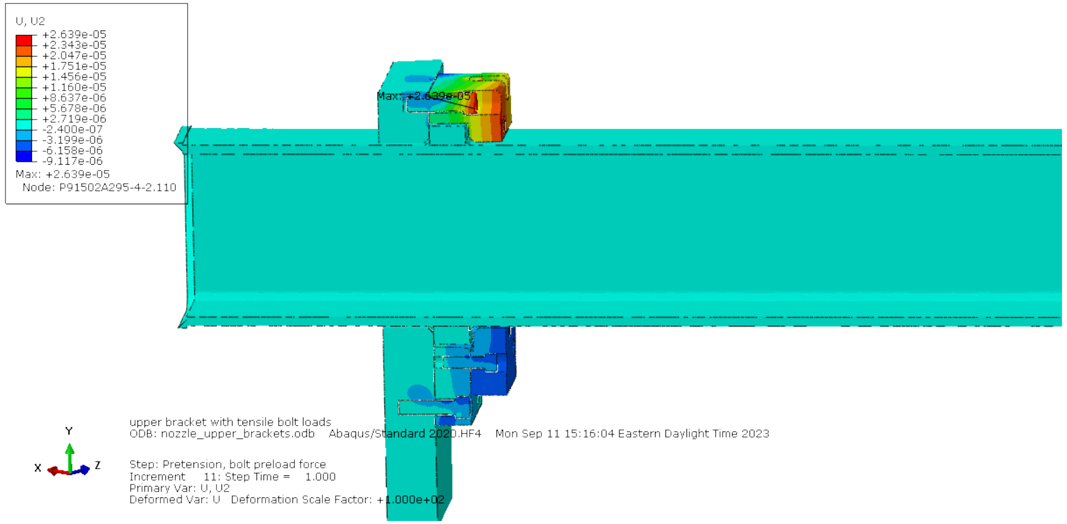




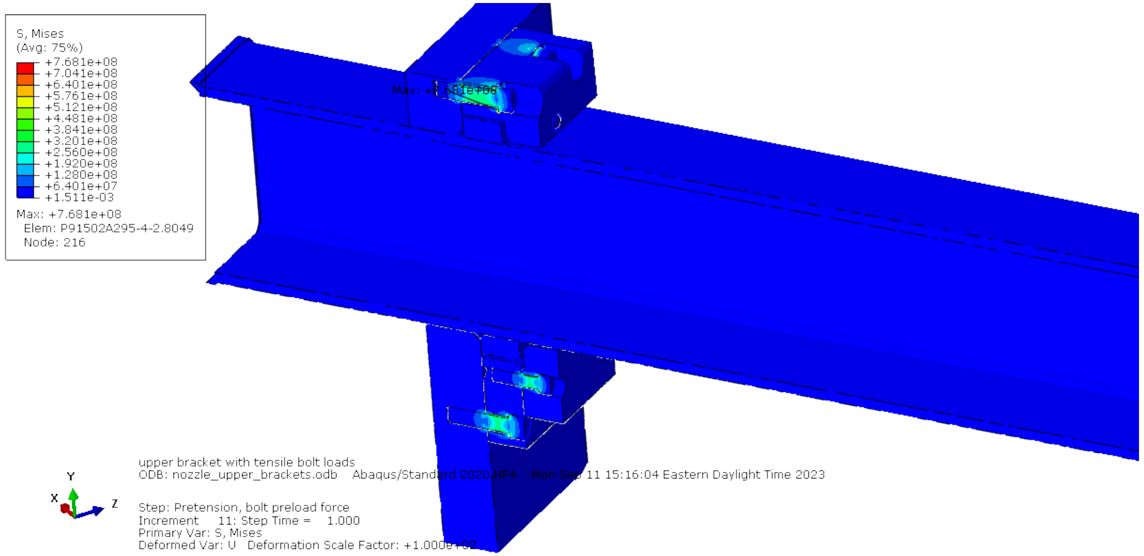


Upper nozzle Prestress step

Vertical Displacement



S Mises



Bolt stresses similar to Lower Nozzle results

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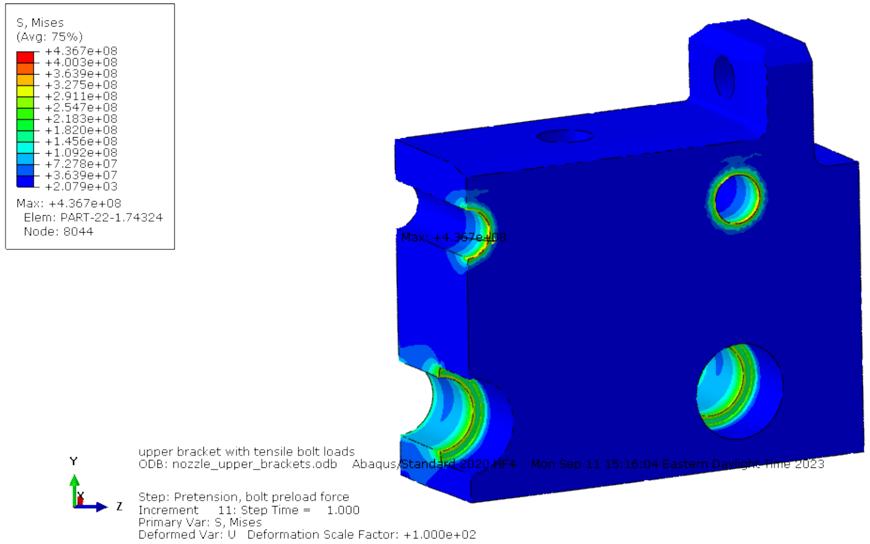
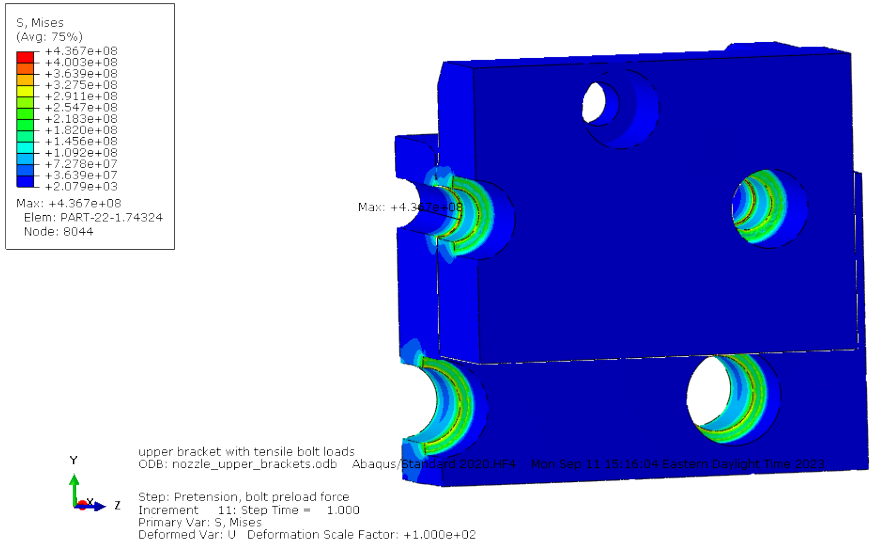
Upper nozzle, lower bracket parts pretension S

Lower bracket inner part S

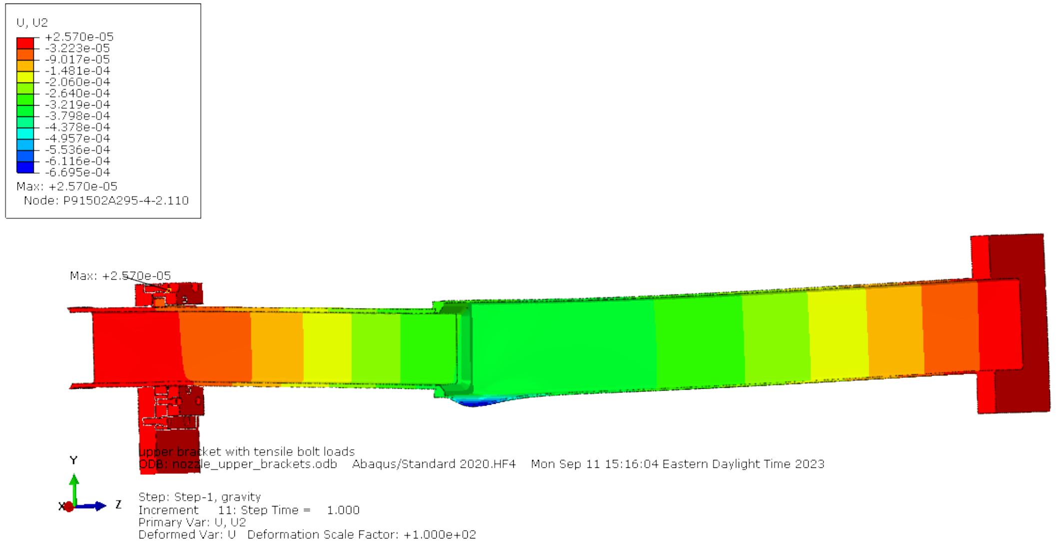


Lower bracket inner and outer parts S Mises

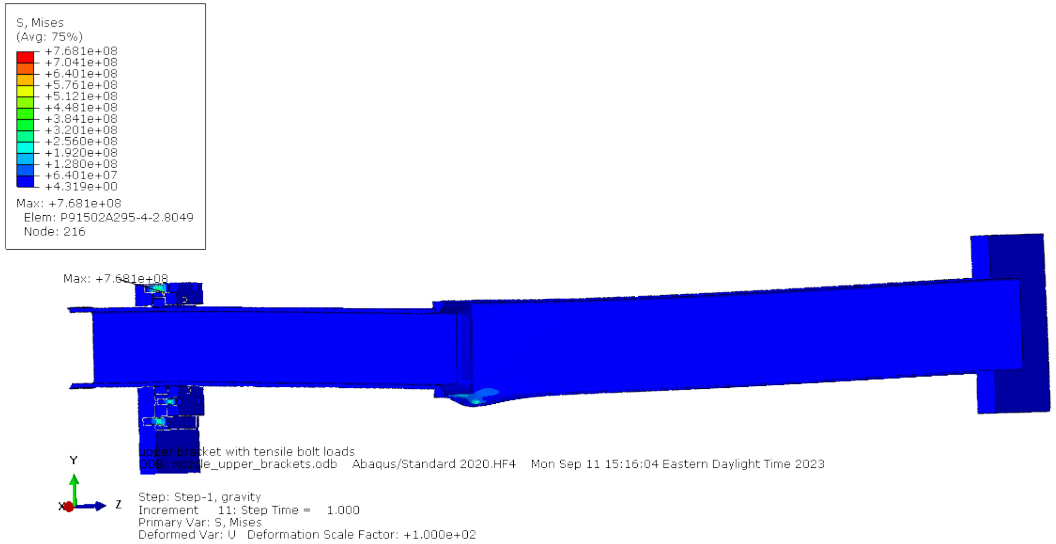


Upper Nozzle Step 1

Vertical Displacement

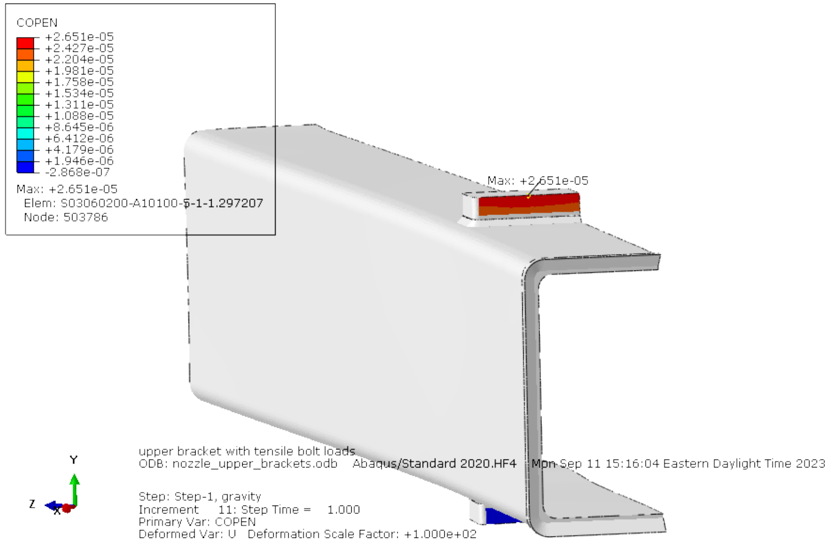


S Mises

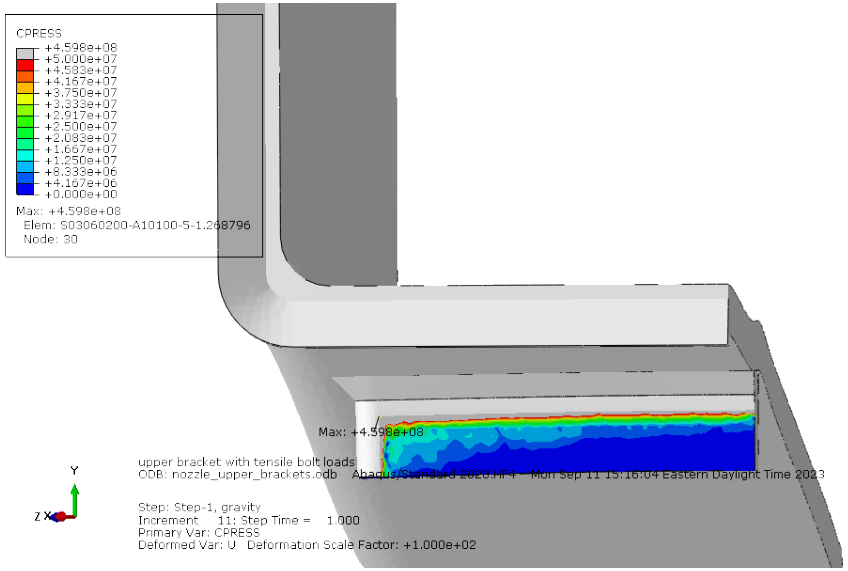


Upper nozzle STEP1 support block contact conditions

COPEN



CPRESS



Similar to lower nozzle assembly - the upper blocks pulls away from core vessel and the lower block has pressure distribution with core vessel

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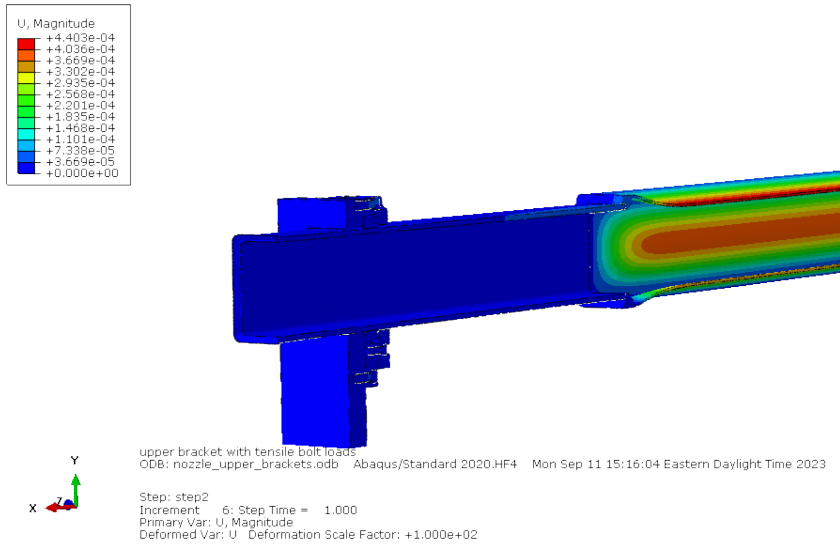
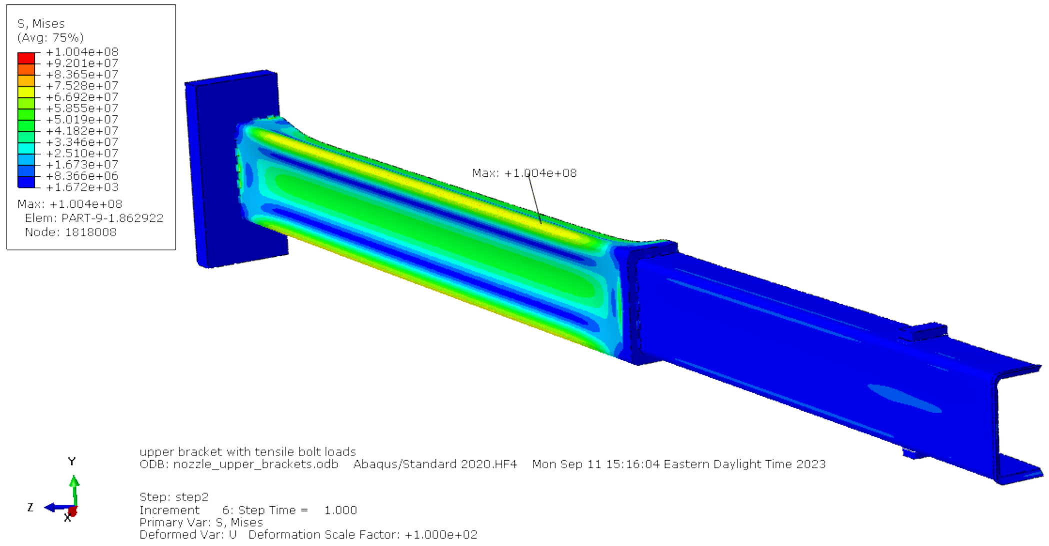
Step 2 – normal operation

Displacement

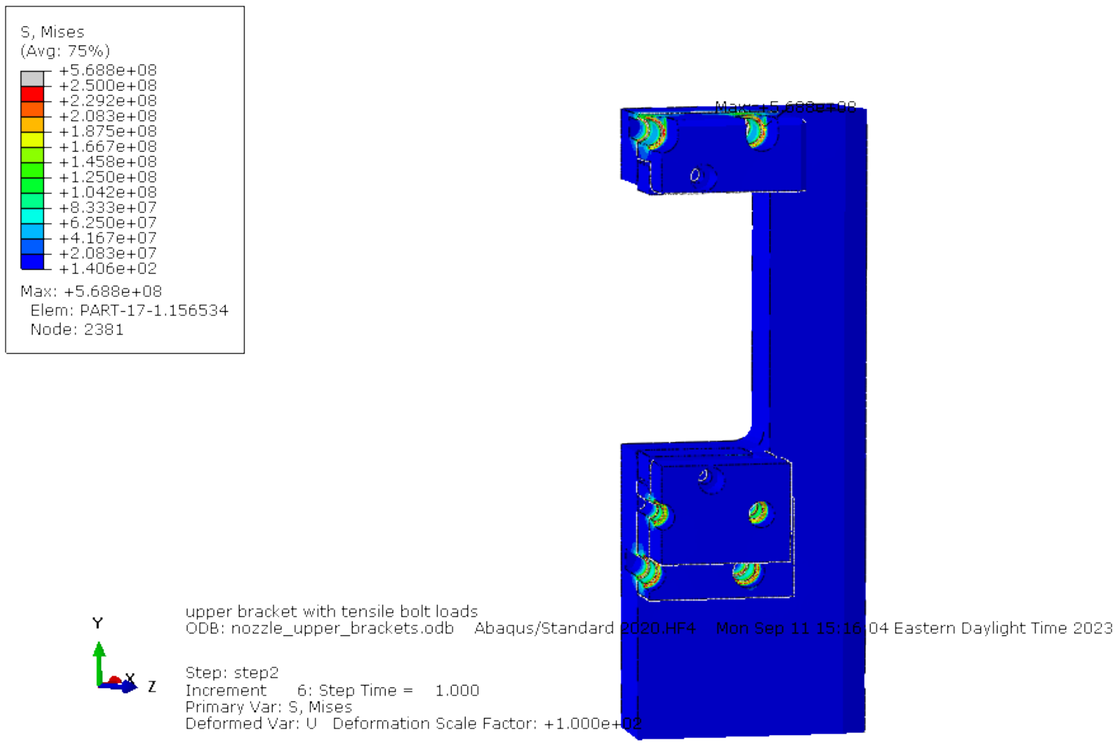


Nozzle parts S Mises

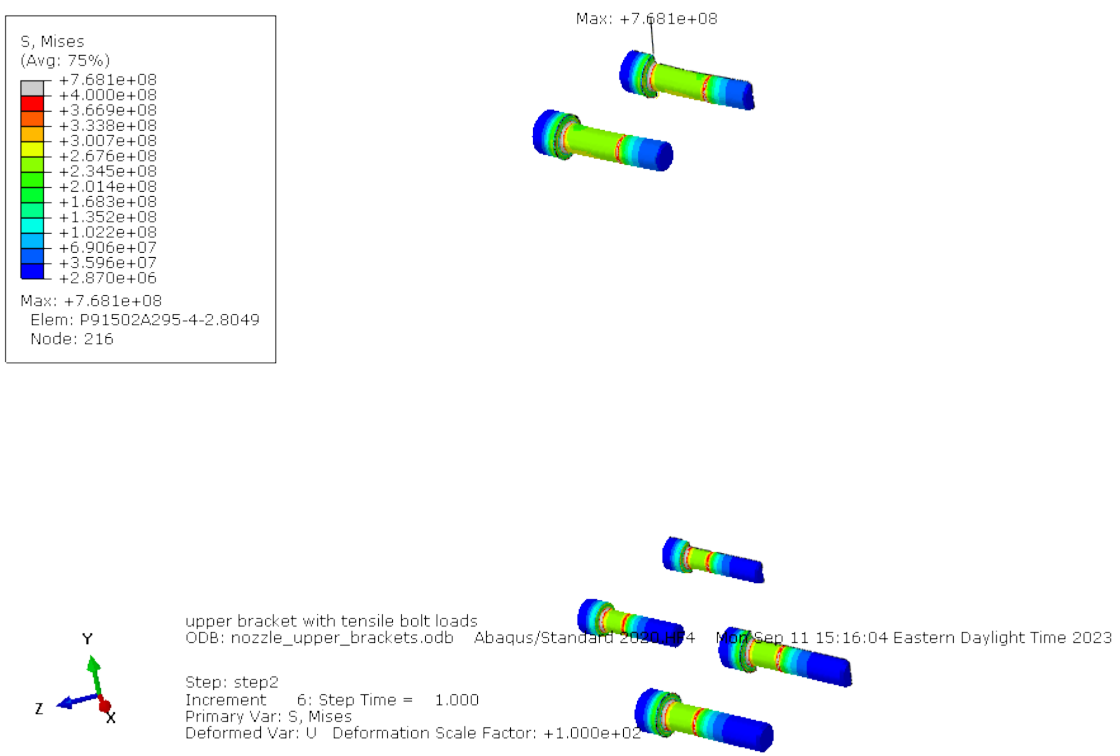


Step 2 Stresses

Brackets S Mises 250 MPa scale



Bolts S Mises 400 MPa scale



Upper Nozzle Assembly Summary

- The results are very similar between the Upper Assembly and Lower assembly results
- Preloads on bolts are approximately 60% of proof loads but do show small zones of yielding around base of head and by core vessel tie and ties to bracket parts
- Bracket parts show some local yielding around edges adjacent to bolt bearing areas
- Upper support bracket does not contact core vessel after loading
- Nearly all nozzle stresses are well below yield for normal operation

CV QIKR NOZZLE Extension 925 Preliminary Analysis

Thomas McManamy

10/2/24

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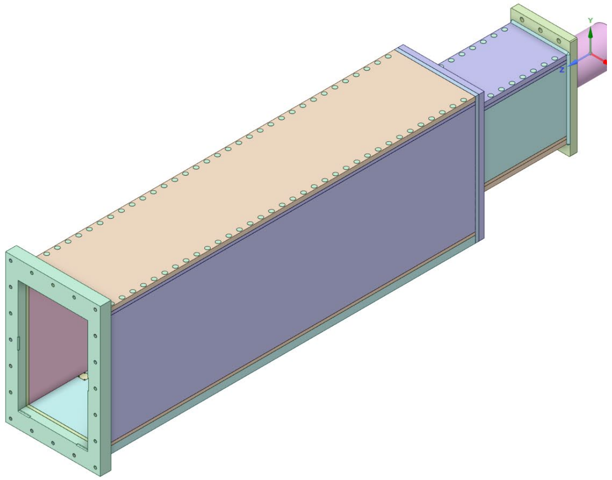
QIKR Nozzle with 10 mm seal welds

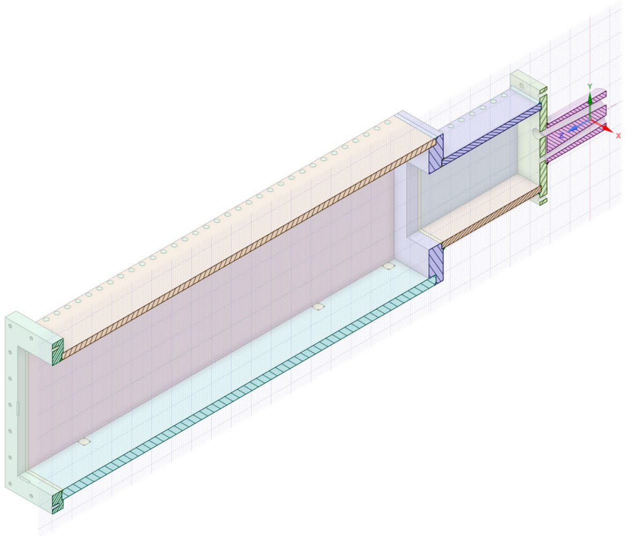
- The QIKR Nozzle model from 9/5/24 includes
  - 10 mm seal welds on the outer surfaces
  - Plate structures instead of forgings
  - Intermediate flange between front and wider rear sections
  - 12 mm bolts on 75 mm centers for side plates
  - 4 25 mm diameter bolts to attach to beltline
- Abaqus model additions
  - 2 Inconel shear pins
  - Inconel rings for interface with shear pins

SpaceClaim model from 9/5/24

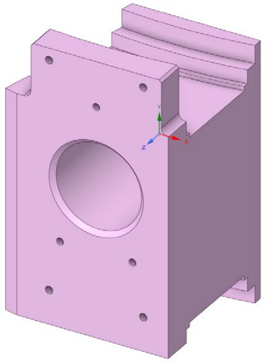
QIKR Nozzle Assembly



Section View



Beltline section



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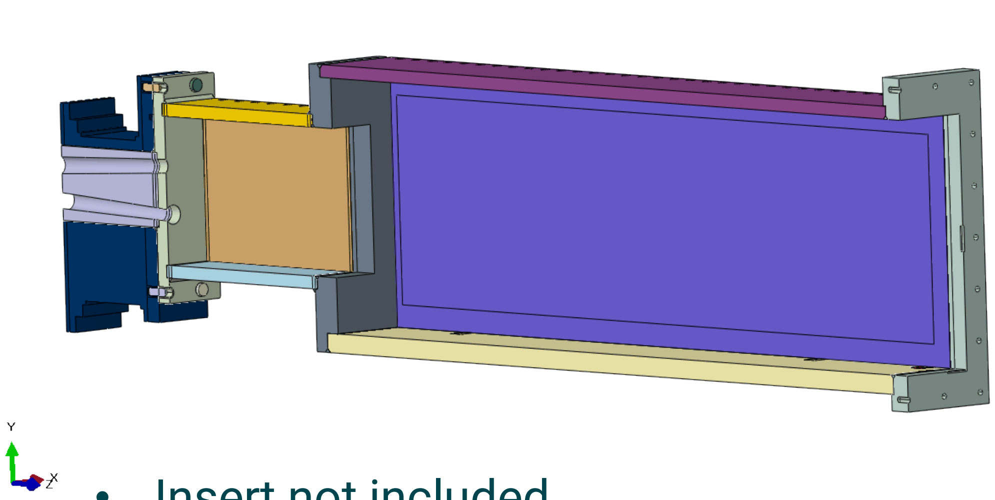
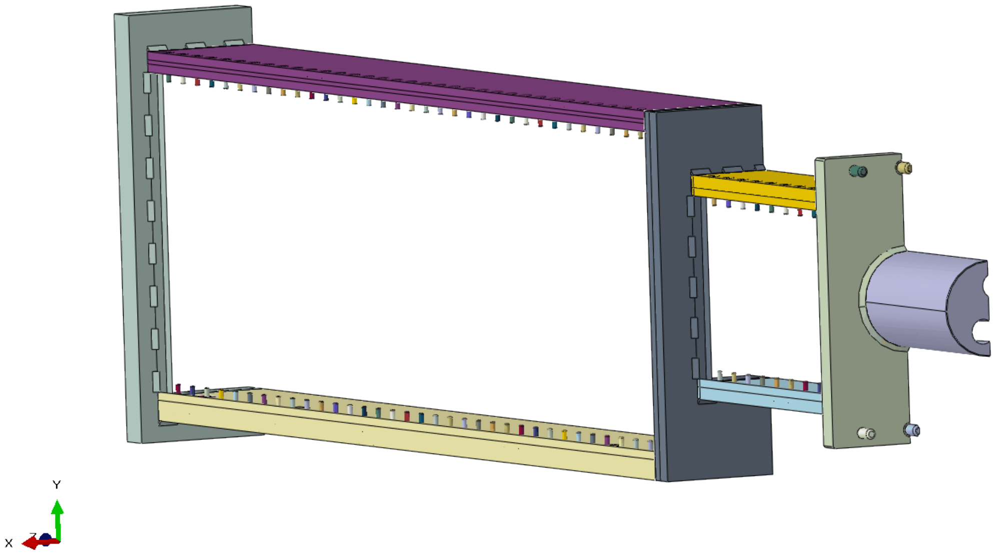
Abaqus model with all welds merged

Abaqus half symmetry model



- Insert not included
- Fillet and groove welds included
- Bolt caps not included
- 2 Shear pins and beltline holes added
- 2 25 mm Diameter Bolts added

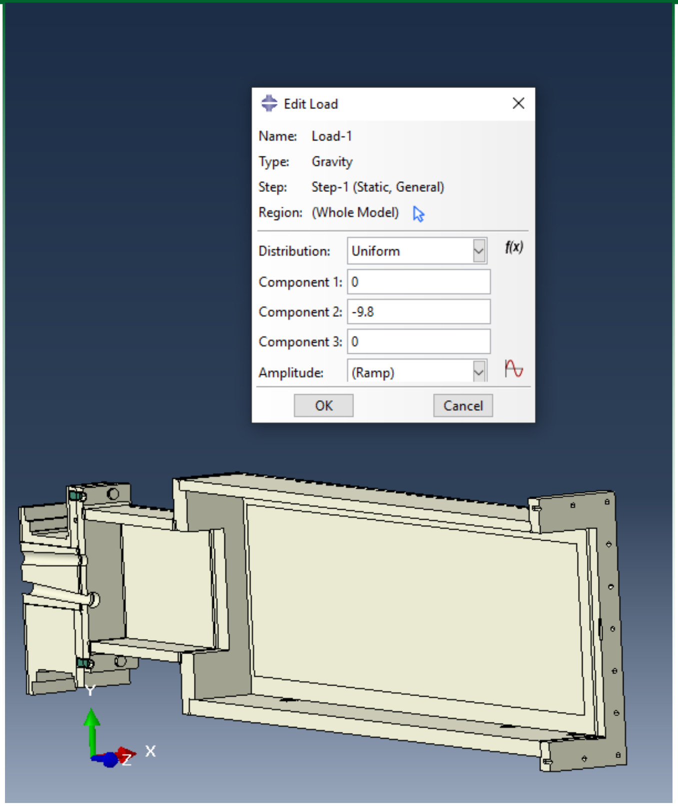
Side Plates removed to show bolting and merged welds



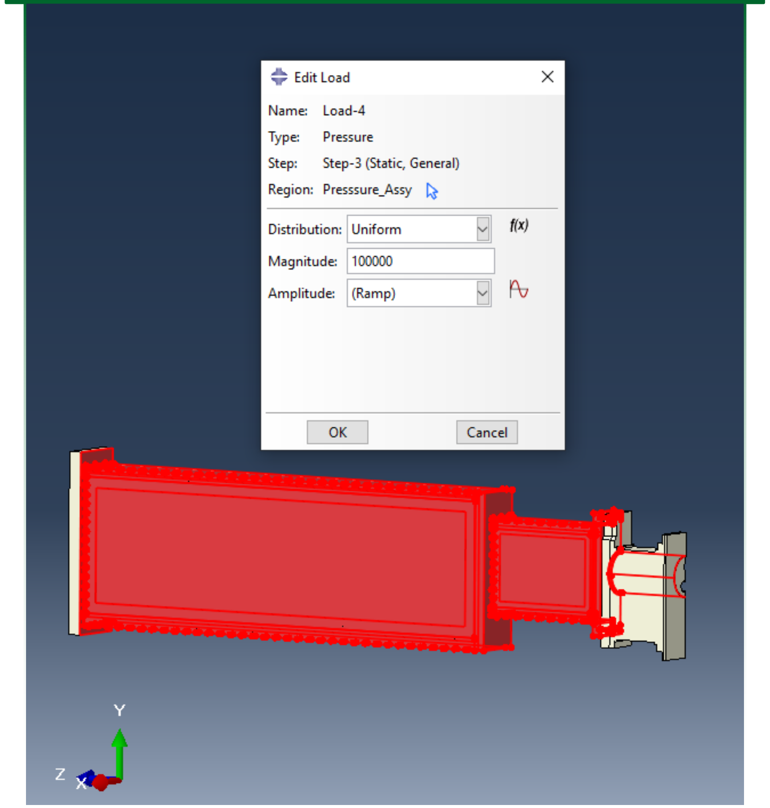
Fillet and skip welds merged with flanges and Groove welds merged with top and bottom plates in front and rear sections

Loads

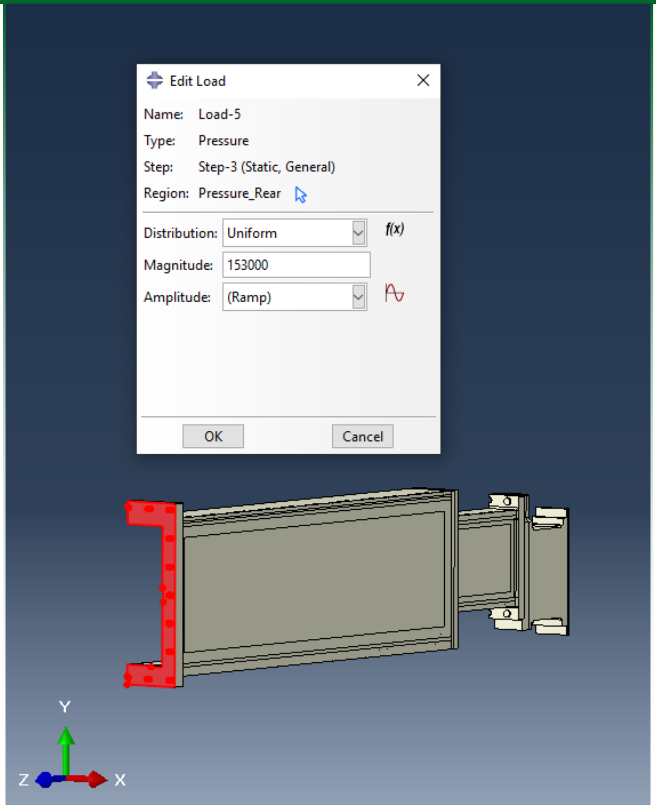
Gravity



Pressure 1 bar



Pressure equivalent on rear flange

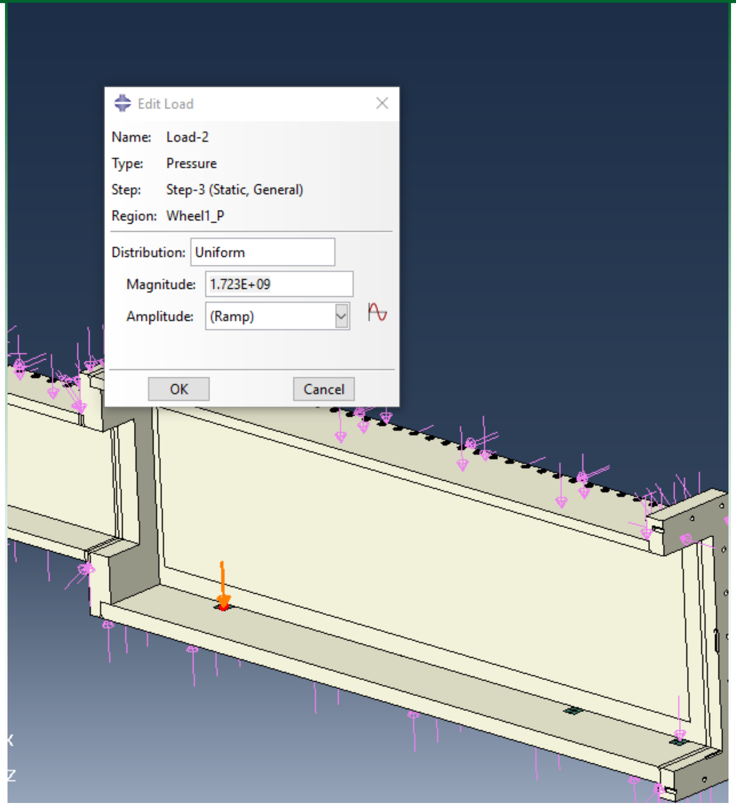


Uniform Pressure (Pa) loads from inserts on wheel pads

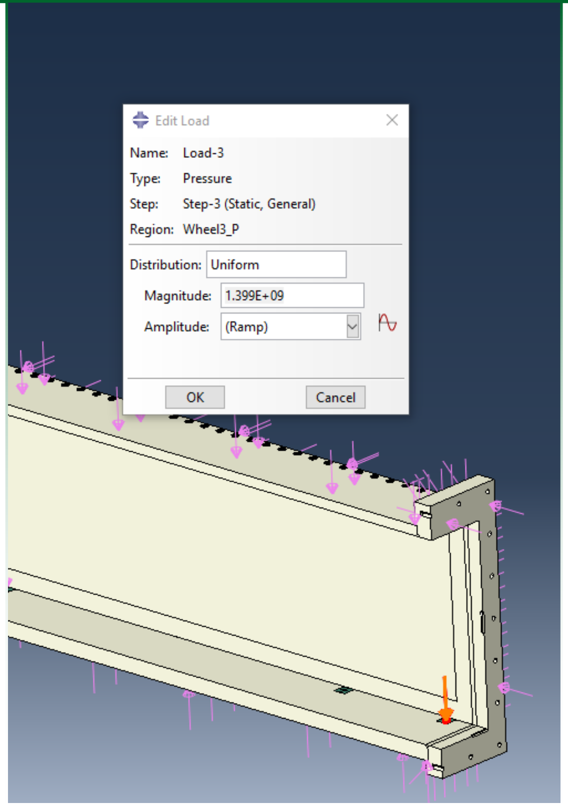
Insert load assumptions

- Insert gravity loads applied to a 1mm x 12m assumed bearing area
- Area approximation from detailed contact model
- Uniform pressure assumed
- Interface loads are 2110 kg for front wheel and 1713 kg for rear wheels

Front wheel load



Rear wheel load



Results

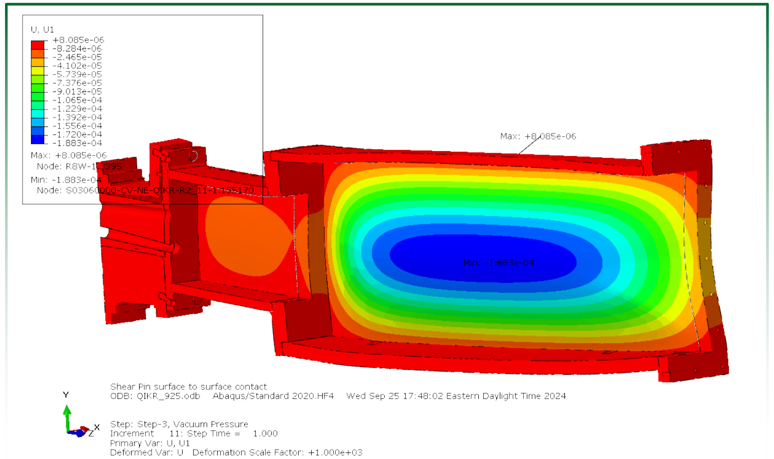
- Step 1 – gravity only load
- Step 2 – gravity and insert loads
- Step 3 – gravity, insert loads and pressure from vacuum operation

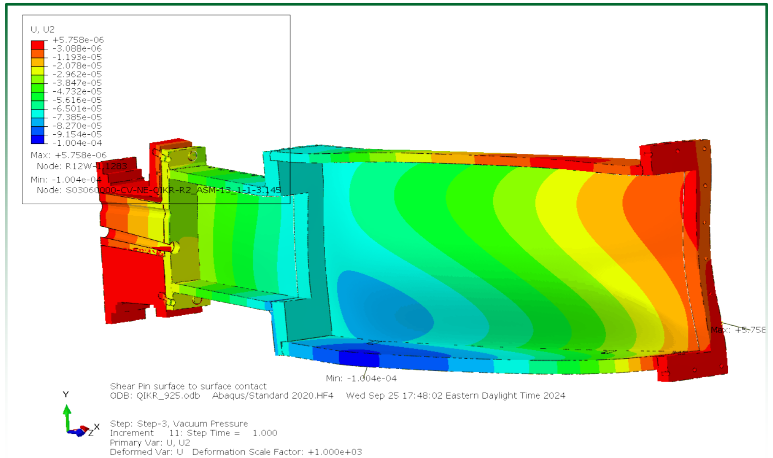
Step 3 Gravity, Insert loads and Pressure loads - displacements

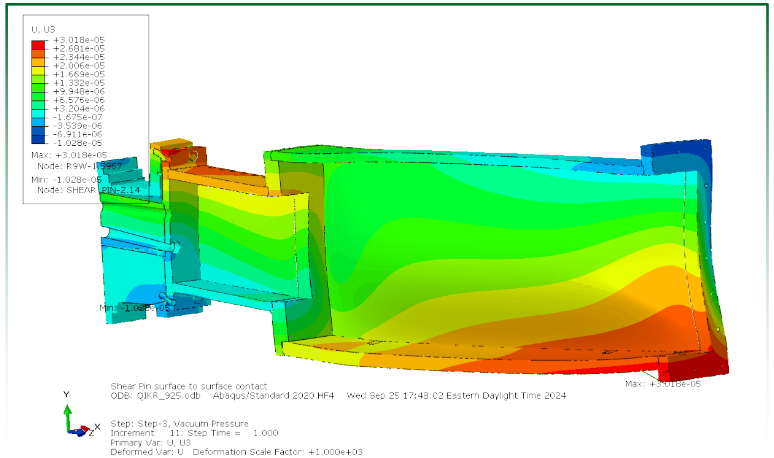
U1 minimum -0.188 mm

U2 minimum -0.10 mm

U3 minimum -0.01 mm

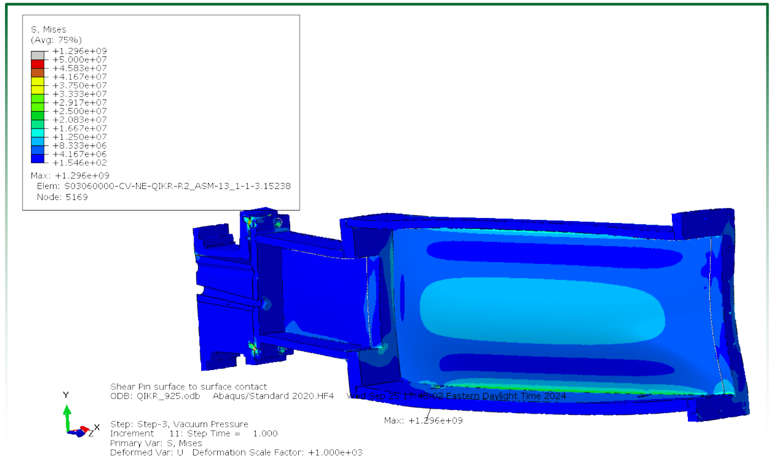




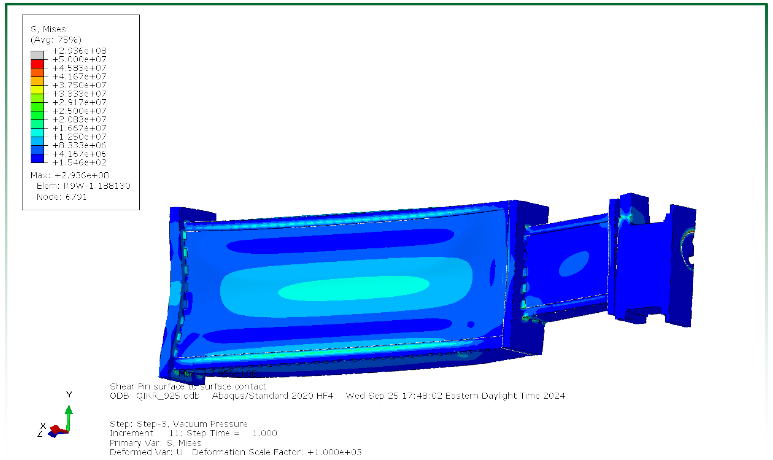


Step 3 Gravity, Insert loads and Pressure loads - Stress

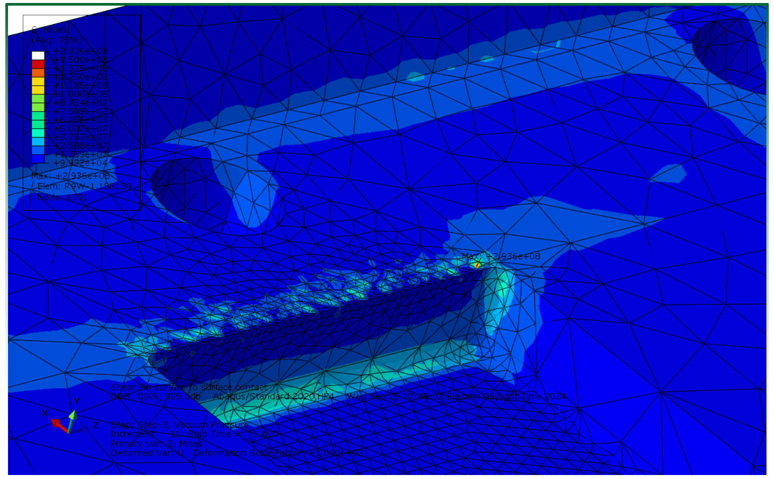
Stress 50 MPa scale peak 1292 MPa in pad



No pads – Stress 50 Mpa scale side view peak 294 MPa in bottom plate



Bottom plate Peak stress in isolated element under contact area with side wall



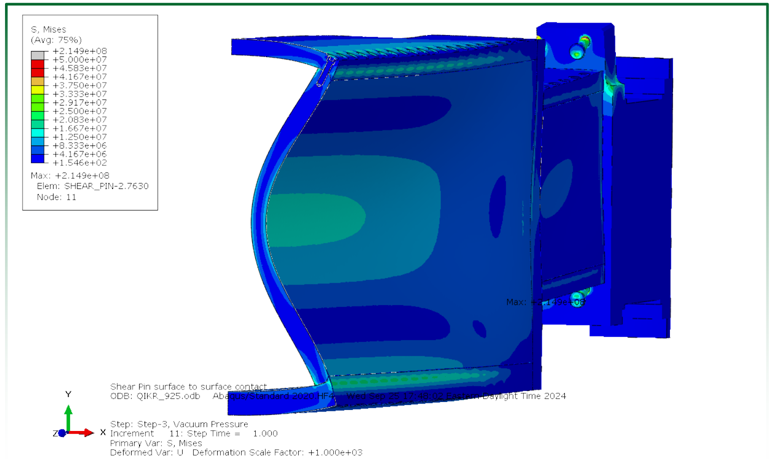
Step 3 Gravity, Insert loads and Pressure loads - Stress

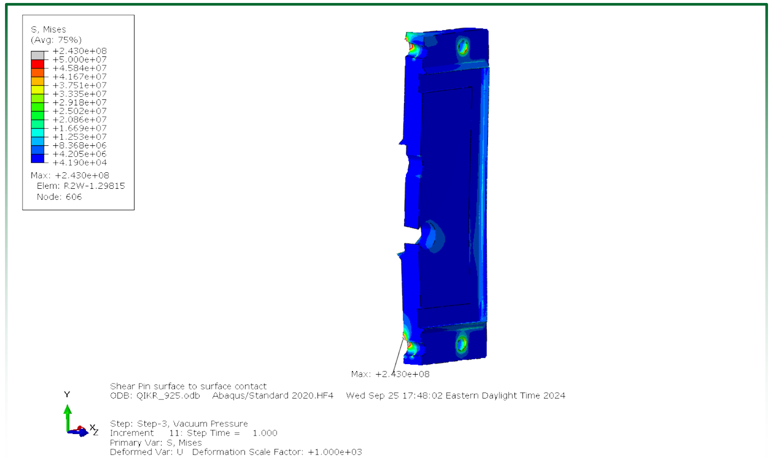
Axial cut with 50 MPa scale

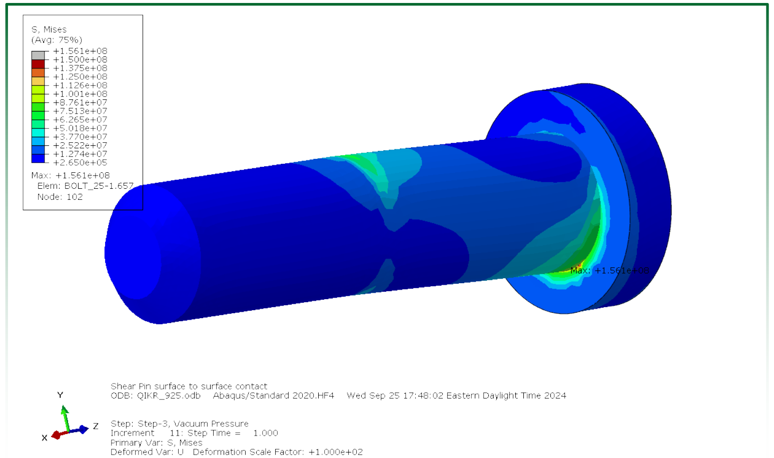
Displacement factor x1000

Front Flange peak 243 MPa by shear pin hole

Top 25 mm bolt peak stress 150 MPa scale peak156 MPa at isolated node at corner by head





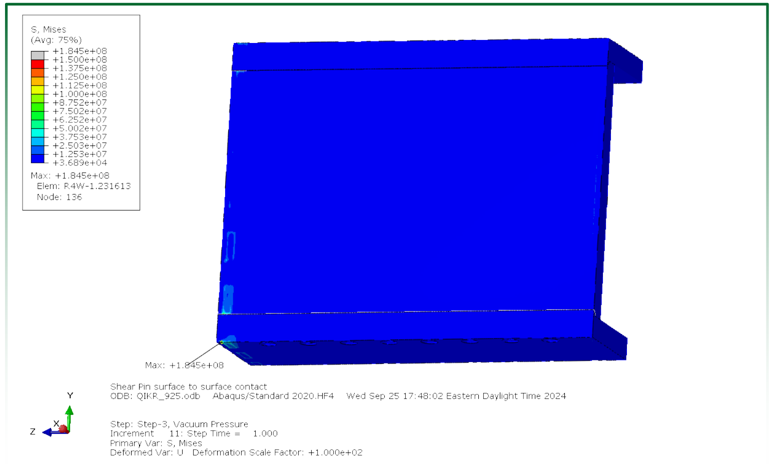


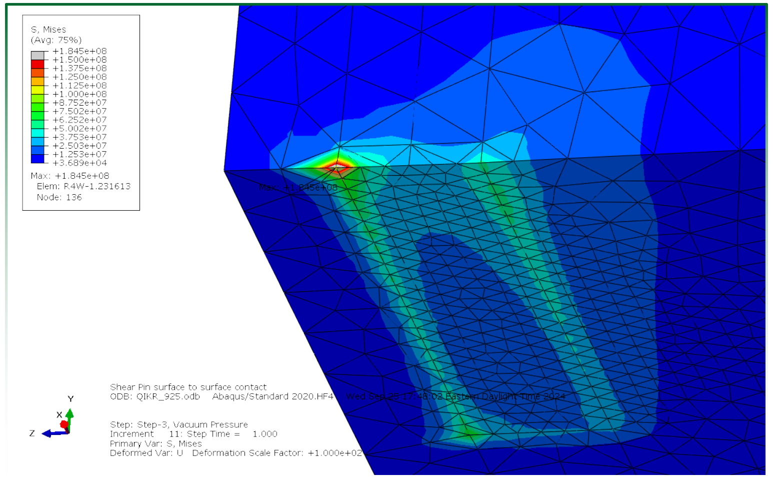
Step 3 Gravity, Insert loads and Pressure loads - Stress

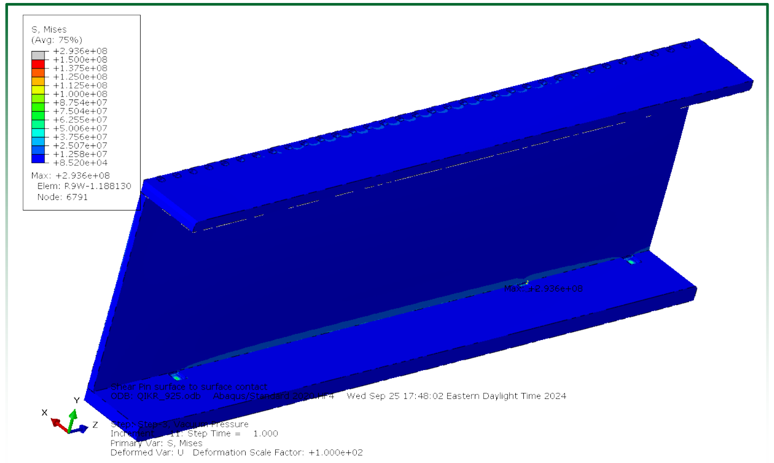
Front, side and bottom plate stress peak 184 MPa

Front Bottom plate stress 150 Mpa scale - peak at edge and corner of skip weld

Rear Top,Side and Bottom plate stress 150 MPa scale peak 294 MPa at isolated element







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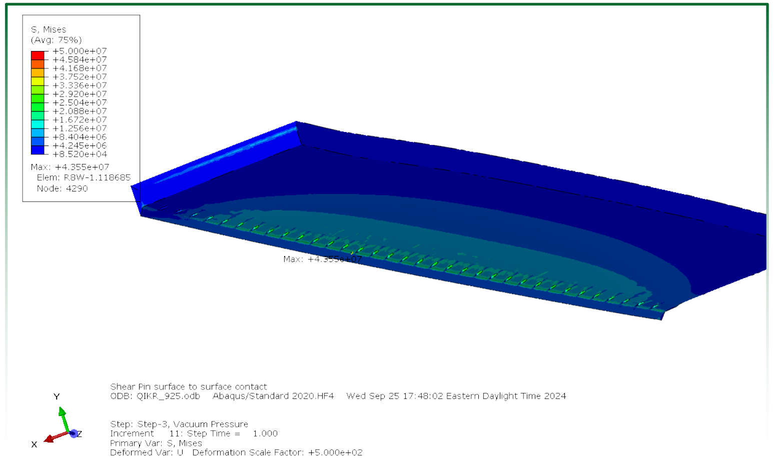
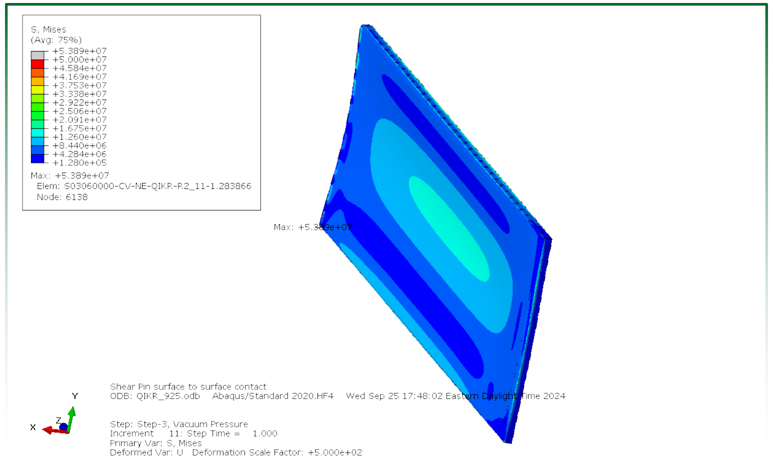
Step 3 Gravity, Insert loads and Pressure loads - Stress

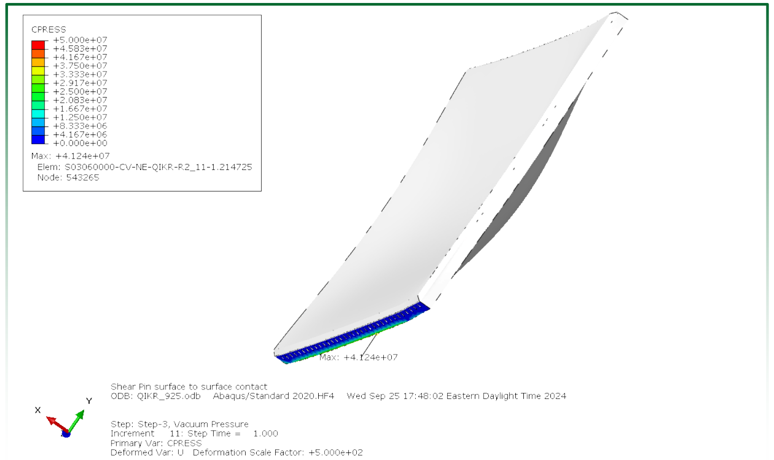
Rear Top Plate 50 Mpa scale peak 43 MPa



Rear Side Plate Stress 50 MPa scale

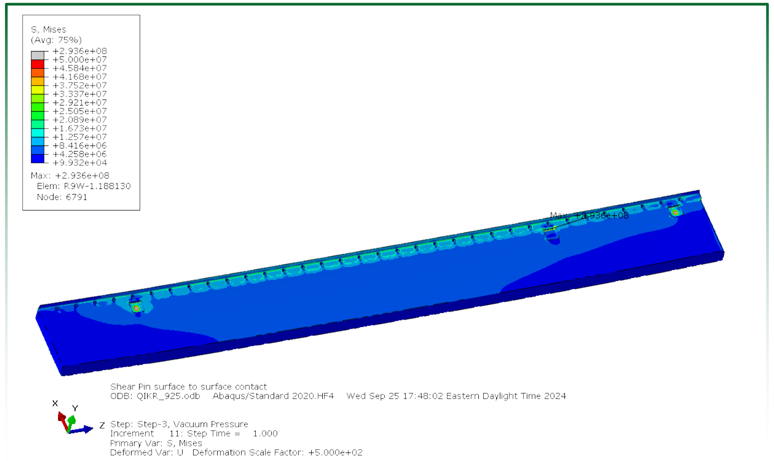


Rear Side Place Contact Pressure

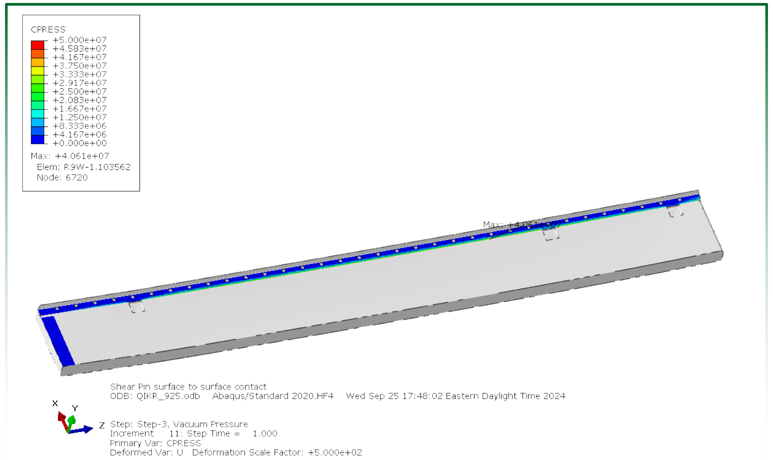


Step 3 Gravity, Insert loads and Pressure loads - Stress

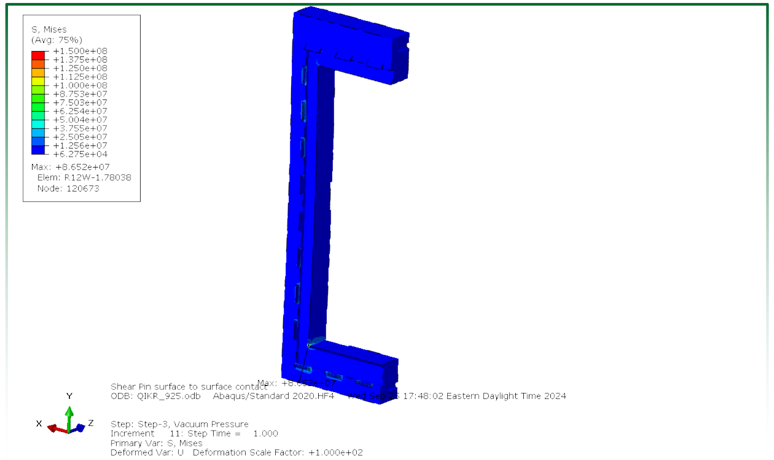
Rear Bottom plate scale 50 MPa peak 294 MPa



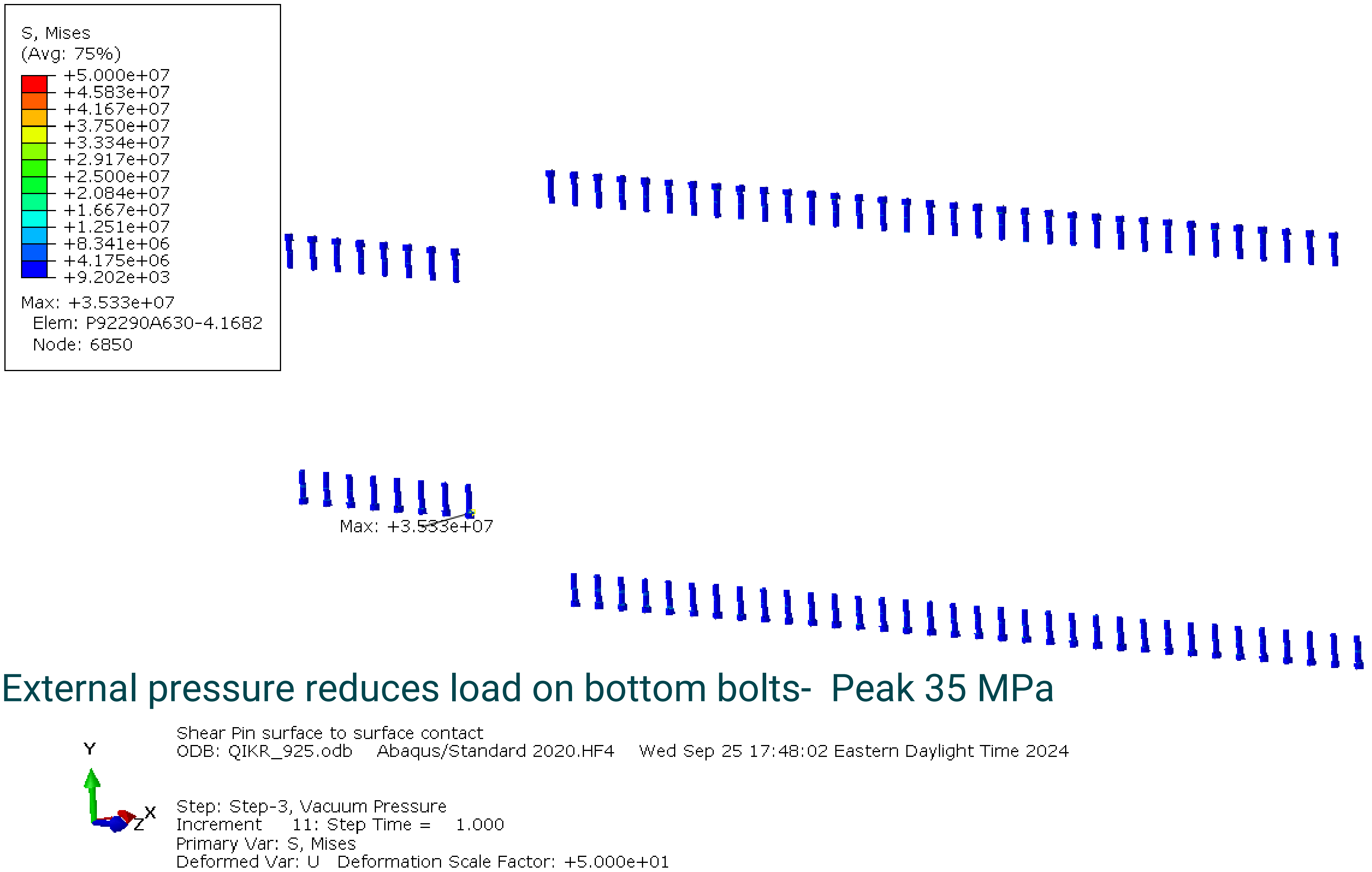
Rear Bottom Plate Contact Pressure



Rear Flange with merged welds 150 MPa scale peak 87 MPa



Step 3 Gravity, Insert loads and Pressure loads – **Bolt** Stress



External pressure reduces load on bottom bolts- Peak 35 MPa

Summary

The stresses and displacements in the model appear acceptable

- All weld stresses are below 100 MPa
- All 316L plate stresses are below 100 MPa, except for one location with two isolated elements with a poor surface to surface mesh interface and at a weld corner singularity
- The highest 12 mm bolt stress was 42 MPa
- The 25 mm bolt stresses were below 150 MPa, except at one node at 156 MPa on head edge with no radii
- Shear pin peak stresses were approximately 215 MPa, well below Inconel yield strength of approximately 1000 MPa
- Use of assumed 4.25 mm Inconel support rings around the shear pins kept mating 316L stress below 100 MPa with ring stress up to about 250 MPa well below Inconel yield strength of approximately 1000 MPa
- The 10 mm Inconel pads under the insert wheels can be expected to have local yielding, in the contact area but they are not part of the pressure boundary

Core Vessel Dual Channel Nozzle Extension Preliminary Analysis

Thomas McManamy

1/22/25

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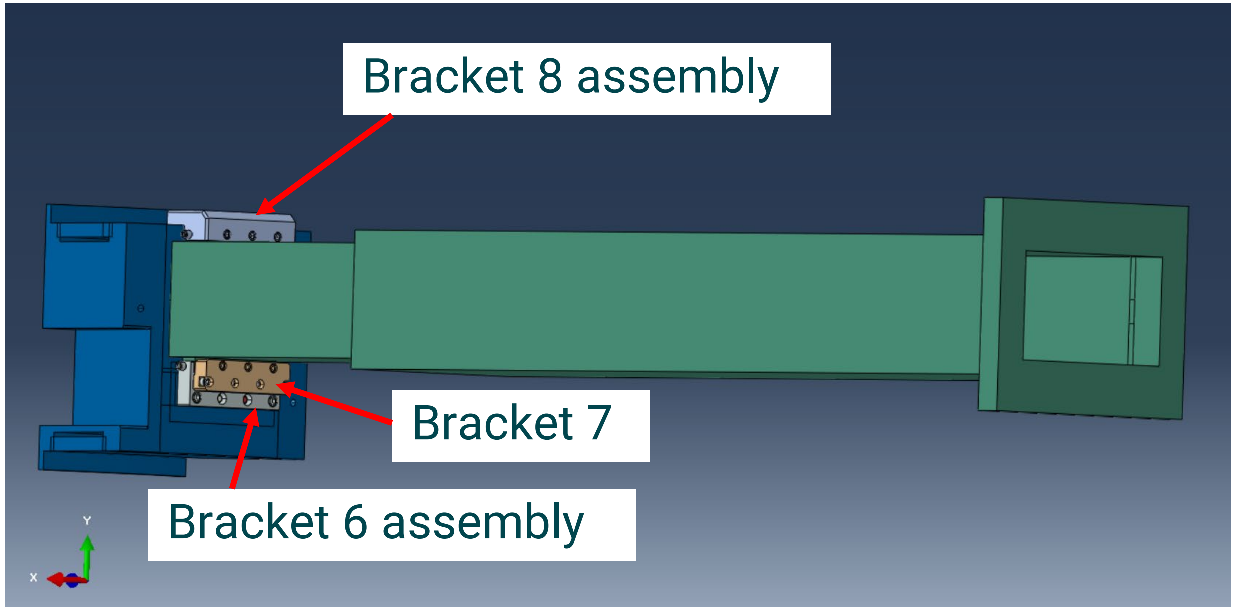
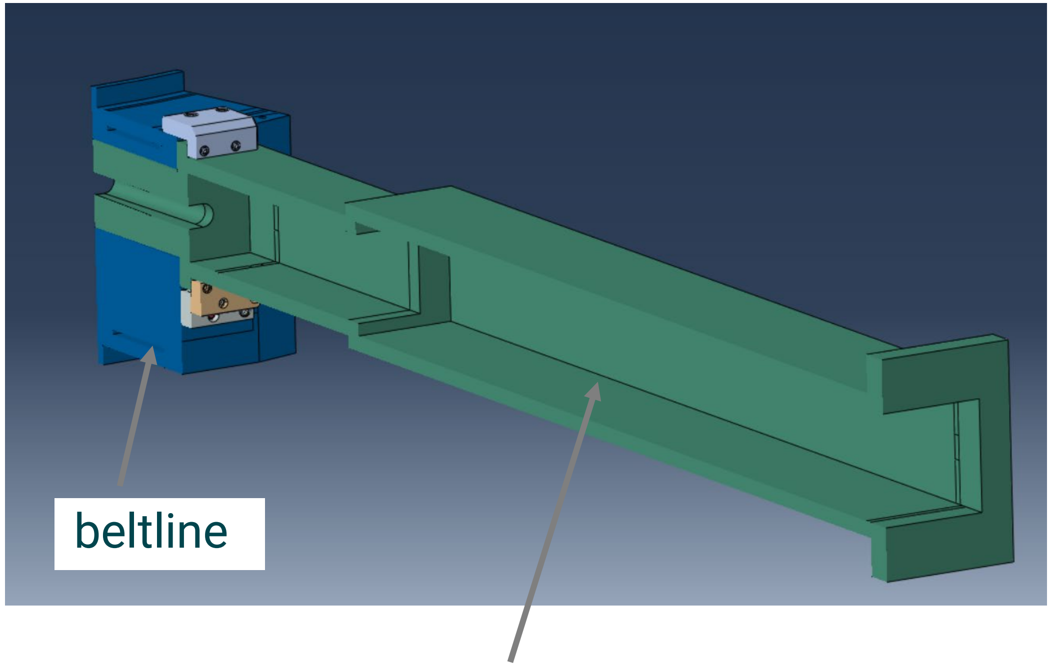
Dual Port Nozzle Abaqus Assembly

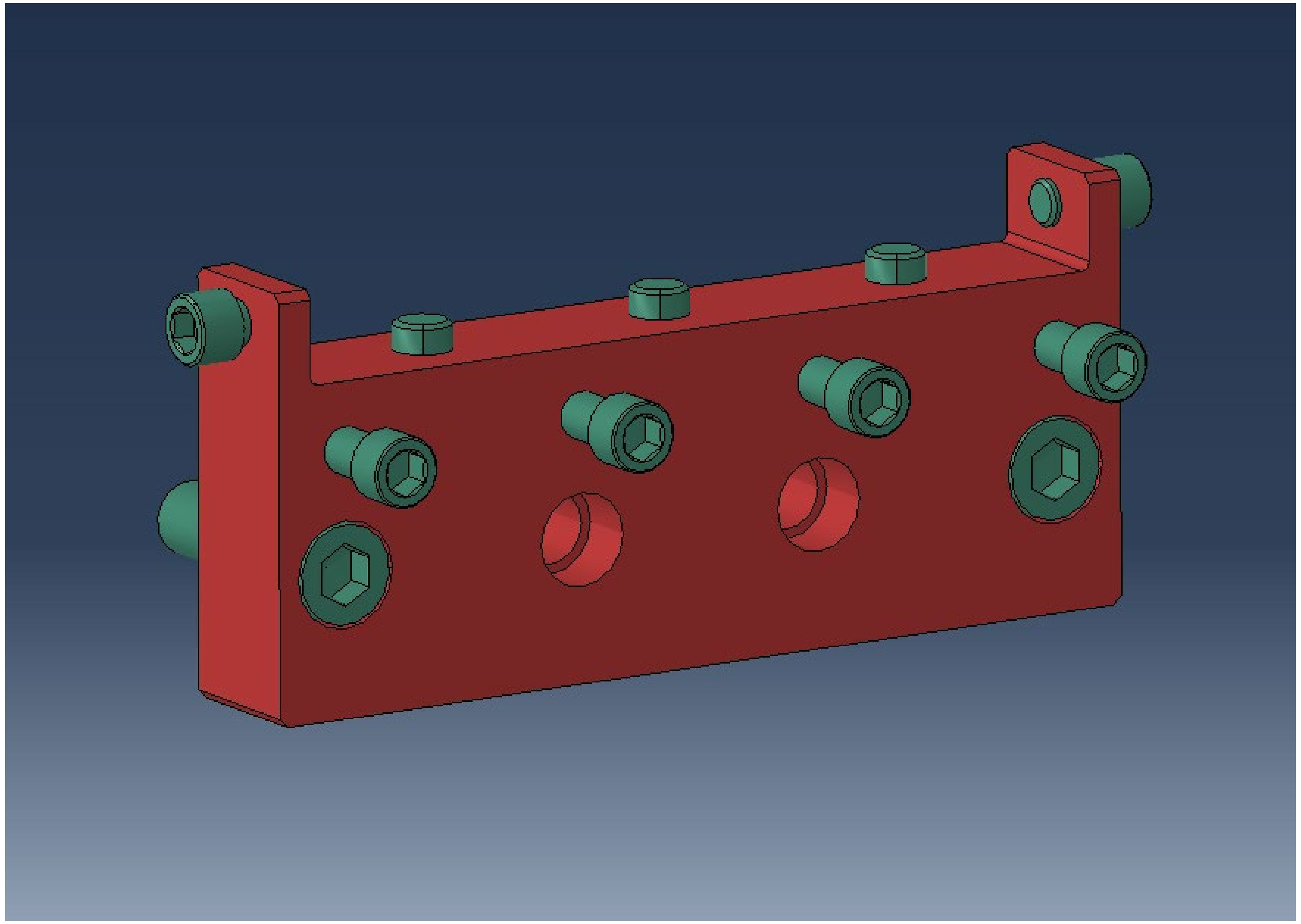




Nozzle

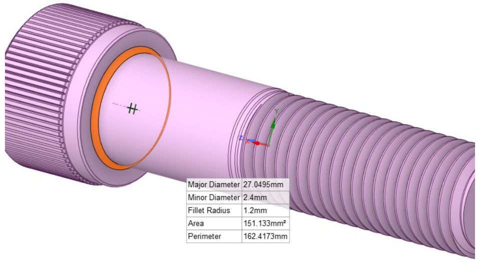
DP5 Proposed design changes to reduce stresses

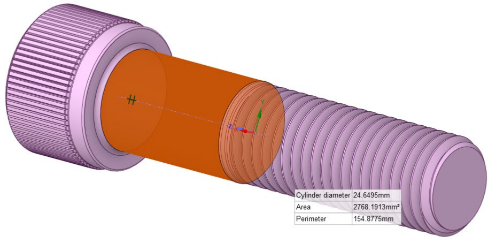
- **Bracket 6 holes enlarged to 24.65 mm Diameter for shank and pins**
- **Bracket bottom extended 25 mm down**



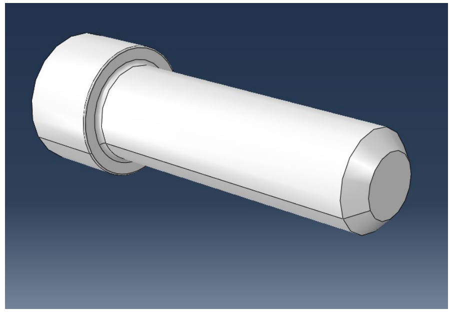
24 mm 316L bolt

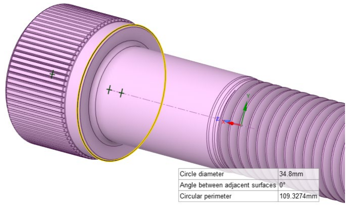
- Shank diameter 24.4649 mm
- Radii near head 1.2 mm
- Head diameter without grooves – 34.8 mm
- Threads not included in model





Simulated bolt modeled



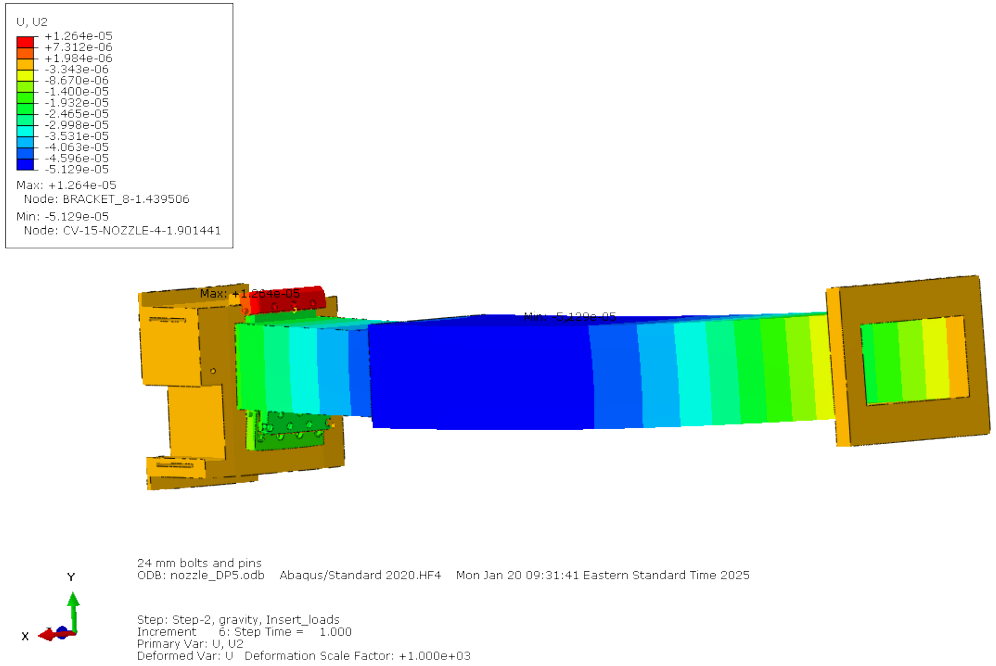


Analysis Step Loads and Boundary Conditions – same as for DP4 model

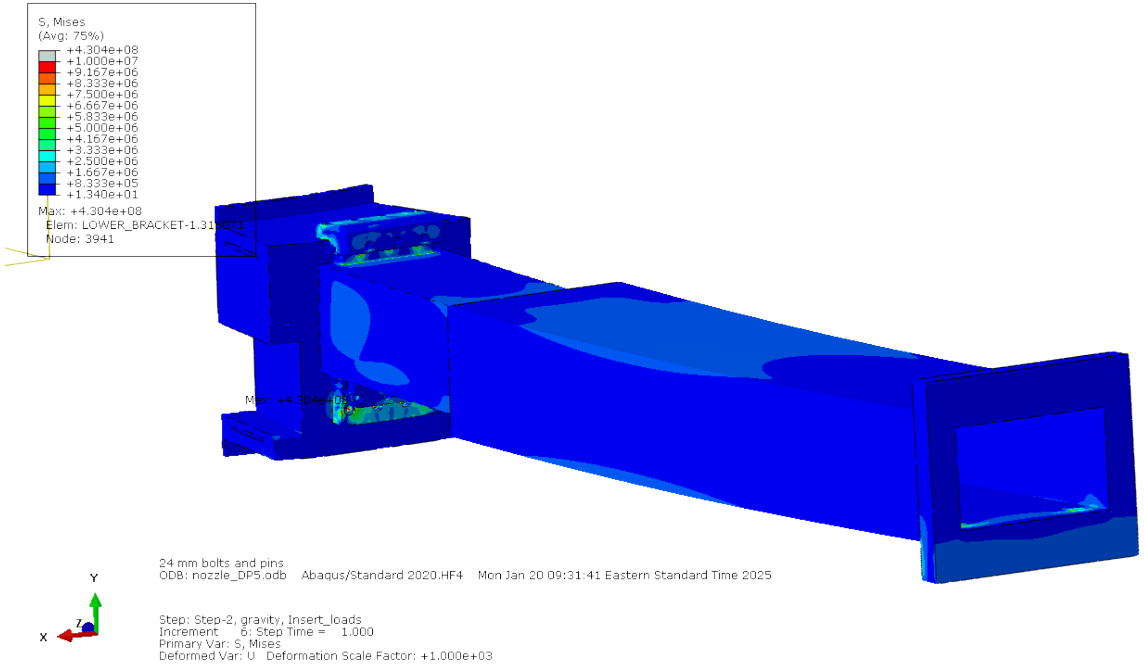
	Loads						Boundary Conditions		
Step	Structure 1 g vertical	Insert mass 1 g vertical	1 bar pressure	Seisimic side load	Seismic axial load	Seismic vertical load	1- Beltline fixed	2- Flange bottom	3 - Flange side
1	X						X	X	
2	X	X					X	X	
3	X	X	X				X	X	
4	X	X	X	X			X	X	
5	X	X	X		X		X	X	X
6			X			X	X	X	

Step2 Gravity with Insert mass

Displacement peak -.05 mm down

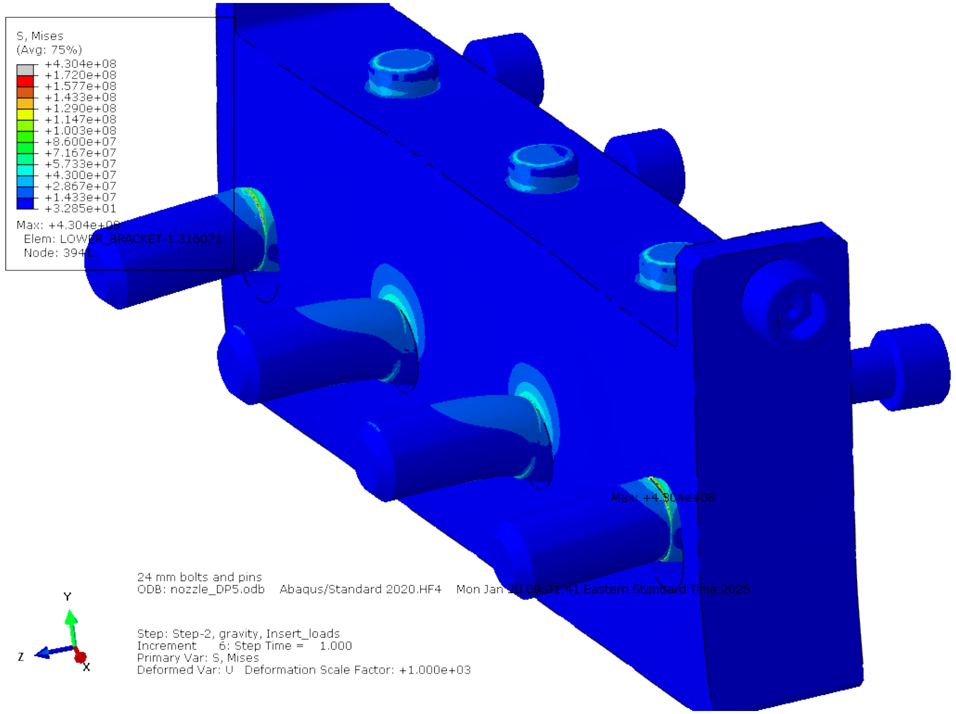


S Mises peak 430 MPa

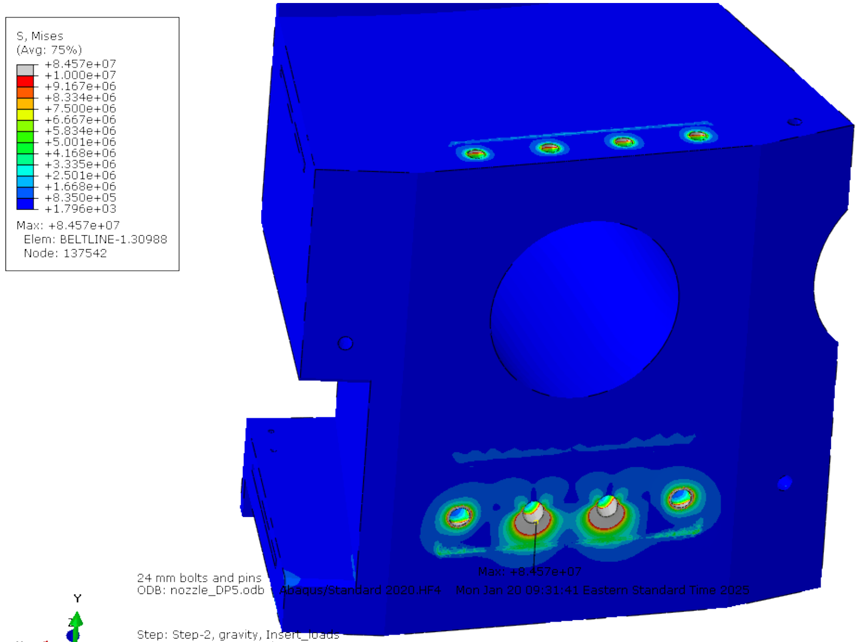


Step 2 Results

Lower Bracket bolt peak 430 MPa

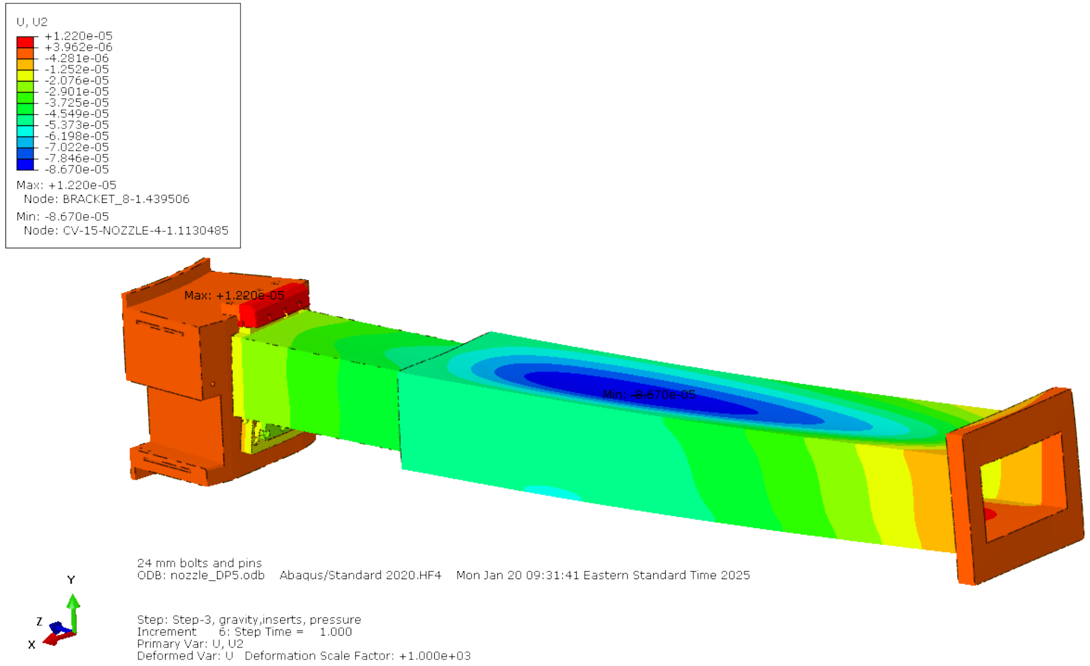


Beltline peak 85 MPa

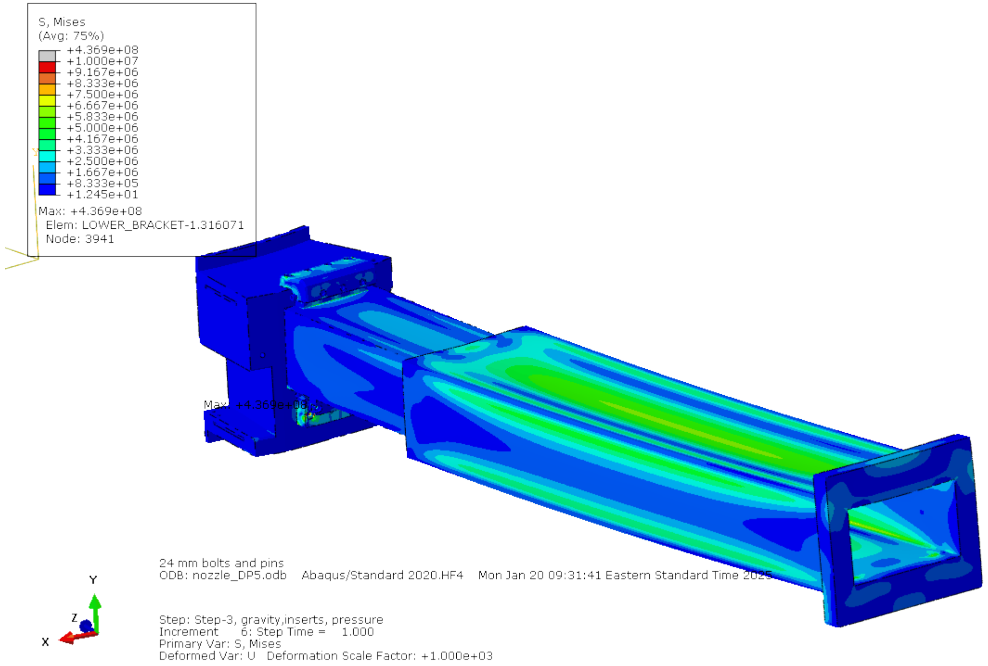


Step 3 Gravity, Insert mass and vacuum loads

U2 min .087 mm down

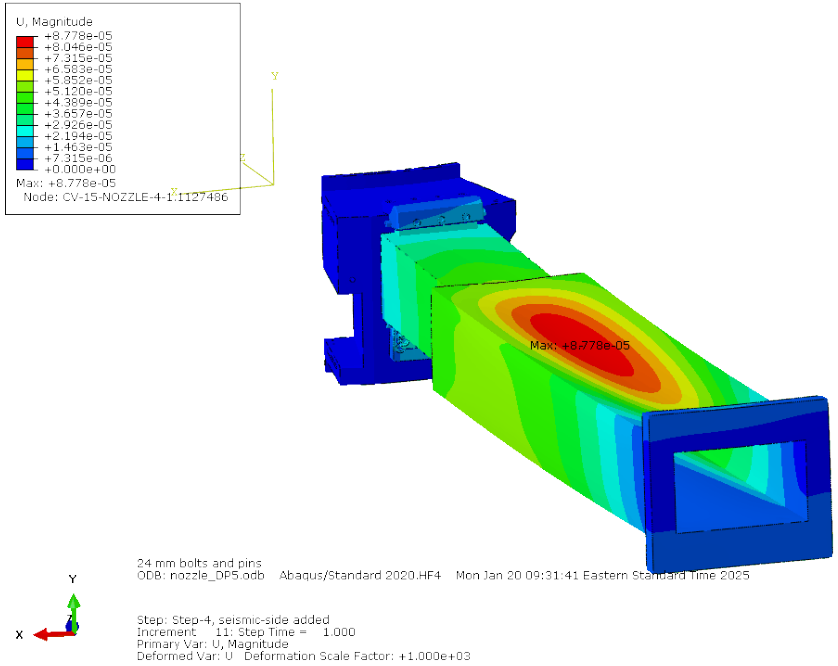


S 436 MPa on lower bolt – 10 MPa scale

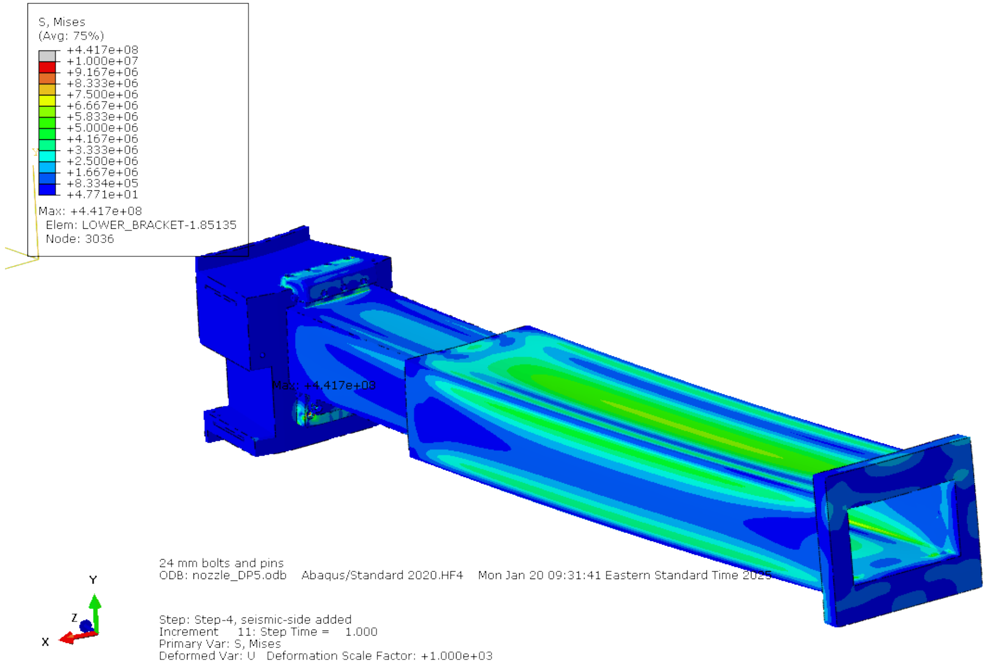


Step 4 Results with seismic side load added

Displacement

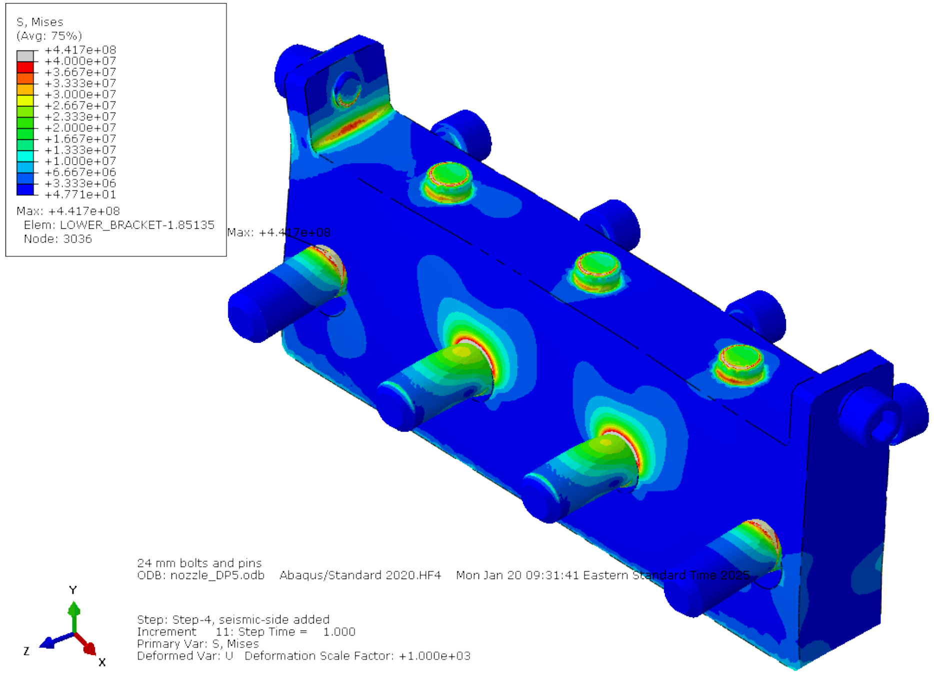


S peak 442 MPa

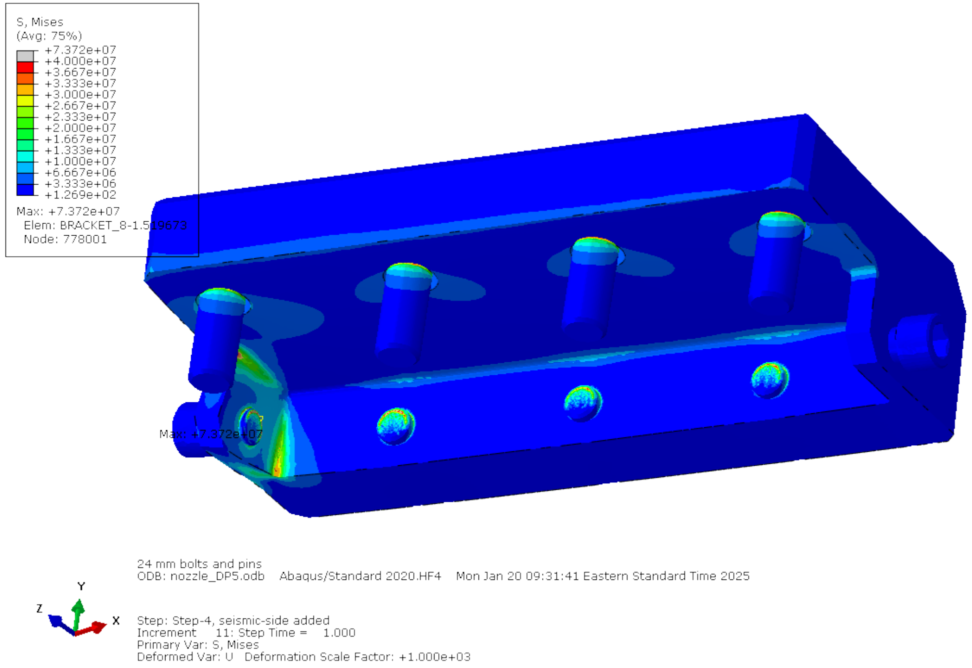


Step 4 Results with seismic side load added

Lower Bracket S peak 442 MPa

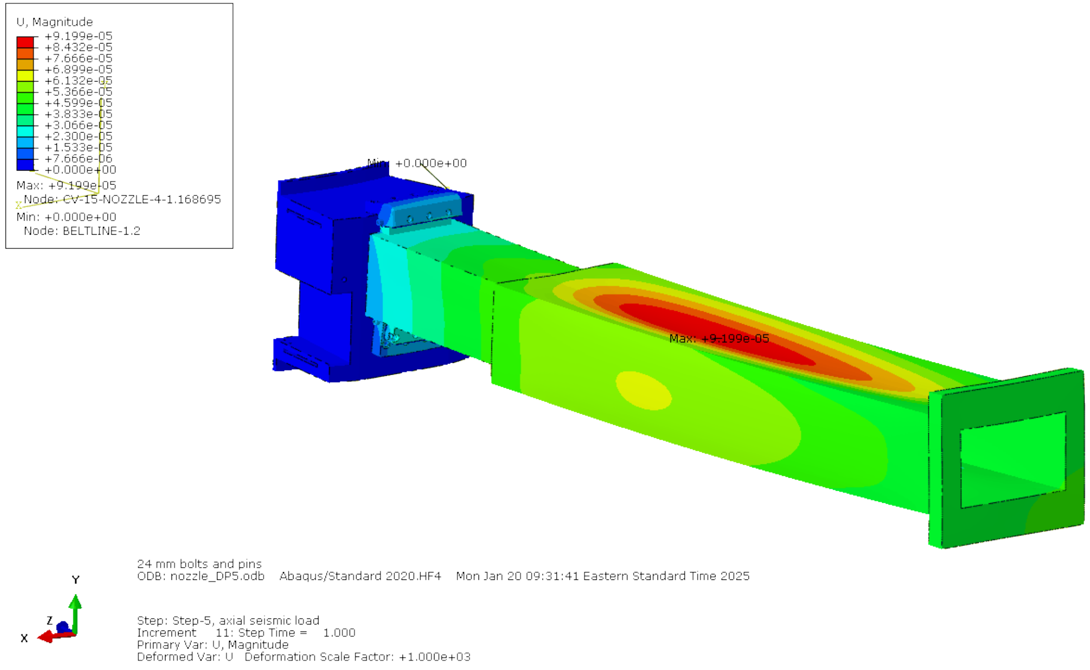


Bracket 8 S peak 74 MPa

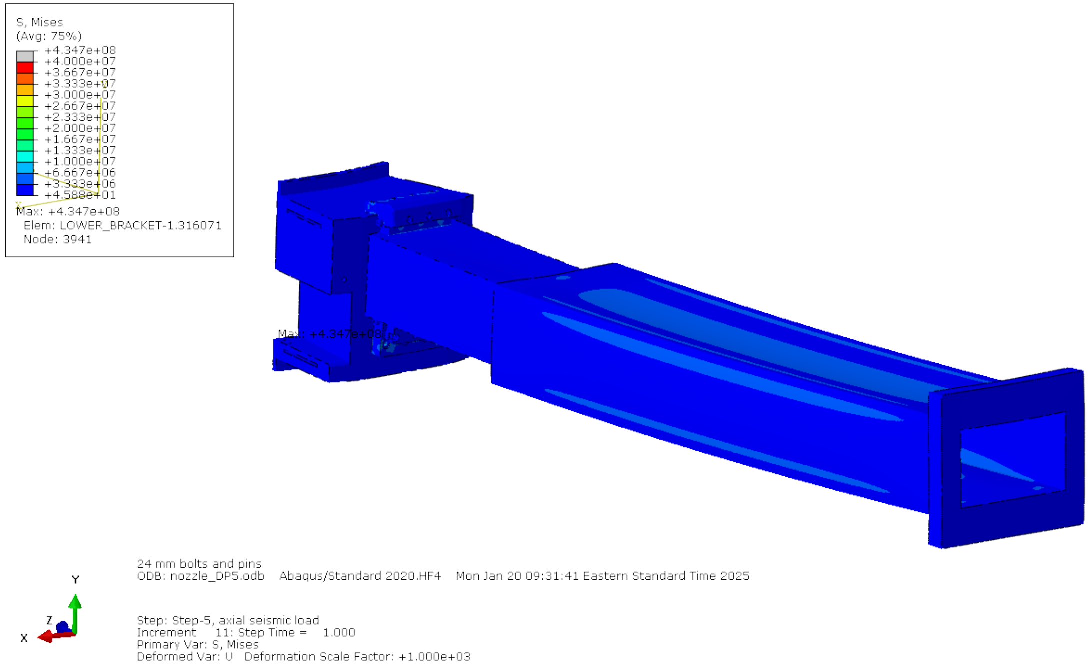


Step 5 Axial seismic .068G load

Displacement U

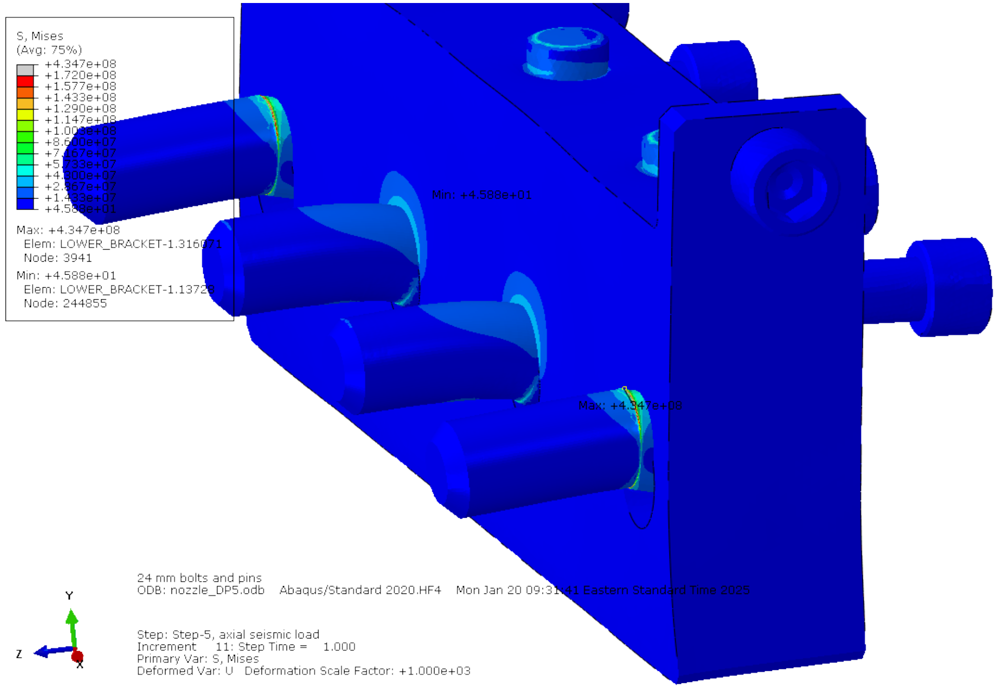


Assembly S peak 435 MPa

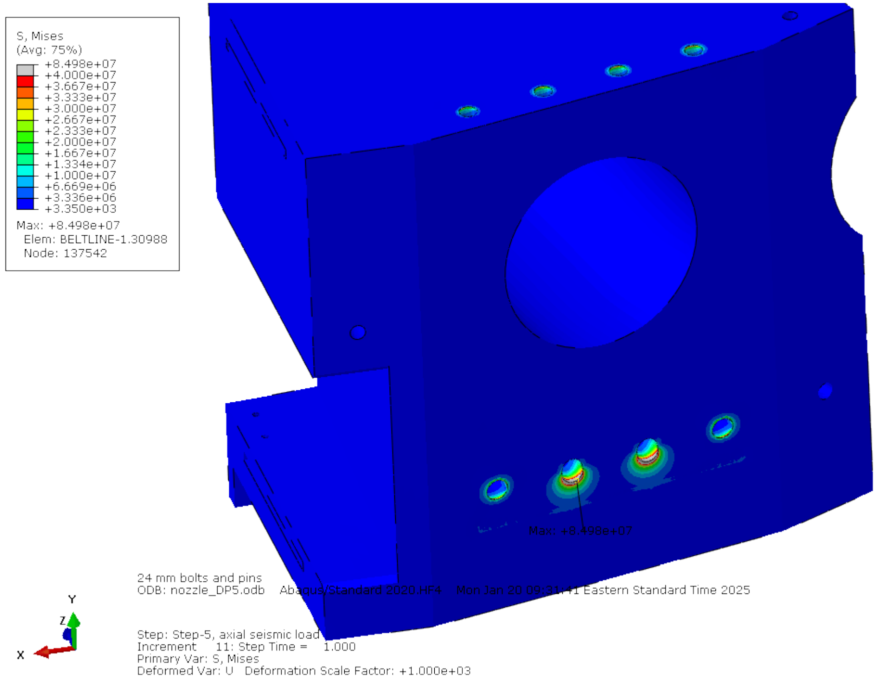


Step 5 Results Axial seismic .068G load

Lower Bracket peak 435 MPa

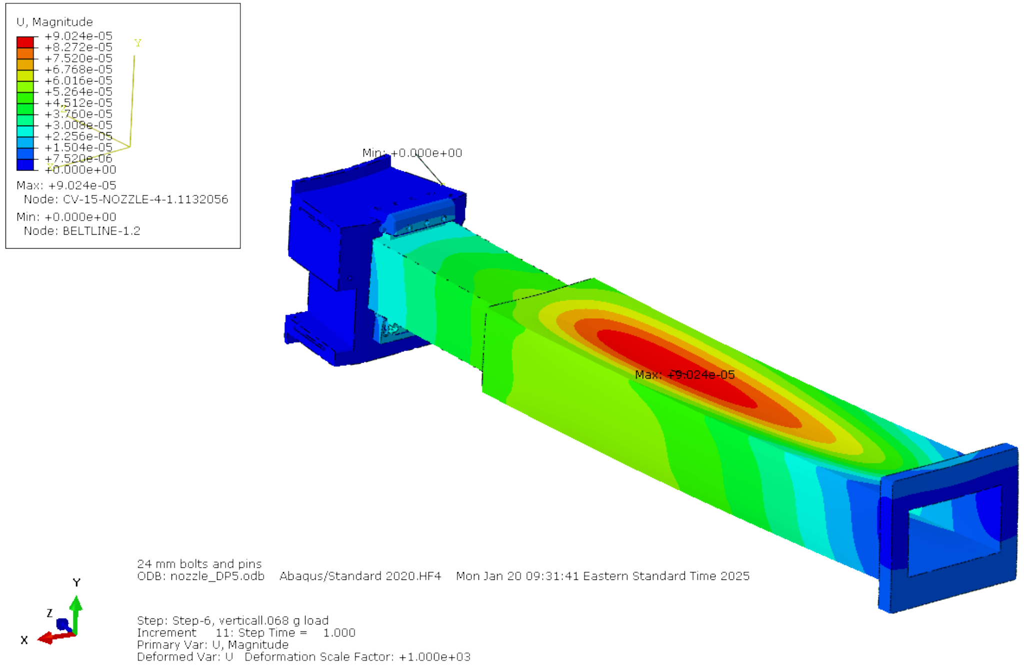


Beltline S peak 85 MPa

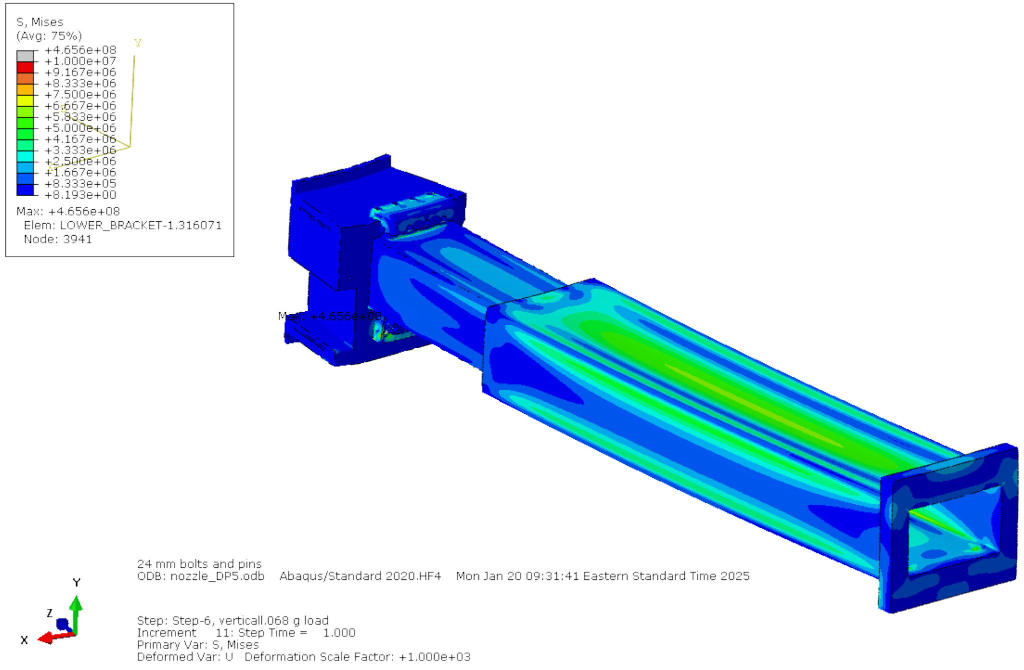


Step 6 Results with vertical seismic load

Displacement

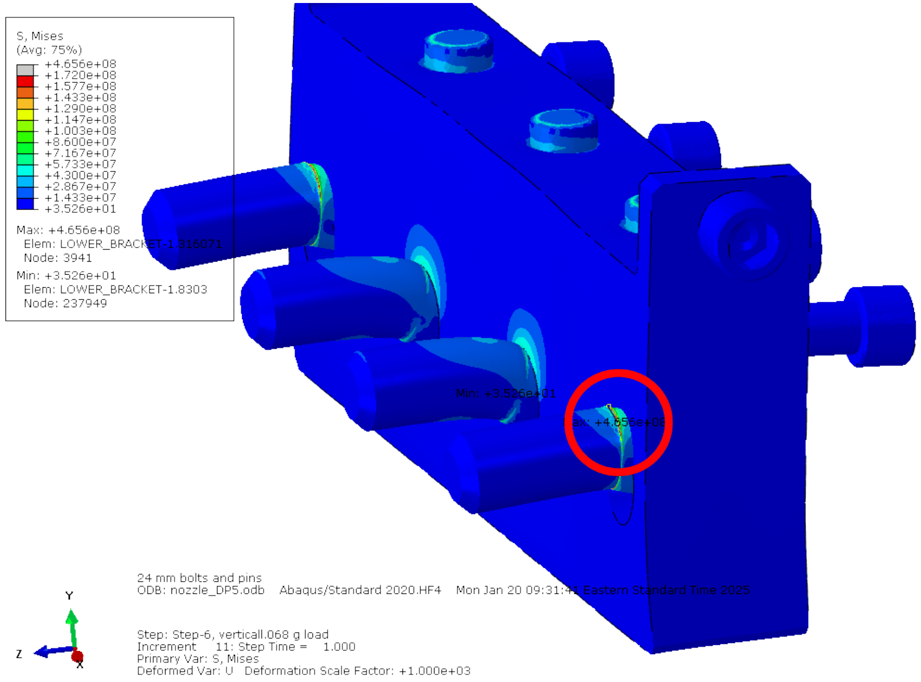


S peak 466 MPa in lower bracket bolt

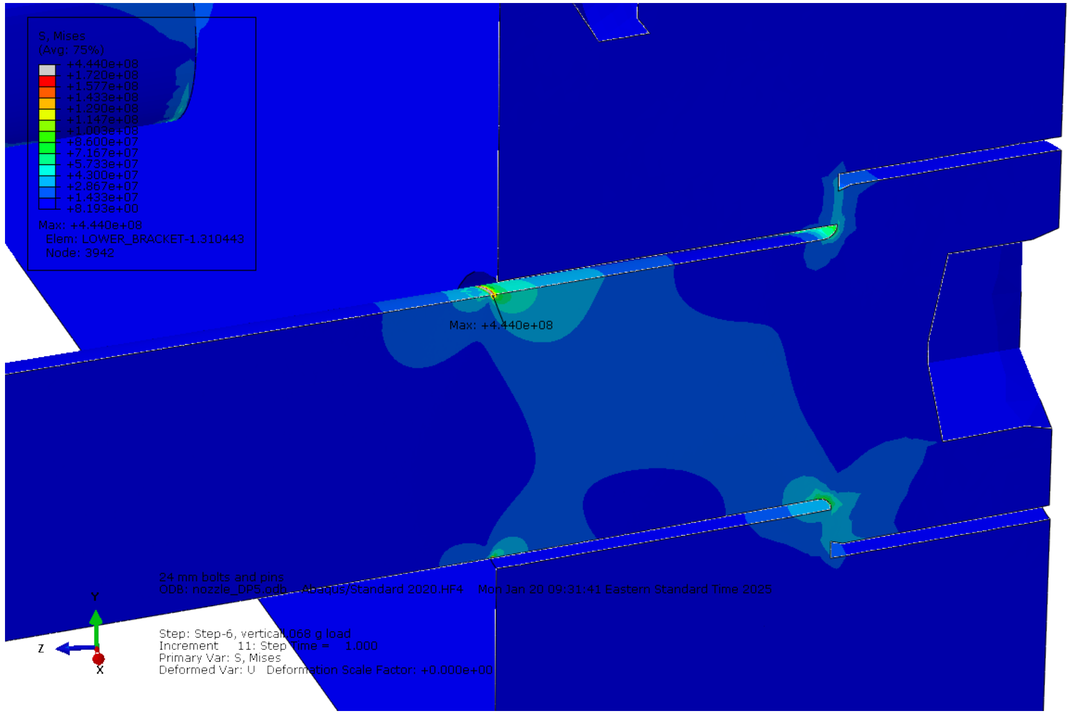


Step 6 Results with vertical seismic load

Lower Bracket S peak 466 MPa



Bolt vertical cut around peak



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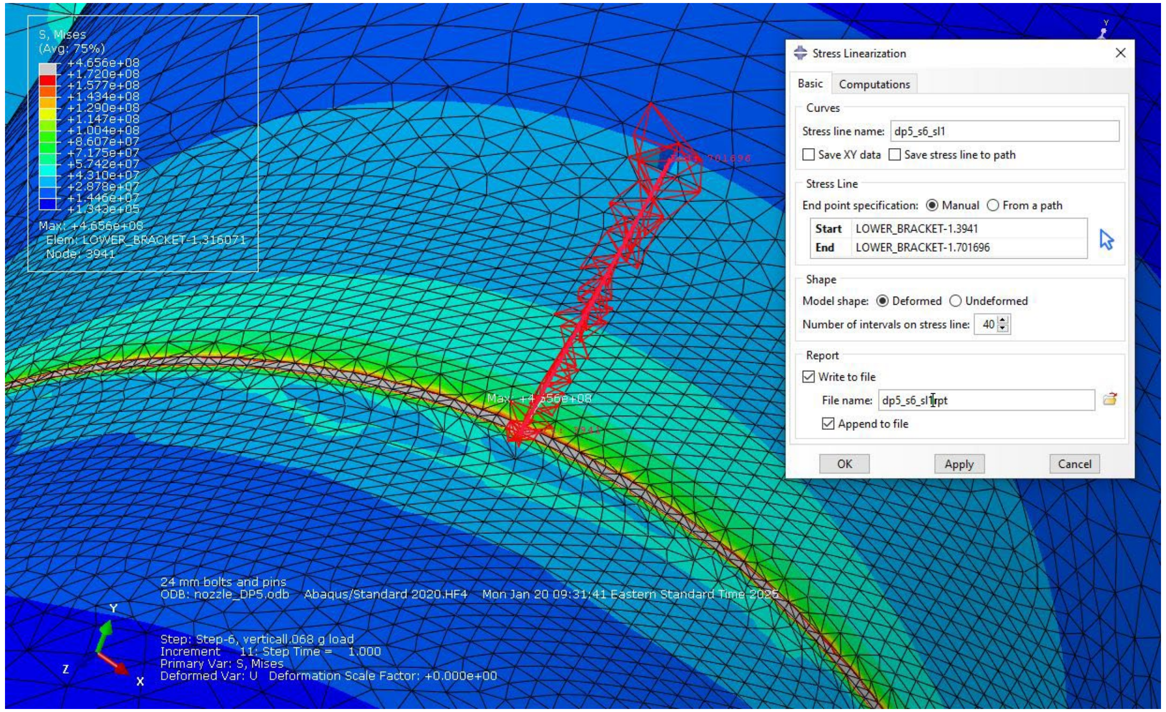
Step 6 Results with vertical seismic load - linearization

Stress linearization path for bolt peak near top surface (sl1)

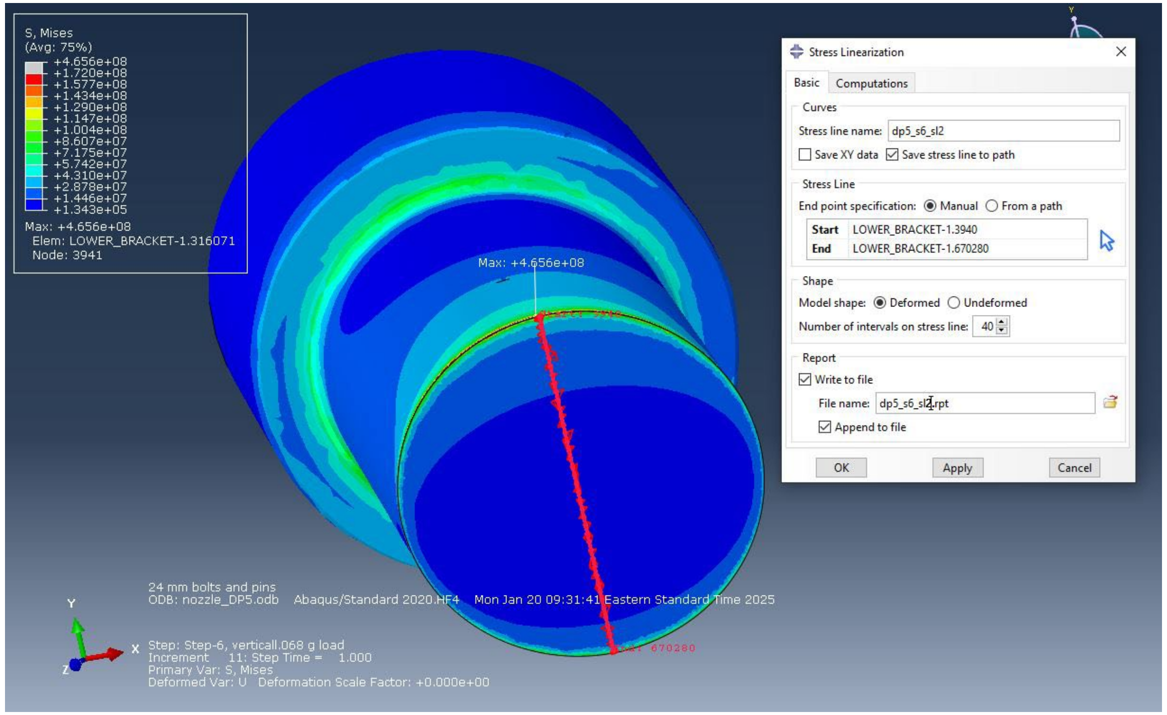


Peak Mises bending + Membrane 77 MPa at point 1

```
------------------------------------ INVARIANT RESULTS -----------------------------------

Bending components in equation for computing
membrane plus bending stress invariants are:   S11, S22, S33, S12, S13, S23

                       Max.        Mid.        Min.        Tresca      Mises
                       Prin.       Prin.       Prin.       Stress      Stress
     Membrane
(Average) Stress  4.9588e+07  7.03284e+06  2.19294e+06  4.73951e+07  4.517e+07

  Membrane plus
Bending, Point 1  9.11205e+07  2.16051e+07  8.50179e+06  8.26187e+07  7.69089e+07

  Membrane plus
Bending, Point 2  9.99376e+06  -6.0522e+06  -7.54135e+06  1.75351e+07  1.684e+07

   Peak Stress,
     Point 1       3.68698e+08  1.26717e+08  7.63148e+07  2.92384e+08  2.70725e+08

   Peak Stress,
     Point 2       1.85583e+07  7.90255e+06  3.06074e+06  1.54976e+07  1.37325e+07
```

Step 6 Results with vertical seismic load - linearization

Vertical path sl2 172 MPa scale



Peak Mises membrane + bending 30 MPa

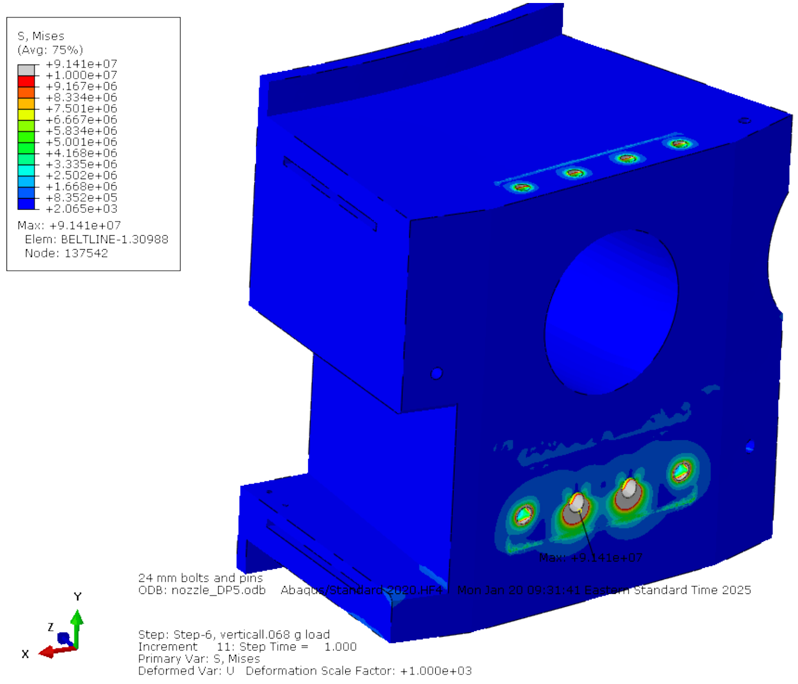
------------------------------------ INVARIANT RESULTS ------------------------------------

Bending components in equation for computing
membrane plus bending stress invariants are: S11, S22, S33, S12, S13, S23

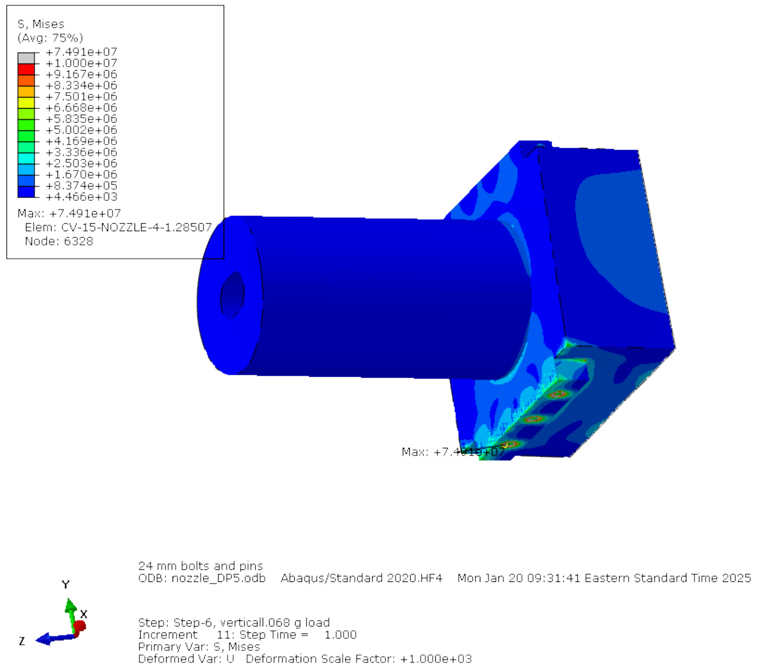
	Max. Prin.	Mid. Prin.	Min. Prin.	Tresca Stress	Mises Stress
Membrane (Average) Stress	1.32668e+07	3.03408e+06	-1.11539e+06	1.43822e+07	1.28214e+07
Membrane plus Bending, Point 1	5.55536e+07	3.21043e+07	2.25867e+07	3.29669e+07	2.93876e+07
Membrane plus Bending, Point 2	-1.65183e+07	-2.85179e+07	-3.48373e+07	1.8319e+07	1.6117e+07
Peak Stress, Point 1	1.97556e+08	6.87966e+07	4.89608e+07	1.48595e+08	1.39737e+08
Peak Stress, Point 2	-1.99517e+07	-3.20104e+07	-9.33546e+07	7.34029e+07	6.81781e+07

Step 6 Results with vertical seismic load

Beltline peak S 91 MPa 10 MPa scale

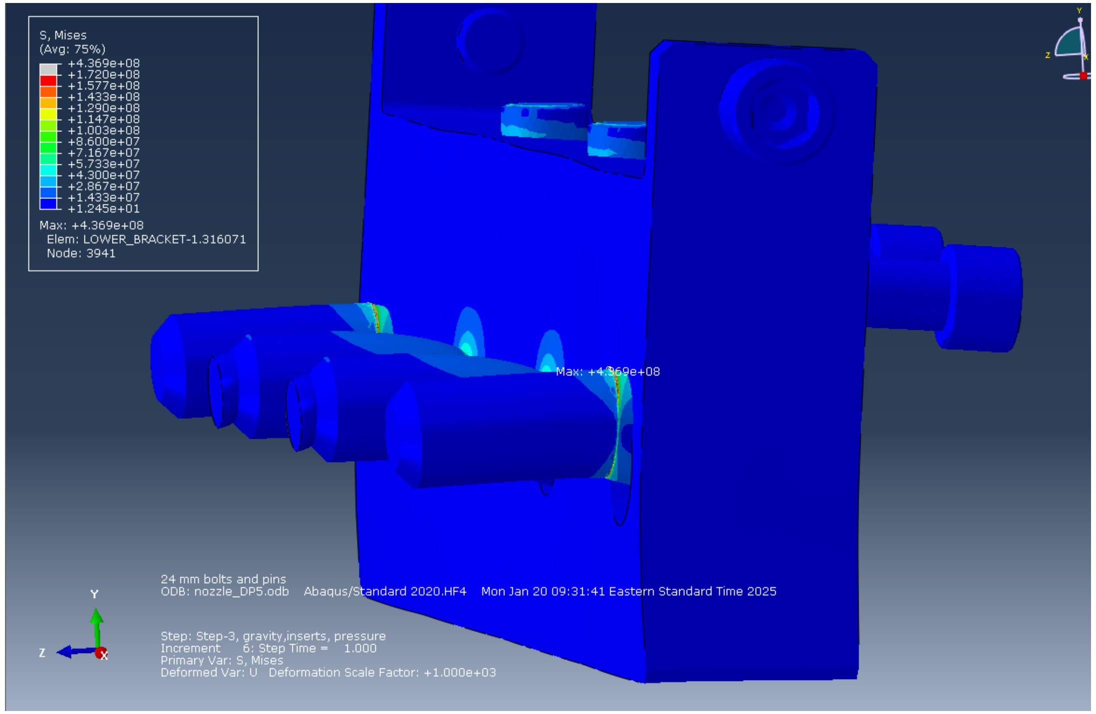


Nozzle peak S 75 MPa 10 MPa scale

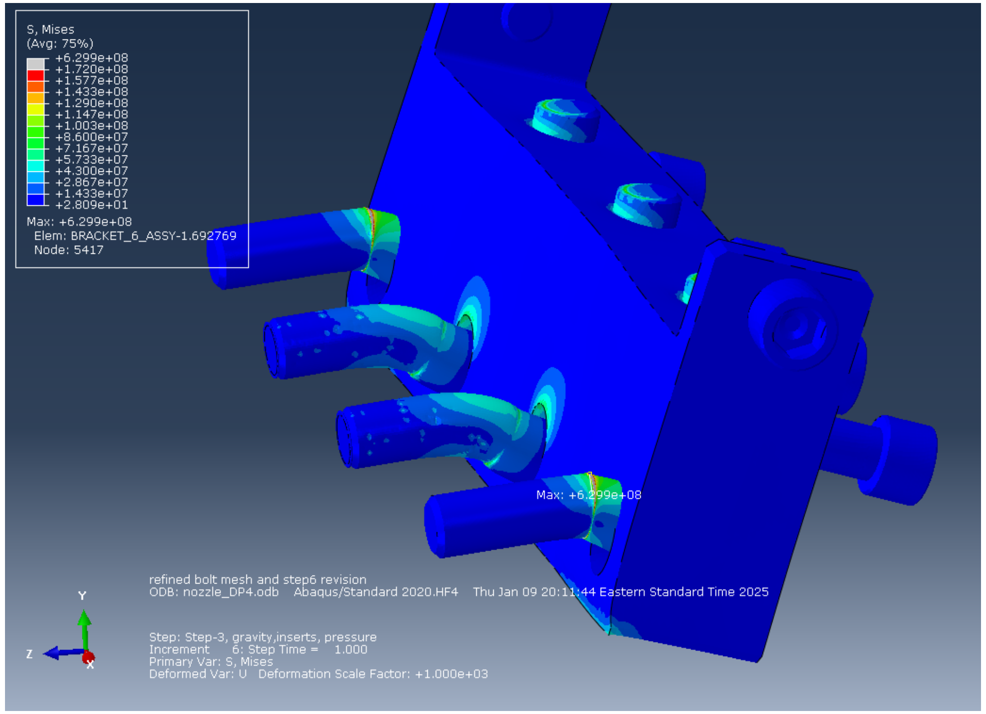


DP4 and DP5 Lower Bracket and pins comparison @ step3 with common Stress scale max of 172 MPa and displacement scale factor of 1000

DP5

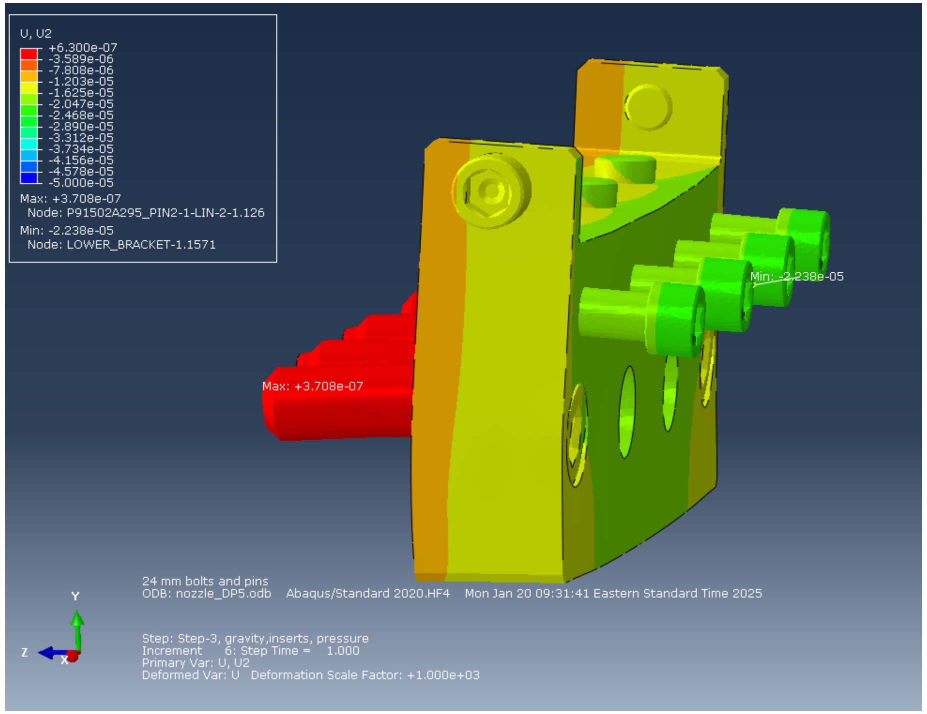


DP4

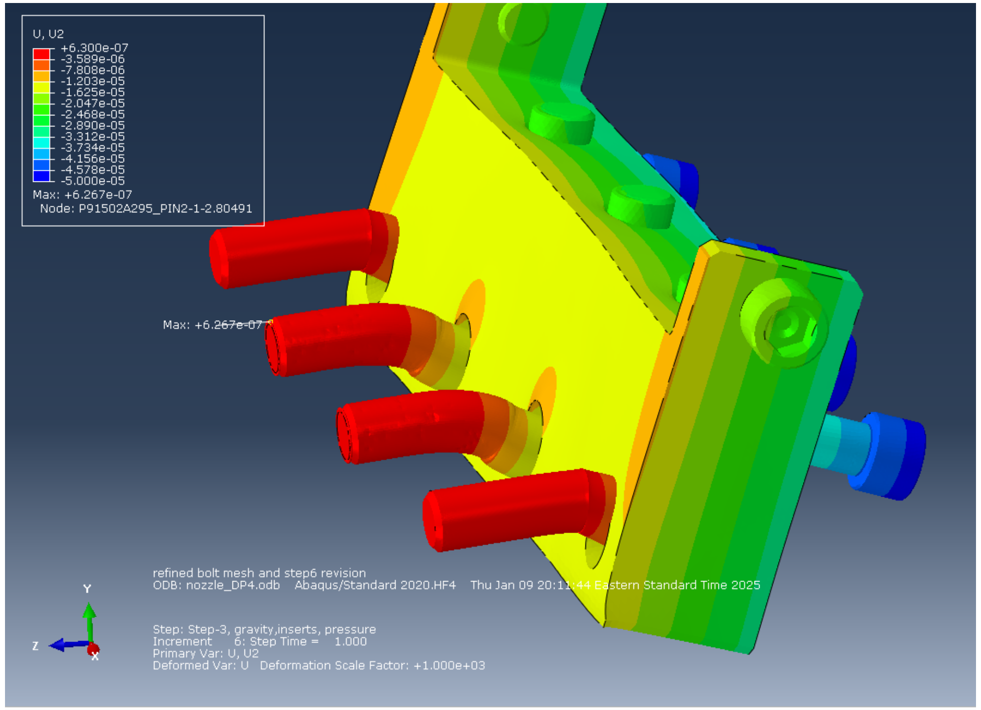


DP4 and DP5 Lower Bracket and pins vertical displacement comparison for step3 with common displacement scale factor of 1000

DP5 24 mm bolts/ pins and 25 mm extended bracket

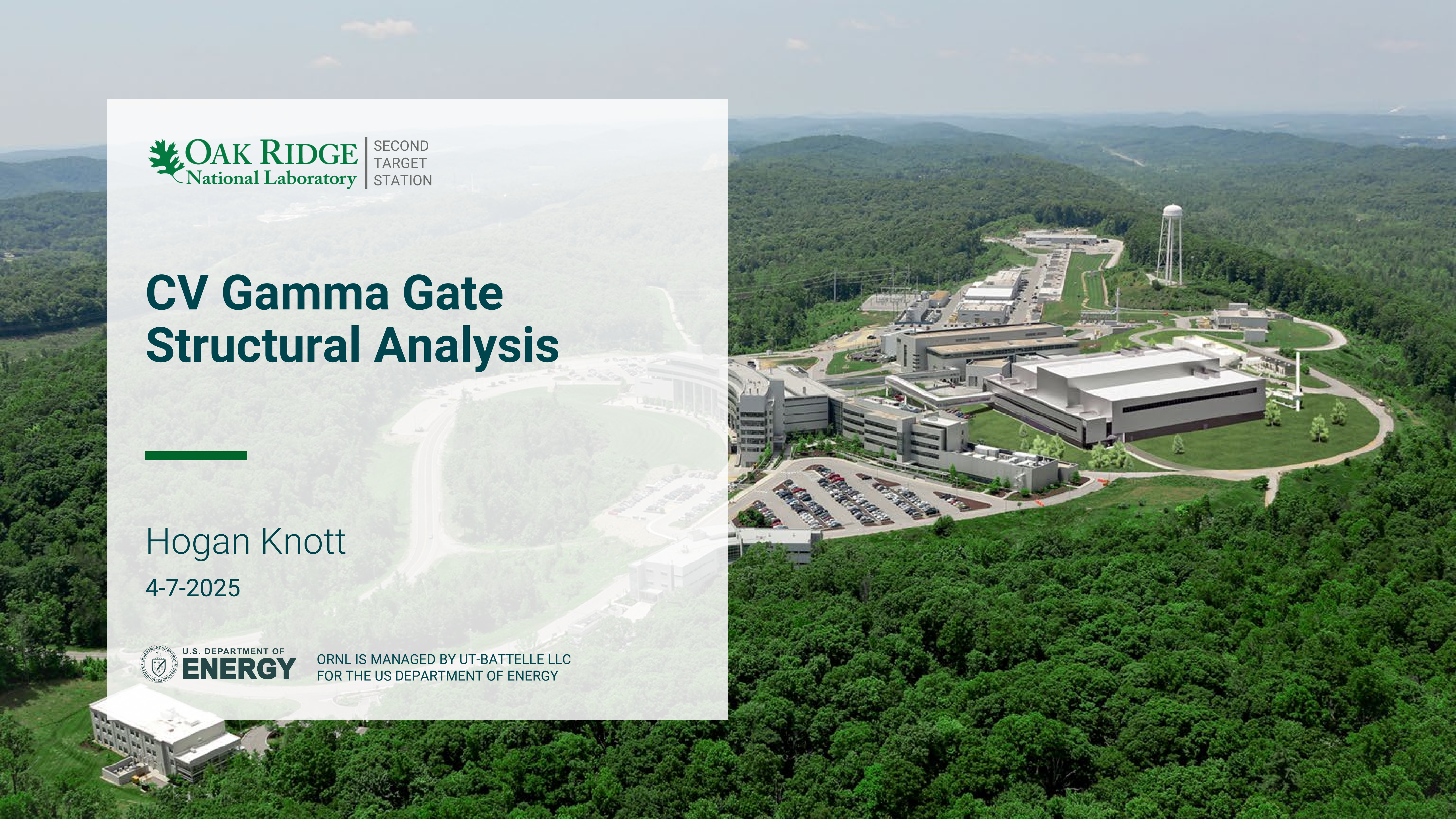


DP4 20 mm bolts/pins



Summary

- Model DP5 with 24 mm bolts and pins and with the bracket extended 25 mm down showed lower peak stresses and significantly reduced displacements
- Stress linearization for DP5 had a peak Mises membrane plus bending of 77 MPa versus 165 MPa for DP4
- Models do not account for actual stress distribution around threads and displacements with threads, but the axial bolt loads are low (~ 3.52e3 N for one bolt in step 6)
- All other locations besides the bolts had stresses well below 1.5 Sm limit of 172 MPa



SECOND TARGET STATION

CV Gamma Gate Structural Analysis

Hogan Knott

4-7-2025

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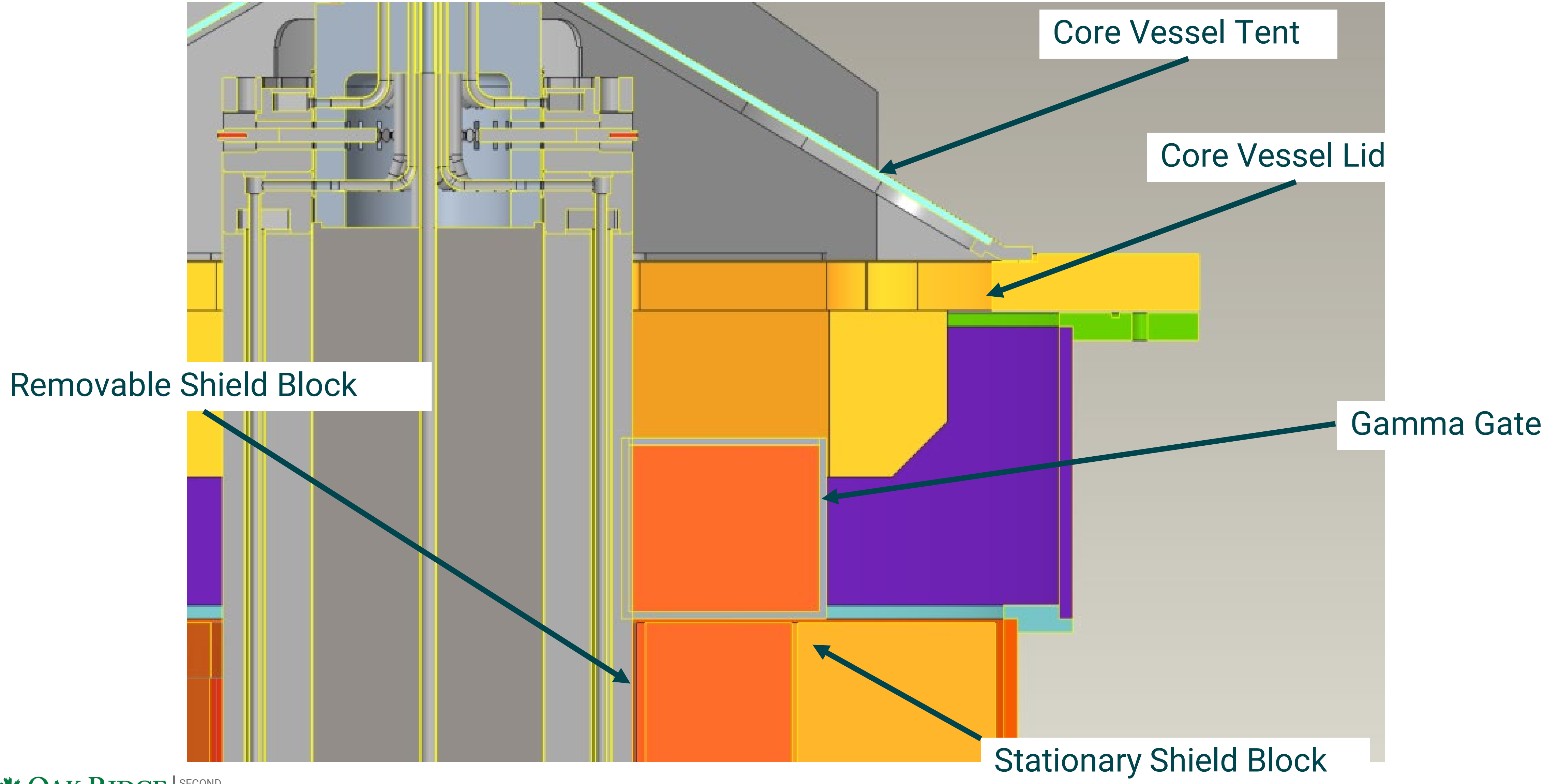
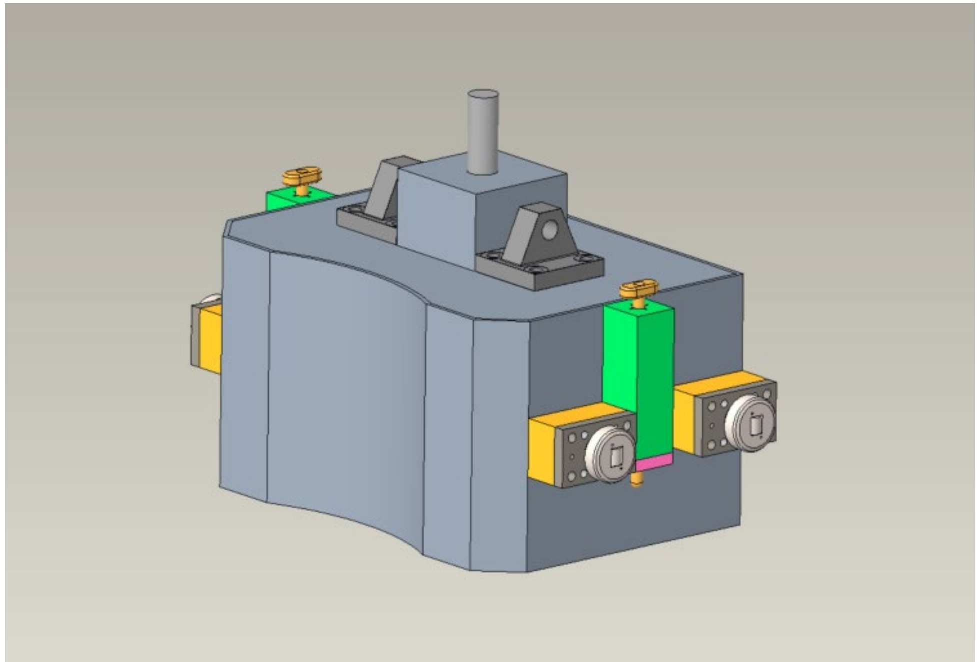
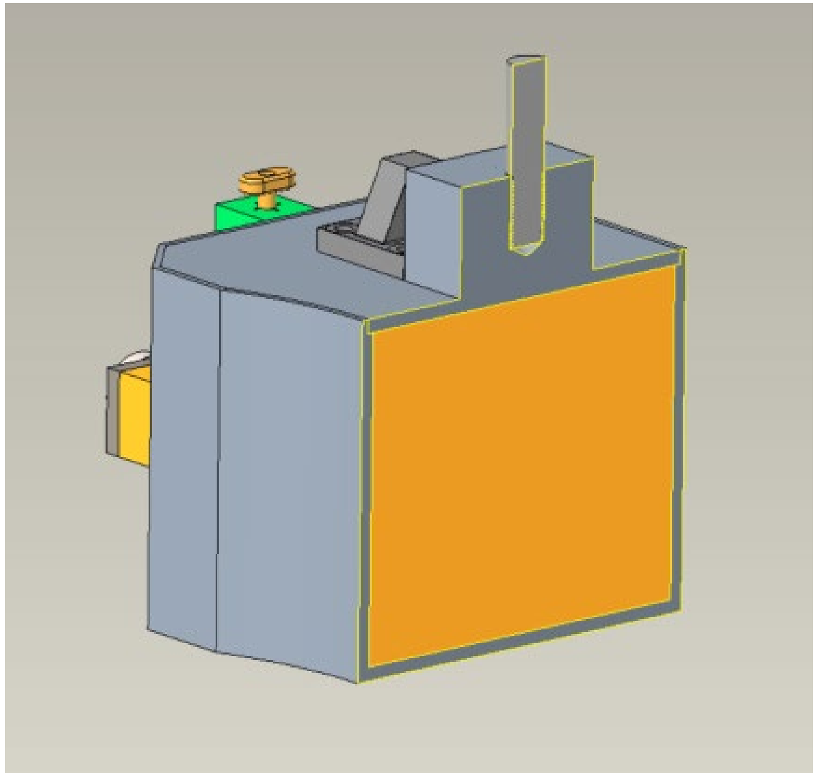
Gamma Gate Area Definition

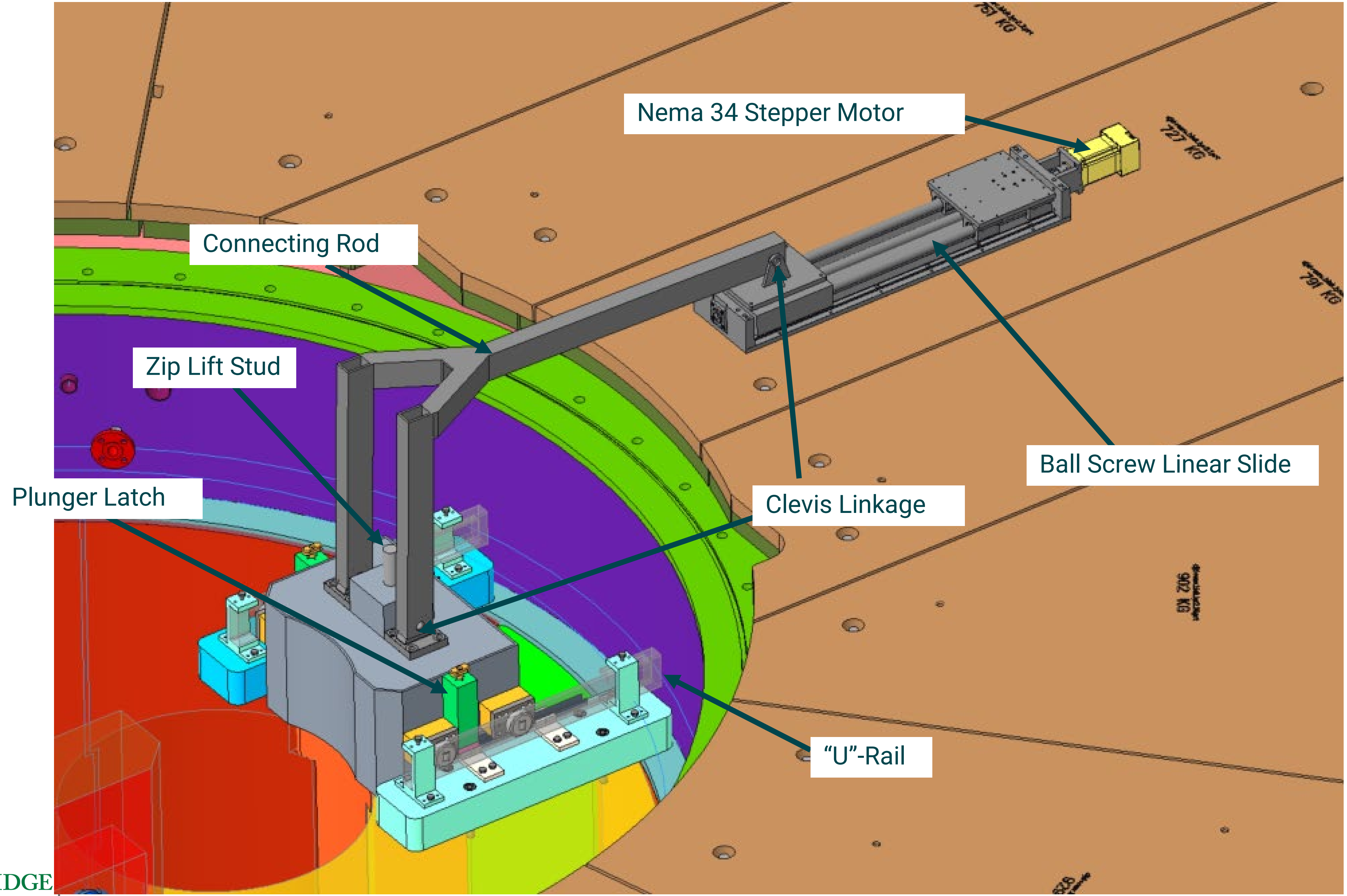


Gamma Gate at a Glance



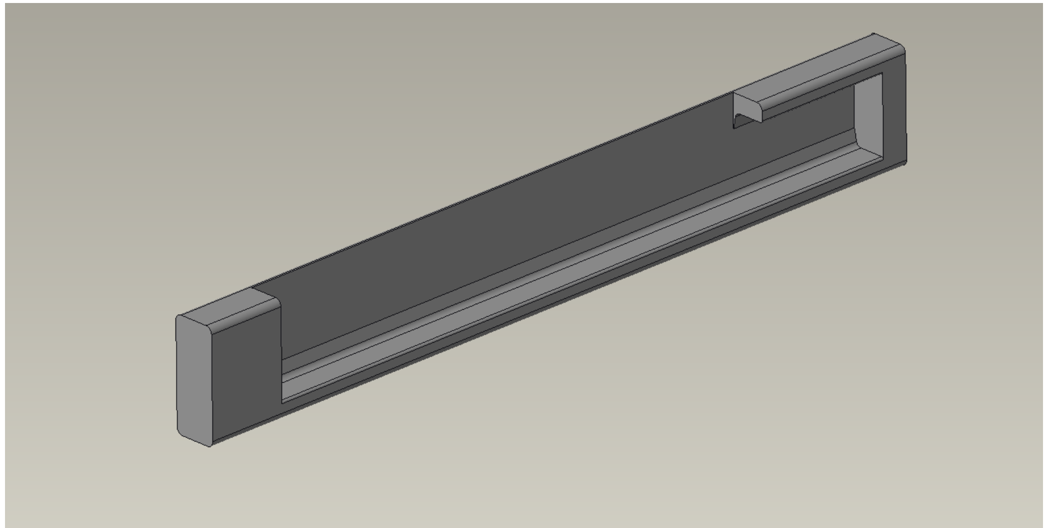
0.5-Inch-Thick Stainless-Steel Vessel
30 cm of lead thickness
~850 kg vessel mass

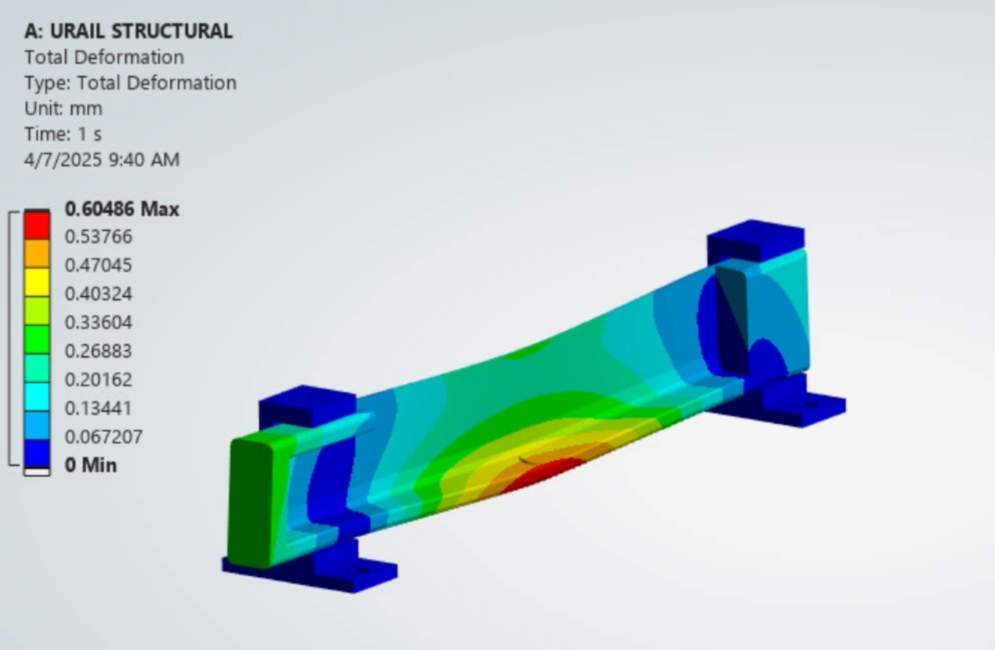


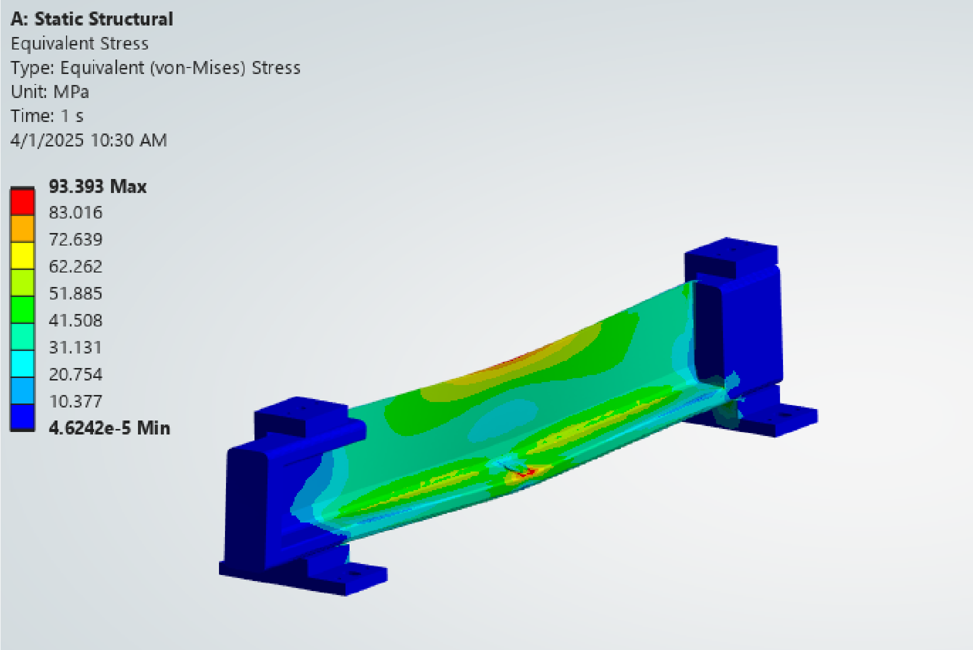

Nema 34 Stepper Motor
Connecting Rod
Zip Lift Stud
Plunger Latch
Clevis Linkage
Ball Screw Linear Slide
"U"-Rail

U-Rail Analysis

Material: Stainless Steel 316L
Load: 10 kN applied at center of the beam







U-Rail Analysis Summary

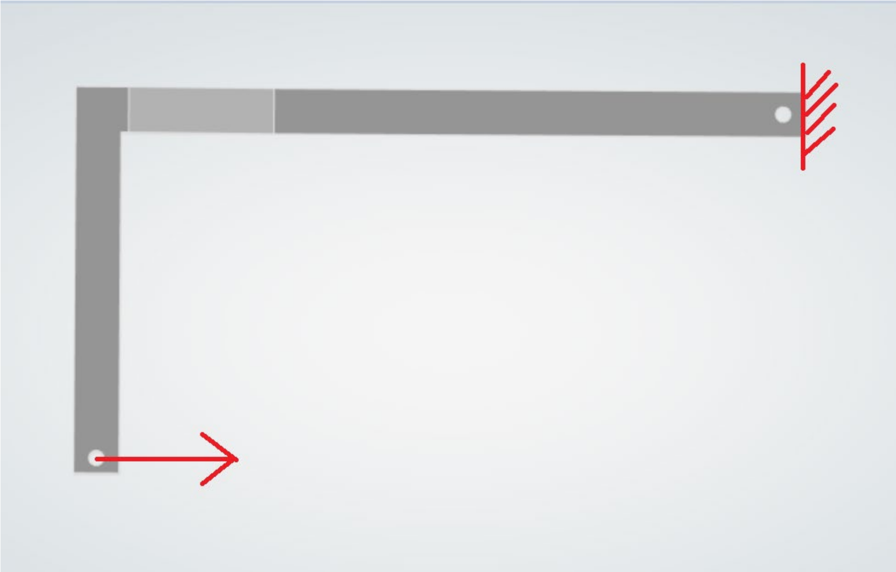
- σ_{max} = 93.4 Mpa
- δ_{max} = 0.6 mm
- U-Rail can support weight of the gamma gate

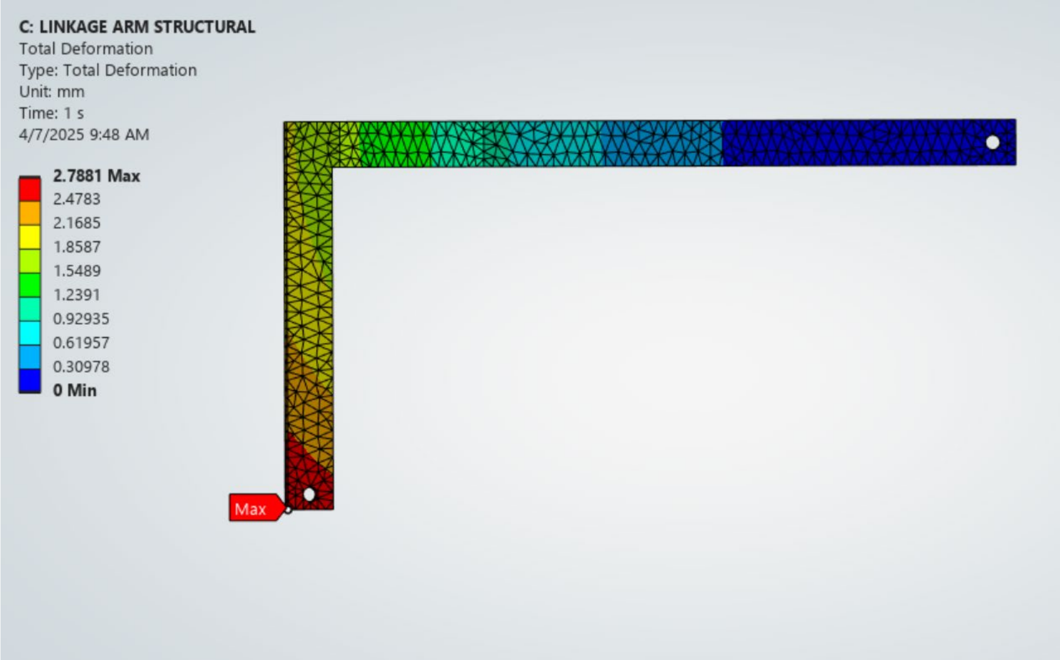
Gamma Gate Friction

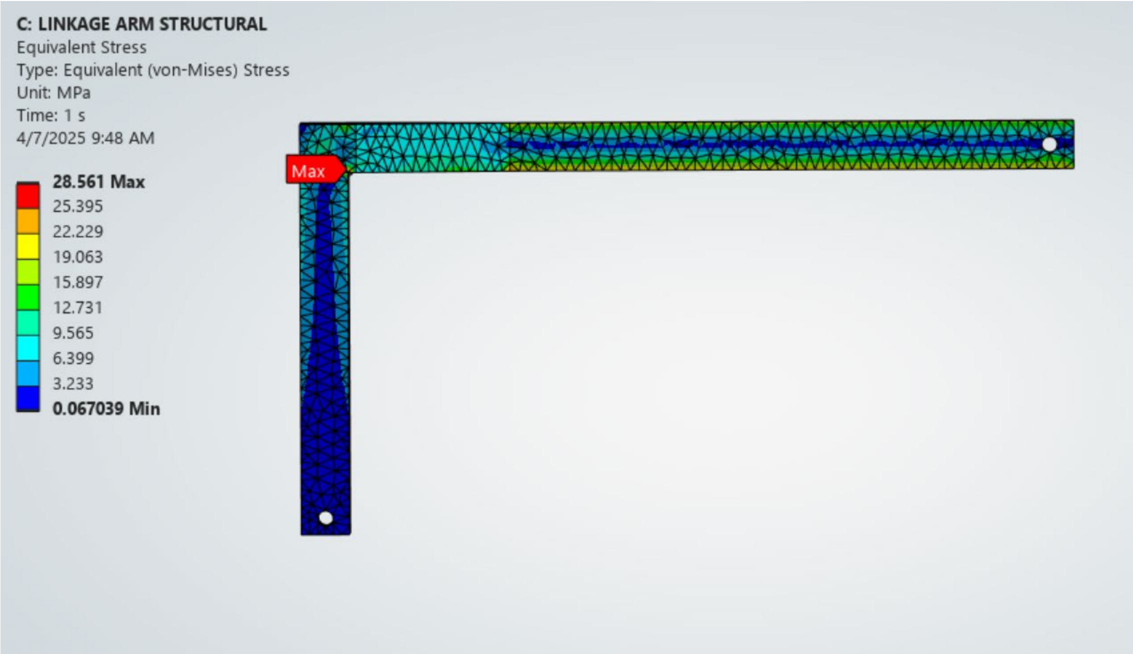
- Gamma Gate Mass = 850 kg
- Normal Force on rail = 850 kg * 9.81m/s^2 = 8338.5 N
- Coefficient of static friction = 0.01 [1]
- Design Factor = 12
- Force required to move gamma gate = 0.01 * 8338.5 N * 12 = 1000 N

Linkage Arm Structural

Material: Stainless Steel 316L
Gage: 3”x2”x.25” rectangular tubing
Load: 1000 N







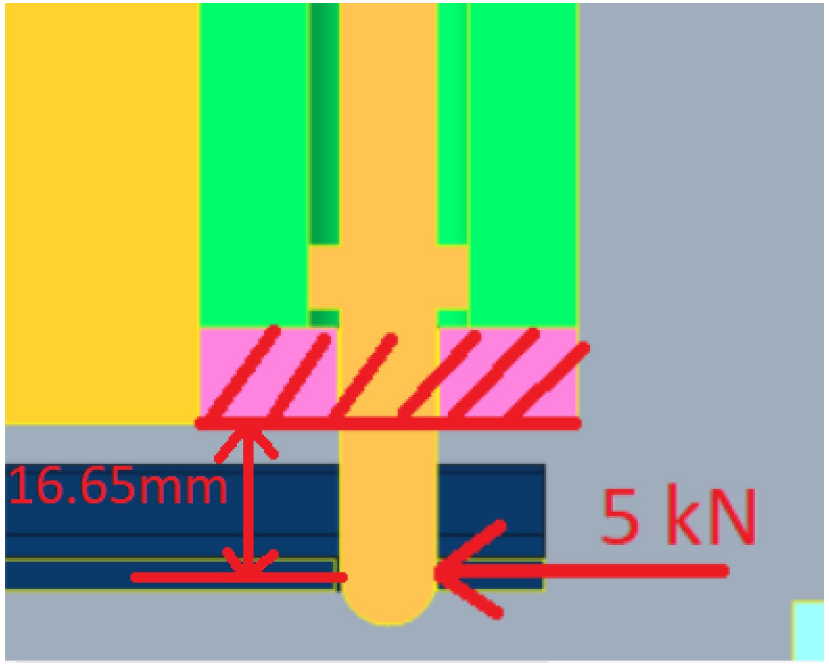
Linkage Arm Analysis Summary

- σ_{max} = 28.6 Mpa
- δ_{max} = 2.8 mm
- Linkage can support load required to actuate the gamma gate

Gamma Gate Under Seismic Loads

- Maximum Horizontal Seismic Force $F_{pmax} = 1.6S_{DS}I_pW_p$: ASCE 7-16 Equation 13.3-2 [2]
- S_{DS}= .485 per USGS at STS coordinates
- I_p= 1.5 : ASCE 7-16 section 13.1.3 [2]
- W_p= 9.81m/s^2 * 850kg = 8338.5 N
- F_{pmax} = 9706 N
- Force per latch pin = 9706 N / 2 = 5000 N

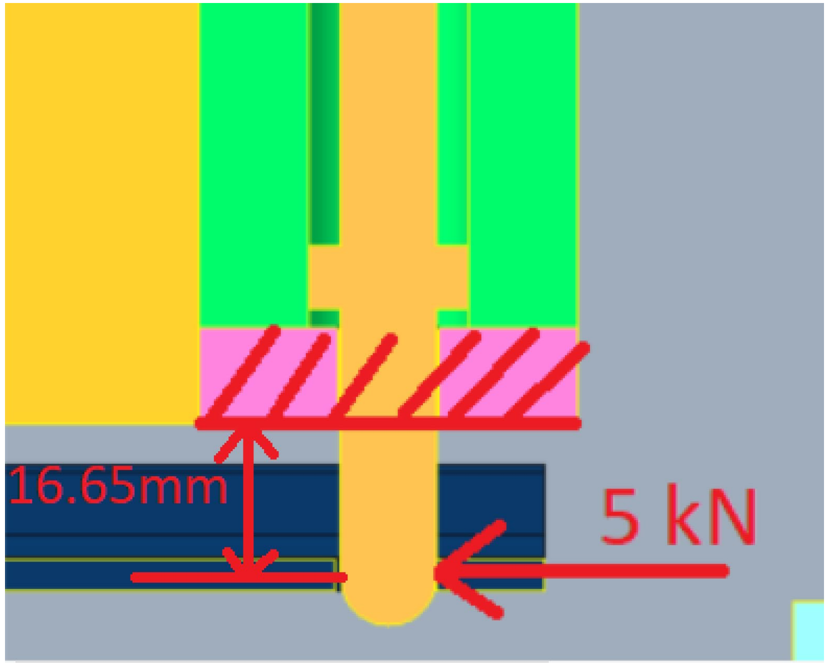
Latch Pin Stress Analysis



- Material: Inconel 718
- 20 mm diameter cylinder cross section
- D = 20 mm
- $\sigma_{max} = (y_{max} * L * F)/(I)$
- $y_{max} = radius = 10\ mm$
- $I = \frac{\pi * D^4}{64} = 7854\ mm^4$
- F = 5 kN
- L = 16.65 mm
- σ_{max} = 106 MPa

Latch Pin Deflection Analysis

- Material: Inconel 718
- 20 mm diameter cylinder cross section
- D = 20 mm
- $\delta_{max} = \frac{P*l^3}{3*E*I}$
- E = 200 Gpa [3]
- $I = \frac{\pi*D^4}{64}$ = 7854 mm^4
- P = 5 kN
- L = 16.65 mm
- δ_{max} = 0.005 mm



Latch Pin Analysis Summary

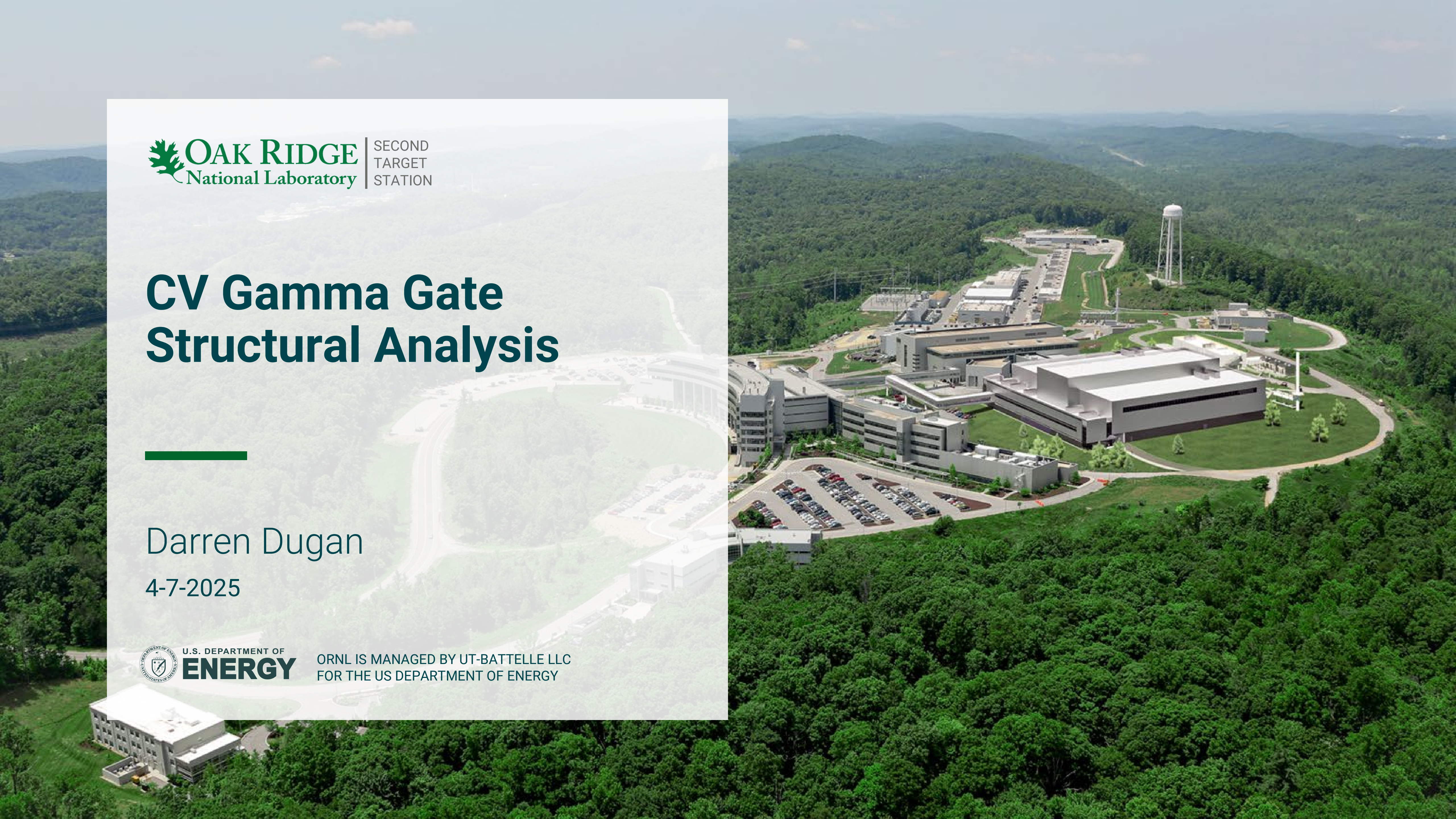
- σ_{max} = 106 Mpa
- δ_{max} = 0.005 mm
- Latch Pin will prevent motion of the gamma gate during a seismic event

References

1. Product-Catalog-CRT - Hevi-Rail.pdf

2. American Society of Civil Engineers, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures (ASCE/SEI 7-16)*, ASCE, 2017.

3. American Society of Mechanical Engineers. (2021). *ASME Boiler and Pressure Vessel Code, Section II: Materials*. ASME.



OAK RIDGE National Laboratory | SECOND TARGET STATION

CV Gamma Gate Structural Analysis

Darren Dugan

4-7-2025

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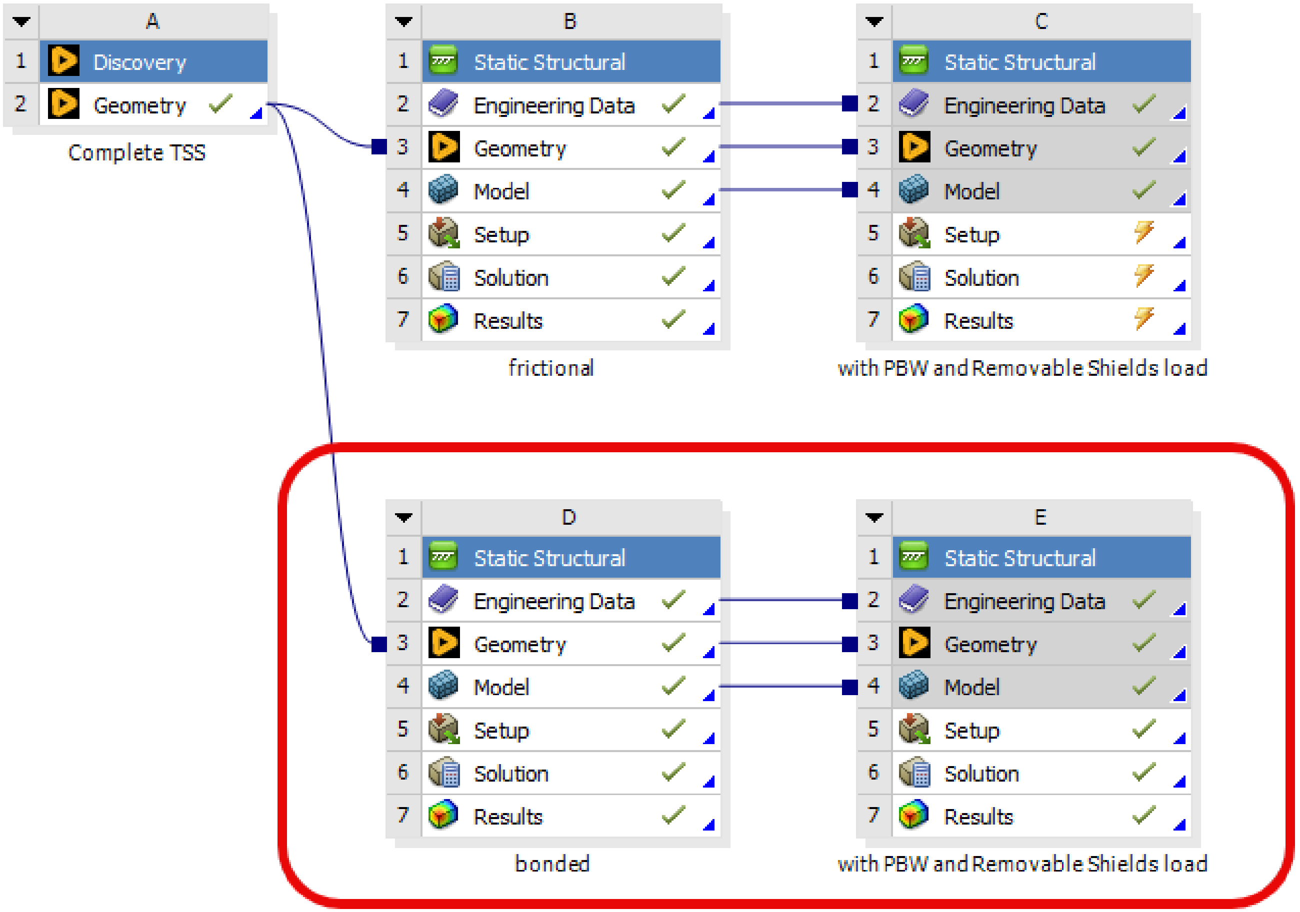
ASCE 7-16 section 13.1.3

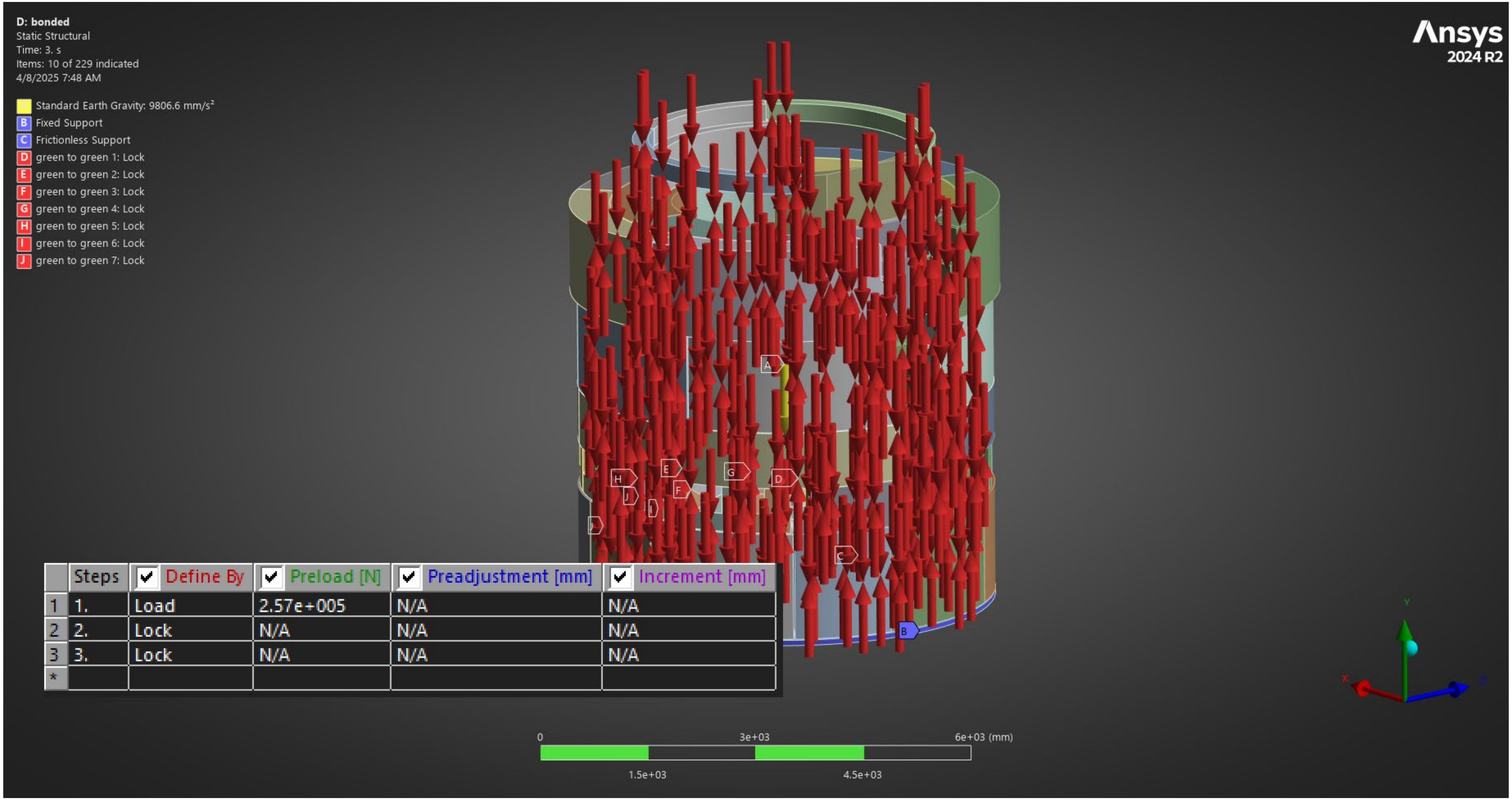
13.1.3 Component Importance Factor. All components shall be assigned a component Importance Factor as indicated in this section. The component Importance Factor, I_p, shall be taken as 1.5 if any of the following conditions apply:

1. The component is required to function for life-safety purposes after an earthquake, including fire protection sprinkler systems and egress stairways.
2. The component conveys, supports, or otherwise contains toxic, highly toxic, or explosive substances where the quantity of the material exceeds a threshold quantity established by the Authority Having Jurisdiction and is sufficient to pose a threat to the public if released.
3. The component is in or attached to a Risk Category IV structure, and it is needed for continued operation of the facility or its failure could impair the continued operation of the facility.
4. The component conveys, supports, or otherwise contains hazardous substances and is attached to a structure or portion thereof classified by the Authority Having Jurisdiction as a hazardous occupancy.

The simulation ran in two parts using a coupled Static-Structural setup to simulate loading removable shields after installation of all permanent shields.

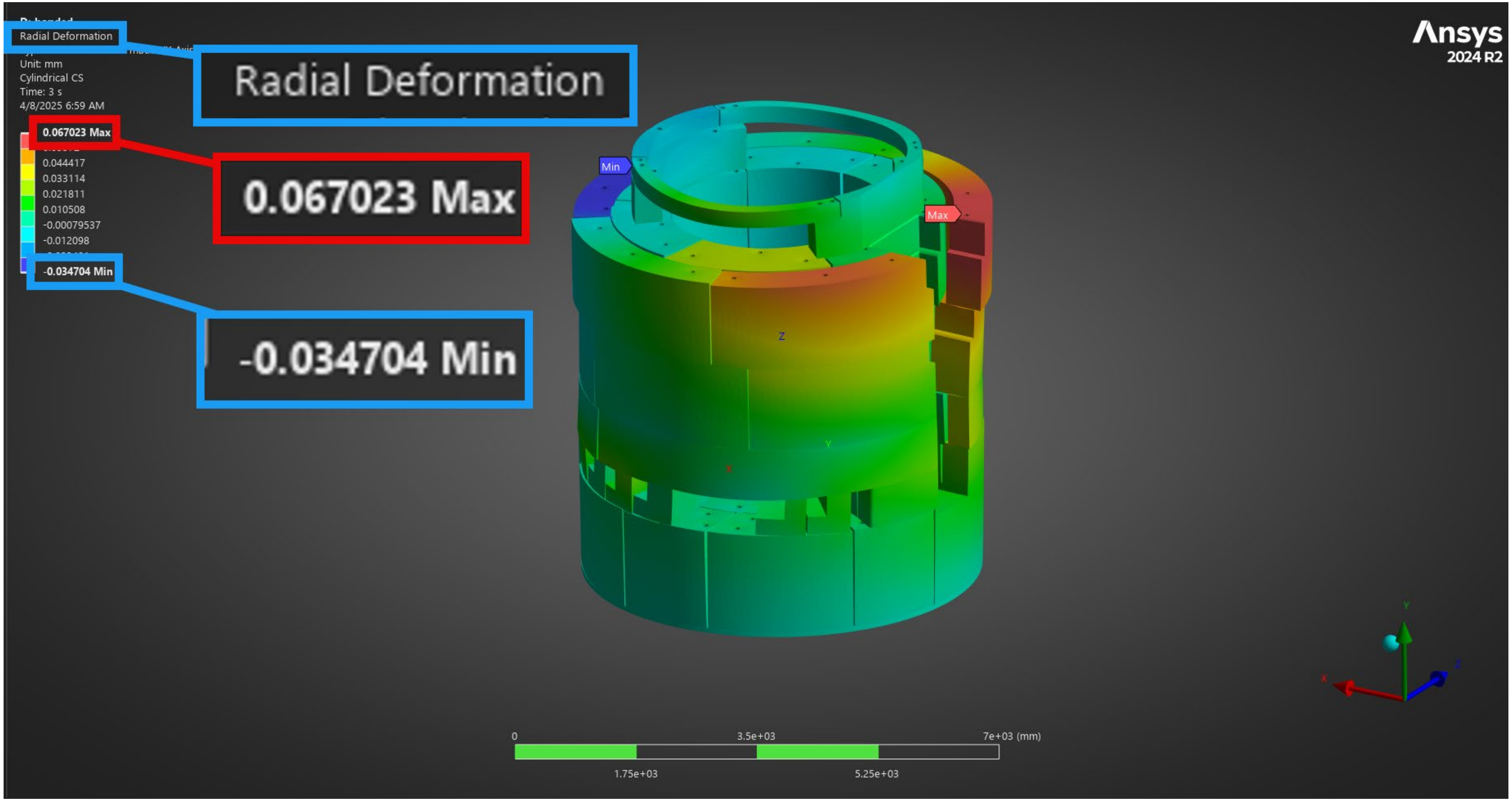


The ANSYS model required dozens of bolt pretension loads for proper simulation.

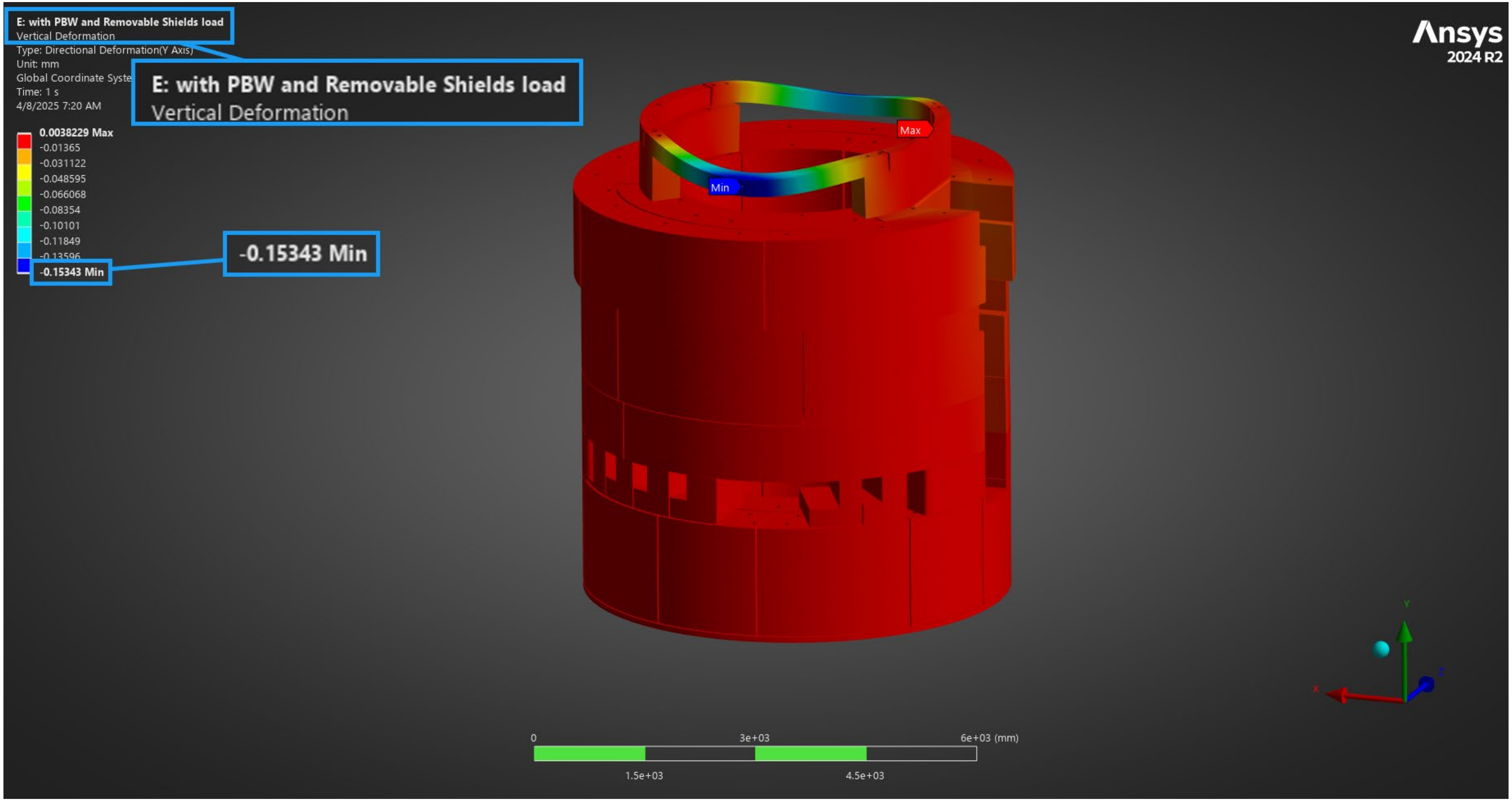


	Steps	Define By	Preload [N]	Preadjustment [mm]	Increment [mm]
1	1.	Load	2.57e+005	N/A	N/A
2	2.	Lock	N/A	N/A	N/A
3	3.	Lock	N/A	N/A	N/A
*					

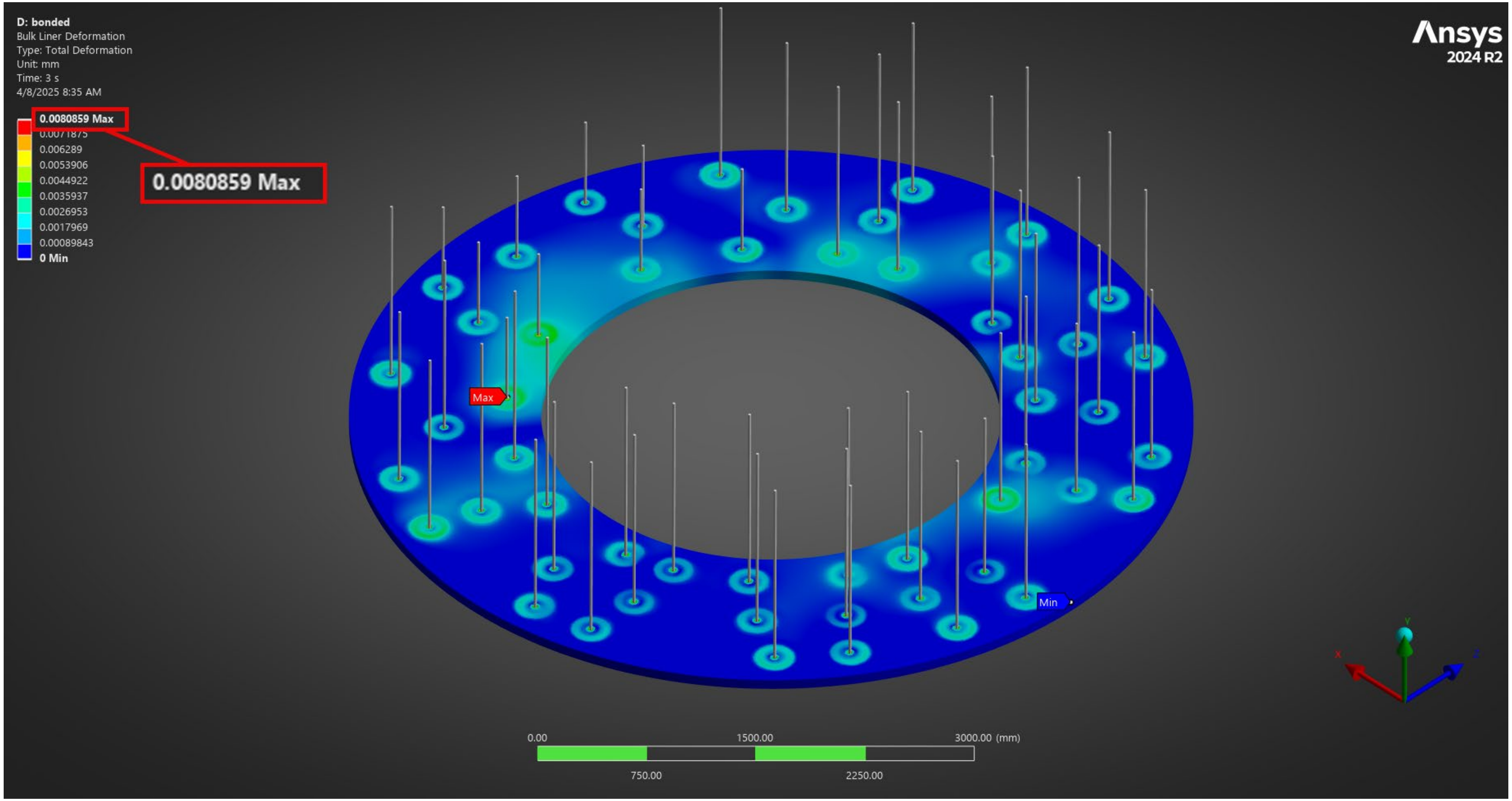
Displacement and tilt were about as expected during the initial analysis without removable shielding.



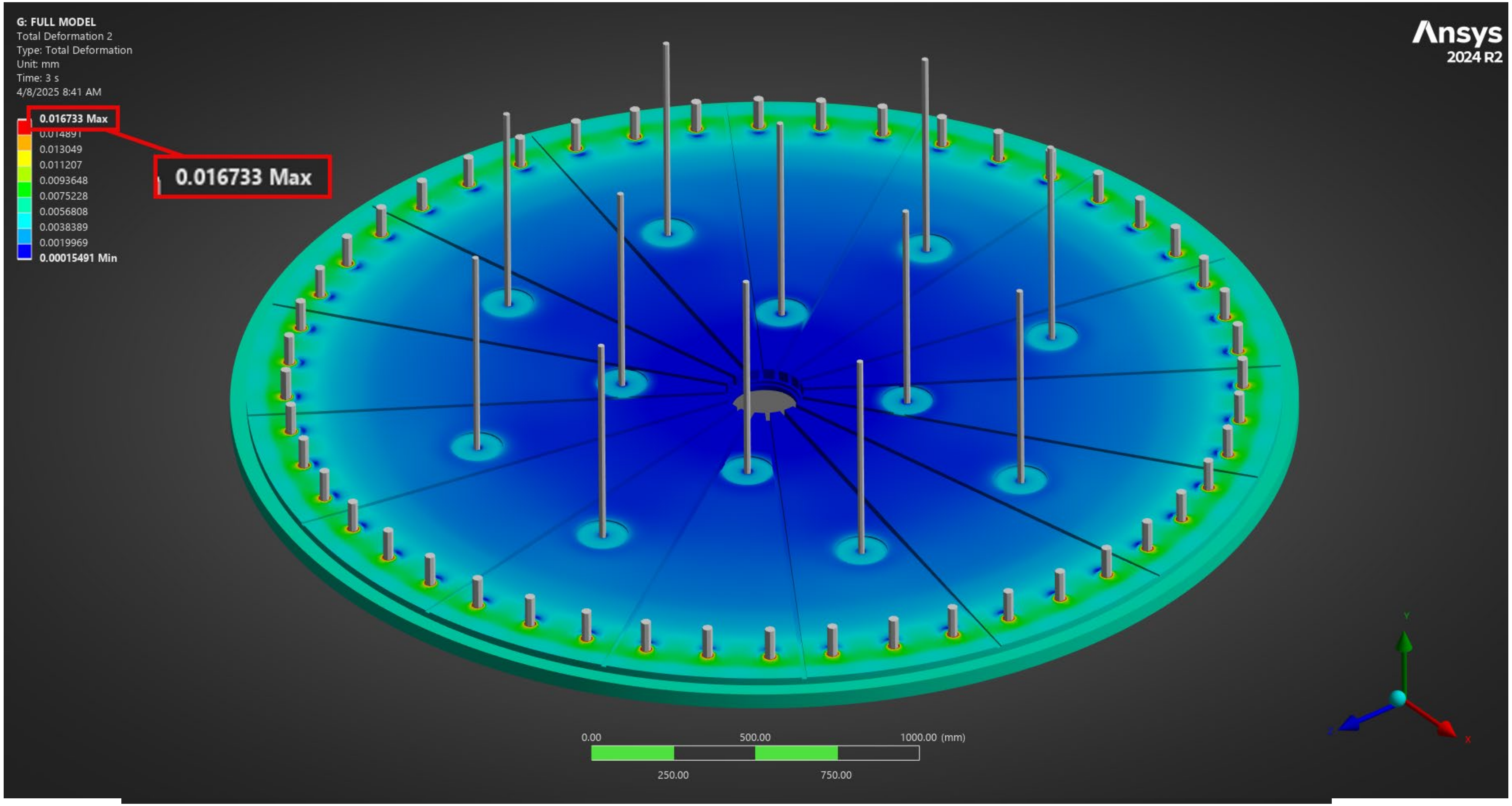
Adding the removable shield loads yielded no surprises.



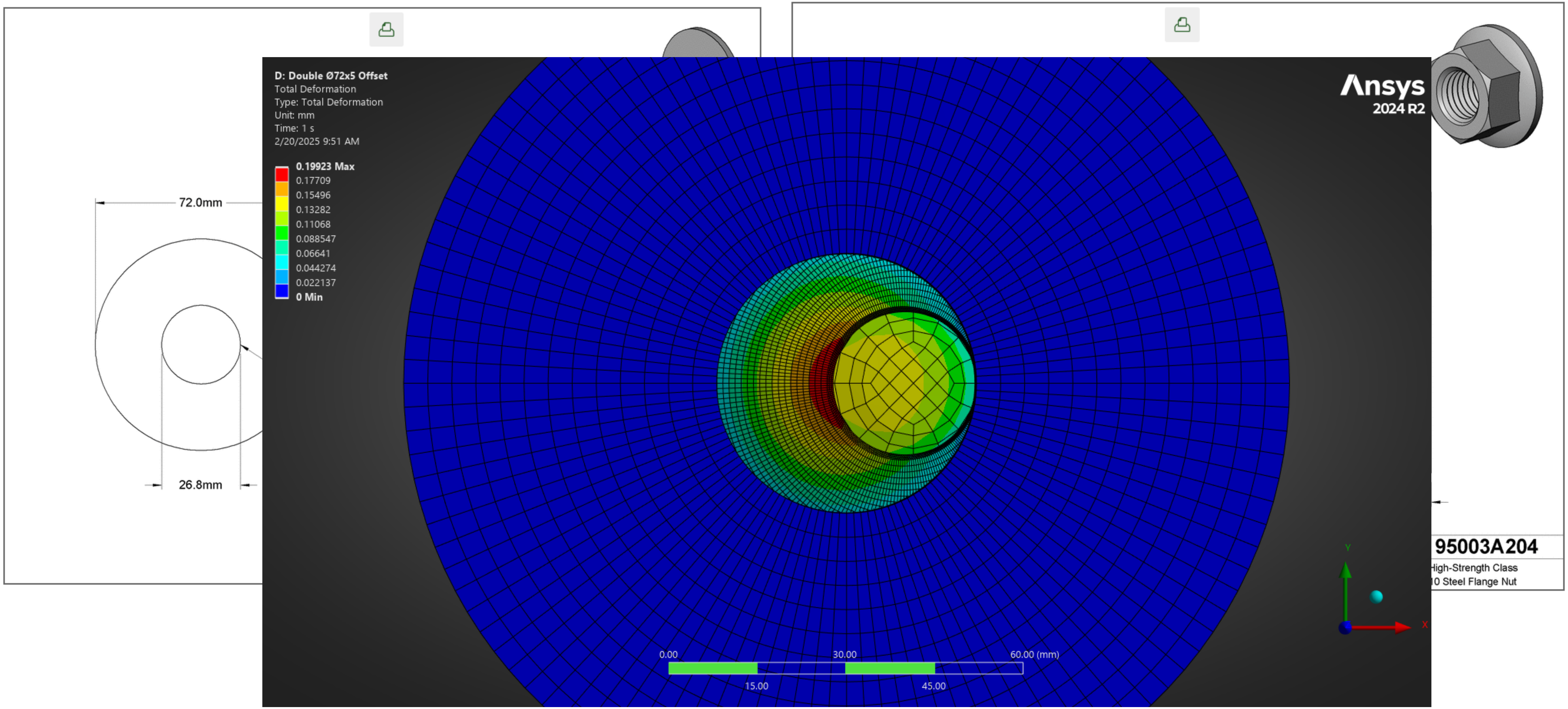
Negligible deformation occurred in the liner below the shielding with max values occurring where bolts anchors were tensioned.



A separate analysis was done for the baseplate and deformation maxed where the M36 bolts were tensioned. No surprises were found.

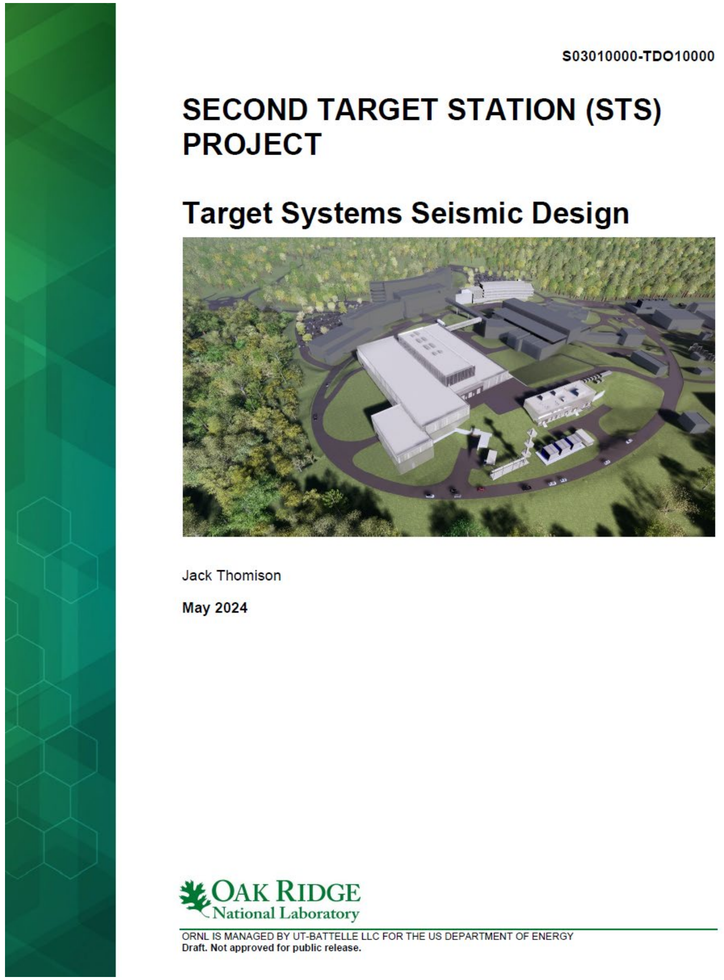


The anchor connections were tested with an exaggerated load using COTS stainless washers and Grade 10 flange nuts in a worst-case setup.



Target Station Shielding Seismic Analysis

Standards Followed:


S03010000-TDO10000

SECOND TARGET STATION (STS) PROJECT

Target Systems Seismic Design

Jack Thomison

May 2024

OAK RIDGE National Laboratory

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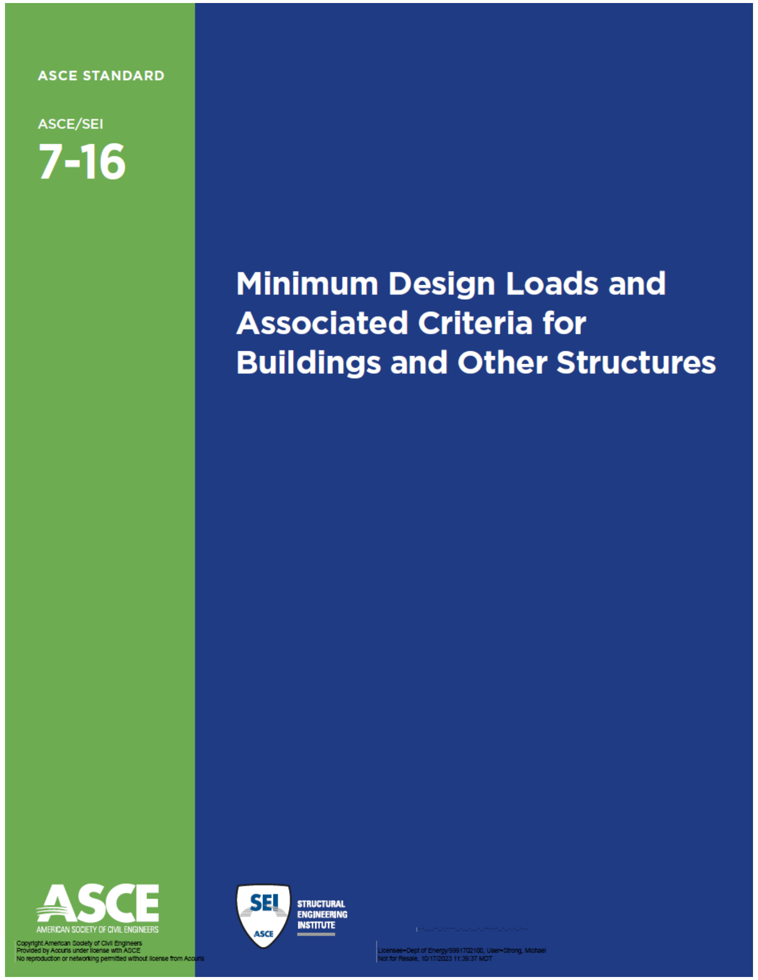
Draft. Not approved for public release.


ASCE STANDARD

ASCE/SEI

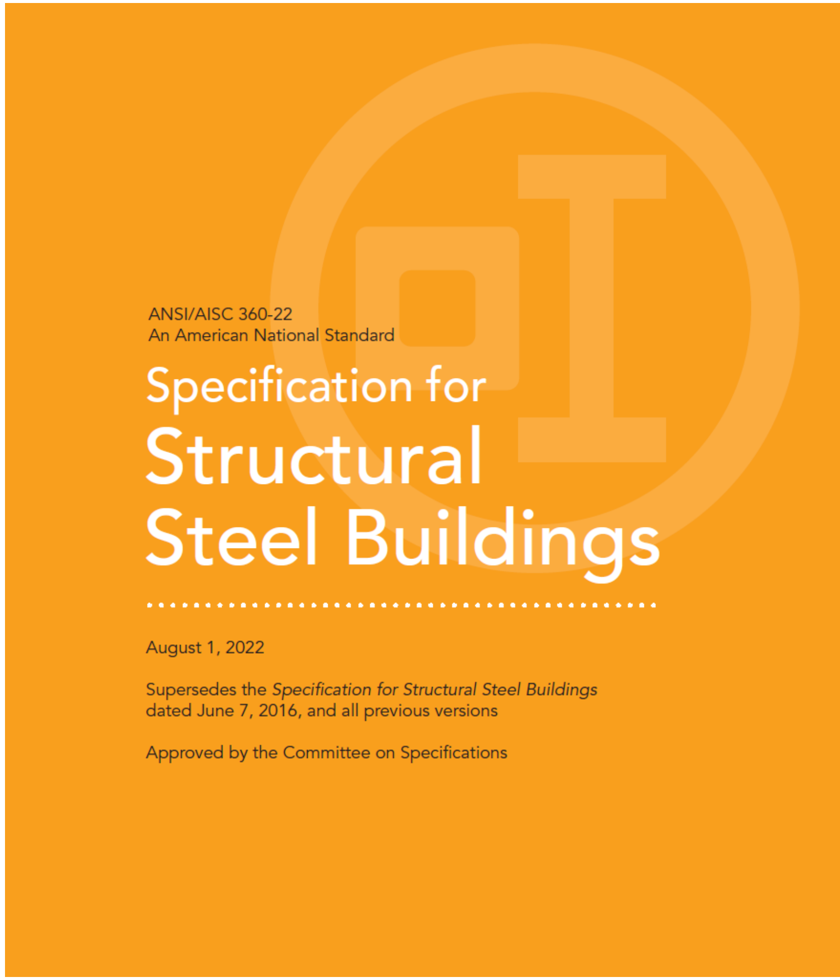
7-16

Minimum Design Loads and Associated Criteria for Buildings and Other Structures

ASCE

AMERICAN SOCIETY OF CIVIL ENGINEERS

SEI STRUCTURAL ENGINEERING INSTITUTE


ANSI/AISC 360-22

An American National Standard

Specification for Structural Steel Buildings

August 1, 2022

Supersedes the *Specification for Structural Steel Buildings* dated June 7, 2016, and all previous versions

Approved by the Committee on Specifications

ASCE 7-16 Equations Used

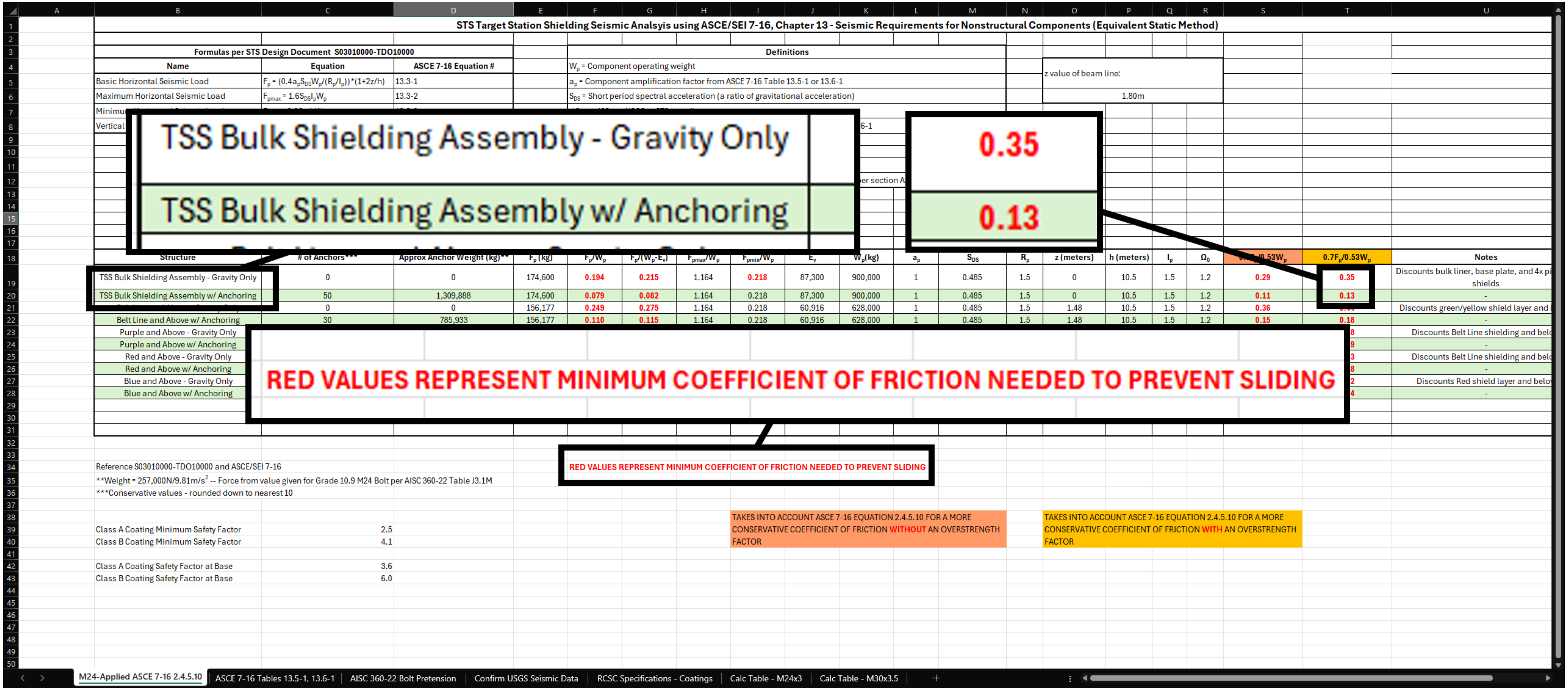
Equation 2.4.5-10

10. $0.6D - 0.7E_v + 0.7E_{mh}$

Formulas per STS Design Document S03010000-TDO10000		
Name	**Equation**	**ASCE 7-16 Equation #**
Basic Horizontal Seismic Force	$F_p = (0.4a_pS_{DS}W_p/(R_p/I_p))*(1+2z/h)$	13.3-1
Maximum Horizontal Seismic Force	$F_{pmax} = 1.6S_{DS}I_pW_p$	13.3-2
Minimum Horizontal Seismic Force	$F_{pmin} = 0.3S_{DS}I_pW_p$	13.3-3
Vertical Seismic Force	$E_v = +/-0.2S_{DS}W_p$	13.3.1.2

Definitions
W_p = Component operating weight
a_p = Component amplification factor from ASCE 7-16 Table 13.5-1 or 13.6-1
S_{DS} = Short period spectral acceleration (a ratio of gravitational acceleration)
*S_{DS} = .485 per USGS at STS coordinates
R_p = Componet response modification factor from ASCE 7-16 Table 13.5-1 or 13.6-1
z = Height above base where attached
h = Average roof height, top of level 3 = 10.5m
I_p = Component importance factor - see ASCE 7-16 section 13.1.3 for more info
Ω_0 = Overstrength factor to be applied for anchorages to concrete or masonry per section ASCE 7-16 section 12.4.3

The Spreadsheet



STS Target Station Shielding Seismic Analsyis using ASCE/SEI 7-16, Chapter 13 - Seismic Requirements for Nonstructural Components (Equivalent Static Method)

Formulas per STS Design Document S03010000-TDO10000		
Name	Equation	ASCE 7-16 Equation #
Basic Horizontal Seismic Load	$F_p = (0.4a_pS_{DS}W_p/(R_p/I_p))*(1+2z/h)$	13.3-1
Maximum Horizontal Seismic Load	$F_{pmax} = 1.6S_{DS}I_pW_p$	13.3-2
Minimu…		
Vertical…		

Definitions

W_p = Component operating weight

a_p = Component amplification factor from ASCE 7-16 Table 13.5-1 or 13.6-1

S_{DS} = Short period spectral acceleration (a ratio of gravitational acceleration)

…6-1

…er section A…

z value of beam line: 1.80m

TSS Bulk Shielding Assembly - Gravity Only | 0.35

TSS Bulk Shielding Assembly w/ Anchoring | 0.13

Structure	# of Anchors***	Approx Anchor Weight (kg)**	F_p (kg)	F_p/W_p	$F_p/(W_p-E_v)$	F_{pmax}/W_p	F_{pmin}/W_p	E_v	W_p(kg)	a_p	S_{DS}	R_p	z (meters)	h (meters)	I_p	Ω_0	[illegible]	$0.7F_p/0.53W_p$	Notes
TSS Bulk Shielding Assembly - Gravity Only	0	0	174,600	0.194	0.215	1.164	0.218	87,300	900,000	1	0.485	1.5	0	10.5	1.5	1.2	0.29	0.35	Discounts bulk liner, base plate, and 4x pi… shields
TSS Bulk Shielding Assembly w/ Anchoring	50	1,309,888	174,600	0.079	0.082	1.164	0.218	87,300	900,000	1	0.485	1.5	0	10.5	1.5	1.2	0.11	0.13	-
[illegible]	0	0	156,177	0.249	0.275	1.164	0.218	60,916	628,000	1	0.485	1.5	1.48	10.5	1.5	1.2	0.36	[illegible]	Discounts green/yellow shield layer and…
Belt Line and Above w/ Anchoring	30	785,933	156,177	0.110	0.115	1.164	0.218	60,916	628,000	1	0.485	1.5	1.48	10.5	1.5	1.2	0.15	0.18	-
Purple and Above - Gravity Only																		…8	Discounts Belt Line shielding and bel…
Purple and Above w/ Anchoring																		…9	-
Red and Above - Gravity Only																		…3	Discounts Belt Line shielding and bel…
Red and Above w/ Anchoring																		…8	-
Blue and Above - Gravity Only																		…2	Discounts Red shield layer and belo…
Blue and Above w/ Anchoring																		…4	-

RED VALUES REPRESENT MINIMUM COEFFICIENT OF FRICTION NEEDED TO PREVENT SLIDING

Reference S03010000-TDO10000 and ASCE/SEI 7-16

**Weight = 257,000N/9.81m/s^2 -- Force from value given for Grade 10.9 M24 Bolt per AISC 360-22 Table J3.1M

***Conservative values - rounded down to nearest 10

RED VALUES REPRESENT MINIMUM COEFFICIENT OF FRICTION NEEDED TO PREVENT SLIDING

Class A Coating Minimum Safety Factor	2.5
Class B Coating Minimum Safety Factor	4.1
Class A Coating Safety Factor at Base	3.6
Class B Coating Safety Factor at Base	6.0

TAKES INTO ACCOUNT ASCE 7-16 EQUATION 2.4.5.10 FOR A MORE CONSERVATIVE COEFFICIENT OF FRICTION WITHOUT AN OVERSTRENGTH FACTOR

TAKES INTO ACCOUNT ASCE 7-16 EQUATION 2.4.5.10 FOR A MORE CONSERVATIVE COEFFICIENT OF FRICTION WITH AN OVERSTRENGTH FACTOR

M24-Applied ASCE 7-16 2.4.5.10 | ASCE 7-16 Tables 13.5-1, 13.6-1 | AISC 360-22 Bolt Pretension | Confirm USGS Seismic Data | RCSC Specifications - Coatings | Calc Table - M24x3 | Calc Table - M30x3.5

BACKUP SLIDES

OAK RIDGE National Laboratory | SECOND TARGET STATION

Core Vessel 4/2025 Preliminary Structural Analysis

T. McManamy

4/7/25

U.S. DEPARTMENT OF ENERGY

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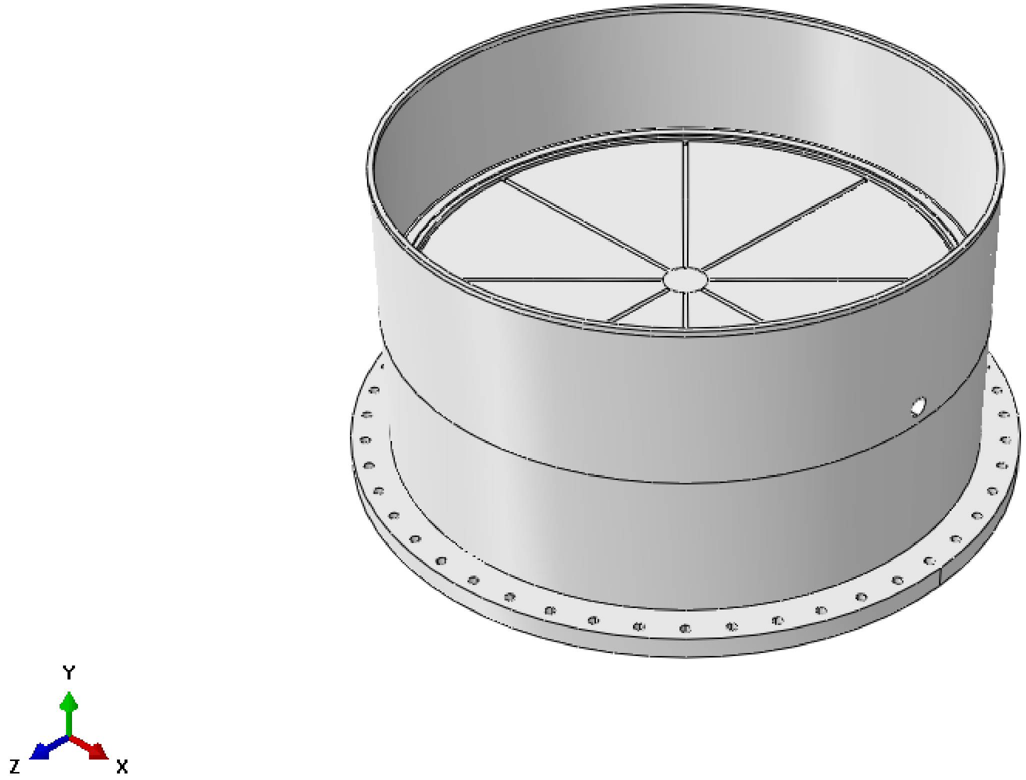
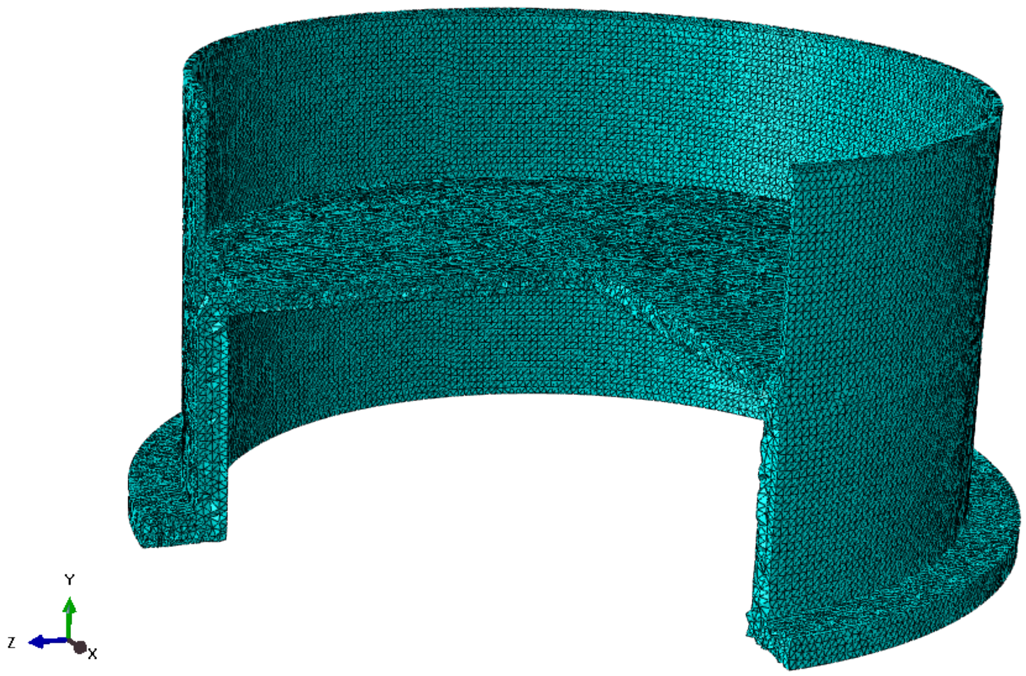
FOR THE US DEPARTMENT OF ENERGY

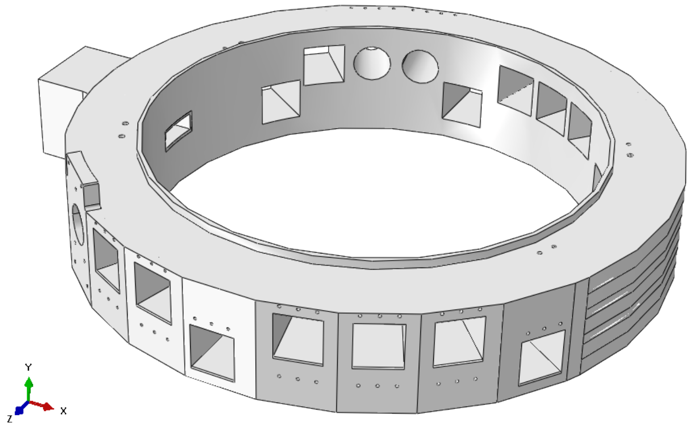
Lower Vessel part and mesh



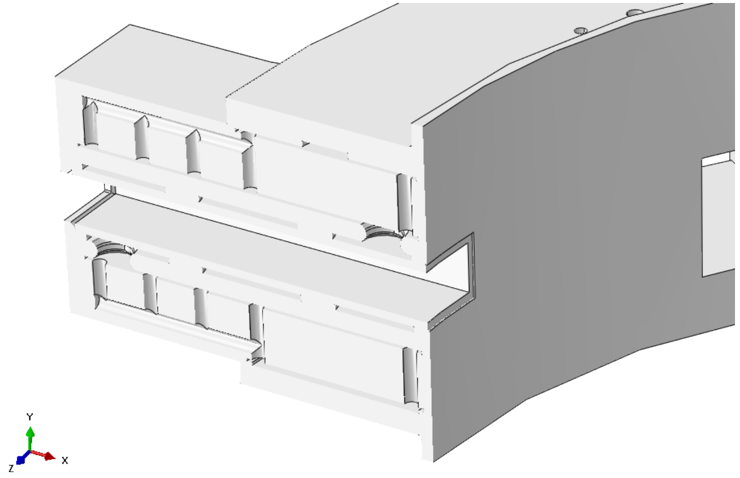


Beltline Part and mesh

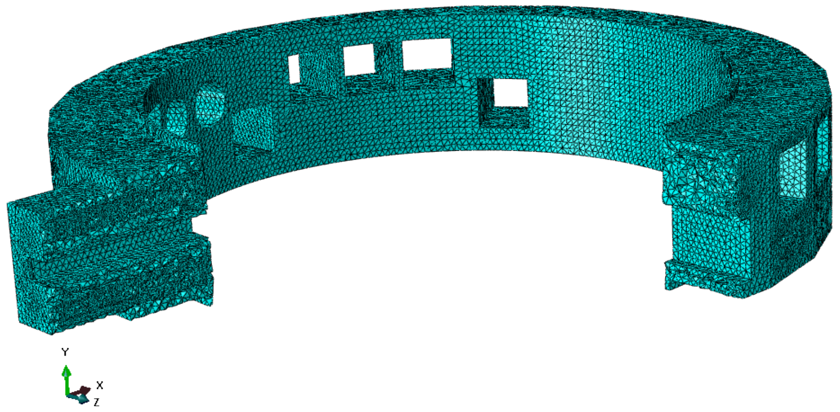
Part



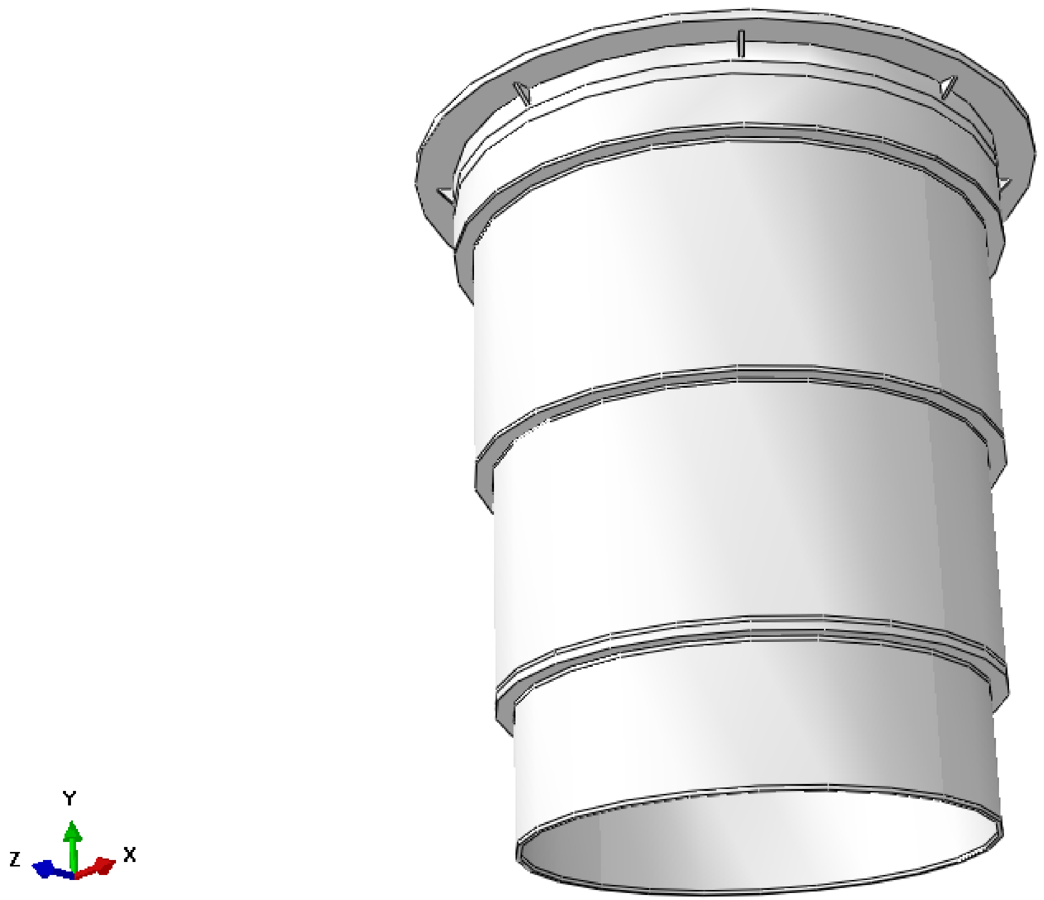
PBW zone with cut

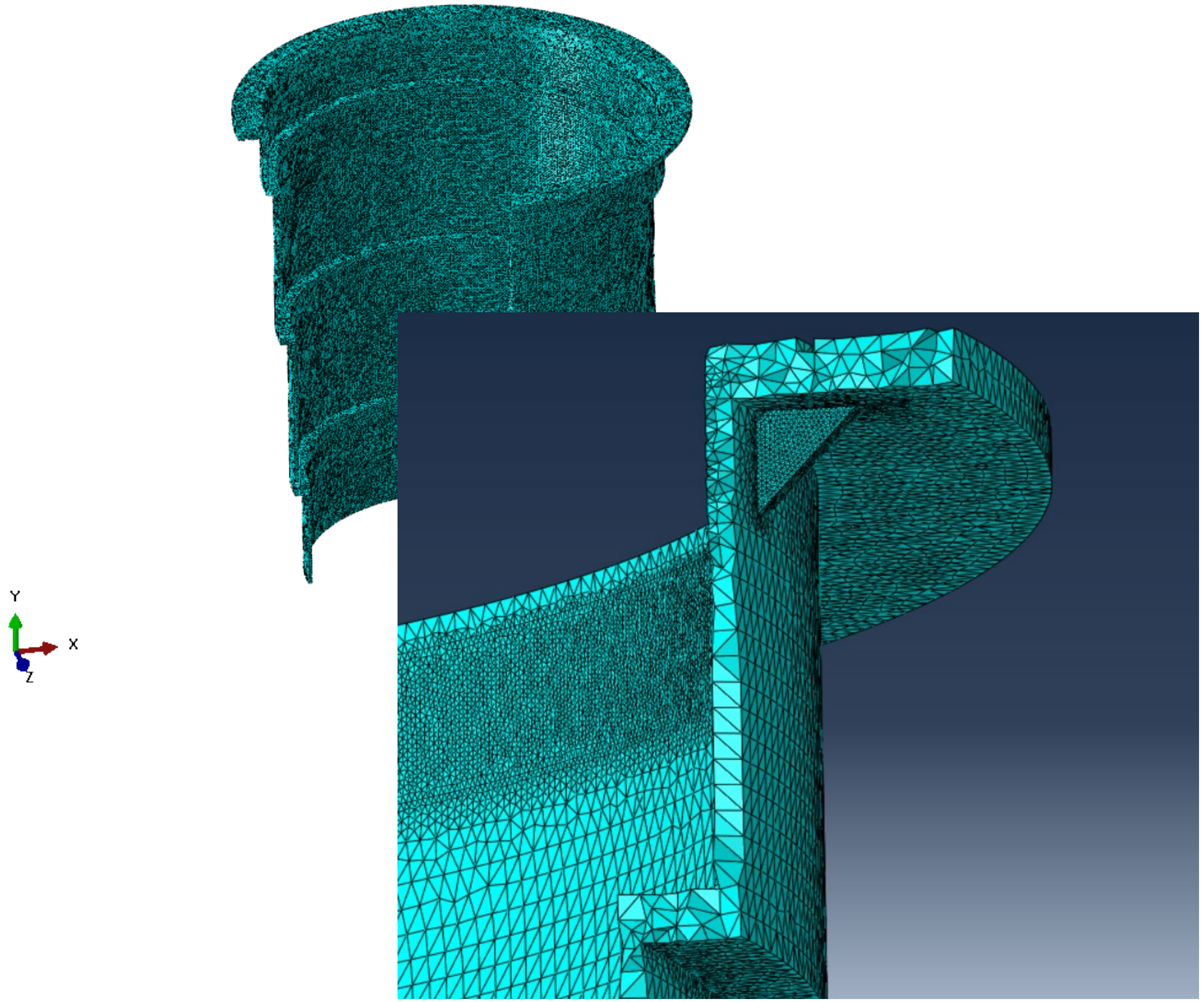


Mesh

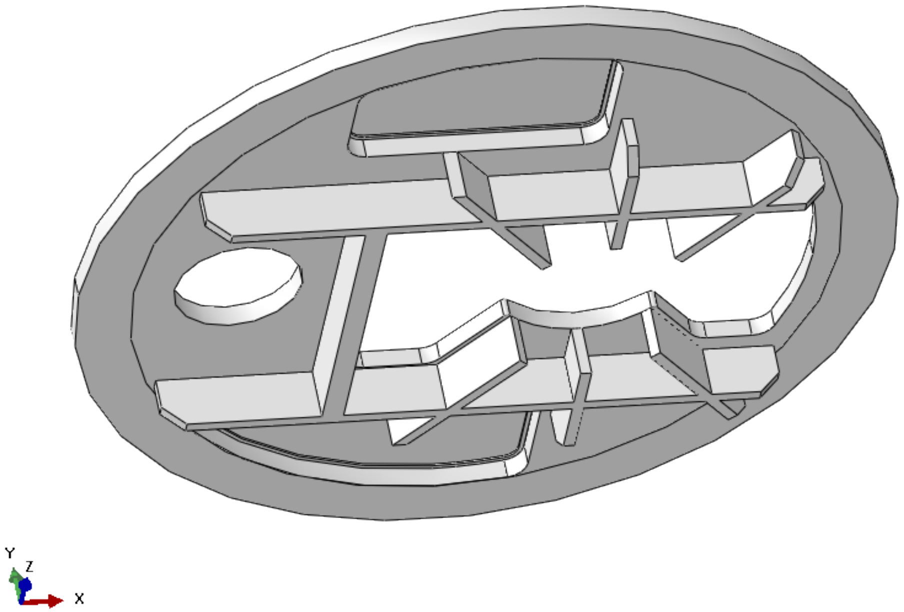


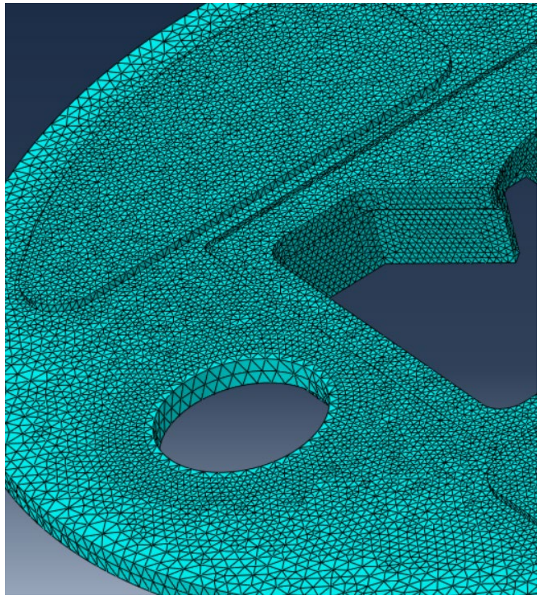
Upper Cylinder Part and mesh



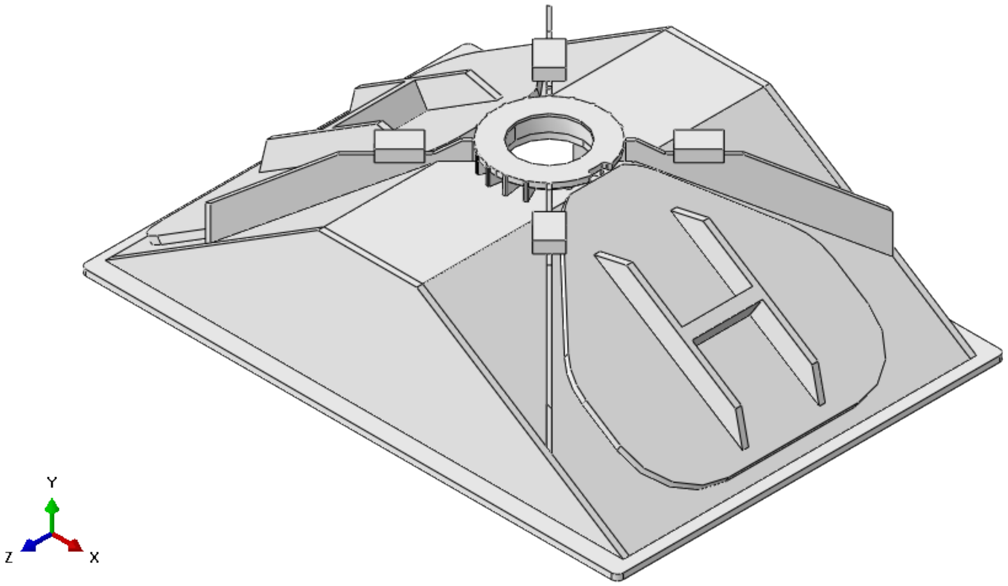


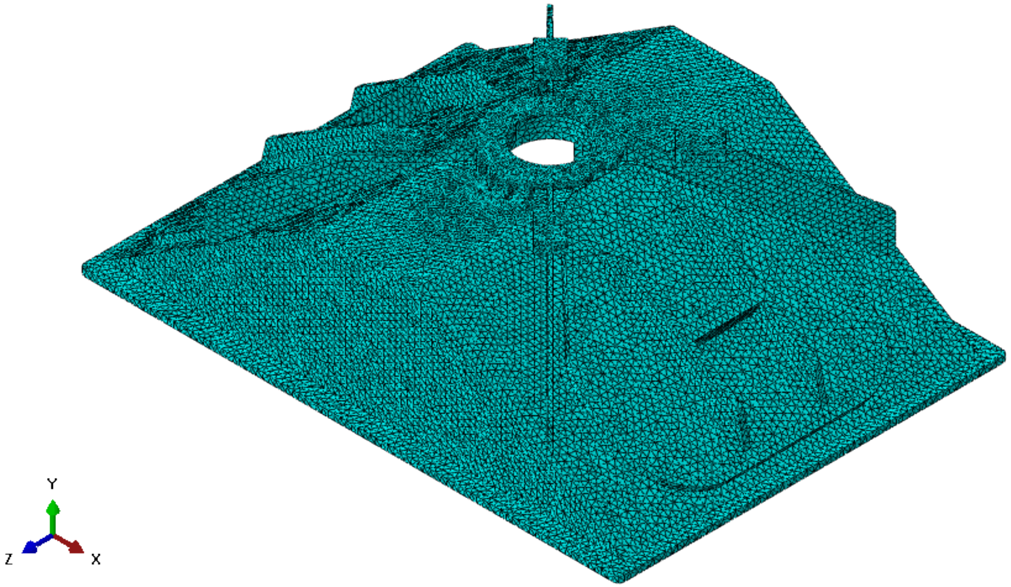
Lid and covers part





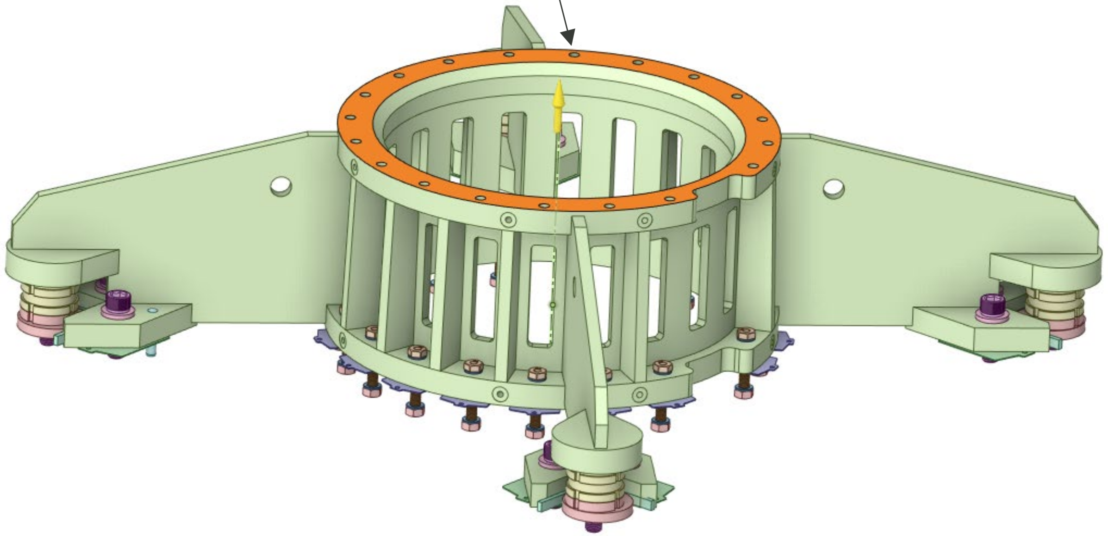
Tent Assembly





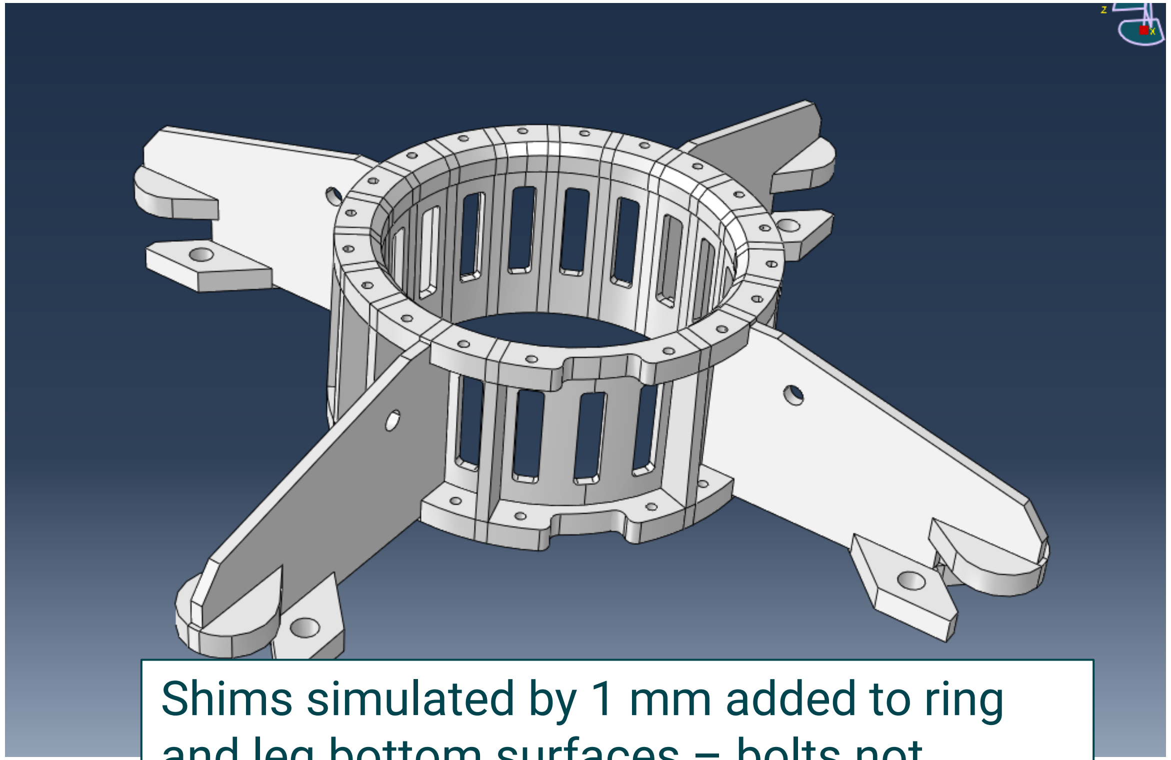
SpaceClaim Upper Shaft model

All target and shaft vertical loads go through upper ring surface



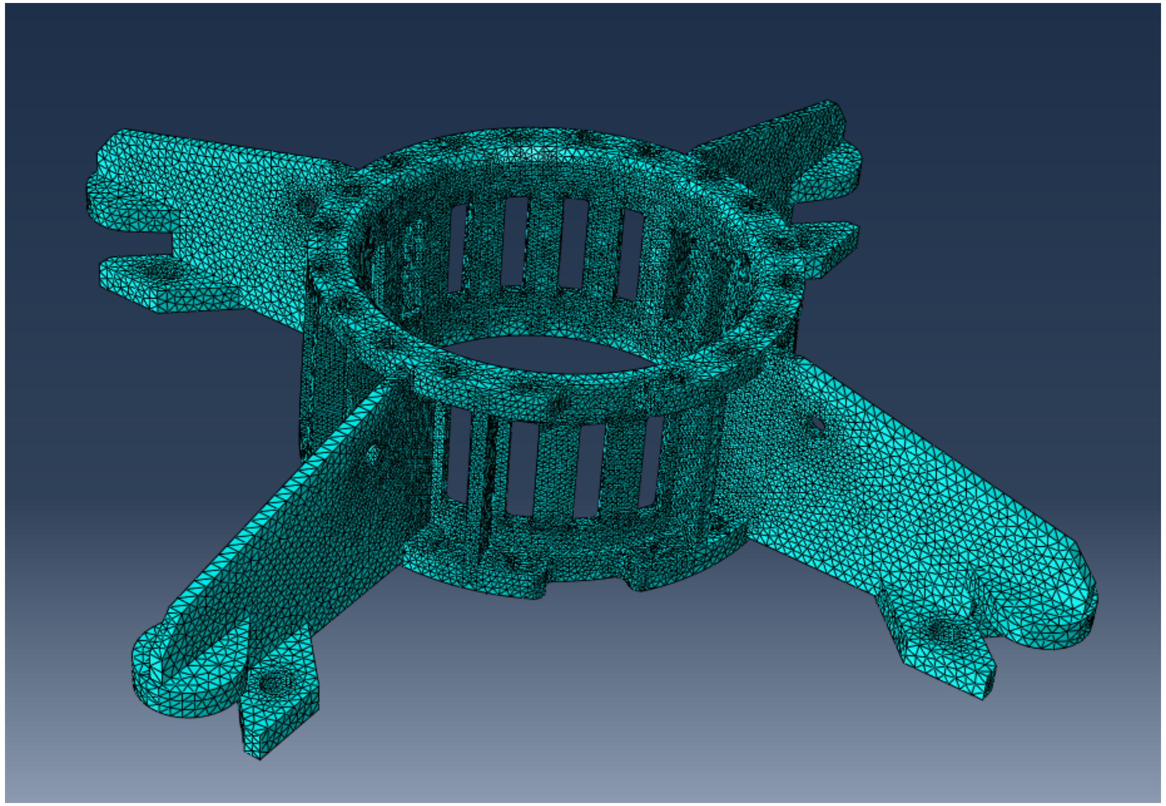
Shaft load ring model in Abaqus

Simplified Abaqus model

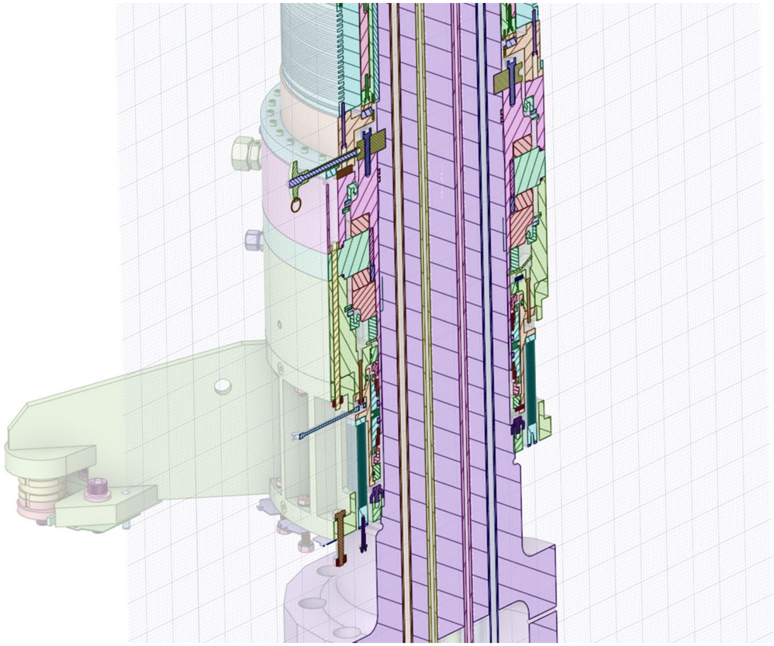


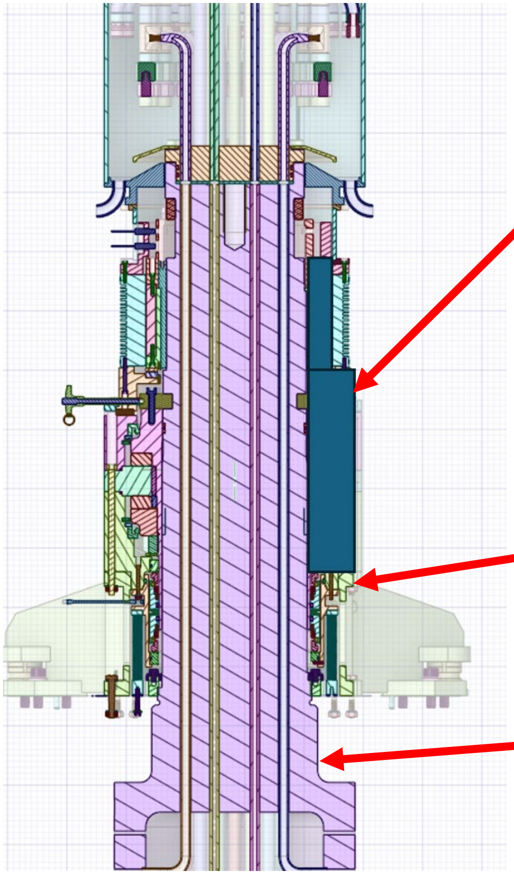
Shims simulated by 1 mm added to ring and leg bottom surfaces – bolts not included

Mesh model with C3D10 elements

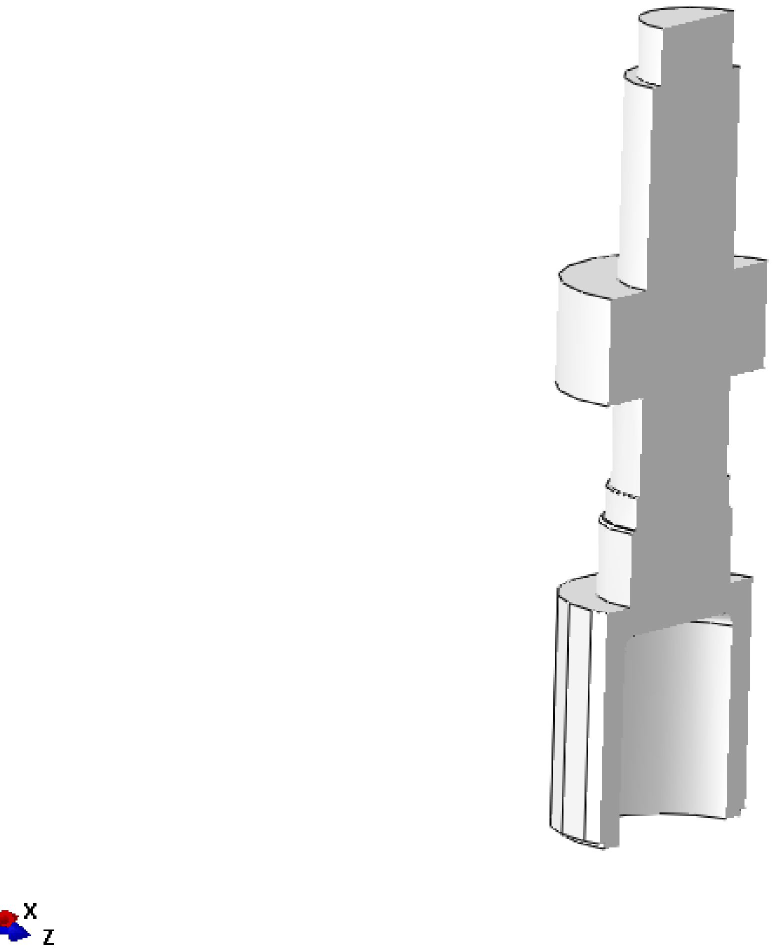


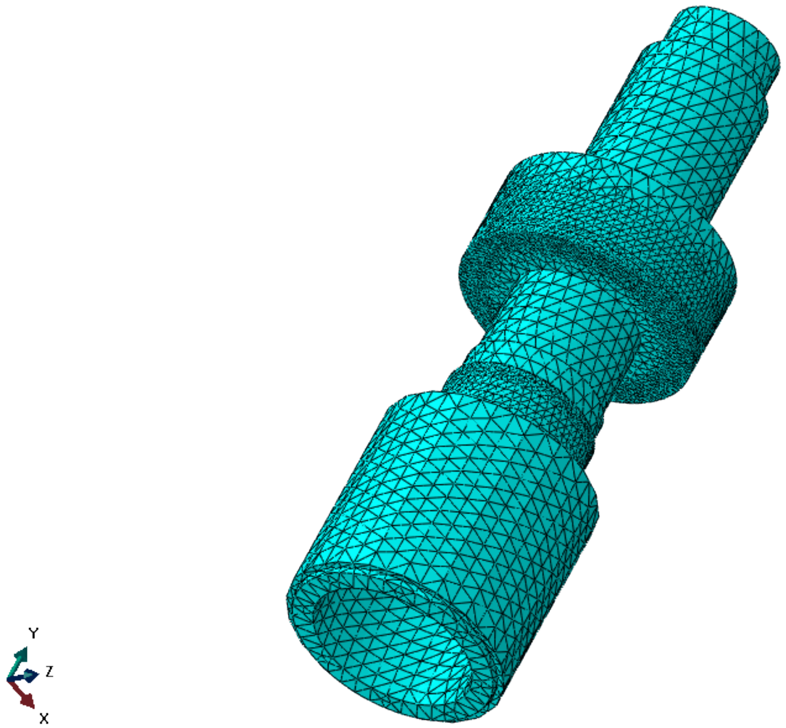
Upper Shaft and Crown SpaceClaim model and approximation



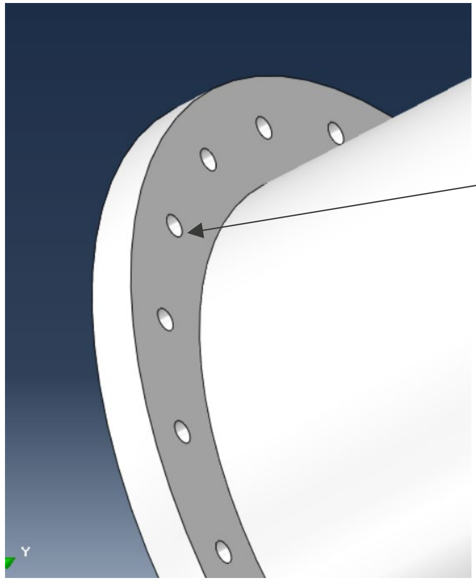


Top 312 Part which includes crown for segment attachment with all holes and cooling tubes suppressed

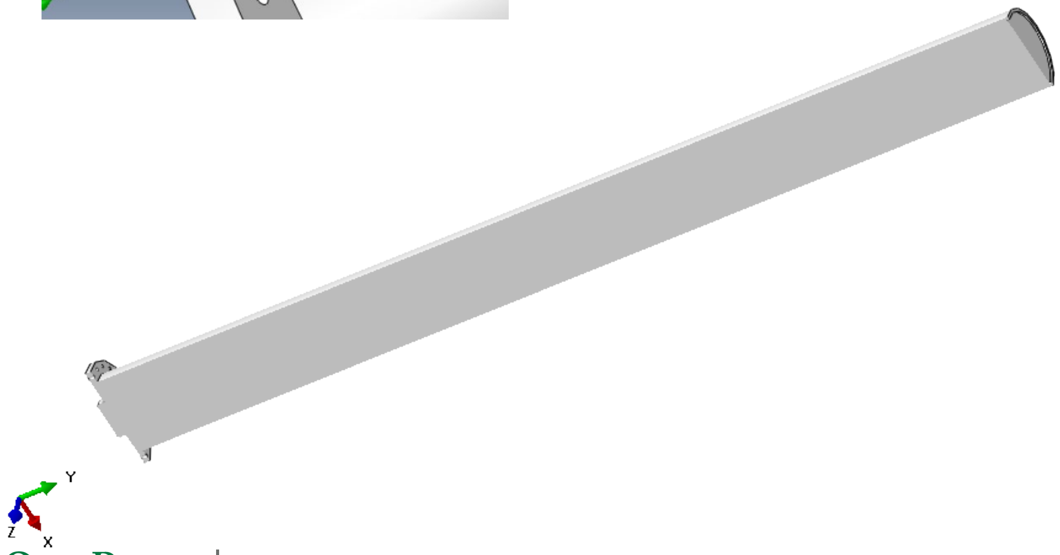


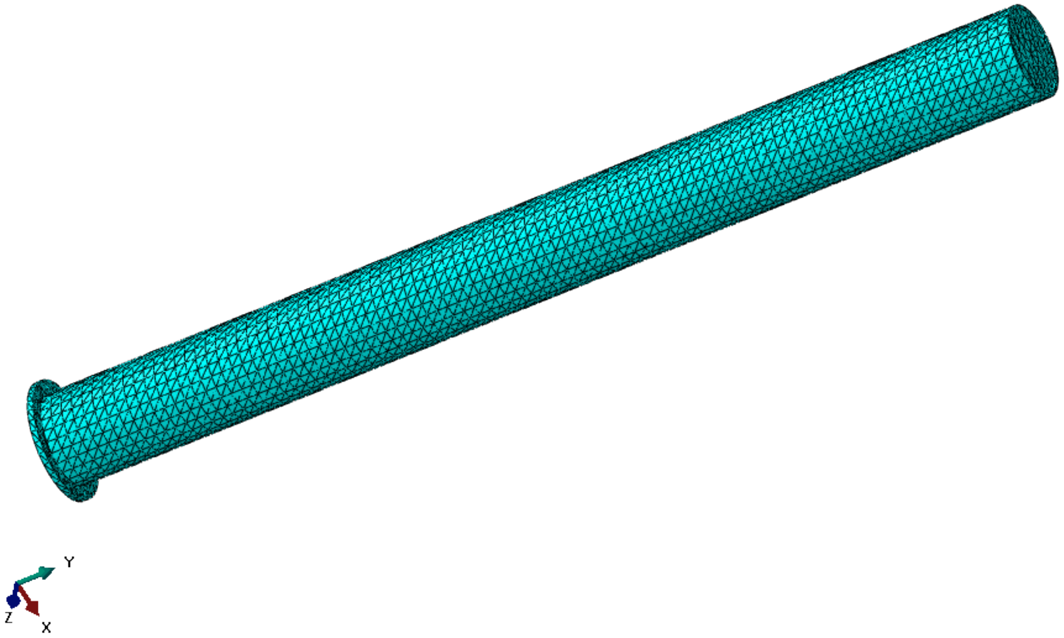


Shaft model as a solid



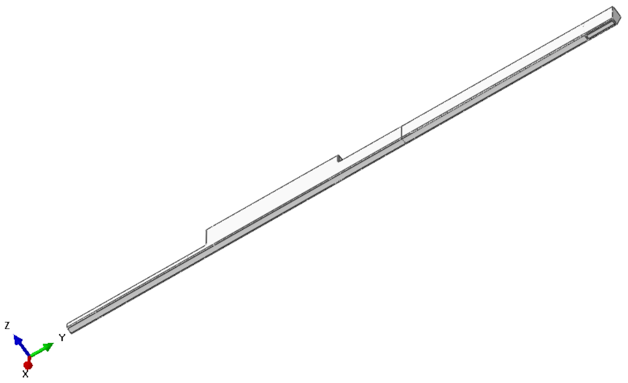
14 mm diameter holes added for target pin interfaces





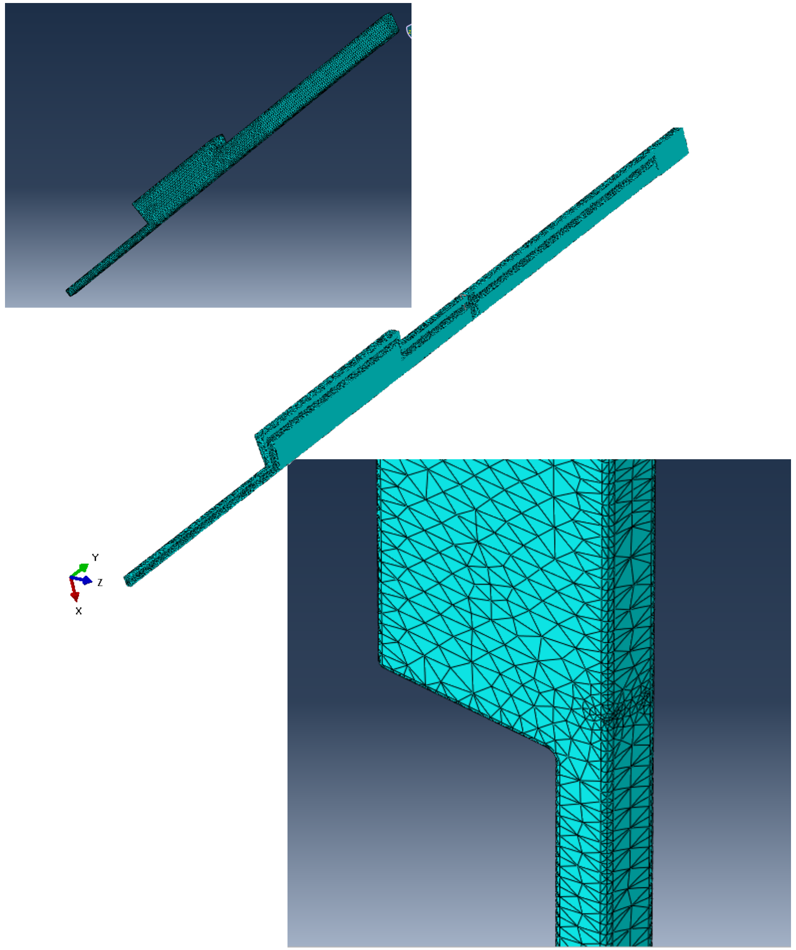
Segment stalk simplified with merged parts and only main coolant channel and remote handling thinning included

Stalk part



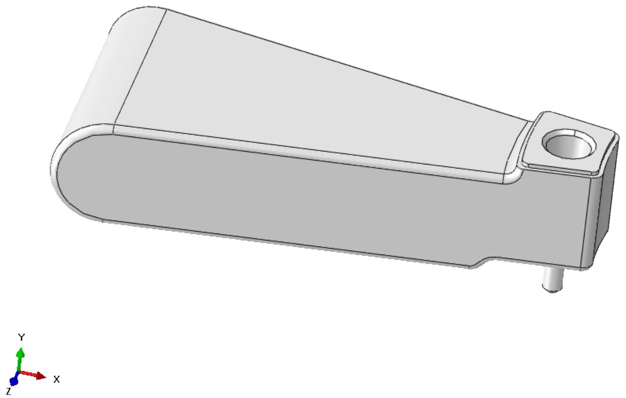
Cut to show channels included

Mesh

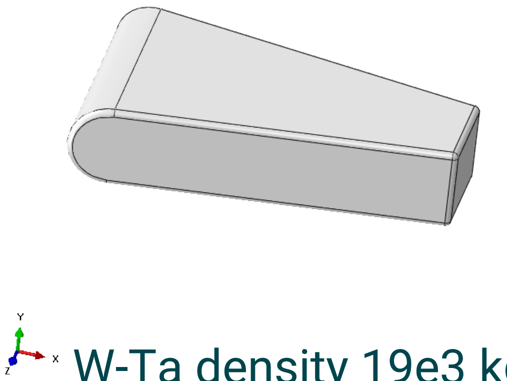


Simplified foot

Foot simplified part

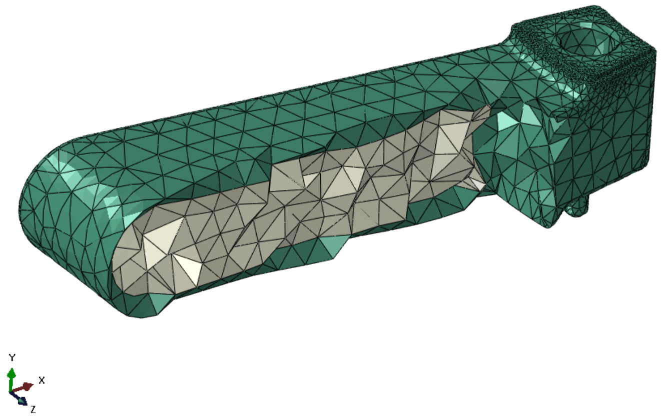


Tungsten and tantalum region

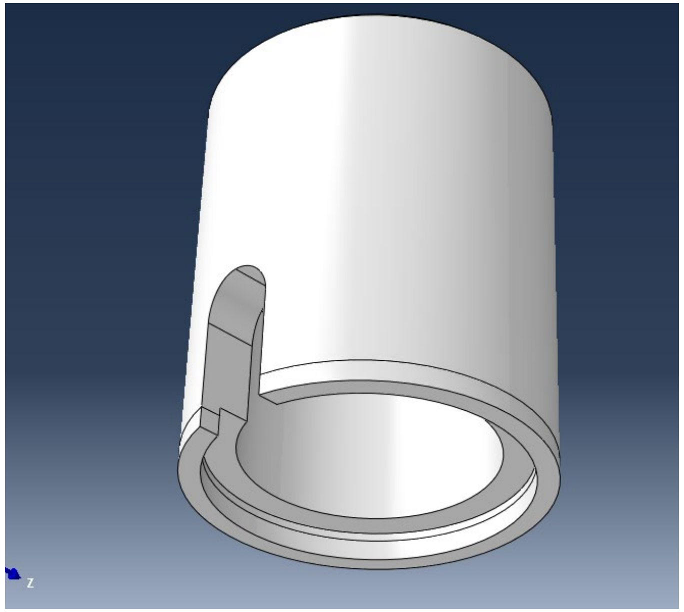


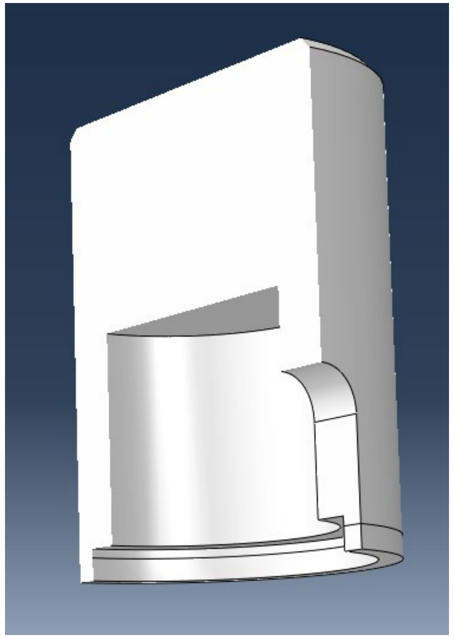
W-Ta density 19e3 kg/m^3

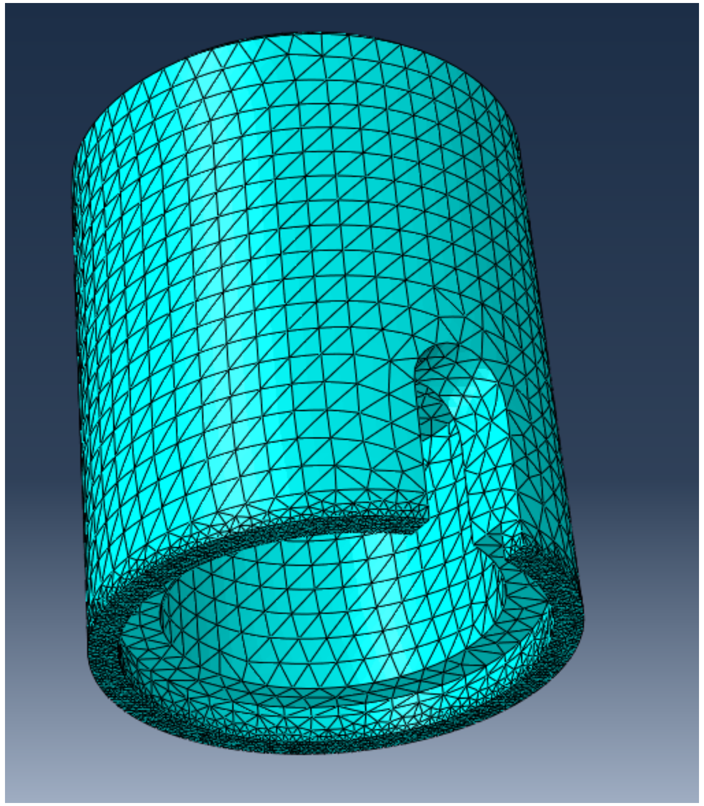
Mesh with materials



Doghouse part



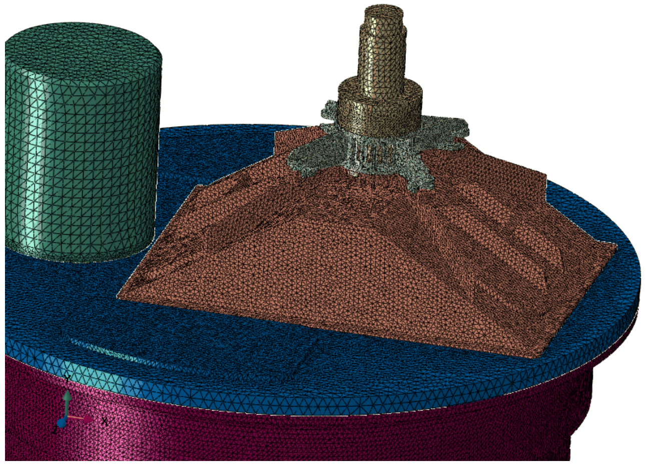




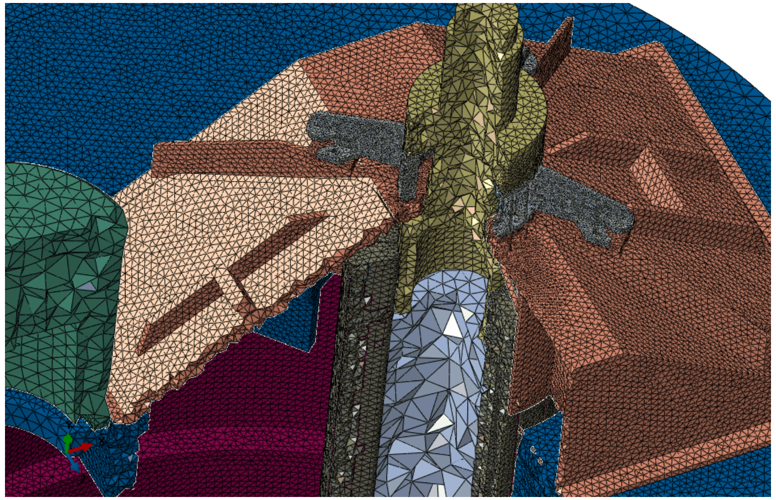
Density assumed 12.3 e3 kg/m3
Mass 5,000 kg

Assembly Mesh model examples

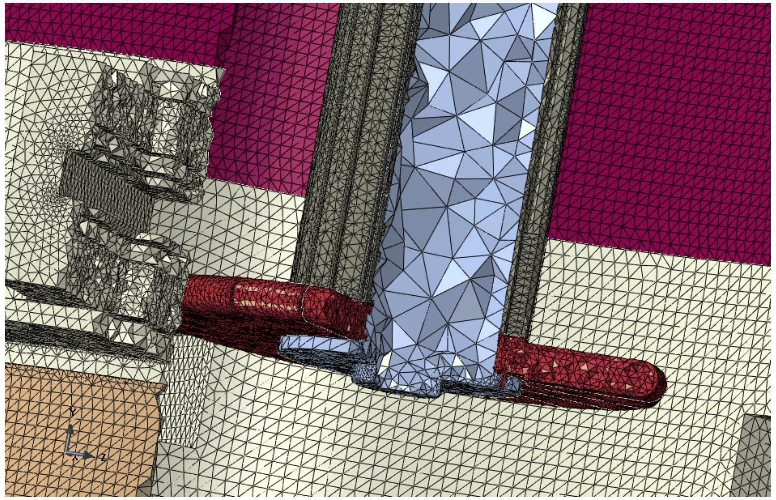
Upper region



Upper region with cut

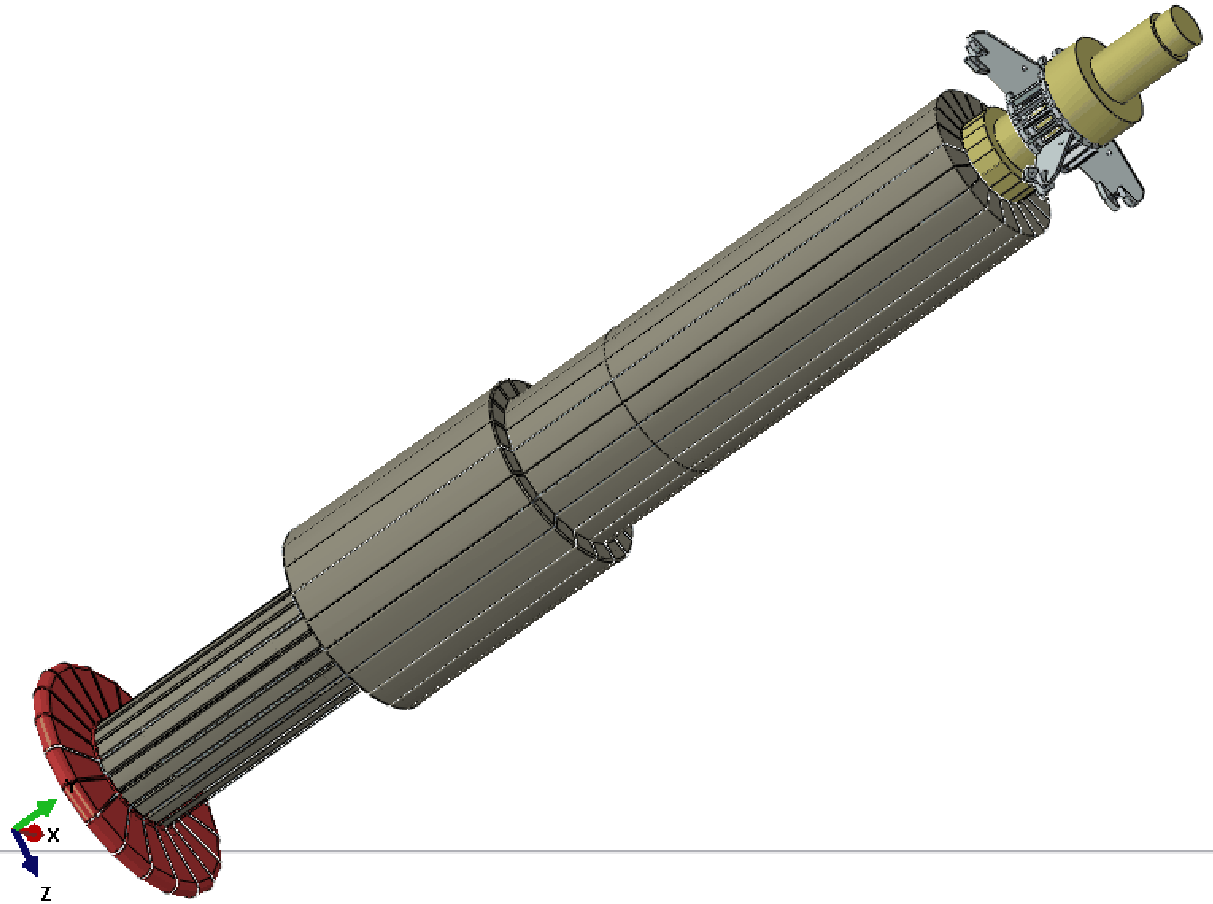


Lower shaft region with cut



Total 6.9 x 10^6 C3D10 elements

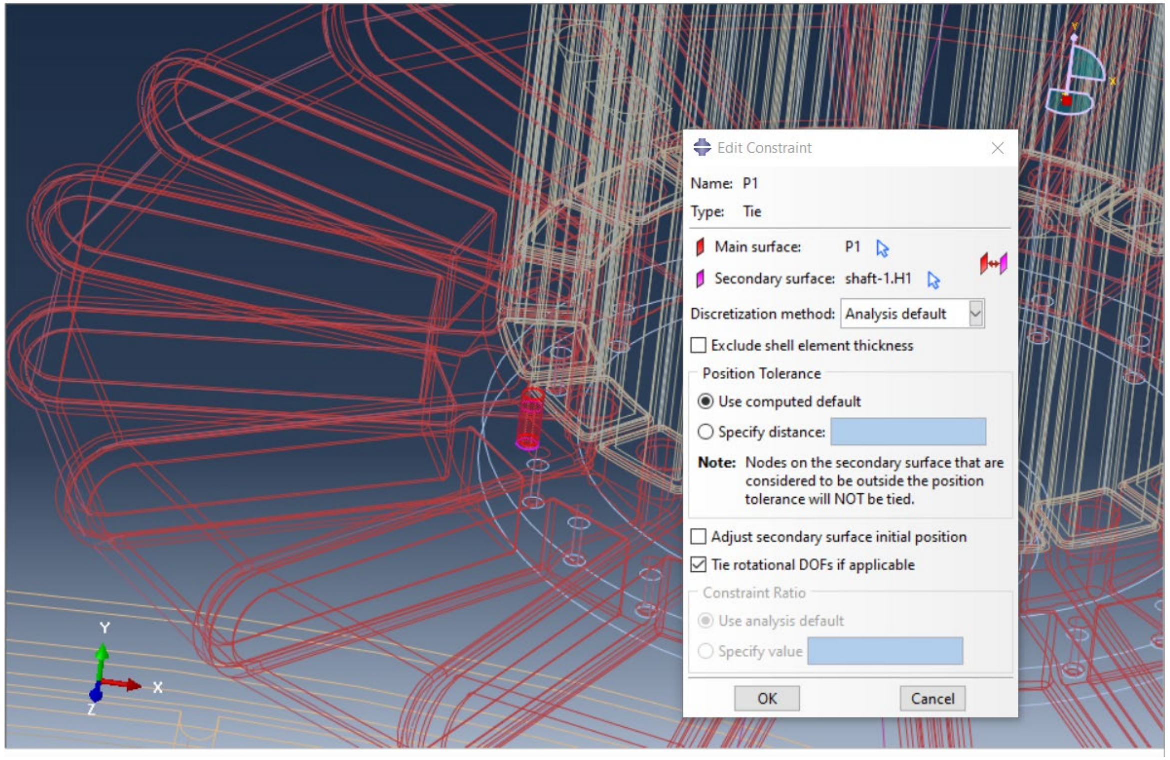
Mass of target components - 17,022 kg



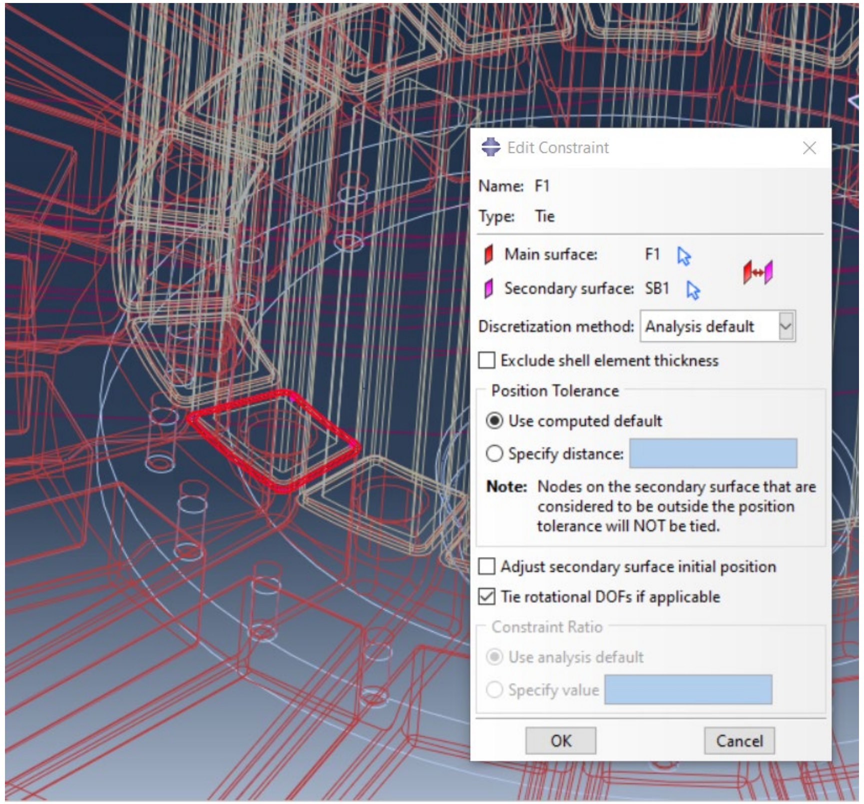

```
Mass properties:
  Volume: 2.07
  Volume centroid: 0.483,2.65,-3.51e-10
  Mass: 17022.18
  Center of mass: 0.483,2.59,-3.43e-10
  Moment of inertia about the center of mass (Ixx, Iyy, Izz, Ixy, Iyz, Izx): 37851.52,1385.02,37851.45,1.00,3.24e-04,-3.69e-05
```

Constraints

Typical target pin tie to shaft flange

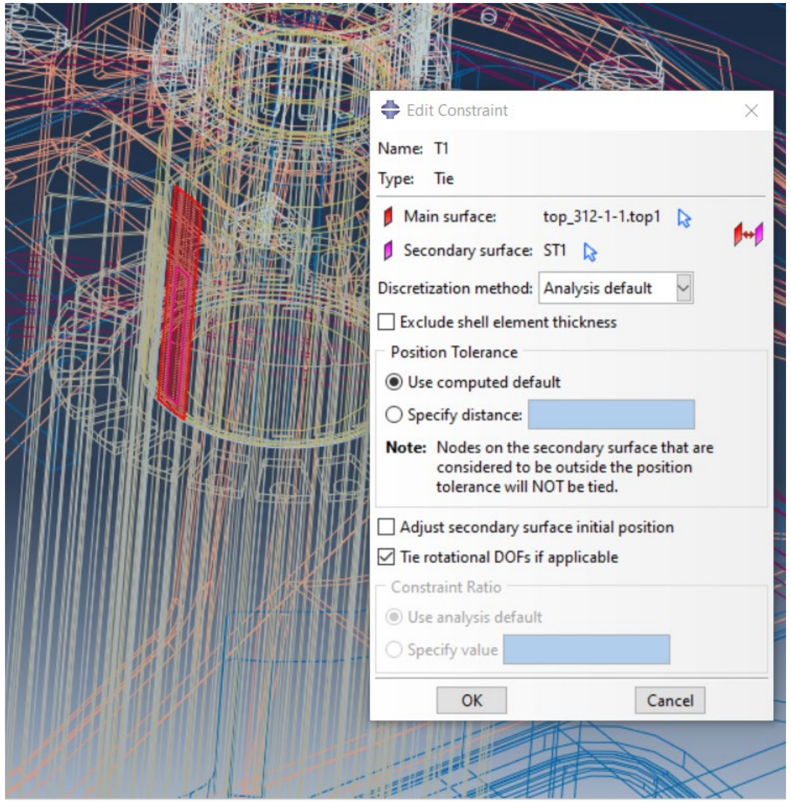


Typical foot to stalk tie

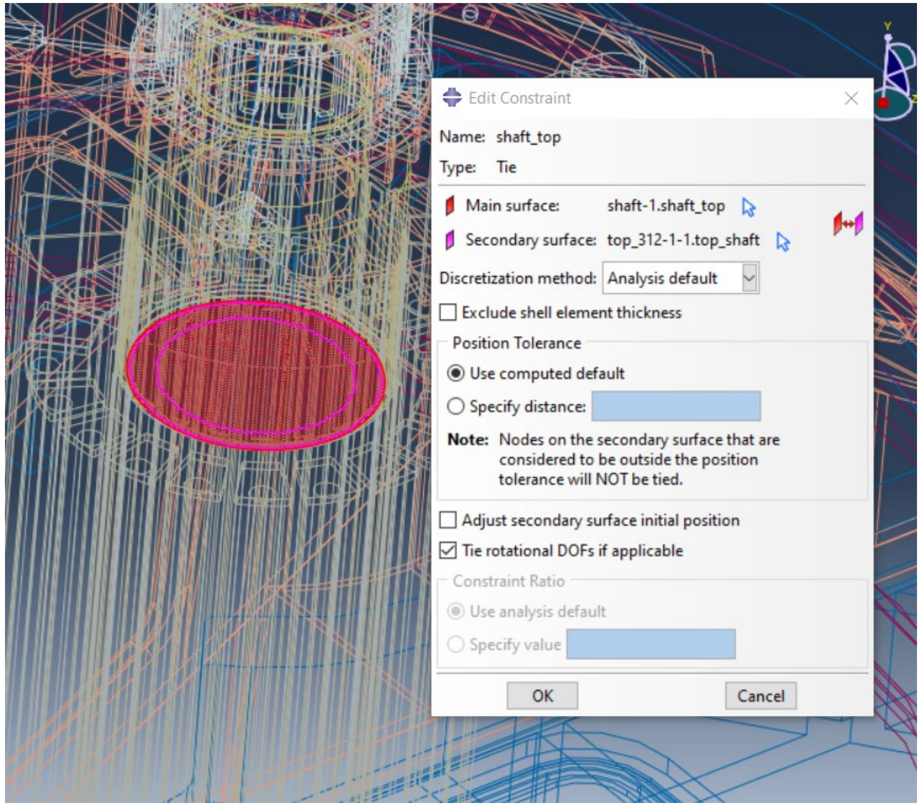


Constraints

Typical stalk to top (crown) tie

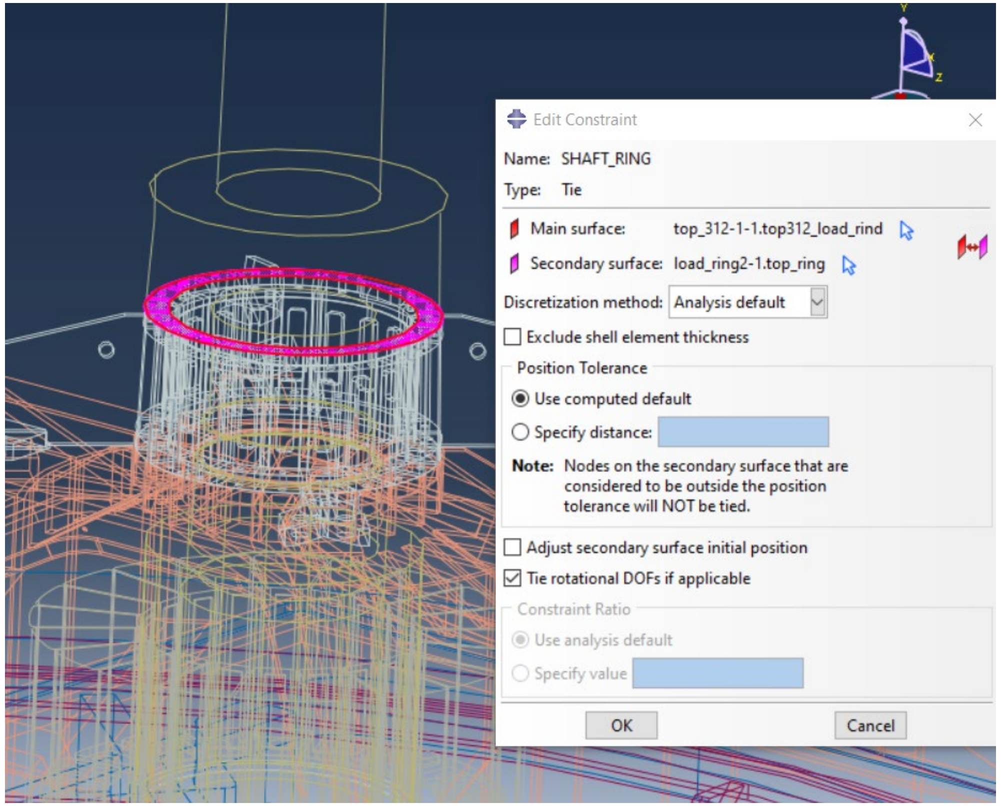


Shaft to top tie

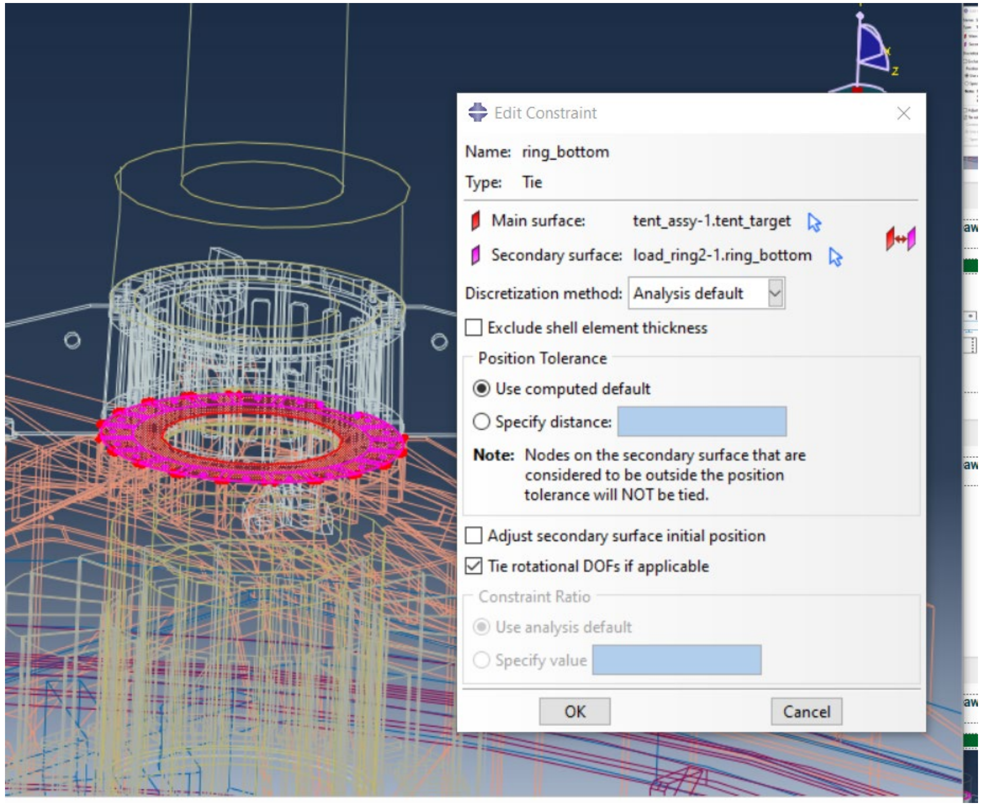


Constraints

Top tie to load ring

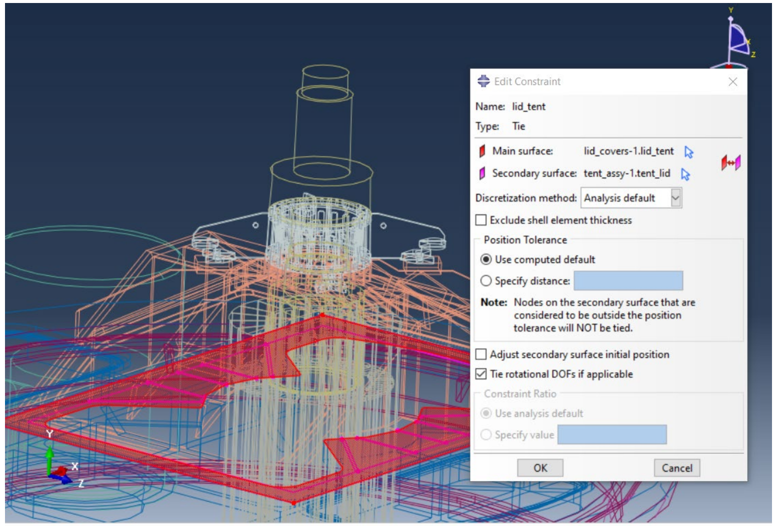


Load ring to tent assembly tie

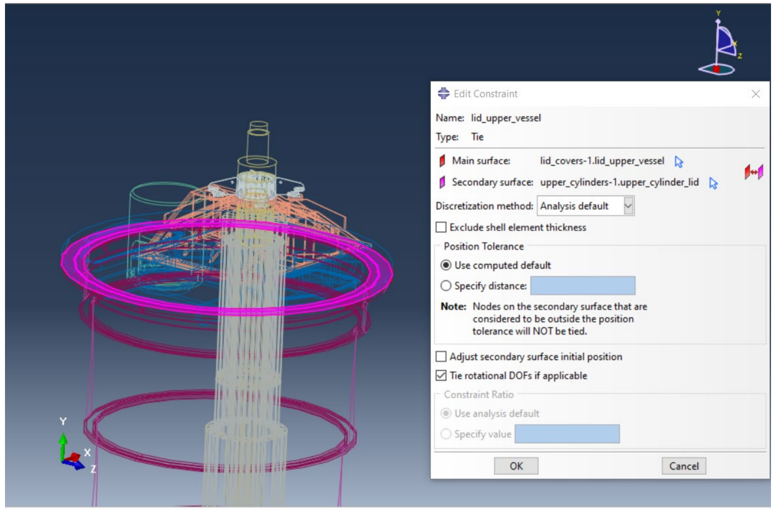


Constraints

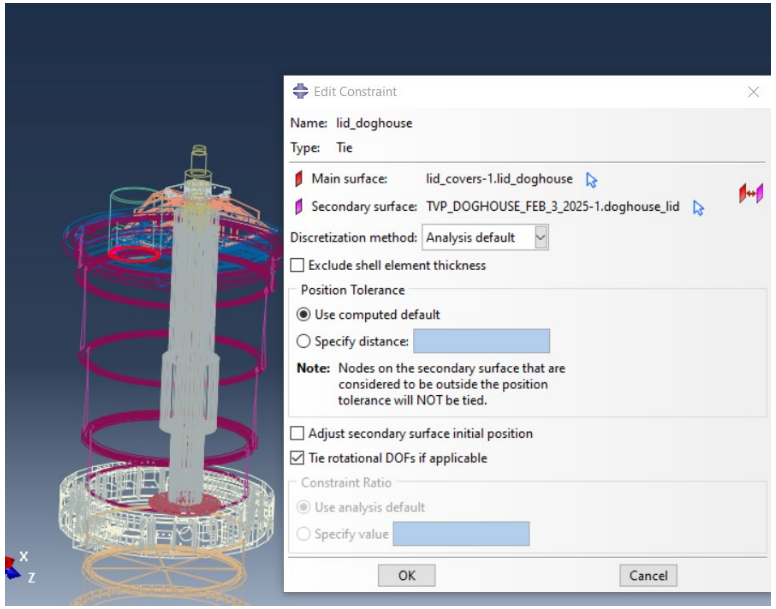
Tent assy to lid tie



Lid to upper cylinders

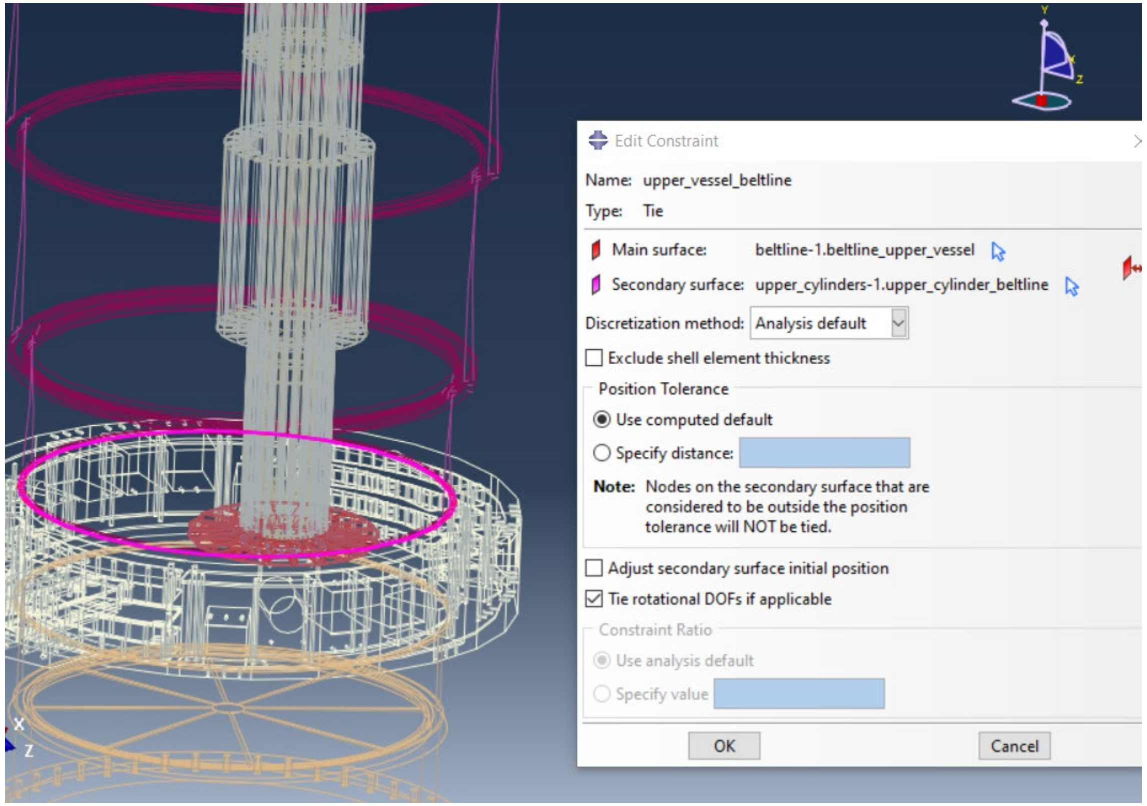


Lid to Doghouse

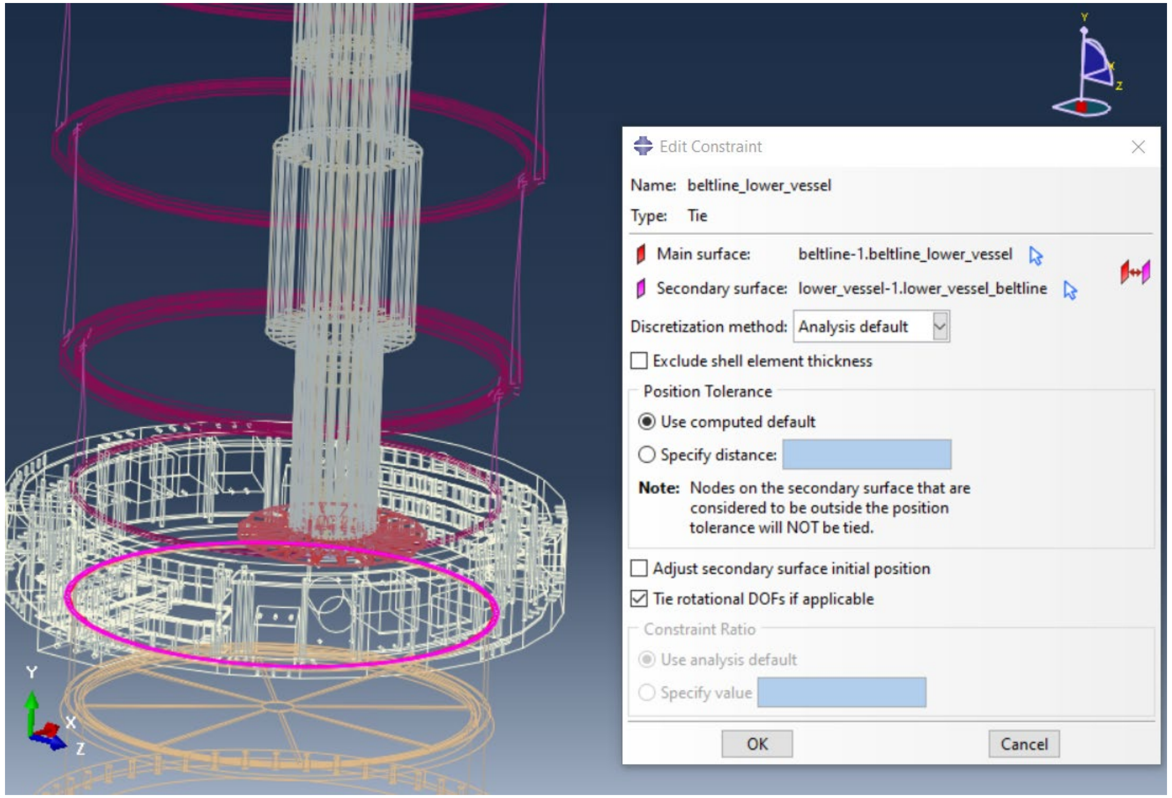


Constraints

Upper Cylinders to beltline

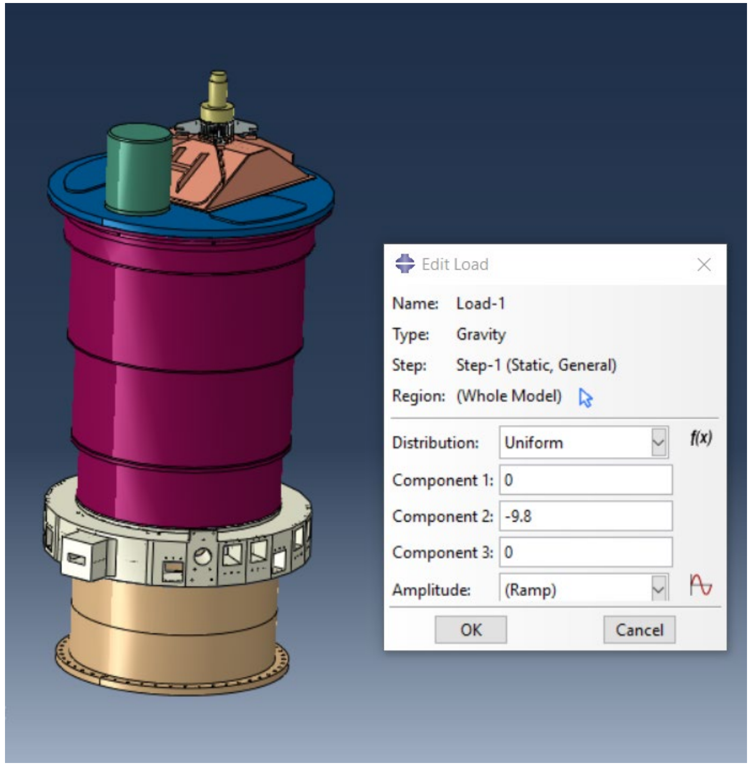


Beltline to Lower Cylinders

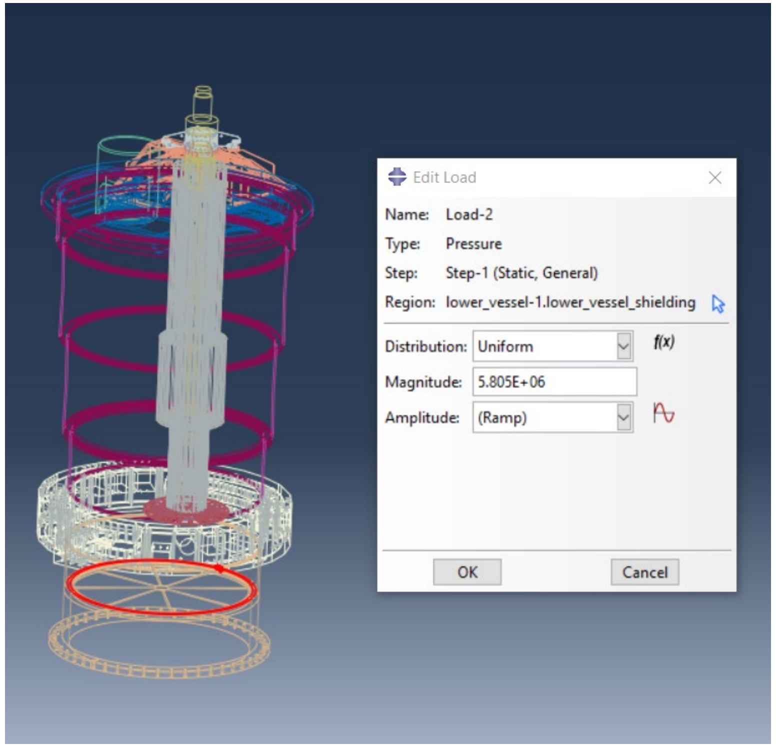


Step 1 Gravity only

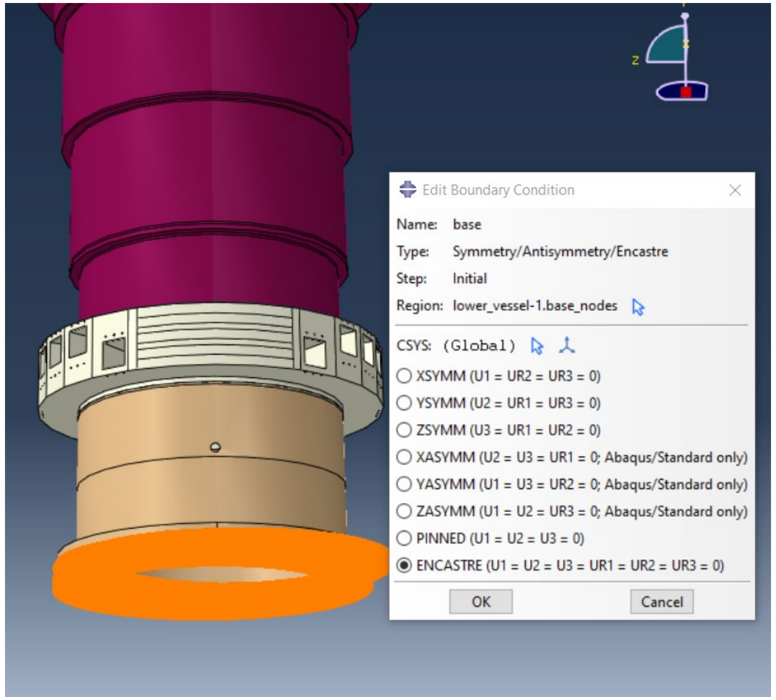
Gravity load



Simulated weight of internal shielding

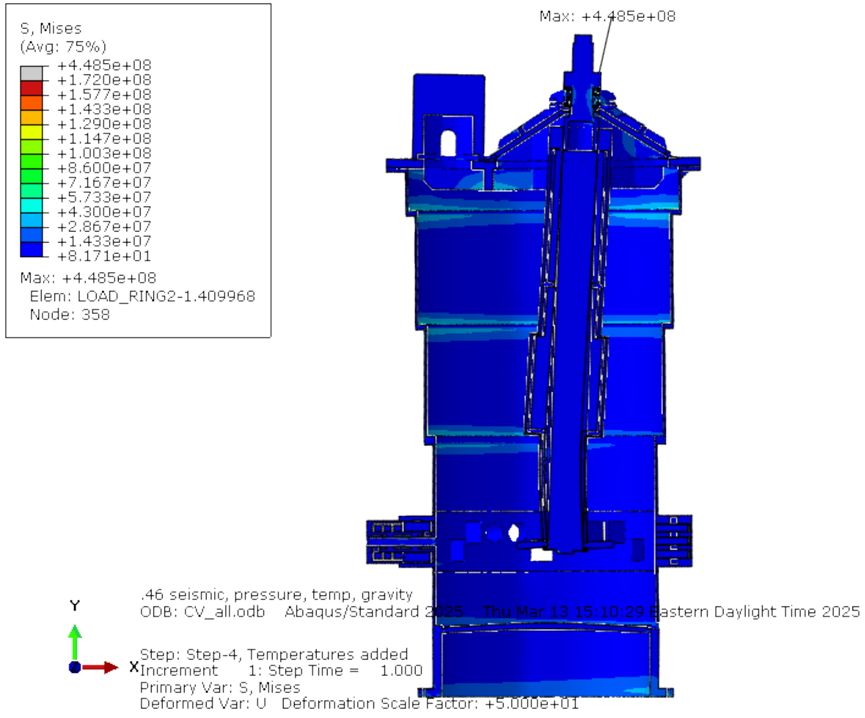


BC Fixed nodes on base

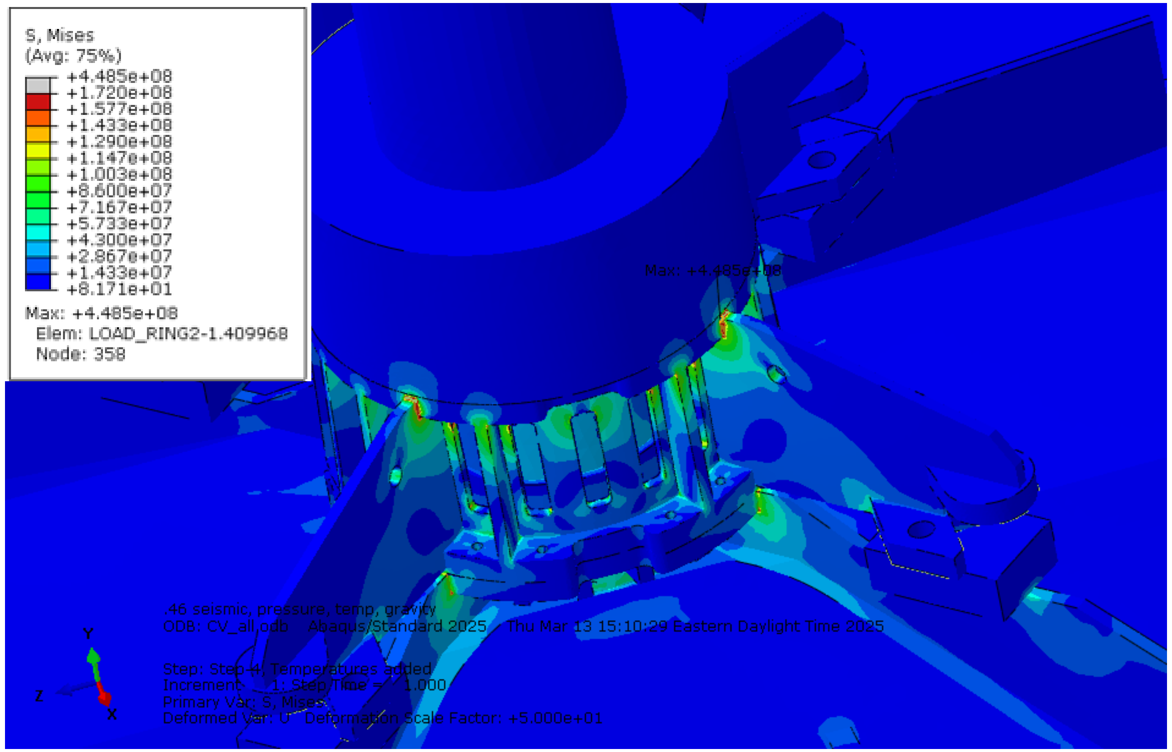


Step 4 Stress Assembly

Stress peak 448 MPa

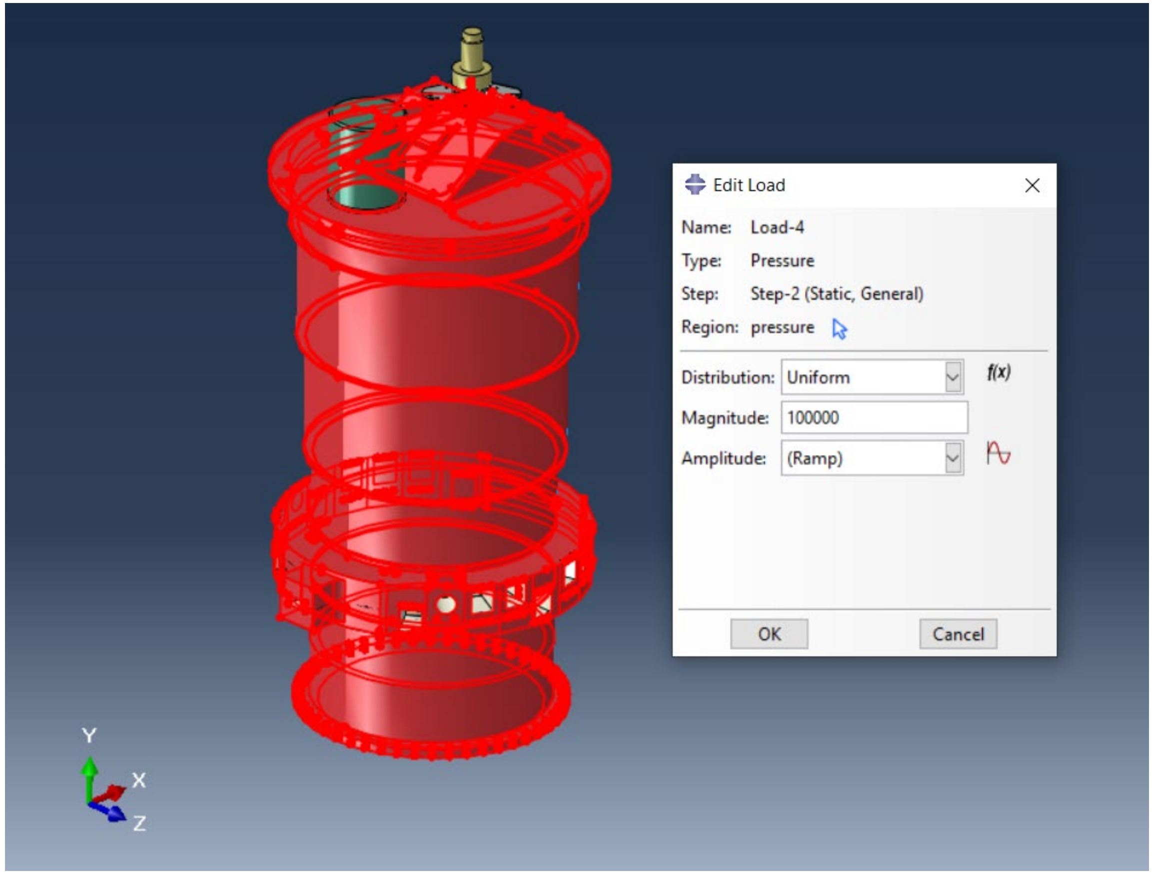


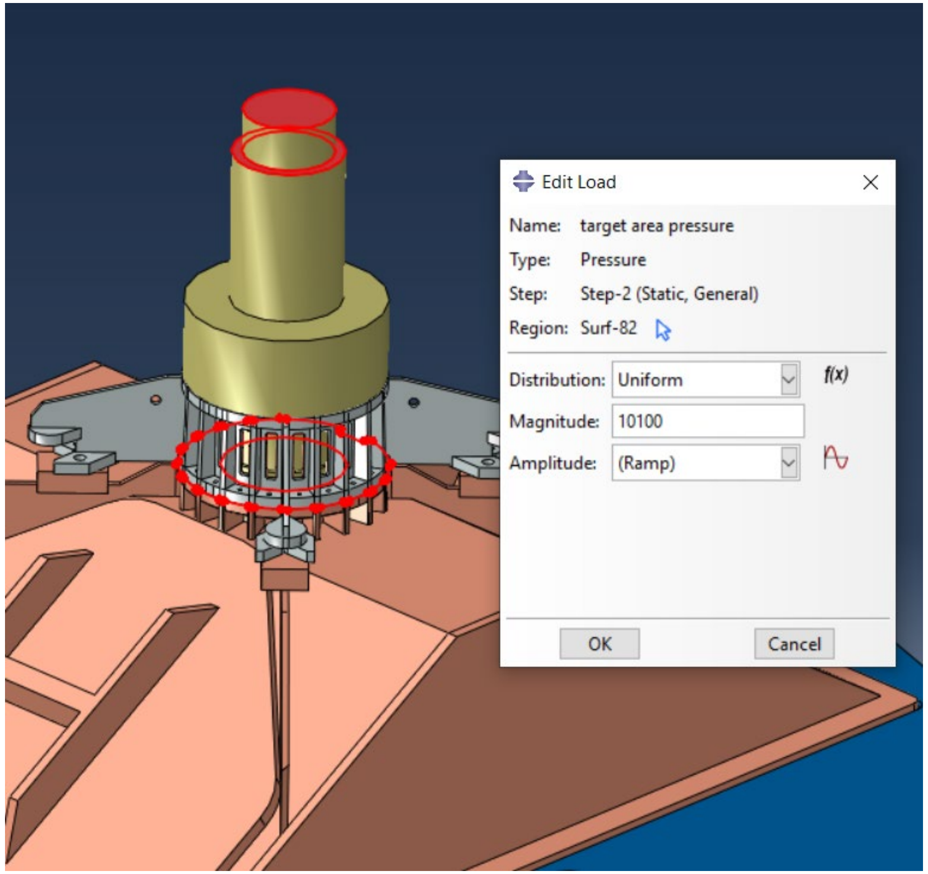
Stress top region – 172 MPa scale max



448 MPa Stress peak is where a load ring leg connects to a ring on the side opposite to the load direction

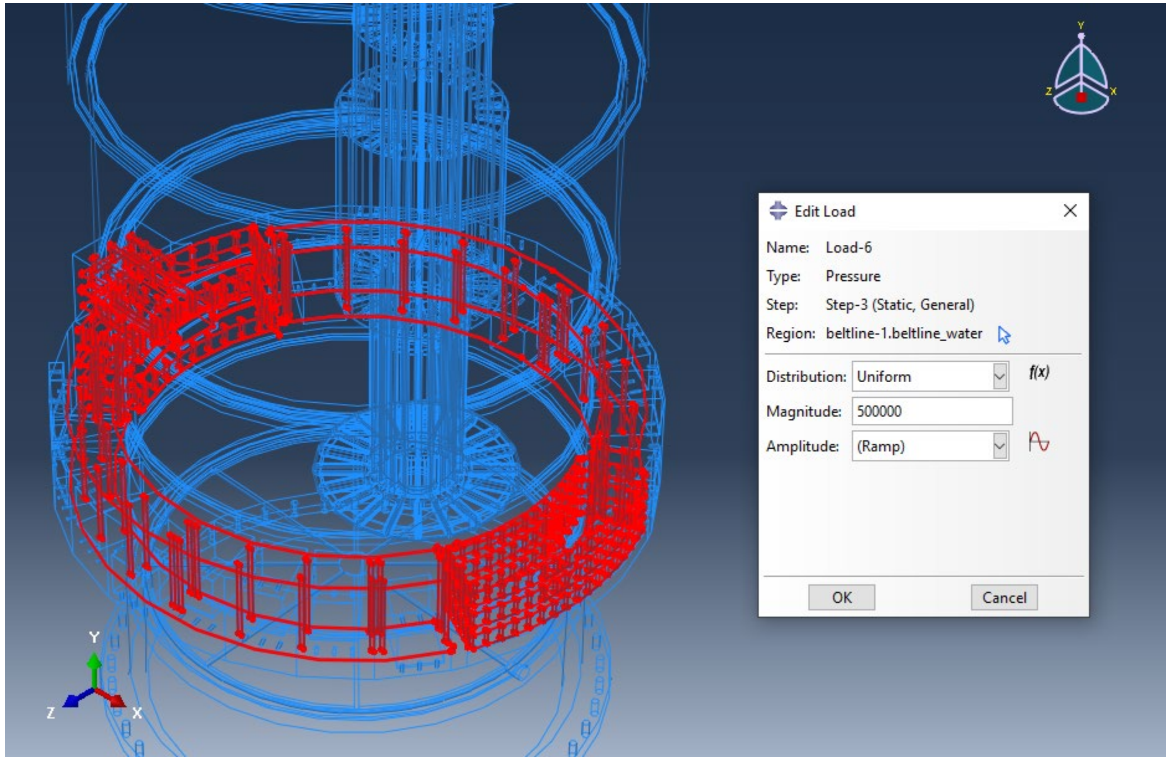
Vacuum pressure loads



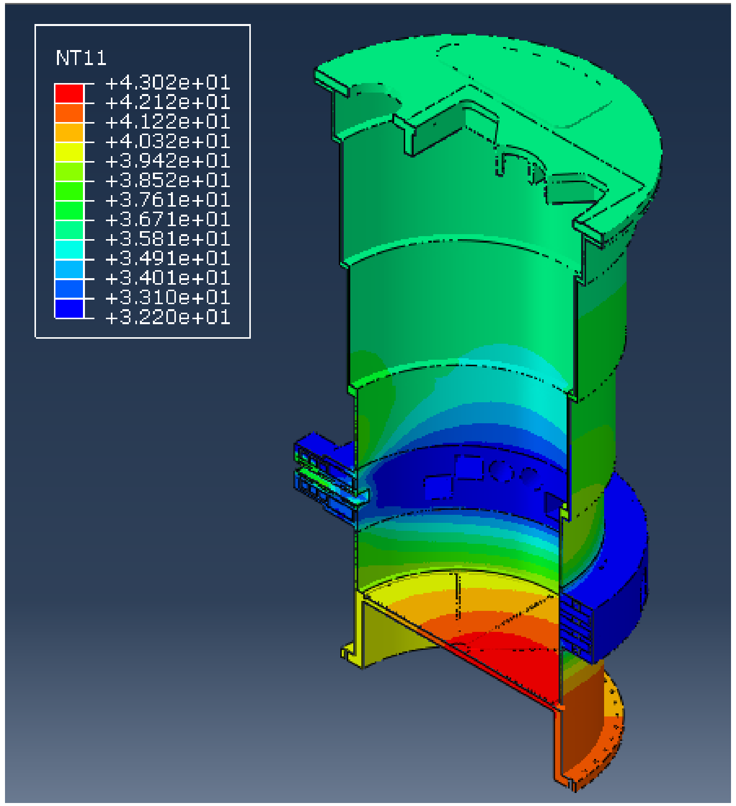


5 Bar water pressure and CFD temperatures added in Steps 3 and 4

Water Pressure



CFD Temperatures applied - all other parts fixed at 36 C



Core Vessel Standard Nozzle Extension Preliminary Analysis

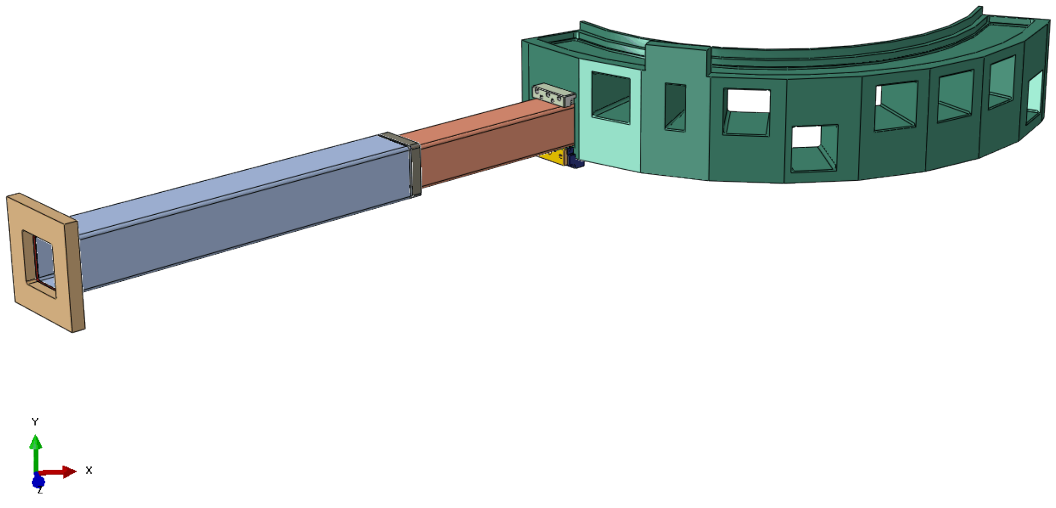
Thomas McManamy

9/19/23

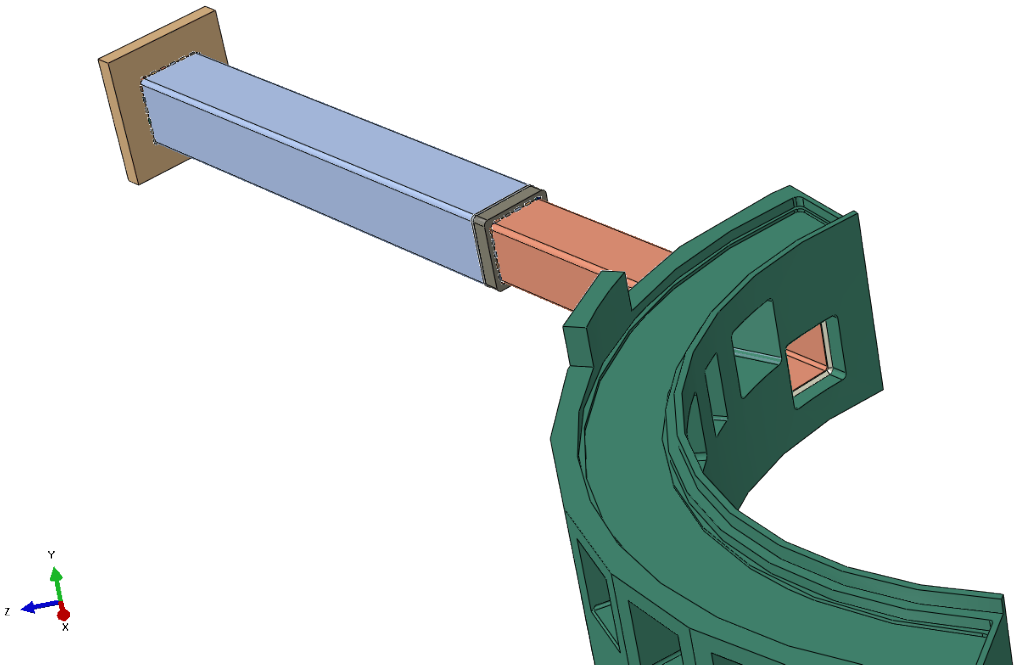
ORNL is managed by UT-Battelle, LLC for the US Department of Energy

Nozzle at lower port and Core Vessel belt line

Parts imported into Abaqus



Parts viewed from CV

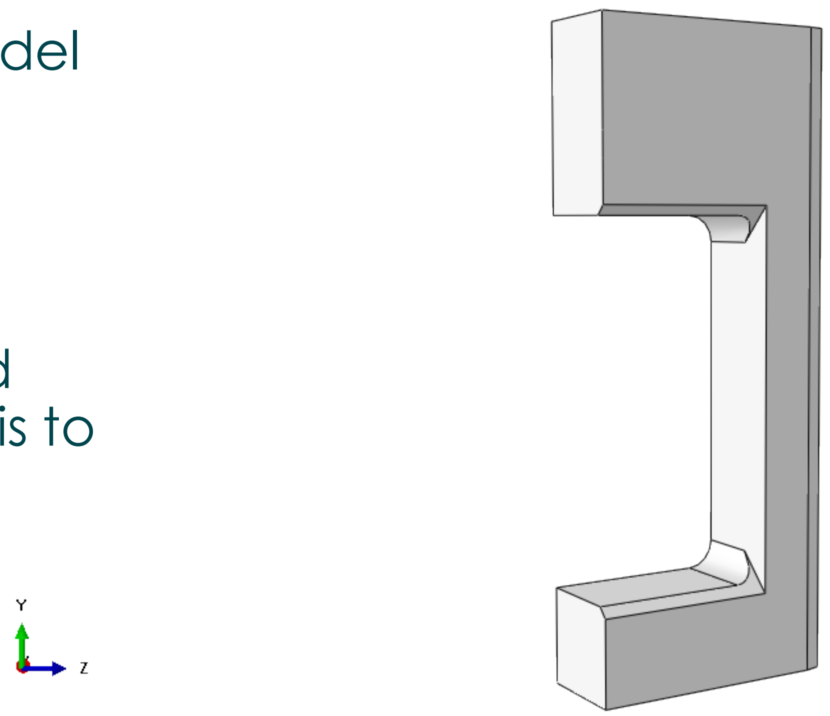


Core vessel model

Core Vessel model

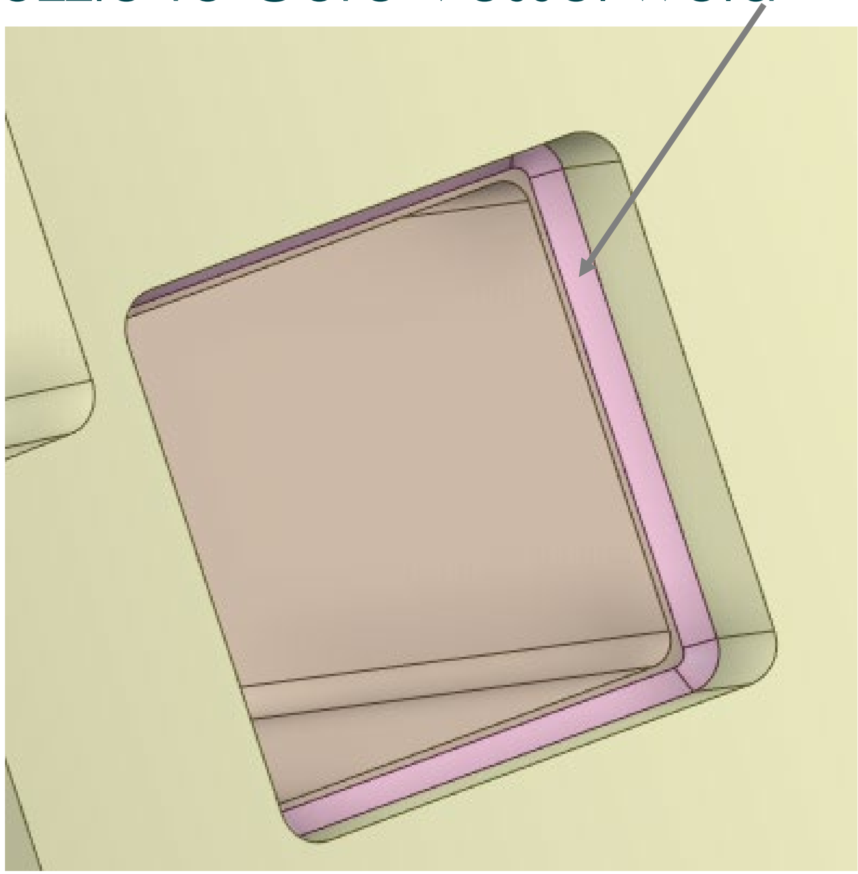
- A simplified core vessel part was constructed from the SpaceClaim model
- Half Symmetry was assumed
- Only the face around one lower port included for the lower nozzle analysis
- An axial depth of 70 mm was included and the rear face was fixed for analysis to simulate a very stiff full assembly

Abaqus Core Vessel part



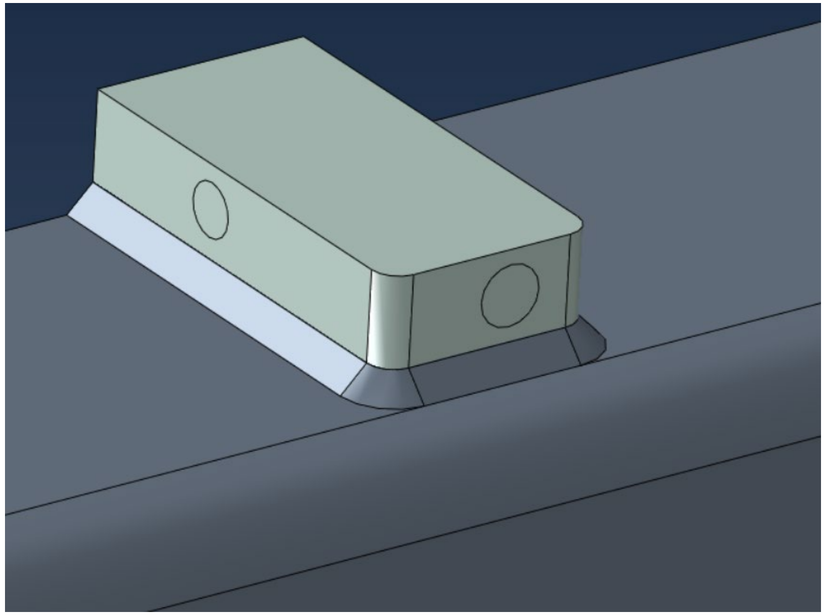
Support blocks and weld to core vessel

Nozzle to Core Vessel weld



SpaceClaim

Upper and lower support blocks are welded to Nozzle plates

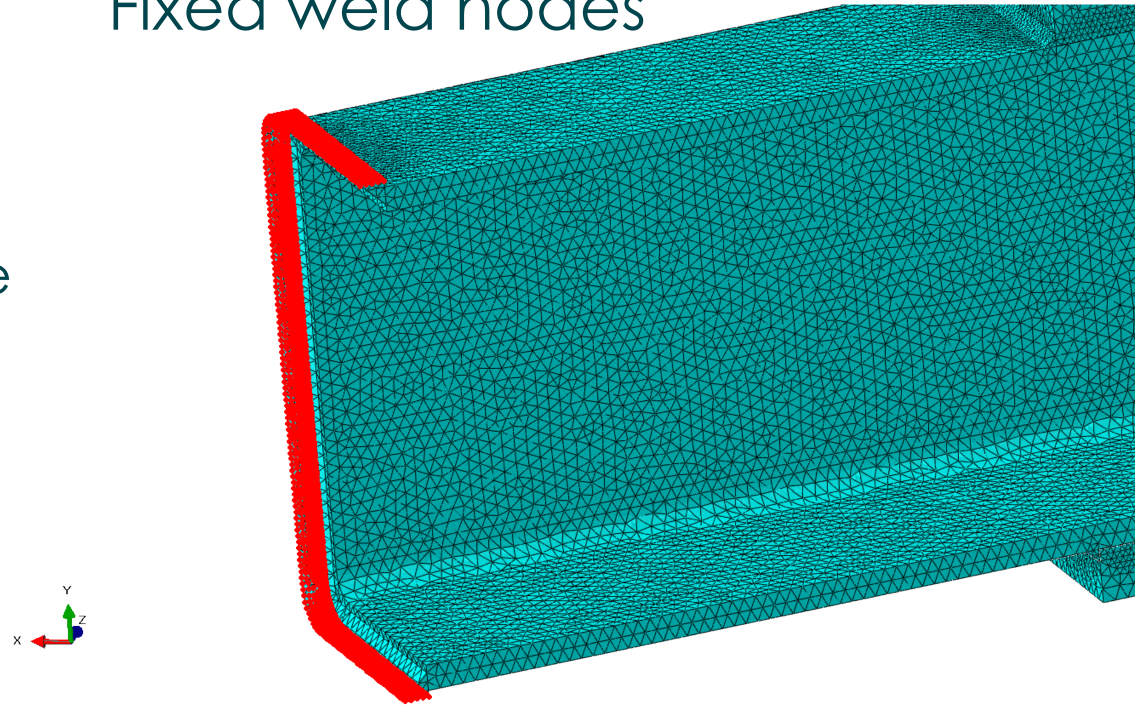


Nozzle to Core Vessel Weld

Nozzle to Core Vessel Weld

- The inner edge of the nozzle was welded to the core vessel
- The stiffness of the core vessel was simulated by fixing the nodes on the core vessel weld surface and the weld was merged with the nozzle plates in Abaqus

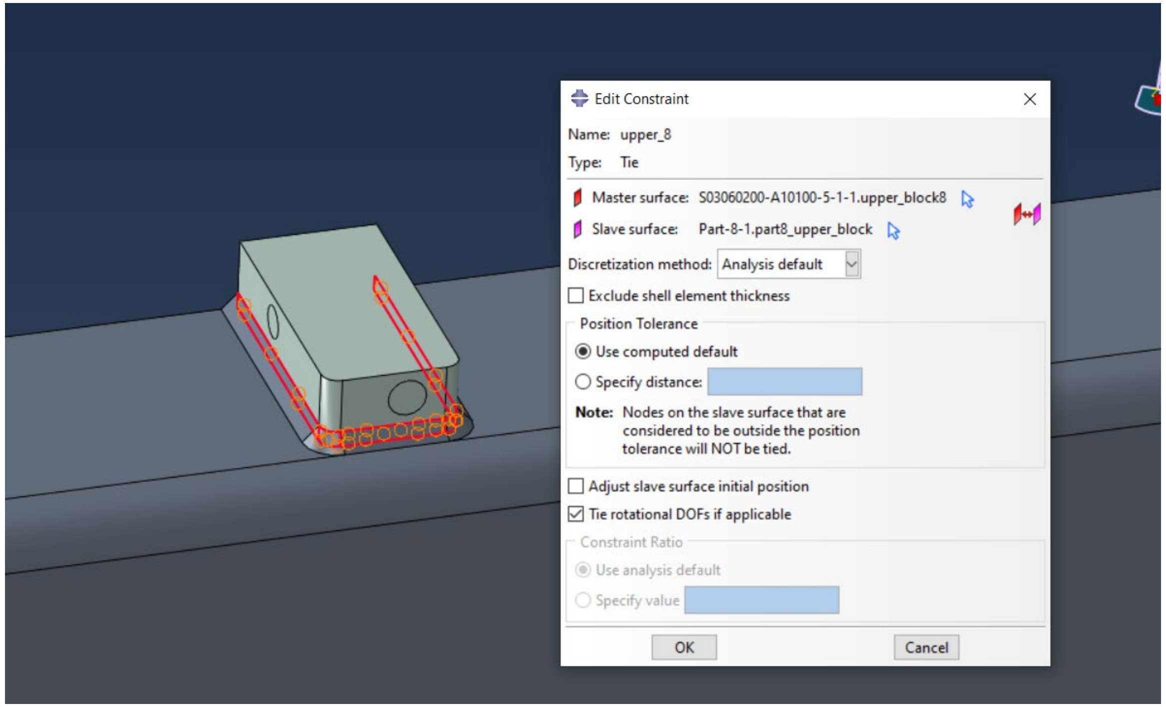
Fixed weld nodes



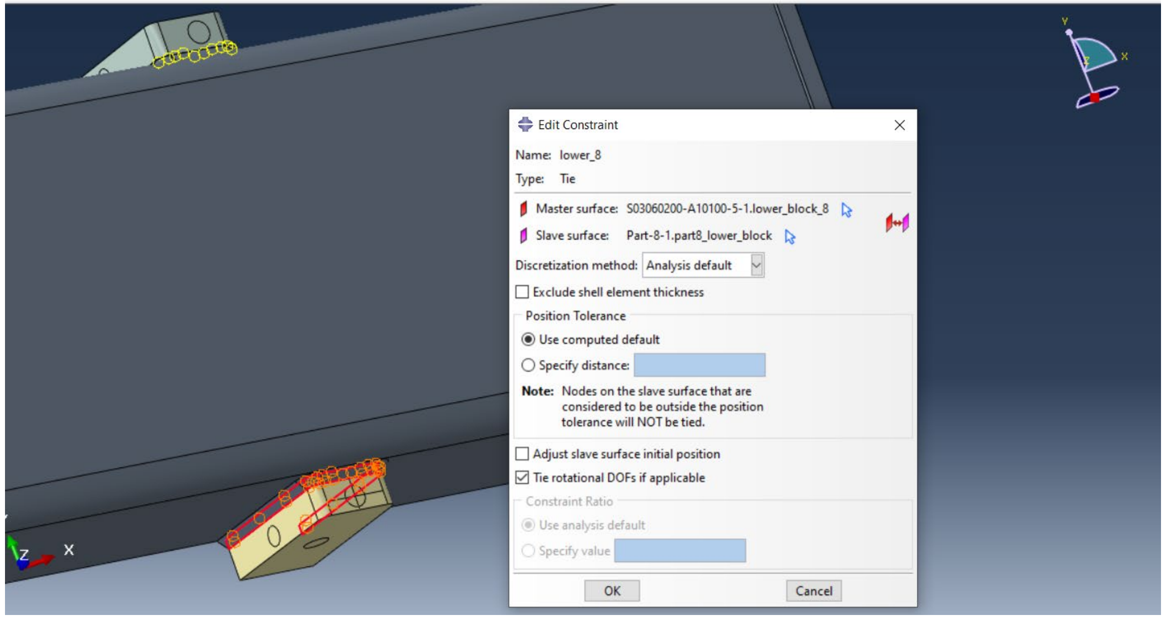
OAK RIDGE National Laboratory | HIGH FLUX ISOTOPE REACTOR | SPALLATION NEUTRON SOURCE

Block to nozzle welds

Weld tie for upper block



Weld tie for lower block



Lower block weld ties are similar

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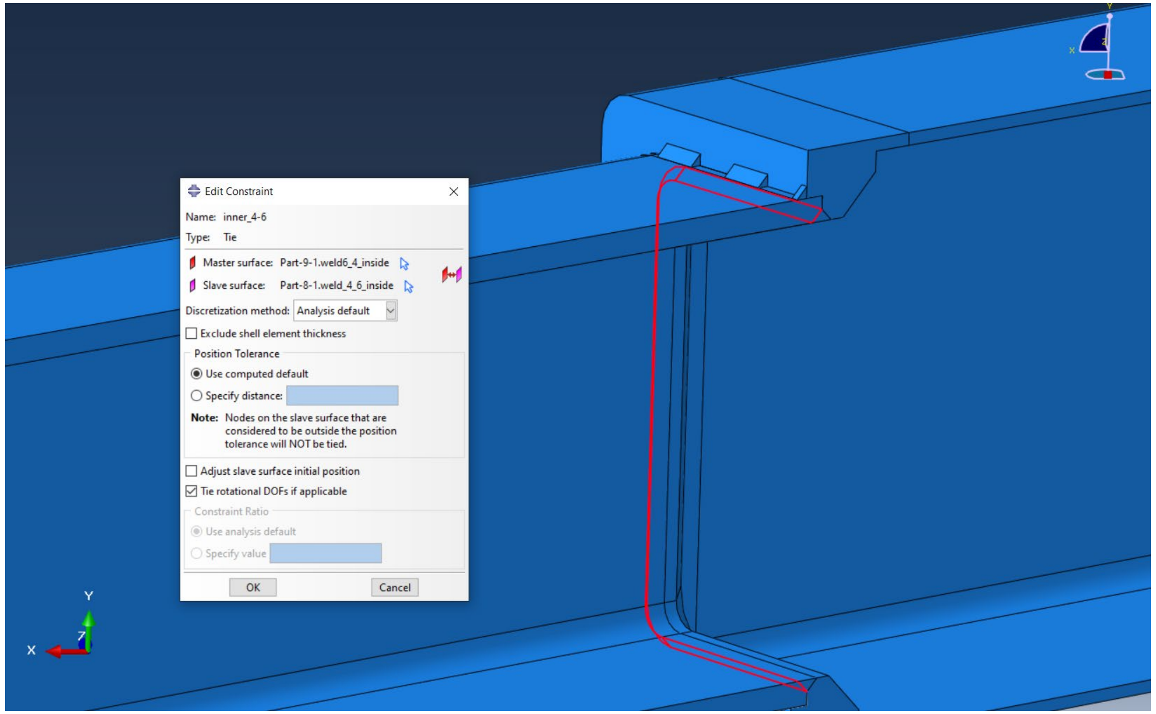
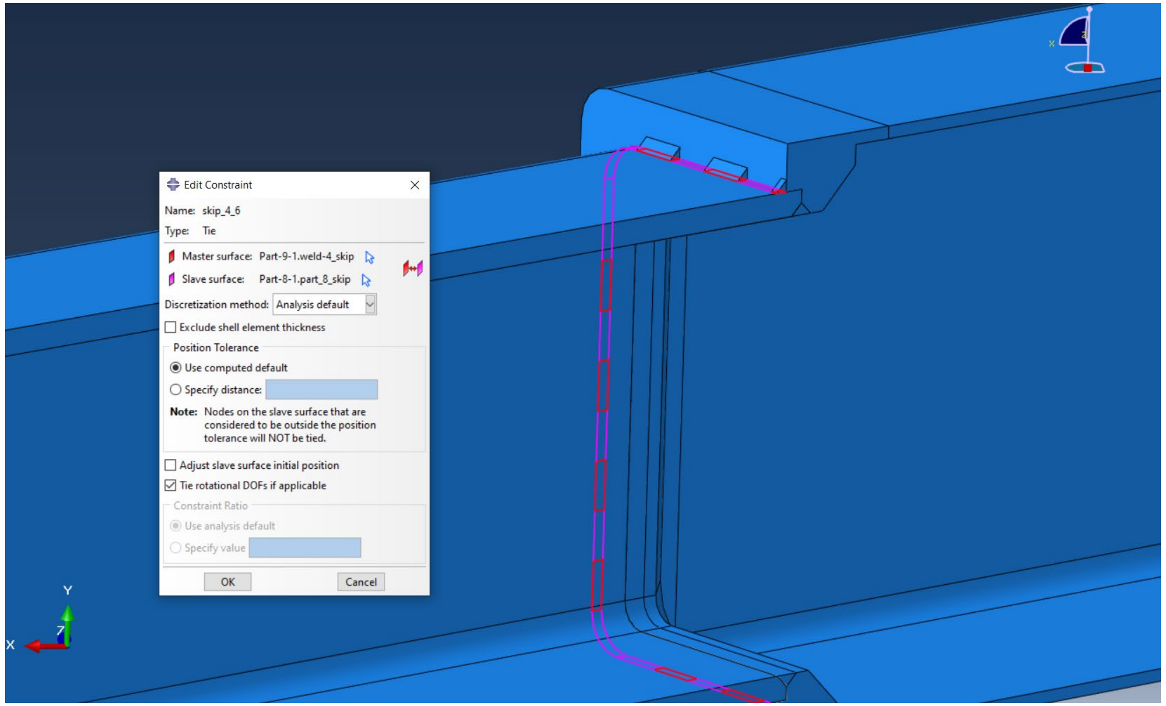
Joint between inner nozzle part and outer nozzle part

Inner to outer nozzle part tie by inner weld surface

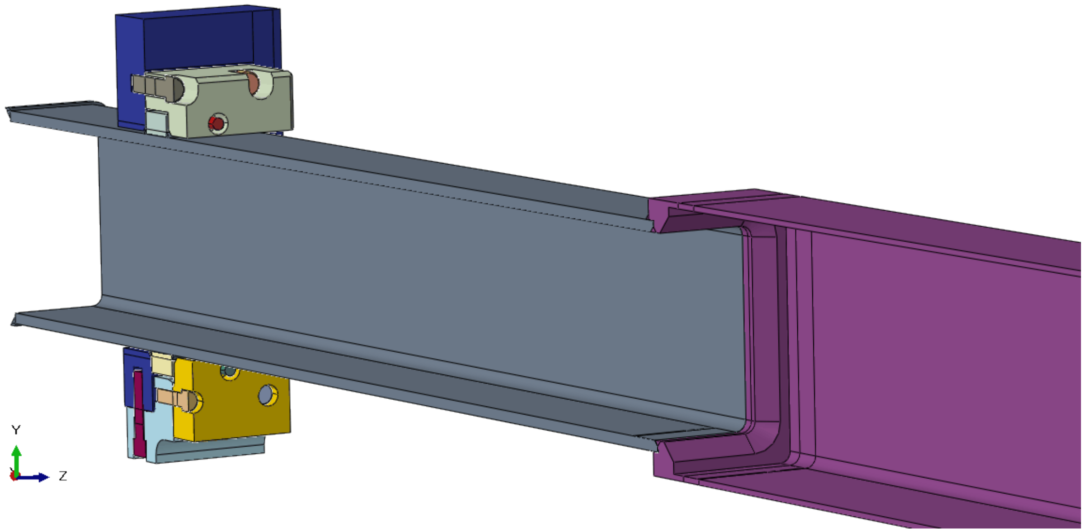


Skip welds merged with outer nozzle part and tied to inner nozzle part

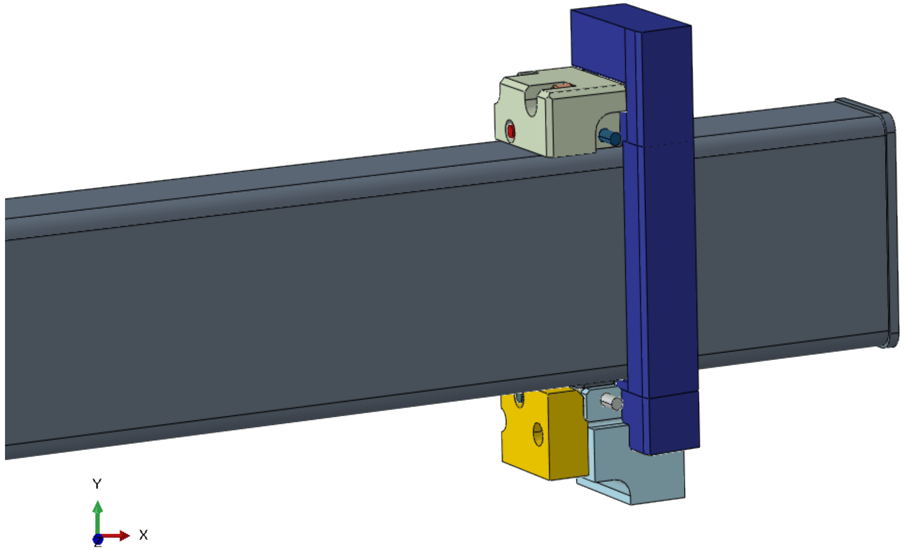


Lower Assembly

Half Symmetry model showing brackets, bolts and studs with a section of the Core Vessel in blue

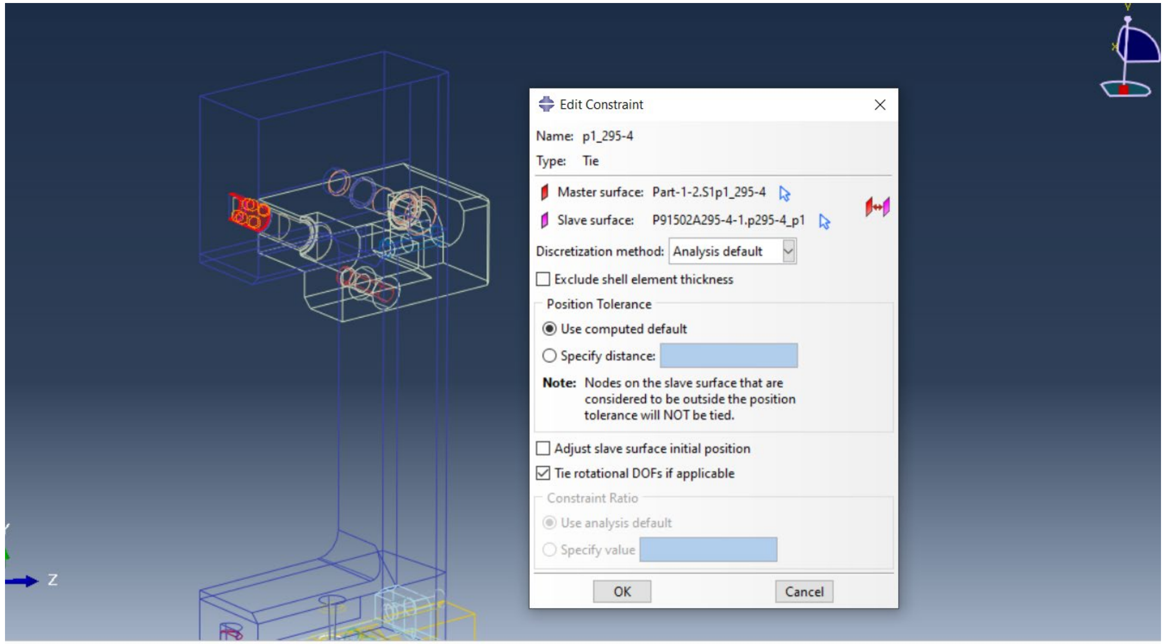


Side View of assembly

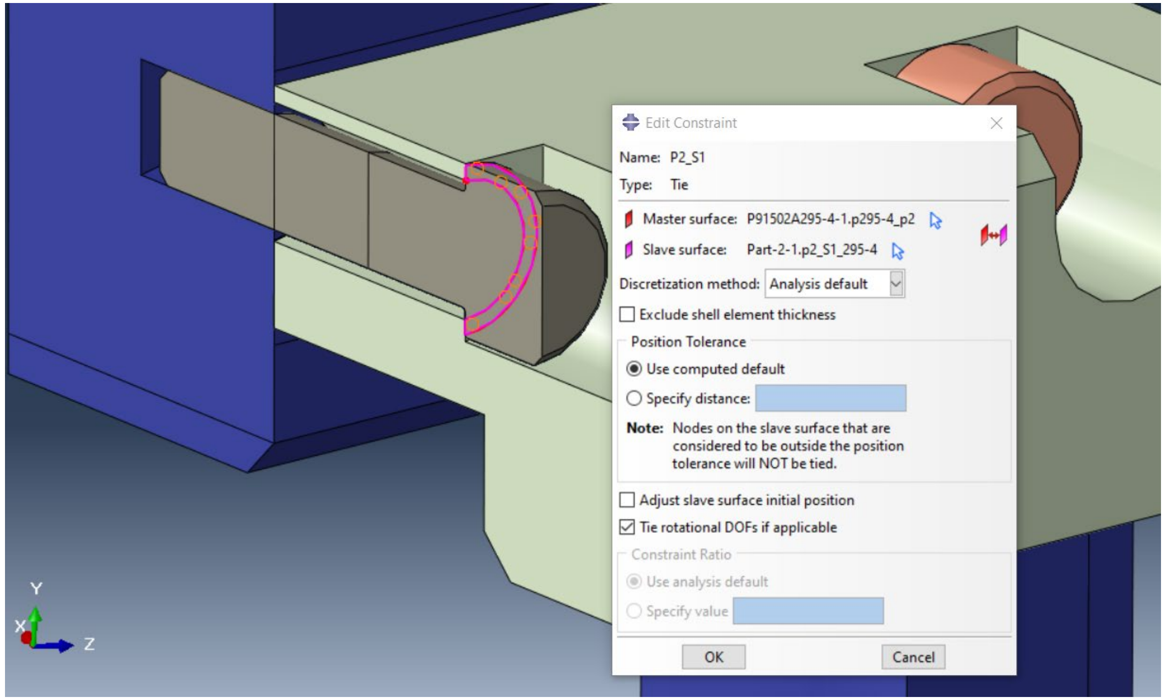


Typical bolt constraints

Typical bolt constraint with tie on mating surfaces within vessel to simulate threaded connection



Typical constraint between bolt head and bearing surface



Tie constraints typical for the 4 20mm Diameter bolts into the core vessel

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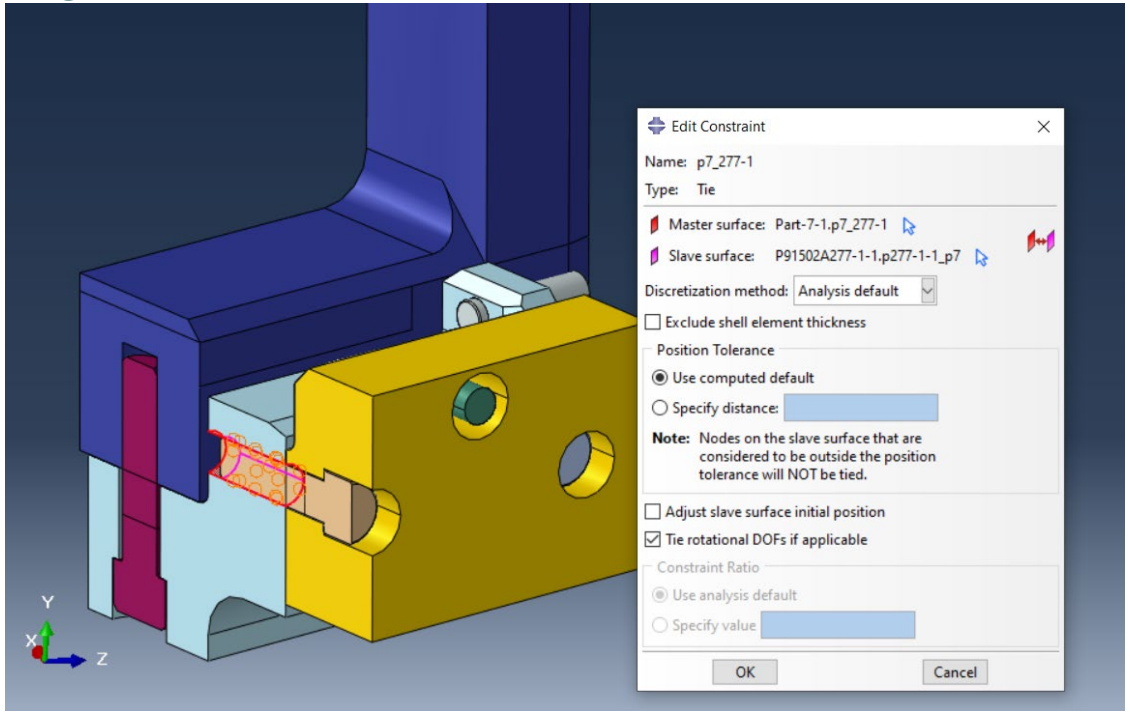
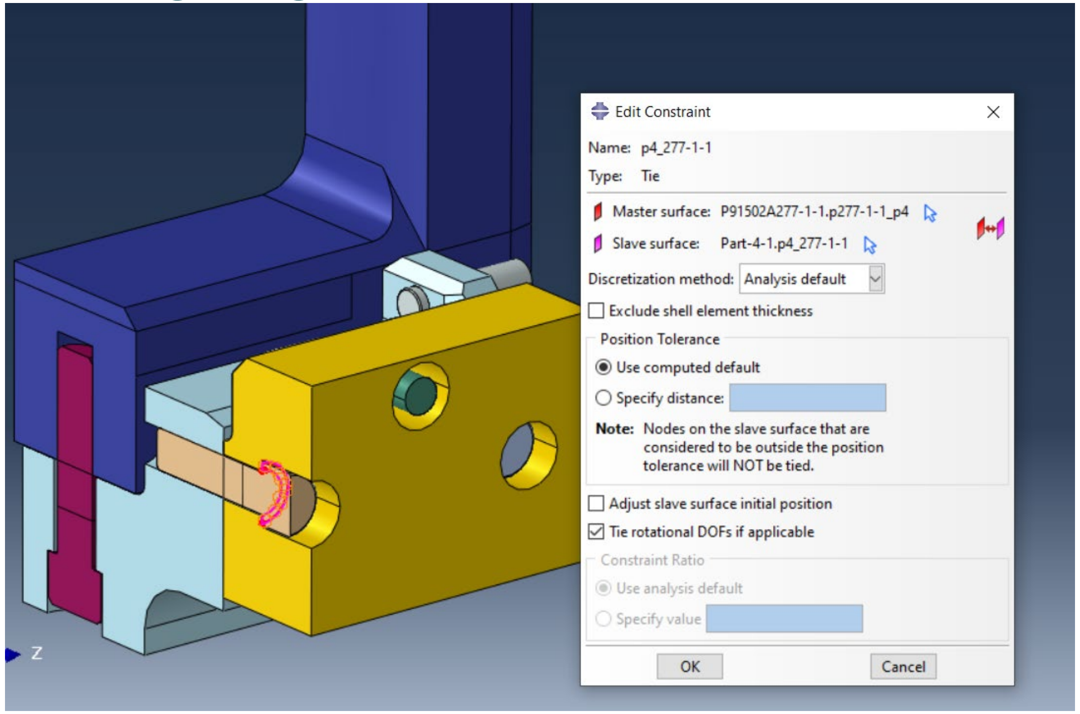
16 mm Diameter bolt constraints

16 mm Diameter bolt threaded region tie



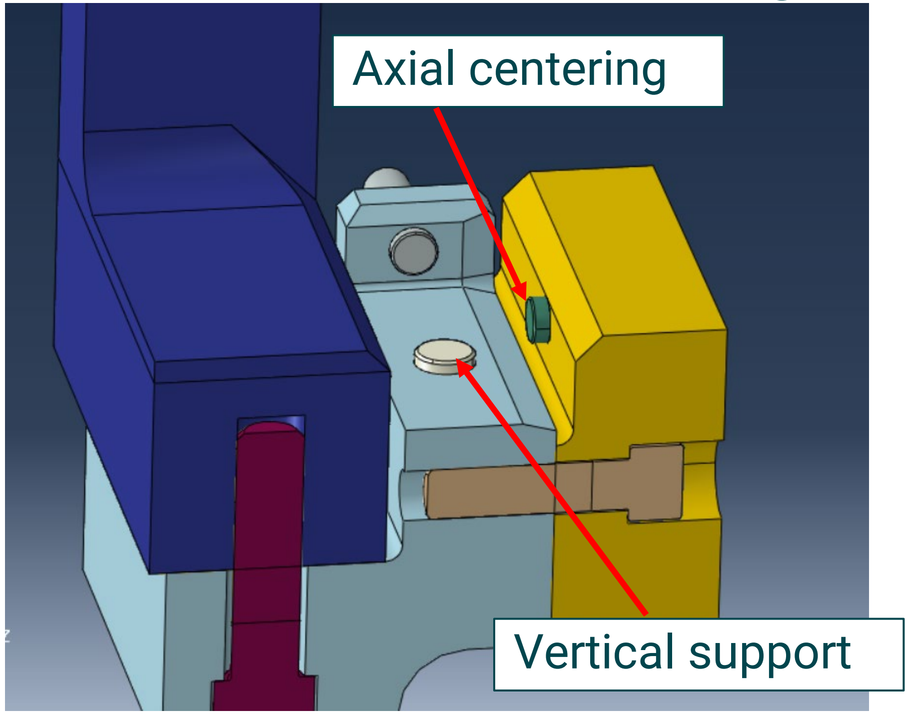
Bearing region tie for 16mm bolt



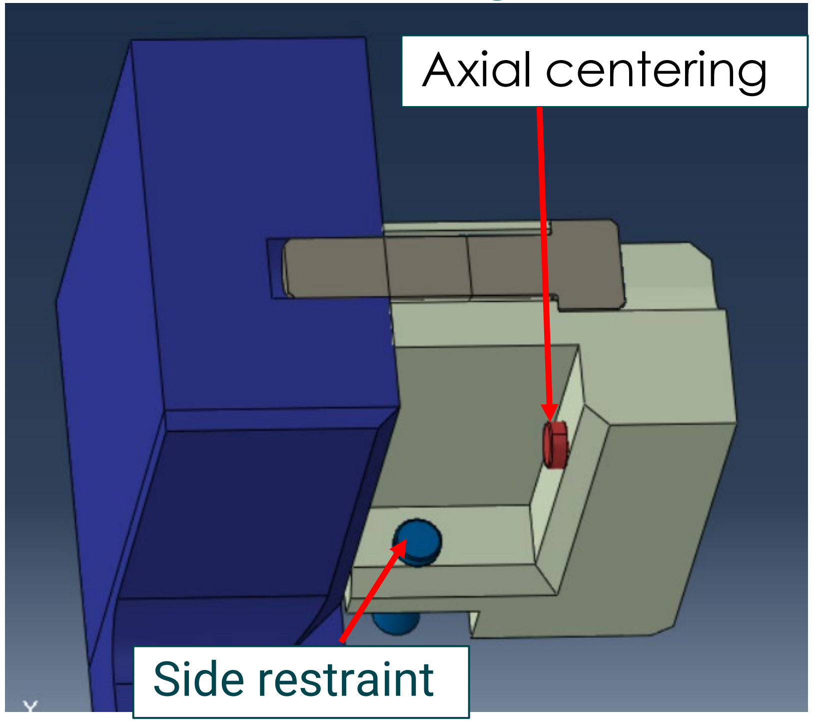
Typical for both 16 mm bolts

Restraint and centering pins

Lower support block centering pins

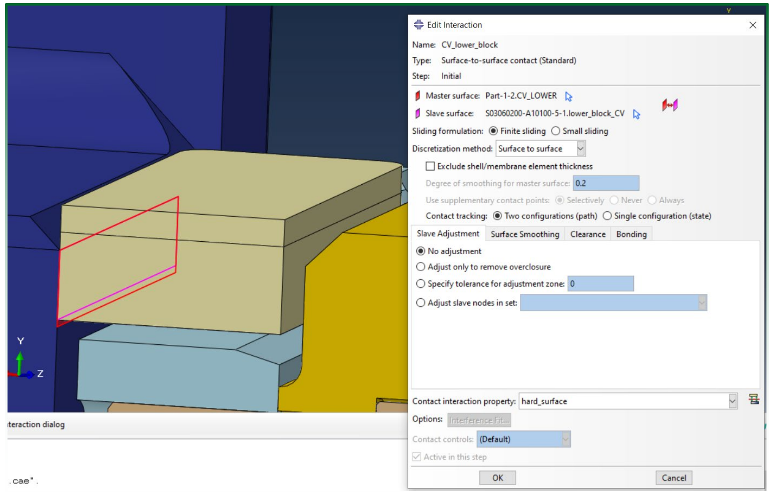


Upper Block centering pins

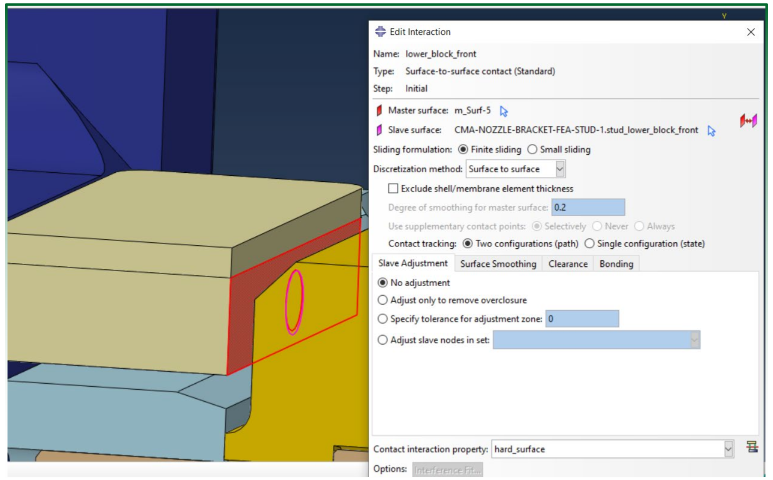


Lower support block restraints

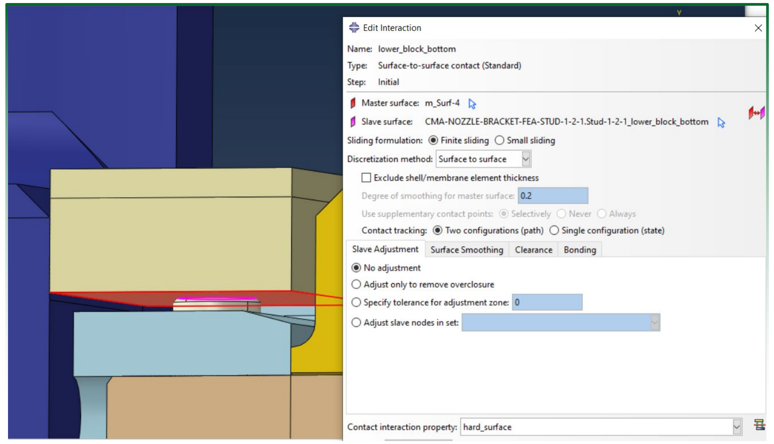
Contact between lower support block and core vessel (no friction)



Contact between lower support block and axial centering pin



Contact between lower support block and vertical support pin



Upper block restraints are similar except without vertical pin

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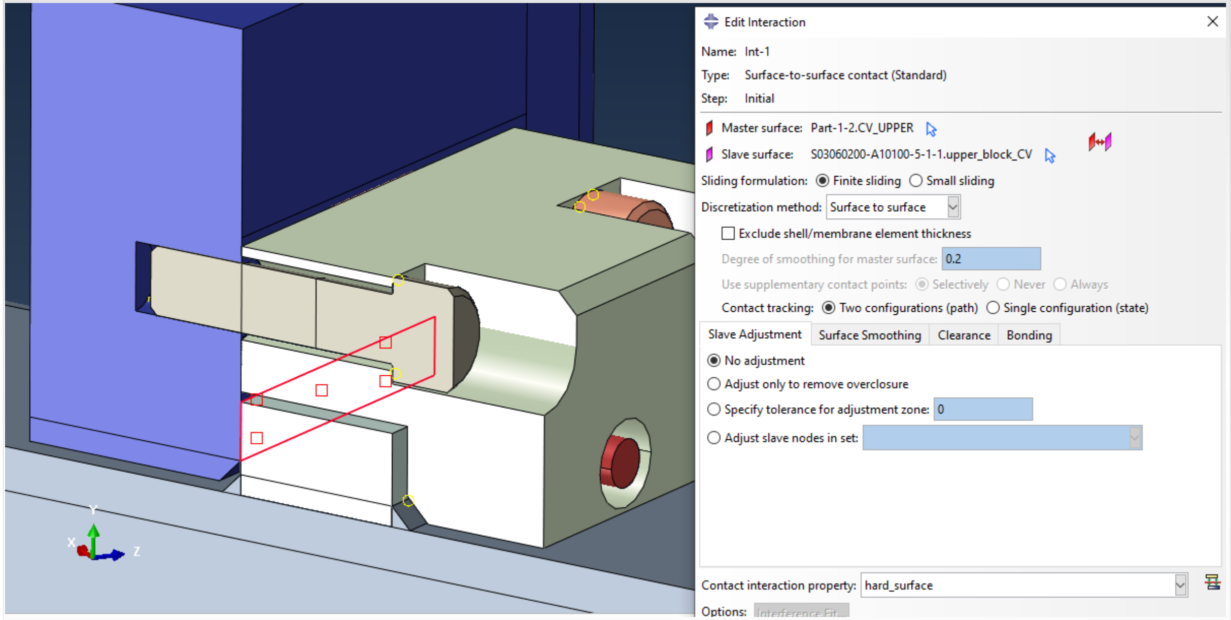
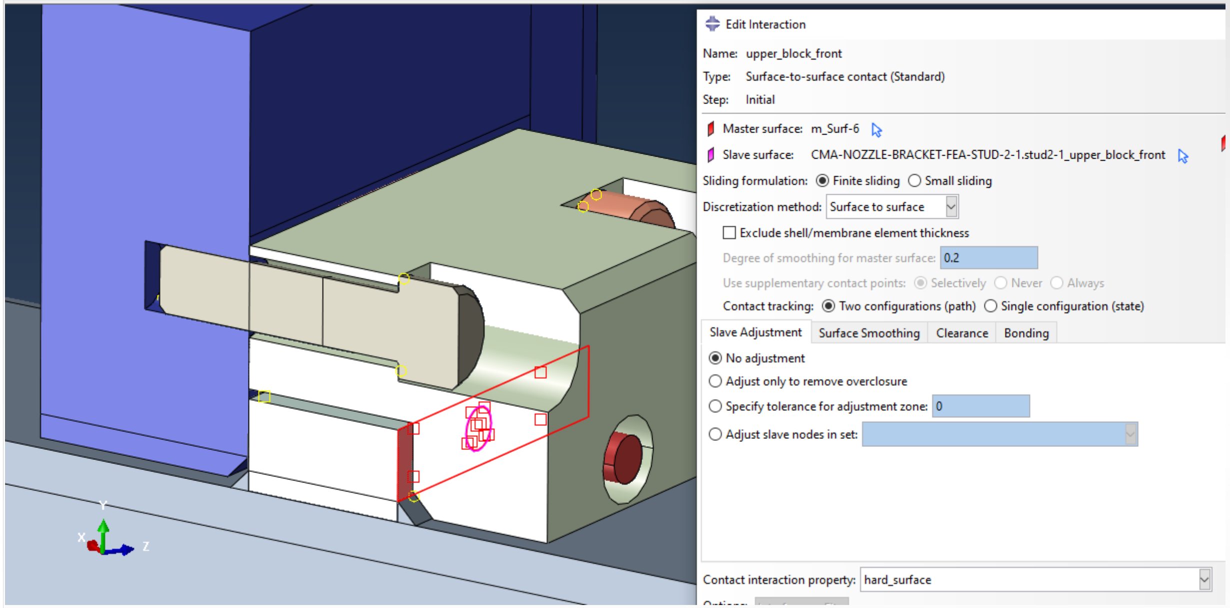
Upper Support block restraints

Contact upper block to core vessel



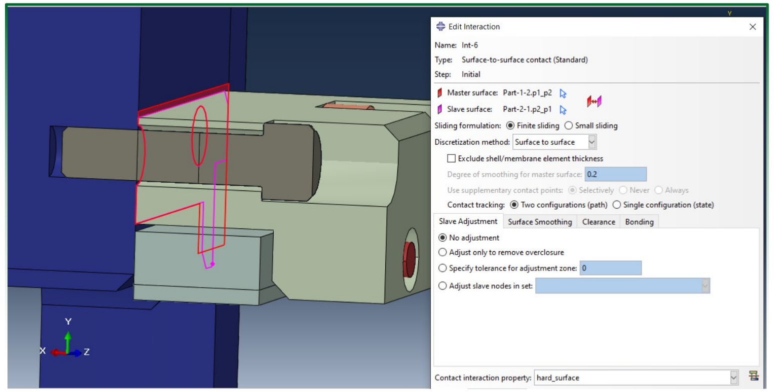
Upper block with front pin



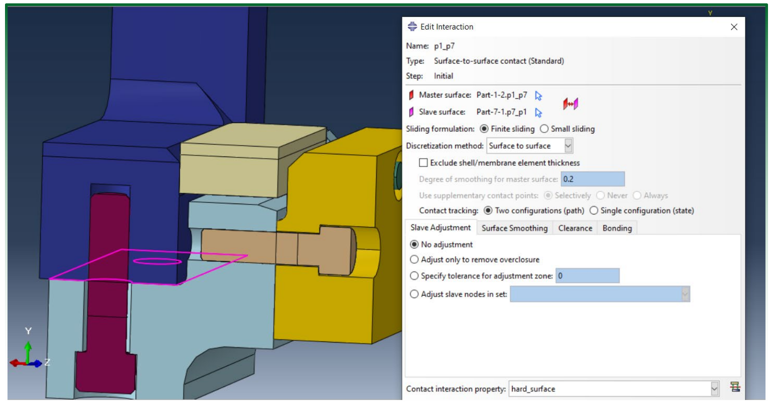
Side support pin not included because symmetry assumption keeps assembly centered

Surface to Surface part contacts

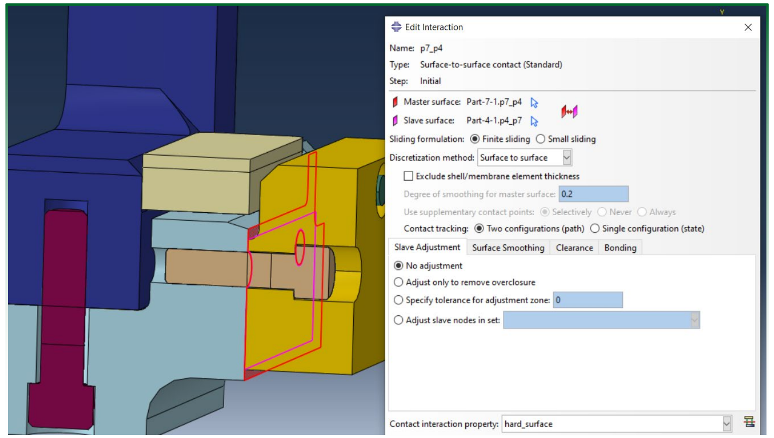
Contact Core vessel to upper bracket



Contact core vessel to lower bracket



Contact lower bracket to outer lower bracket

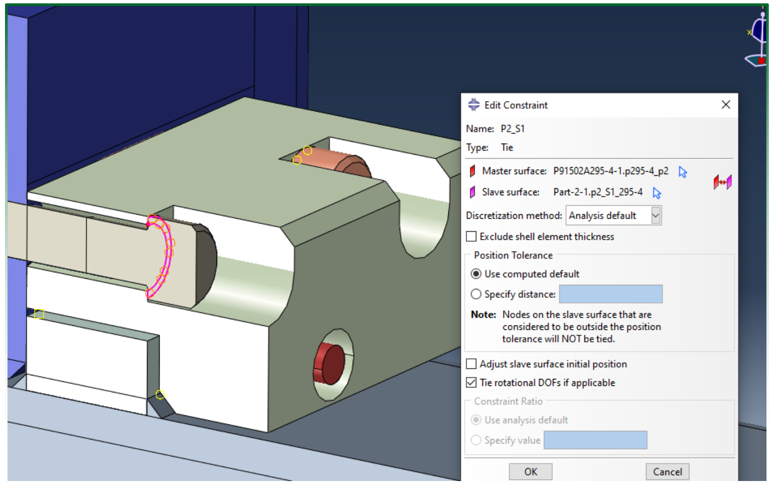


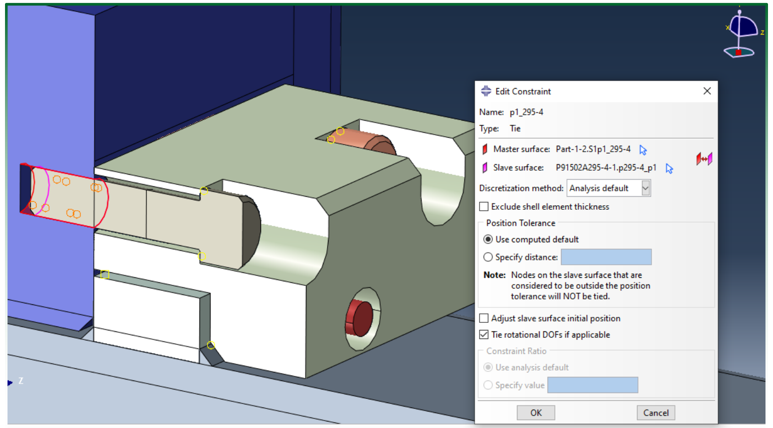
Tie Constraints

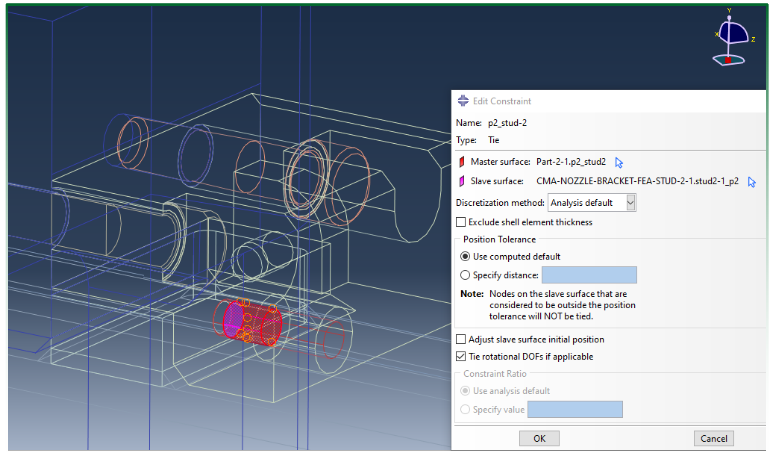
Typical tie between 20 mm bolt head and bearing surface on bracket part

Typical tie between simulated bolt thread area to core vessel

Typical tie for upper block centering pin to bracket part in threaded region

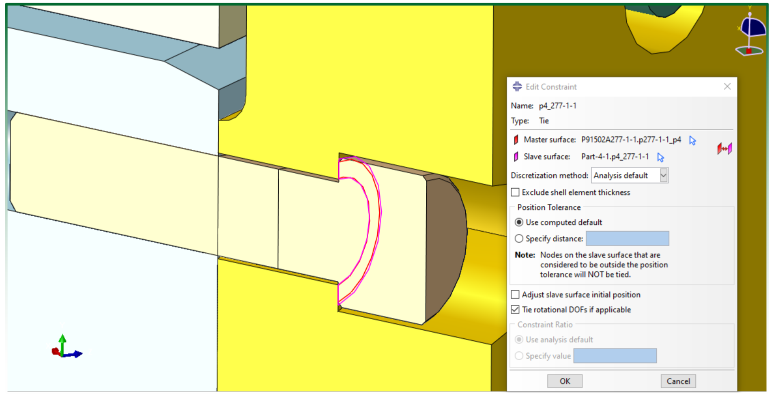




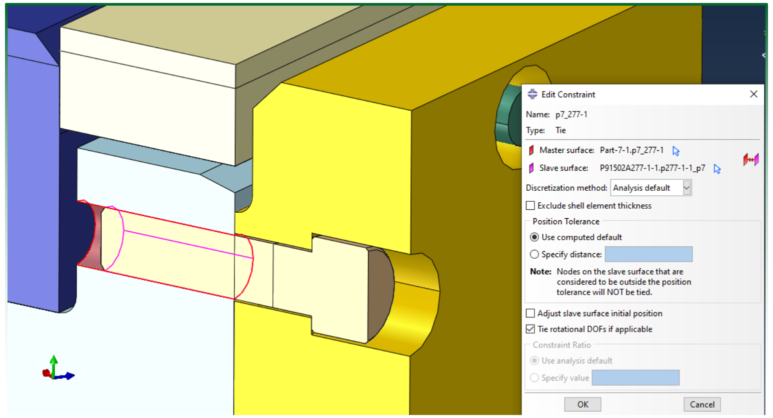


Tie Constraints on bolts and pins

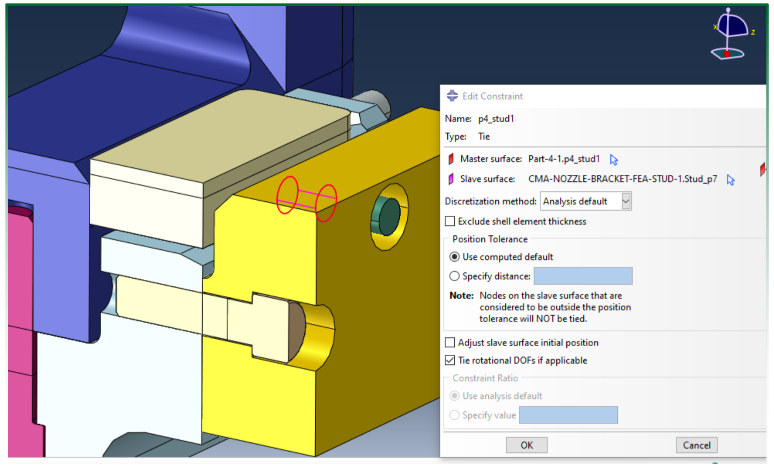
Typical 16 mm bolt head tie to bracket part



16 mm bolt tie in threaded region to bracket part

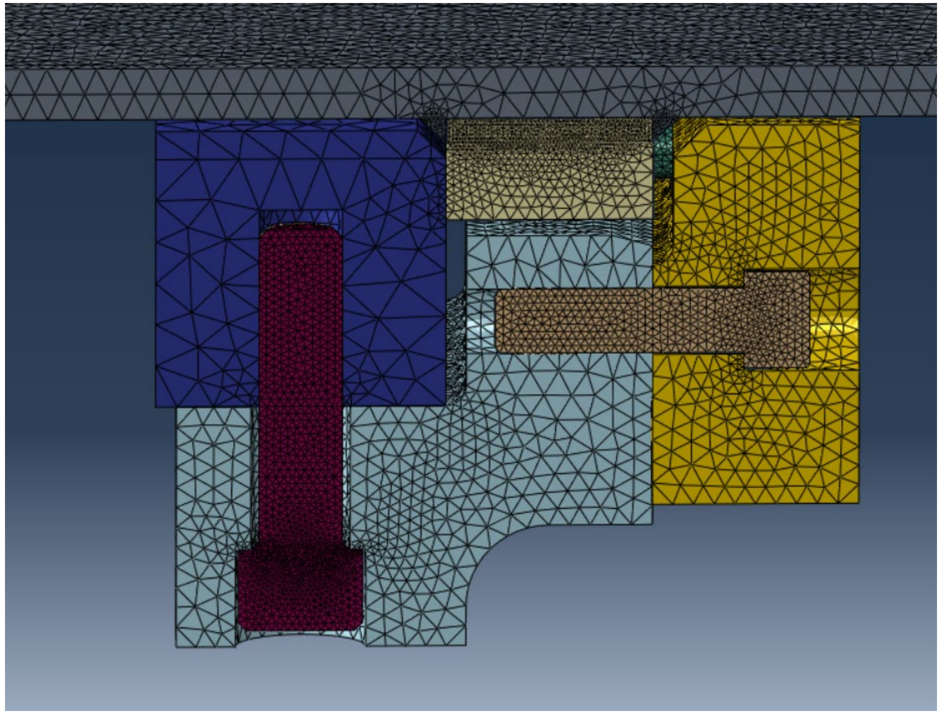


Tie lower block front pin to bracket in threaded area

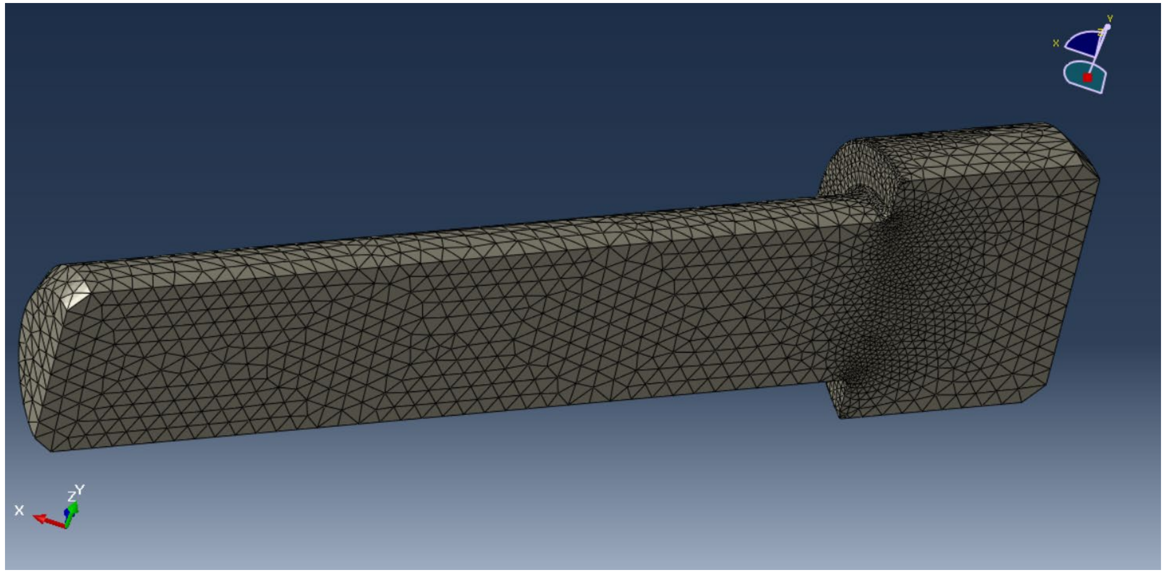


Tet Mesh around lower support bracket and typical bolt

Typical bracket and both tet mesh



20 mm Bolt mesh



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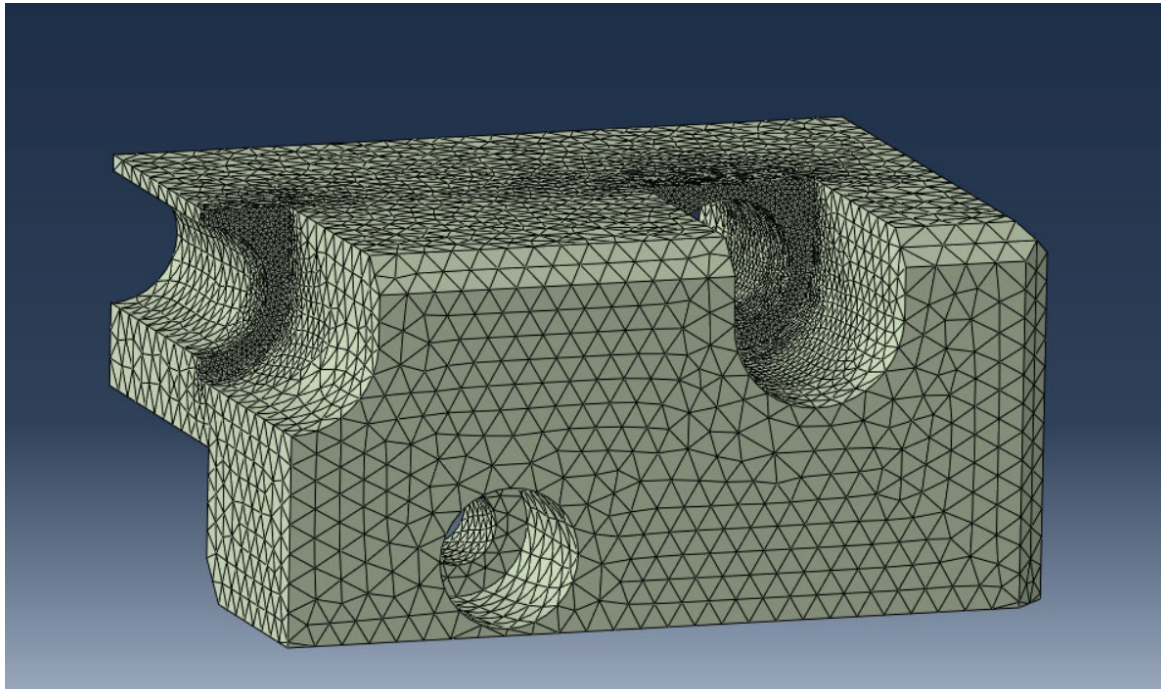
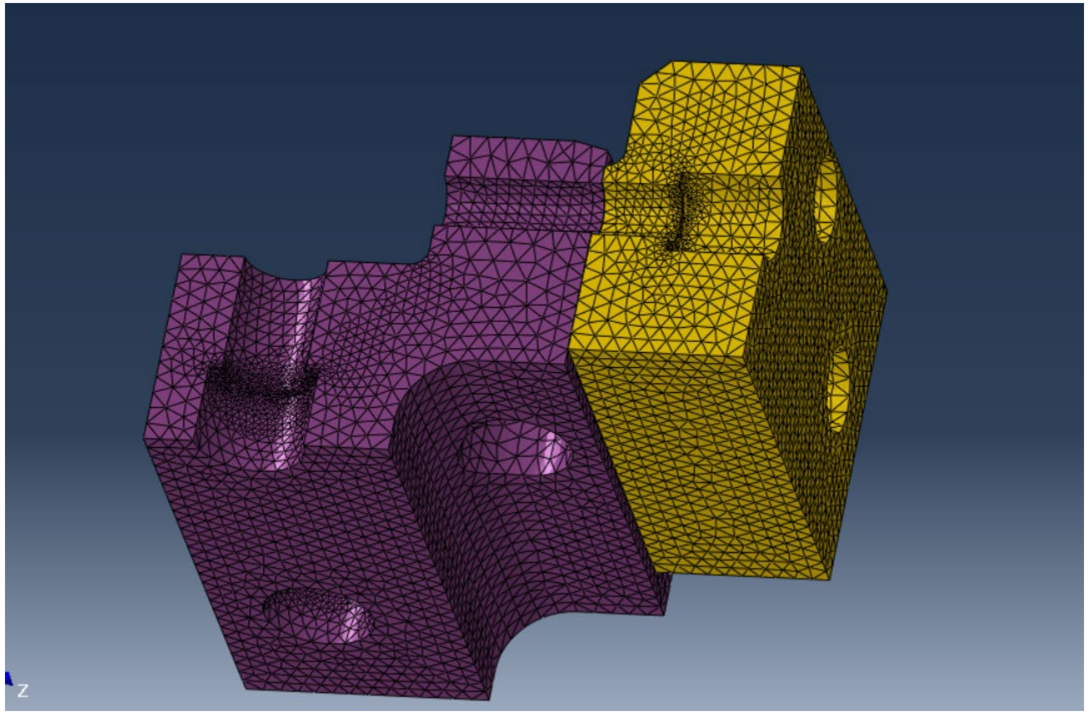
Tet Mesh for bracket parts

Upper Bracket mesh

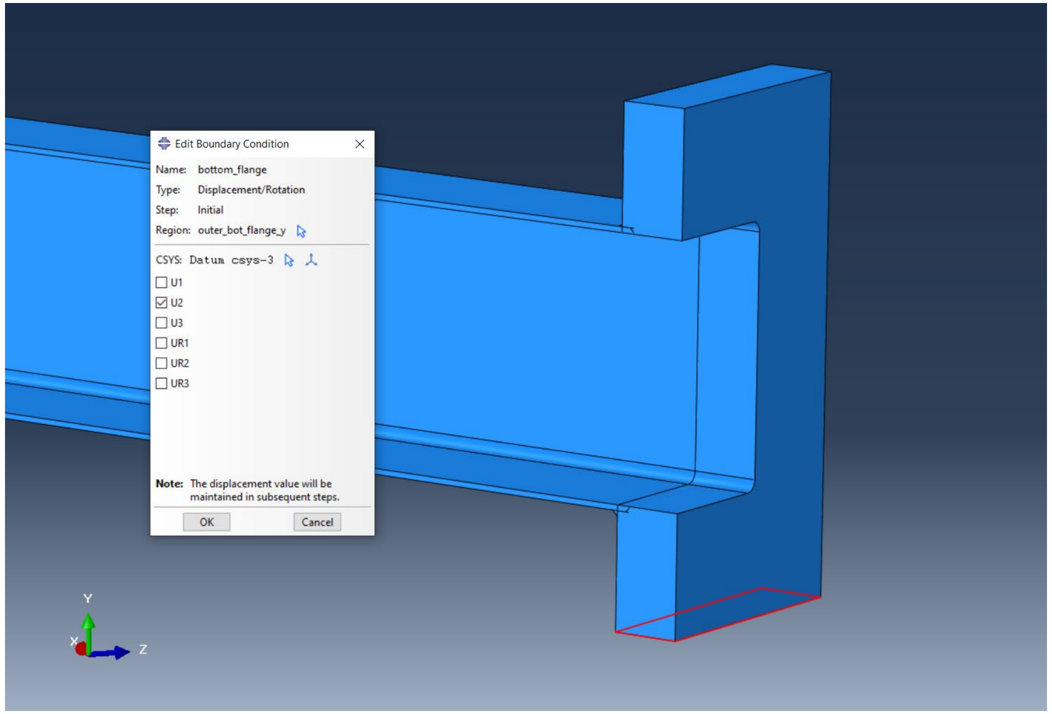


Lower Bracket part mesh

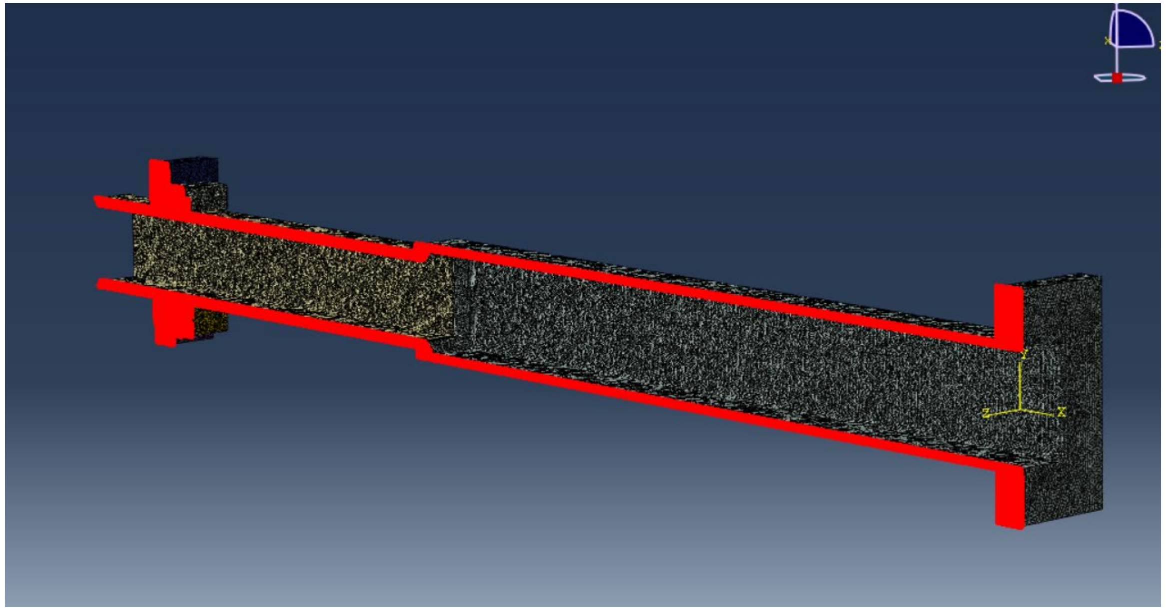


Boundary Conditions

Boundary Condition on outer flange – only vertical restraint on bottom surface



Z symmetry constraint in local coordinate system



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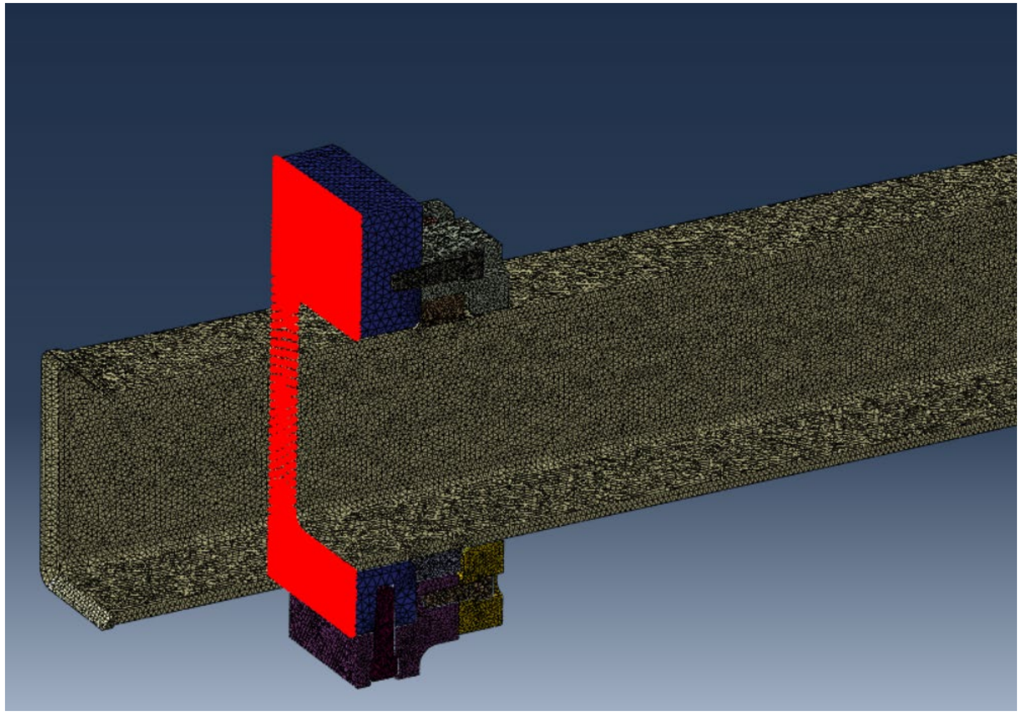
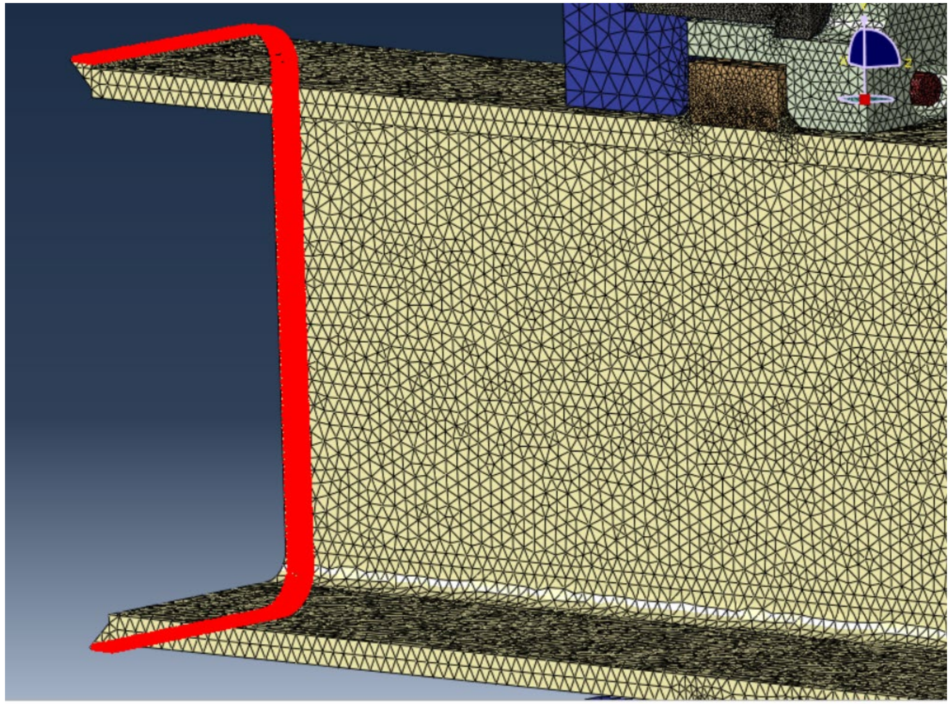
Boundary Conditions

Boundary condition fixed nodes on core vessel rear section



Boundary condition fixed nodes on weld to core vessel



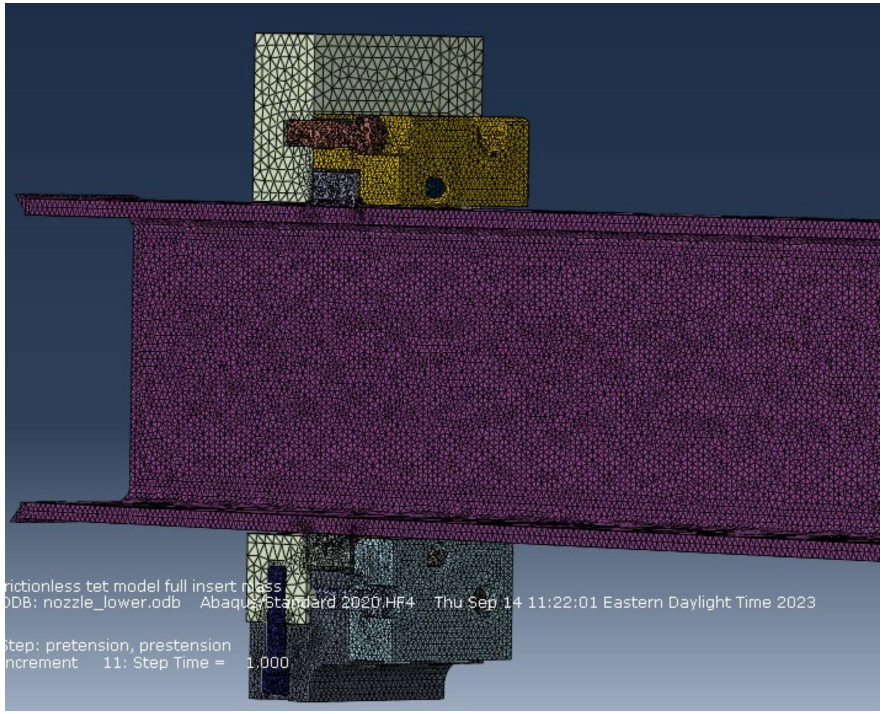
- The stiffness of the core vessel was simulated by fixing the nodes on the core vessel weld surface and the weld was merged with the nozzle plates in Abaqus

Lower Nozzle Assembly Model Statistics

Model Summary

- Tet mesh used for all parts
- Mesh refined around welds and bolt bearing areas
- Total 2,770,170 elements
- 8 surface to surface hard frictionless interactions
- 22 tie constraints

Tet Mesh Model



Oak Ridge National Laboratory

CV QIKR NOZZLE Extension 925 Preliminary Analysis

Thomas McManamy

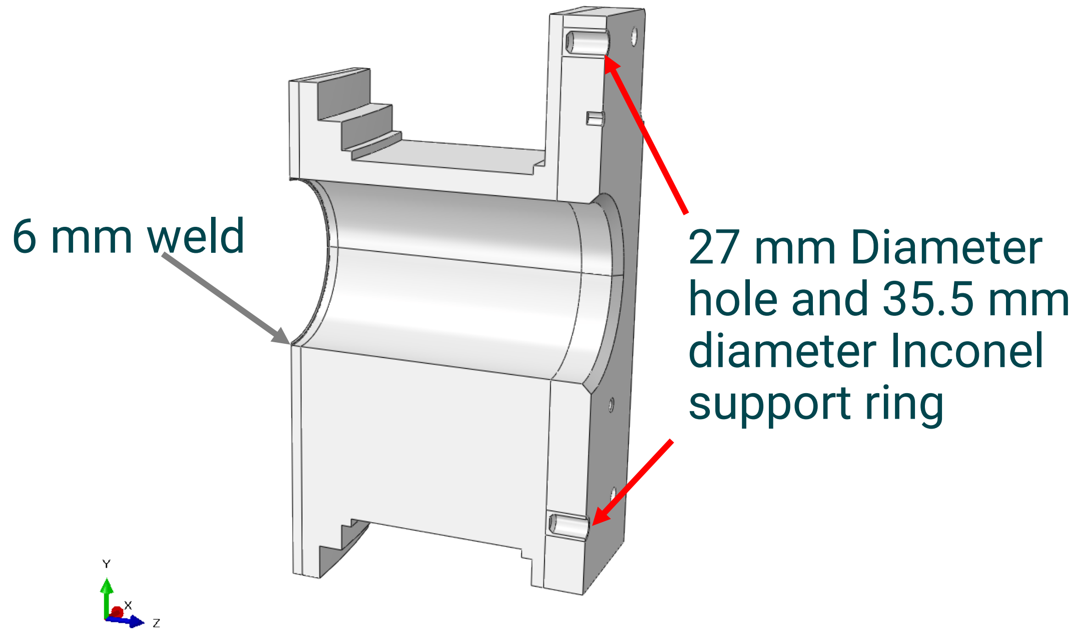
10/2/24

ORNL is managed by UT-Battelle, LLC for the US Department of Energy

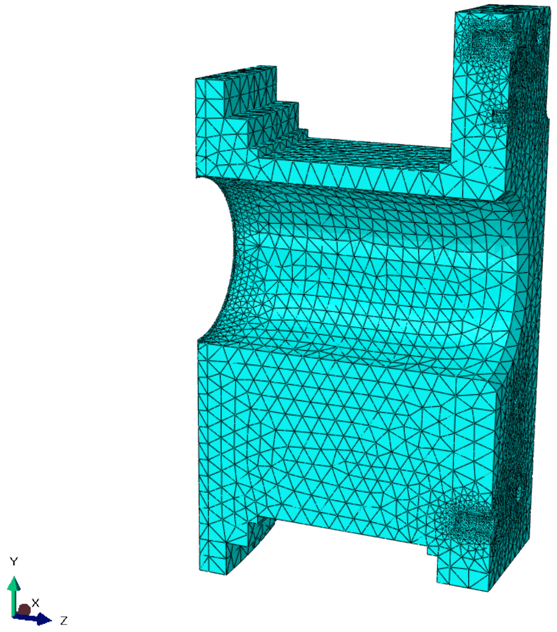
U.S. DEPARTMENT OF ENERGY

Beltline Part

Beltline part

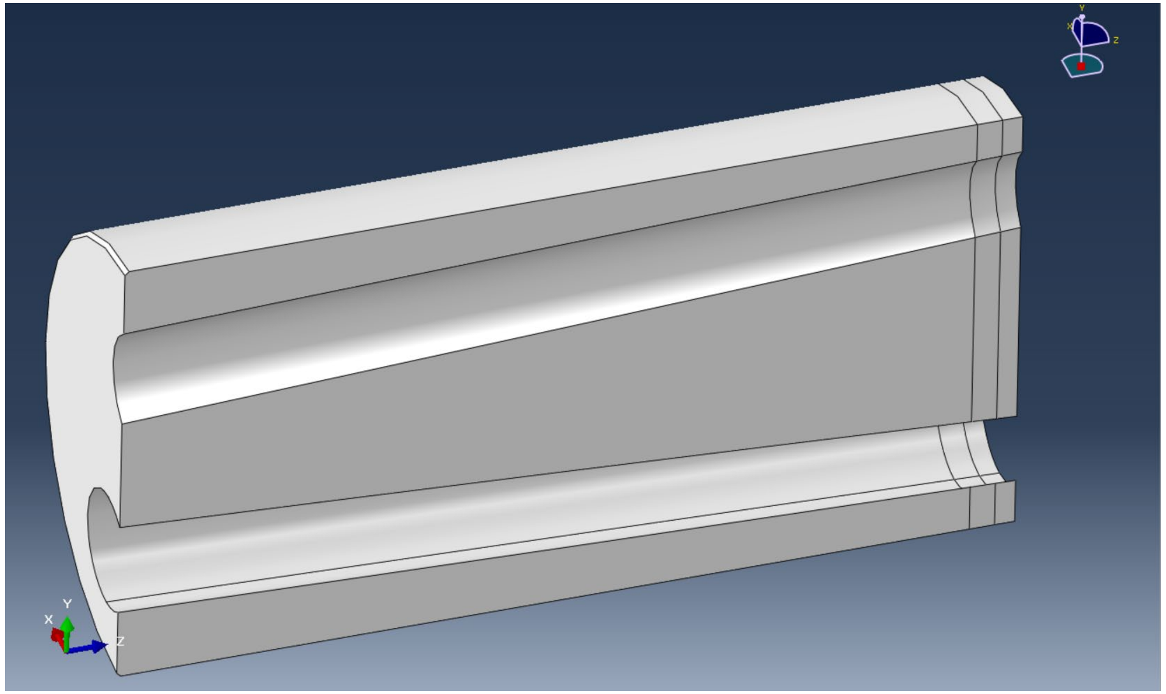


Beltline mesh with 89,403 C3D10 elements

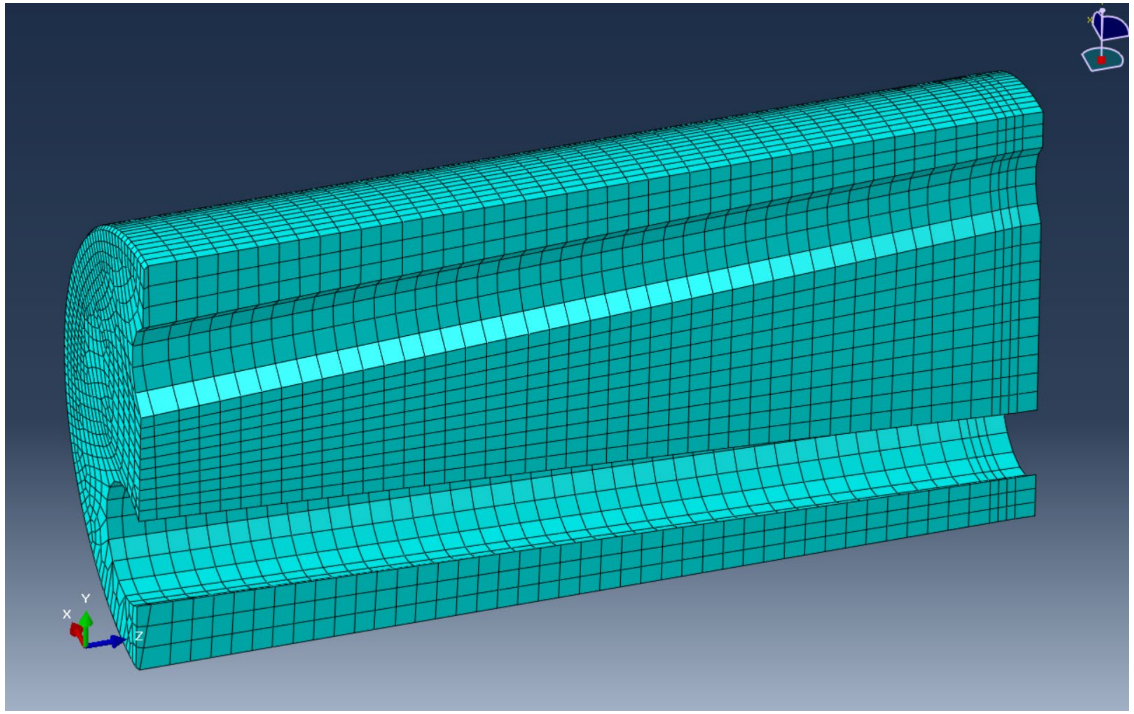


Front part

Front beam guide Part 1

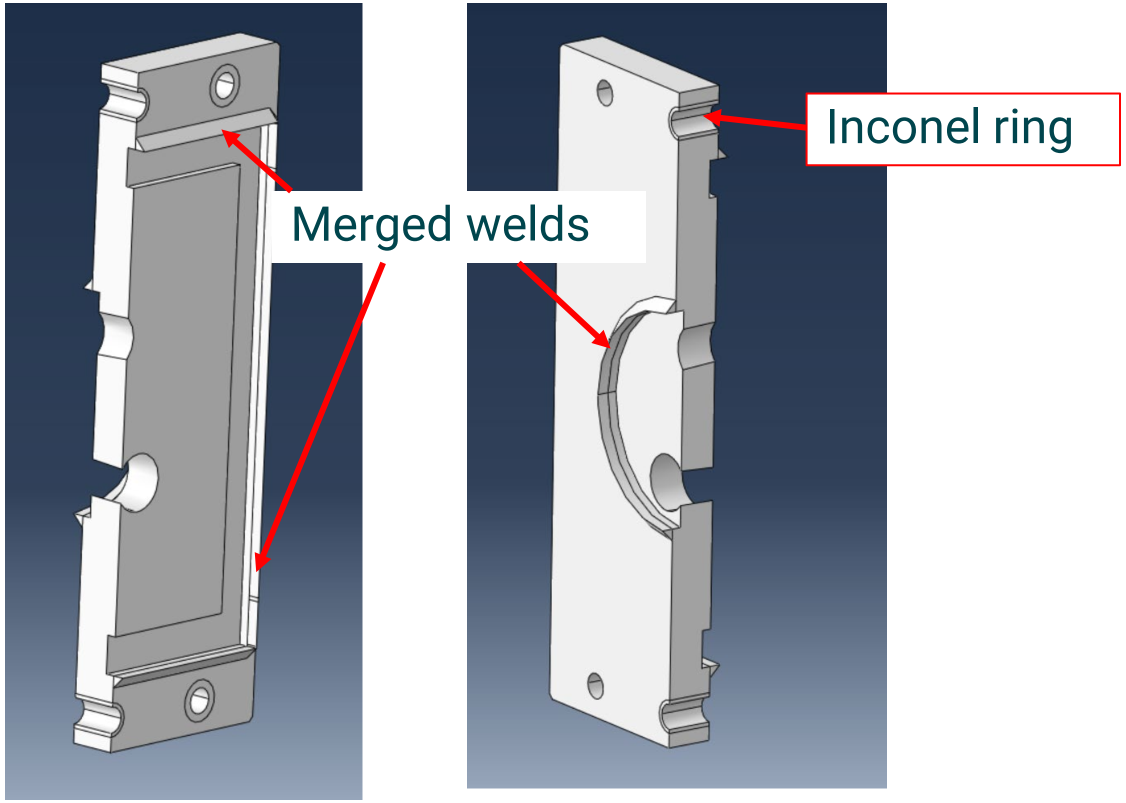


C3D8R Mesh with 22494 elements

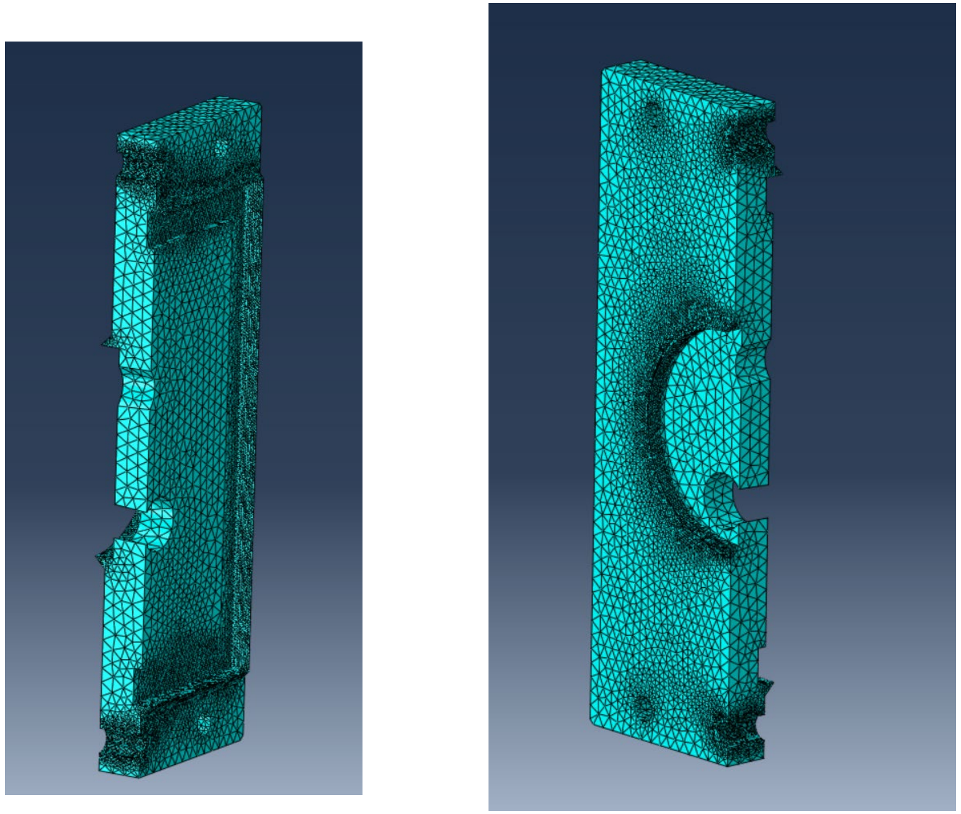


Front Flange

Front flange (R2W)



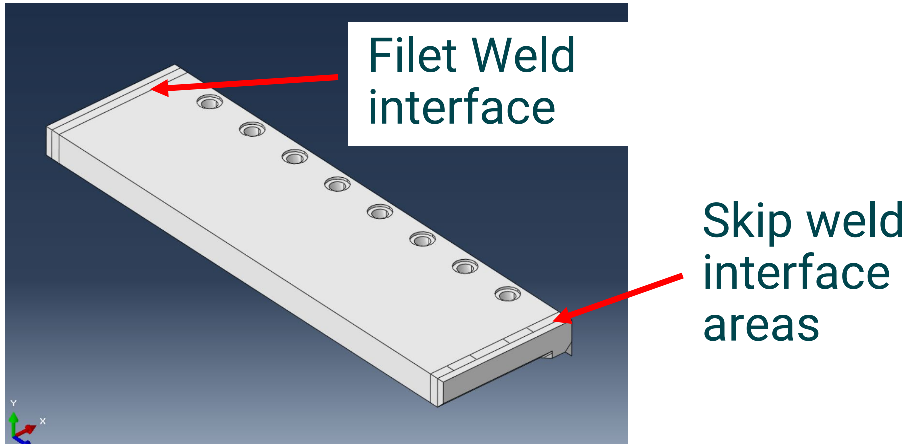
Mesh with C3D10 elements

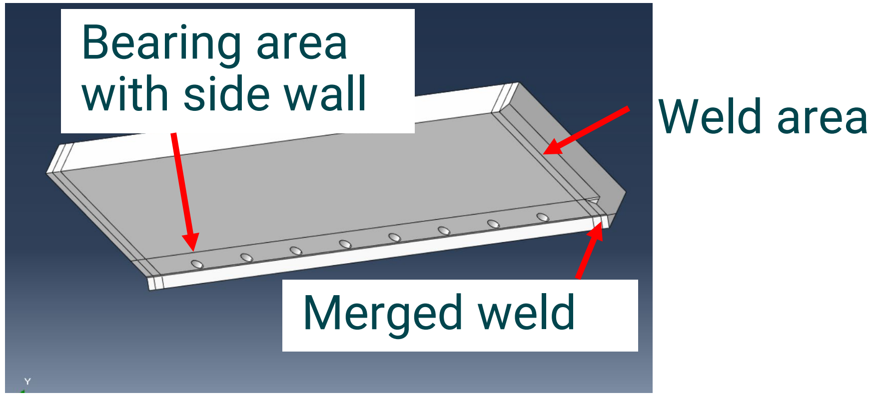


Front Section top plate

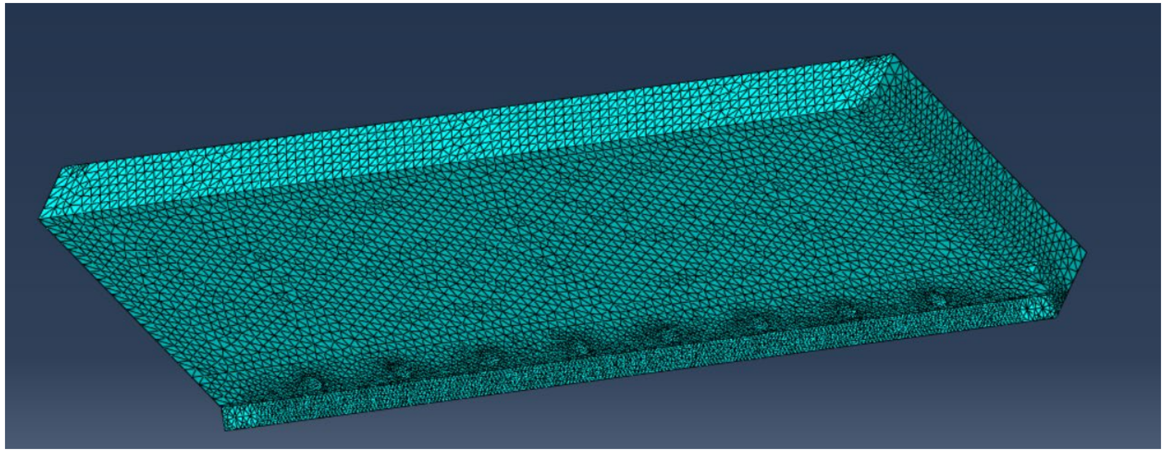
Bottom plate has similar geometry with merged weld material

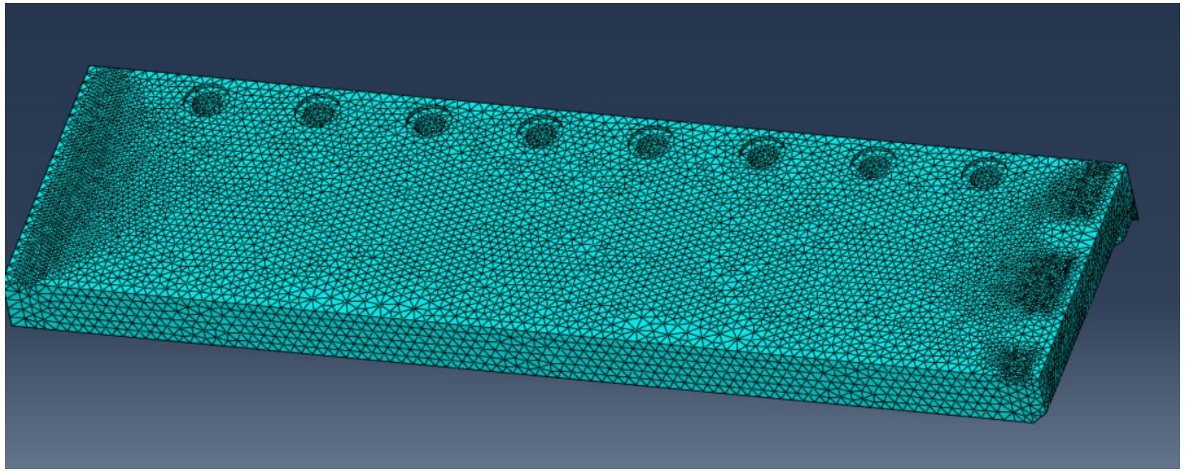
Top front plate (R3W) – bottom (R4W) similar





Mesh model with C3D10 elements

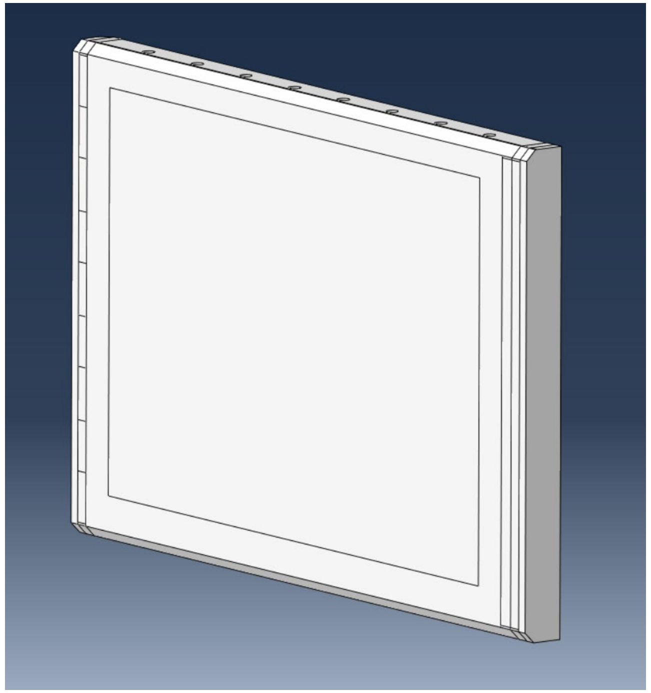


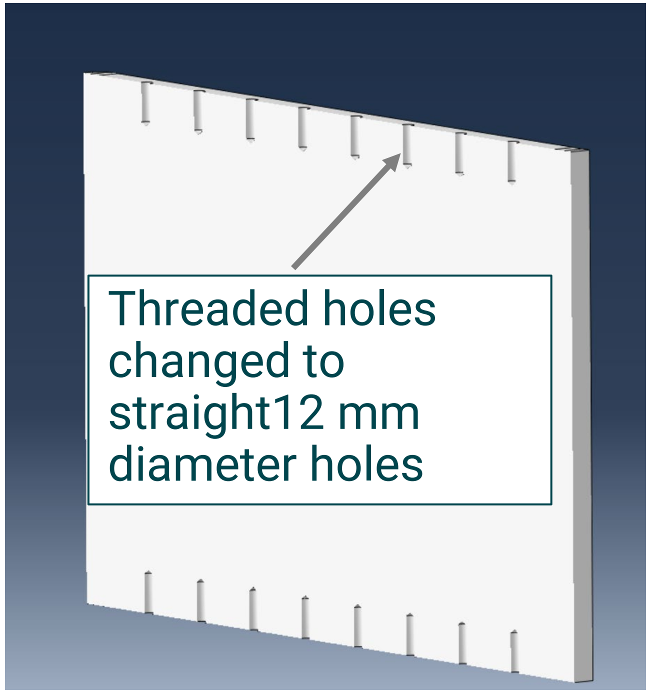


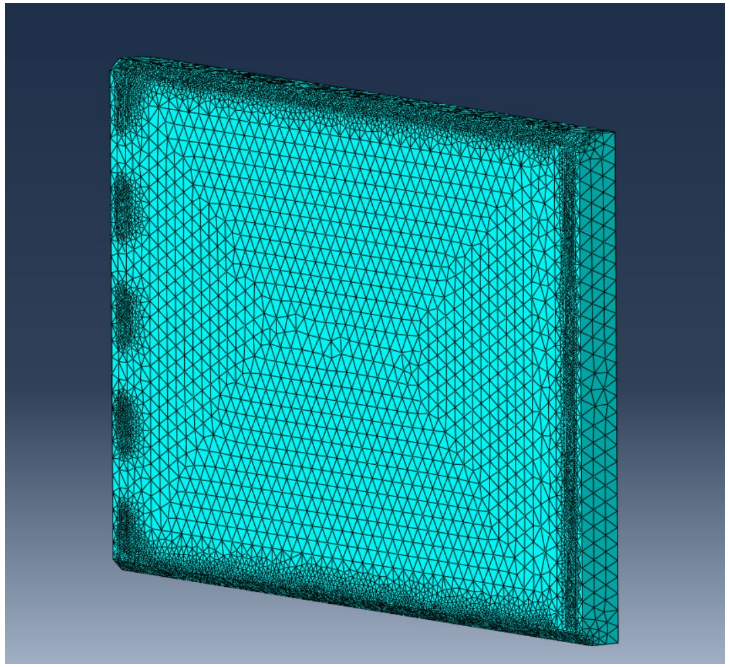
Front side Wall (R5)

Chamfers to mate with welds -bolt holes 12 mm diameter-face partitions to define contact and weld areas

C3D10 elements with Finer mesh around weld areas

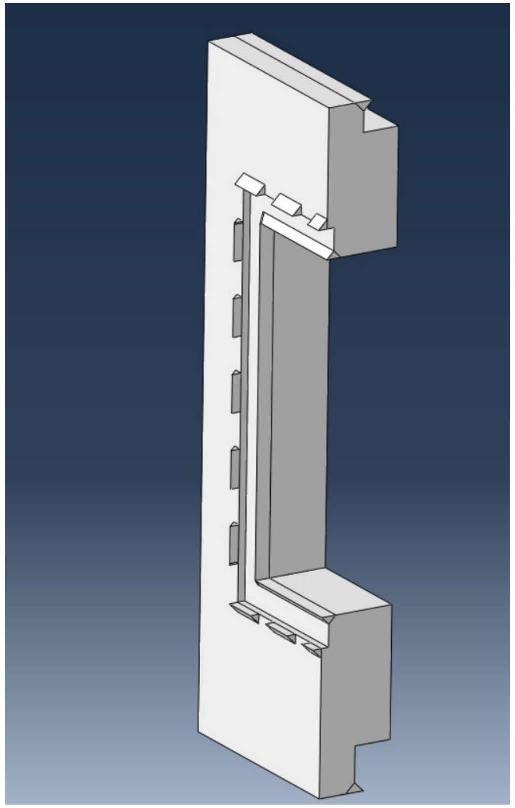


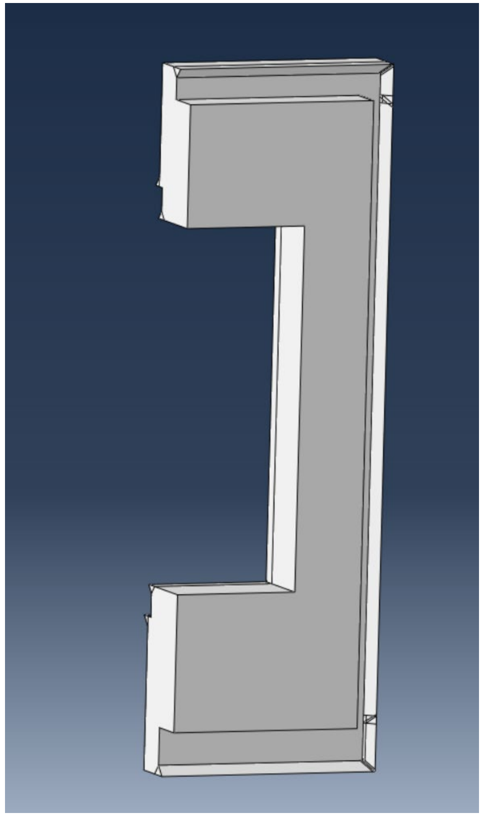




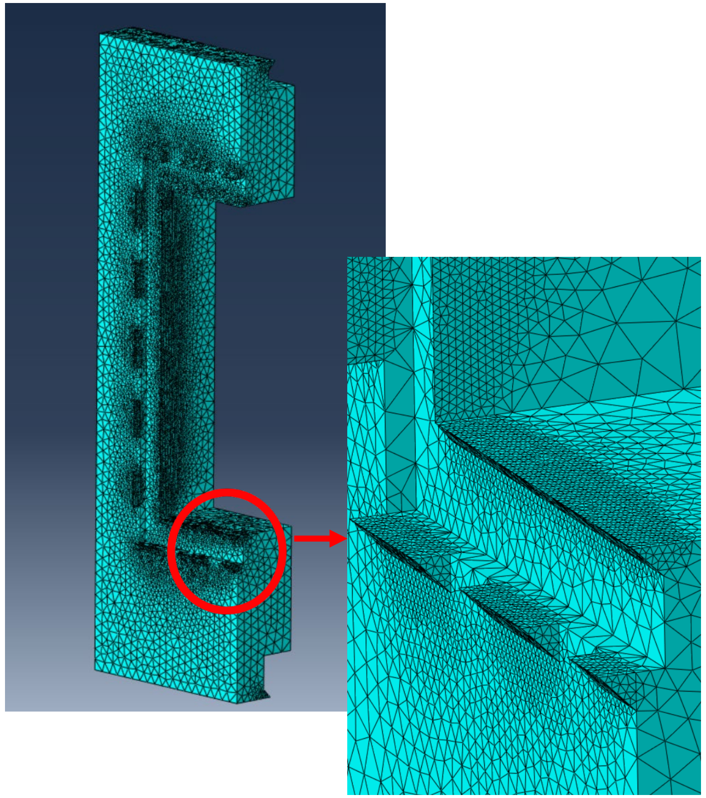
Intermediate Flange

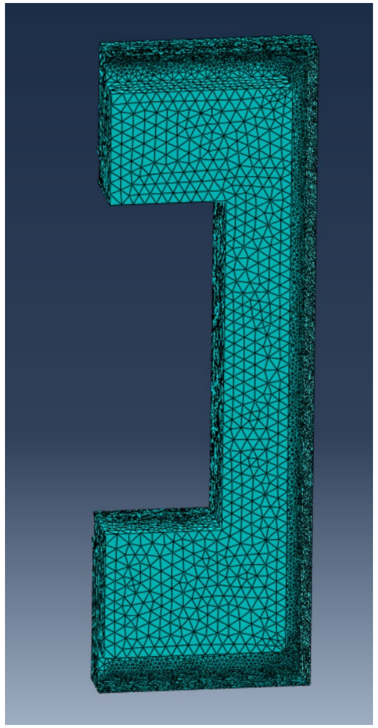
Flange (R7W) with merged fillet and skip welds





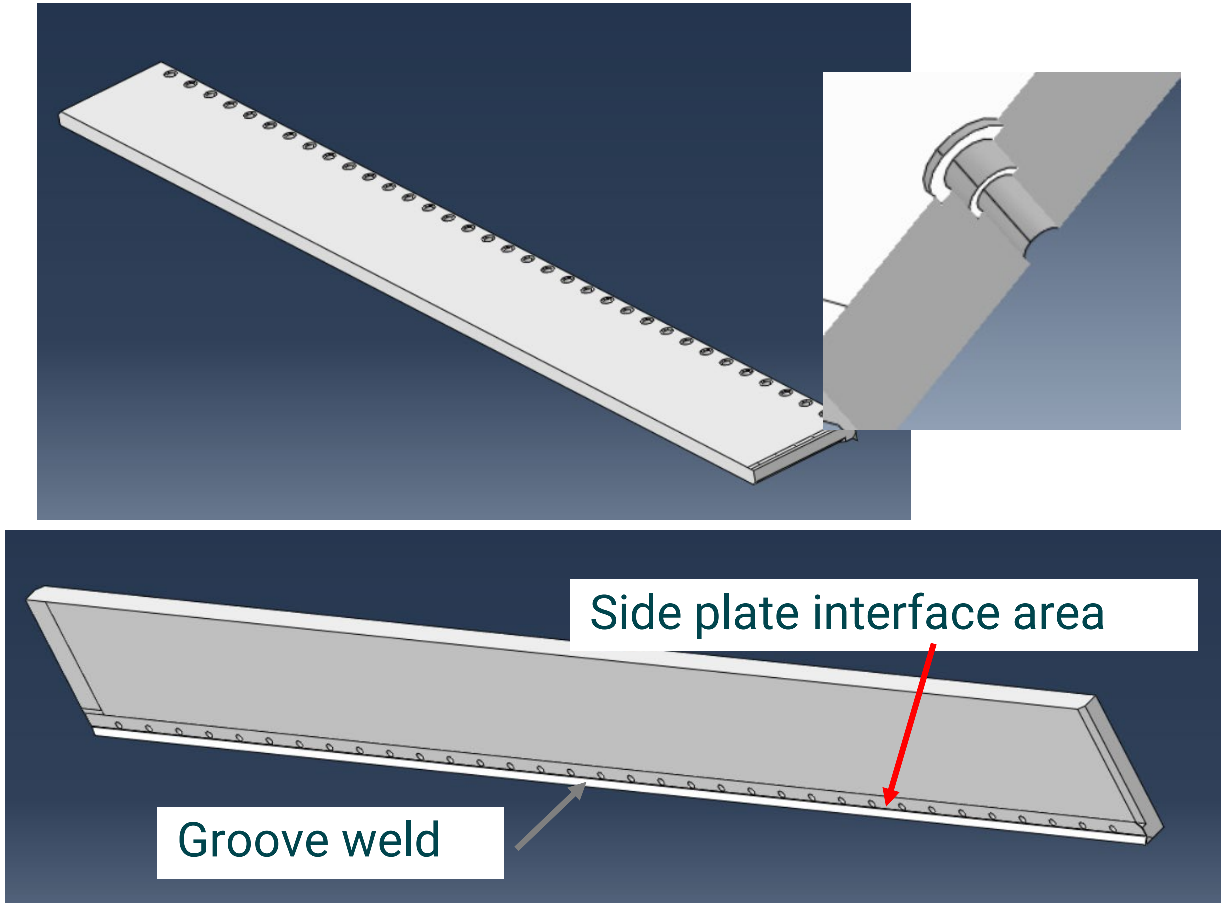
C3D10 Mesh model



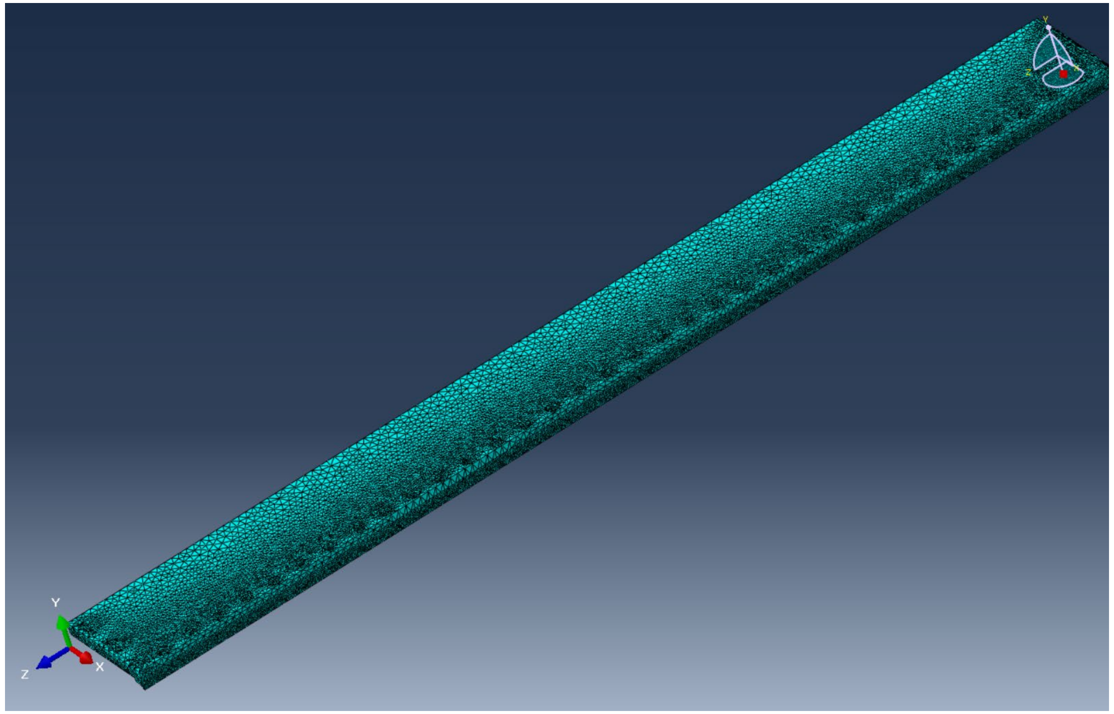


Top rear plate (R8W) with merged groove weld

Top plate

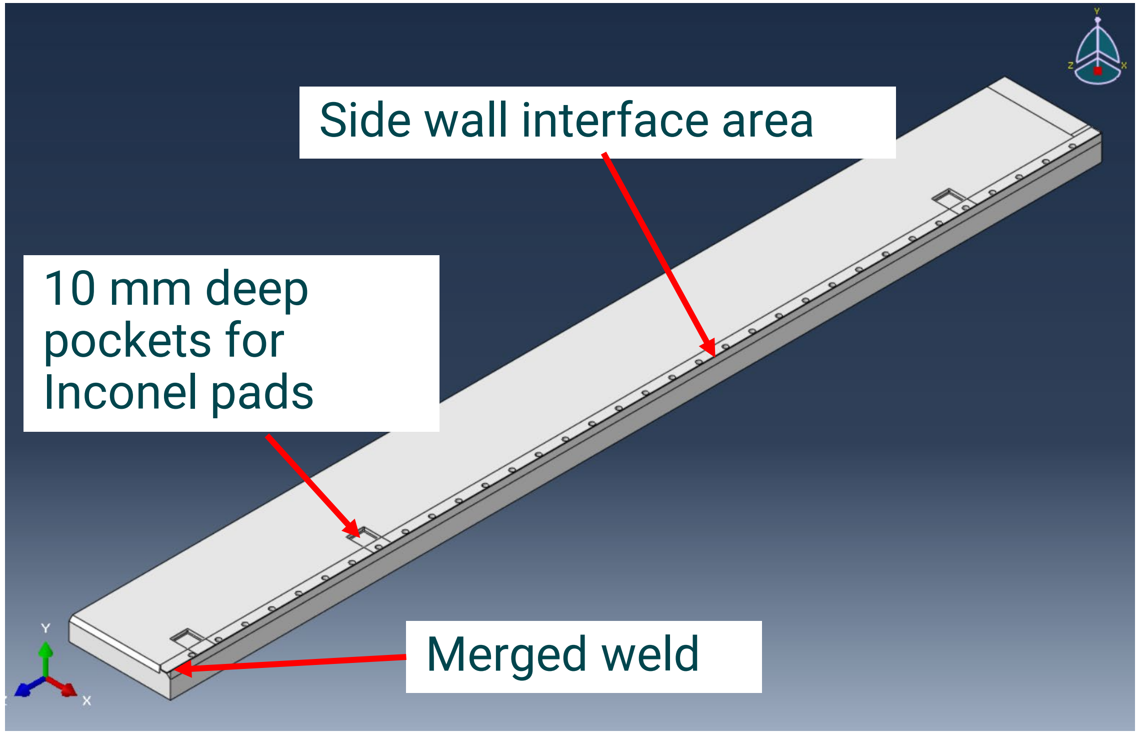


C3D10 Mesh model

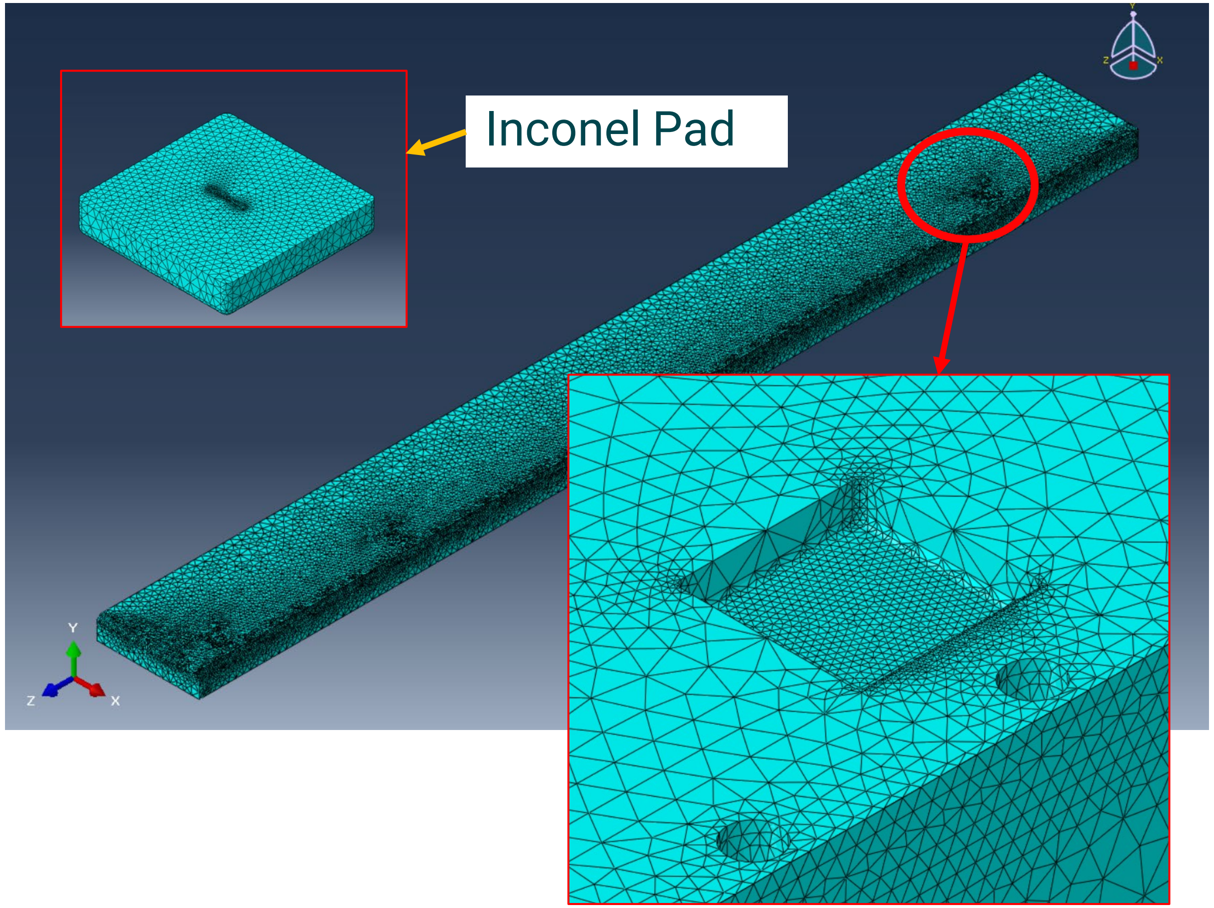


Rear Bottom plate

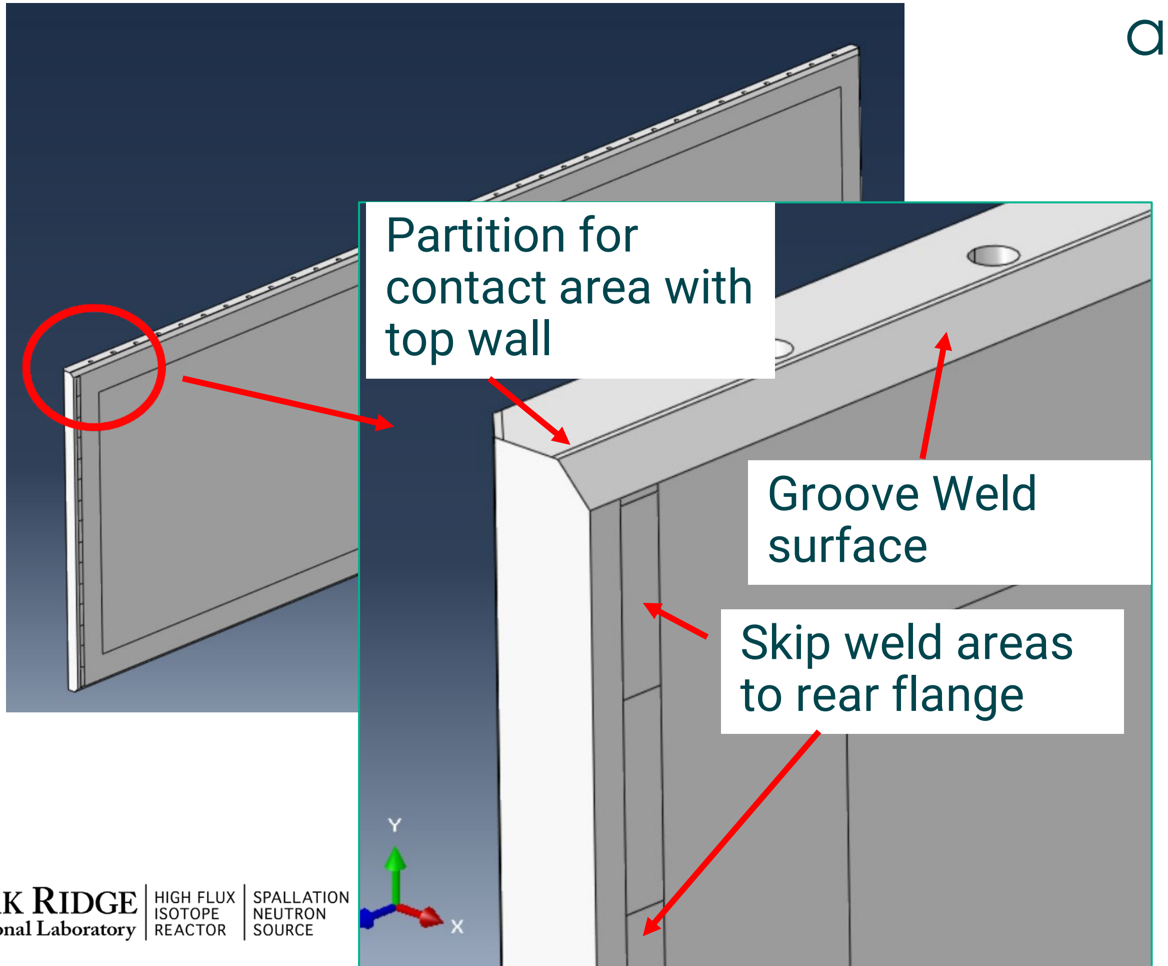
60 mm thick bottom plate (R9W)



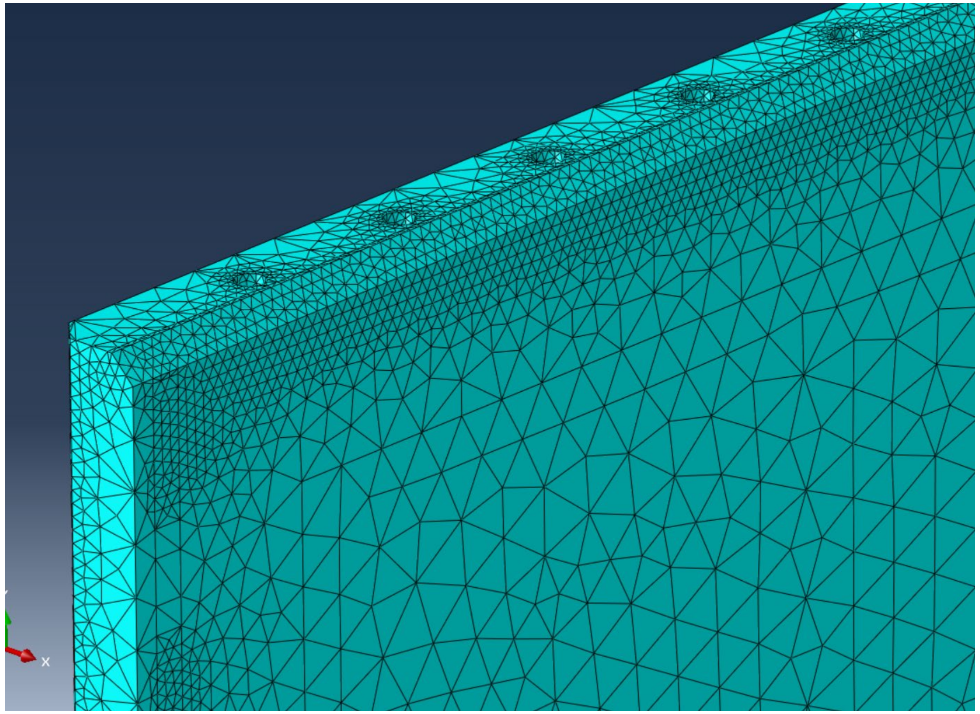
C3D10 Mesh



Rear Side Walls

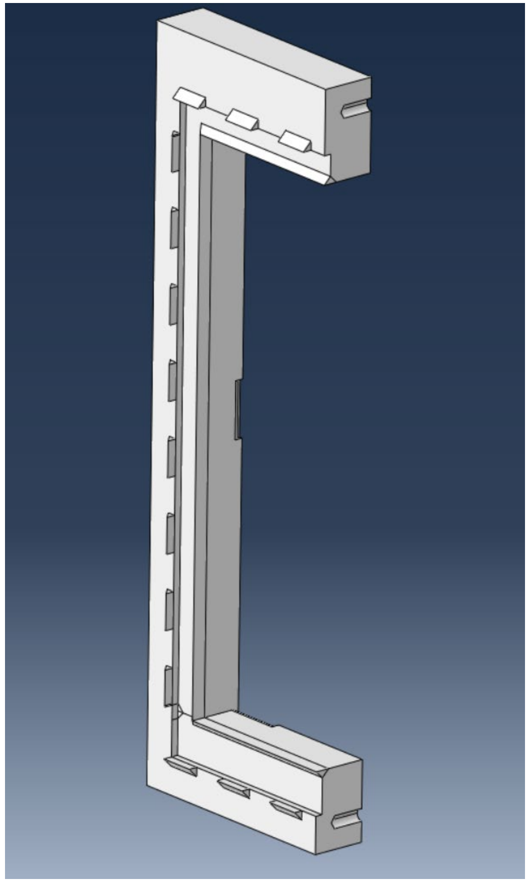


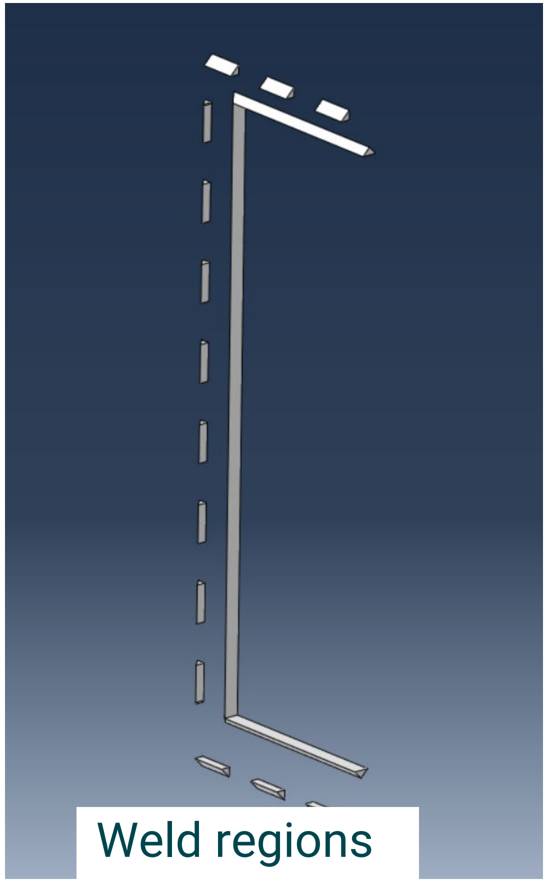
Representative C3D10 mesh with nominal 5 mm element size in weld and 20 mm in plate middle



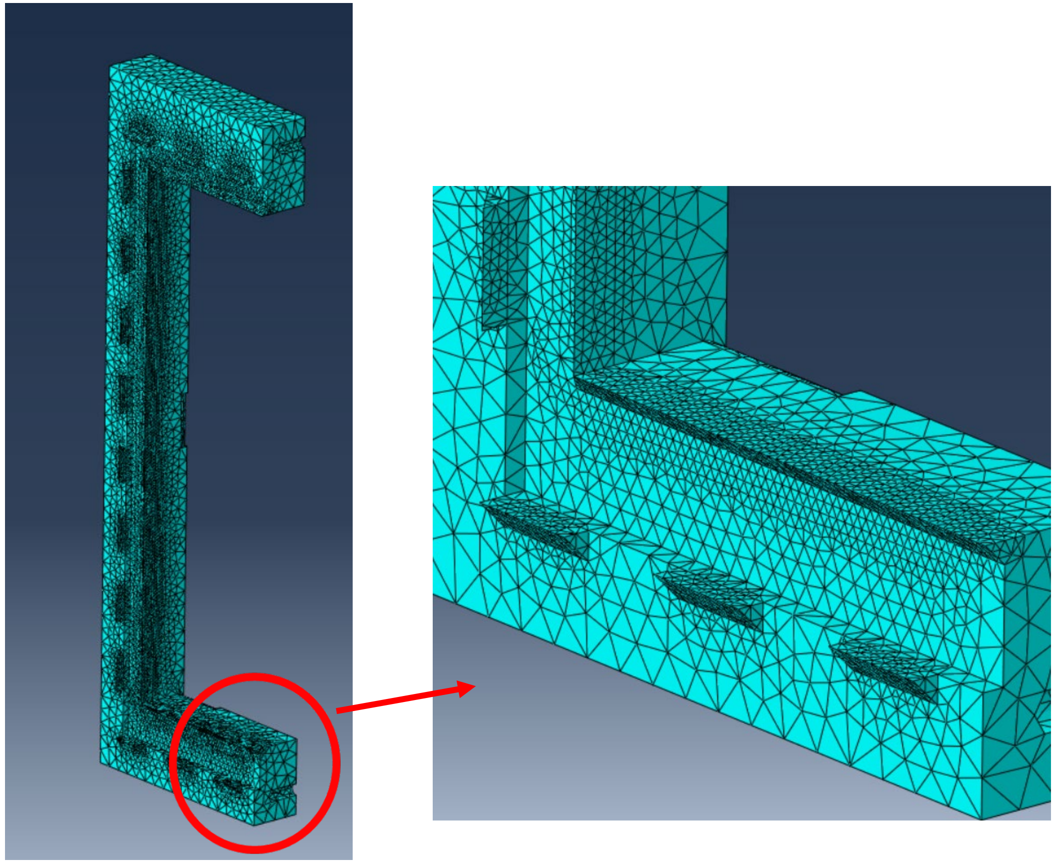
Rear Flange

Rear flange (R12W) with merged welds



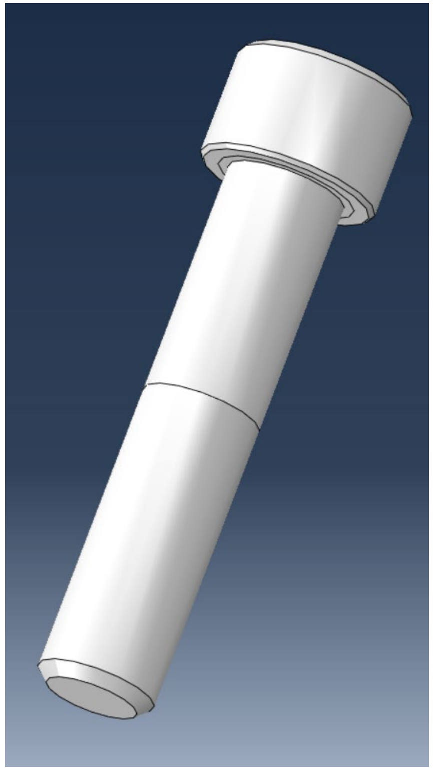


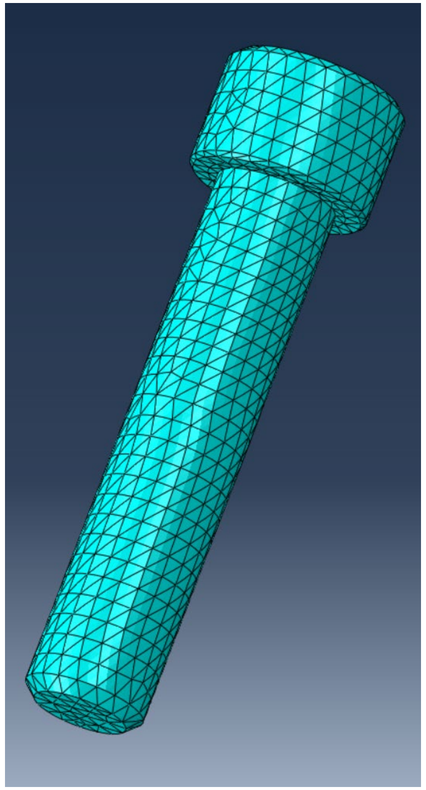
C3D10 mesh model



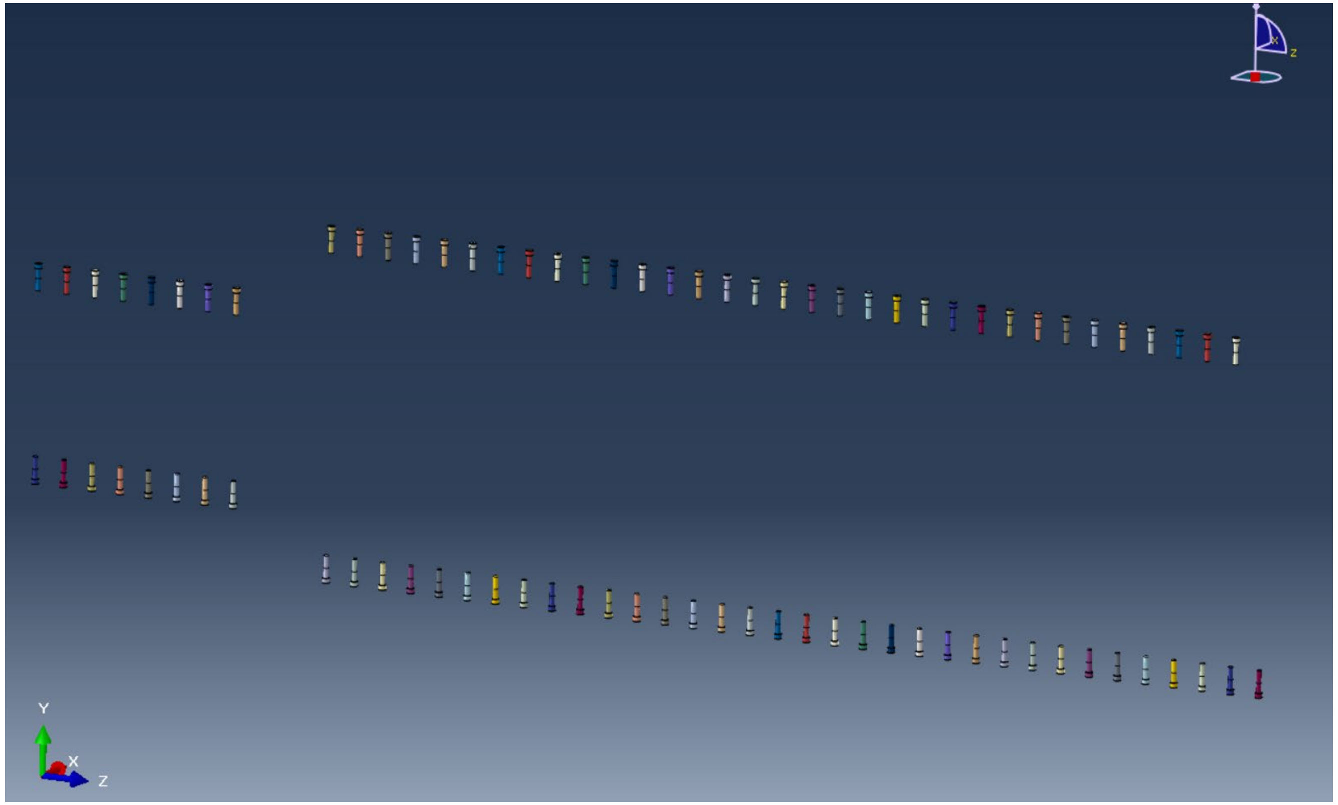
Bolts

12 mm diameter bolt



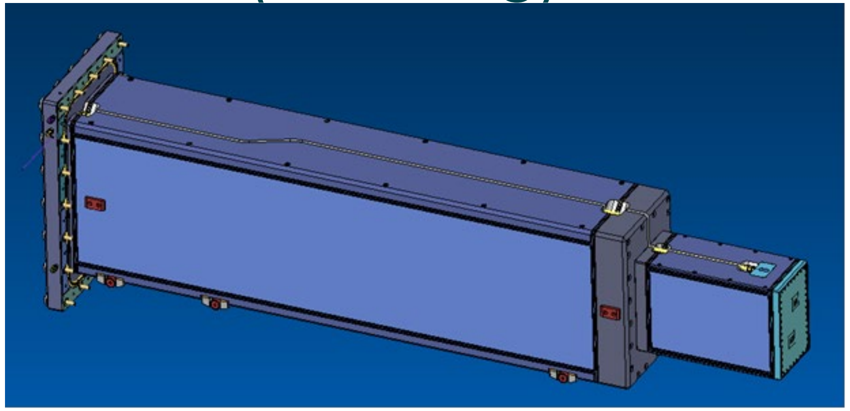


Array of 84 bolts in model

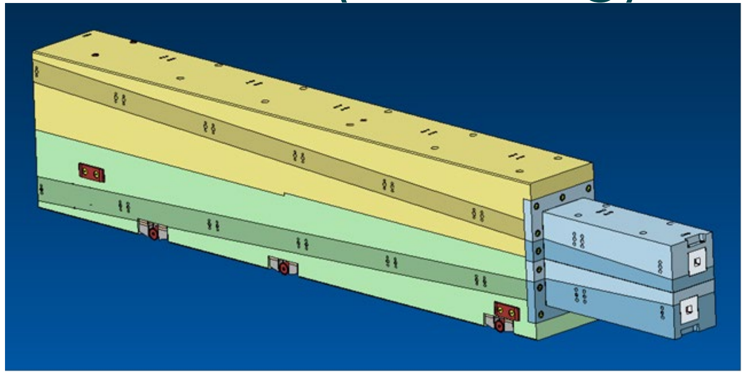


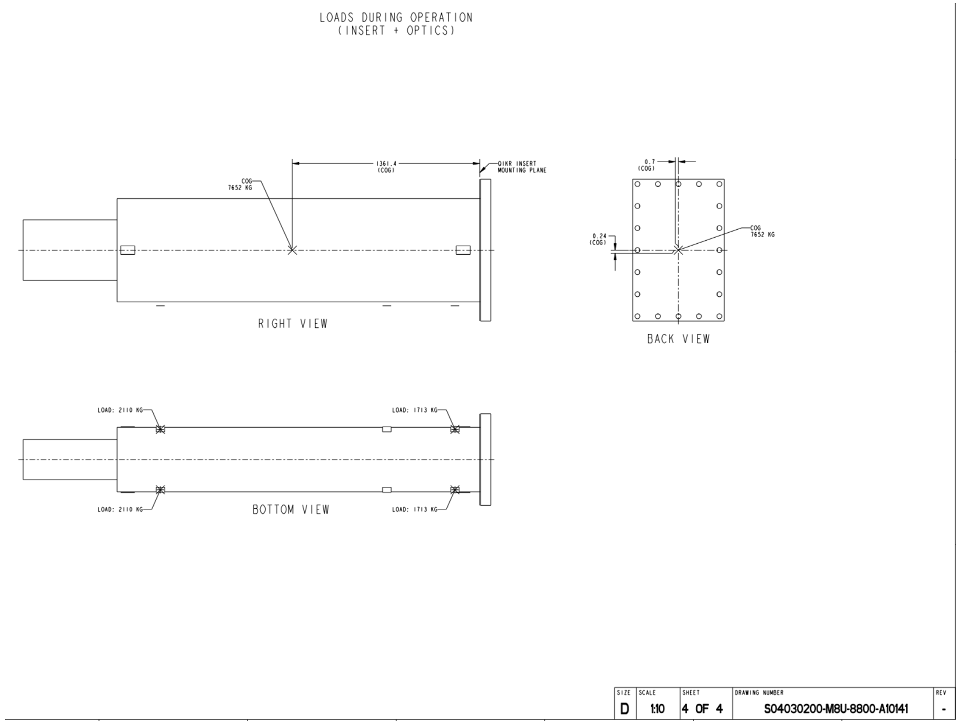
Inserts for QIKR Nozzle

7541lbs (3420.6kg)



9228lbs (4185.6kg)



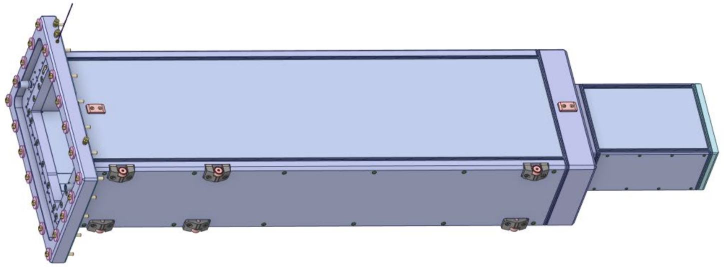


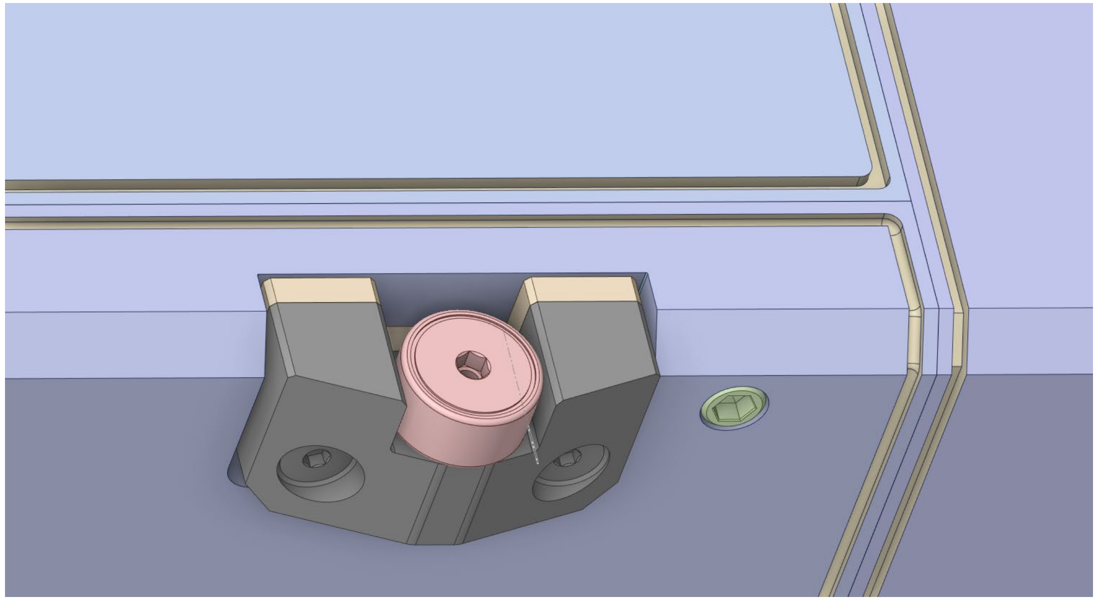
Wheel loads from Interface dwg
- 2110 kg front wheels
- 1713 kg rear wheels

Wheel to plate contact analysis

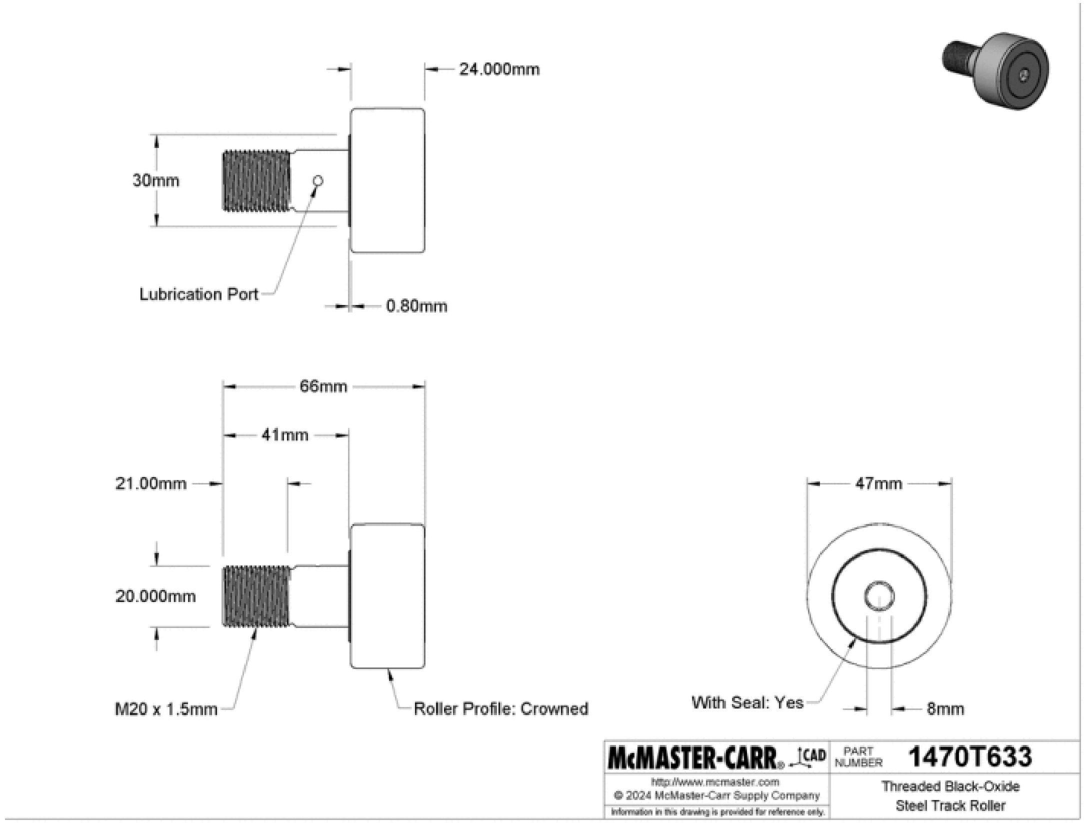
- An idealized analysis of the wheel to plate contact was made
- The intent was to find the contact stress distribution in the nozzle plate structure using a finer mesh than could be used for full assembly model
- The load on a front wheel from the mass of the insert and optics was 2110 Kg
- A quarter symmetry model of the wheel was made and the load applied by increasing the material density to give ¼ of the total load
- Linear elastic material properties for steel or inconel were used

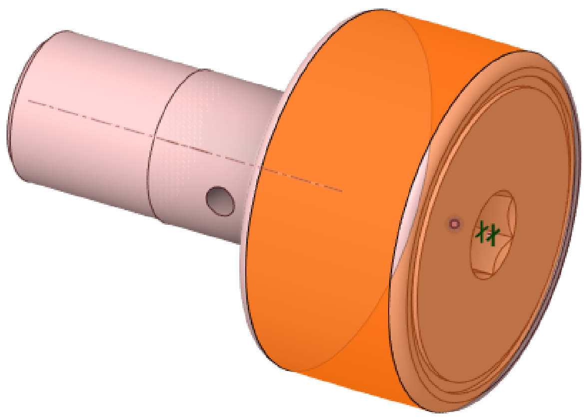
Insert SpaceClaim model





Wheel geometry with crown surface





Major Diameter	0
Minor Diameter	1000mm
Fillet Radius	500mm
Area	3053.4385mm²
Perimeter	293.9622mm

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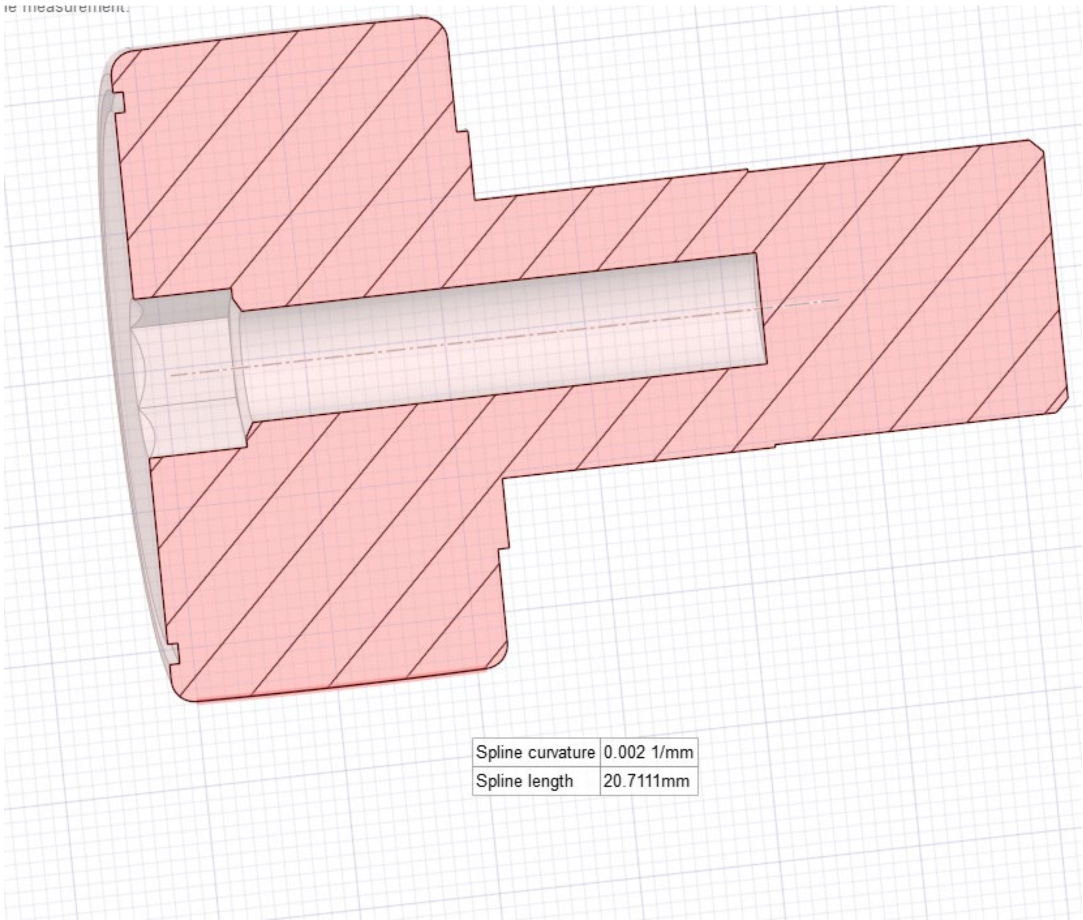
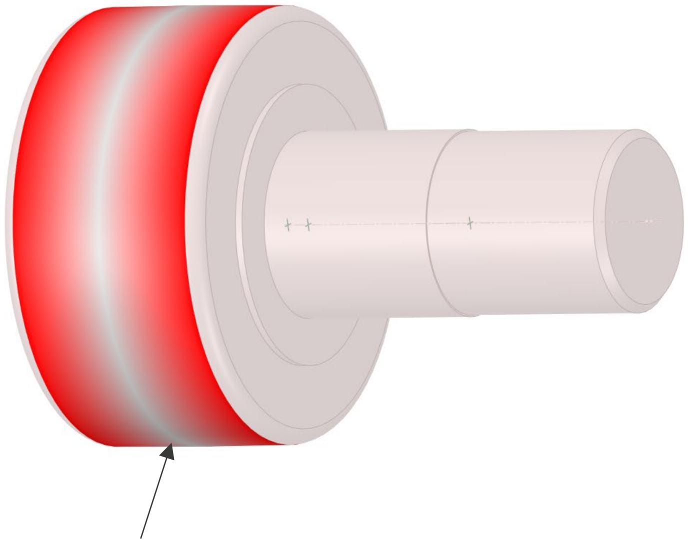
Wheel cross section and curvature on contact face

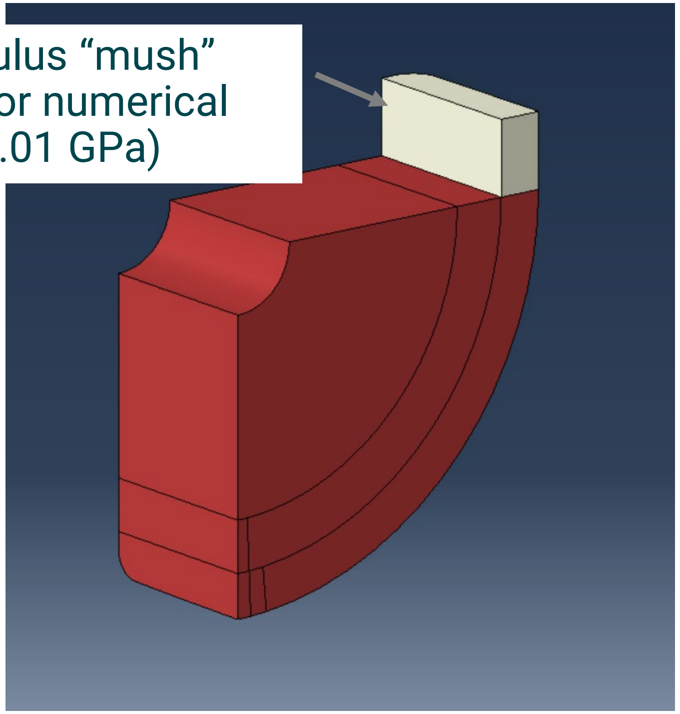




Crown radius = 500 mm

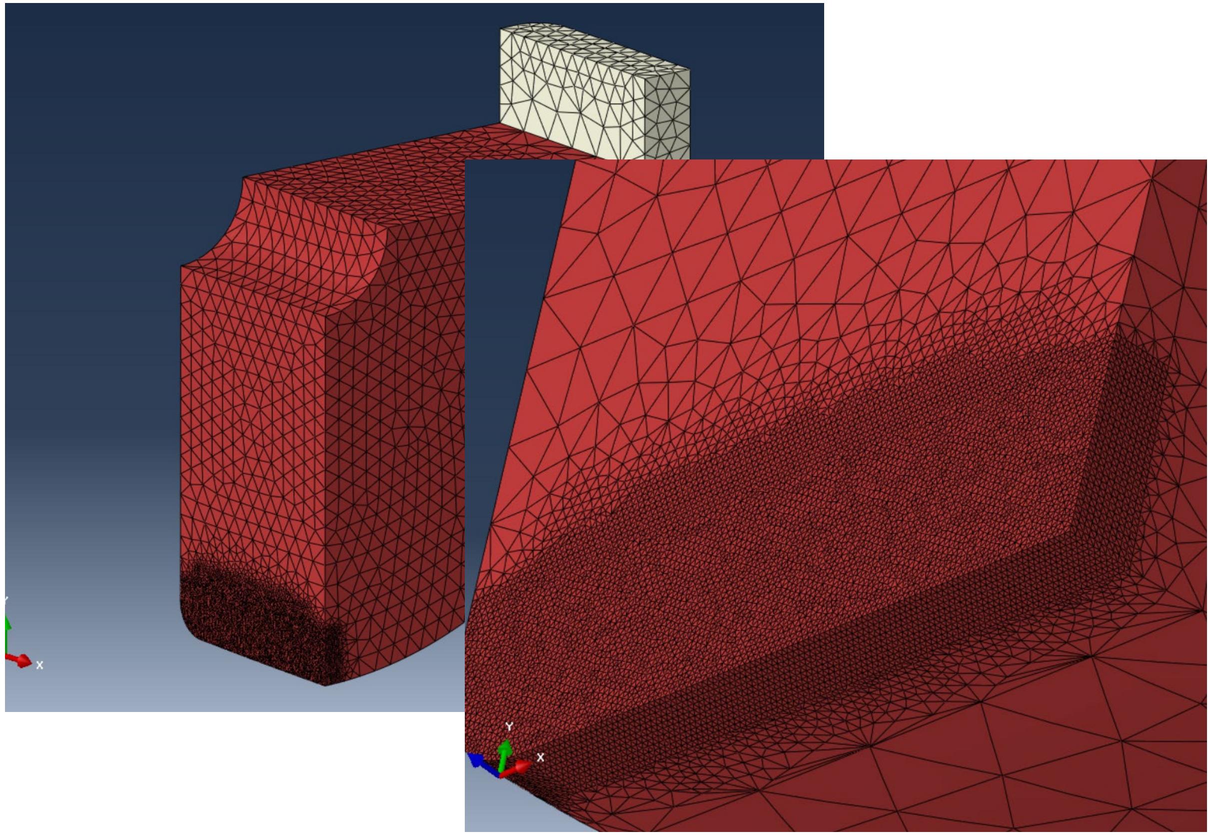
Wheel Abaqus model

Idealized ¼ symmetry wheel model



Low modulus “mush” addition for numerical stability (.01 GPa)

C3D10 mesh with 0.1 mm size in contact area



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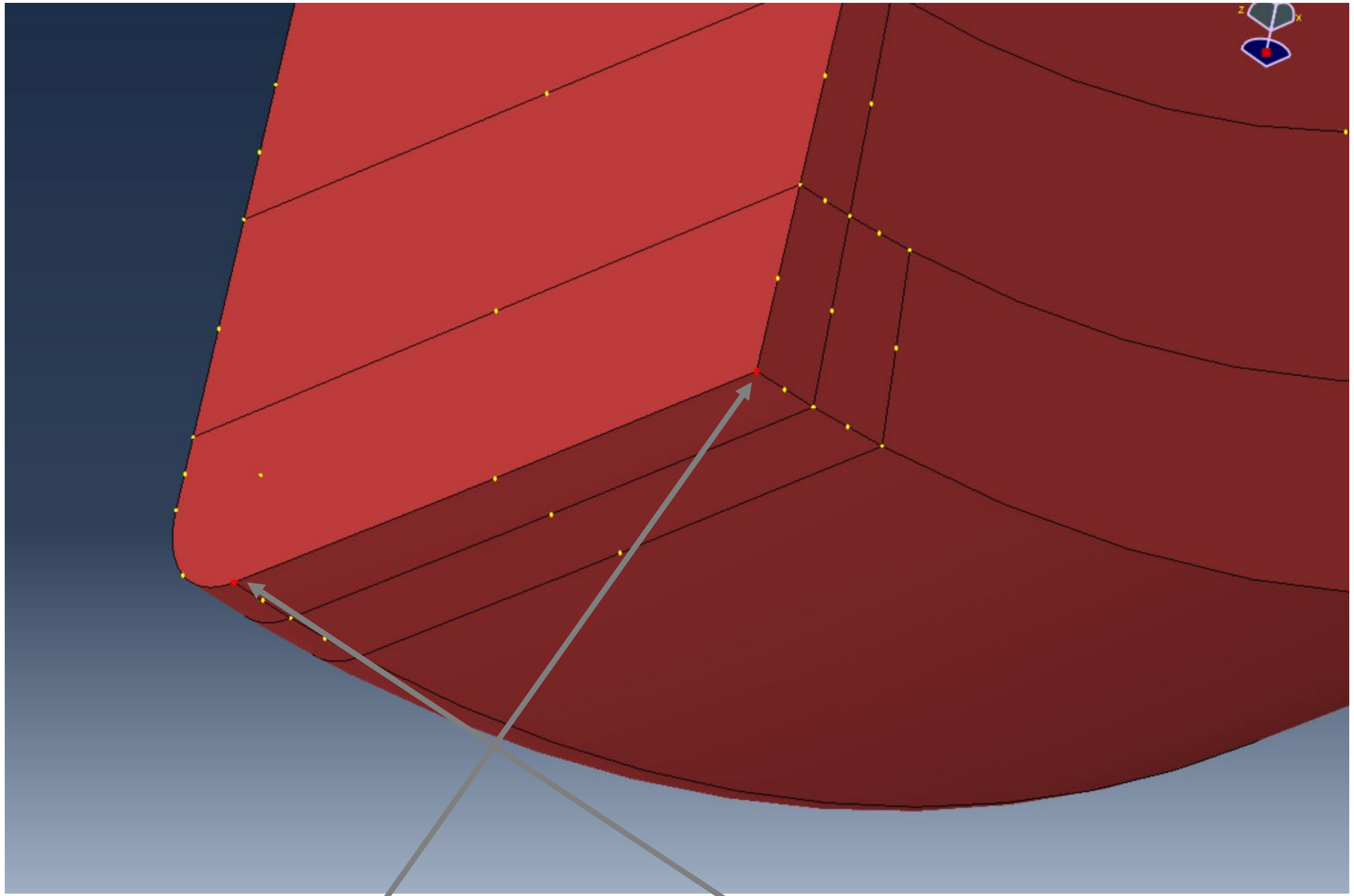
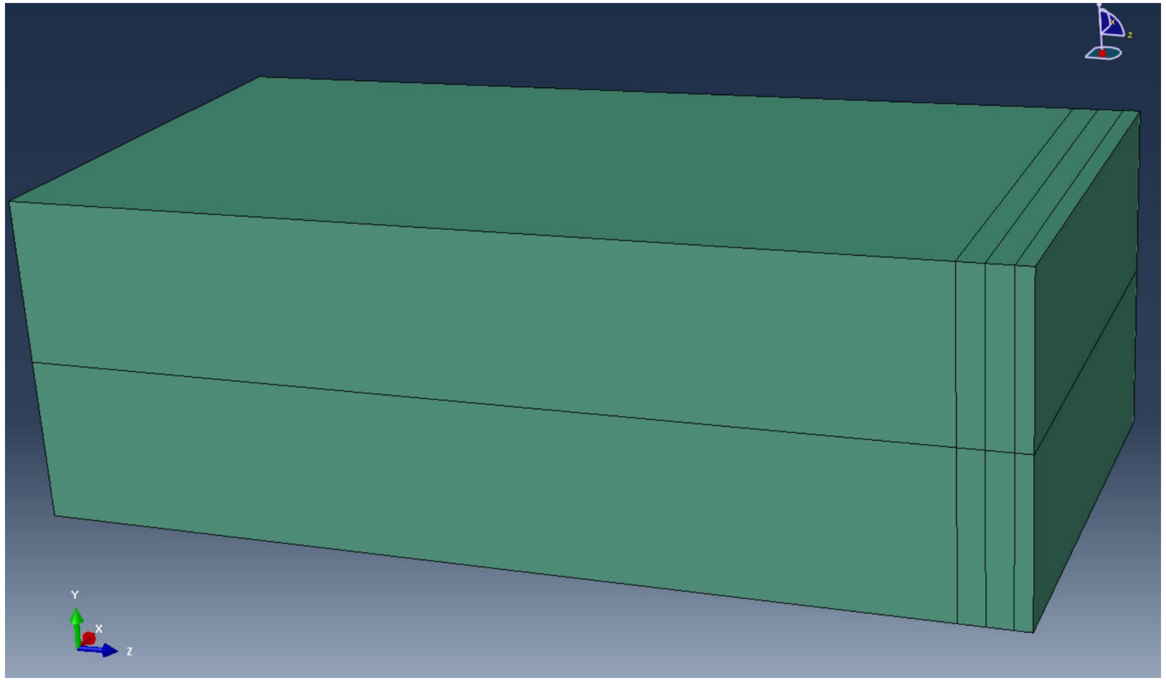
Bottom center to edge elevation change 0.107 mm



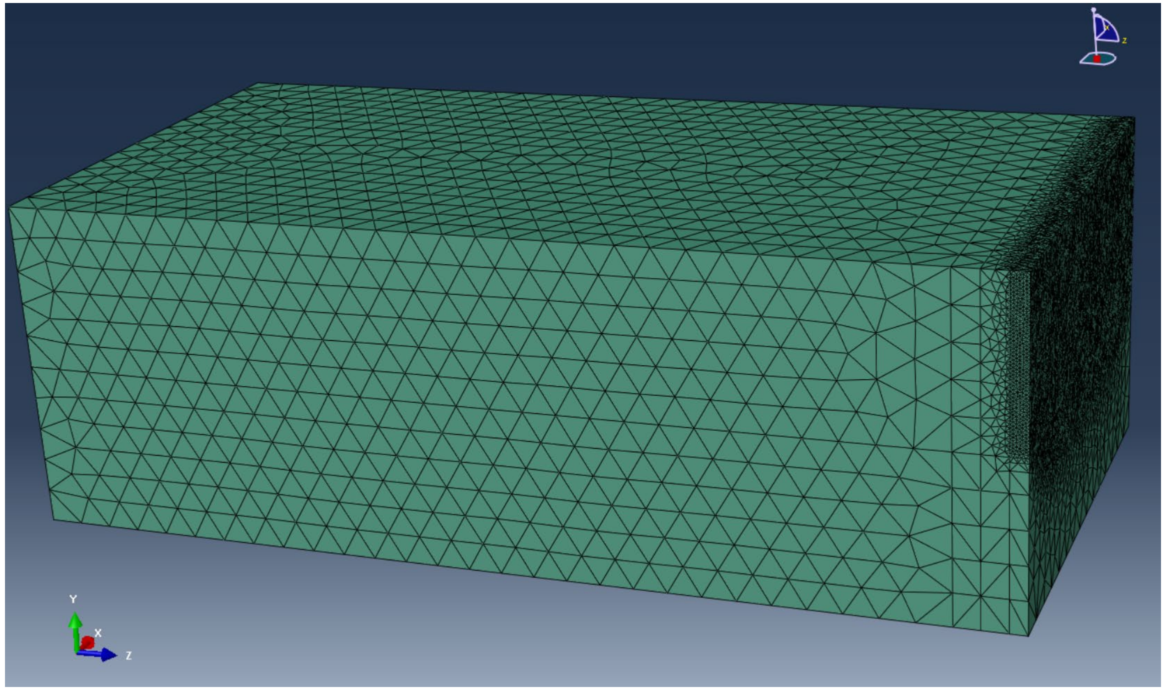
Point 1: 219.7E-03, -404.E-03, 2.84435 Point 2: 209.345E-03, -403.893E-03, 2.84435
Distance: 10.355E-03 Components: -10.355E-03, 107.E-06, 0.

10 mm thick Inconel block

Contact block 10 mm thick

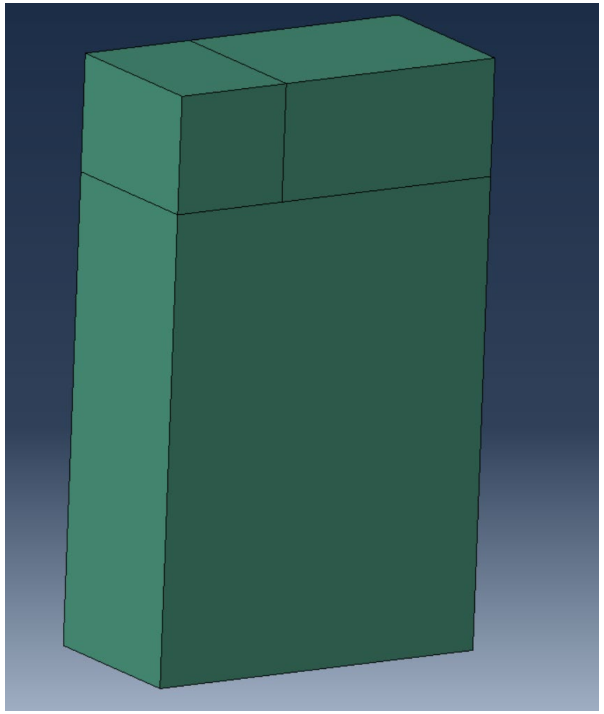


C3D10 mesh with 0.1mm spacing in contact region

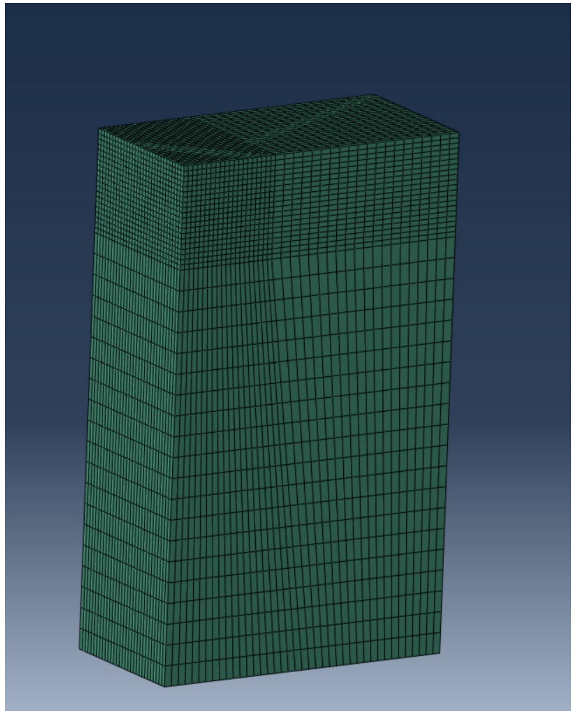


316L plate

50 mm thick 316L block



C3D8 Hex mesh



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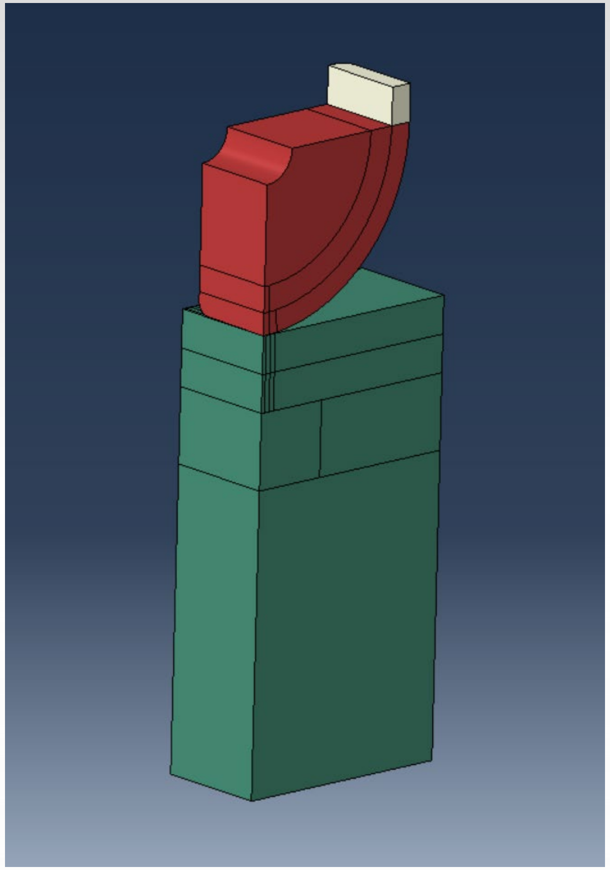
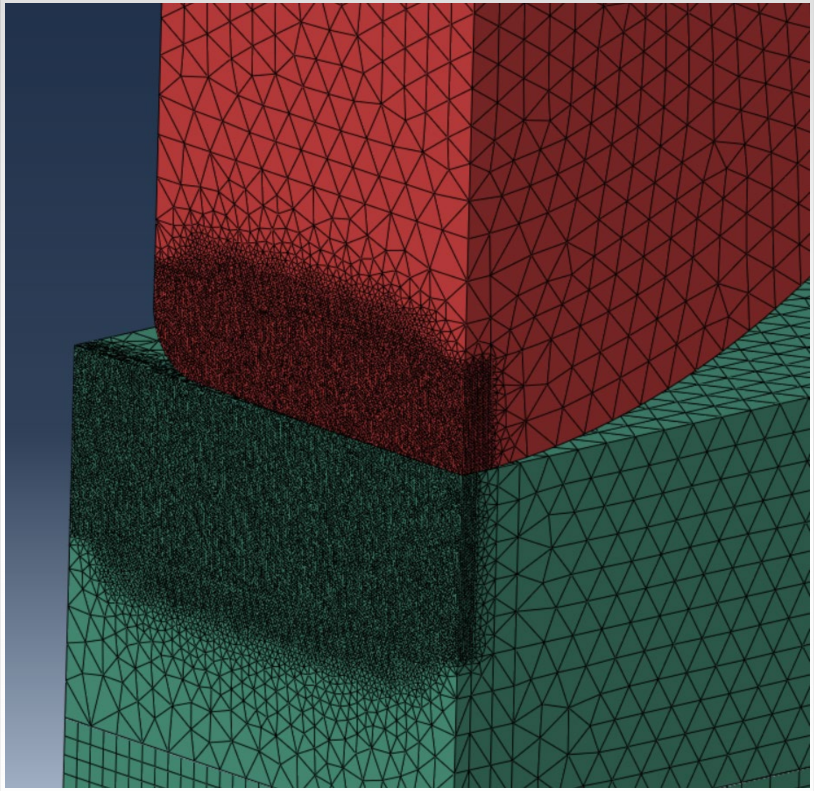
Assembly model

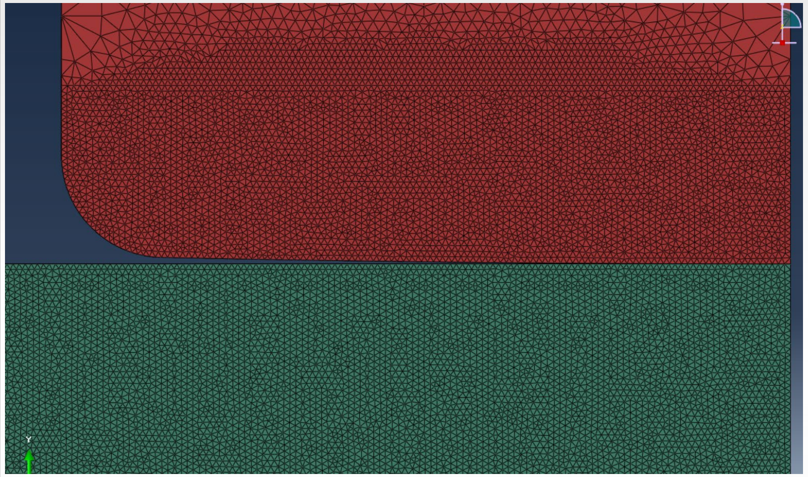
Assembly



Assembly mesh by contact zone

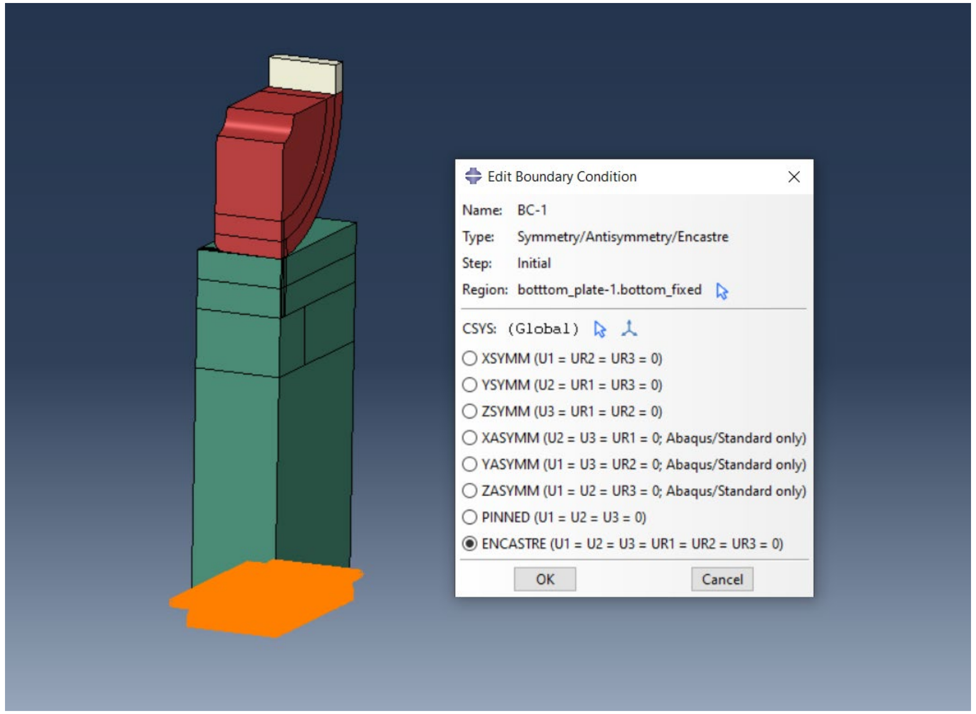


Curvature gap across width

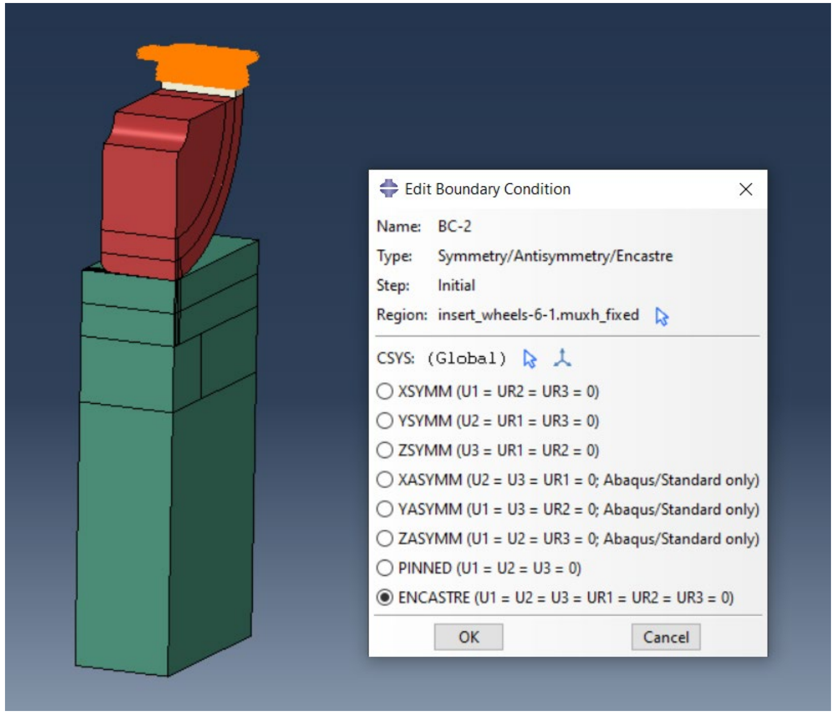


Boundary Conditions

Bottom fixed nodes

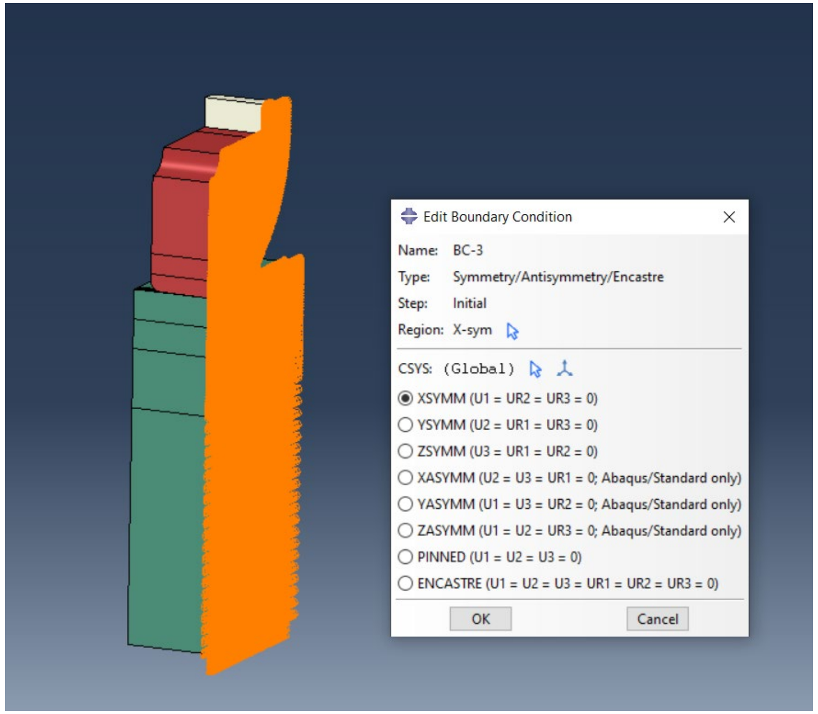


Top surface nodes of "mush" fixed to have a vertical constraint

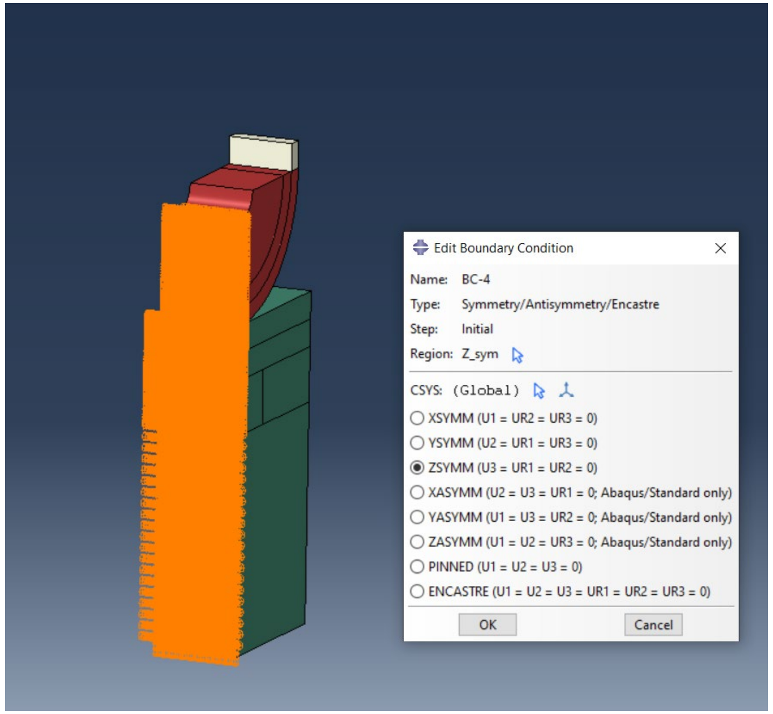


Symmetry boundary conditions

X symmetry

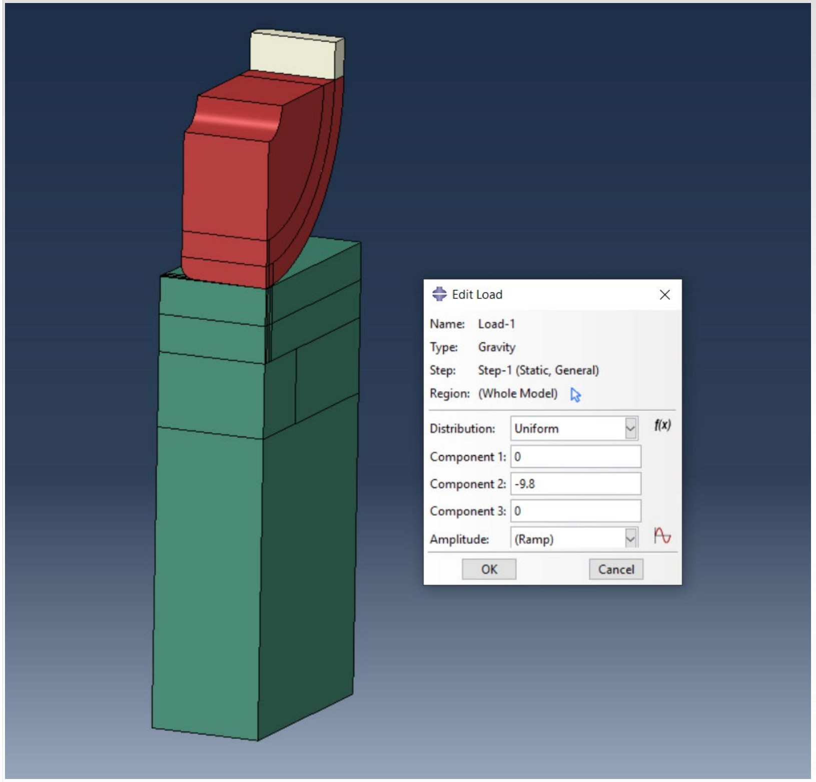


Z symmetry

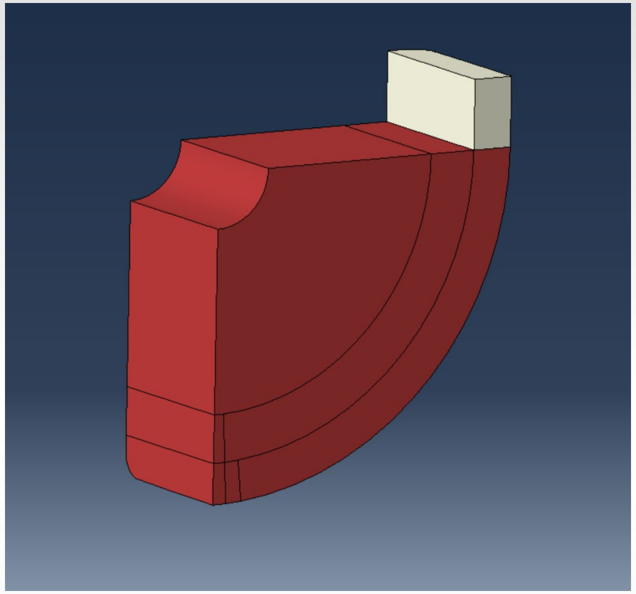


Assembly model loads and materials

Loads



¼ wheel mass 529 kg



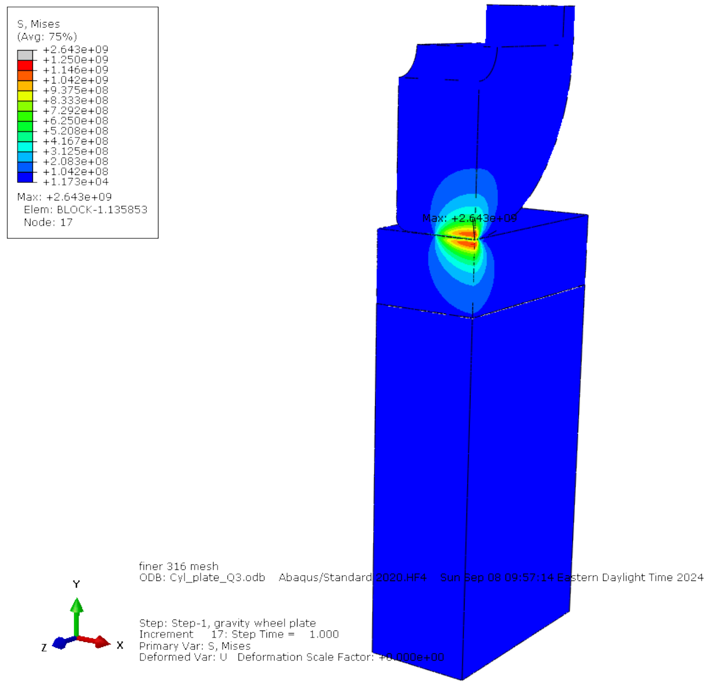
```
Mass properties:
  Volume: 5.18e-06
  Volume centroid: 0.214,-0.390,2.83
  Mass: 528.77
  Center of mass: 0.214,-0.391,2.83
  Moment of inertia about the center of mass (Ixx, Iyy, Izz, Ixy, Iyz, Izx): 0.0395,0.0260,0.0260,8.69e-05,0.00736,8.69e-05
```

Material input

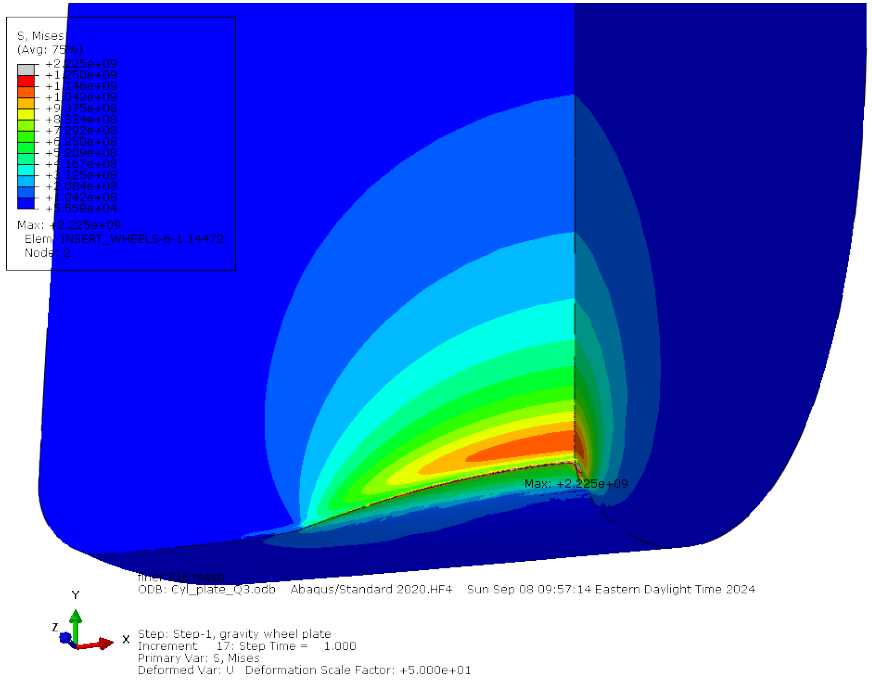
```
** MATERIALS
**
*Material, name=SS316L
*Density
8000.,
*Elastic
 2e+11, 0.292
*Material, name=mush
*Density
1.,
*Elastic
 2e+06, 0.3
*Material, name=steel_wheel
*Density
 1.055e+08,
*Elastic
 2e+11, 0.3
**
```

Assembly Von Mises Stress with 1250 MPa scale

Assembly S Mises 1250 MPa scale peak 2643 MPa

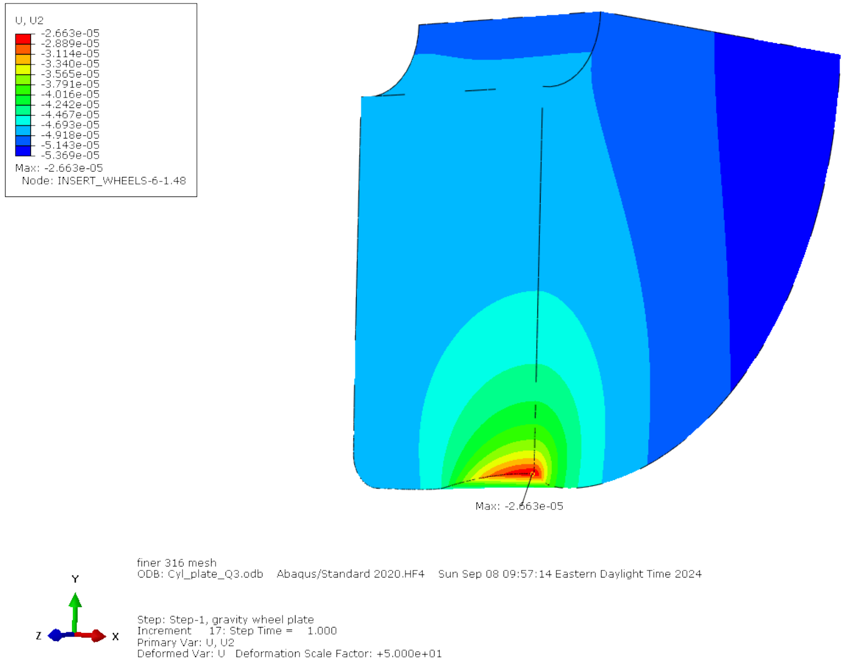


Wheel S 1250 MPa scale

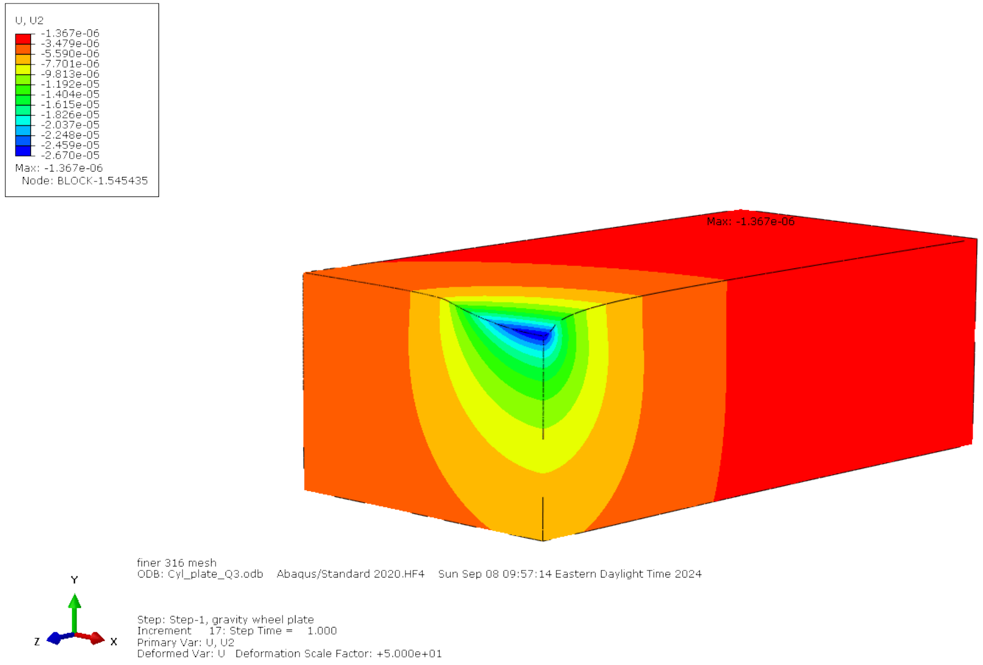


Vertical Displacements

Wheel

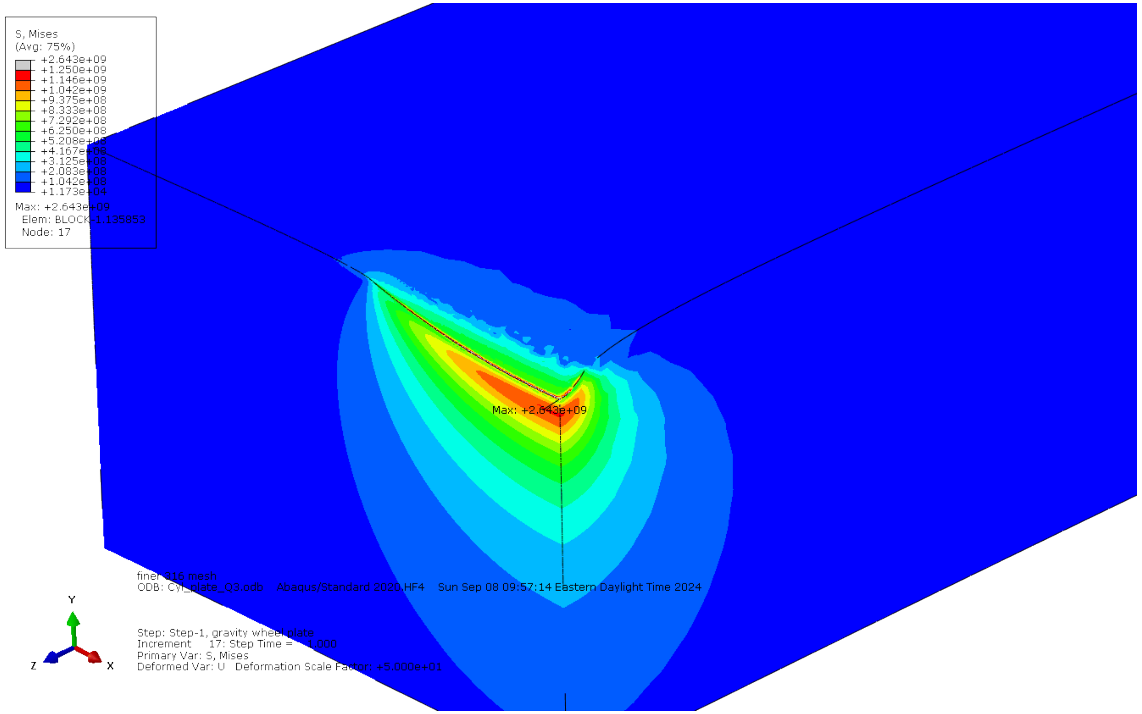


Block

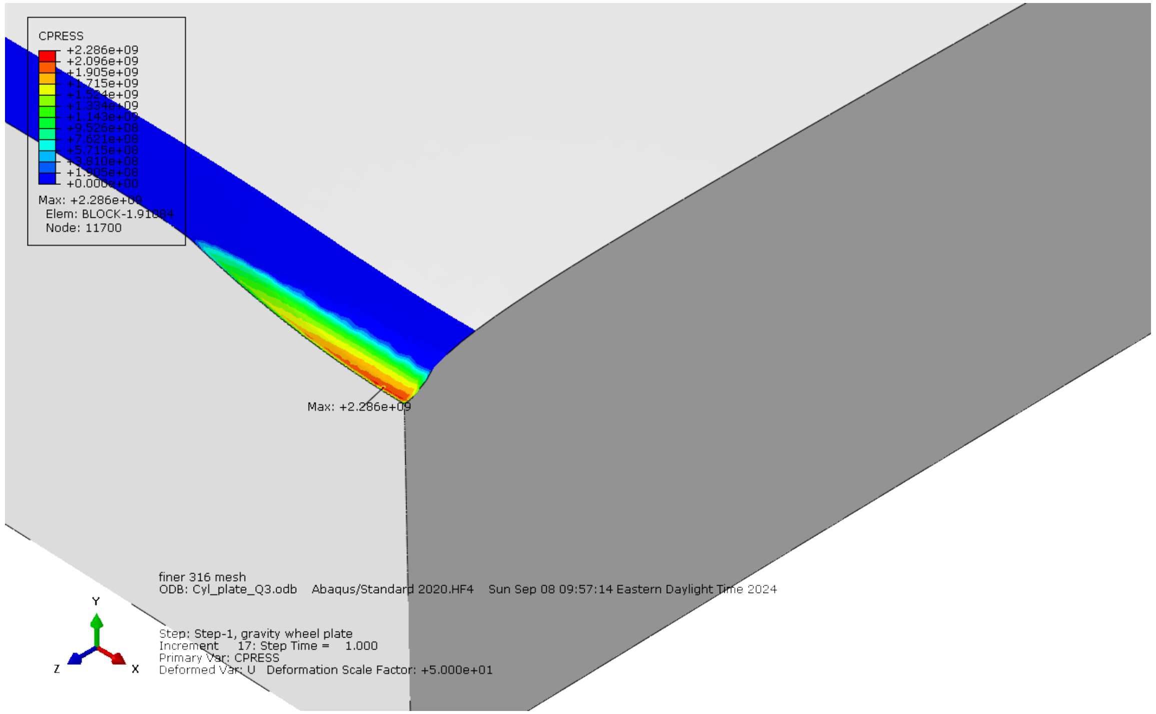


Inconel plate

S 1250 Scale 50x displacements

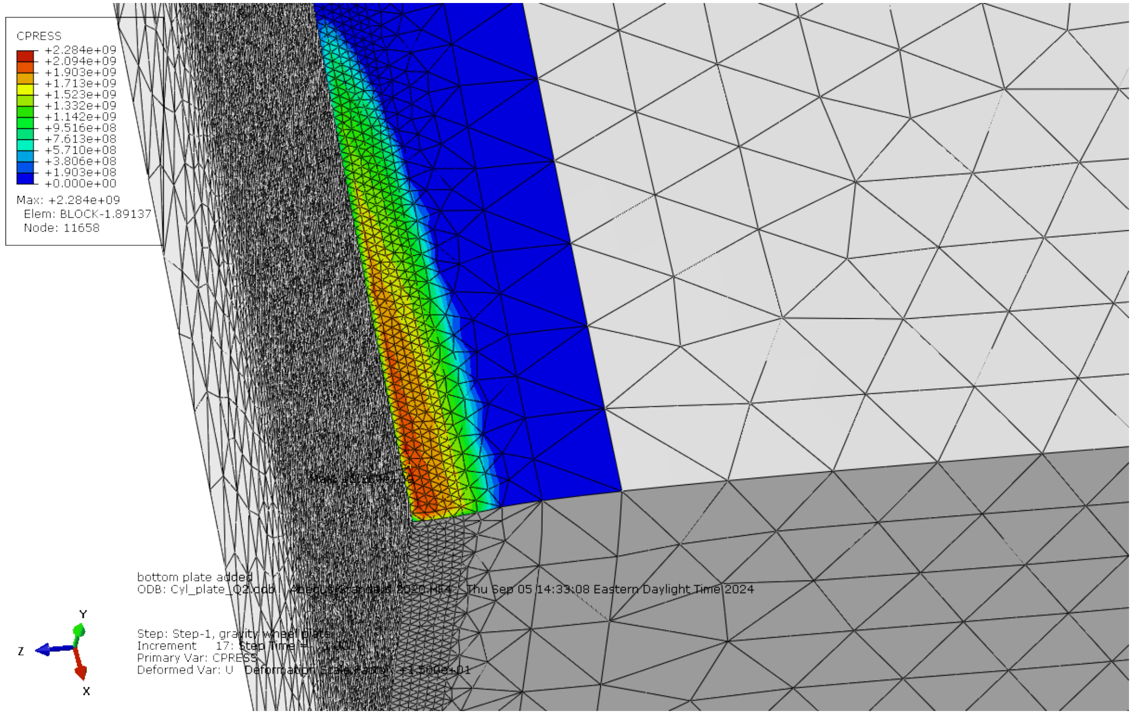


Block Contact pressure –peak 2286 MPa

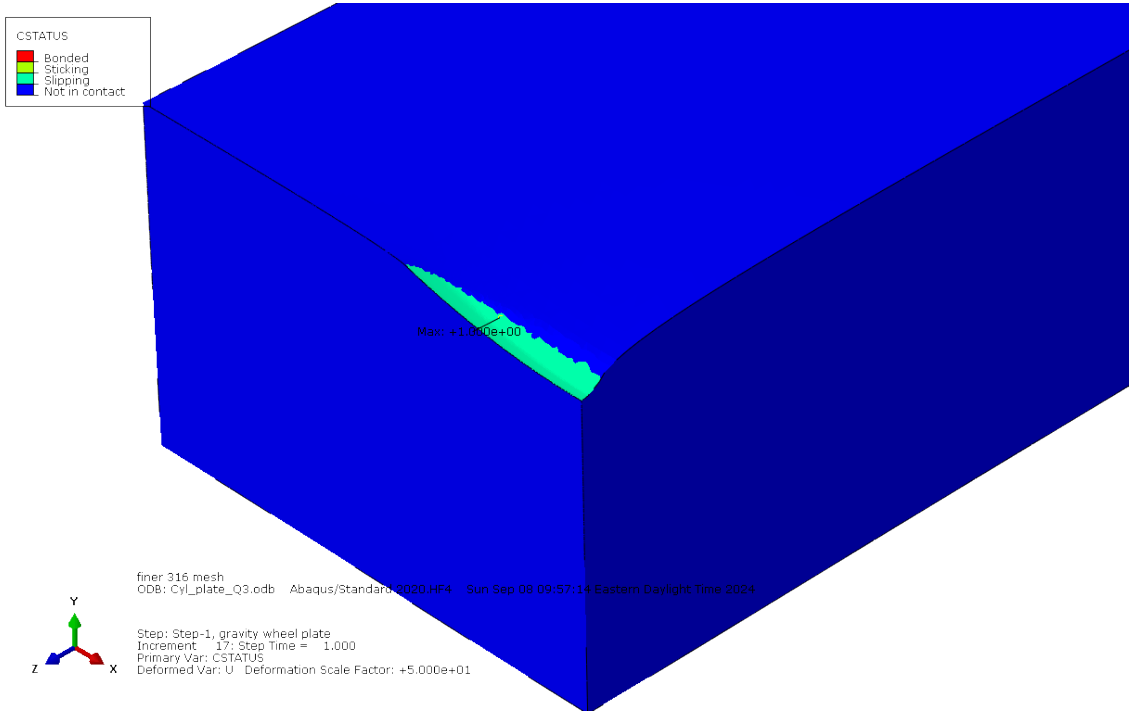


Inconel plate contact surface

Pressure with mesh shown



Block Contact status



Contact area roughly .5mm x 6mm or 1mm x 12 mm for full model

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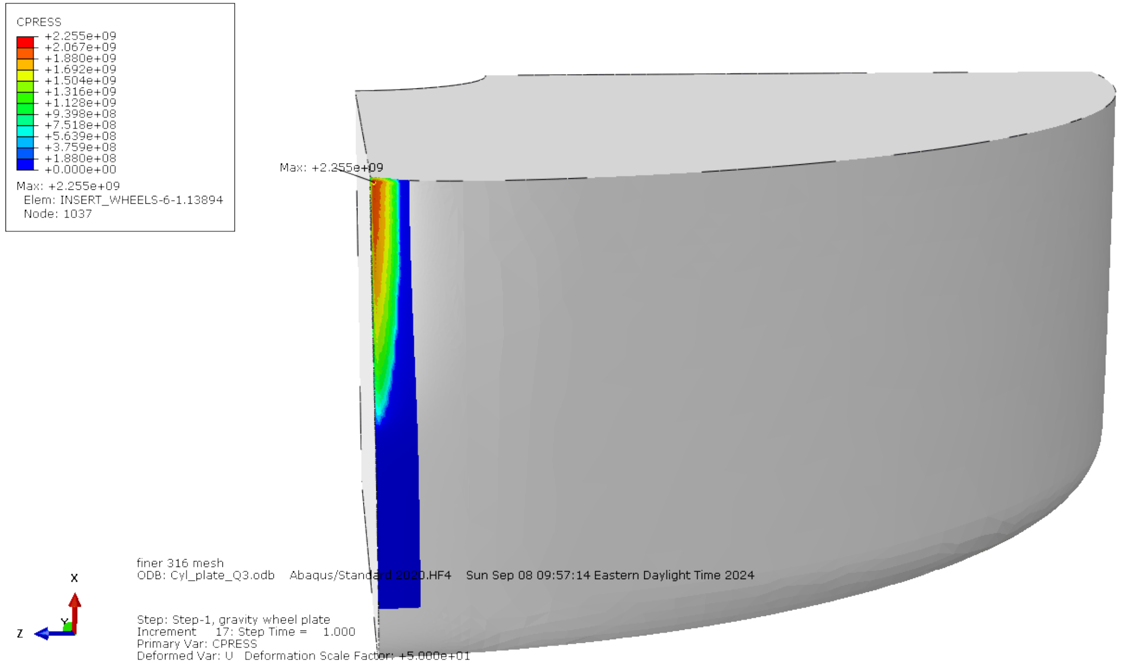
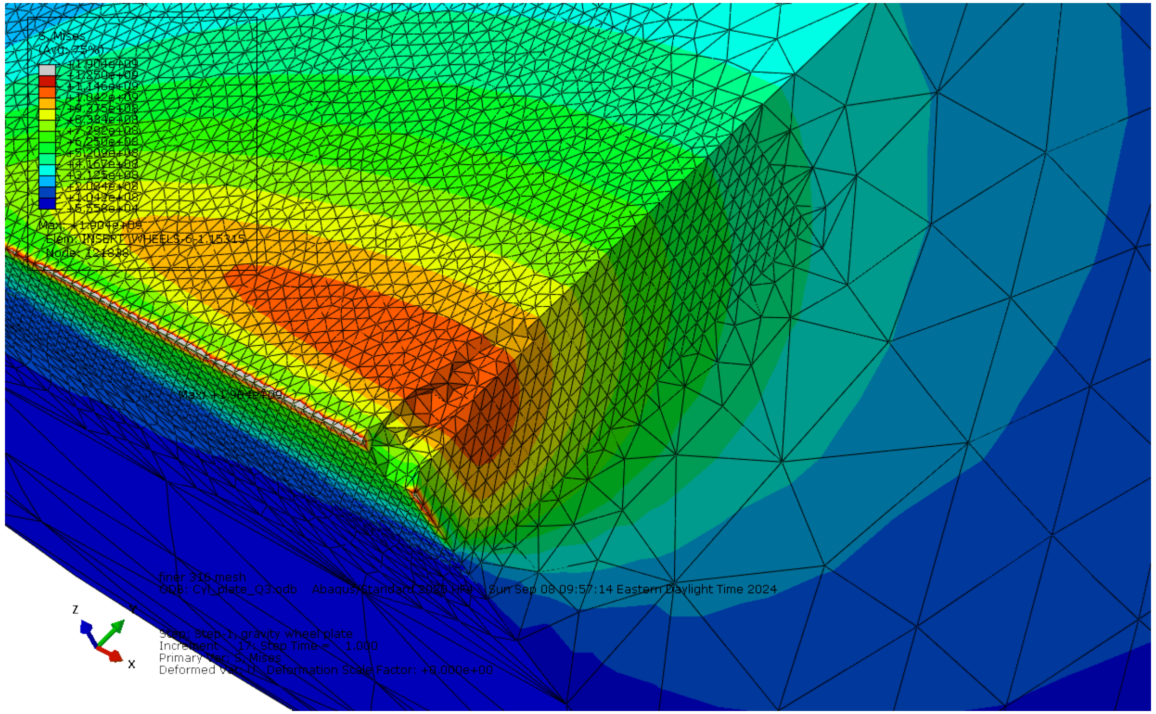
Wheel contact pressure and stress

Wheel Contact pressure



Wheel S 1250 MPa scale mesh with cut to interior



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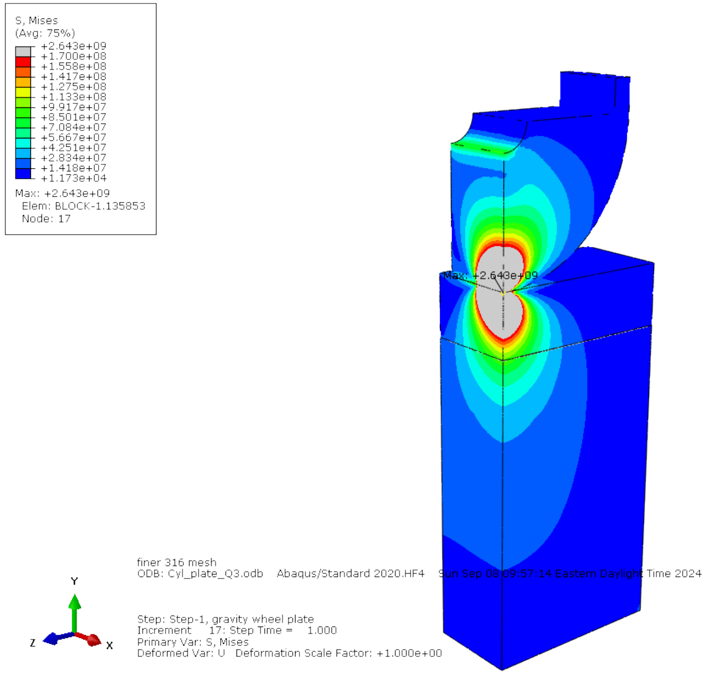
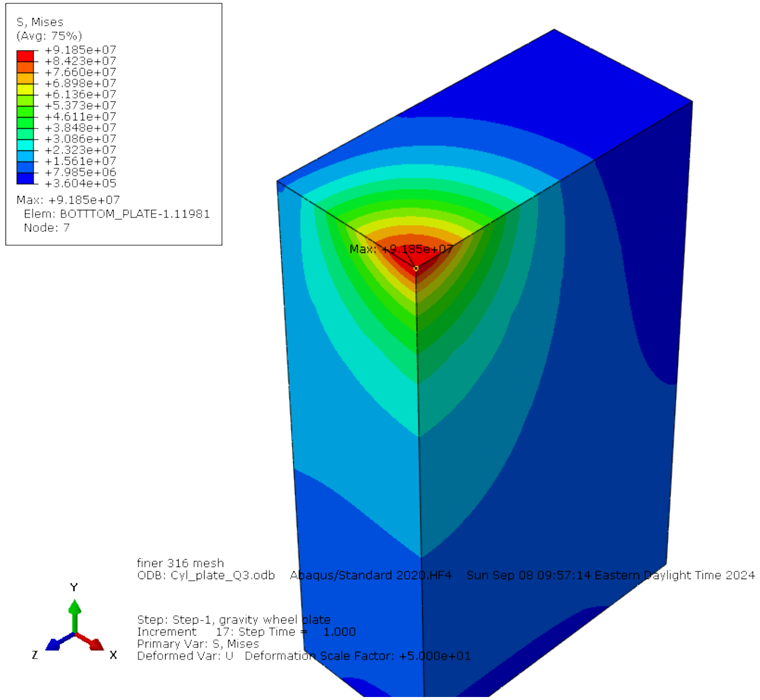
Assembly stress with 170 MPa scale

Von Mises stress 170 MPa scale



Bottom 316L section Stress peak 91 MPa

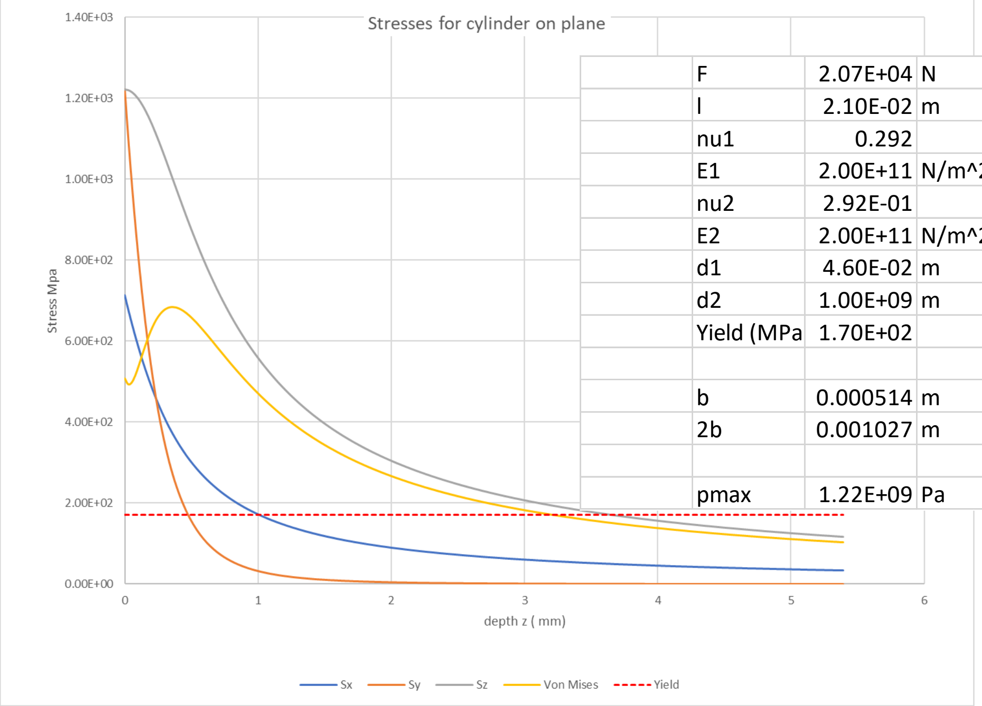


Comparison to ideal cylinder on plate

Summary

- Ideal contact give a bearing width of 1 mm and contact pressure of 1220 MPa
- Crown on Abaqus model wheel width reduces the contact width by about half and doubles the contact pressure
- Abaqus results appear consistent with ideal case with accounting for reduced contact area

46 mm Diameter – 21 mm wide cylinder with 2110 kg gravity load



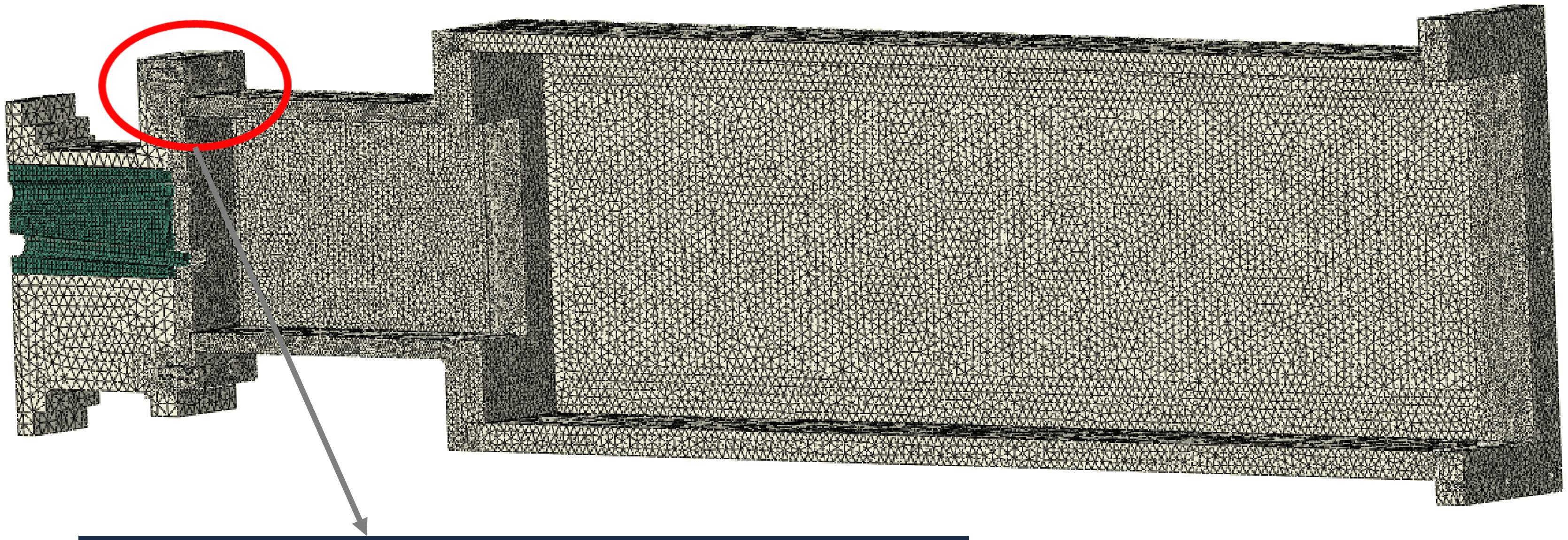
F	2.07E+04	N
l	2.10E-02	m
nu1	0.292	
E1	2.00E+11	N/m^2
nu2	2.92E-01	
E2	2.00E+11	N/m^2
d1	4.60E-02	m
d2	1.00E+09	m
Yield (MPa	1.70E+02	
b	0.000514	m
2b	0.001027	m
pmax	1.22E+09	Pa

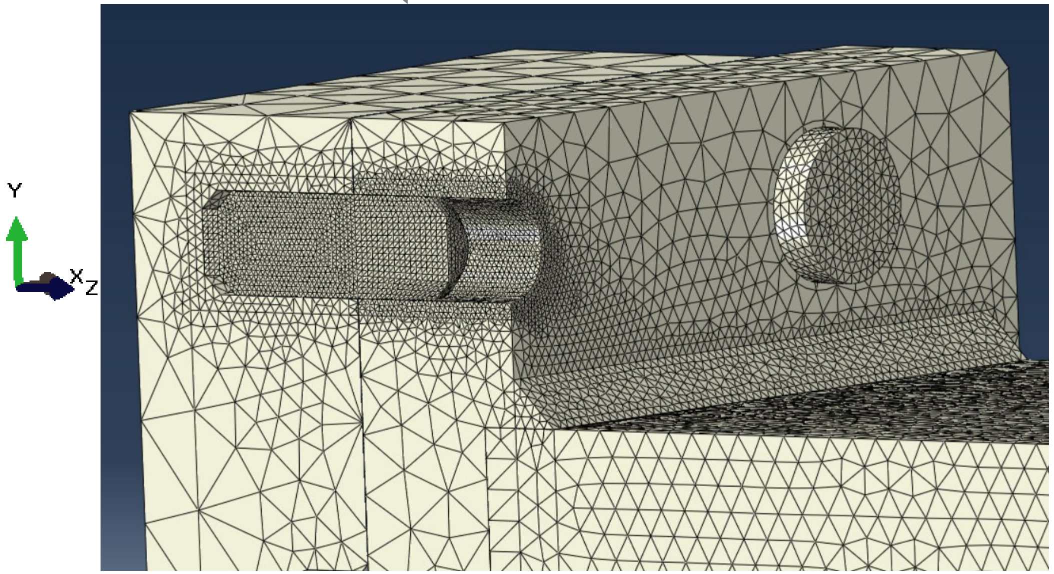
Contact model Analysis Summary

- Elastic analysis gives subsurface Von Mises stresses of approximately 1200 MPa for wheel and mating plate
- The 316L material beneath a 10 mm thick plate has a peak stress of approximately 90 MPa
- No analysis of the loading from the axle included for the wheel
- The 2110 kg/4642 lbs load is less than half the rated 10,000 lbs
- Local yielding can be expected in the mating plate
- A reasonable approximation of the contact area is an axial length of 1 mm and a horizontal width of 12 mm

Assembly Mesh Model

- 3,462,970 elements
- C3D10 tet elements except for front in green C3D8R elements

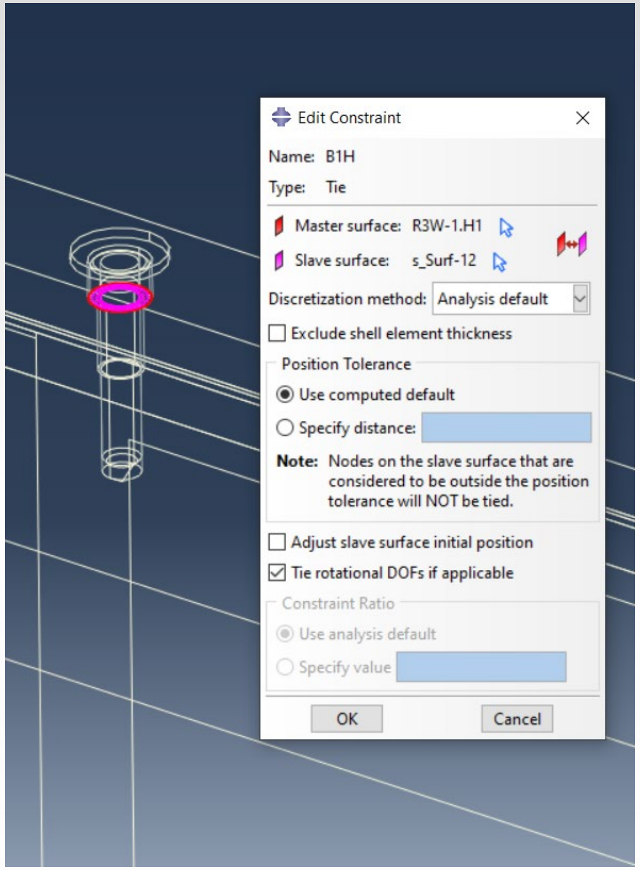




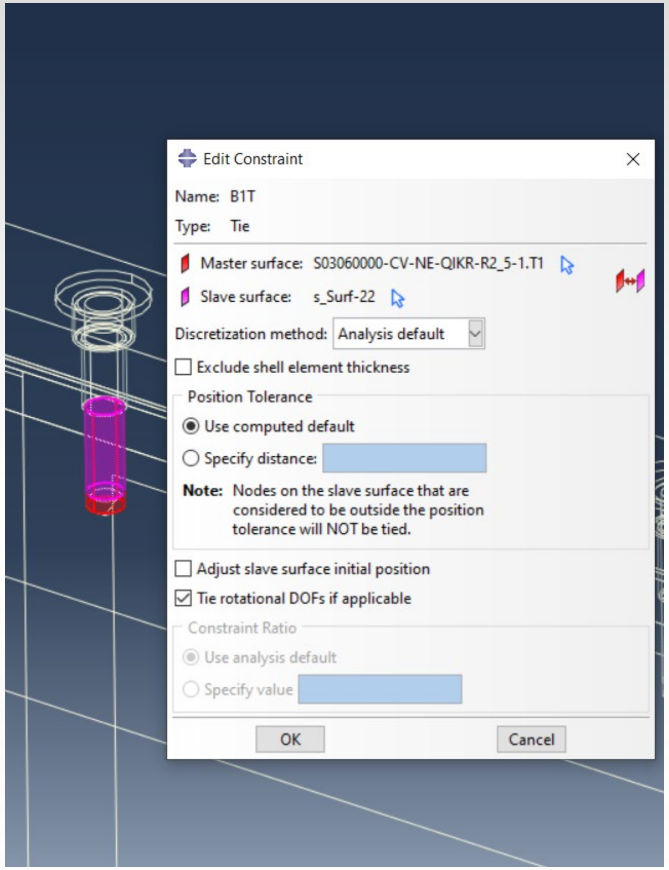
12 mm bolt Constraints -168

- Each of 84 12 mm bolts was tied on the head surface to the facing plate and tied within the threaded zone of the side plates
- Each bolt surface given a unique name
- Each plate surface give unique name
- No pre-load assumed

Typical bolt head tie

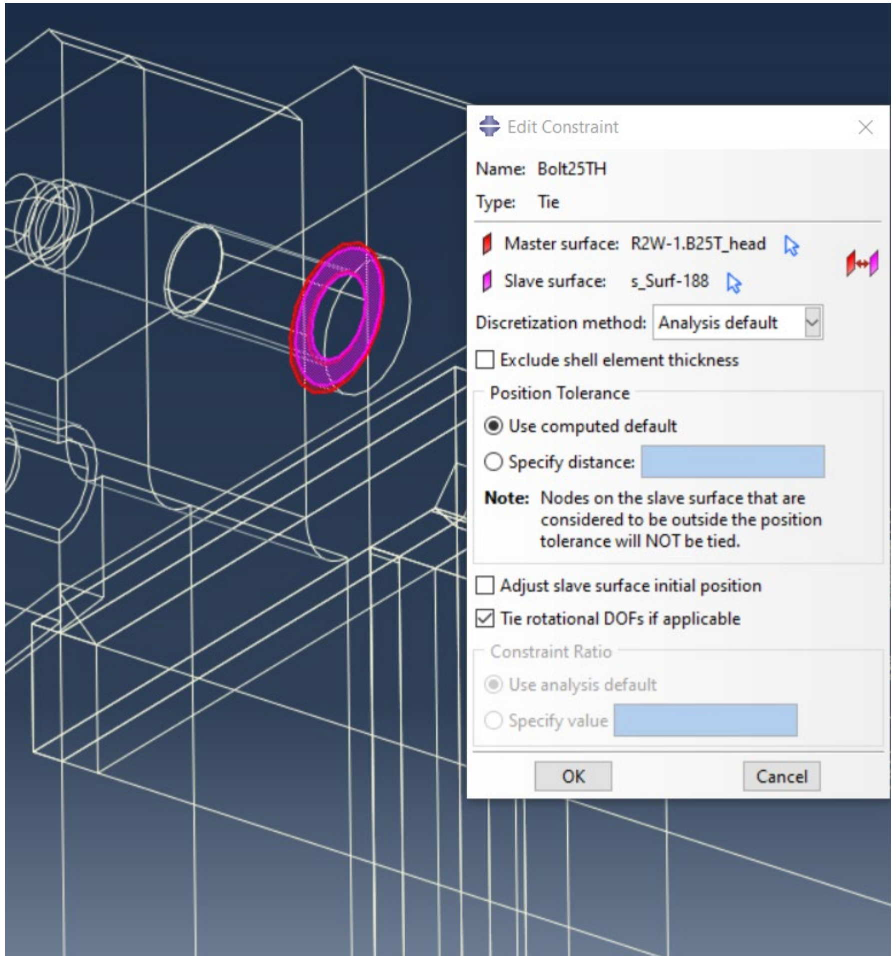


Typical threaded zone tie

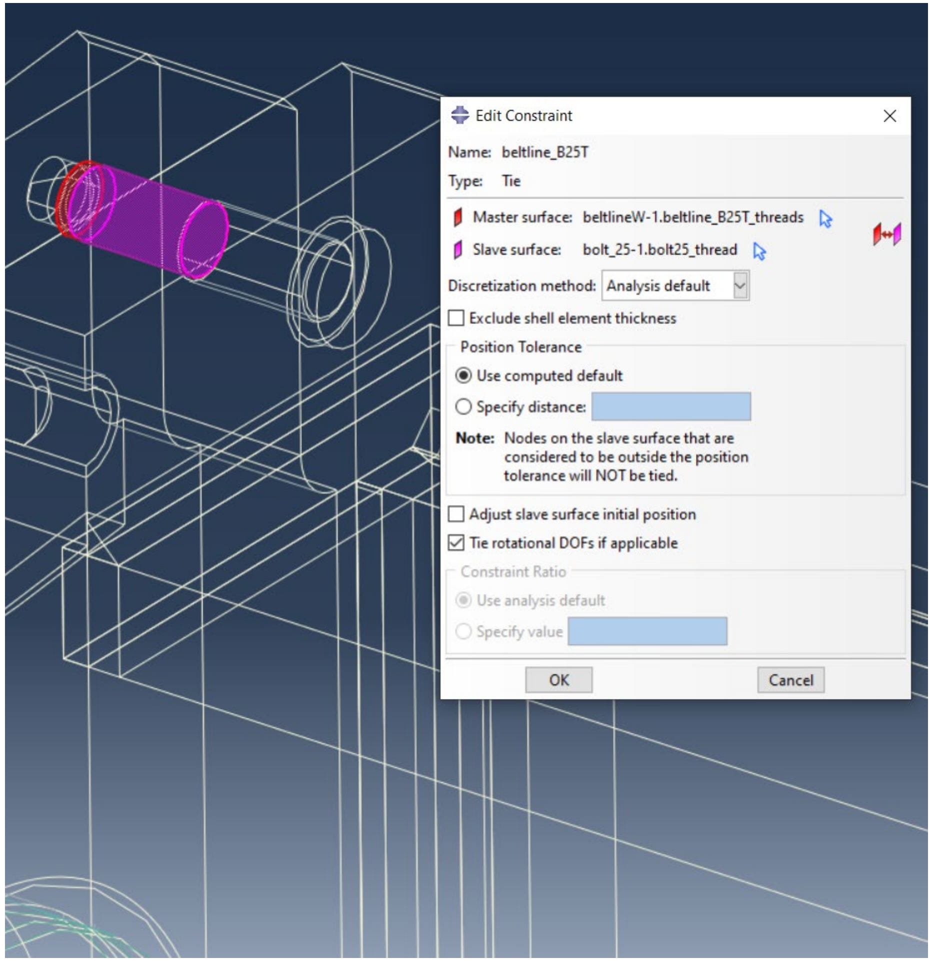


Front flange top bolt tie constraints - bottom constraints similar

Upper bolt head to flange tie

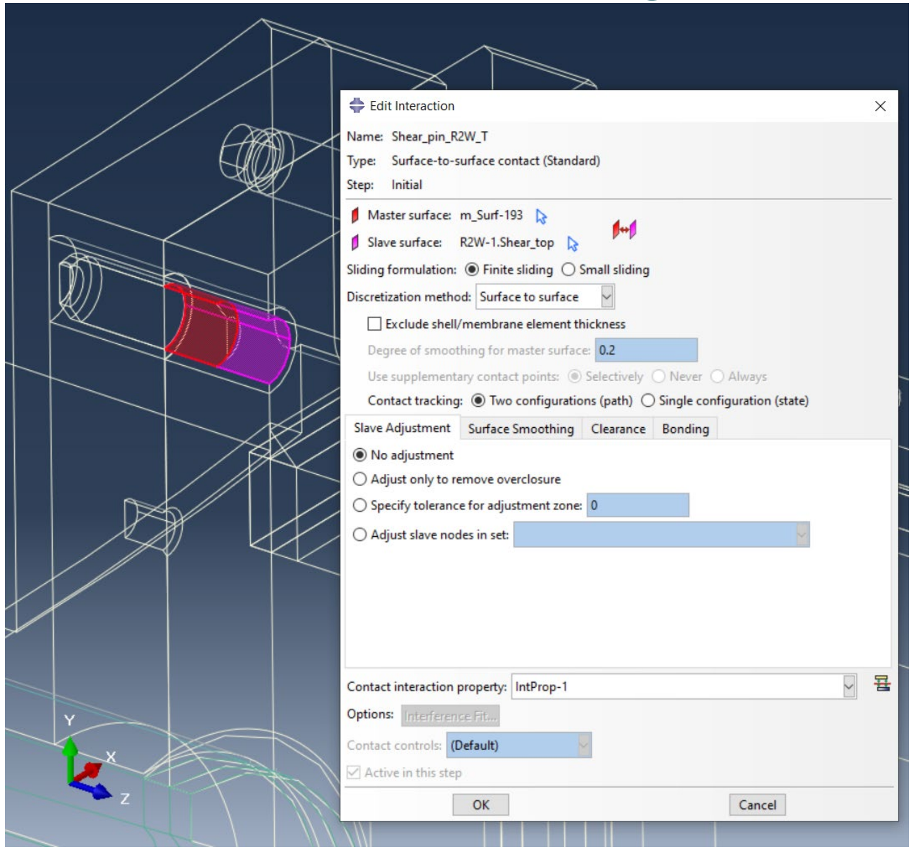


Threaded area tie to beltline

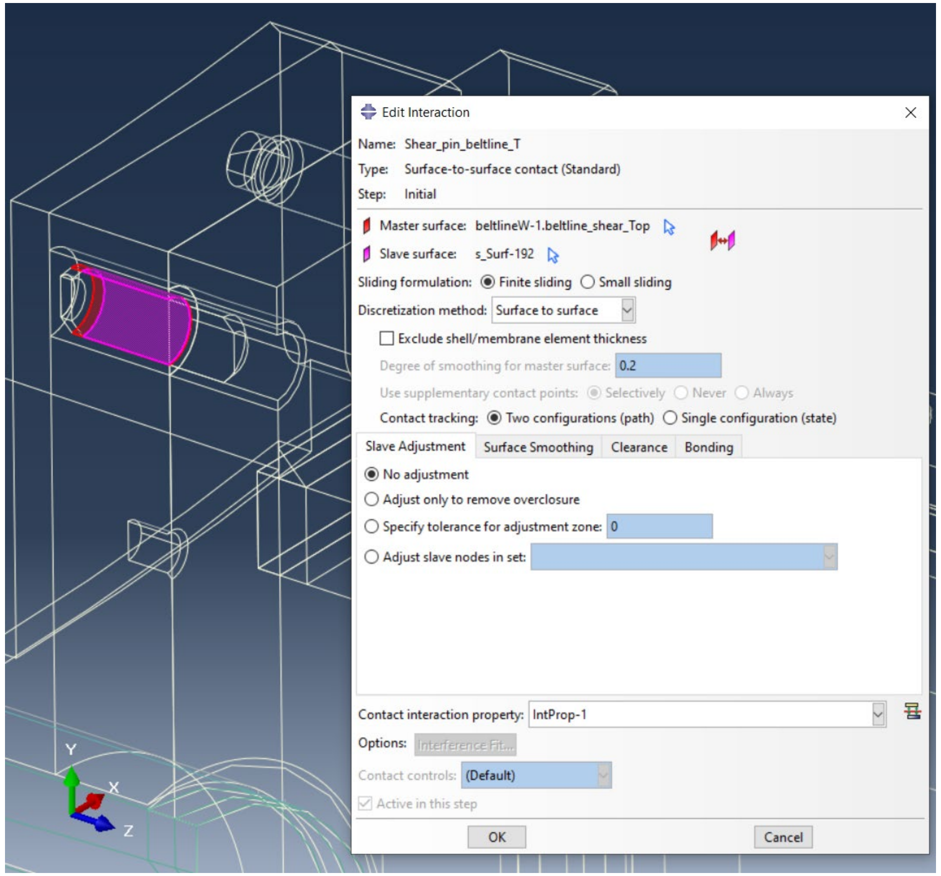


Shear Pin Surface to Surface Interactions – top shown – bottom similar

Shear Pin to Front Flange



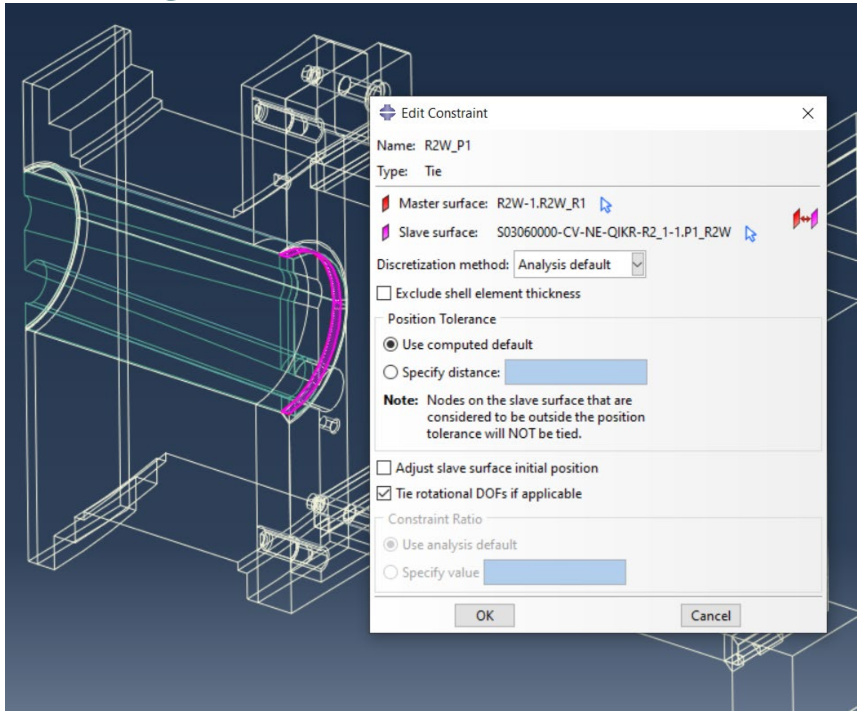
Shear Pin to Beltline



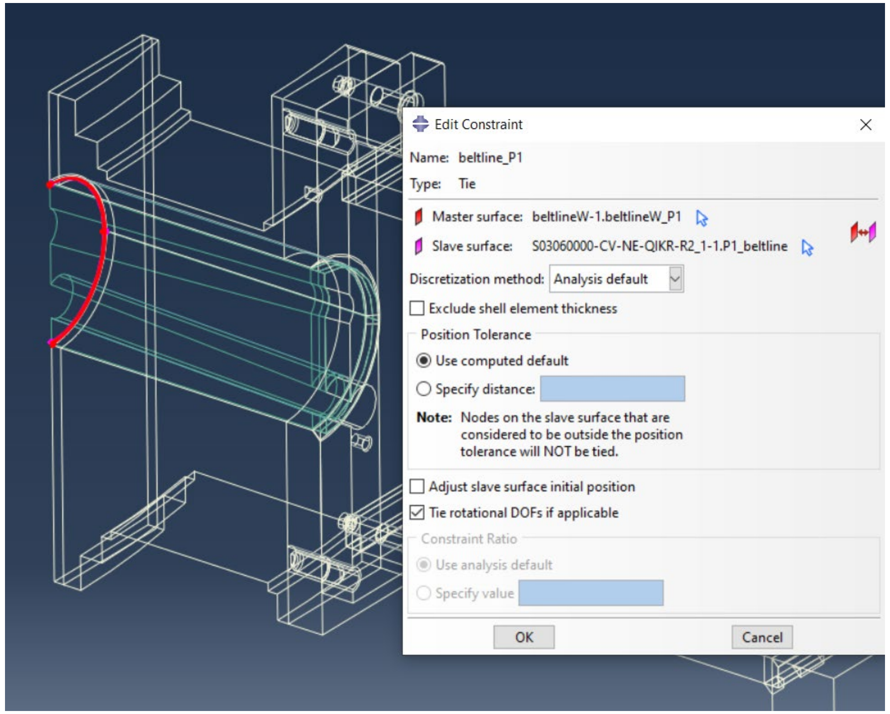
Weld Tie Constraints

Front Flange (R5W) and Beltline welds

Front Flange to Part 1

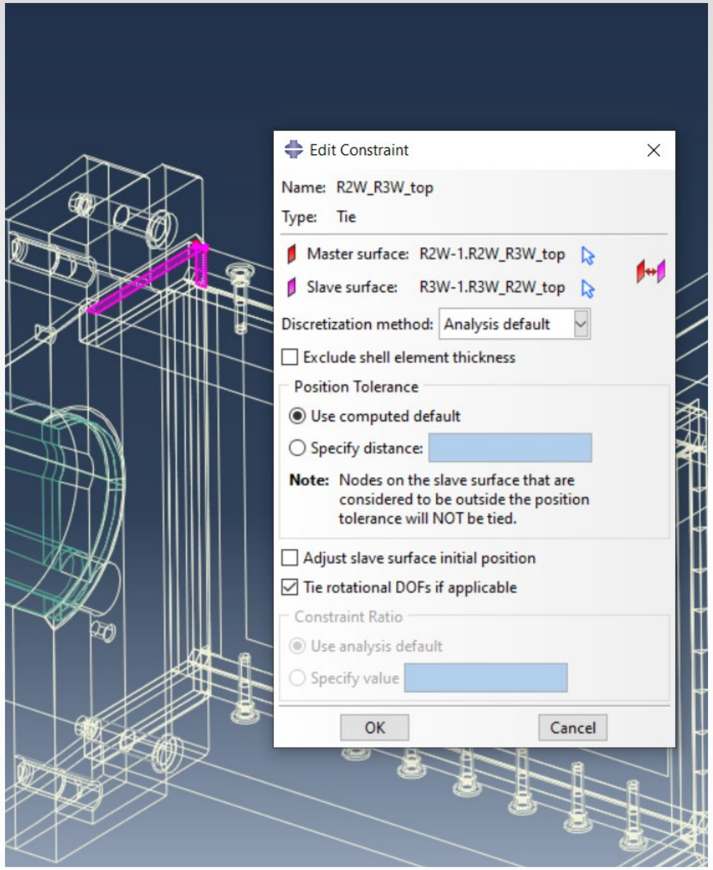


Beltline to Part 1

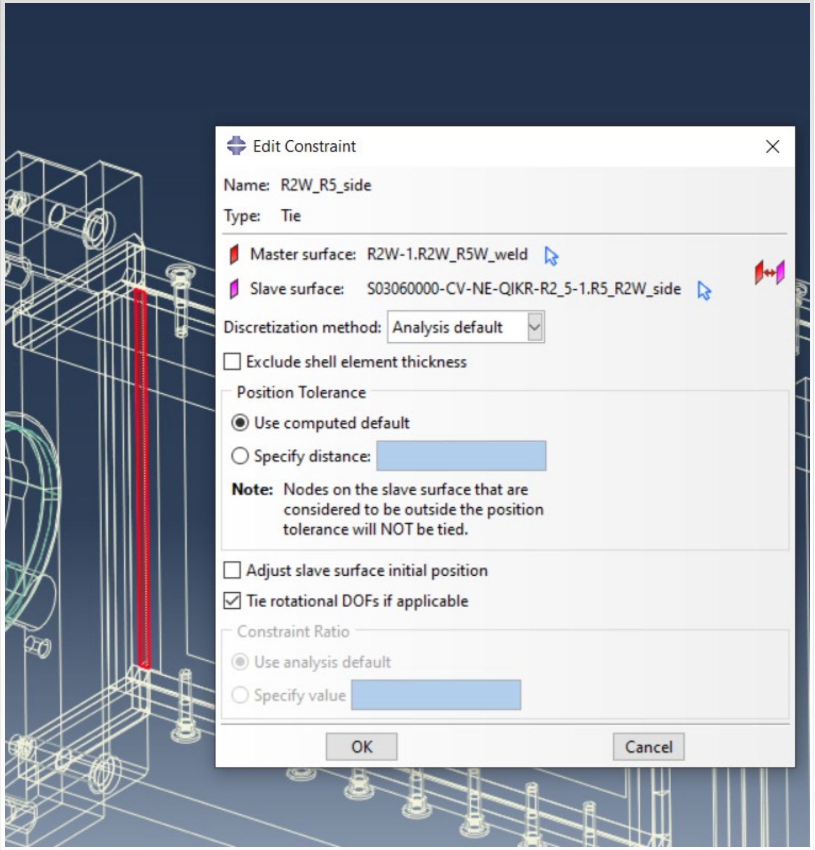


Front Flange (R2W) welds

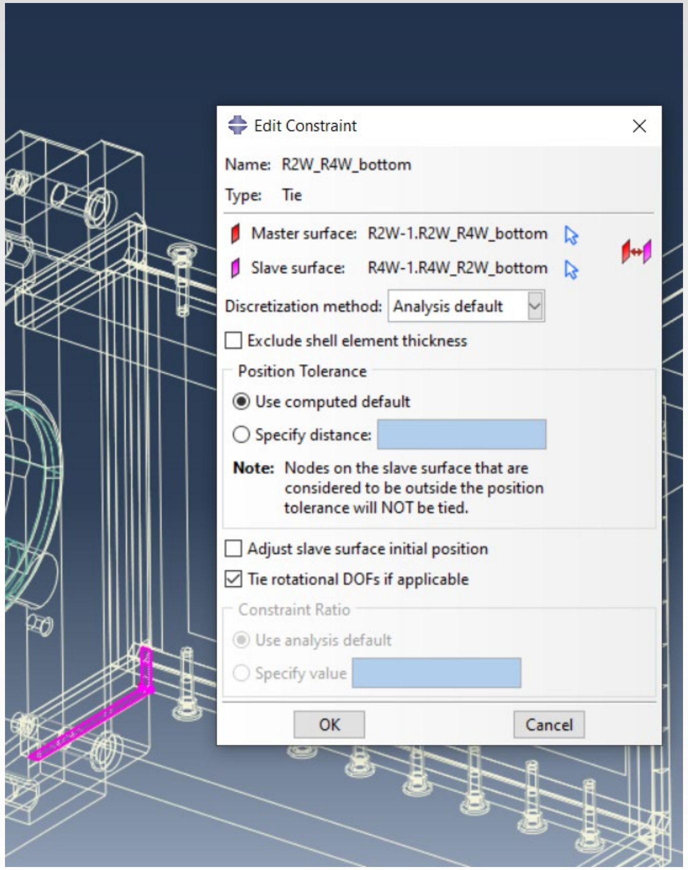
Front Flange to front top plate



Front Flange to front side plate

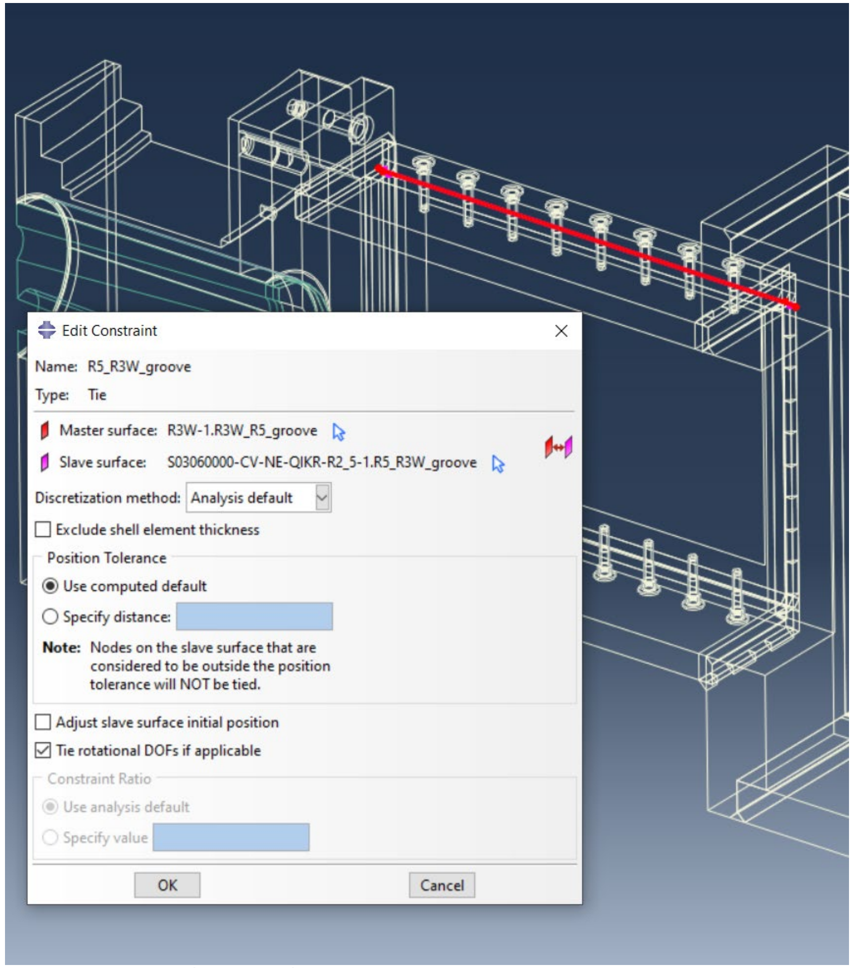


Front Flange to front bottom plate

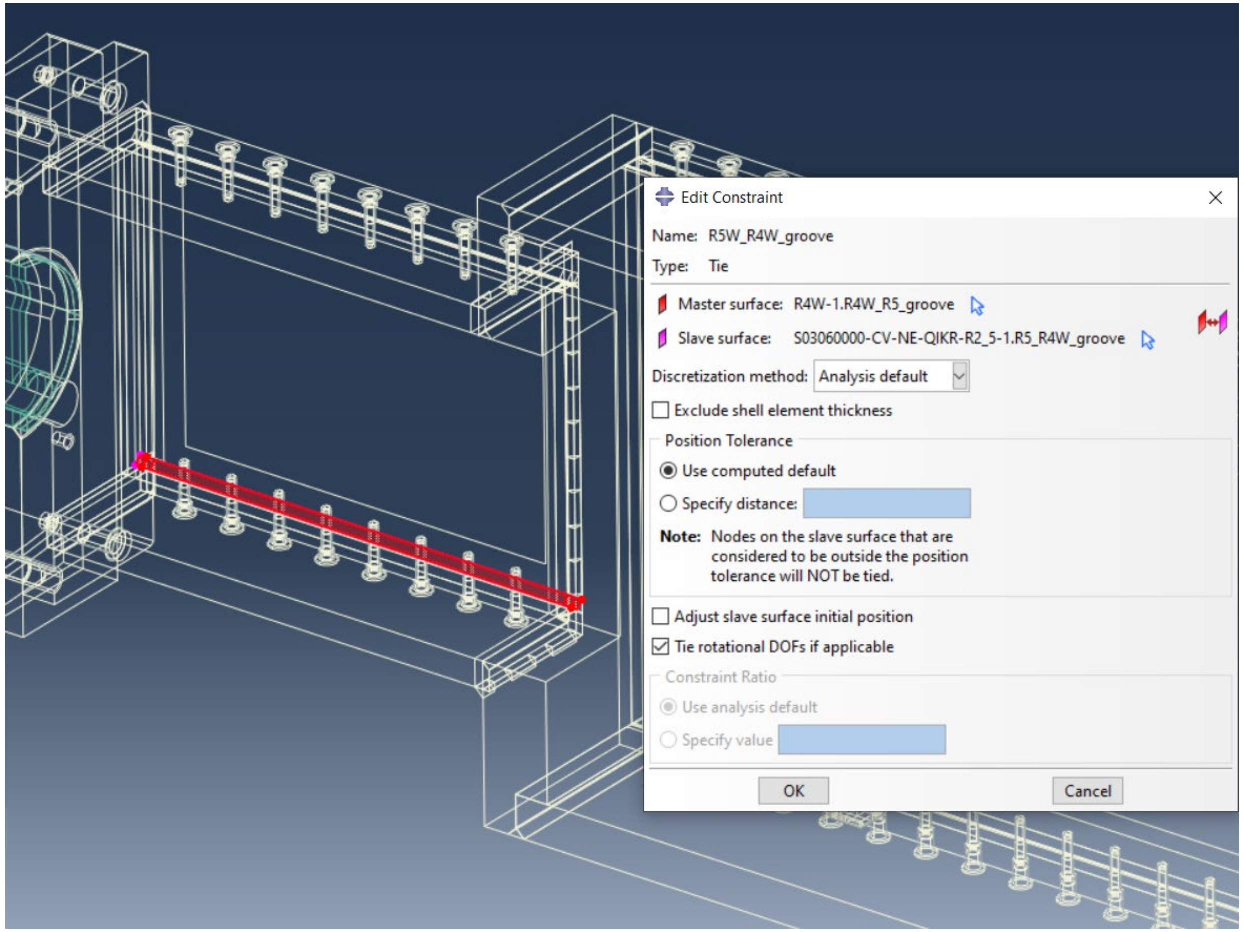


Front 10 mm Groove welds

Front top plate groove weld

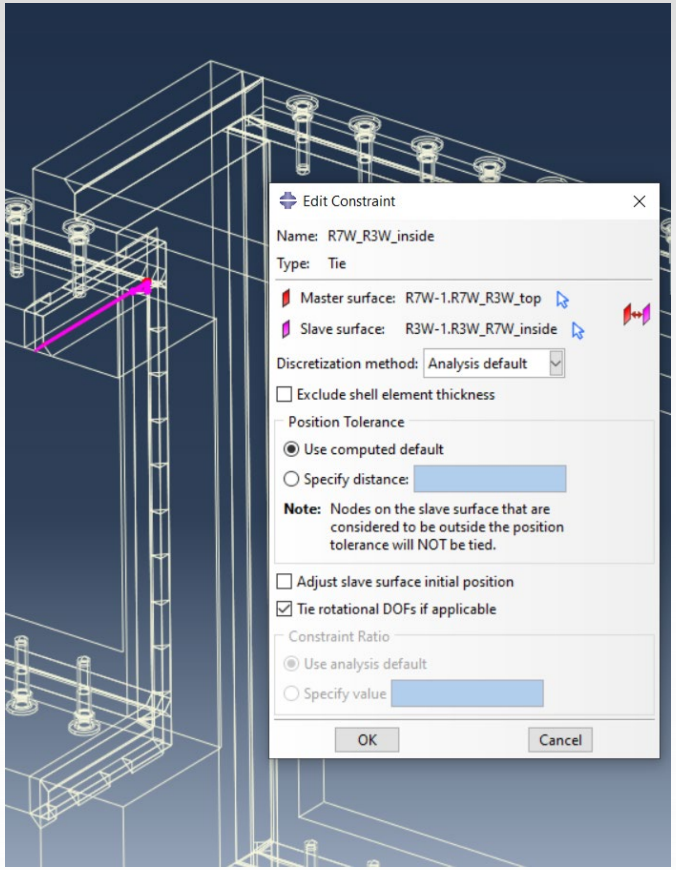


Front bottom plate groove weld

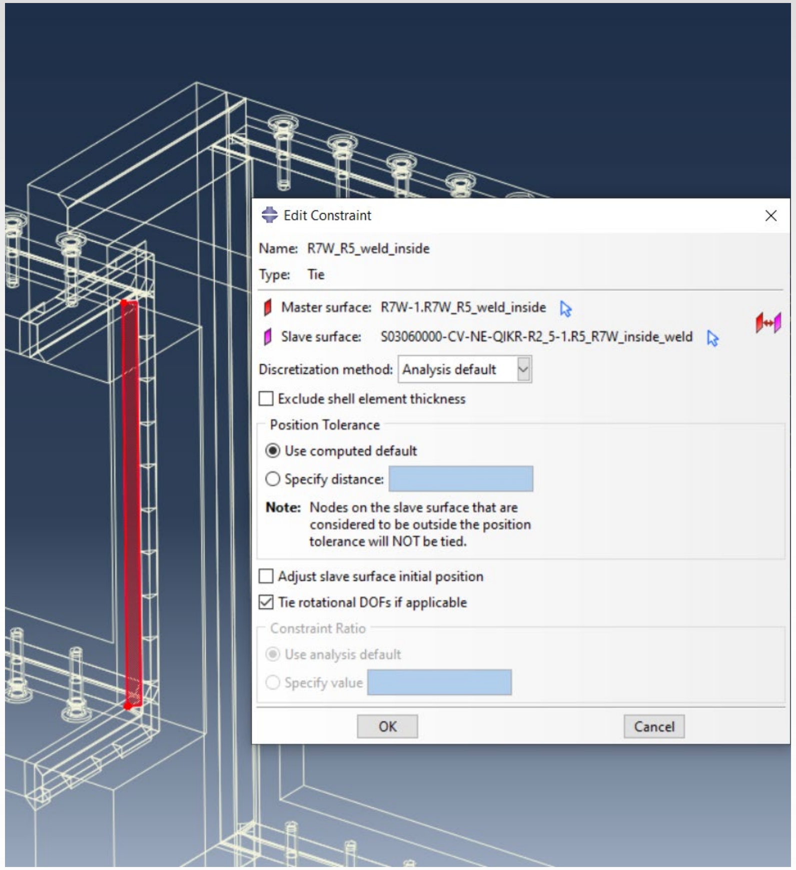


Intermediate flange (R7W) welds

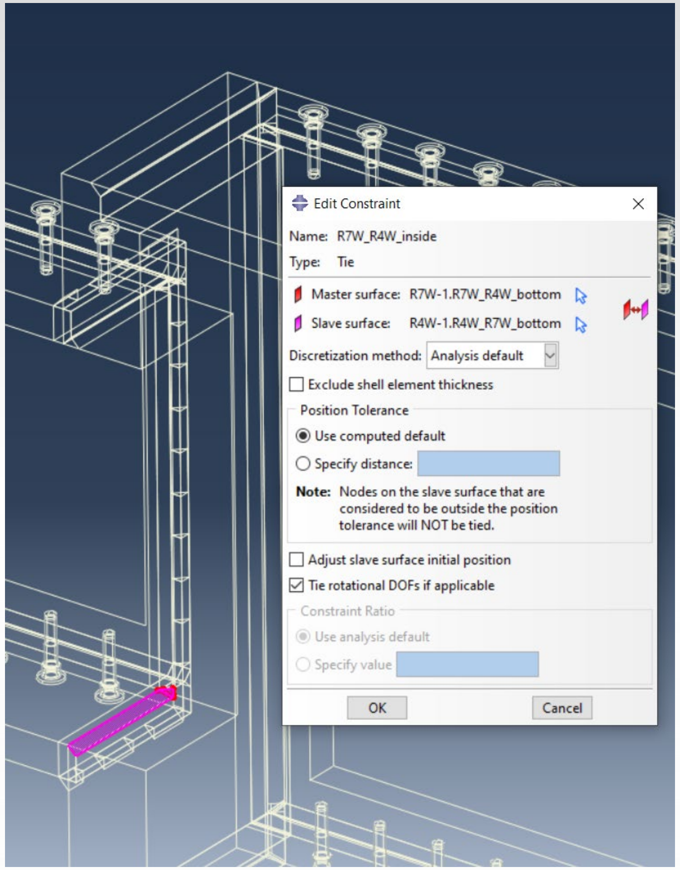
Intermediate flange to front top plate



Intermediate flange to front side plate

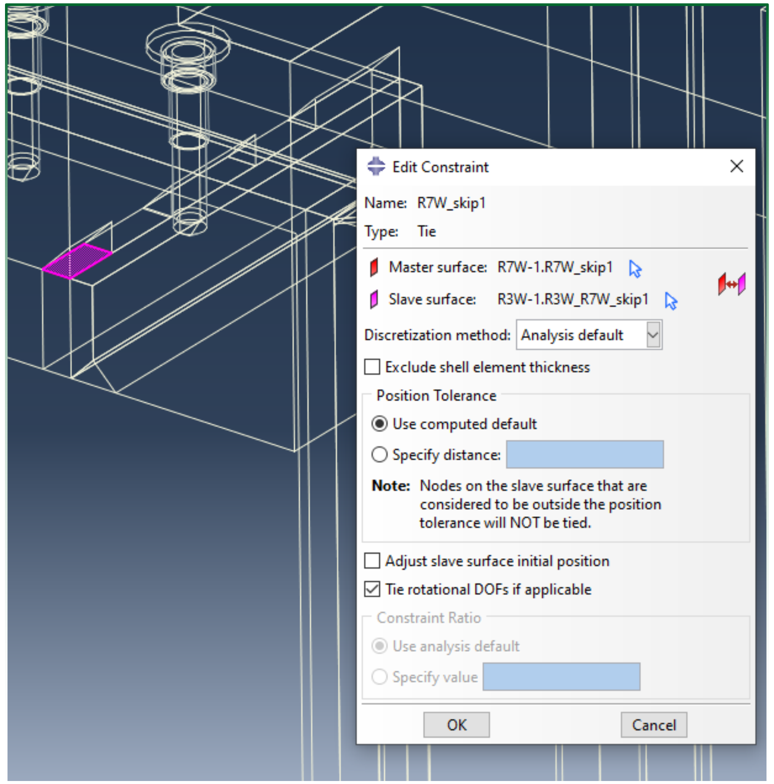


Intermediate flange to front bottom plate

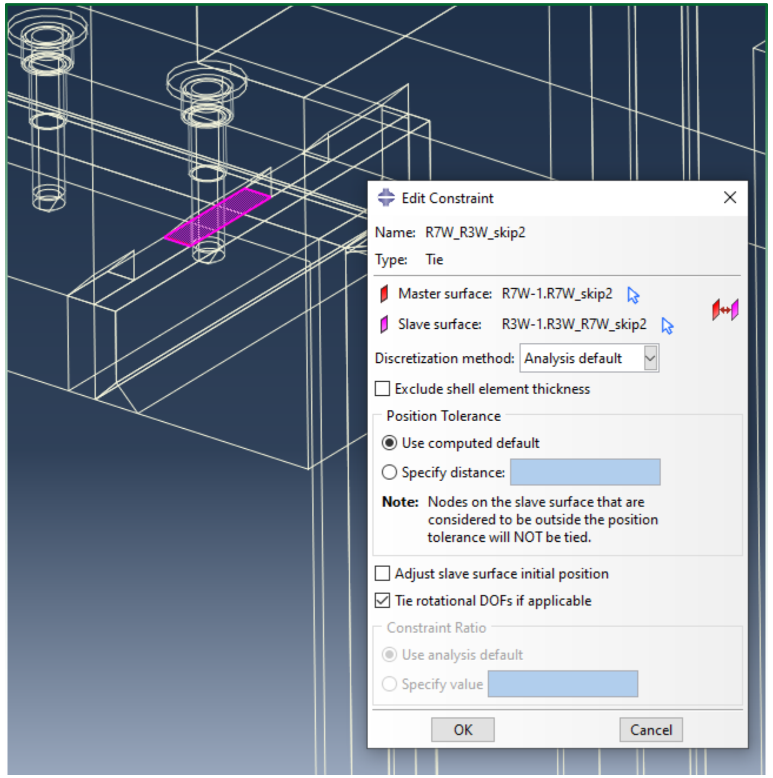


Skip weld ties around Intermediate flange – 11 total

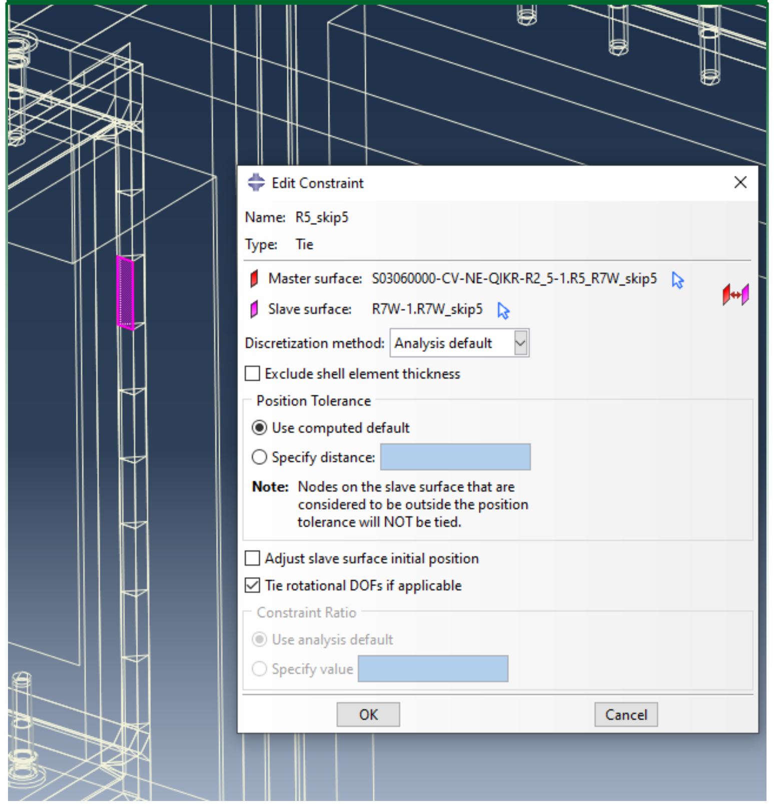
Skip weld tie to top plate



Typical skip weld tie to top or bottom plate

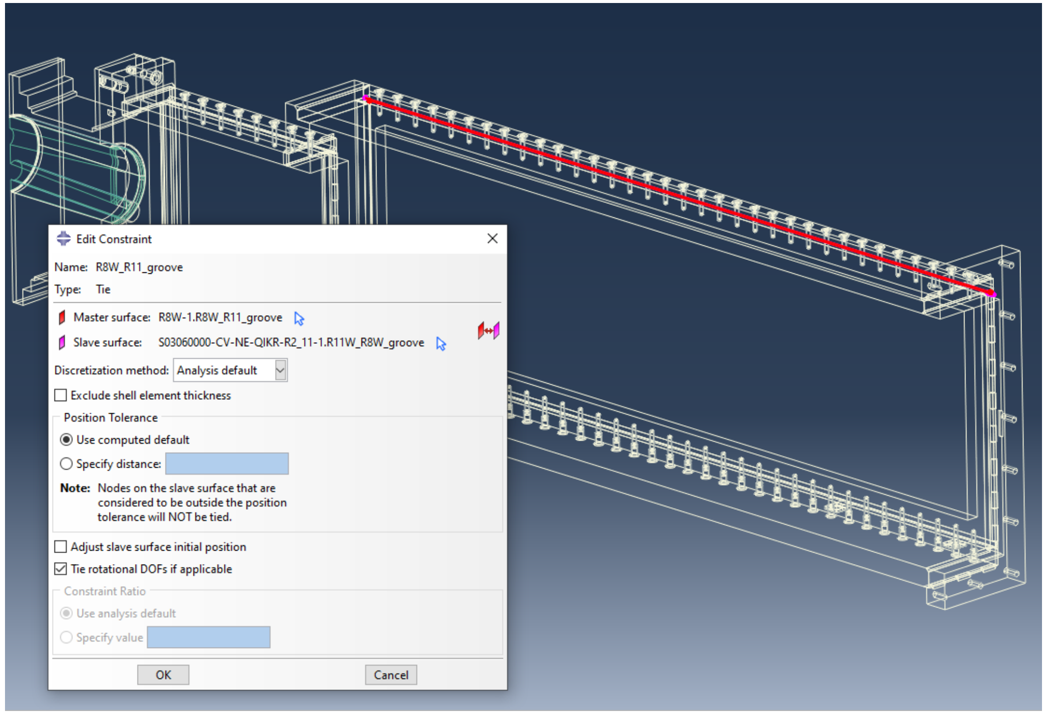


Typical Skip weld tie to front side wall

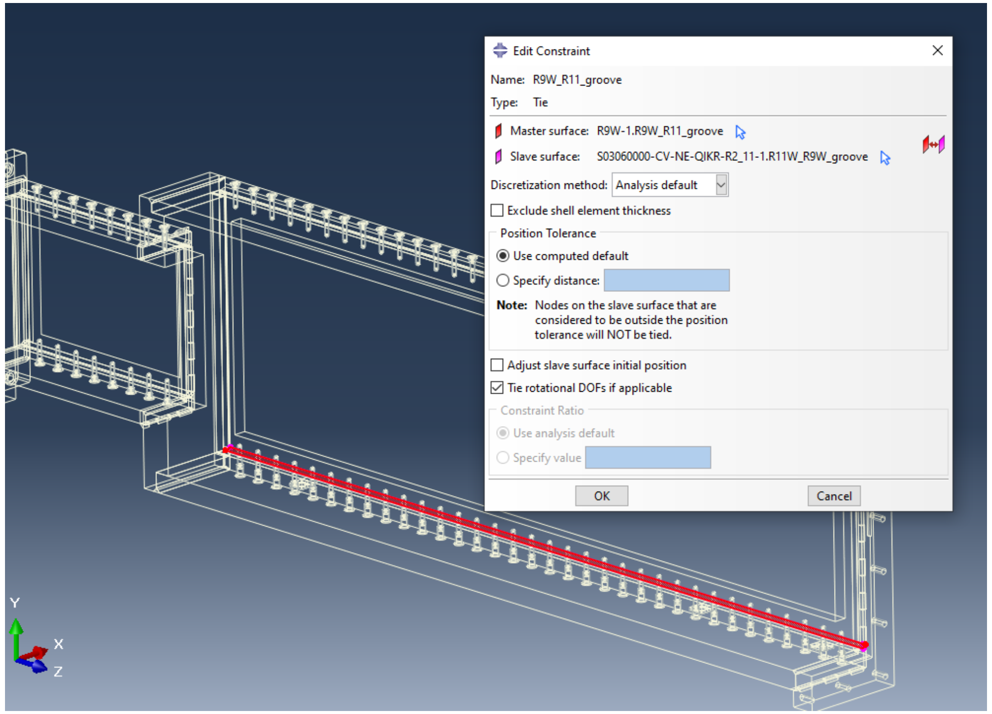


Groove Weld Tie Constraints to rear side wall

Rear Top Groove Weld

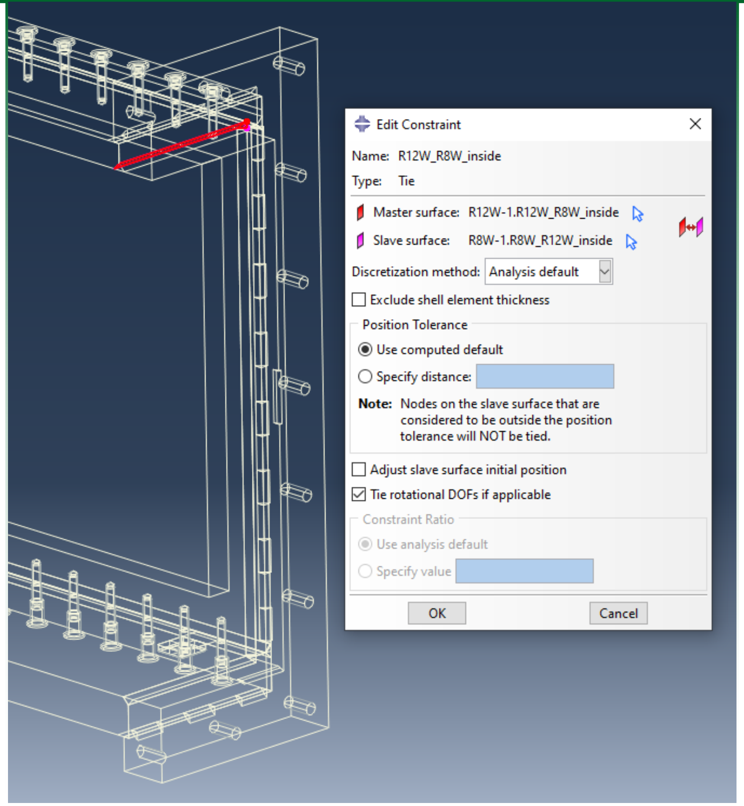


Rear Bottom Groove Weld

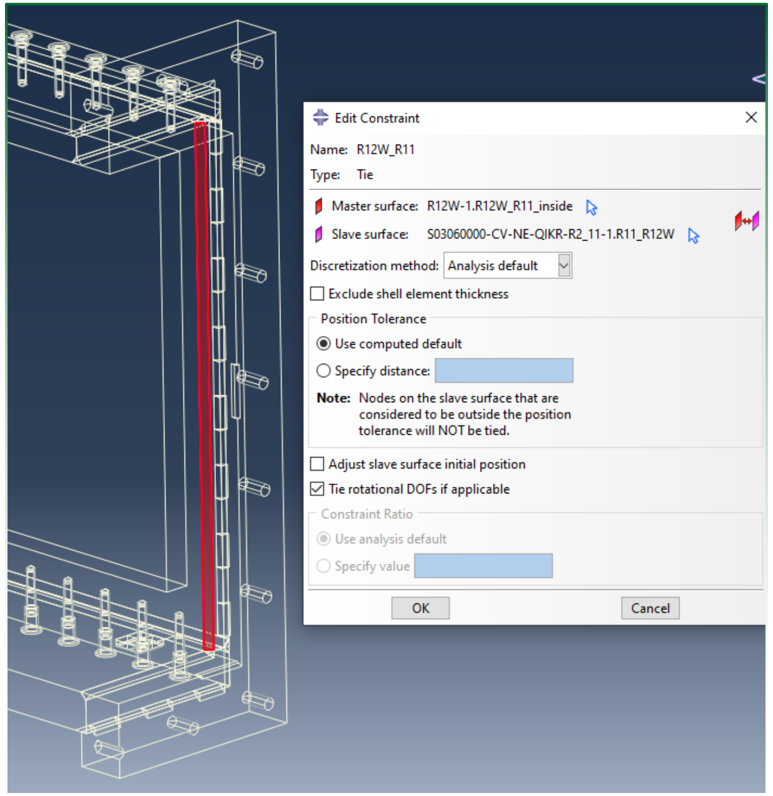


Rear Flange Weld tie constraints

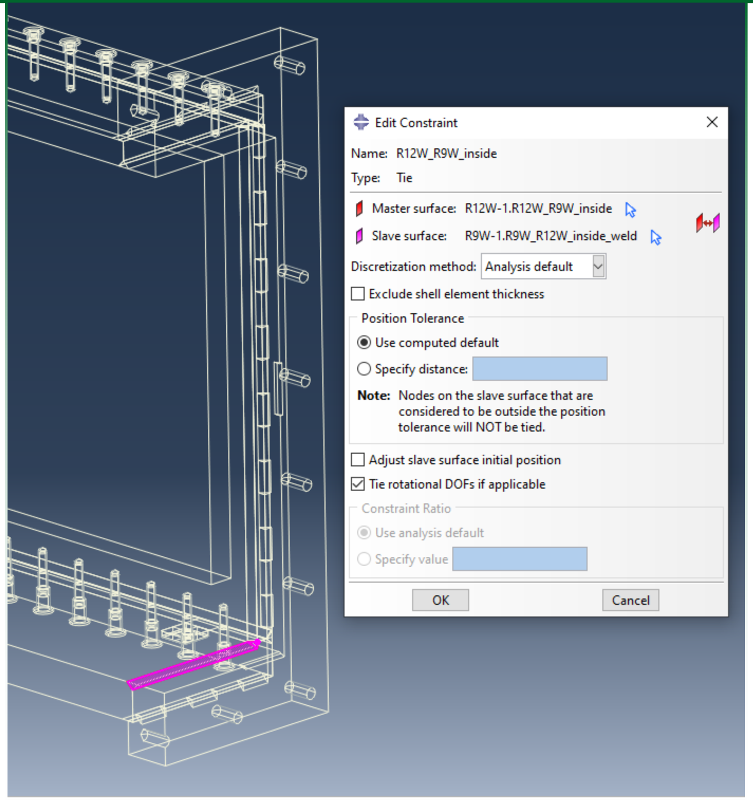
Rear Flange to top plate inside



Rear Flange to side plate

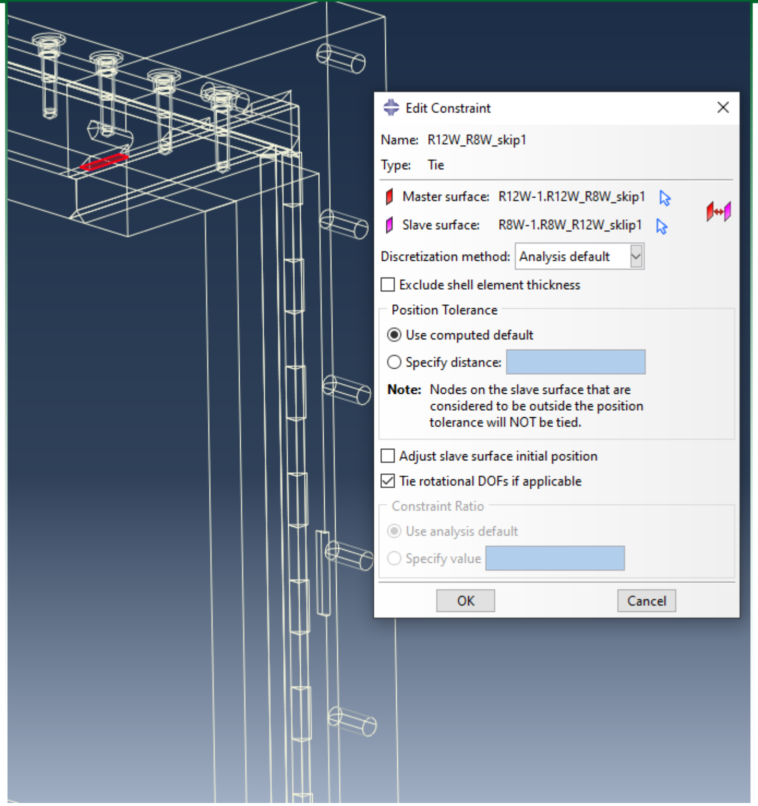


Rear Flange to bottom plate inside

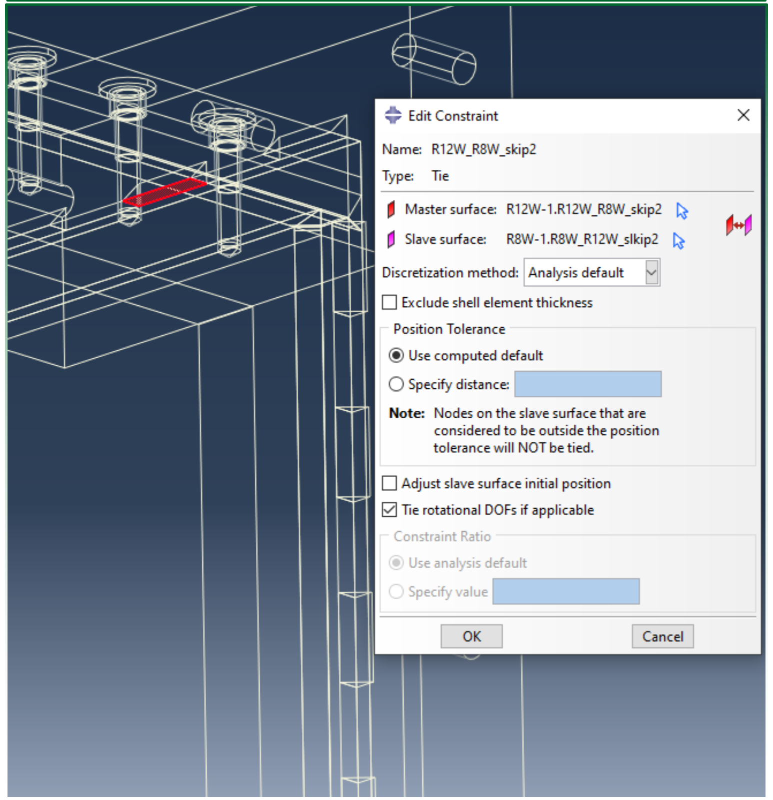


Skip weld tie constraints with rear flange – total 14

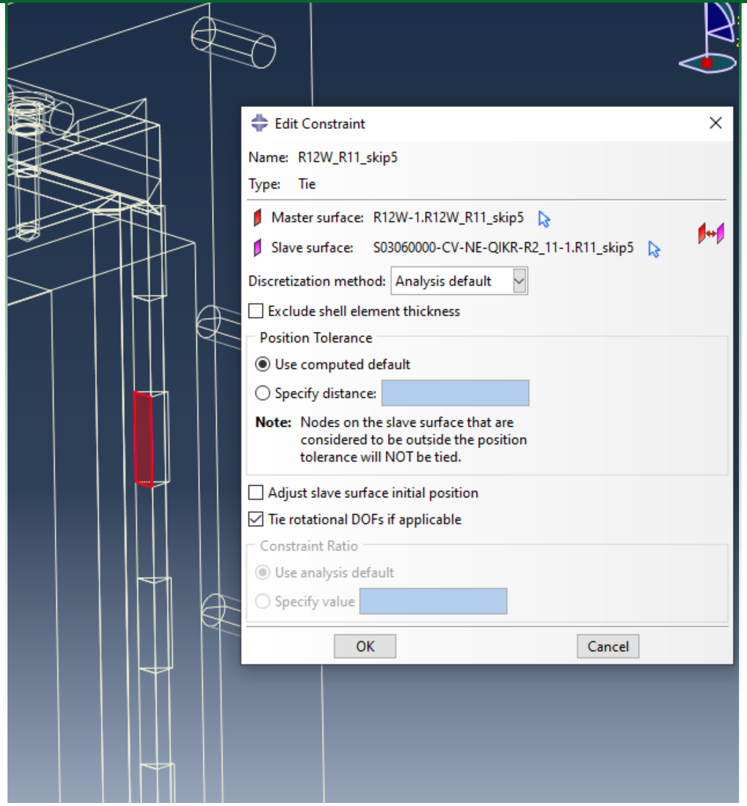
Centerline skip weld



Typical top or bottom skip weld



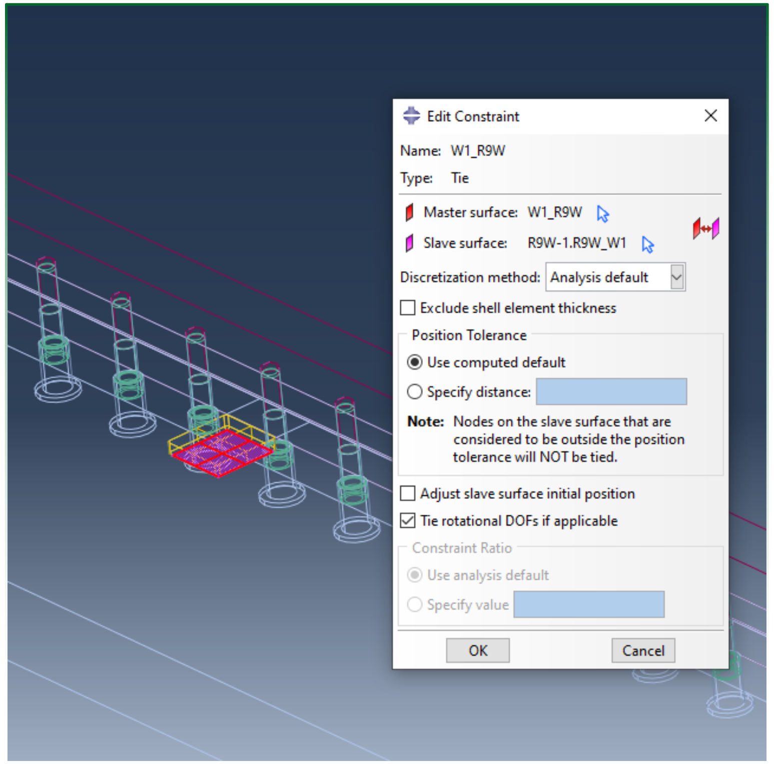
Typical side wall skip weld



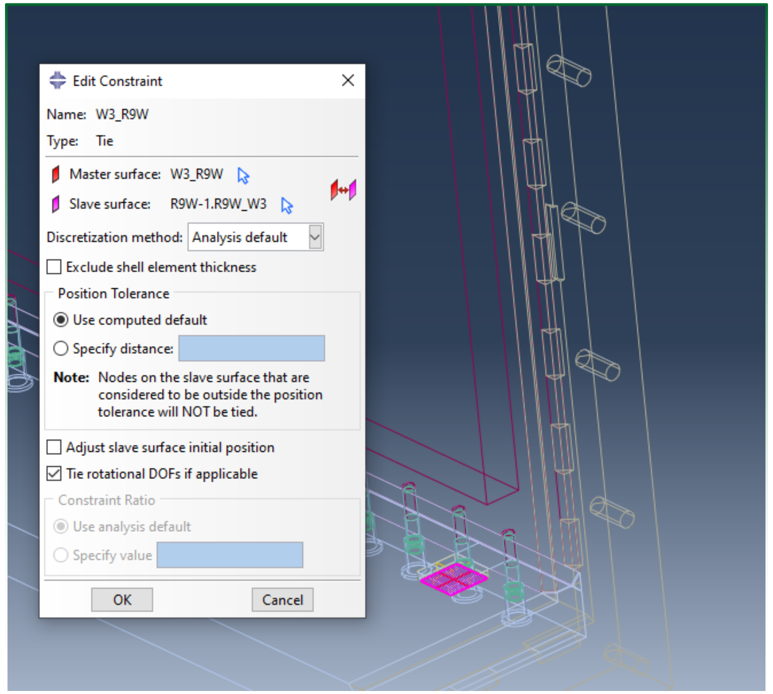
Inconel pad tie constraints to bottom plate (3 locations)

The SpaceClaim model included 4 mm screws and mating holes in the corners of the pads and bottom plate which were defeatured for the Abaqus model

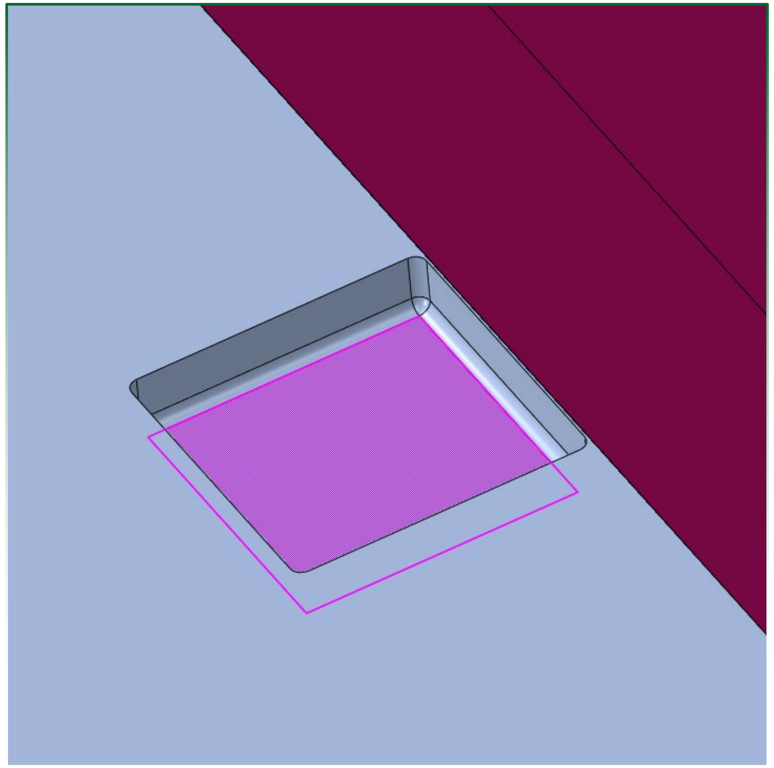
Front Wheel pad tie



Rear Wheel tie

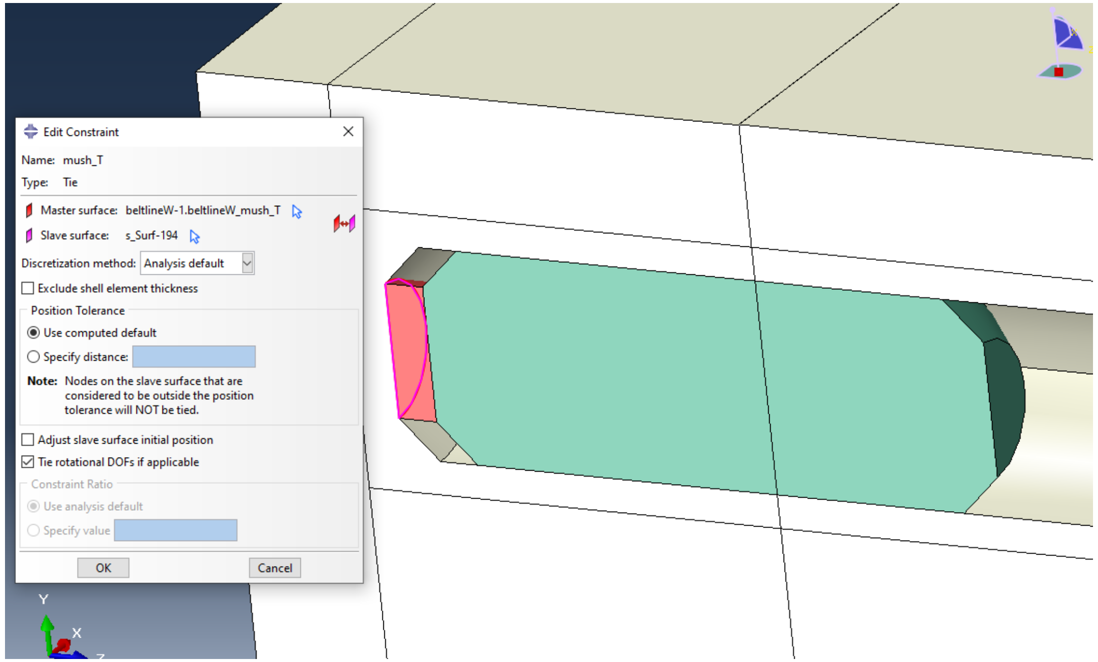


Bottom plate tied surface



Shear pin tie constraint

- With only frictionless surface to surface interactions for the shear pins there would be no axial restraint
- For numerical stability a very low modulus (.01 GPa) extrusion was added to the rear and tied to the beltline
- No significant effect on stress or displacement

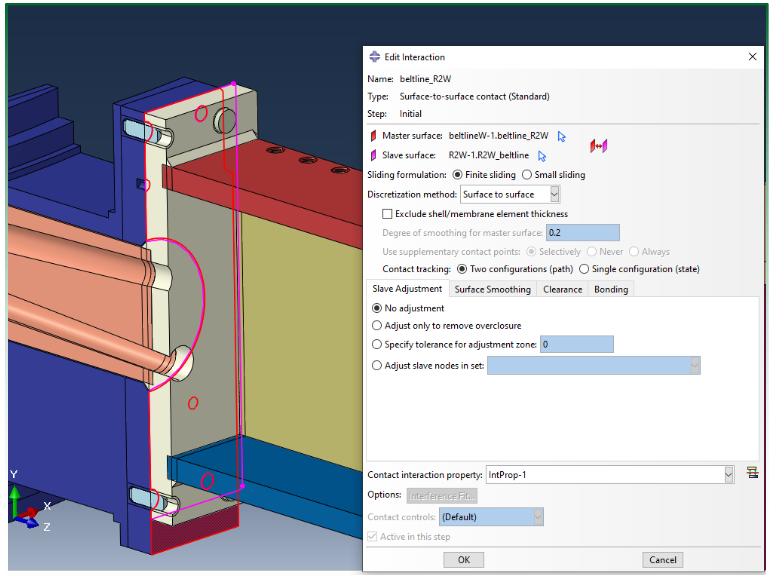


Interactions

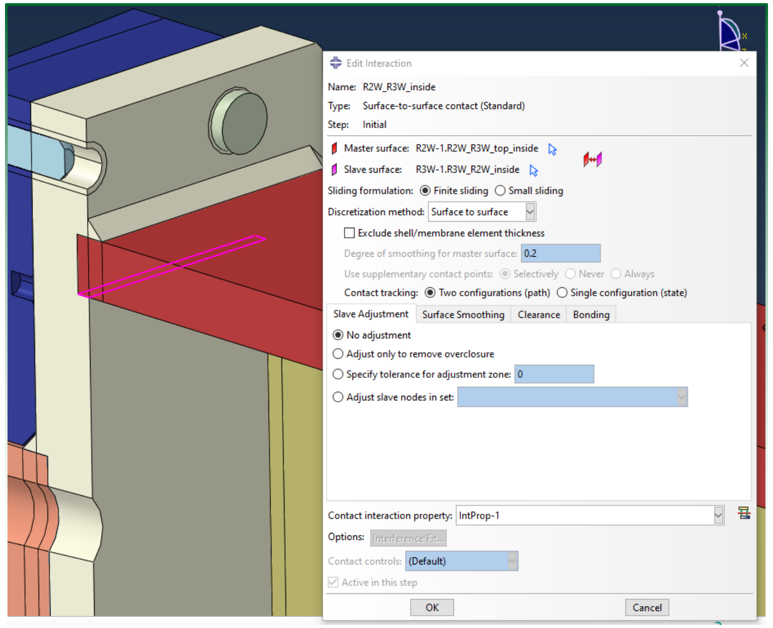
- All Hard Frictionless
- Allows separation

Interactions around front flange

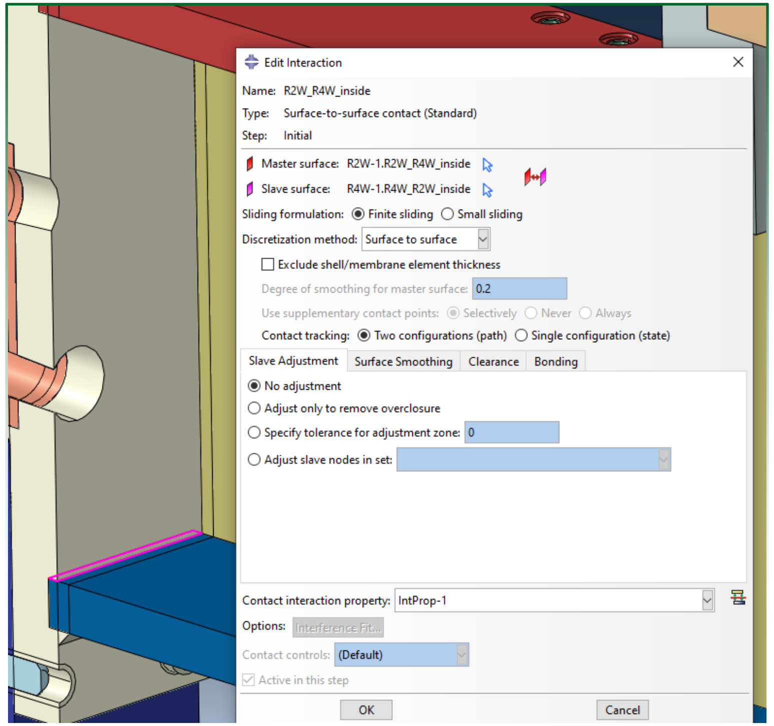
Beltline and Front Flange



Front top plate bottom inside to front flange

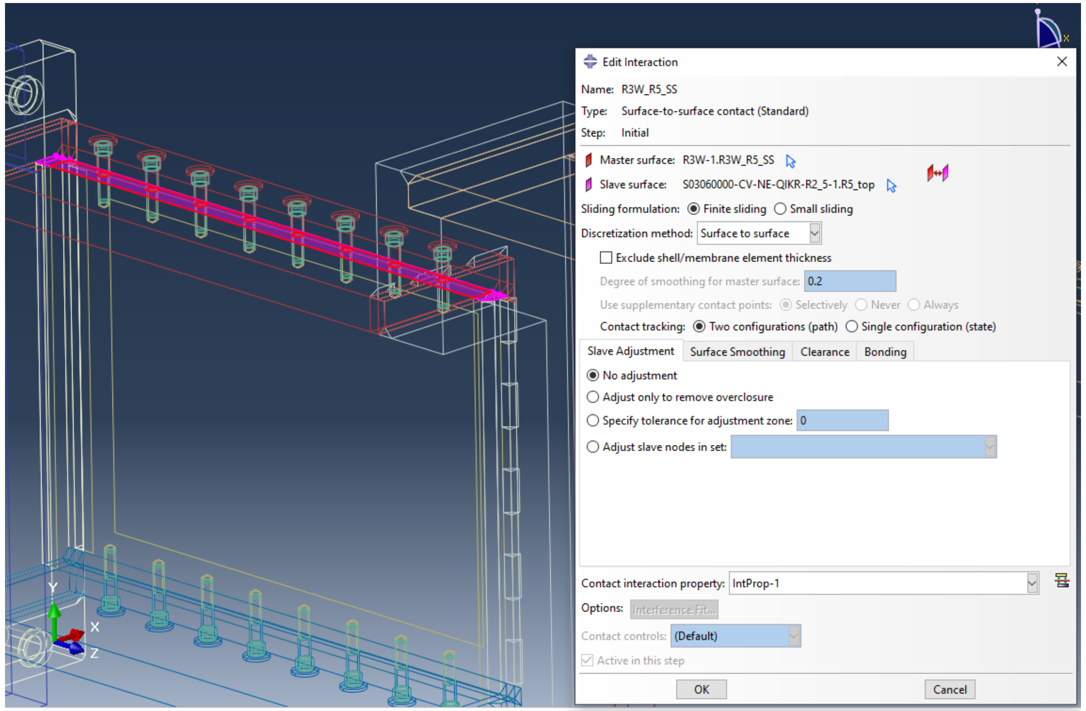


Front bottom plate top inside to front flange

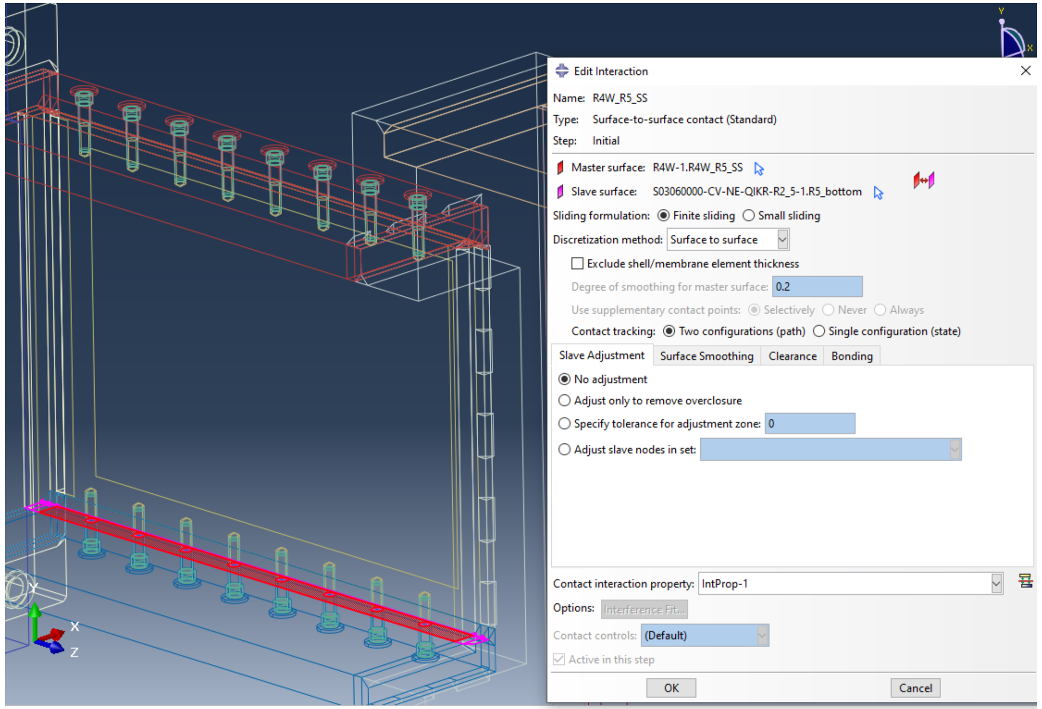


Front Side Wall interactions

Front top plate to front side all

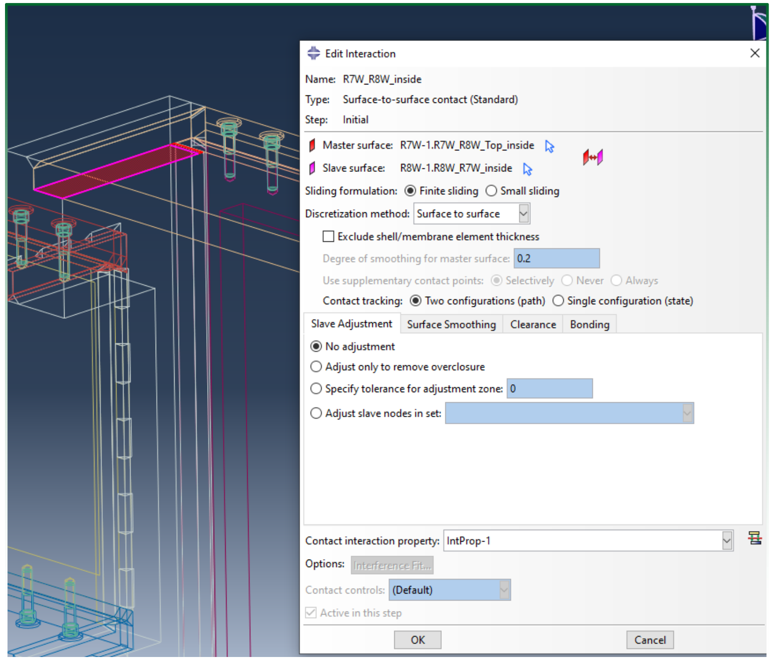


Front bottom plate to front side wall

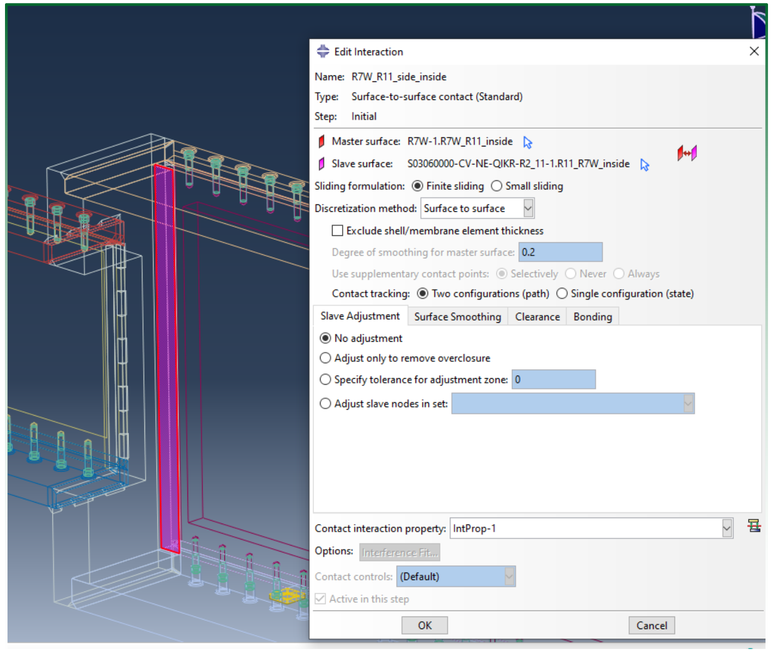


Intermediate flange interactions

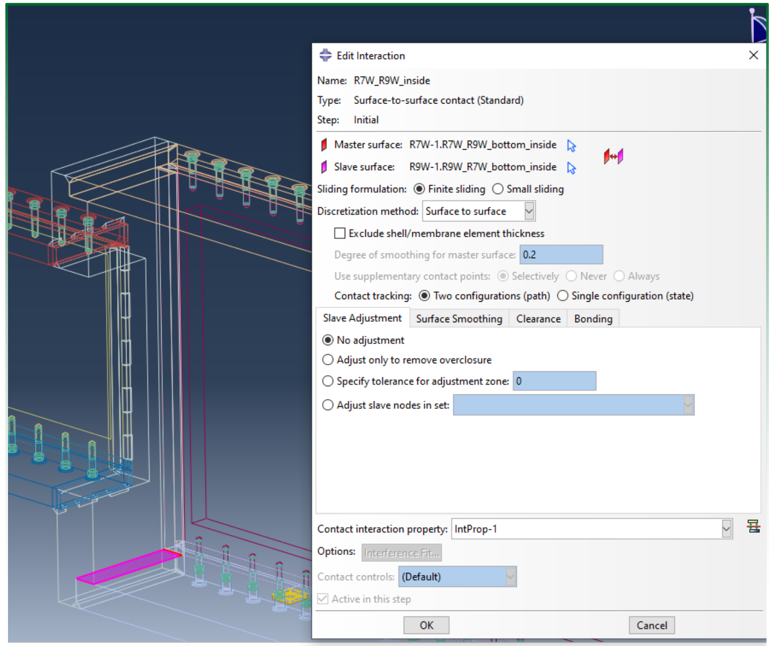
Intermediate flange to rear top plate



Intermediate flange to rear side wall

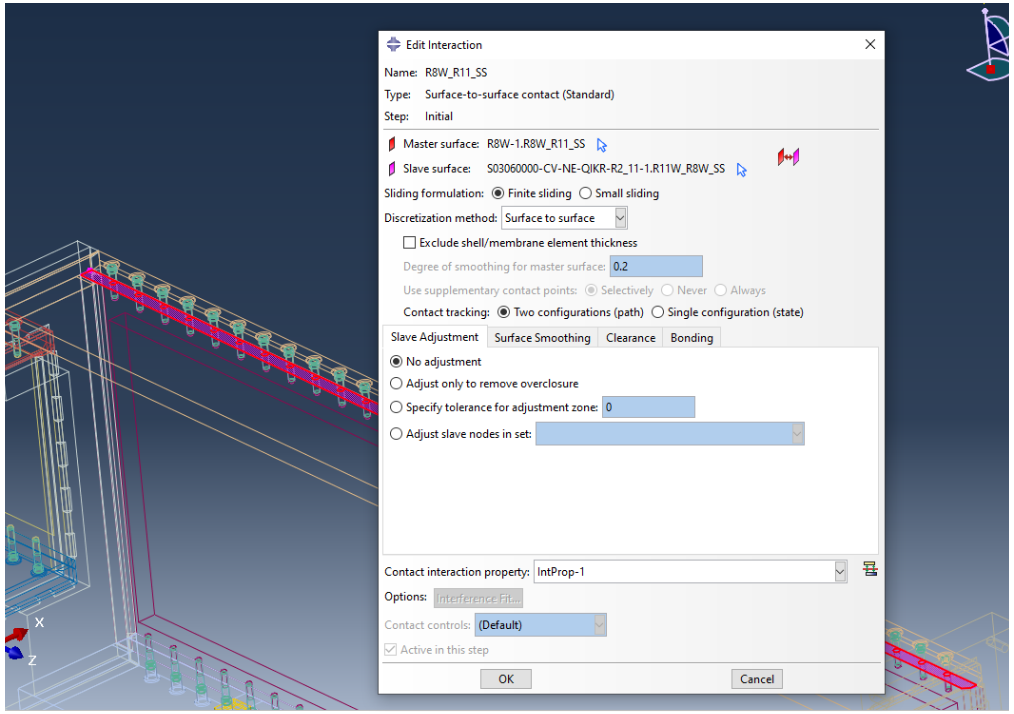


Intermediate flange to rear bottom plate

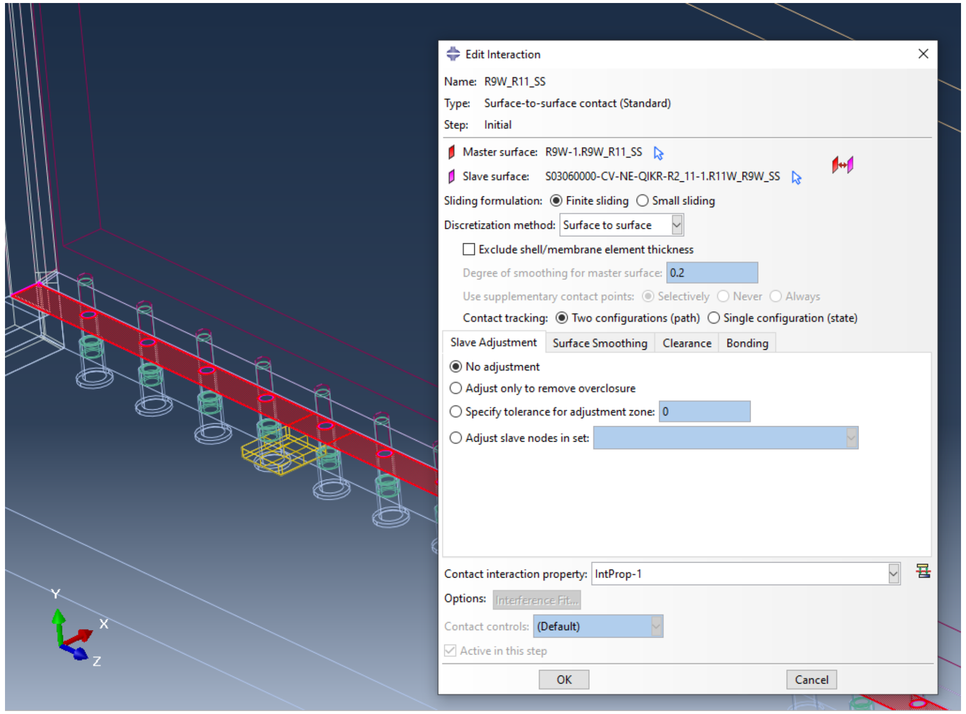


Rear side wall (R11) interactions

Rear top plate to rear side wall



Rear bottom plate to side wall

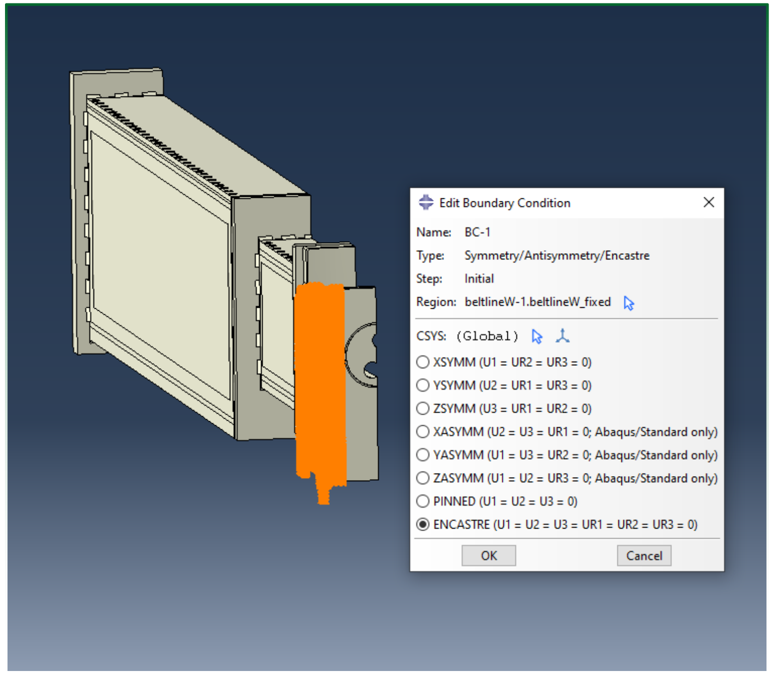


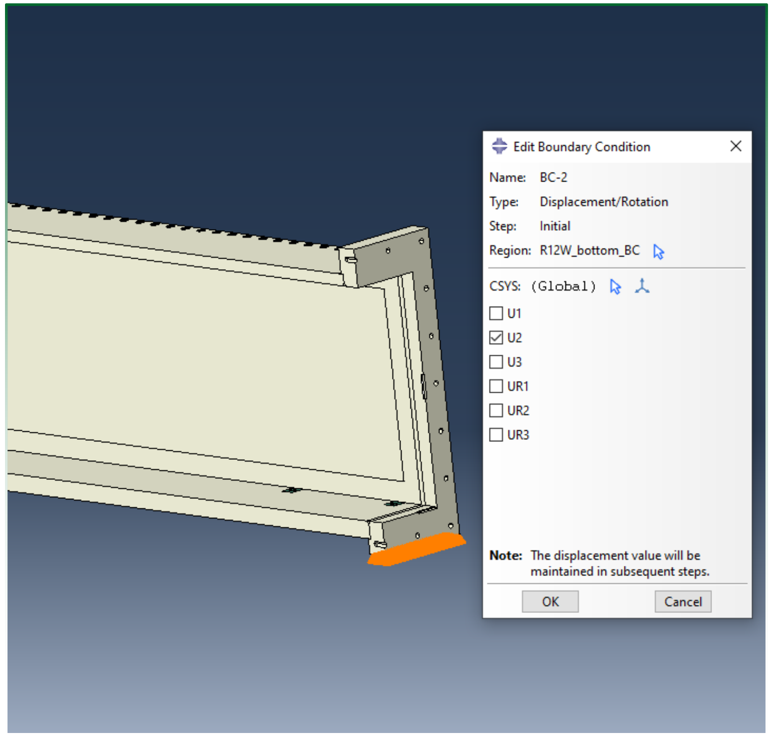
Boundary Conditions

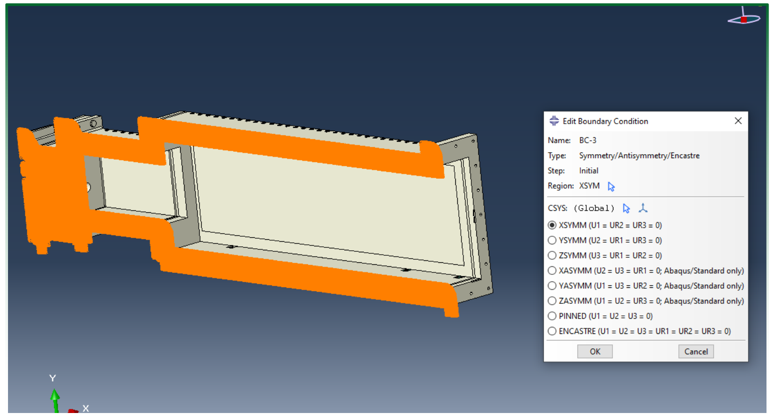
Beltline side nodes fixed

Rear flange bottom nodes restrained vertically

X symmetry boundary condition





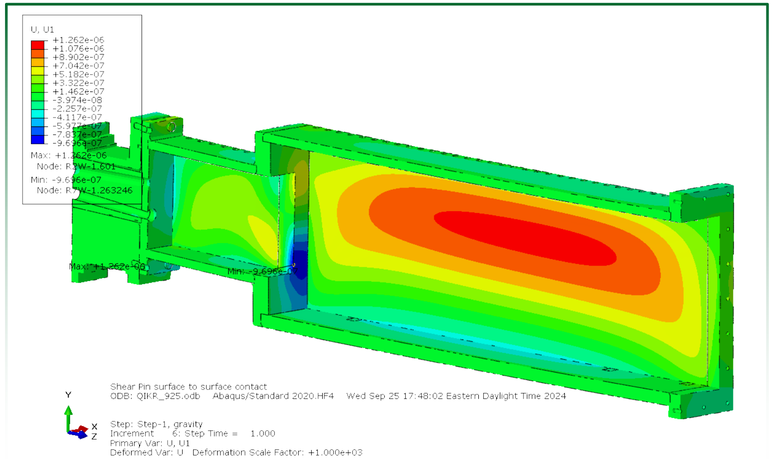


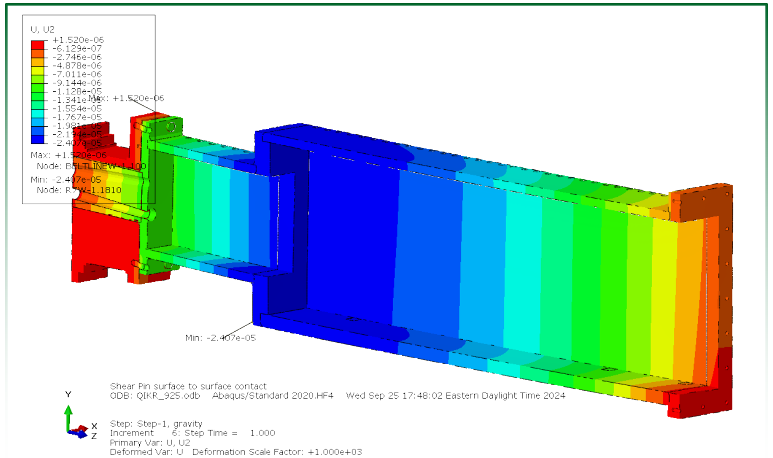
Displacements with only gravity and no inserts

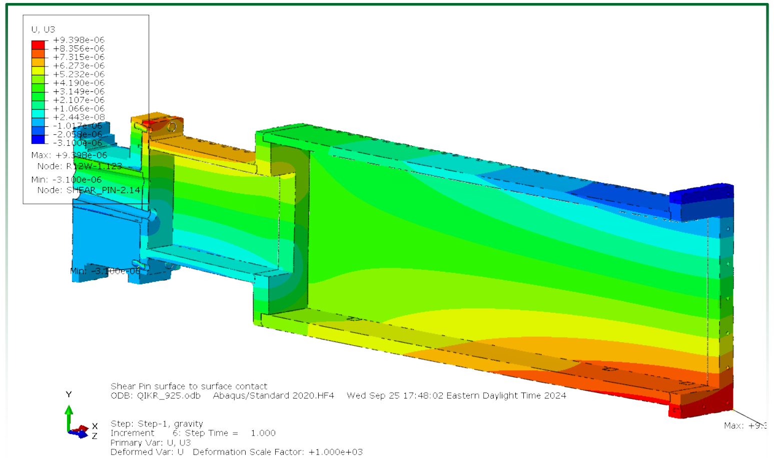
U1(x) minimum -.01mm

U2 (y) minimum -0.025 mm

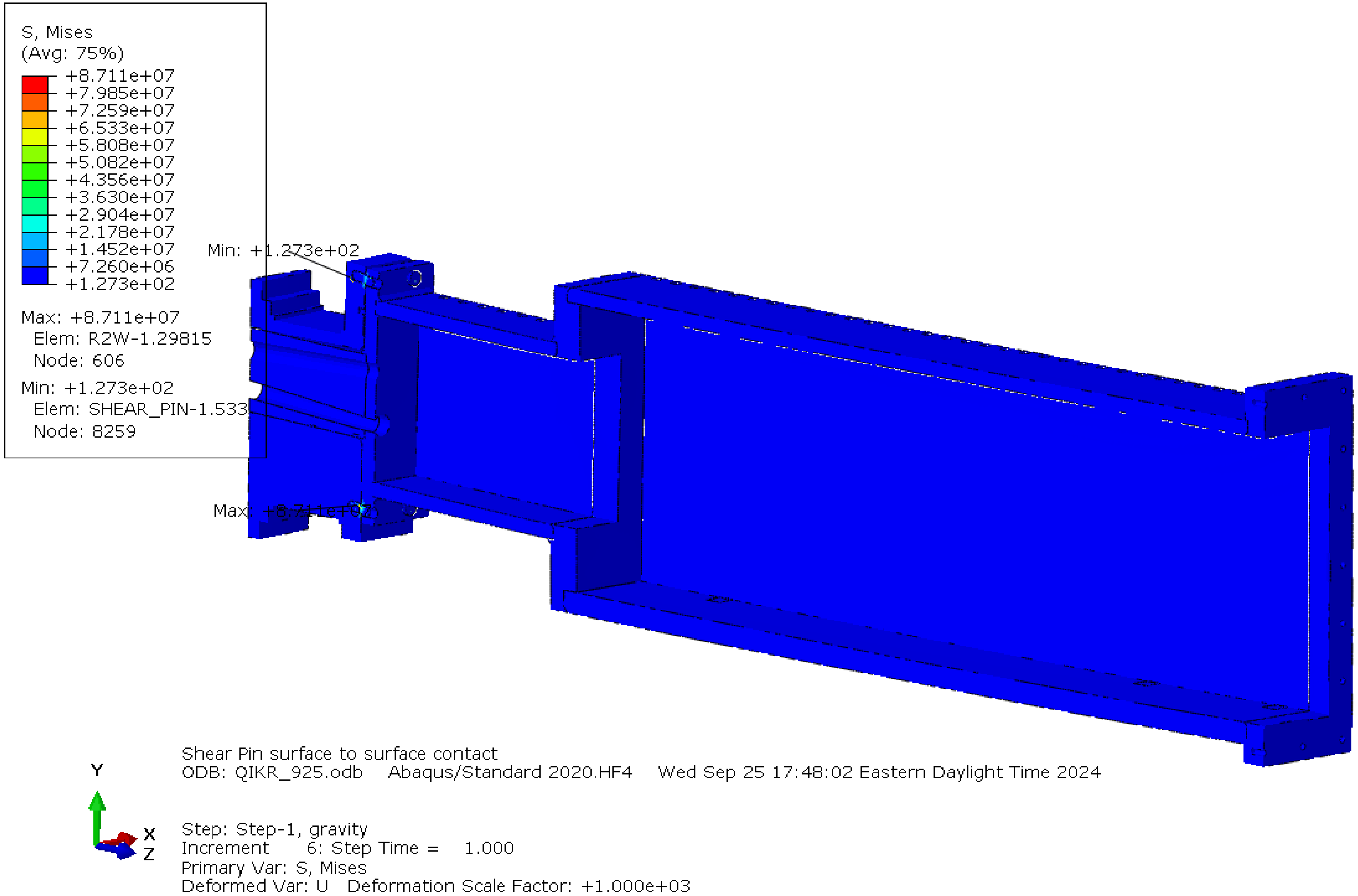
U3 (z) minimum -.03 mm







Assembly Gravity only no inserts peak S 87 MPa in bottom shear pin



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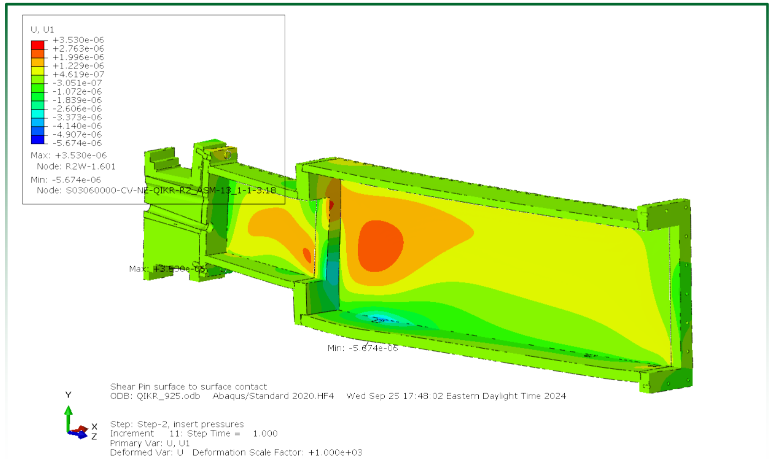
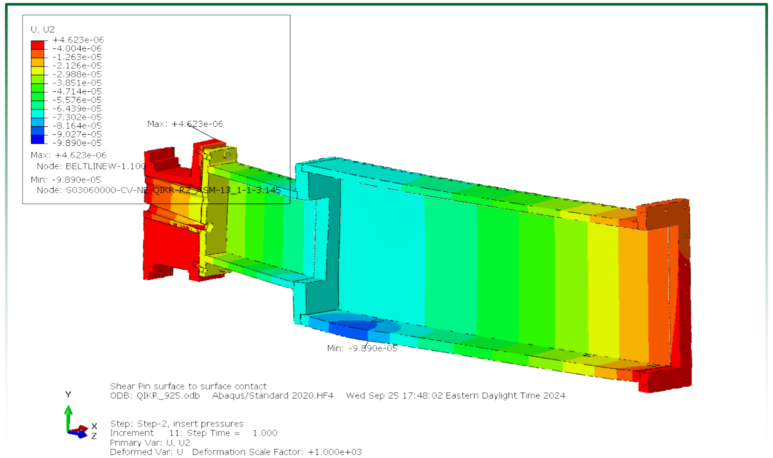
Assembly Displacement with gravity including insert loads

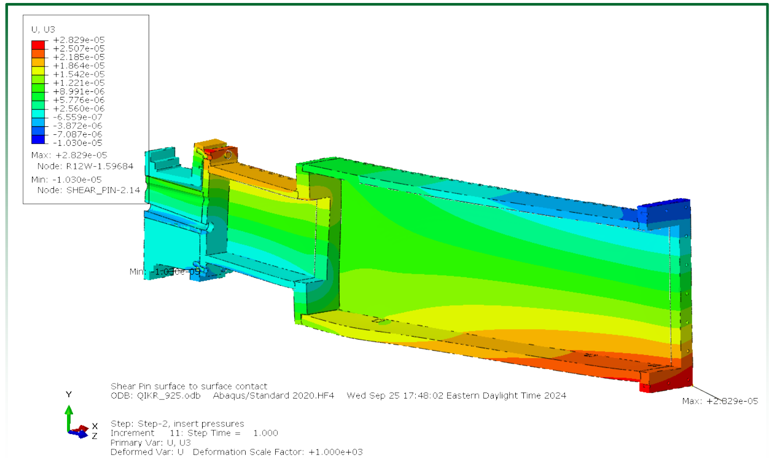
U1(x) minimum -0.006mm

U2 (y) minimum -0.1 mm

U3 (z) minimum -0.01 mm







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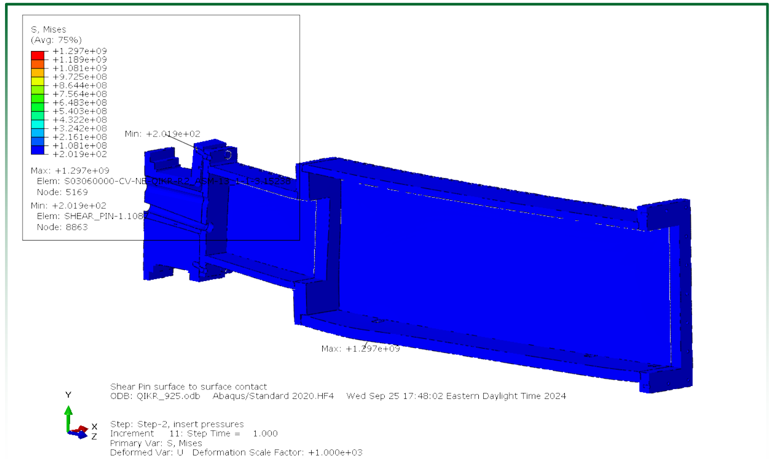
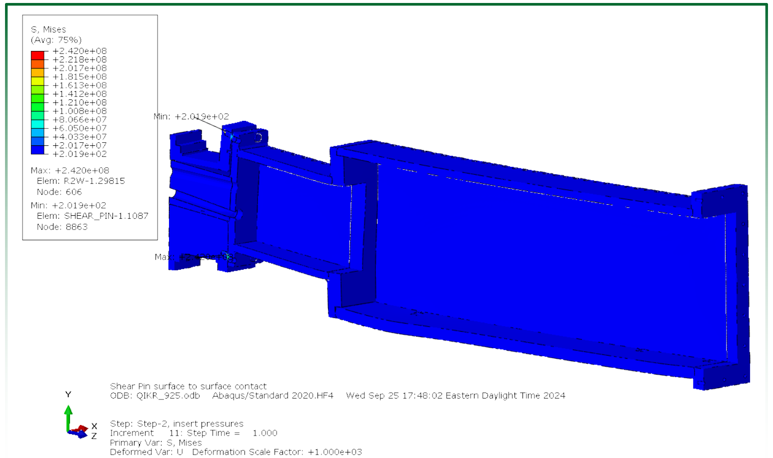
Assembly Stresses with gravity and insert loads

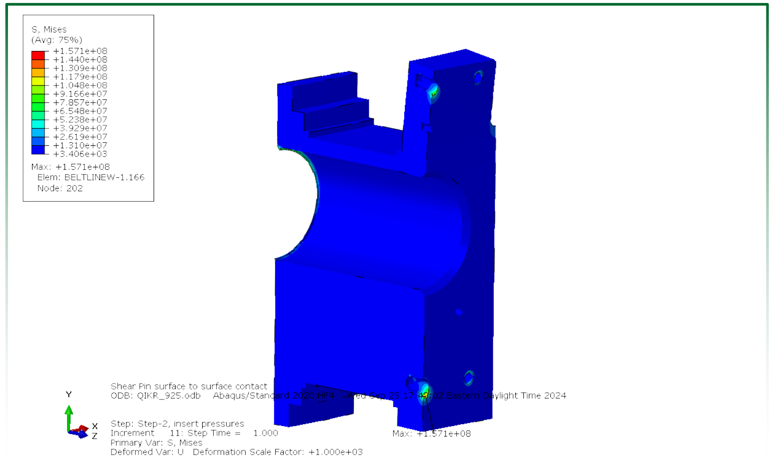
Peak 1297 MPa in Inconel Pad

Peak without Inconel pads 242 MPa in front flange by bottom shear pin

Beltline Peak157 MPa by bottom shear pin hole







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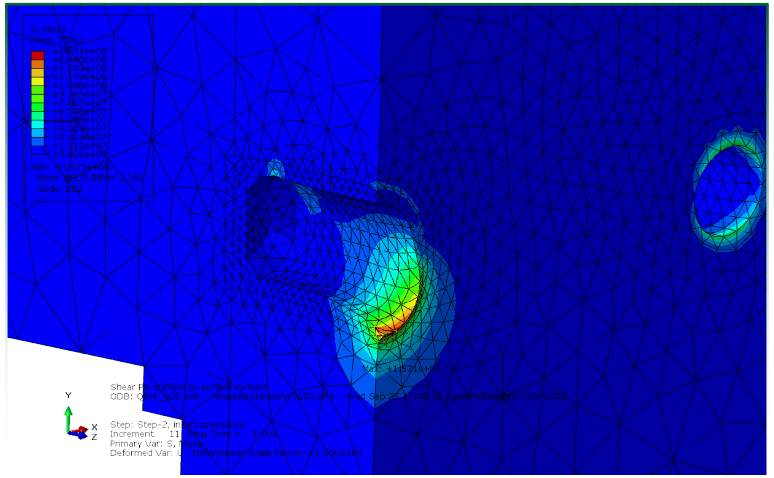
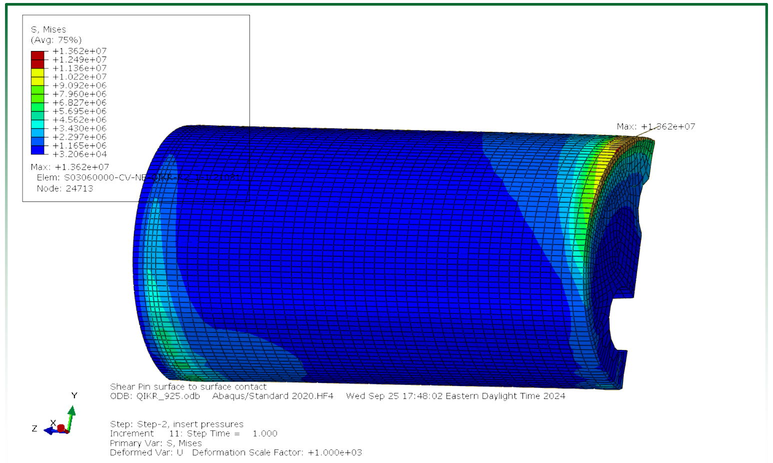
Assembly Stresses with gravity and insert loads

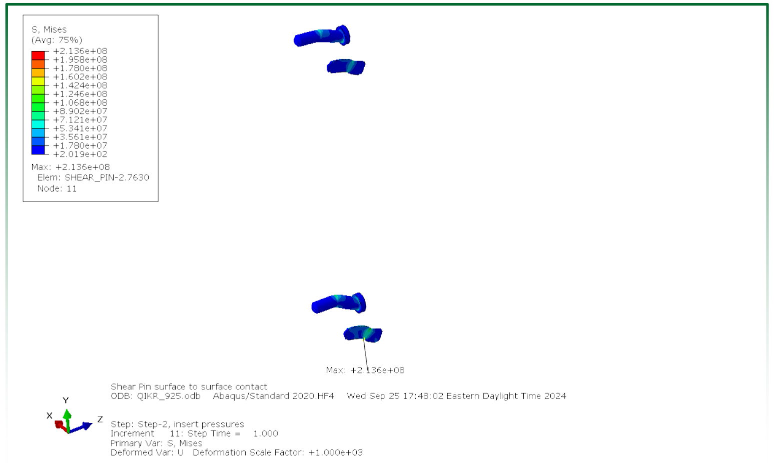
Beltline peak stress location



Part 1 beam line guide peak stress 13.7 MPa by weld to front flange



25 mm Bolts and Shear Pin stresses peak 214 MPa in bottom shear pin

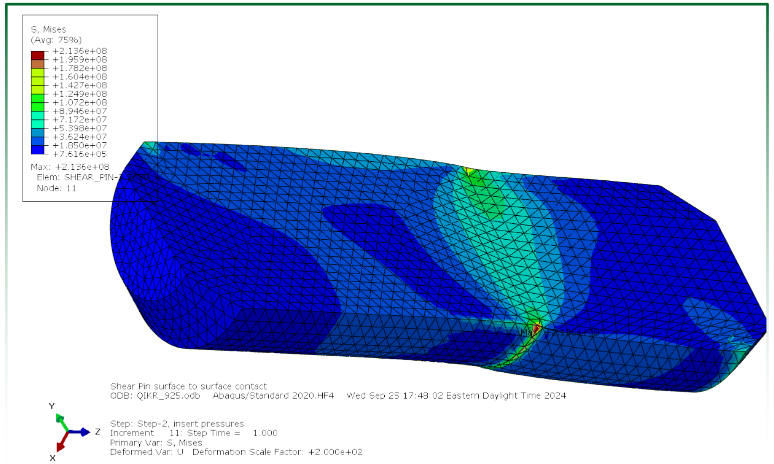


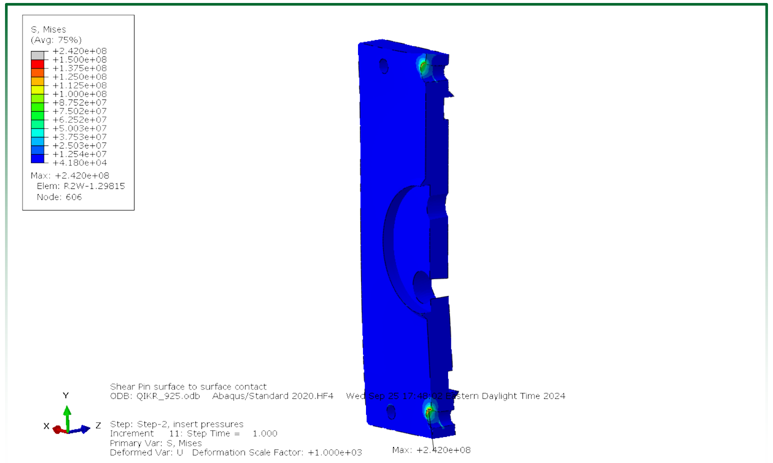
Assembly Stresses with gravity and insert loads

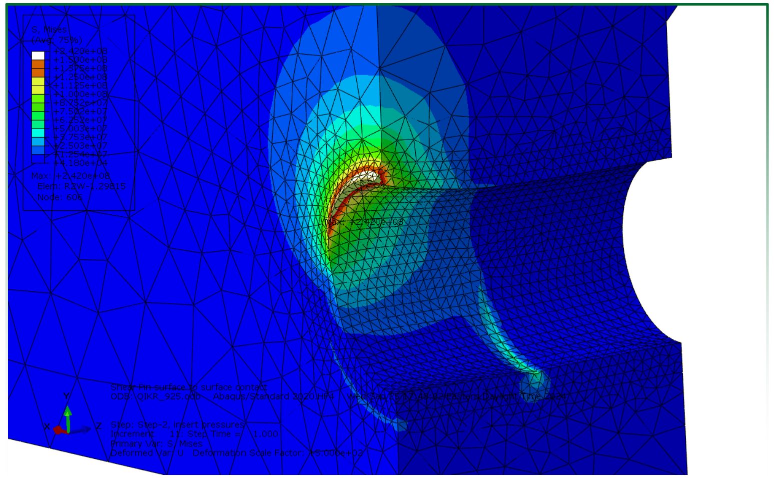
Bottom Shear Pin peak 213 MPa with mesh shown

Front Flange with merged welds peak 242 MPa by bottom shear pin hole

Front Flange Peak stress location within 4.25 mm ring and < 100 MPa outside ring







0.5 mm bearing surface offset for rear to avoid common nodes for both surfaces

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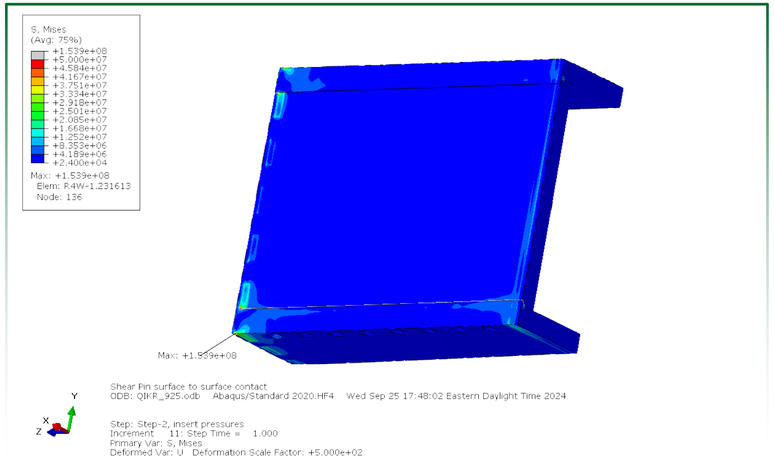
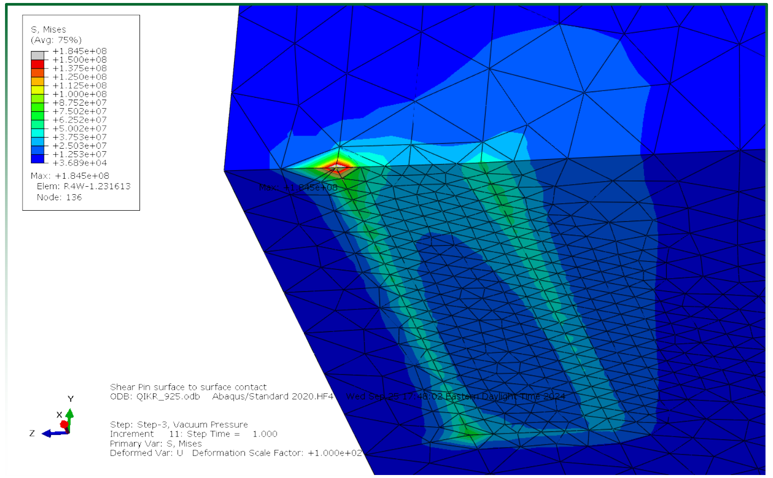
Assembly Stresses with gravity and insert loads

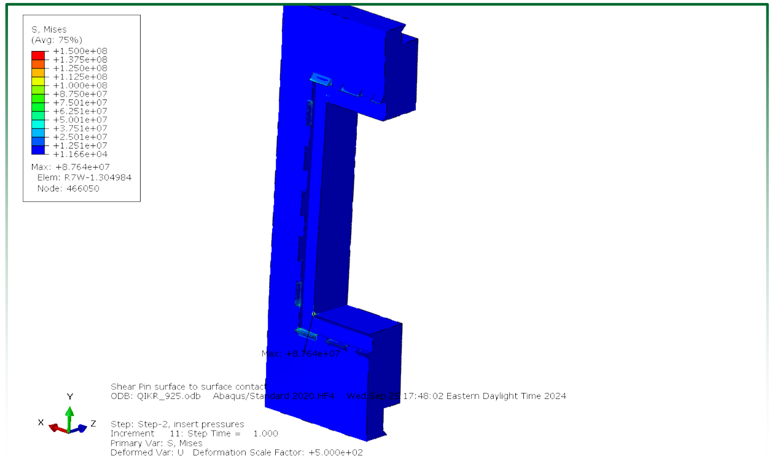
Stresses in front top, side and bottom plates – 50 MPa scale - peak 154 MPa



Front bottom plate peak at side edge and corner of skip weld tie



Intermediate Flange with merged welds – peak 88 MPa

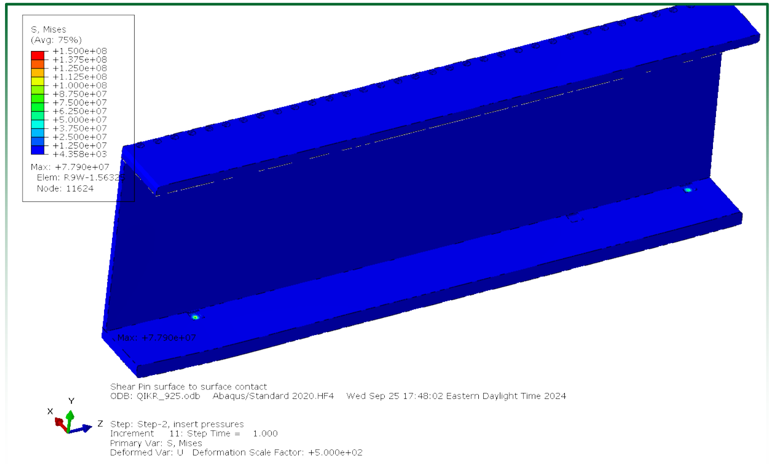


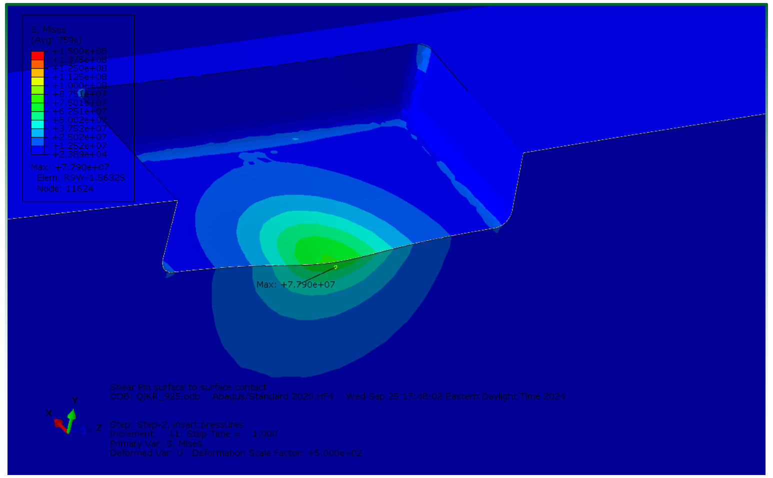
Assembly Stresses with gravity and insert loads

Rear Top, Side and Bottom plates peak stress 77 MPa under front wheel pad

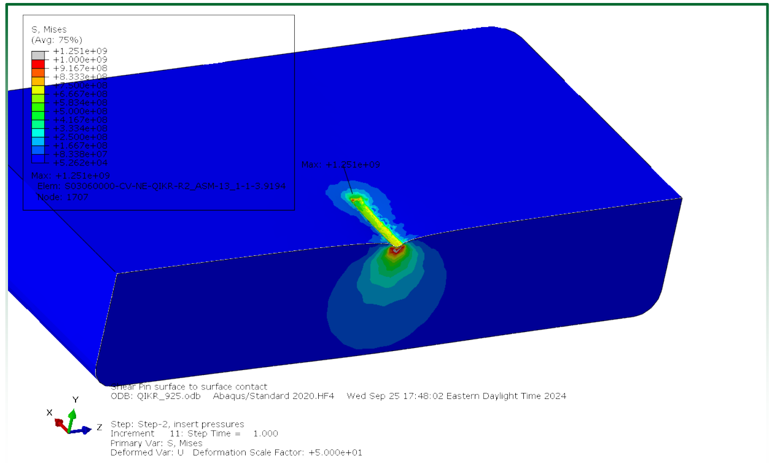
Bottom Plate stress under Inconel pad – 77 MPa peak

Inconel pad Stress Peak 1251 MPa (50x displacement)





¼ symmetry contact model peak was 91 MPa in 316l under pad



¼ symmetry contact model Inconel peak was 2643 MPa using elastic model with no yielding

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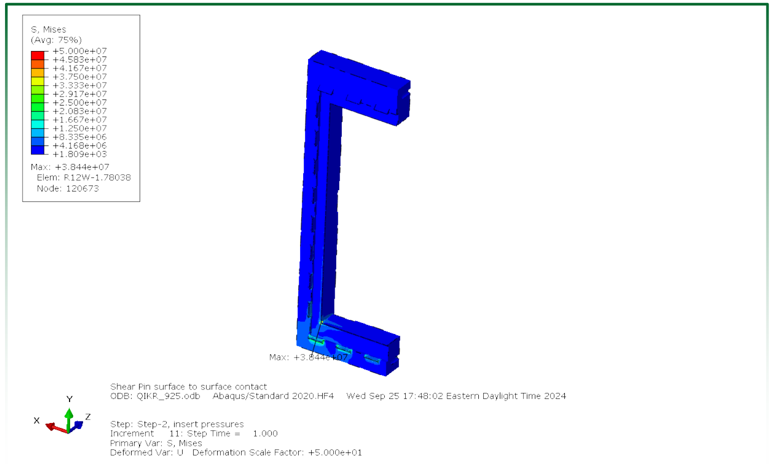
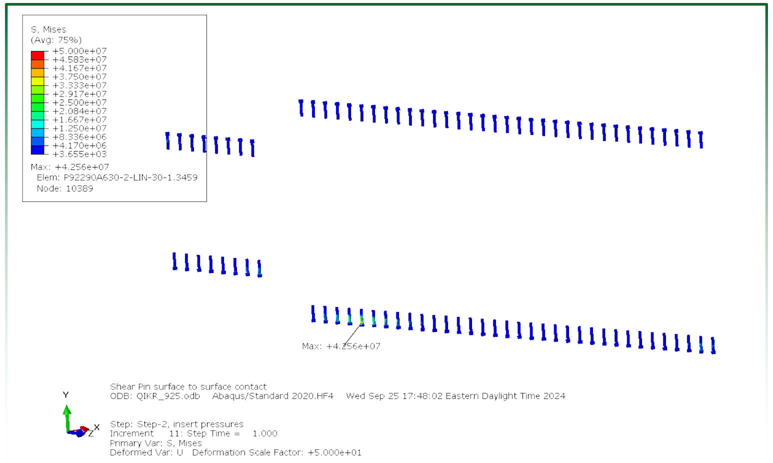
Stresses with gravity and insert loads

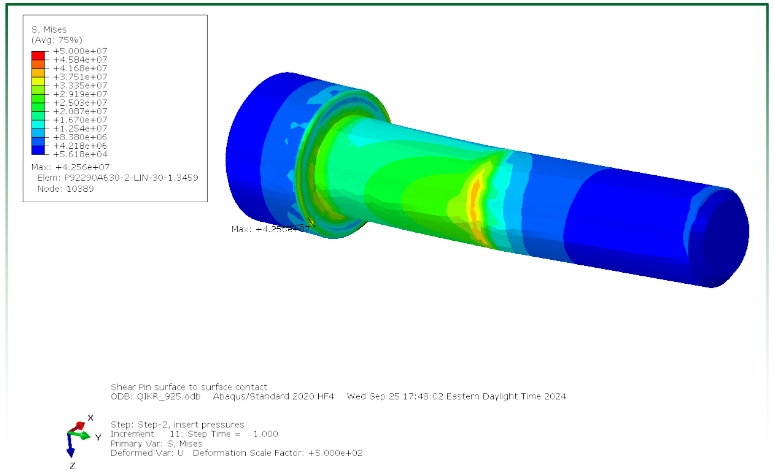
Rear Flange with merged welds peak stress 38 MPa



Peak 12 mm Bolt stress 42.6 MPa



Highest Stressed bolt – peak 42.6 MPa



Oak Ridge National Laboratory

Core Vessel Dual Channel Nozzle Extension Preliminary Analysis

Thomas McManamy

1/22/25

ORNL is managed by UT-Battelle, LLC for the US Department of Energy

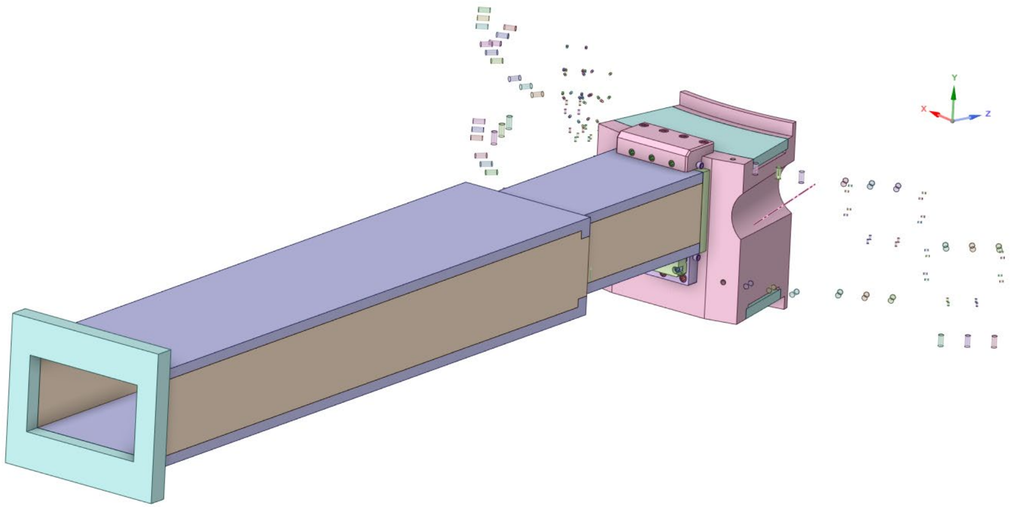
U.S. DEPARTMENT OF ENERGY

SpaceClaim model and changes

Main changes made for Abaqus model

- Nozzle plate and flange parts merged
- Bolt thread areas deleted, and holes enlarged to match bolt diameters
- Lower bracket two center bolts changed to shear pins with the same diameter

SpaceClaim model



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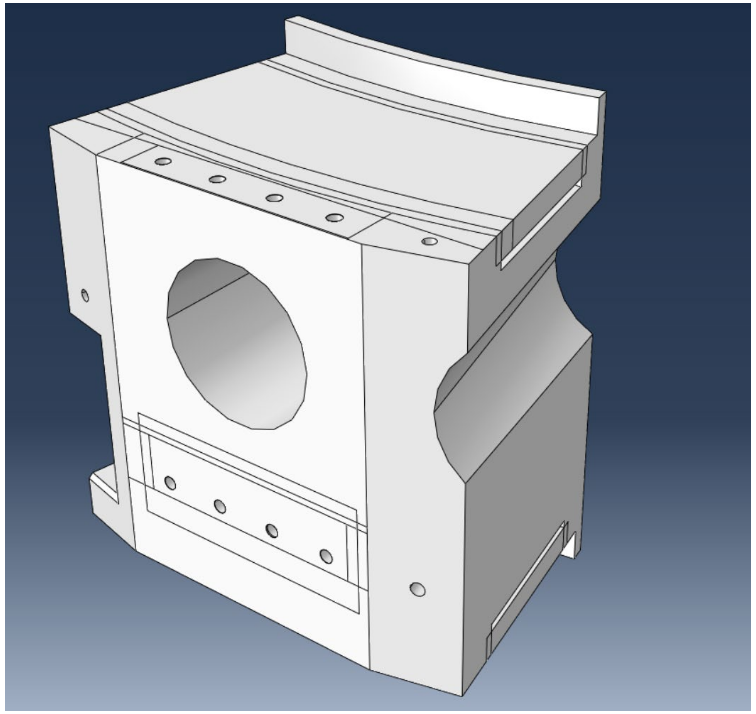
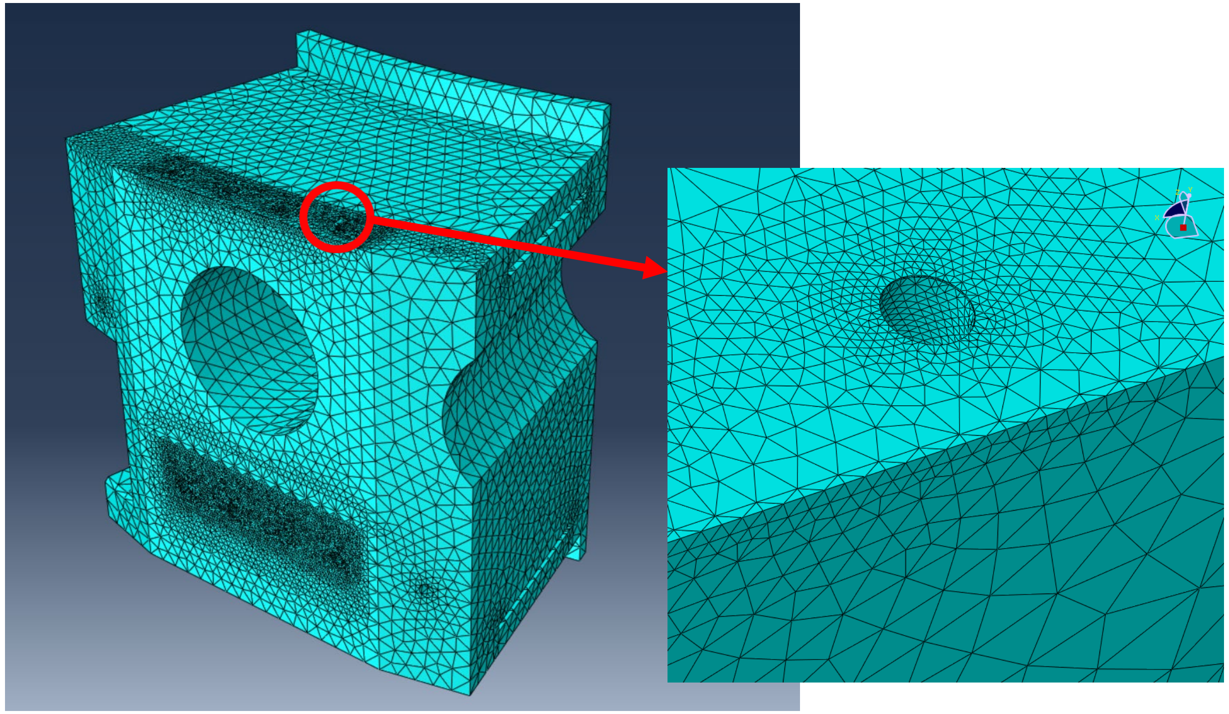
Beltline part with partitions added to define contact zones and merged water manifold plates

Beltline Part

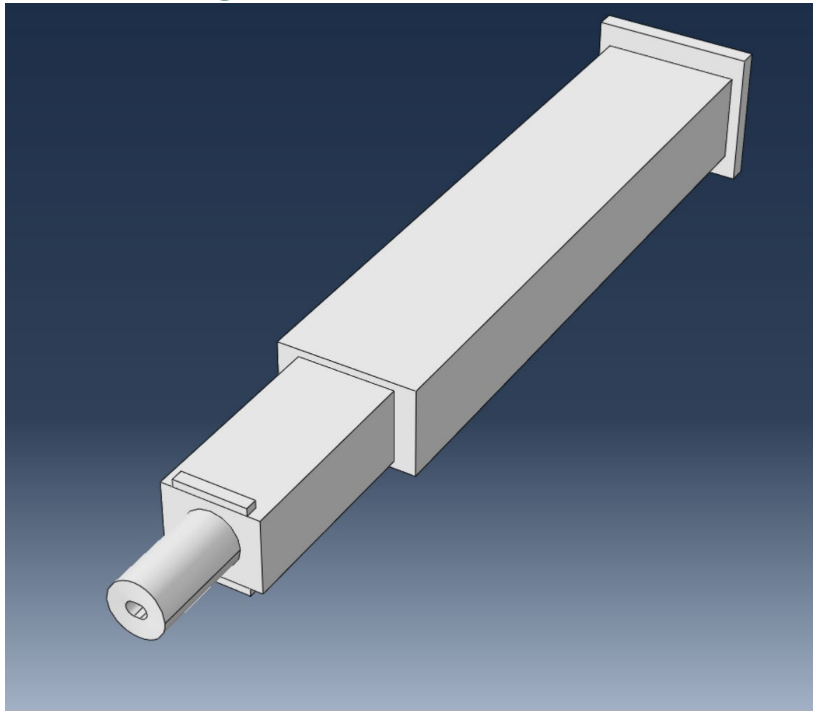


C3D10 Mesh

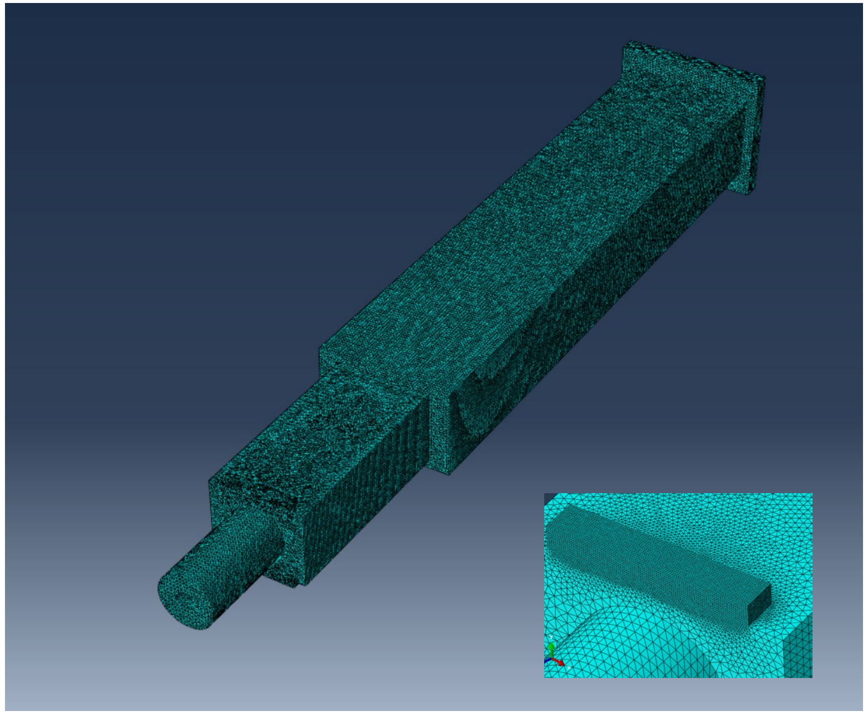


Nozzle

Parts all merged



C3D10 Mesh



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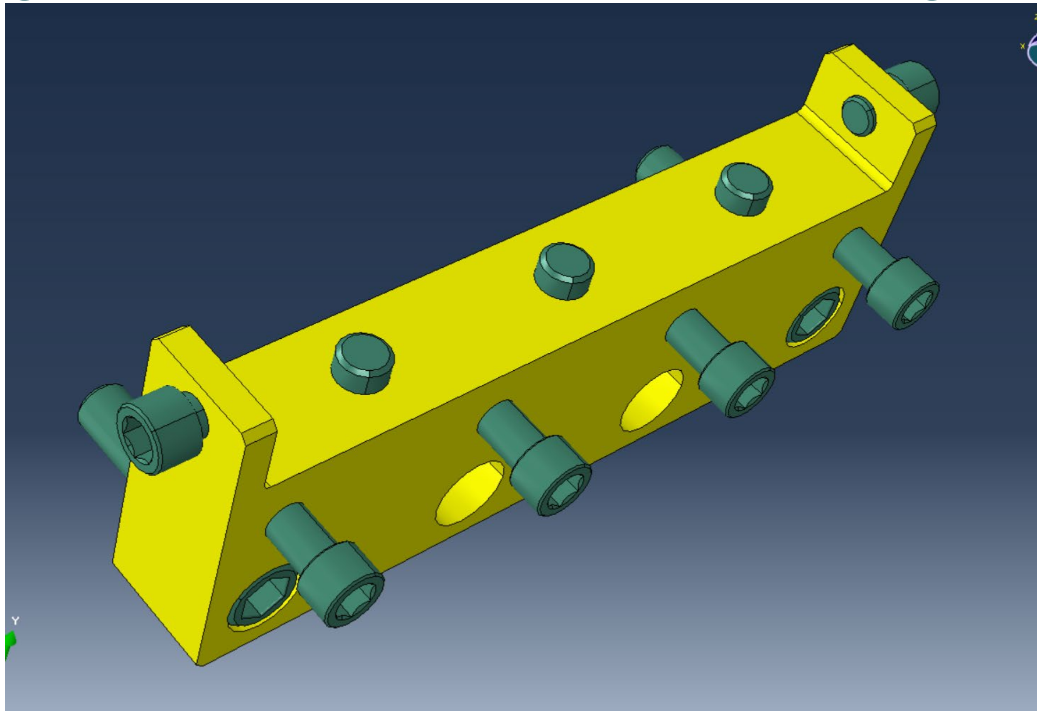
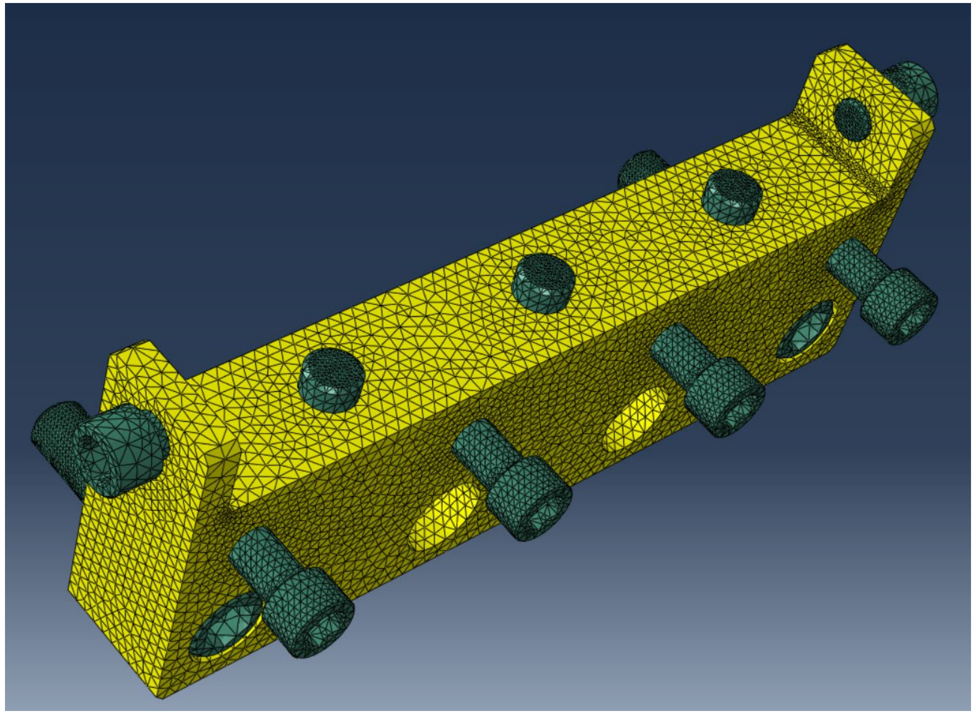
Bracket 6 Assembly

Bolts merged with body in threaded regions – separate material assigned



C3D10 Tet mesh



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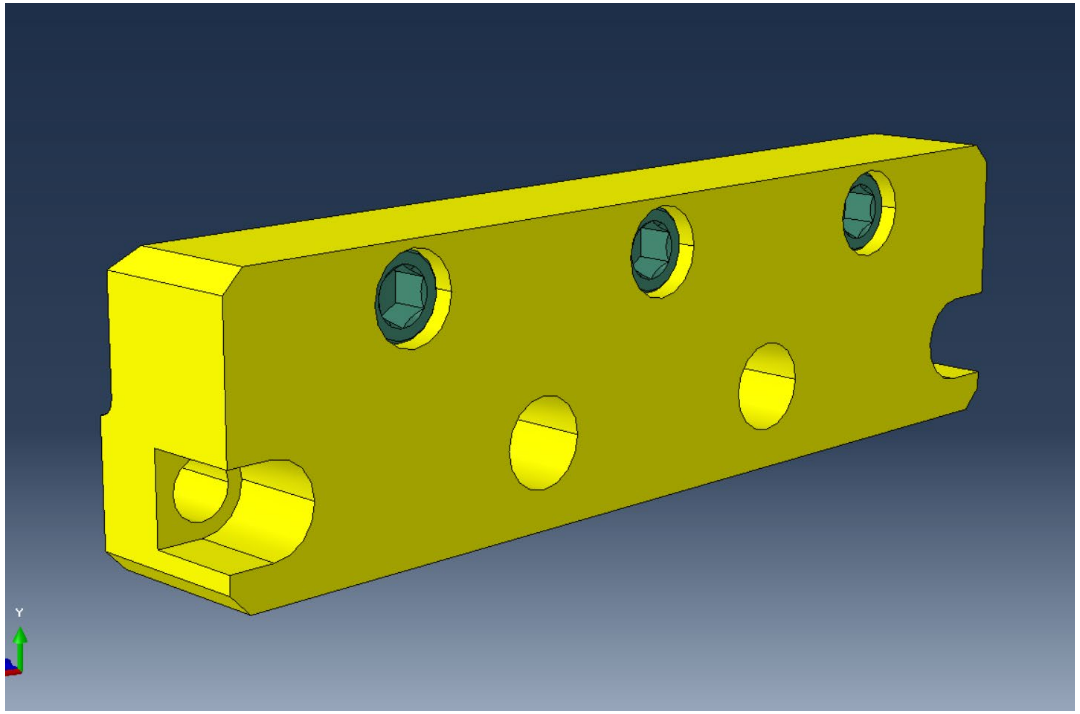
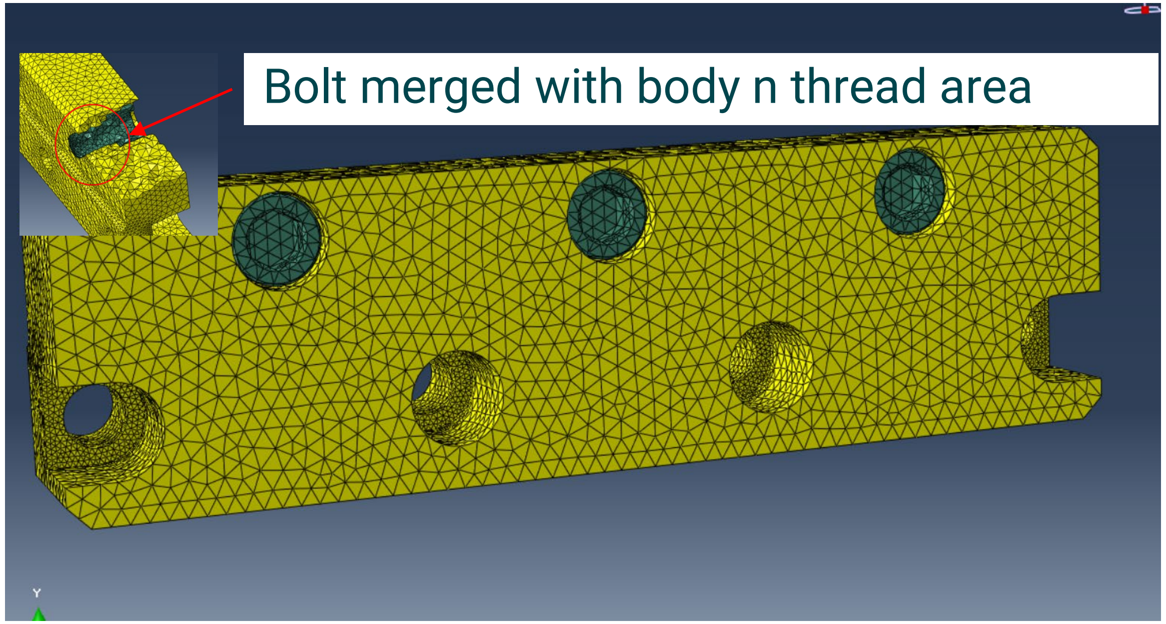
Bracket 7 with body and bolts

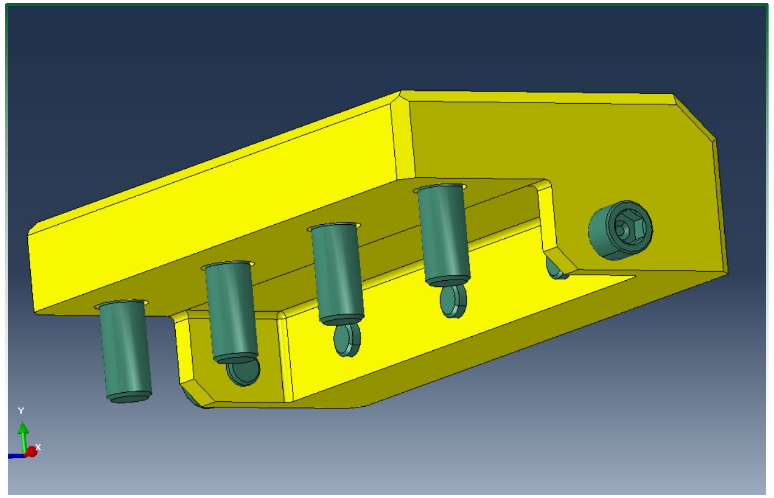
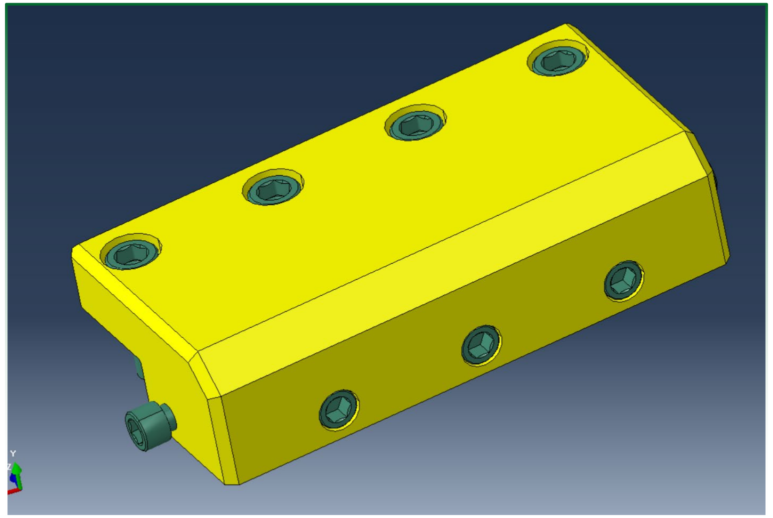
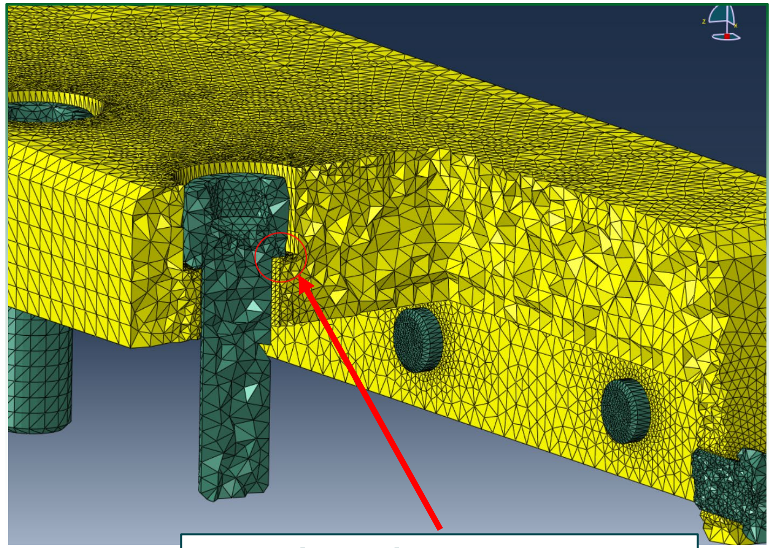
Part with bolts merged in contact area of heads



C3D10 Mesh



Bracket 8 Assembly

Threaded area of bolts merged with body	Top view	Bolt head merged
		

Bolt head contact area merged with body

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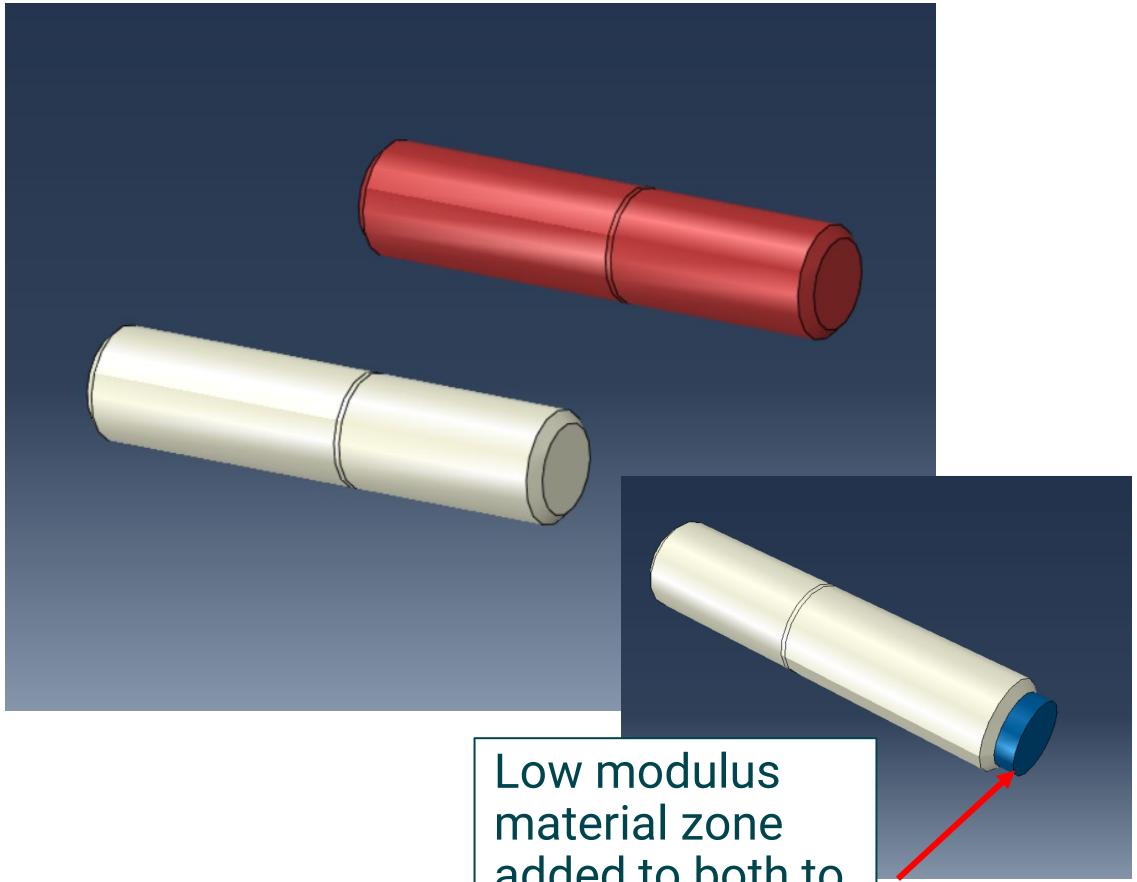
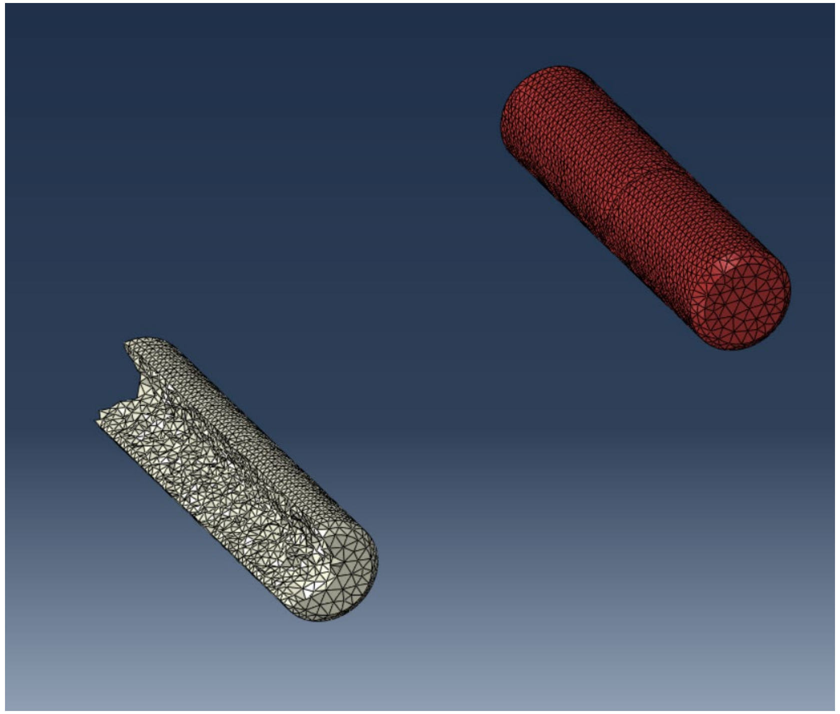
20 mm diameter shear pins used in bracket 6

parts



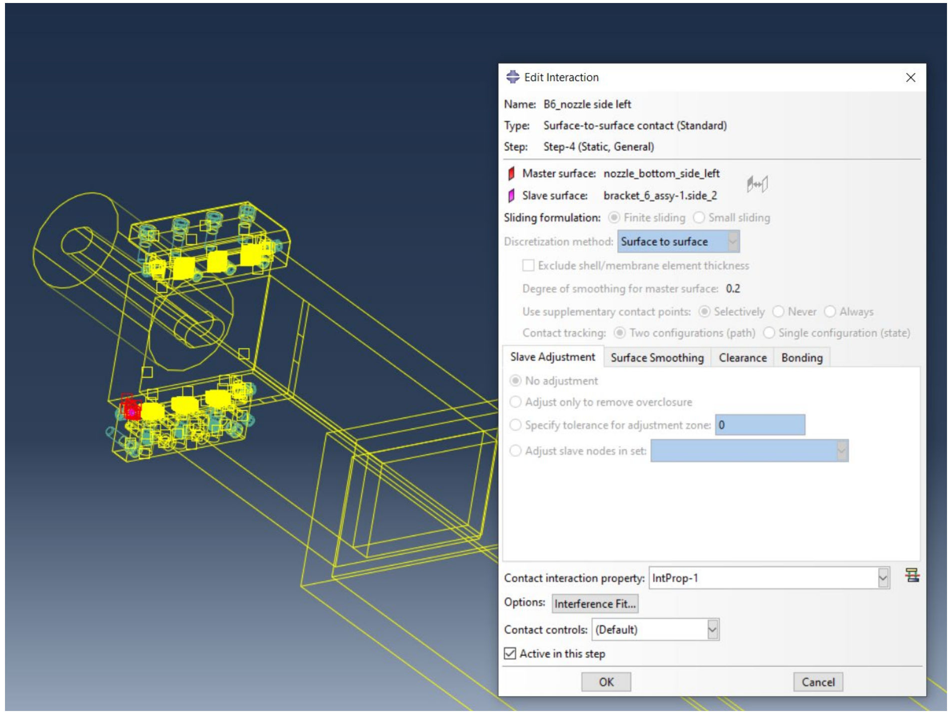
Low modulus material zone added to both to make weak ties to beltline

C3D10 mesh

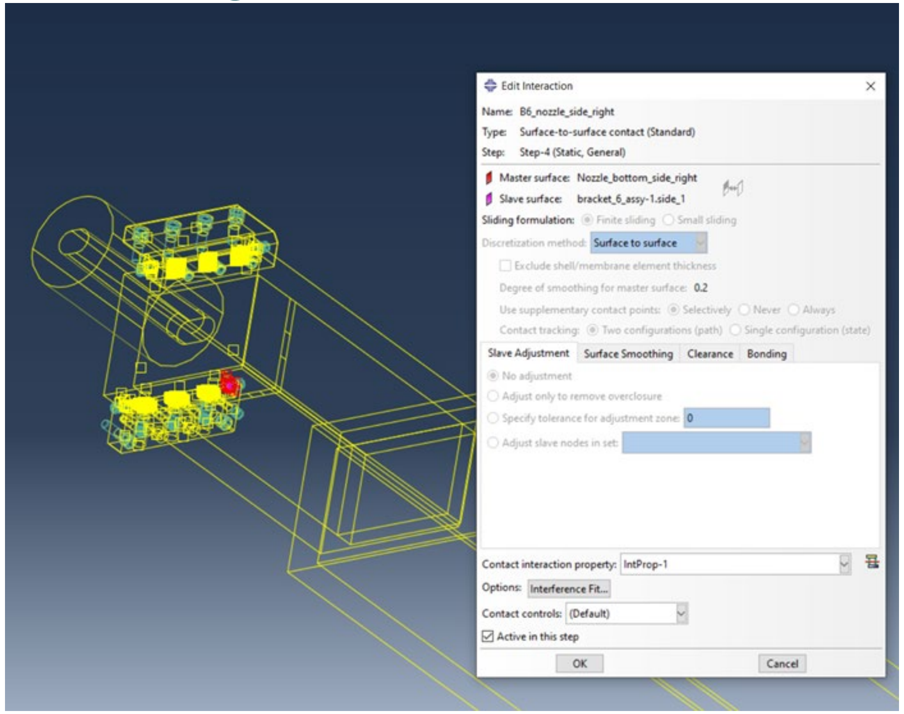


Surface to Surface Interactions

Bracket 6 left side to Nozzle bottom

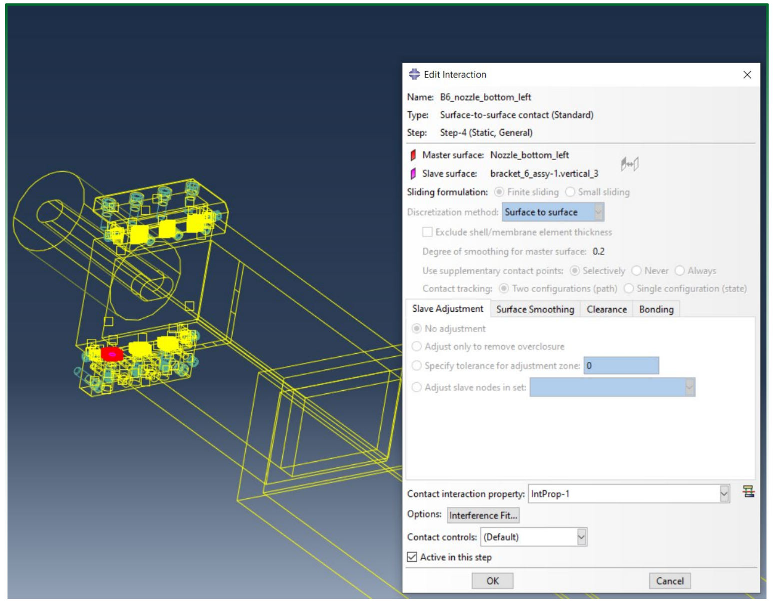


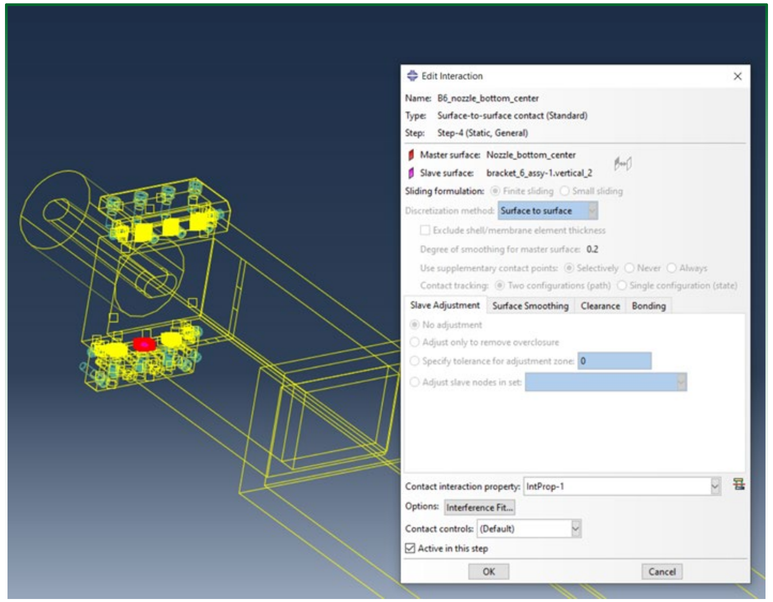
Bracket 6 right side to Nozzle bottom

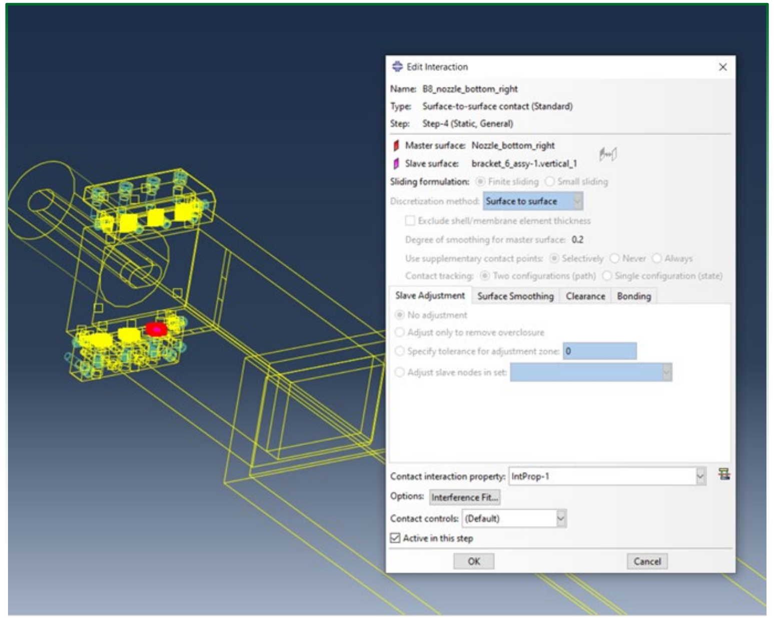


Surface to Surface Interactions – bracket 6 bottom vertical

Left bolt to nozzle	Center bolt to nozzle	Right bolt to nozzle

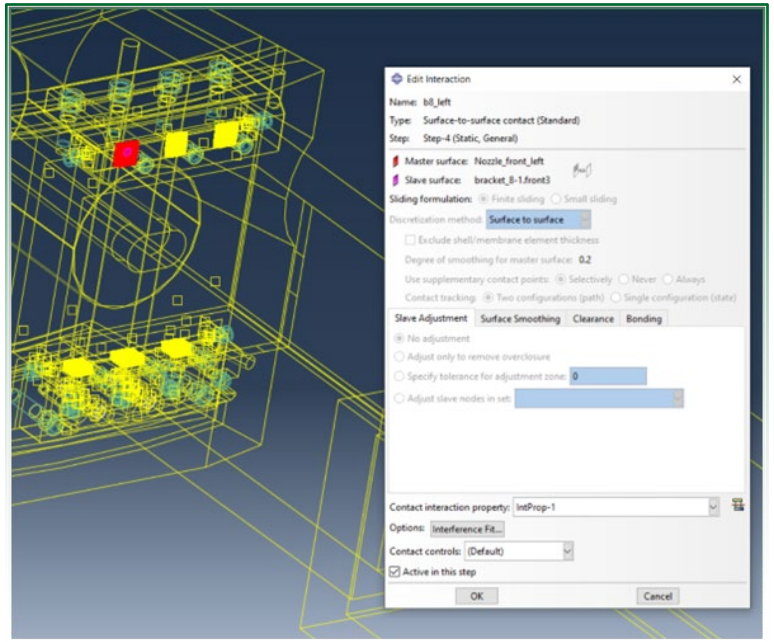




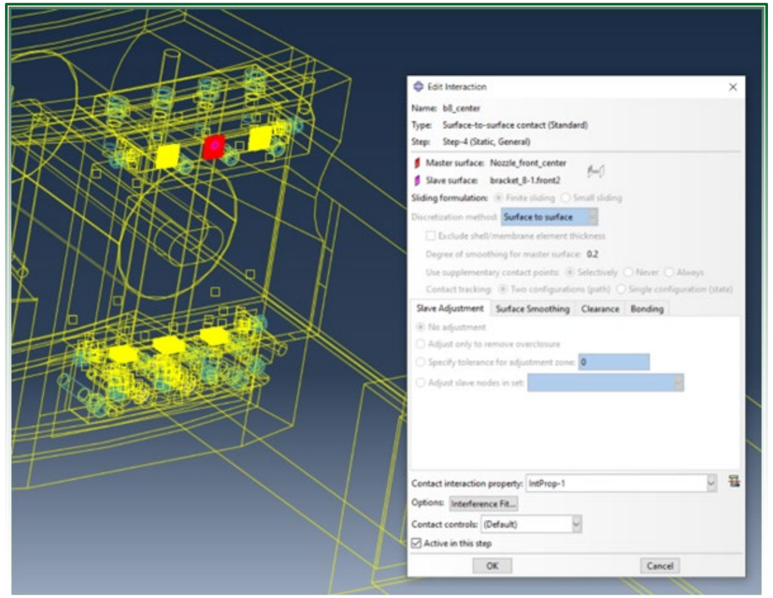


Surface to Surface Interactions – bracket 8 top horizontal

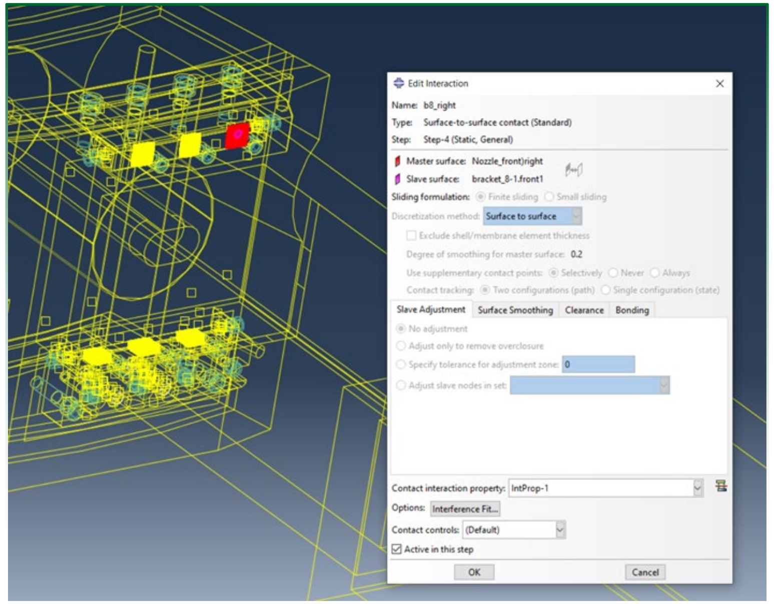
left



center

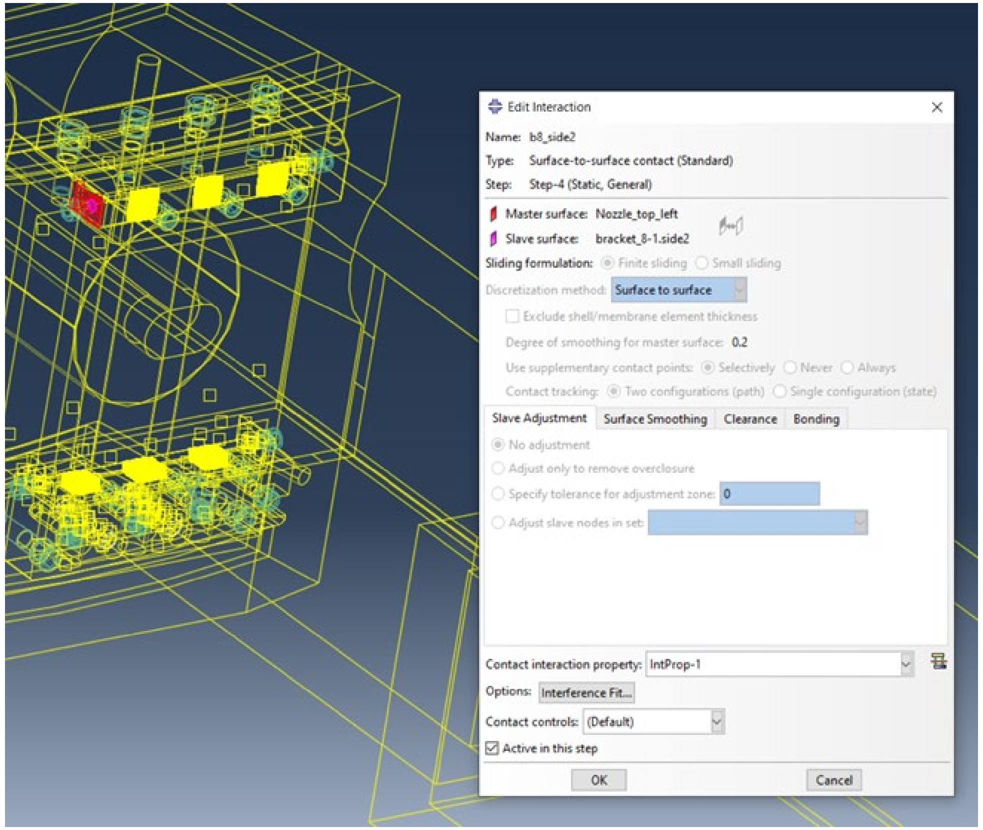


right

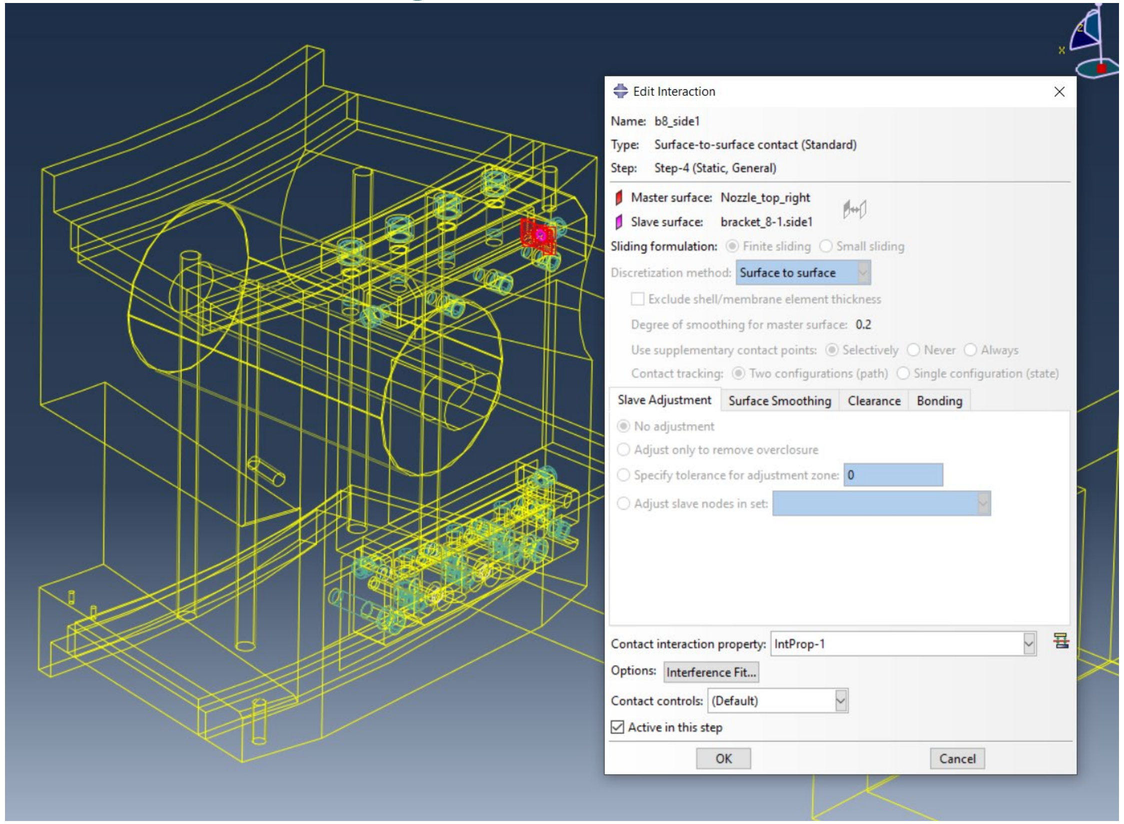


Surface to Surface Interactions –bracket 8 top lateral

Left side to nozzle

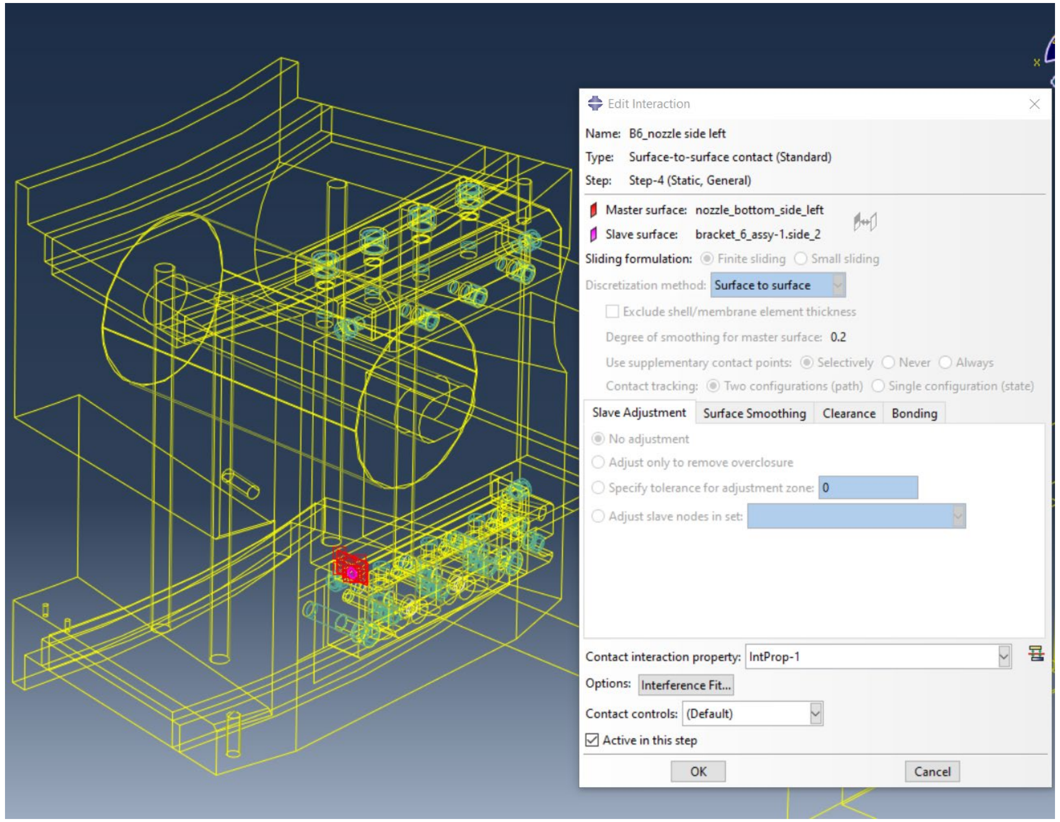


Right side to nozzle



Surface to Surface Interactions – bracket 6 bottom lateral

Left side to nozzle



Right side to nozzle

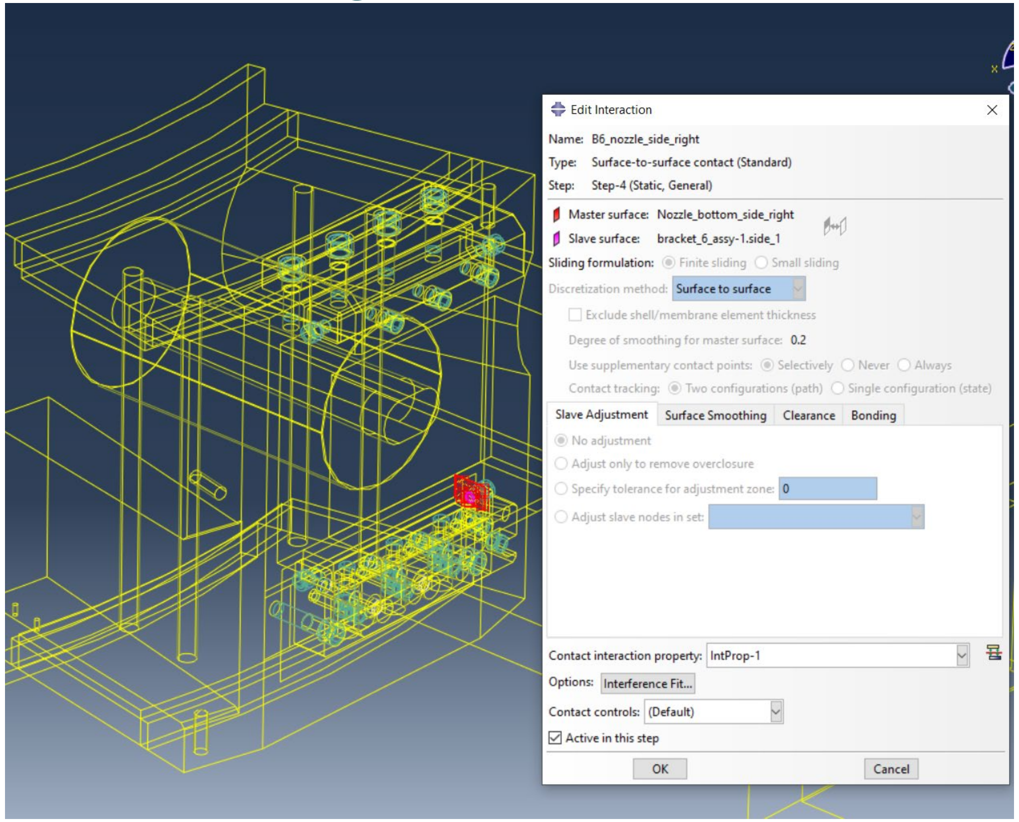
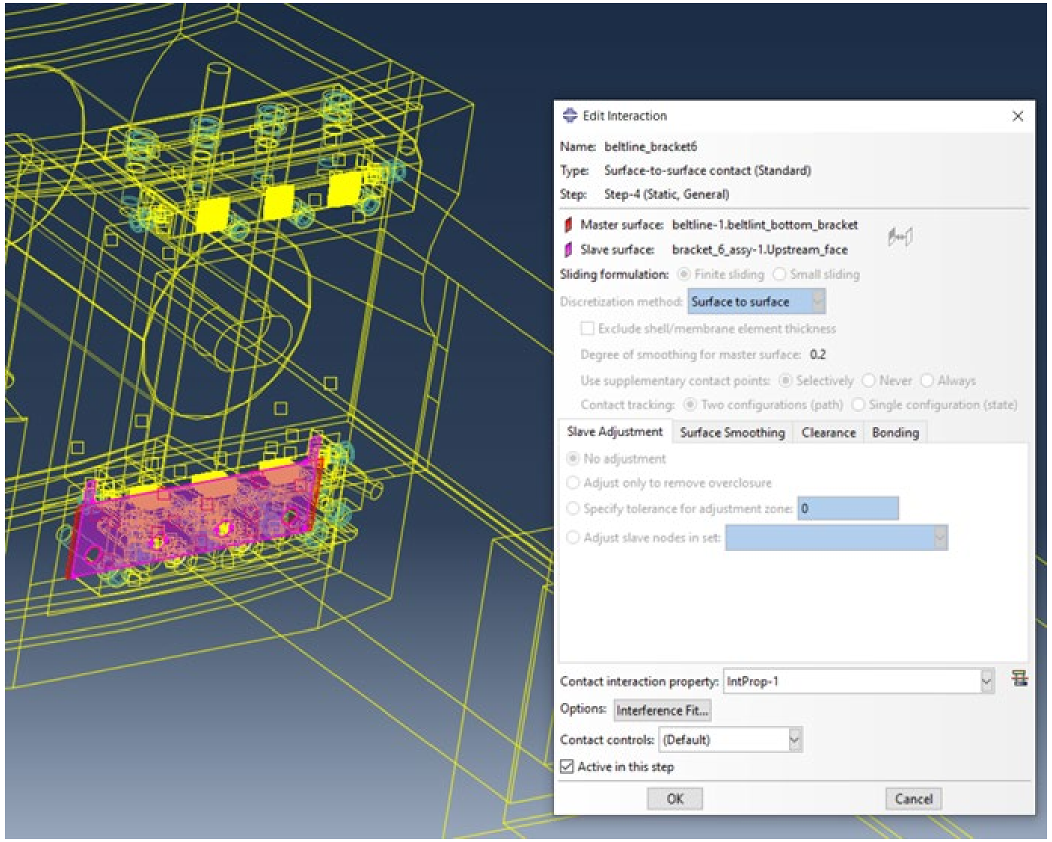


Plate surface to surface interaction

Bracket 6 upstream face to beltline



Bracket 8 bottom to beltline

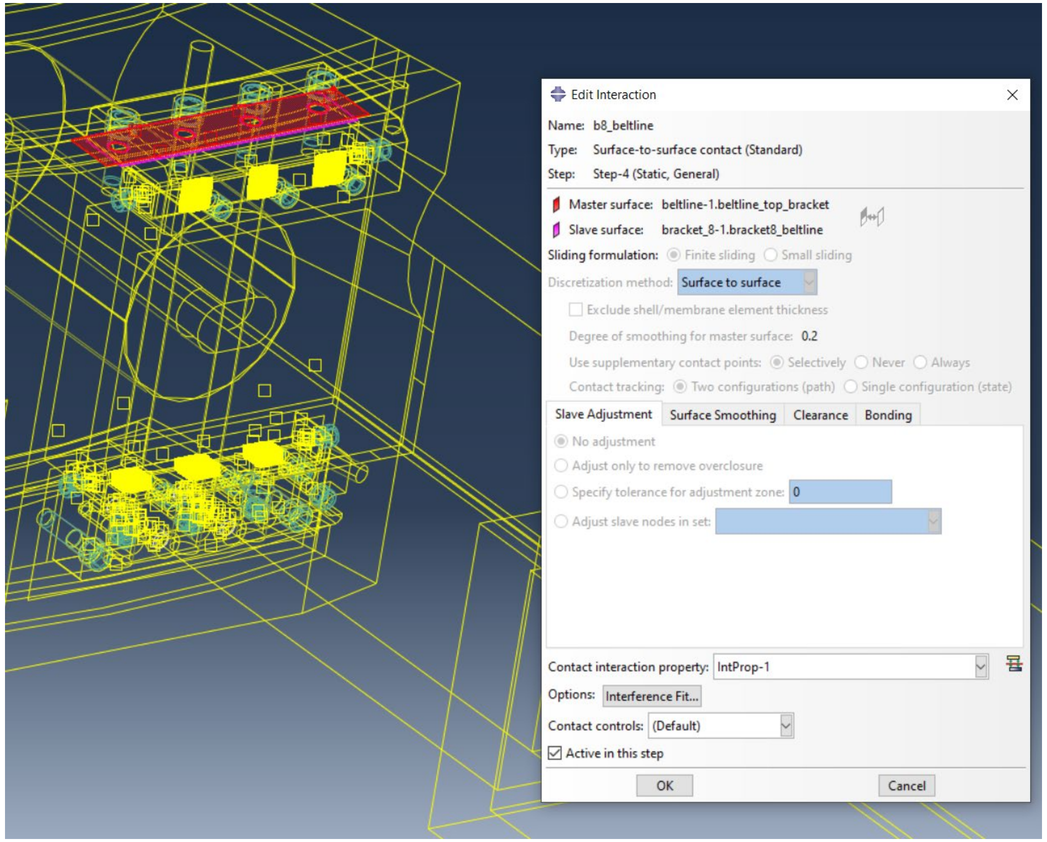
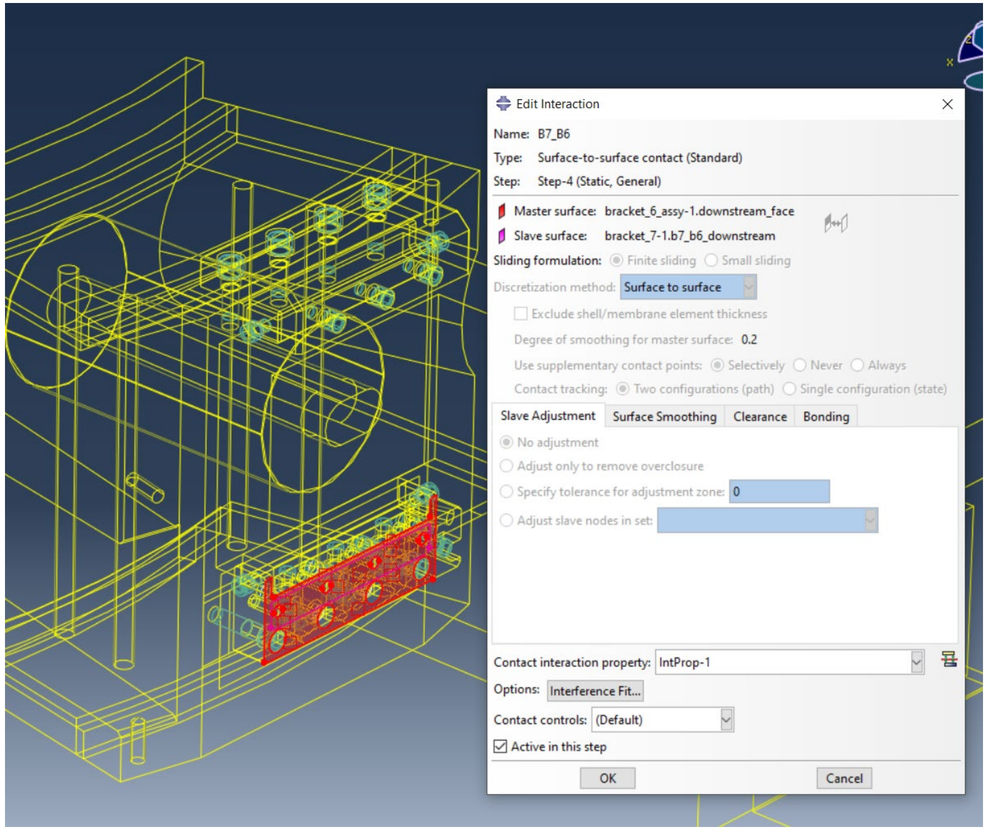
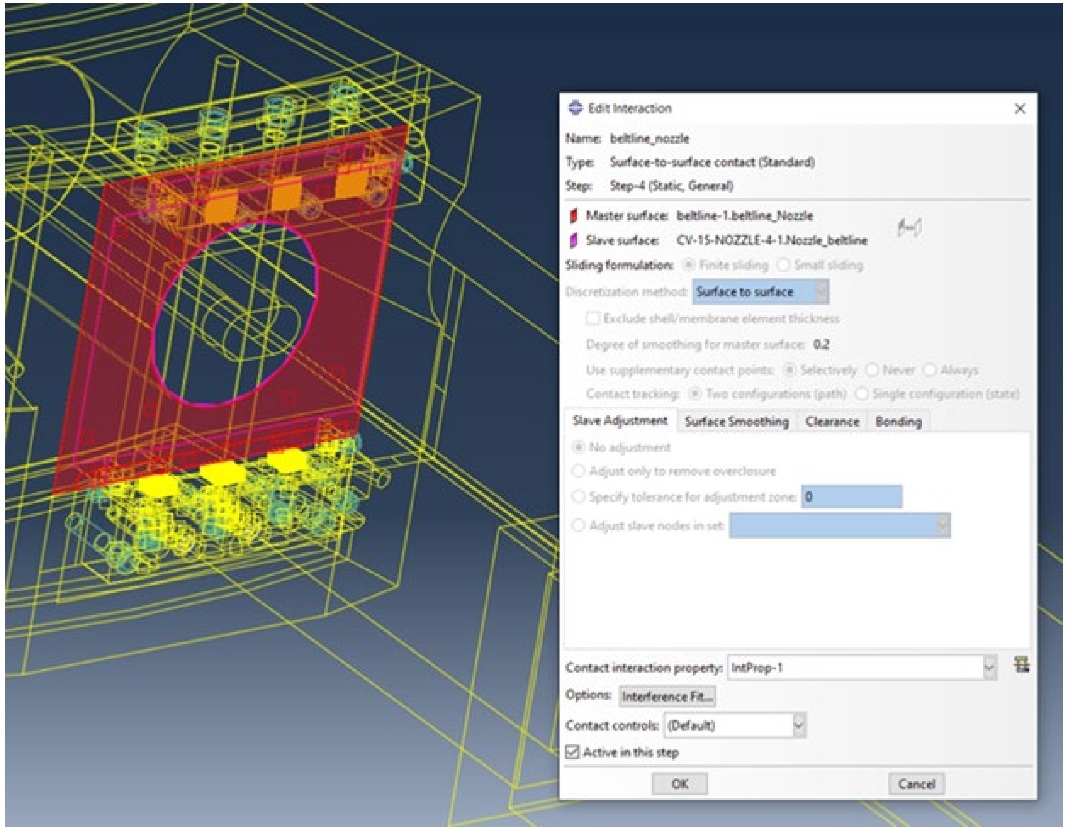


Plate surface to surface interaction

Bracket 7 upstream face to bracket 6

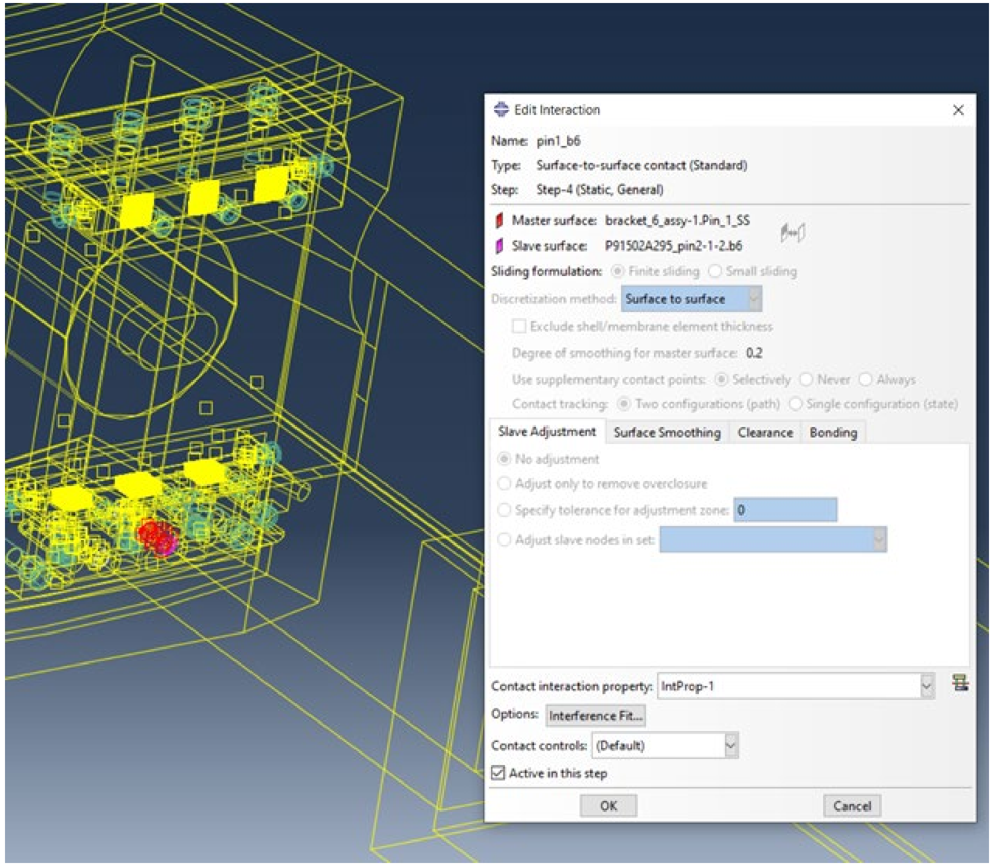


Nozzle upstream face to beltline

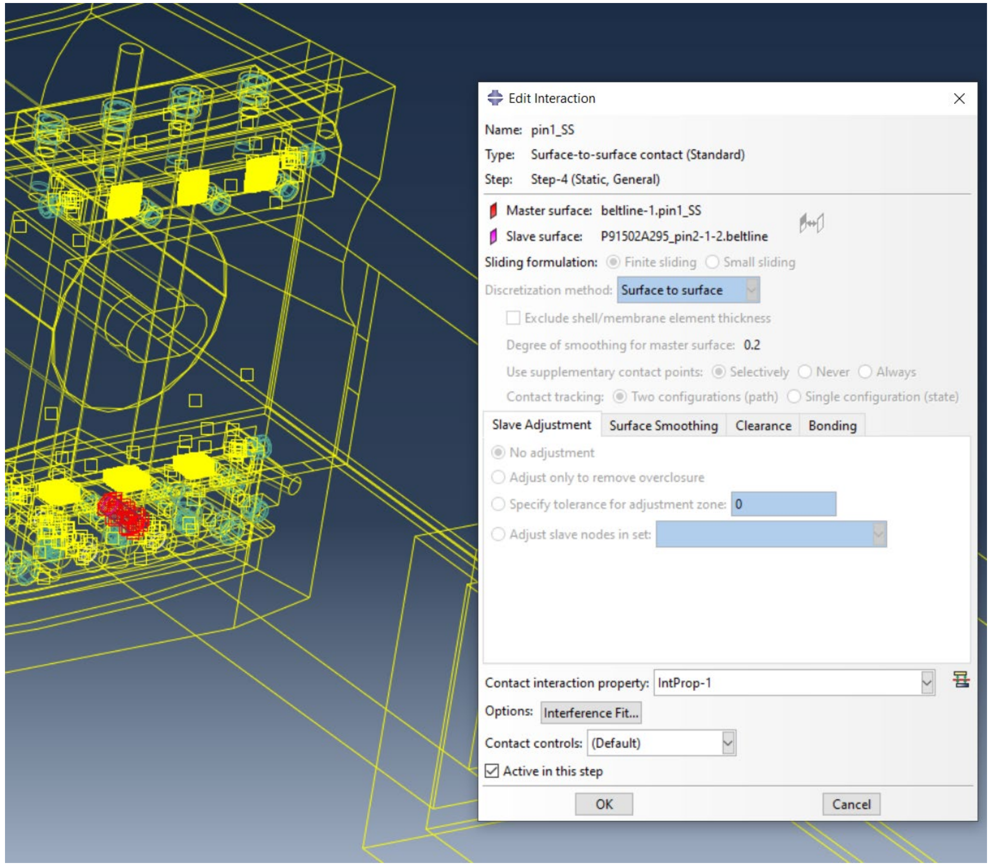


Shear pin surface to surface interactions

Pin 1 to bracket 6

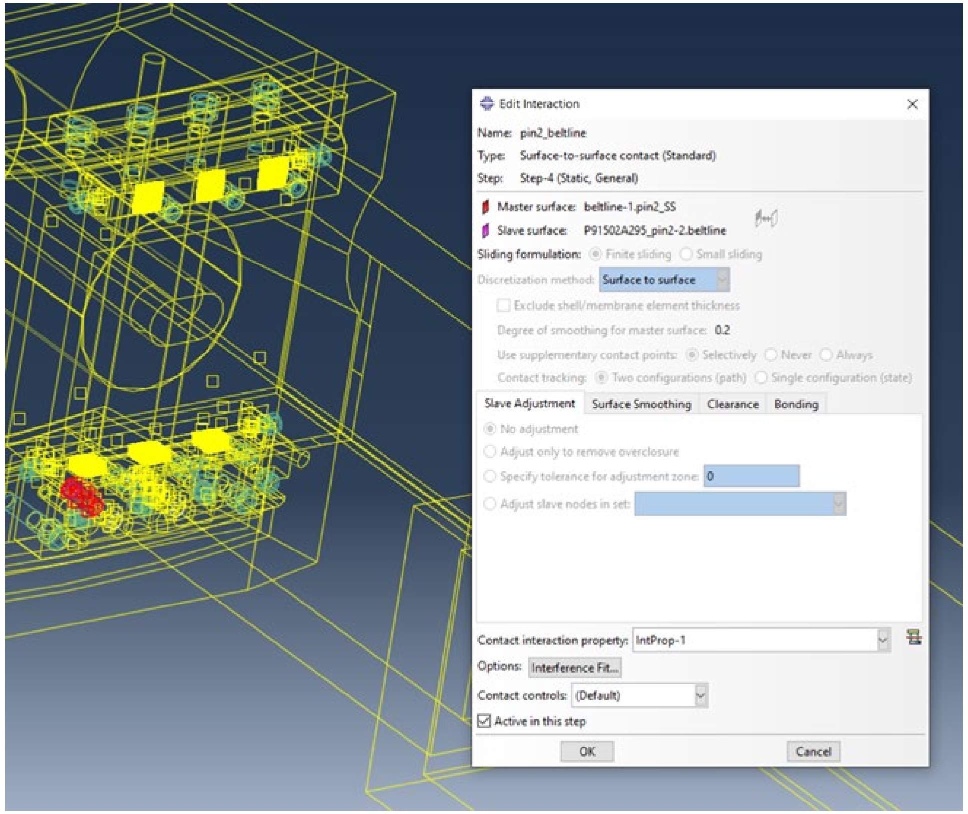


Pin 1 to beltline

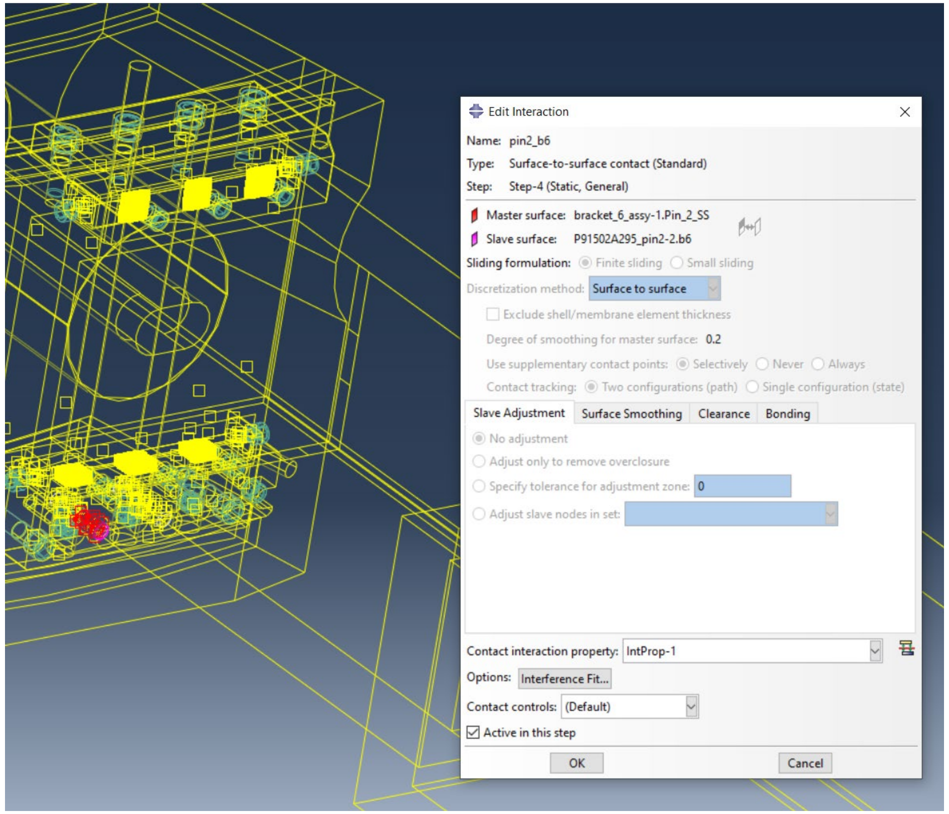


Shear pin surface to surface interactions

Pin 2 to beltline

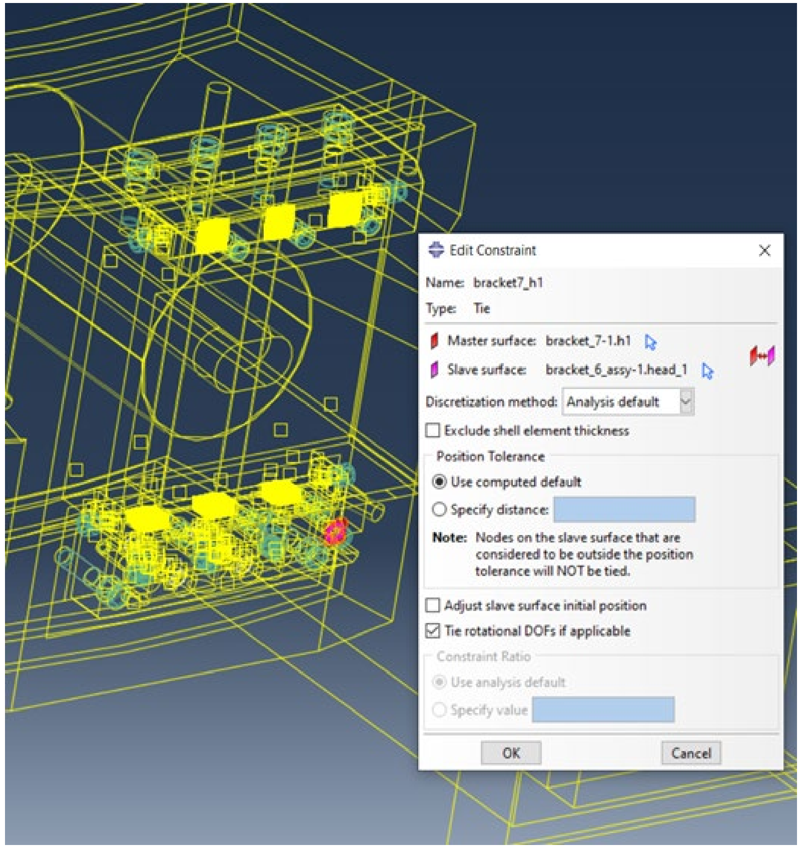


Pin 2 to bracket 6

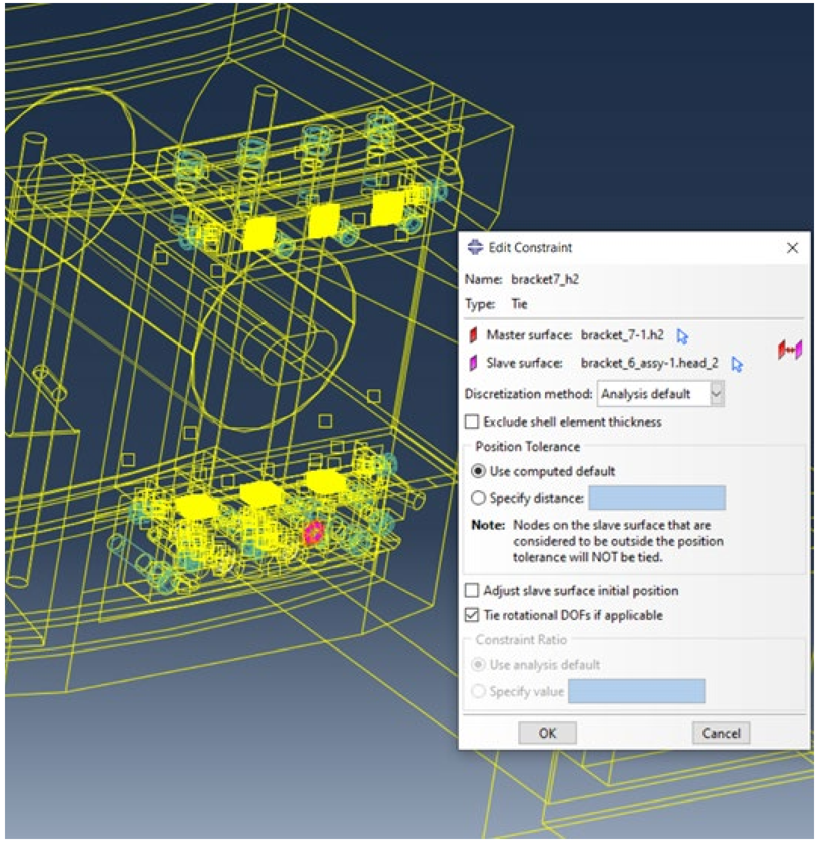


Bracket 6 Tie Constraints

Bracket 6 bolt 1 head to bracket 7

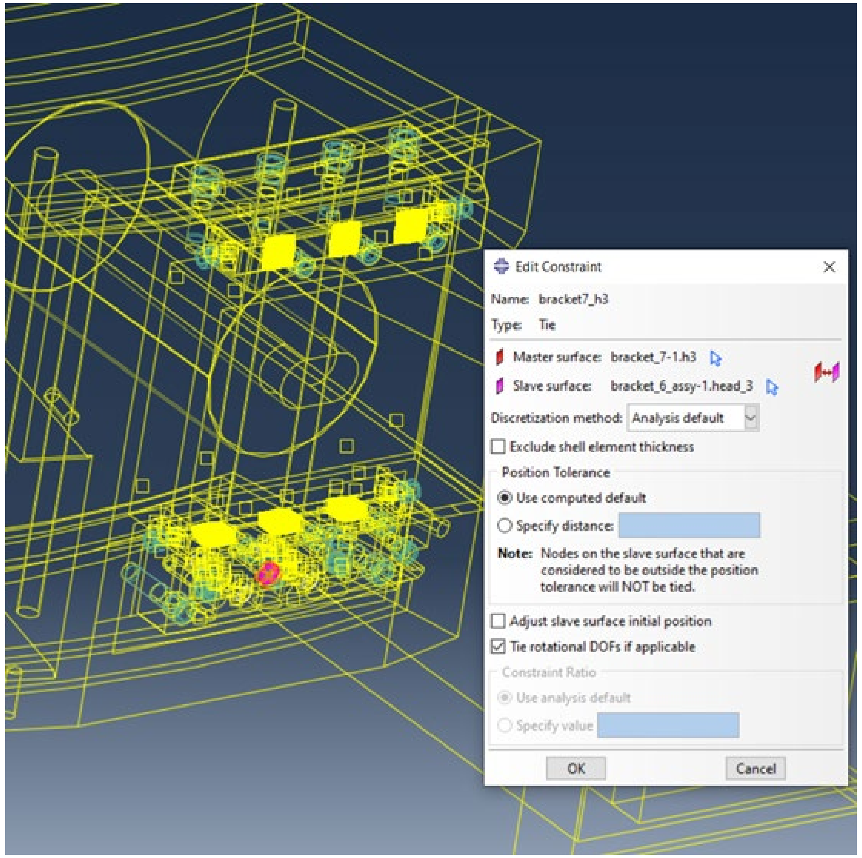


Bracket 6 bolt 2 head to bracket 7

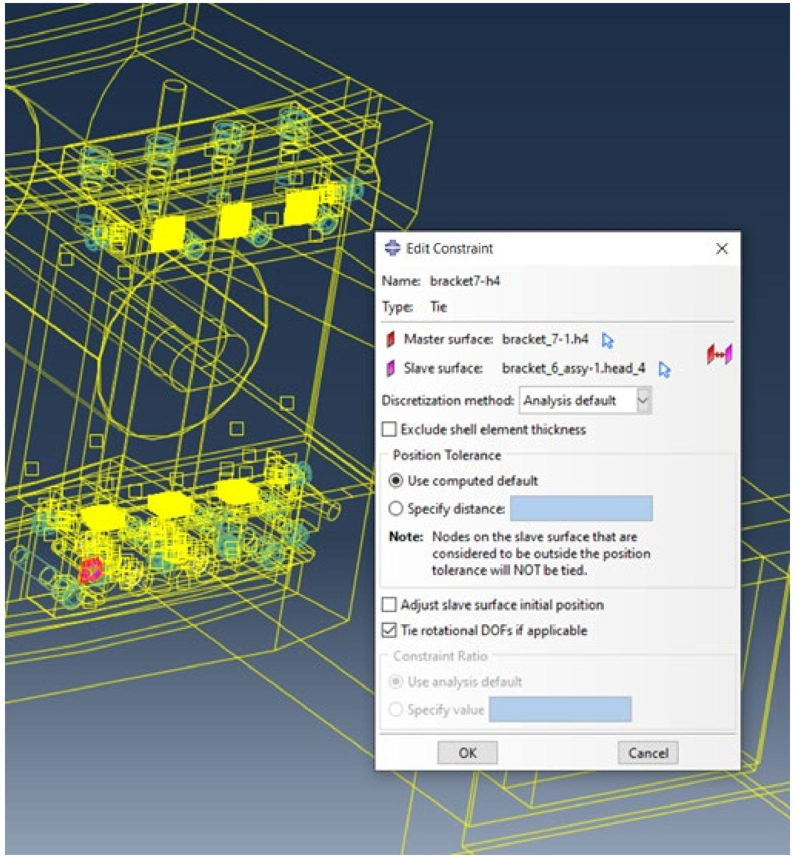


Bracket 6 Tie Constraints

Bracket 6 bolt 3 head to bracket 7

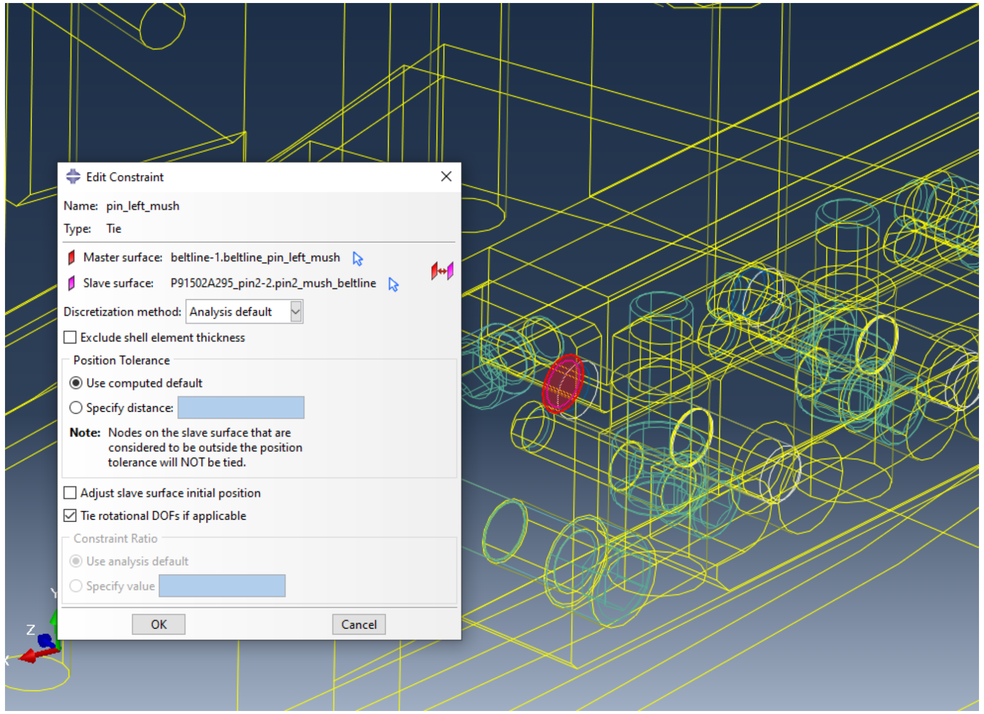


Bracket 6 bolt 4 head to bracket 7

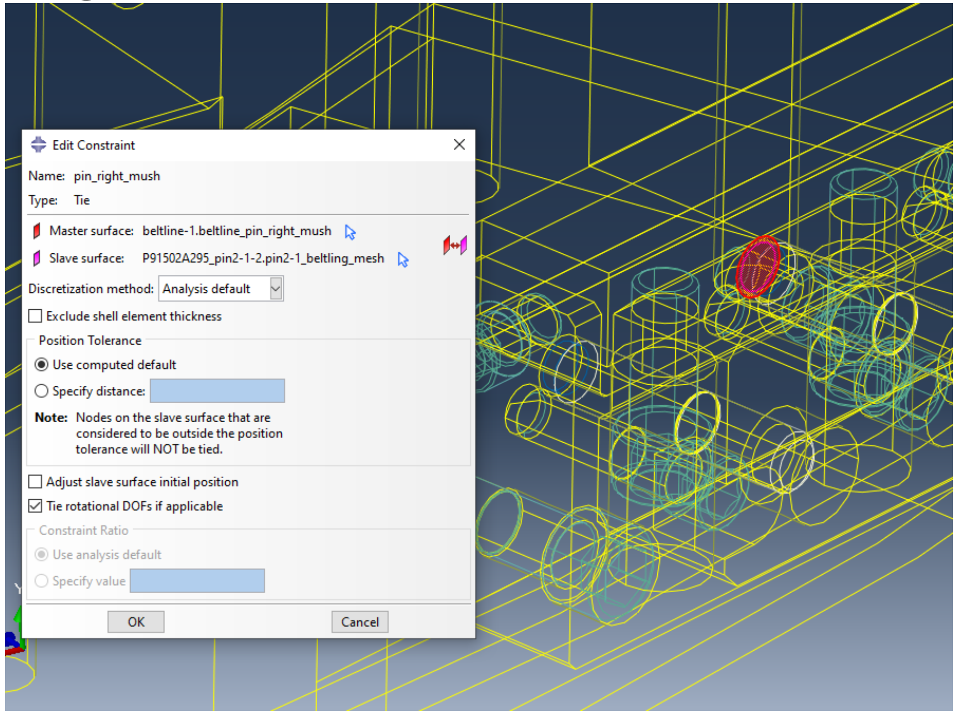


Shear pin ties to beltline for numerical stability

Left pin "mush" tie to beltline



Right pin "mush" tie to beltline



"mush" modulus = 2 MPa

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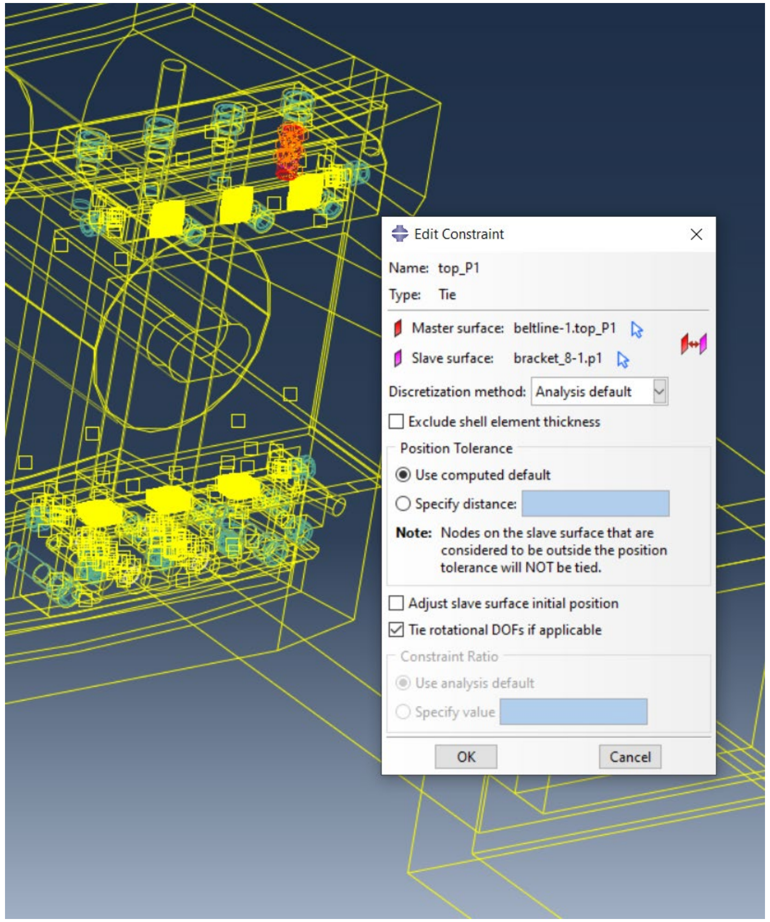
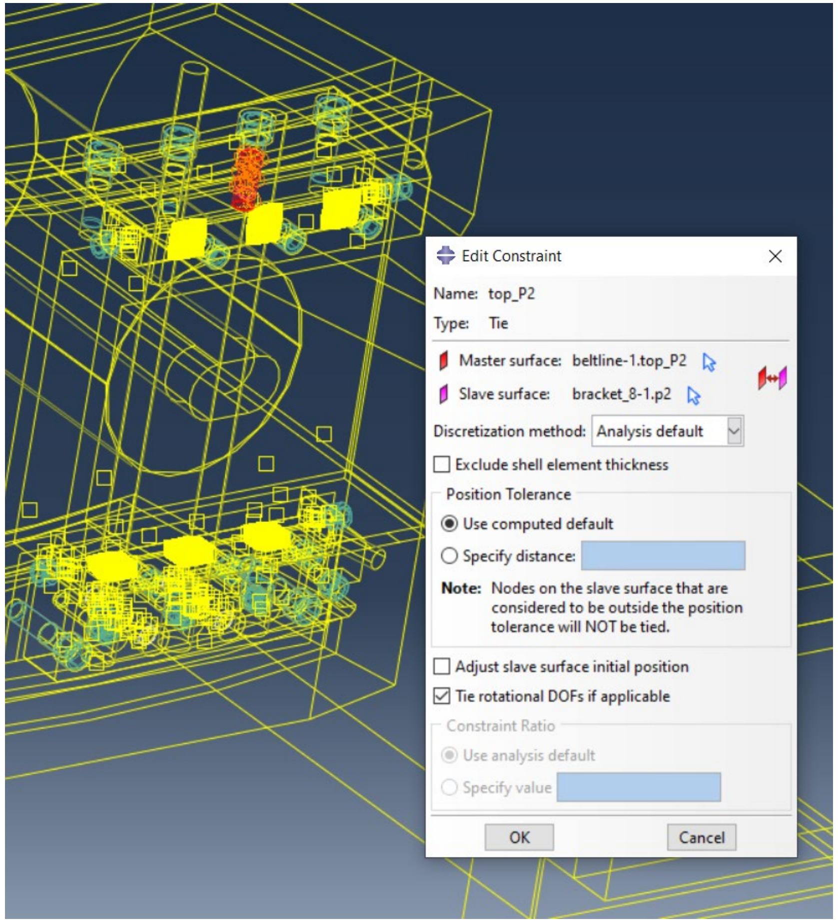
Bracket 8 bolt tie constraints

Vertical Bolt 1 to beltline



Vertical Bolt 2 to beltline



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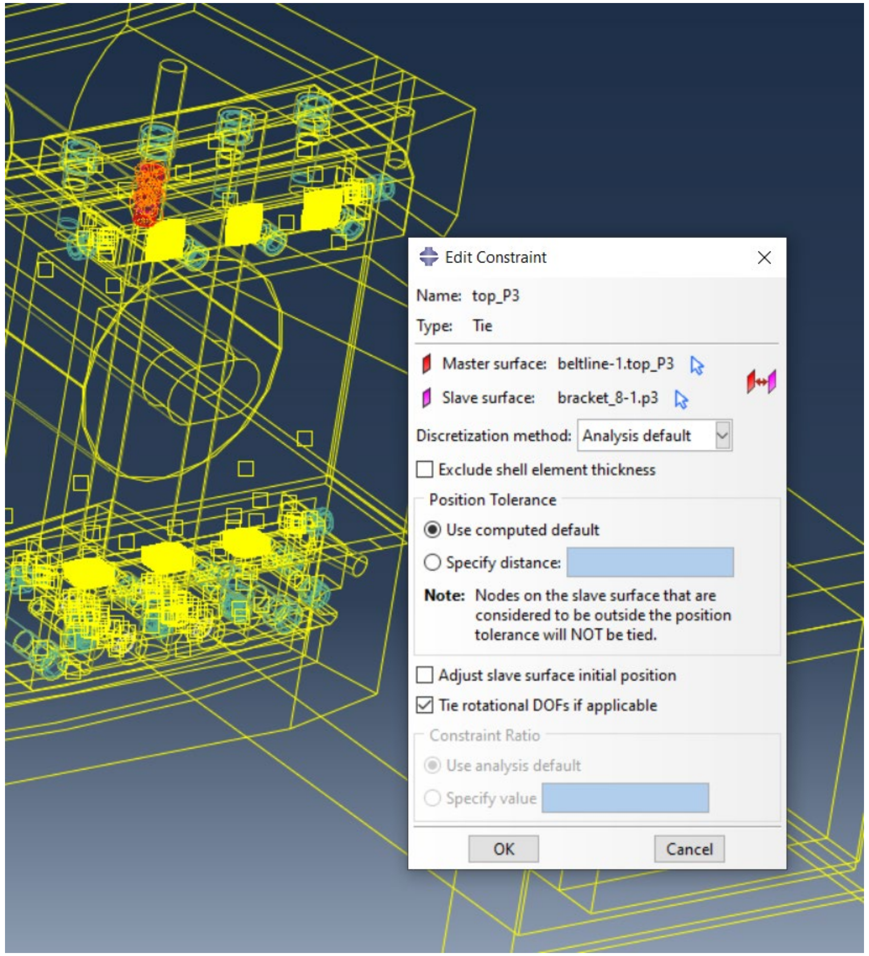
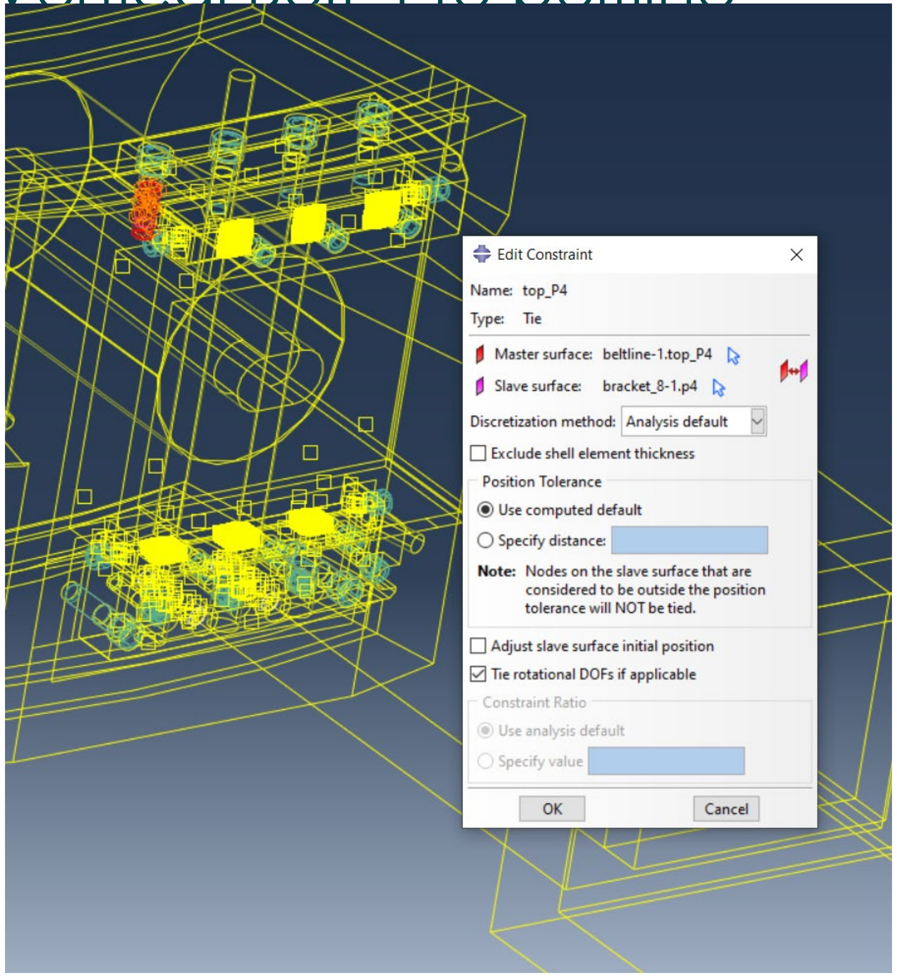
Bracket 8 bolt tie constraints

Vertical Bolt 3 to beltline

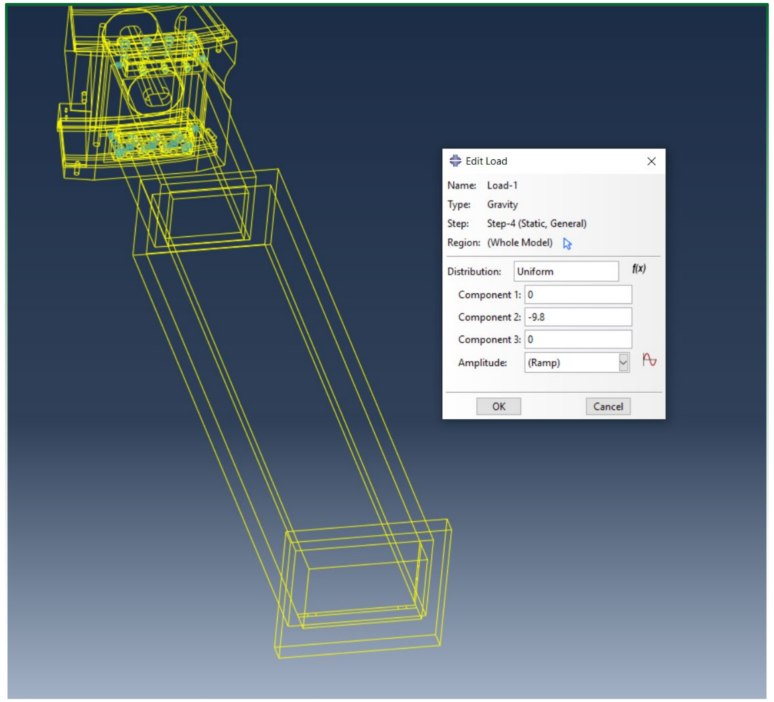


Vertical Bolt 4 to beltline

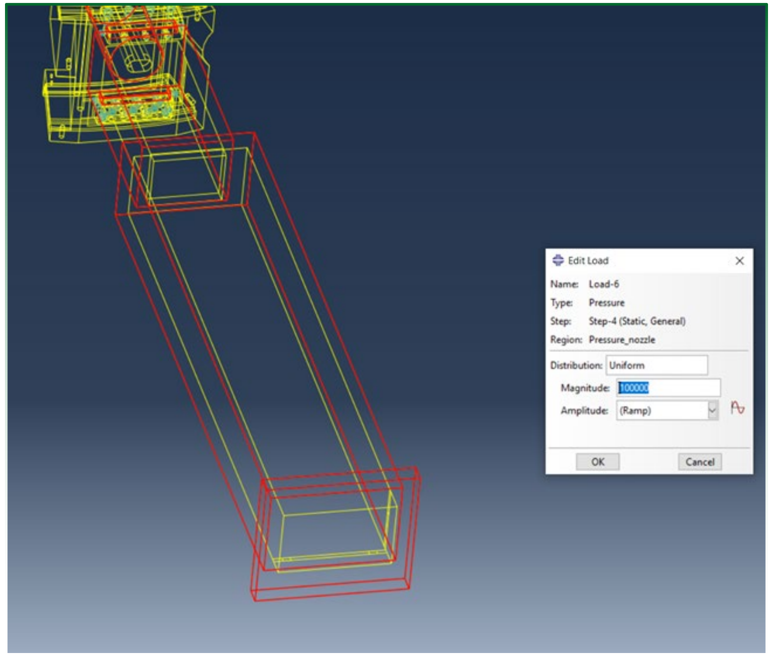


Gravity and Pressure Loads

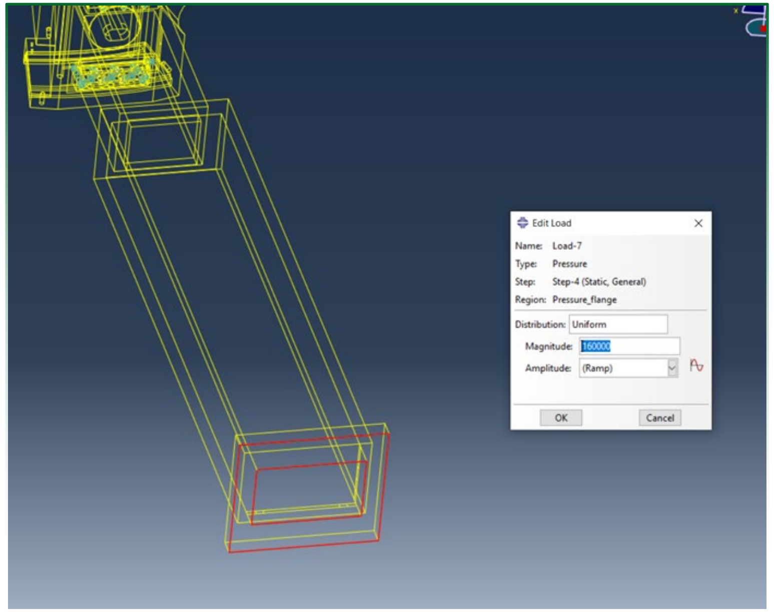
1 G vertical gravity



1 bar side external pressure

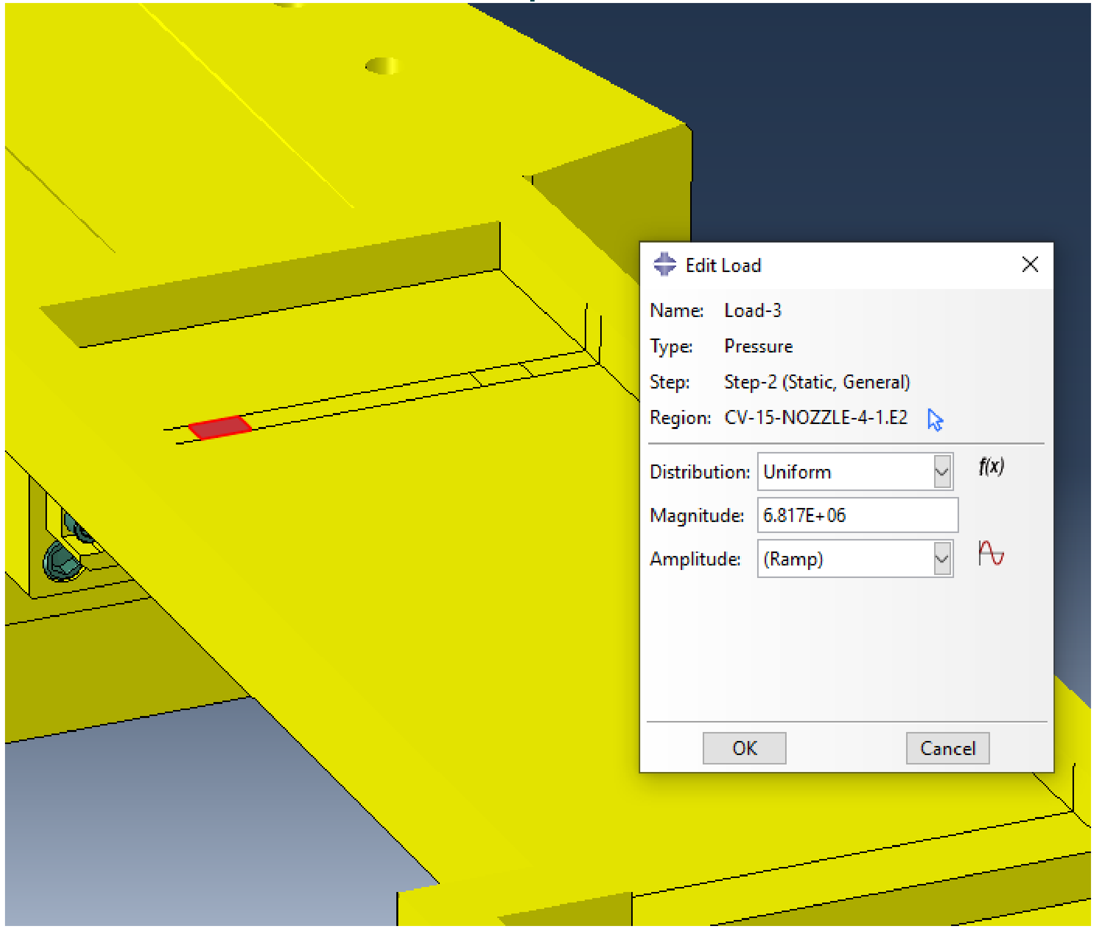


Axial pressure on flange for 1 bar axial pressure

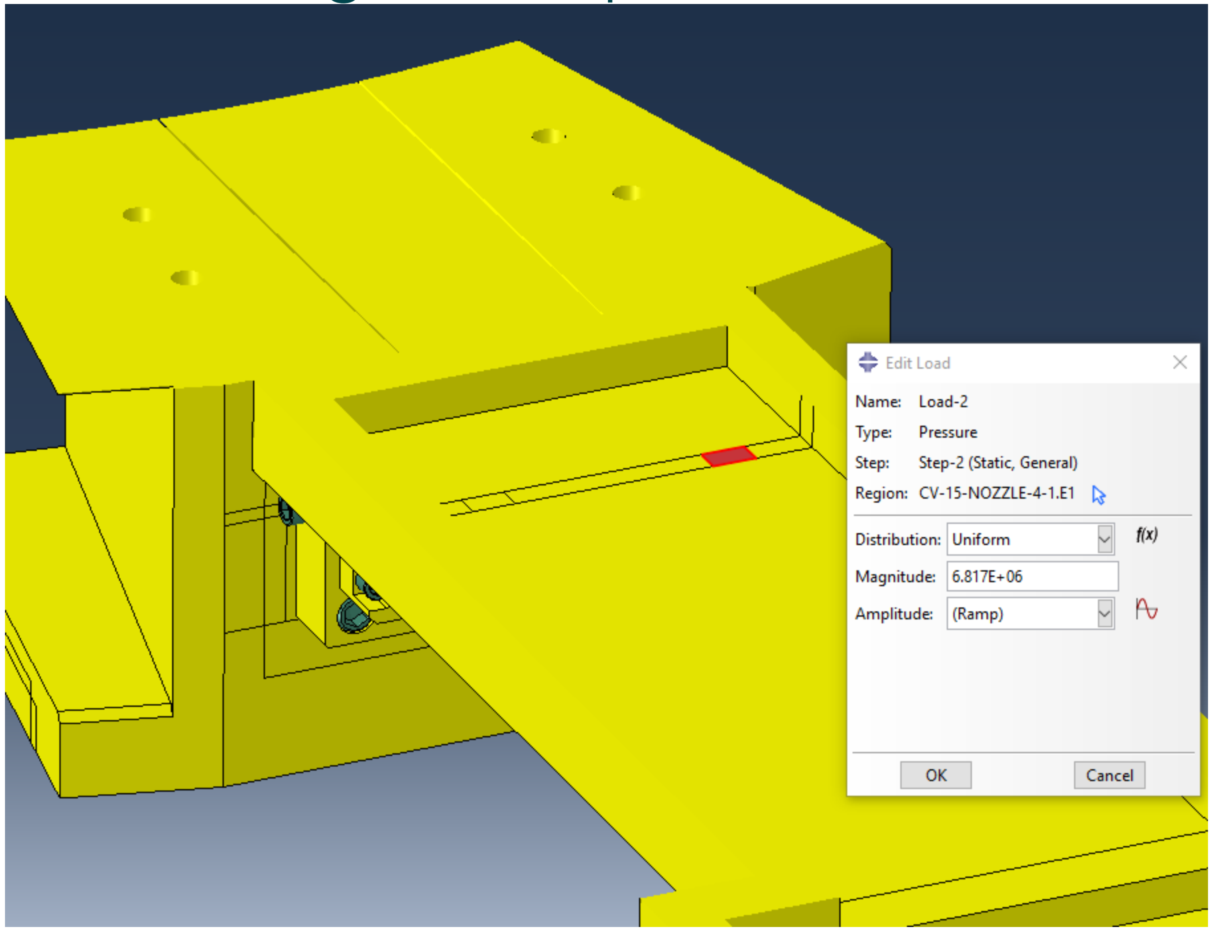


Insert Gravity loads as pressures on pad areas

Left front pad area

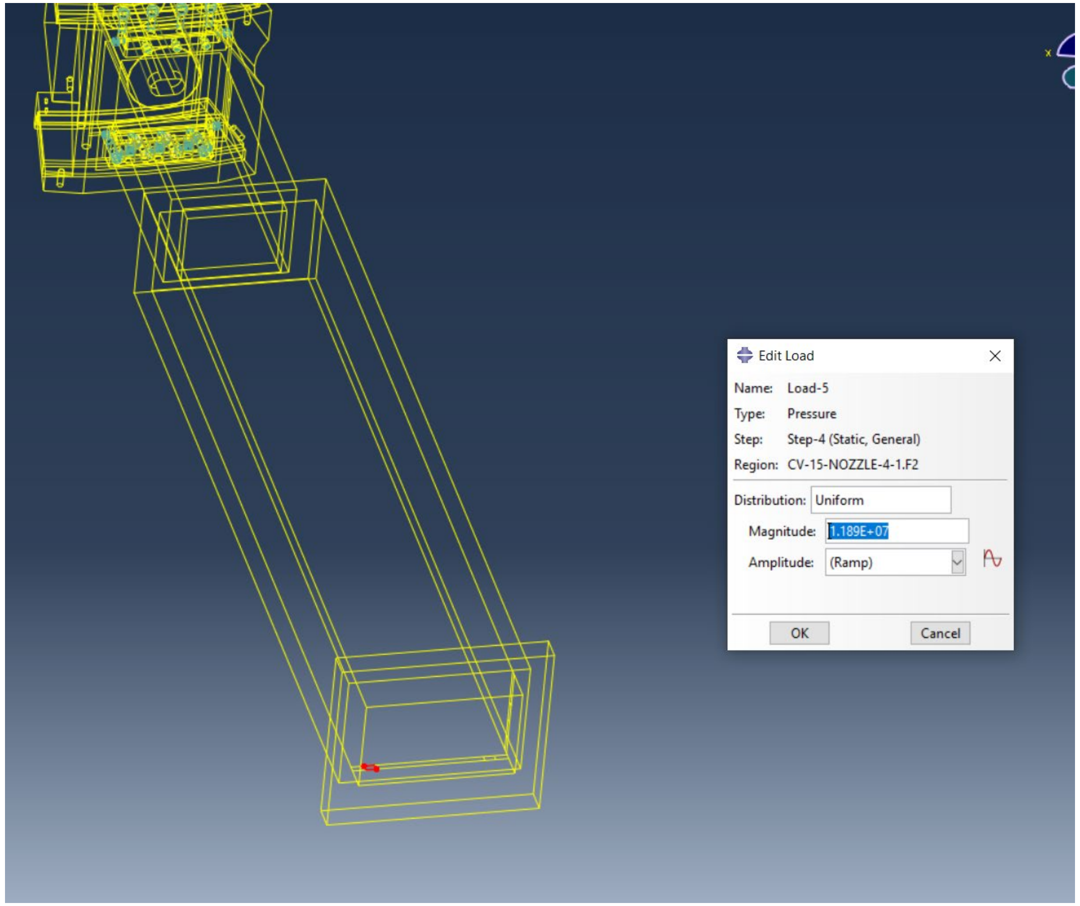


Right front pad area

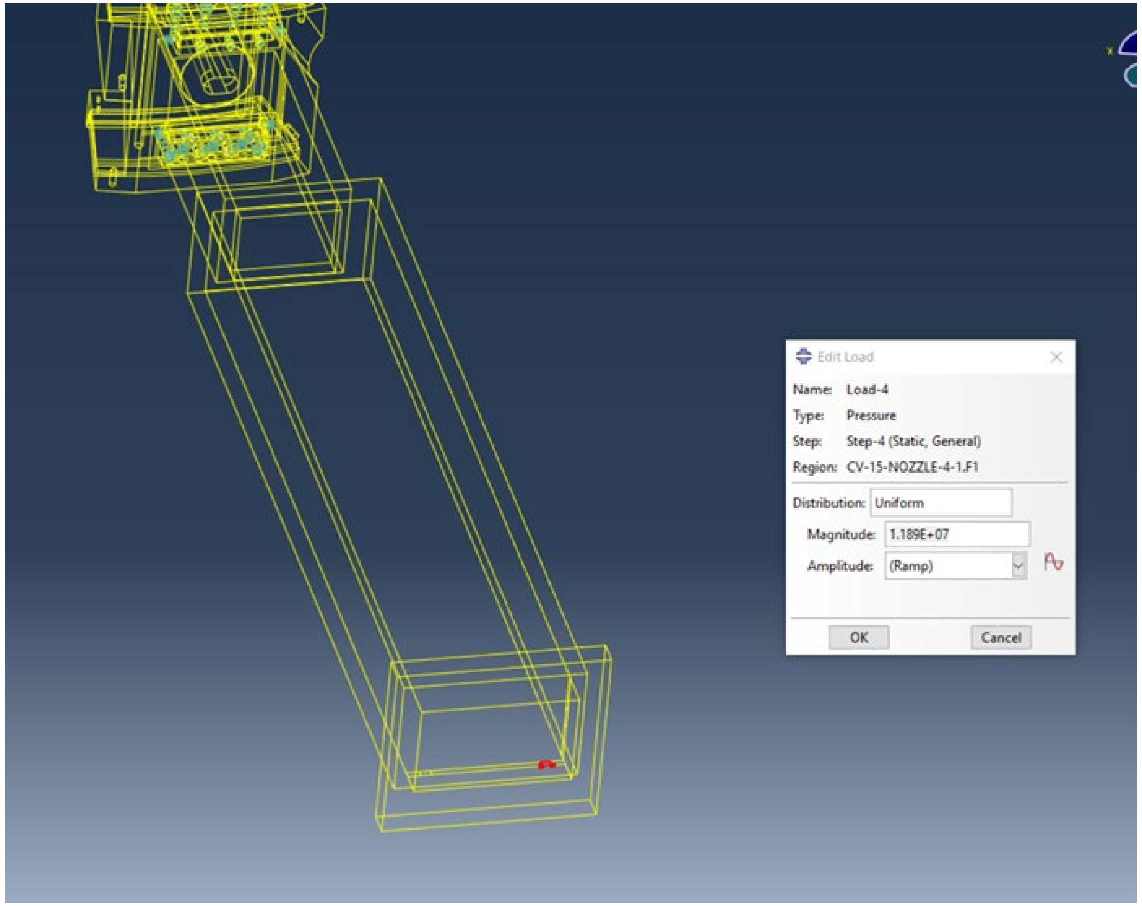


Insert Gravity load as pressure

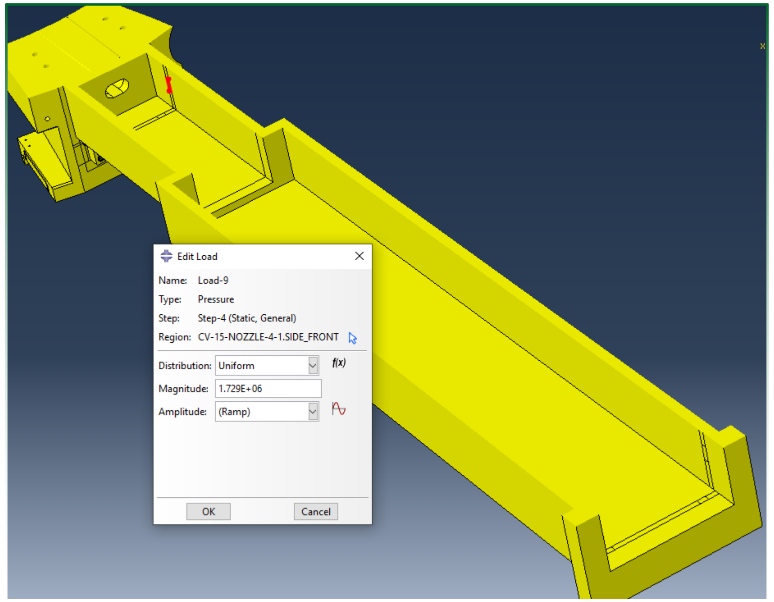
Left rear pad

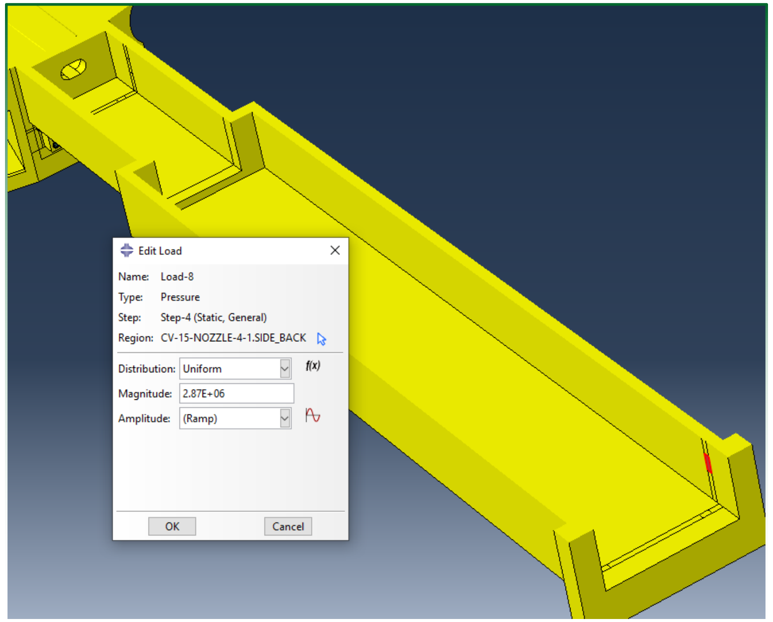


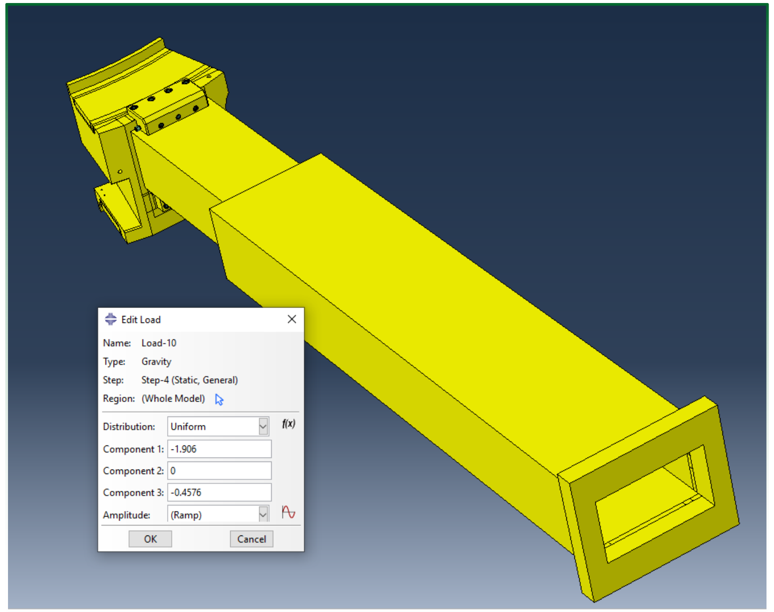
Right rear pad



Seismic .231 g side loads for insert and structure







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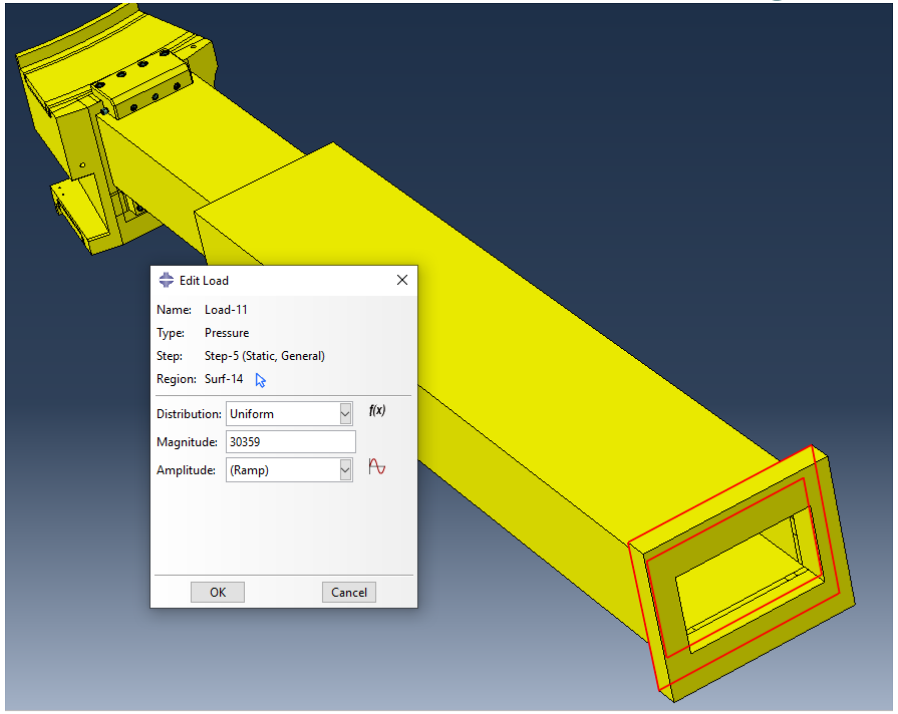
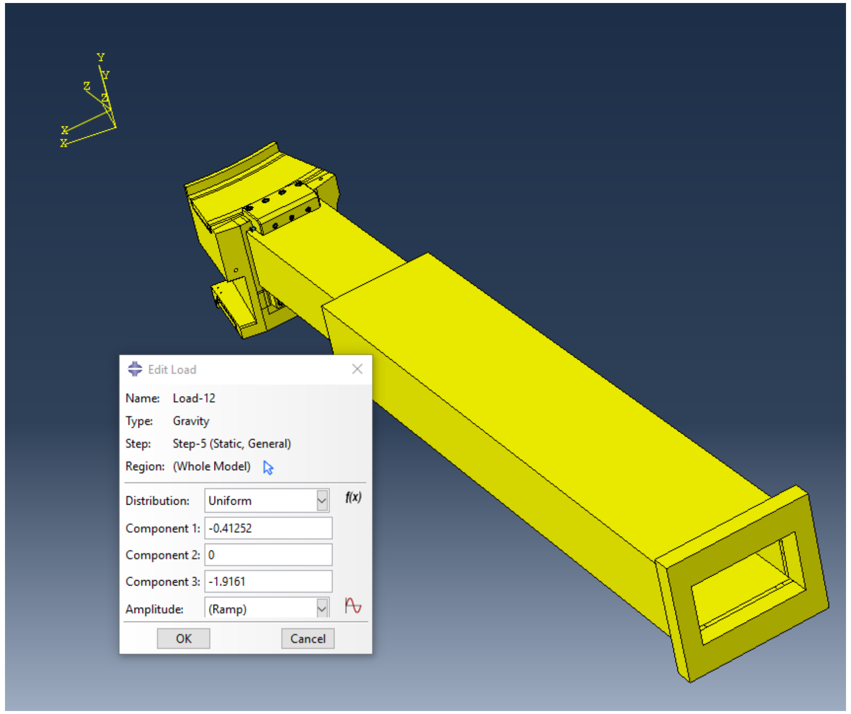
Axial loads from .231 G seismic load in nozzle axial direction (STEP 5)

Axial load from insert .231 g seismic as pressure on upstream flange face

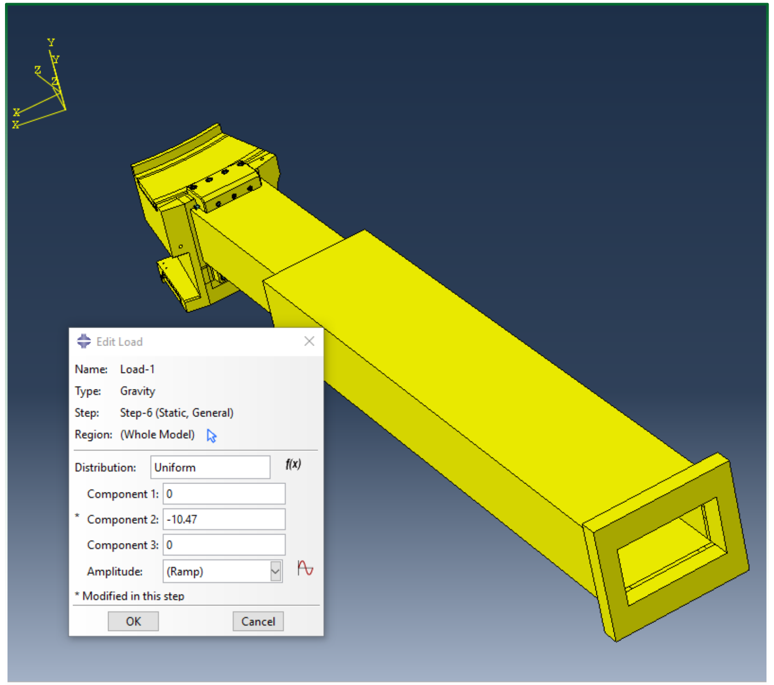


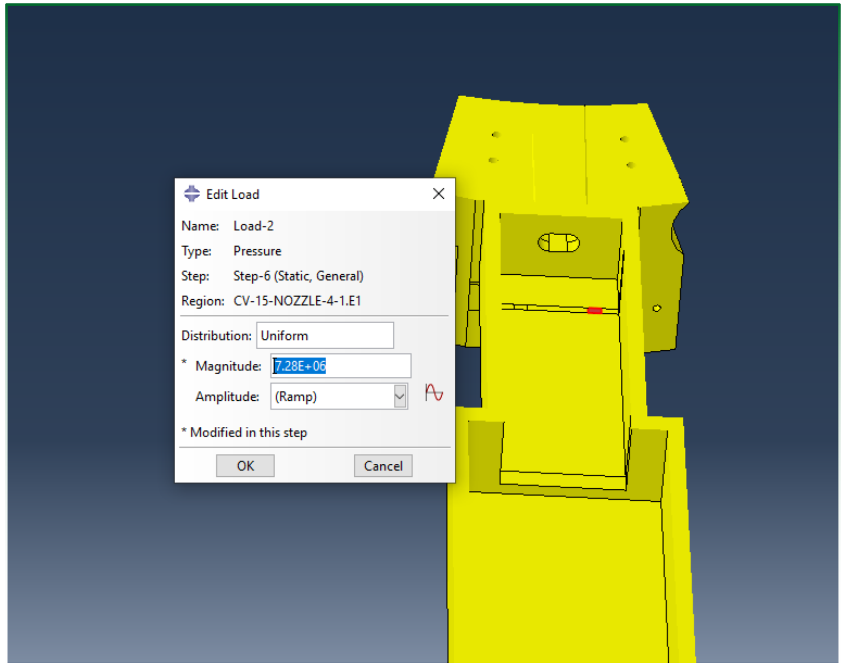
Axial load on structure from .231 g seismic in axial direction

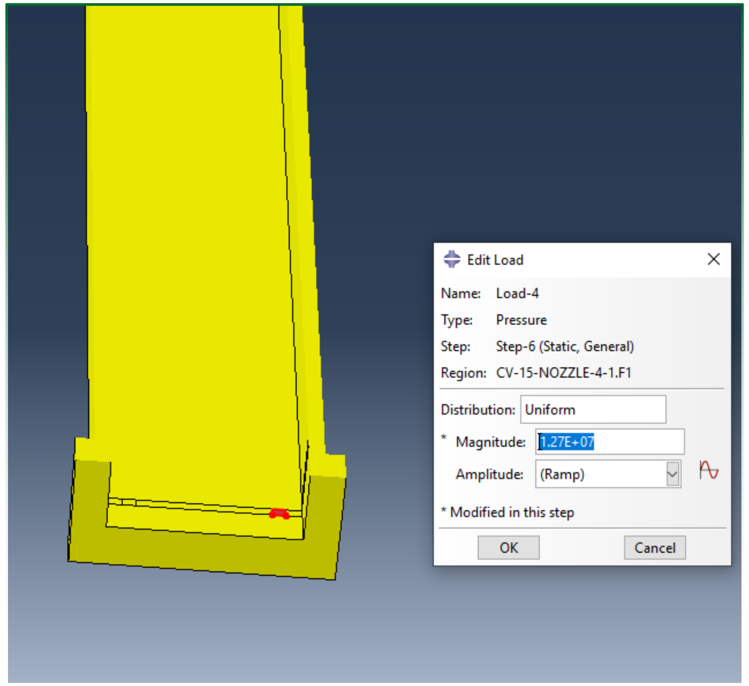


Gravity loads modified to include 0.068 G vertical seismic load

Structure	Front insert load (typ)	Rear insert load (typ)

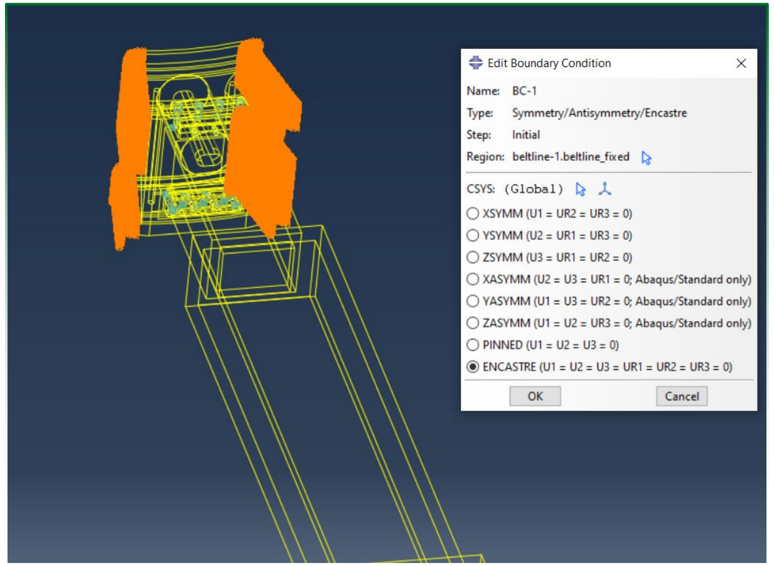




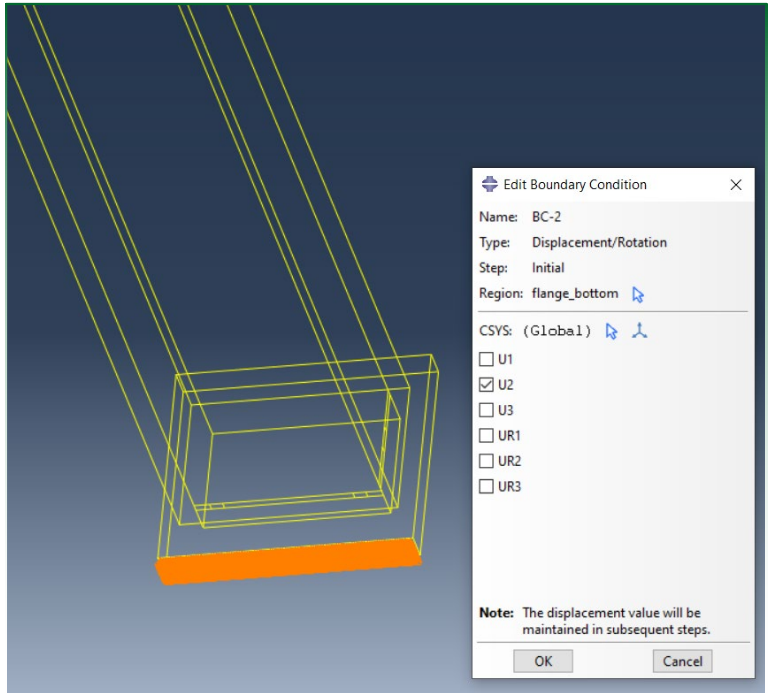


Boundary Conditions

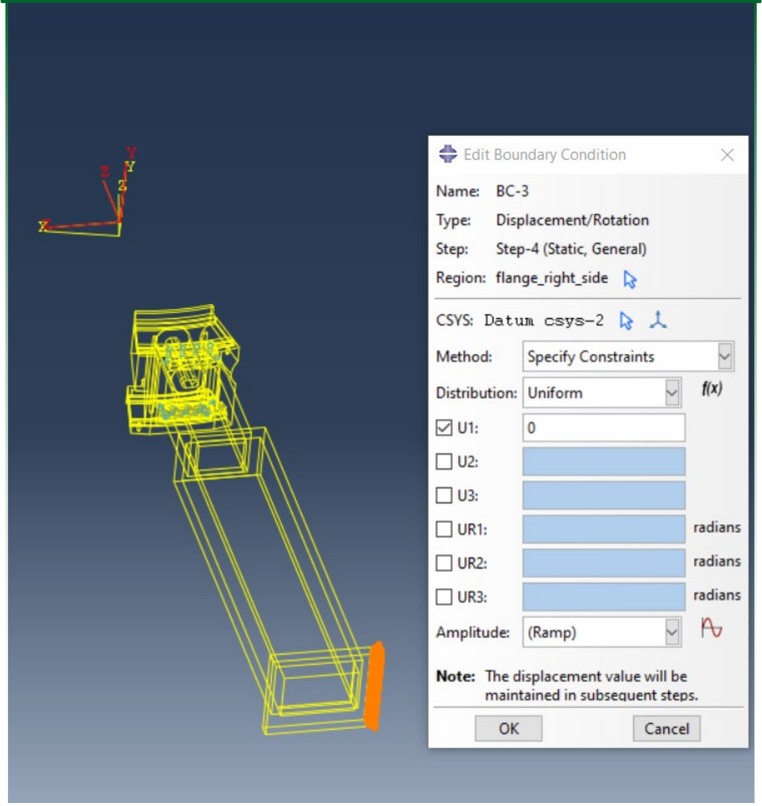
Beltline fixed



Flange Bottom displacement



Flange right side displacement



Analysis Step Loads and Boundary Conditions

	Loads						Boundary Conditions		
Step	Structure 1 g vertical	Insert mass 1 g vertical	1 bar pressure	Seisimic side load	Seismic axial load	Seismic vertical load	1- Beltline fixed	2- Flange bottom	3 - Flange side
1	X						X	X	
2	X	X					X	X	
3	X	X	X				X	X	
4	X	X	X	X			X	X	
5	X	X	X		X		X	X	X
6			X			X	X	X	

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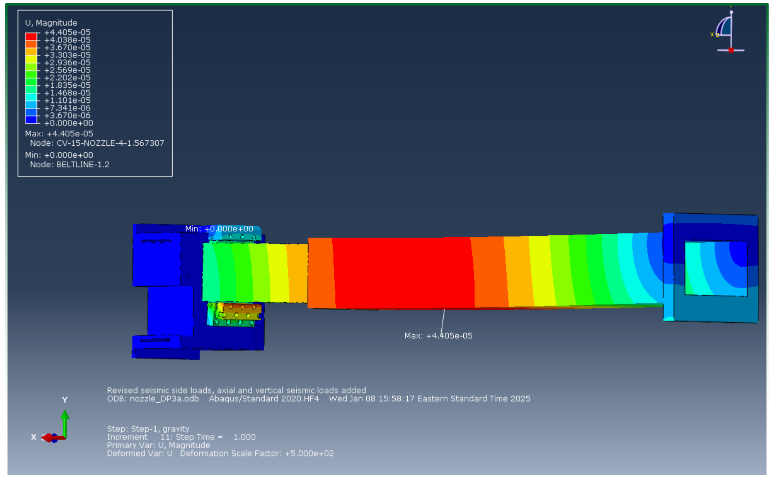
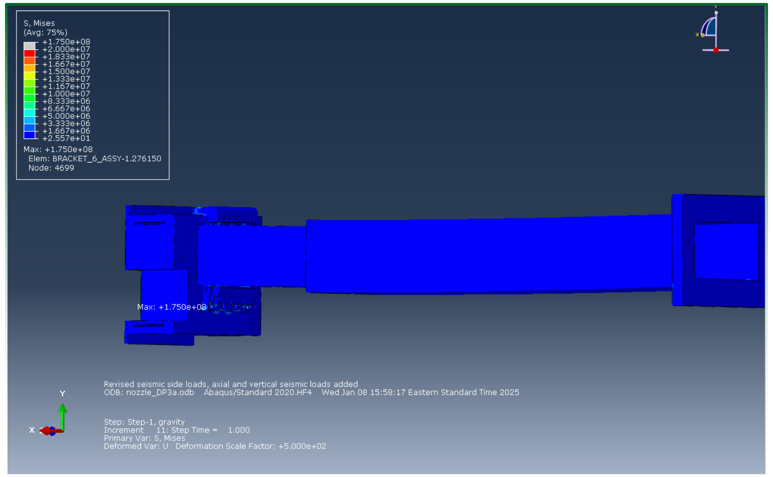
Step 1 Gravity

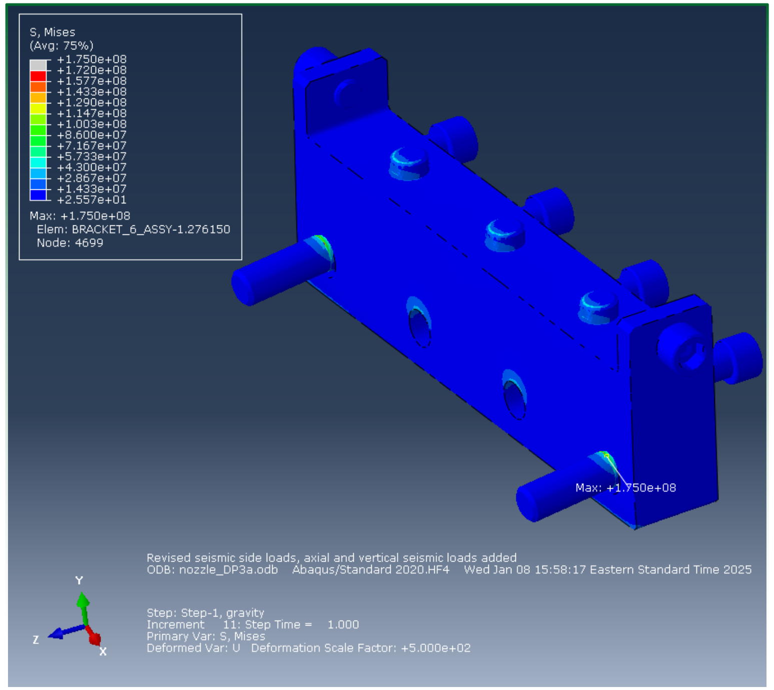
U



S peak 175 MPa

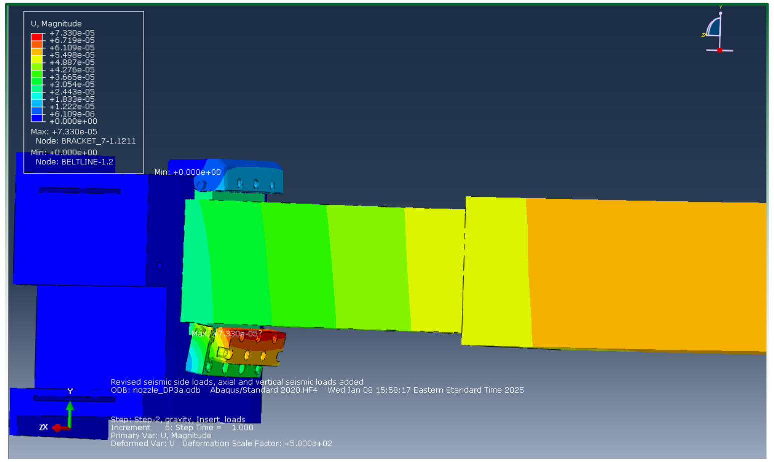


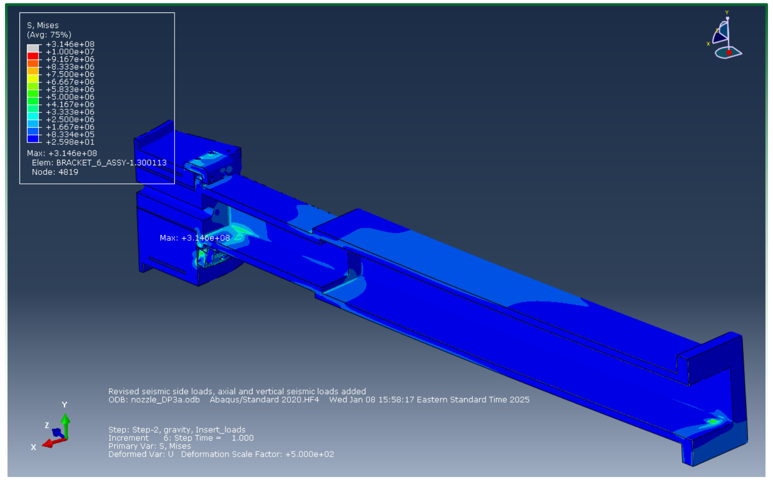
Bracket Detail

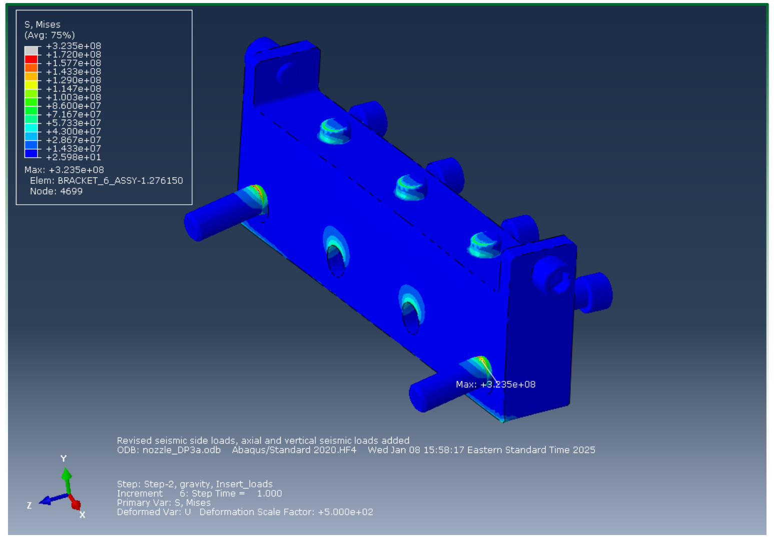


Step 2 Insert loads added

U	S 10 MPa scale max	S peak 324 MPa







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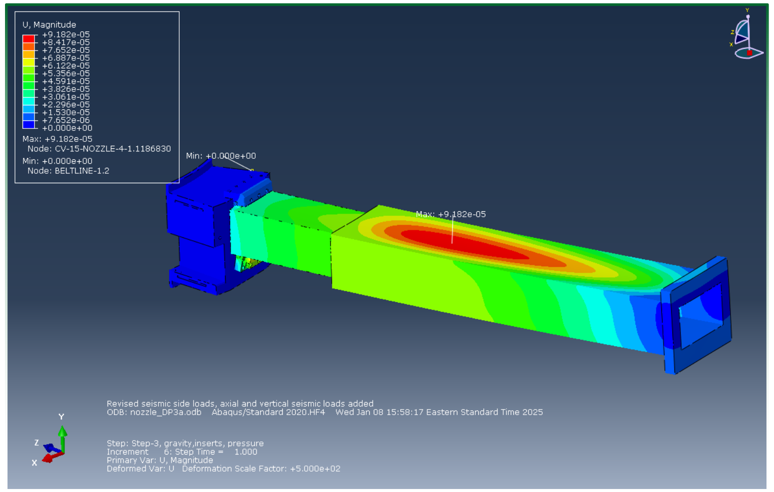
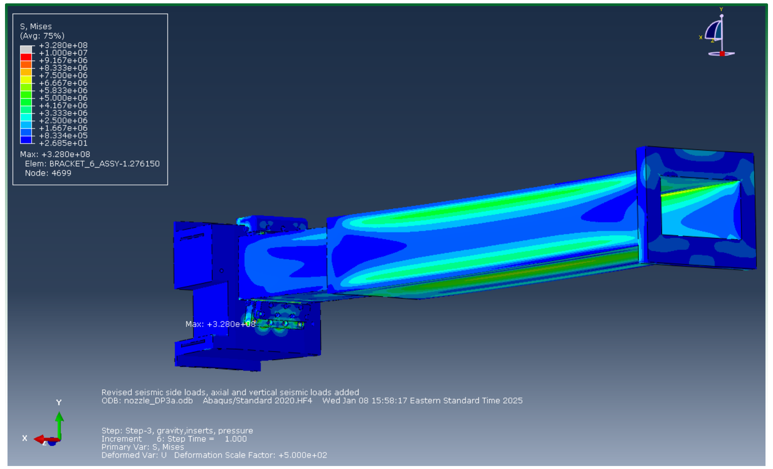
Step 3 gravity inserts and pressure

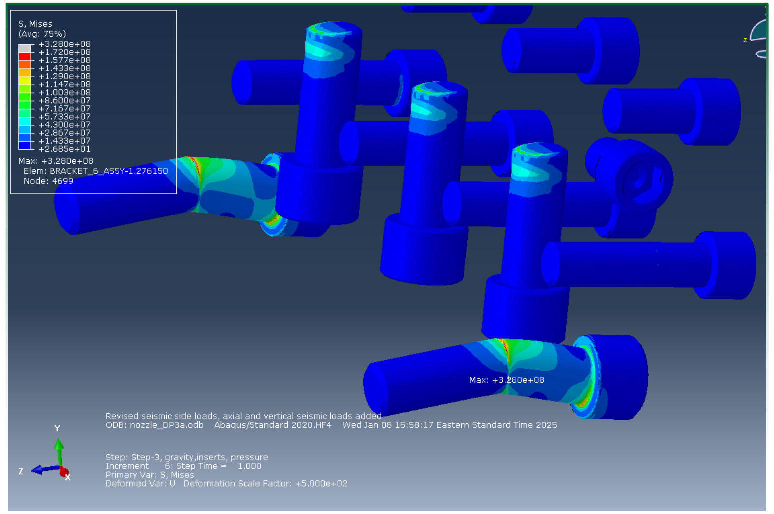
U

S max 328 MPa in bracket bolt

Bracket bolt stresses







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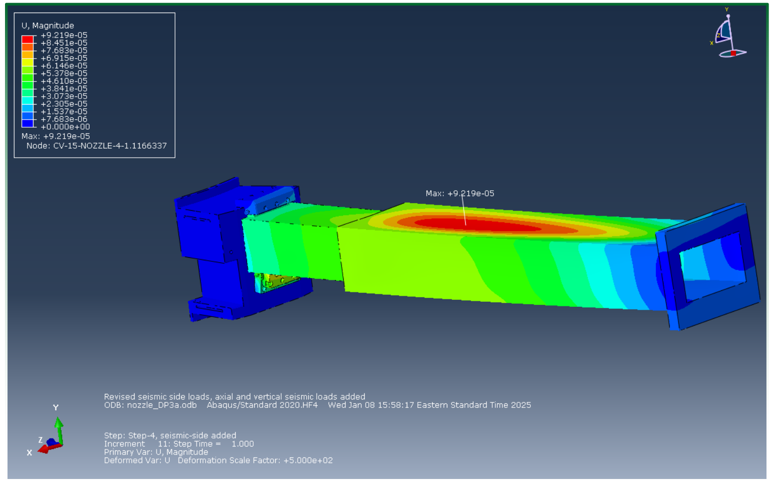
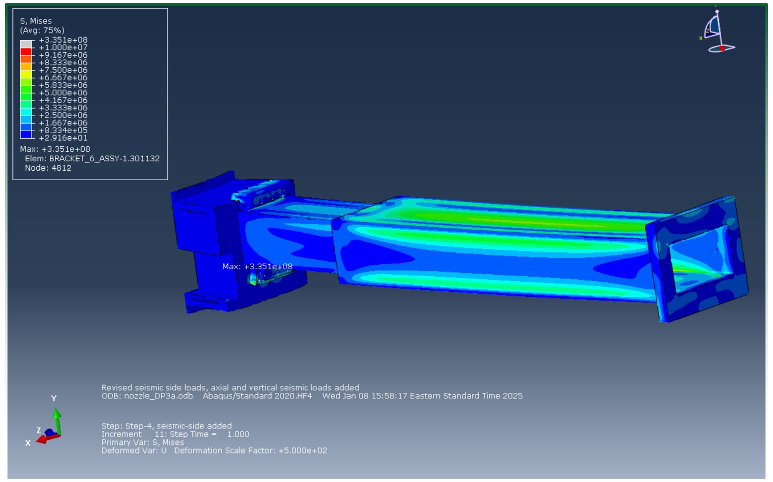
Step 4 gravity, inserts, vacuum and seismic side load

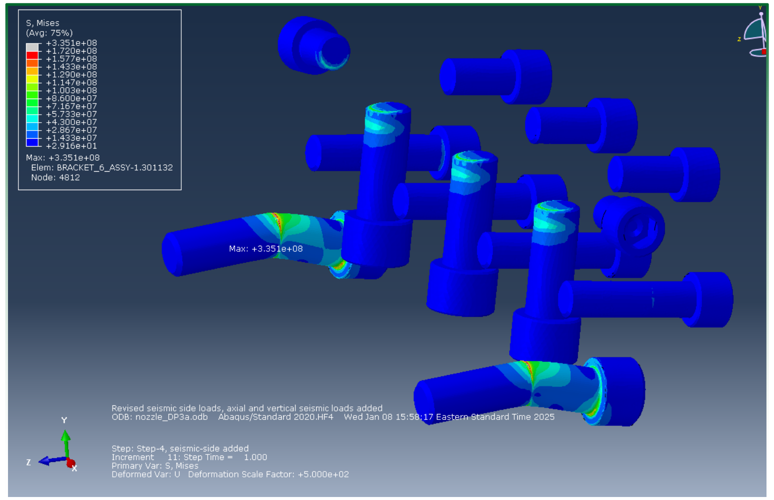
U



Peak 335 MPa in bracket 6 bolts



Bracket 6 bolts



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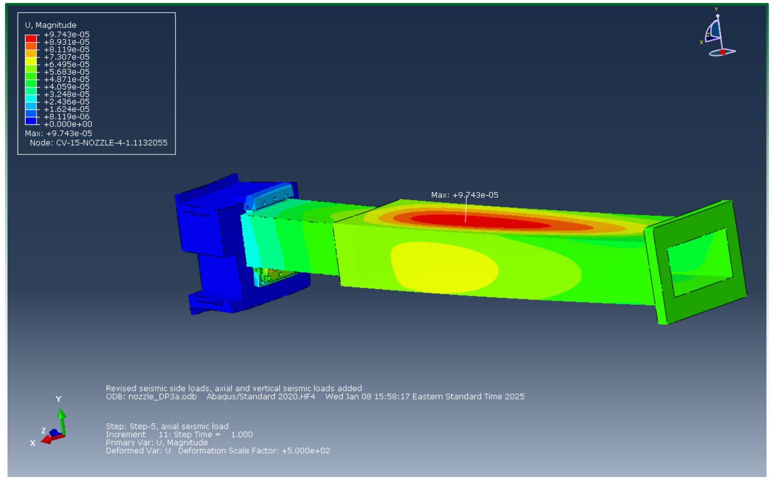
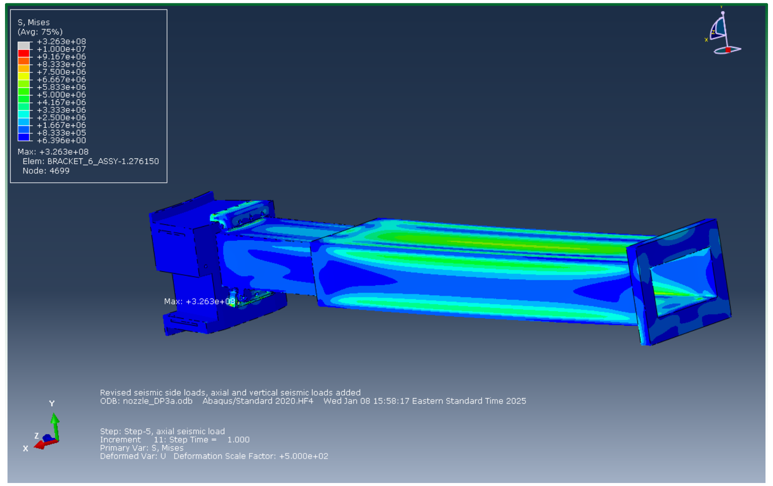
Step 5 gravity, inserts, vacuum and axial seismic load

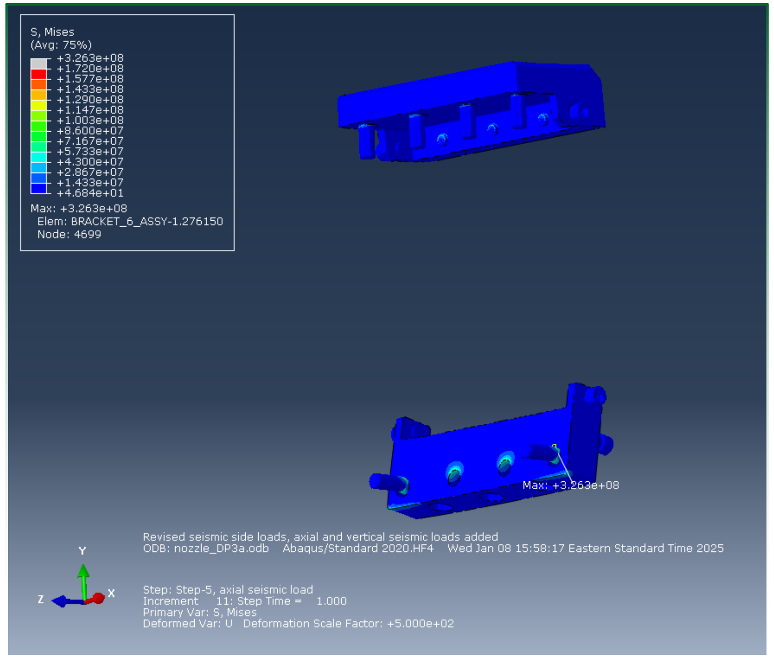
u

S peak 326 MPa in bracket 6 bolt 10 MPa scale max

Brackets 6 and 8 172 MPa scale maximum 326 Mpa peak

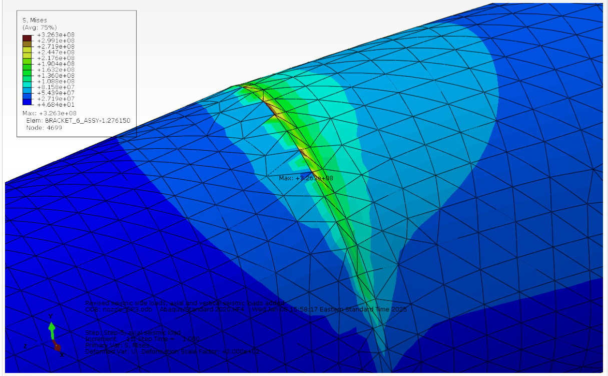




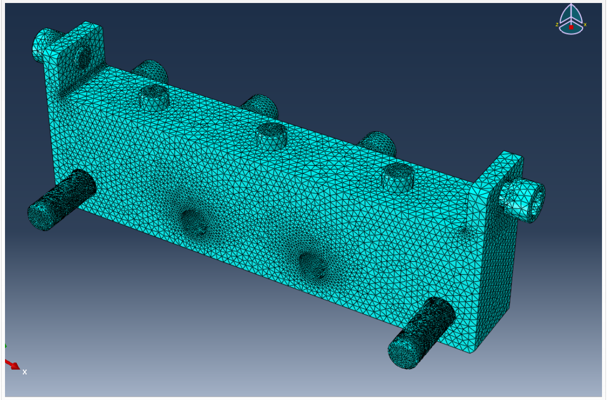


Bolt high stress and refined mesh used in next submission

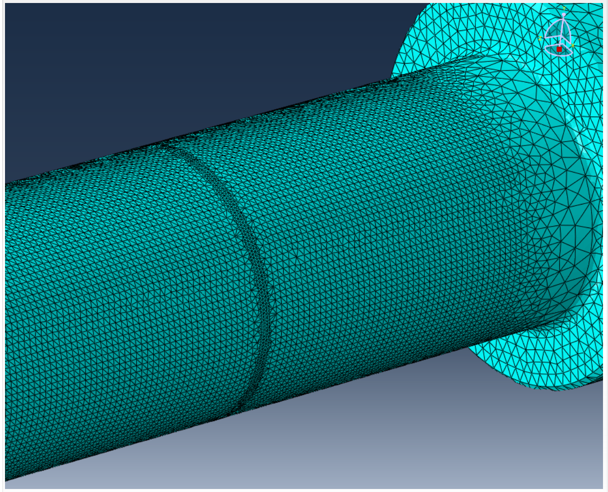
Original bolt mesh and stress



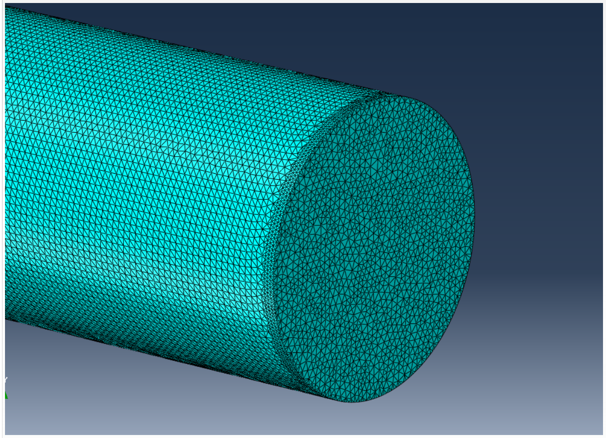
Bracket 6 with bolts



.25 mm mesh around high stress zone

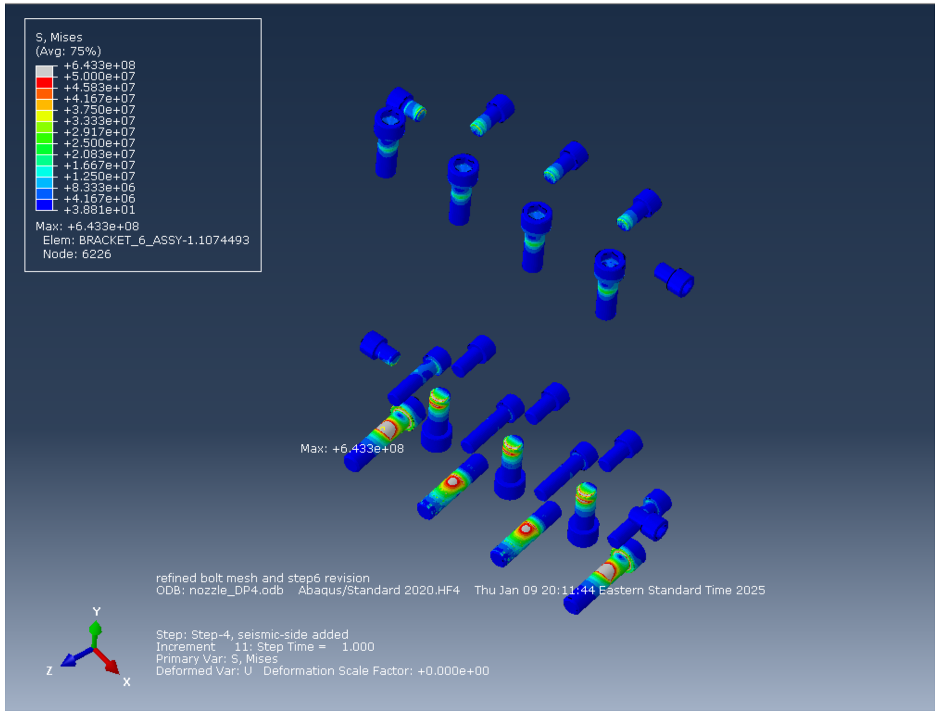


Internal mesh

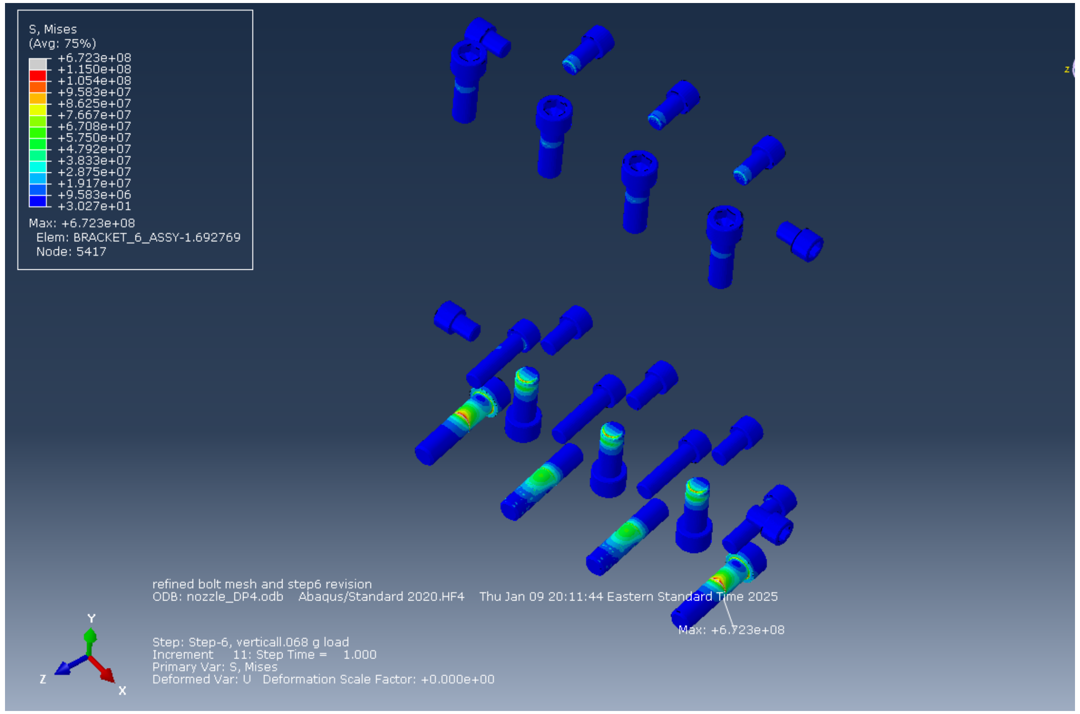


Bolt and Pin Stresses

Bolt and Pin stress Step 4 643 MPa peak 50 MPa scale

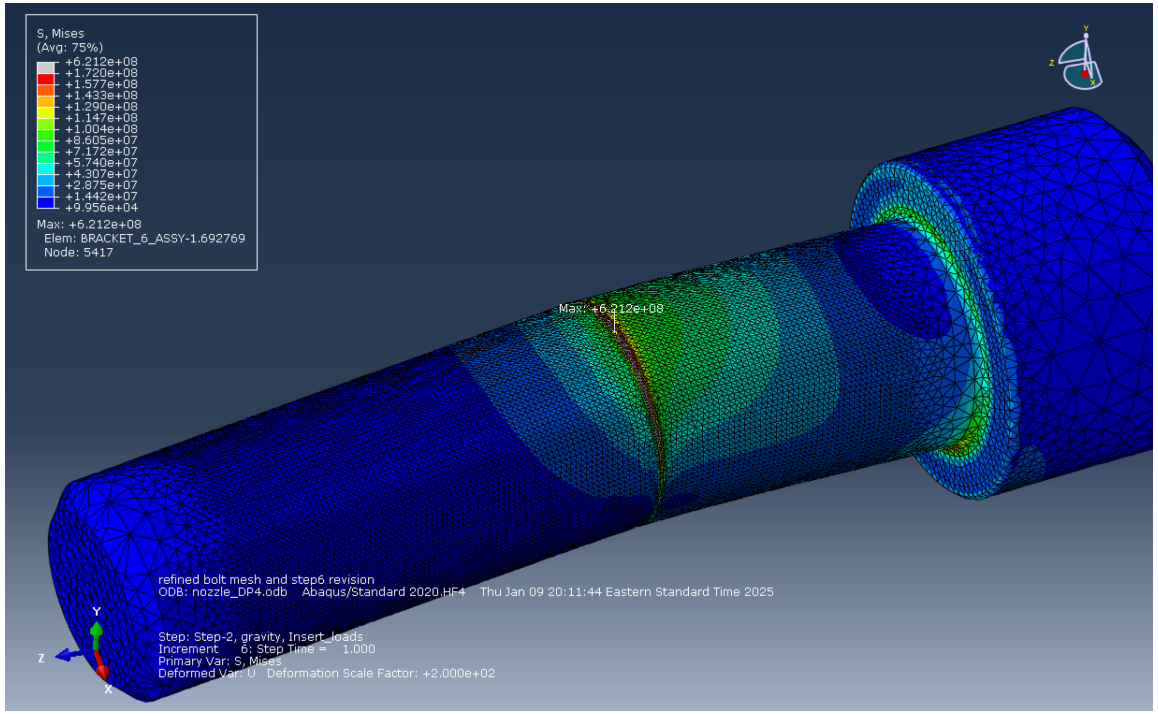


Bolt and Pin stress Step 6 672 MPa peak 115 MPa scale

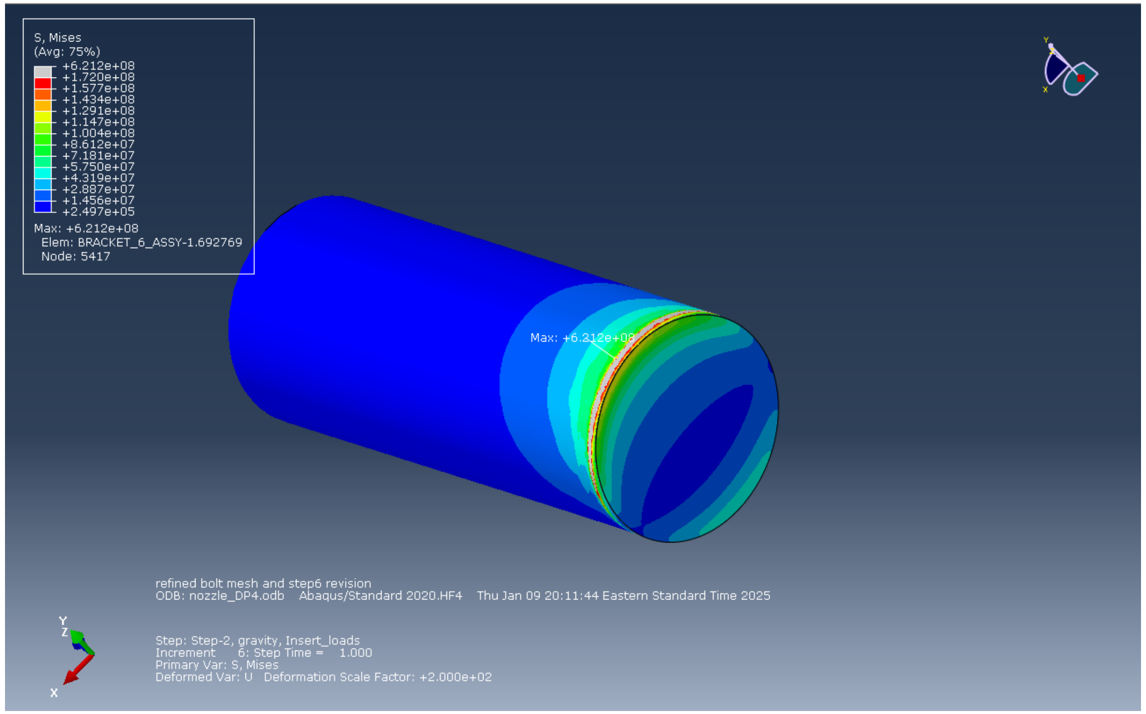


Step 2 Bolt stresses

Bolt peak stress Step 2 621 MPa

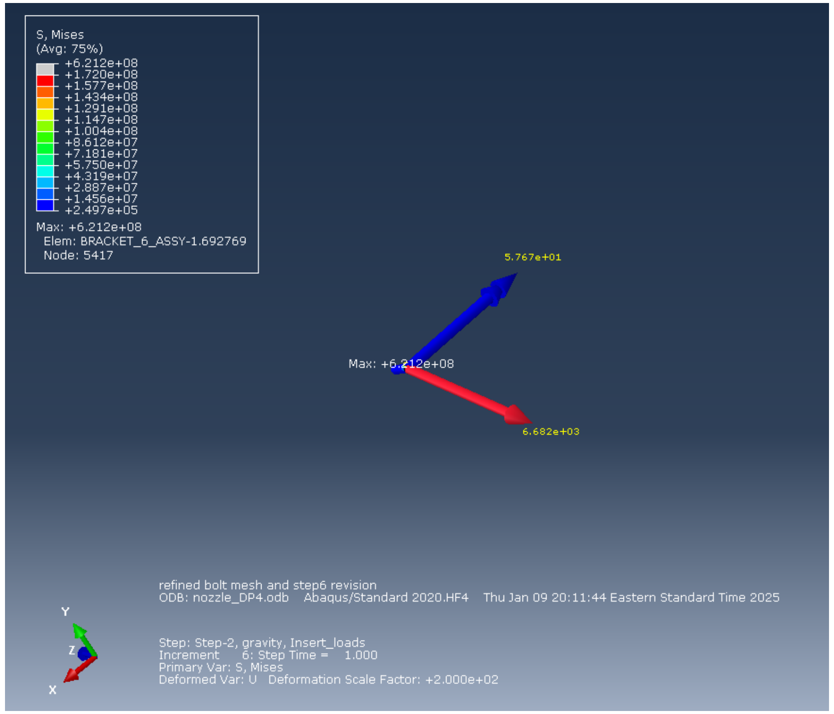


Bolt cross section just downstream of tie to beltline

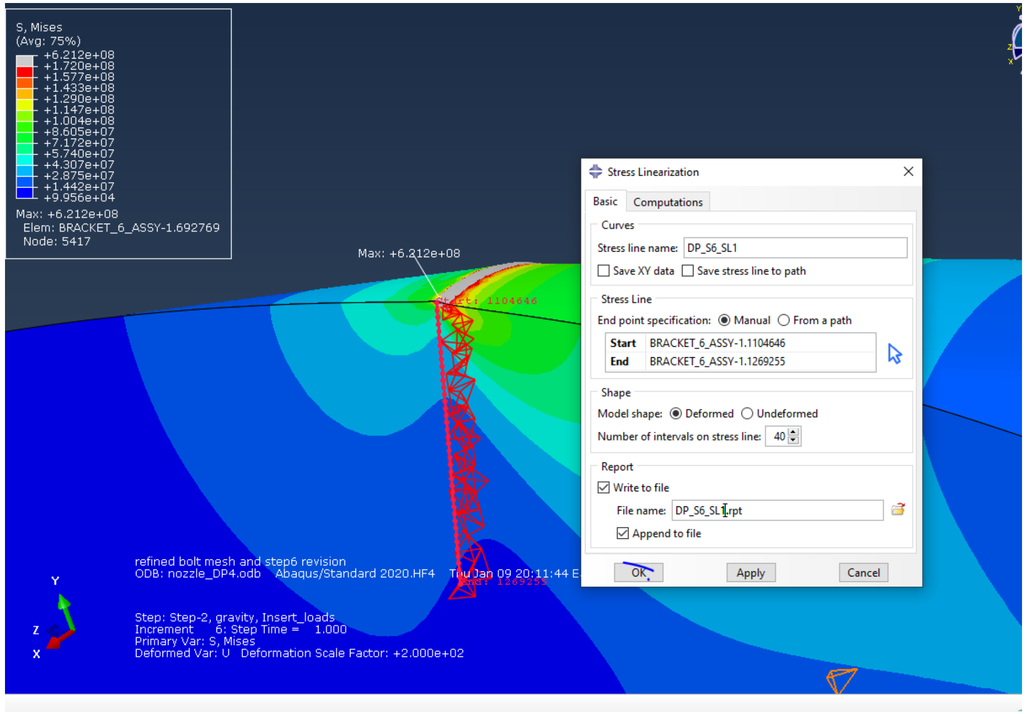


Step 2 bolt cross section loads

Load on cross section primarily in axial direction 6.6e3 N

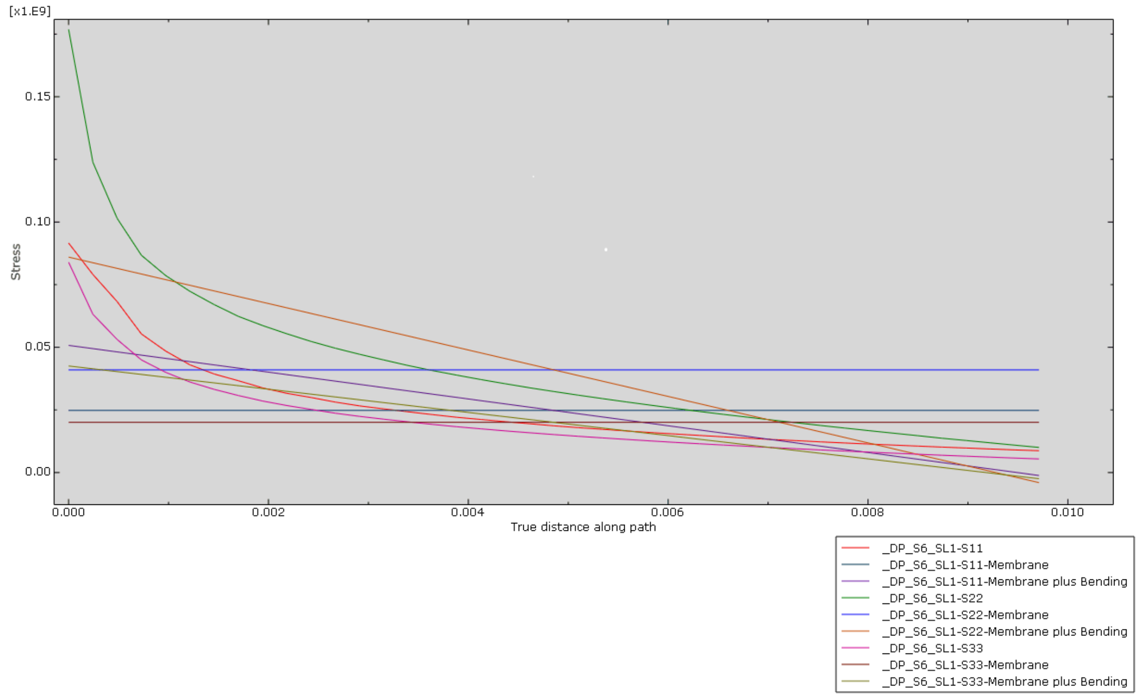


Stress linearization path



Step 2 Stress linearization path 1 ~normal to surface

Stress component plots along path



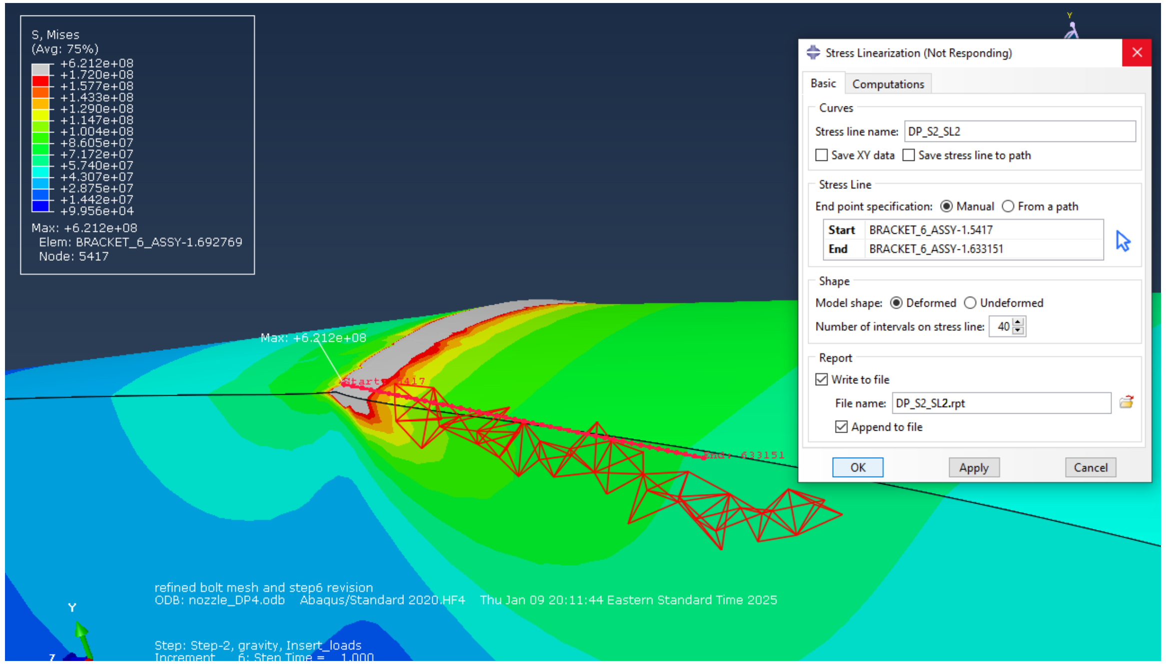
Mises Membrane + Bending well below 172 MPa limit

Bending components in equation for computing
membrane plus bending stress invariants are: S11, S22, S33, S12, S13, S23

	Max. Prin.	Mid. Prin.	Min. Prin.	Tresca Stress	Mises Stress
Membrane (Average) Stress	4.50465e+07	2.397e+07	1.68146e+07	2.82319e+07	2.5421e+07
Membrane plus Bending, Point 1	9.16743e+07	5.09364e+07	3.66877e+07	5.49866e+07	$\boxed{4.94273e+07}$
Membrane plus Bending, Point 2	8.14907e+06	-3.06693e+06	-1.27184e+07	2.08675e+07	1.80887e+07
Peak Stress, Point 1	1.12659e+08	3.70211e+07	2.34531e+07	8.92055e+07	8.32549e+07
Peak Stress, Point 2	1.64539e+07	8.2149e+06	7.14416e+06	9.30969e+06	8.82318e+06

Step 2 Stress linearization path 2 ~parallel to surface

Path 2



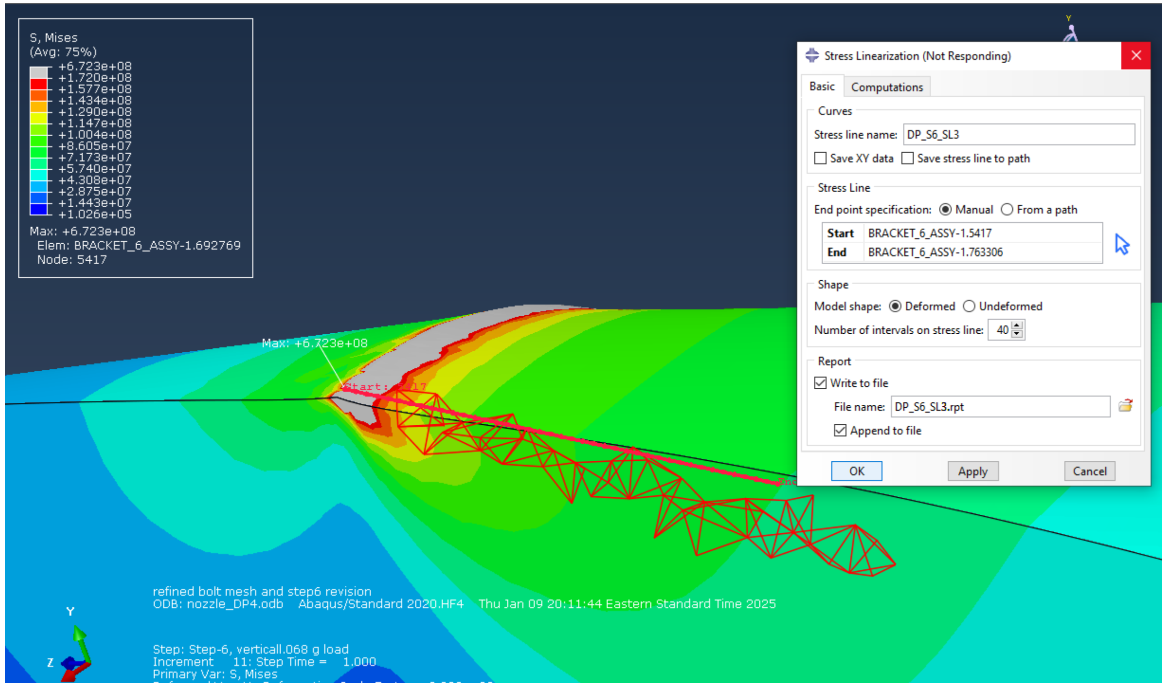
Membrane plus Bending peak 154 MPa

Bending components in equation for computing
membrane plus bending stress invariants are: S11, S22, S33, S12, S13, S23

	Max. Prin.	Mid. Prin.	Min. Prin.	Tresca Stress	Mises Stress
Membrane (Average) Stress	1.07829e+08	1.66243e+07	2.17056e+06	1.05659e+08	9.92244e+07
Membrane plus Bending, Point 1	1.76307e+08	4.29358e+07	8.11872e+06	1.68189e+08	1.53765e+08
Membrane plus Bending, Point 2	4.18686e+07	-6.18459e+06	-9.79781e+06	5.16664e+07	4.99579e+07
Peak Stress, Point 1	3.19407e+08	1.03548e+08	5.34196e+07	2.65987e+08	2.44803e+08
Peak Stress, Point 2	3.37888e+07	1.25284e+07	2.87543e+06	3.09134e+07	2.73936e+07

Linearized Stress for Mises Membrane + Bending just below 172 MPa limit for Step 6 with vertical seismic load

Stress linearization path



Membrane + Bending 165 MPa

------------------------------------ INVARIANT RESULTS ------------------------------

Bending components in equation for computing
membrane plus bending stress invariants are: S11, S22, S33, S12, S13, S23

	Max. Prin.	Mid. Prin.	Min. Prin.	Tresca Stress	Mises Stress
Membrane (Average) Stress	1.15706e+08	1.85194e+07	3.09464e+06	1.12612e+08	1.05746e+08
Membrane plus Bending, Point 1	1.91302e+08	1.72327e+07	1.15477e+07	1.79754e+08	1.64835e+08
Membrane plus Bending, Point 2	4.28968e+07	-8.12843e+06	-1.02103e+07	5.31071e+07	5.20974e+07
Peak Stress, Point 1	3.37837e+08	1.11243e+08	6.24541e+07	2.75383e+08	2.5452e+08
Peak Stress, Point 2	3.61125e+07	1.35838e+07	4.11398e+06	3.19985e+07	2.84704e+07

```
ODB: E:/CV 2023_2024/Nozzle_dual_port/nozzle_DP4.odb
Step: Step-6
Frame: Increment     11: Step Time =    1.000
```

```
inearized Stresses for stress line 'DP_S6_SL3'
 Start point, Point 1 - (-0.2916299700737, -0.14190374314785, -1.71695816516876)
 End point, Point 2   - (-0.292371213436127, -0.142926007509232, -1.7225593328476)
 Number of intervals  - 40
```

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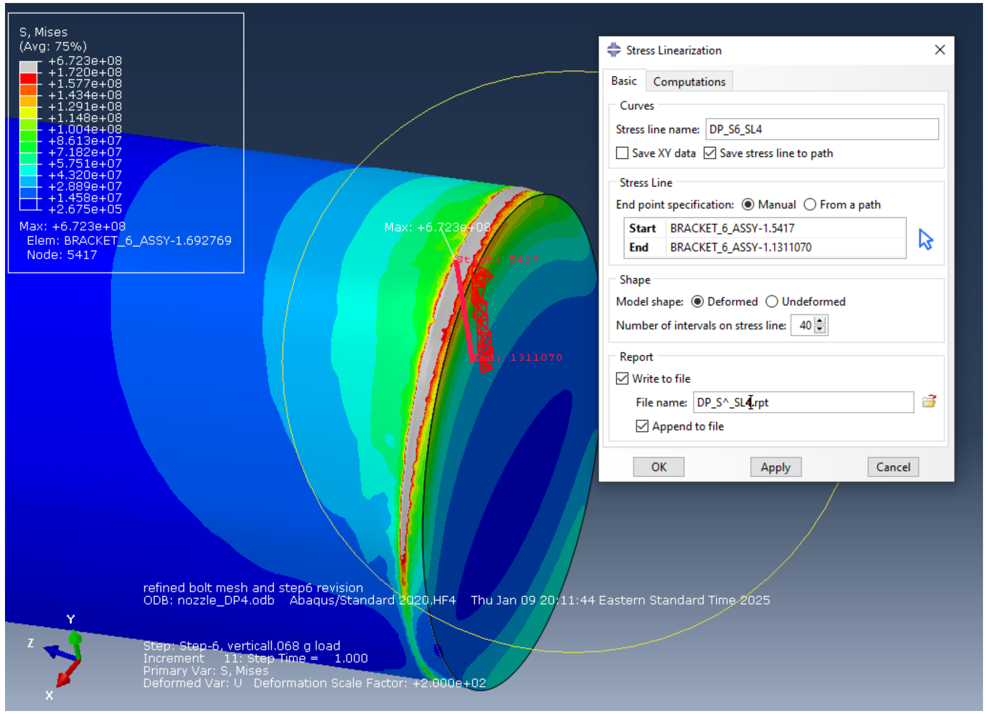
Step 6 Stress linearization Path 2

Stress SL4 path



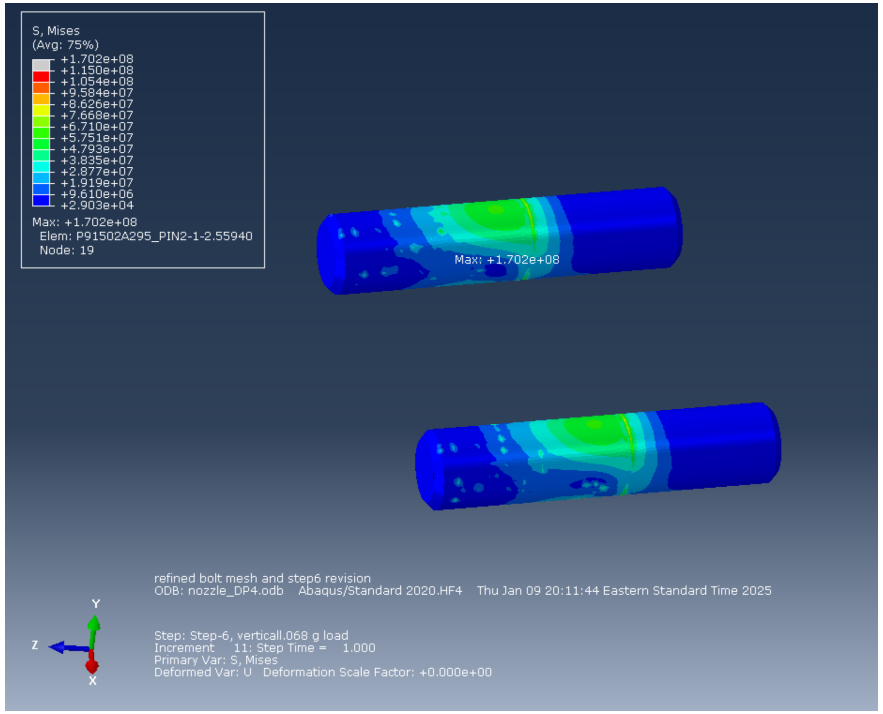
Mises mebrane + bending 99.6 MPa

```
------------------------------------ INVARIANT RESULTS --------------------------------

Bending components in equation for computing
membrane plus bending stress invariants are:   S11, S22, S33, S12, S13, S23

                      Max.        Mid.        Min.        Tresca      Mises
                      Prin.       Prin.       Prin.       Stress      Stress
     Membrane
(Average) Stress  9.20399e+07  4.9585e+07  3.62583e+07  5.57816e+07  5.04559e+07

  Membrane plus
Bending, Point 1  1.76165e+08  8.66837e+07  6.88391e+07  1.07326e+08  9.96099e+07

  Membrane plus
Bending, Point 2  2.45693e+07  3.62892e+06  -4.11999e+06  2.86893e+07  2.57062e+07

   Peak Stress,
     Point 1       3.0069e+08  8.9398e+07  3.98405e+07  2.60849e+08  2.3994e+08

   Peak Stress,
     Point 2       3.84861e+07  1.44351e+07  1.28711e+07  2.56151e+07  2.487e+07

*************************************************************************************
Statically Equivalent Linear Stress Distribution across a Section,
written on Tue Jan 14 13:33:34 2025
```

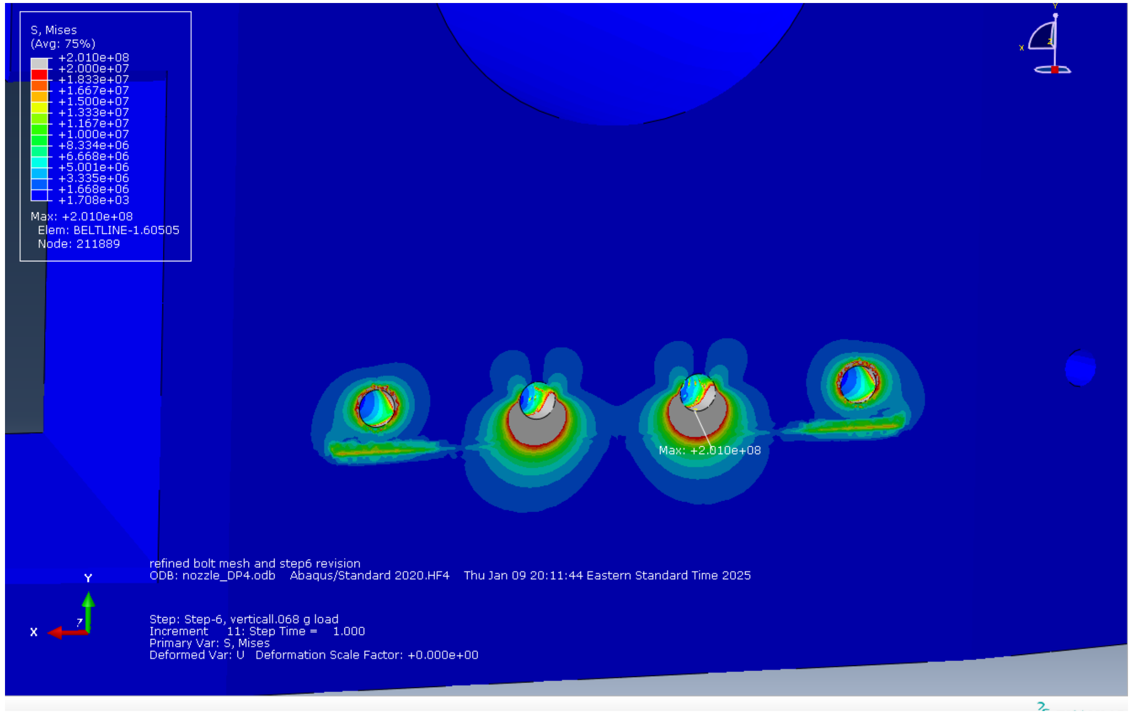
```
Linearized Stresses for stress line 'DP_S6_SL4'
  Start point, Point 1 - (-0.2916299700737, -0.14190374314785, -1.71695816516876)
  End point, Point 2   - (-0.291449248790741, -0.14552815258503, -1.71590042114258)
  Number of intervals  - 40
```

Beltline and shear pin stresses

Shear Pin peak stress 170 MPa



Step 6 peak stress 201 MPa



Peak membrane + bending 80 MPa from stress linearization around peak

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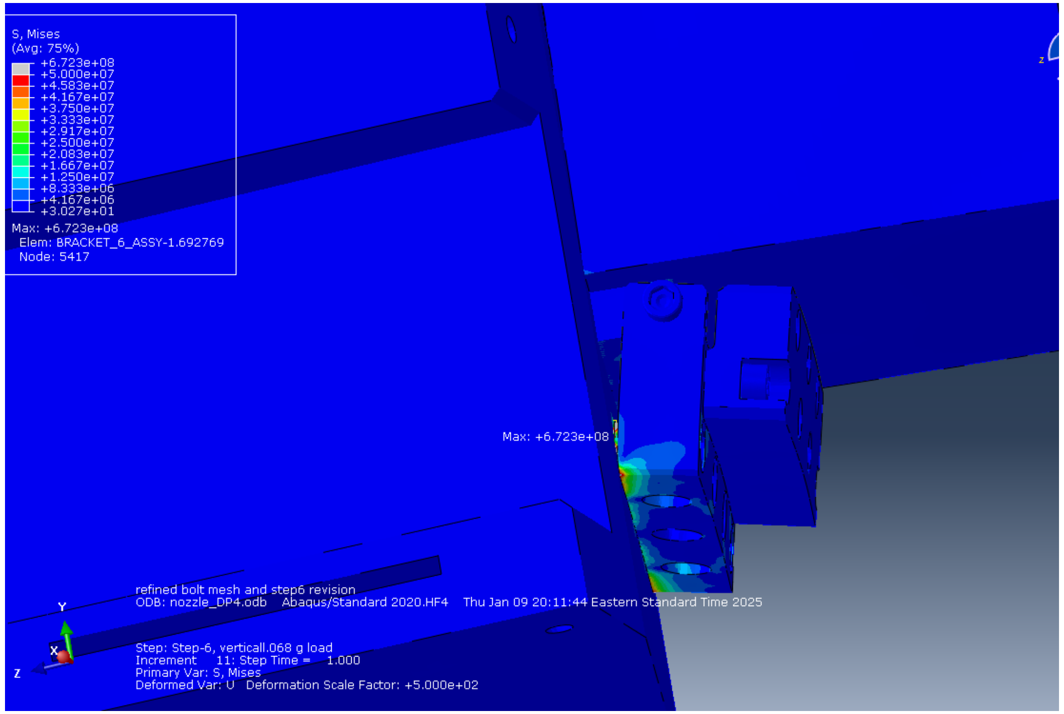
Option to reduce lower bolt stress

Option to add margin

- The vertical gravity and seismic loads near the beltline are carried by the vertical pins in the lower bracket
- The moment created around the beltline from these pins is resisted by the bolt tension with bending and lower bracket edge in compression against the beltline
- Extending the bracket lower edge should reduce the loads on the bolts
- Using 25 mm bolts in the lower bracket would also help

Lower Bracket Stress 50 MPa scale



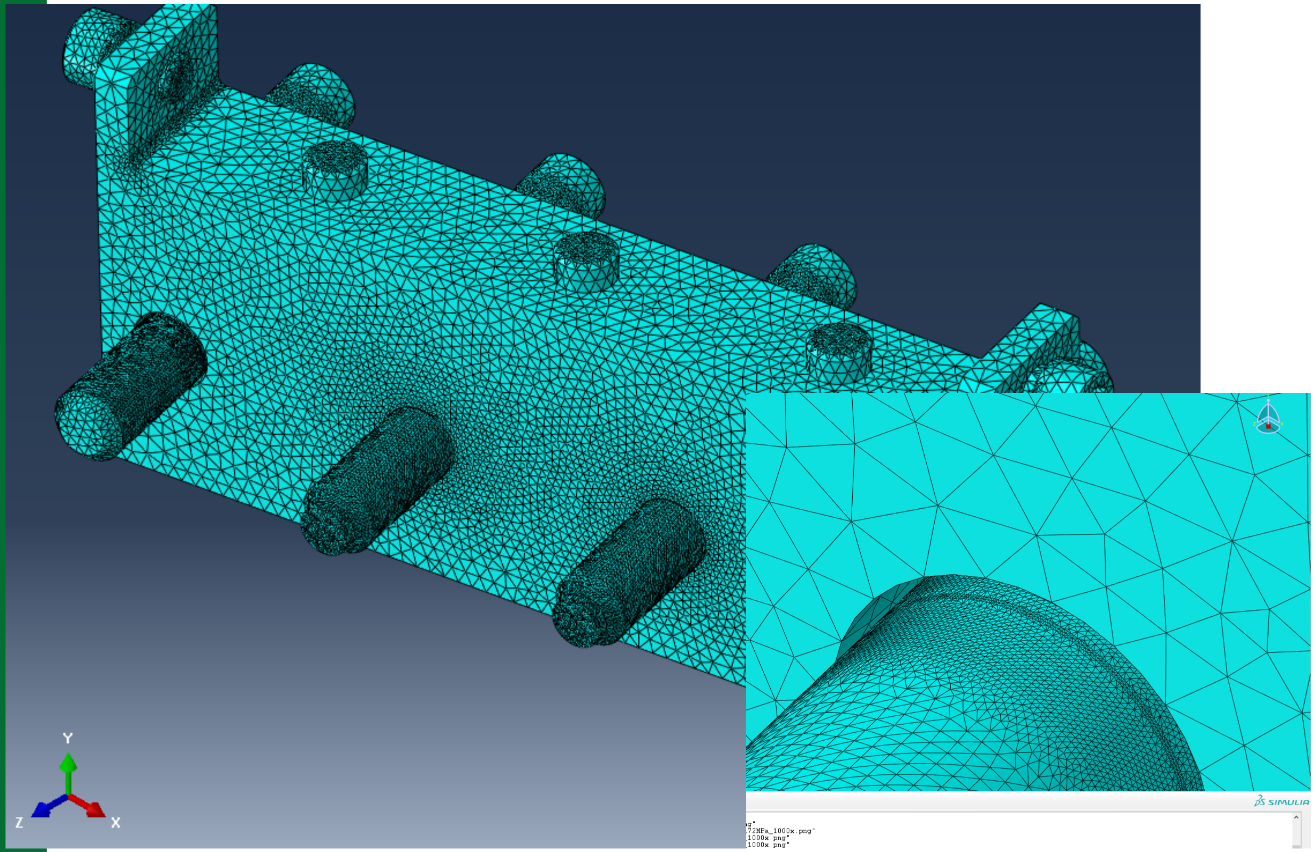
Displacement x 500

Summary- model DP4

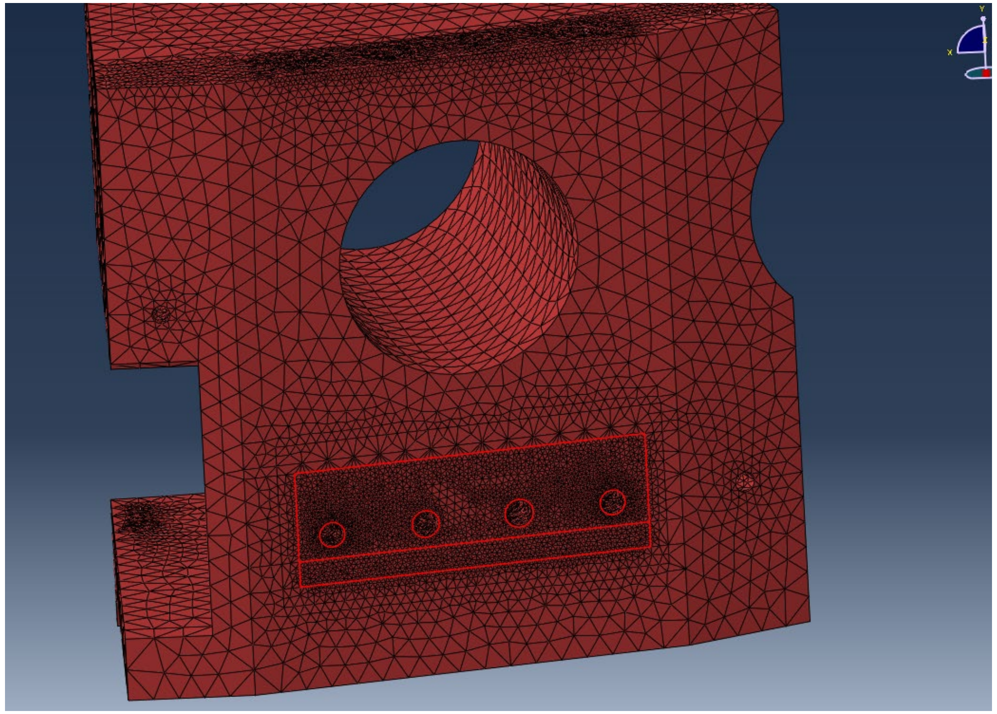
- The peak stresses were on the lower bracket bolts from vertical loads and resulting bending moment
- The peak of 167 MPa in Step 6 was very localized just downstream of where the bolt entered the beltline thread area
- Stress linearization Mises peak membrane plus bending was 165 MPa close but below the 1.5 Sm limit of 172.5 MPa
- The bolt load on the 20 mm diameter bolts was approximately 6.5 kN which would give an average axial stress of about 21 MPa
- Design changes such as enlarging the lower bracket increasing the distance from the lower bracket edge to the bolt centerline should reduce the bolt loads

Lower bracket model similar to previous DP4 model with changes to bolt and pin diameters and 25 mm extension

Bracket bolts use .25 mm mesh around tie contact to beltline

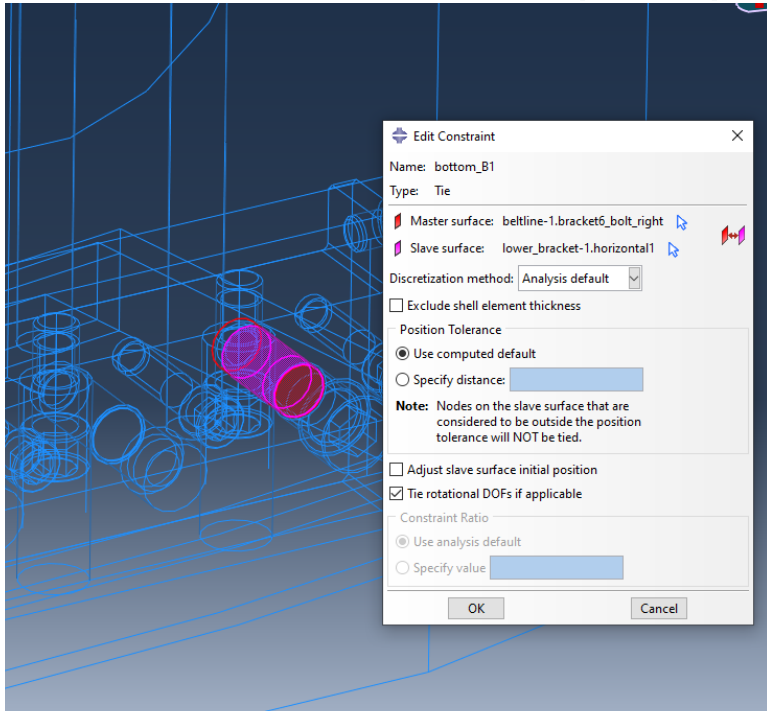


Beltline mesh refined and contact area with lower bracket defined

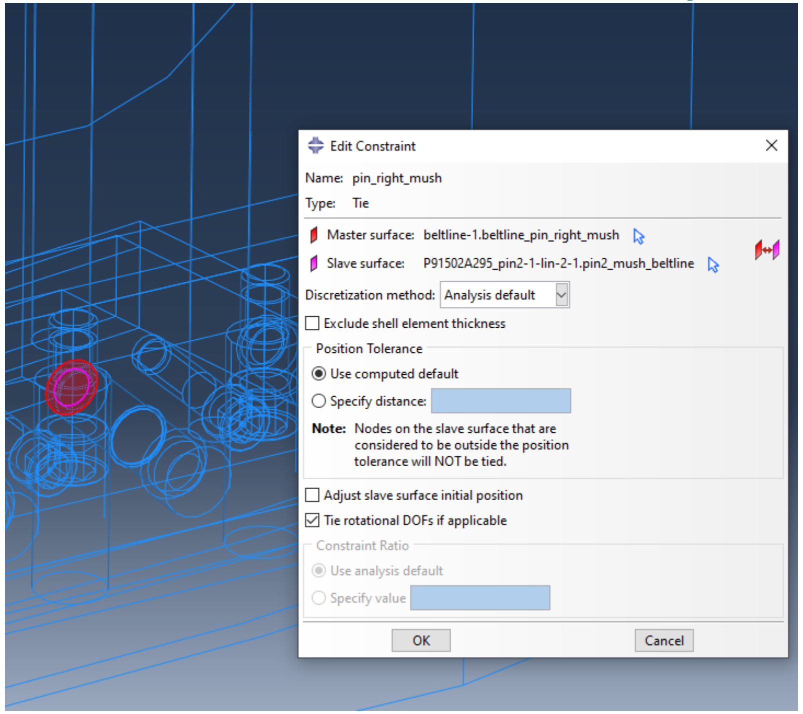


Revised Tie constraints with 24.65 mm diameter bolts/pins

Lower bolt tie to beltline (typ)

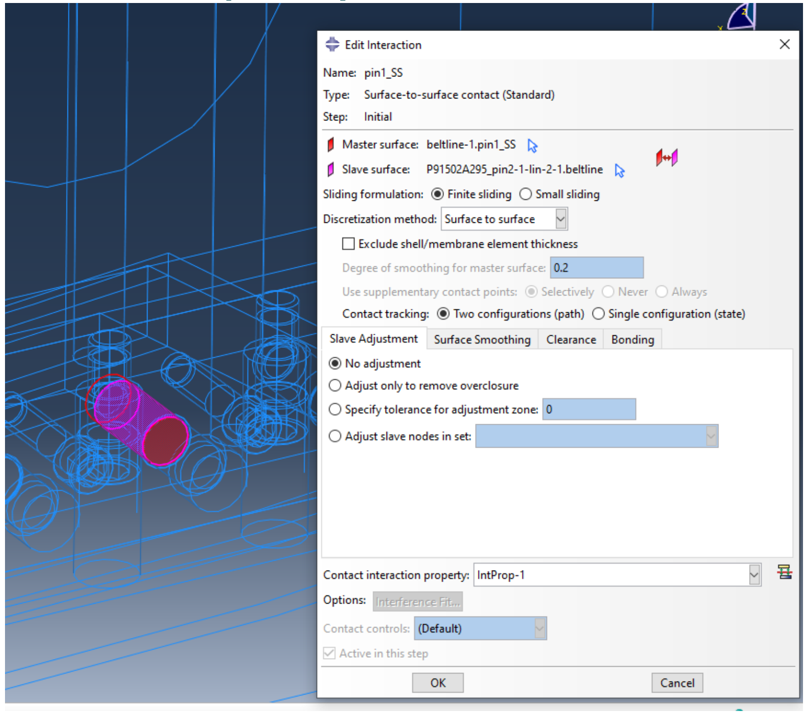


Shear pin soft tie to beltline (typ)

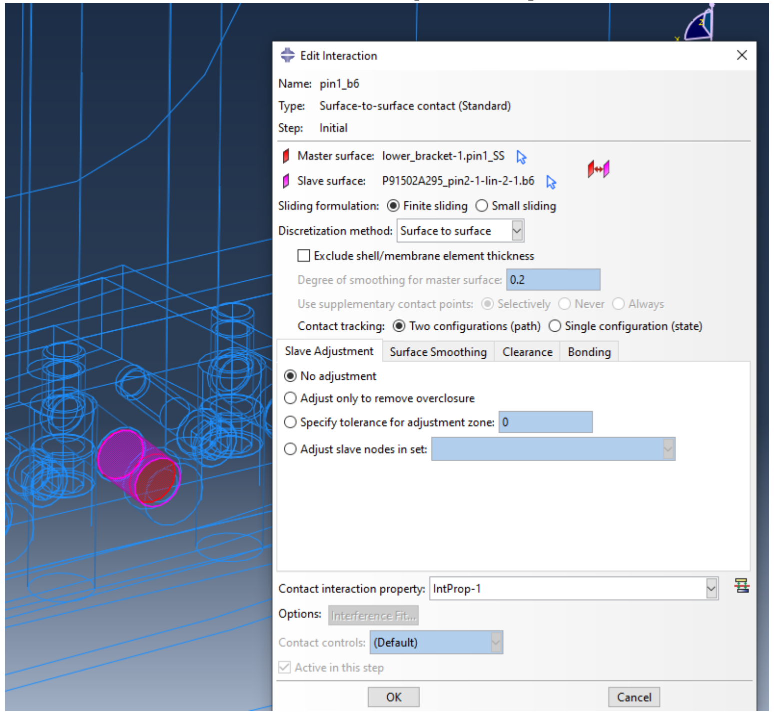


Revised pin Interactions

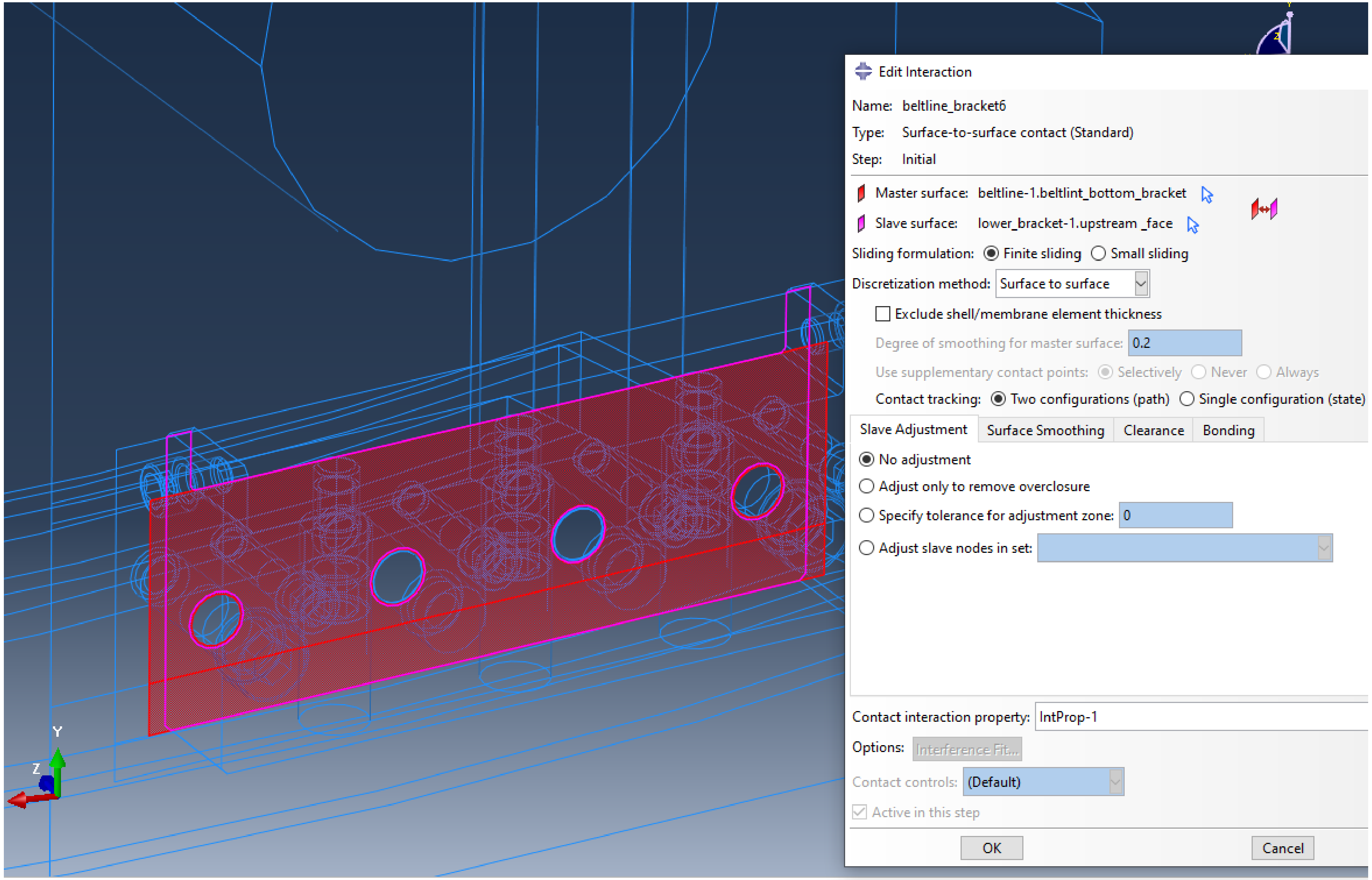
Shear pin surface to surface contact with beltline (typ)



Shear pin surface to surface contact with lower bracket (typ)



Revised surface to surface contact lower bracket to beltline



DP5 model Assembly mesh around lower bracket