OAK RIDGE National Laboratory

Core Vessel Standard Nozzle Extension Preliminary Analysis

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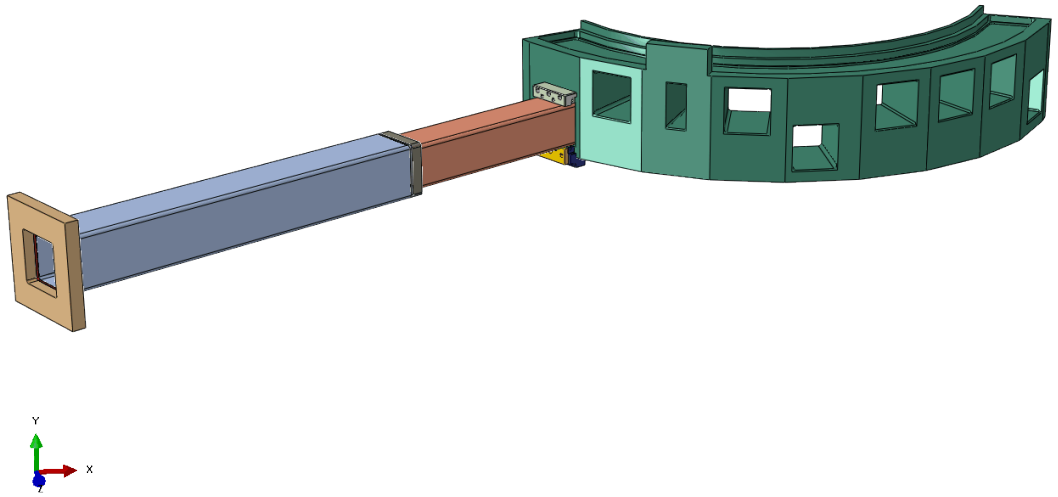
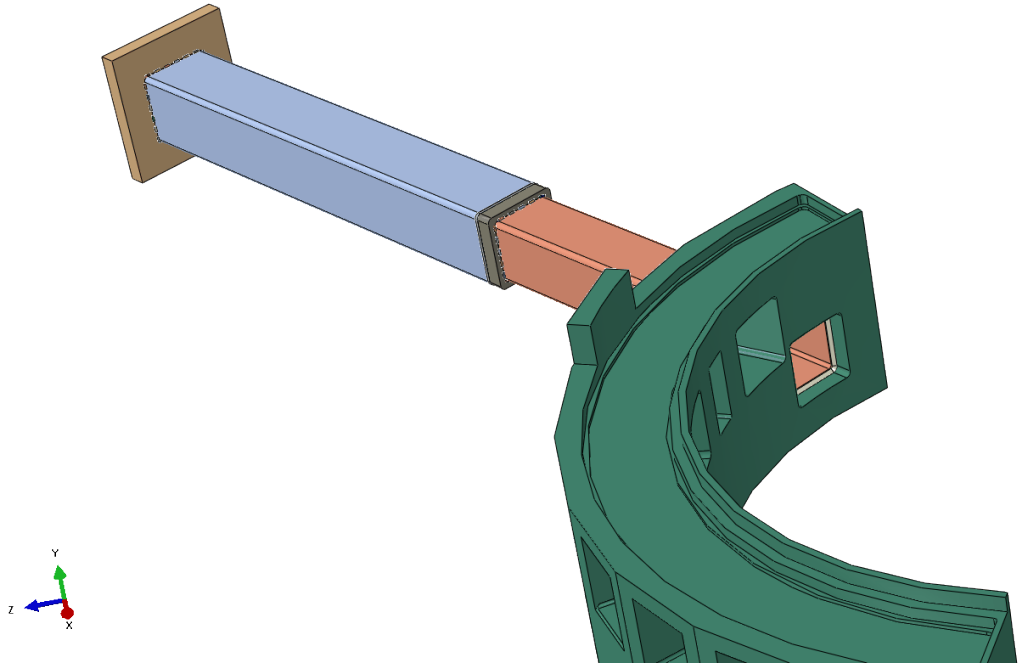
U.S. DEPARTMENT OF ENERGY

Nozzle at lower port and Core Vessel belt line

Parts imported into Abaqus



Parts viewed from CV

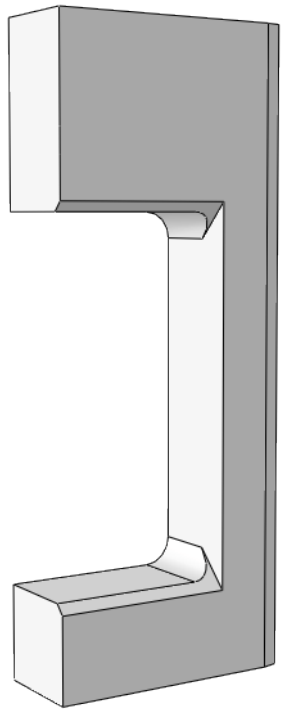


Core vessel model

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

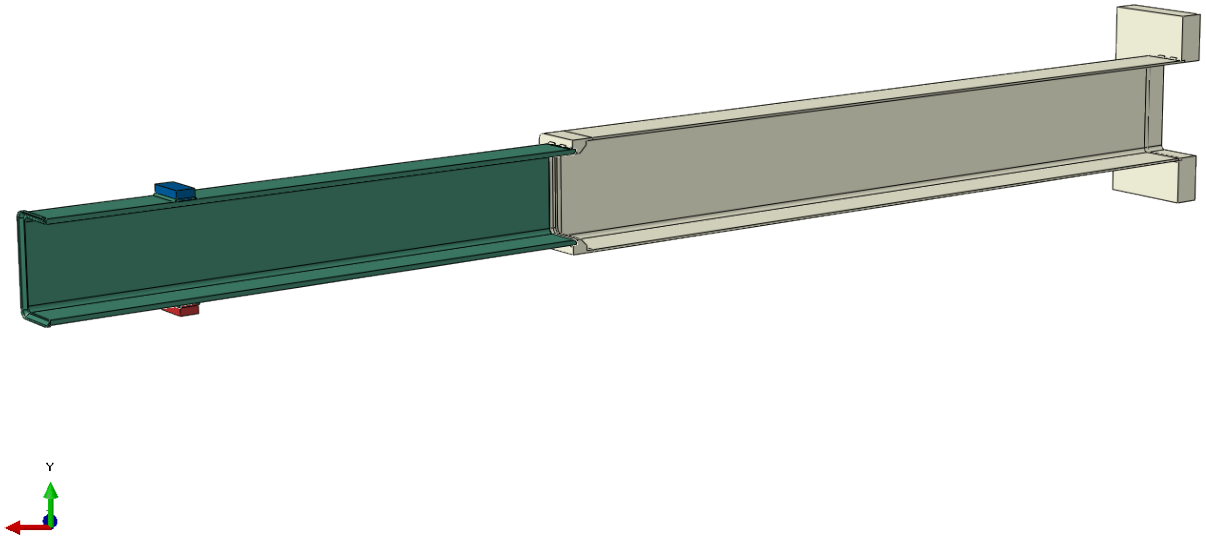


Abaqus model of Nozzle Assembly

Assembly with Four Parts Half Symmetry

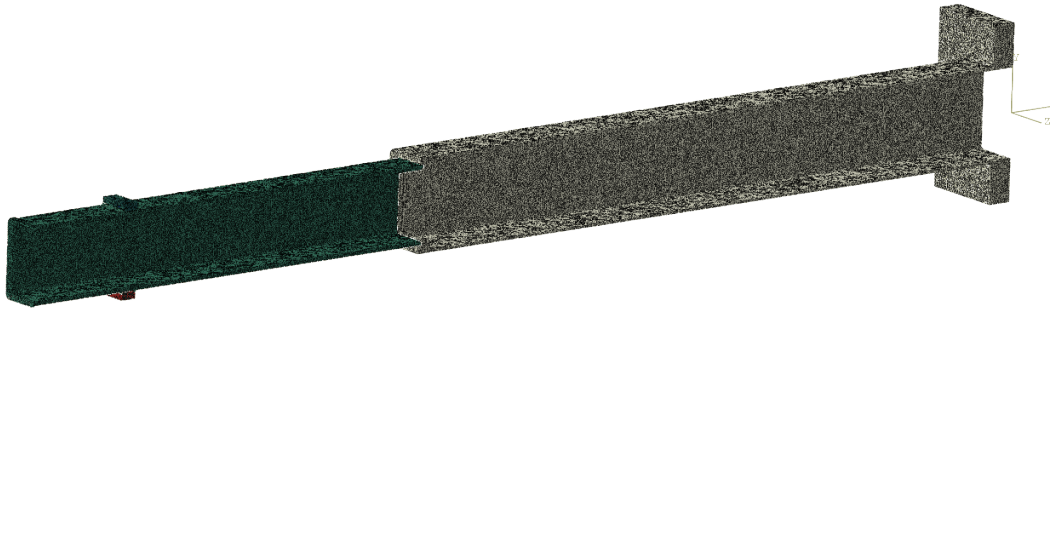
- Most welds and flanges were merged
- Four parts
  - Outer nozzle, flange, most welds
  - Inner nozzle and weld to core vessel and welds to upper and lower support blocks
  - Upper support block
  - Lower support block
- Skip welds on curved edges not modeled
- Outer to inner nozzles connected by tie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

Merged Assembly

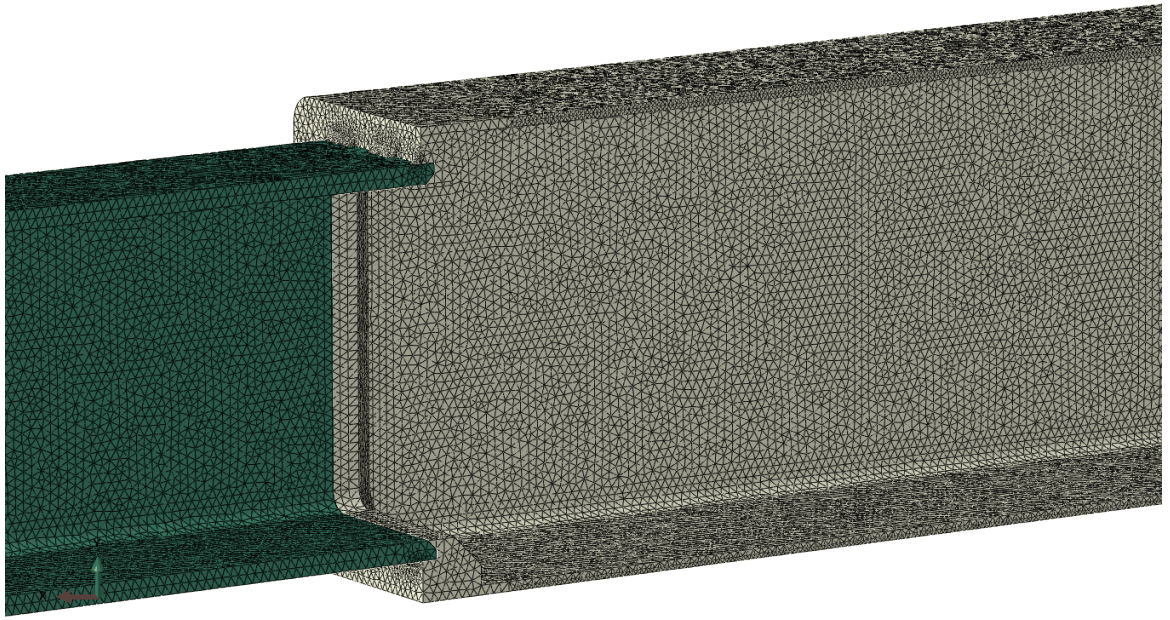


Nozzle Mesh

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

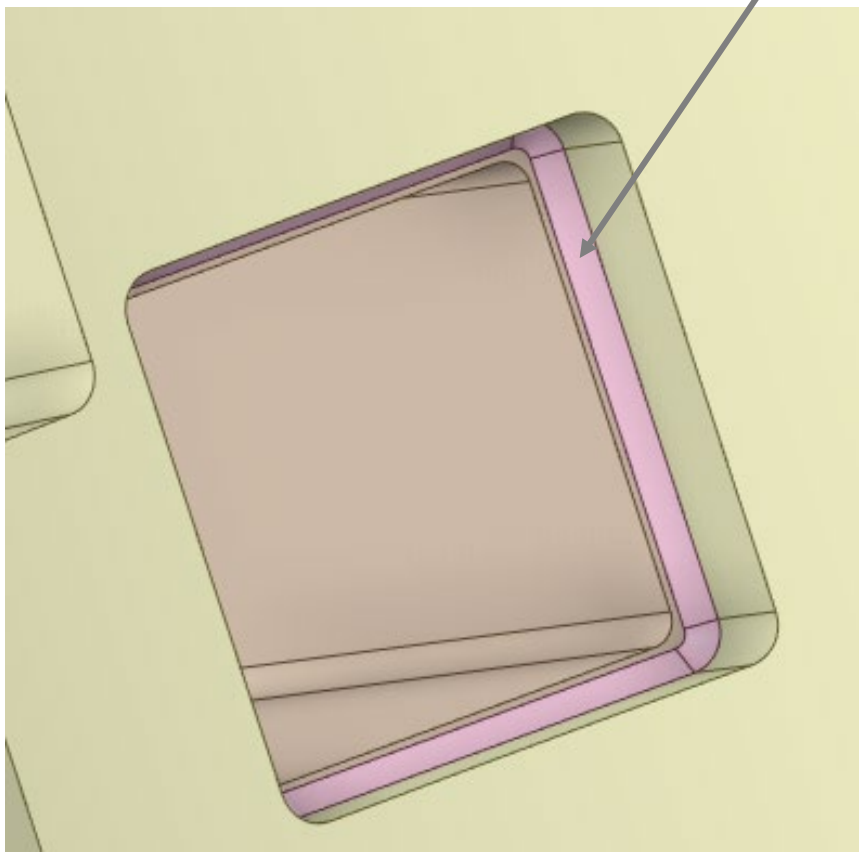


Mesh around Joint region



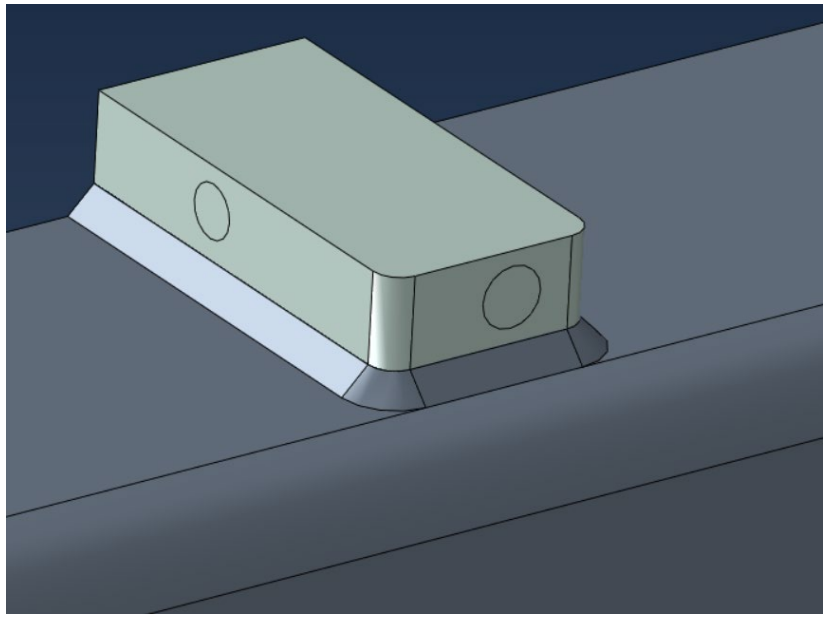
Support blocks and weld to core vessel

Nozzle to Core Vessel weld



SpaceClaim

Upper and lower support blocks are welded to Nozzle plates

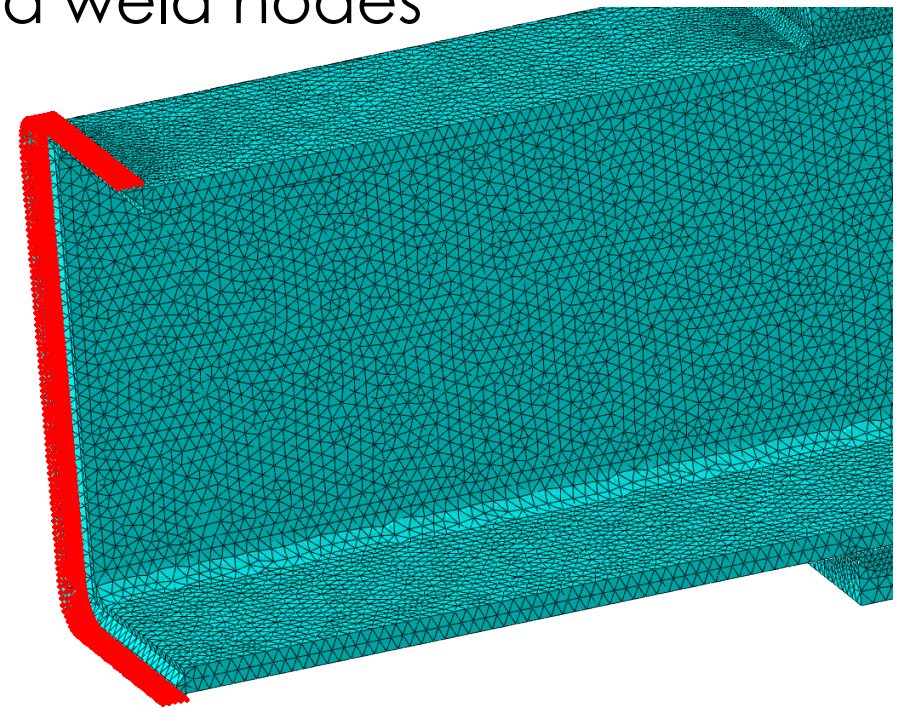


Nozzle to Core Vessel Weld

Nozzle to Core Vessel Weld

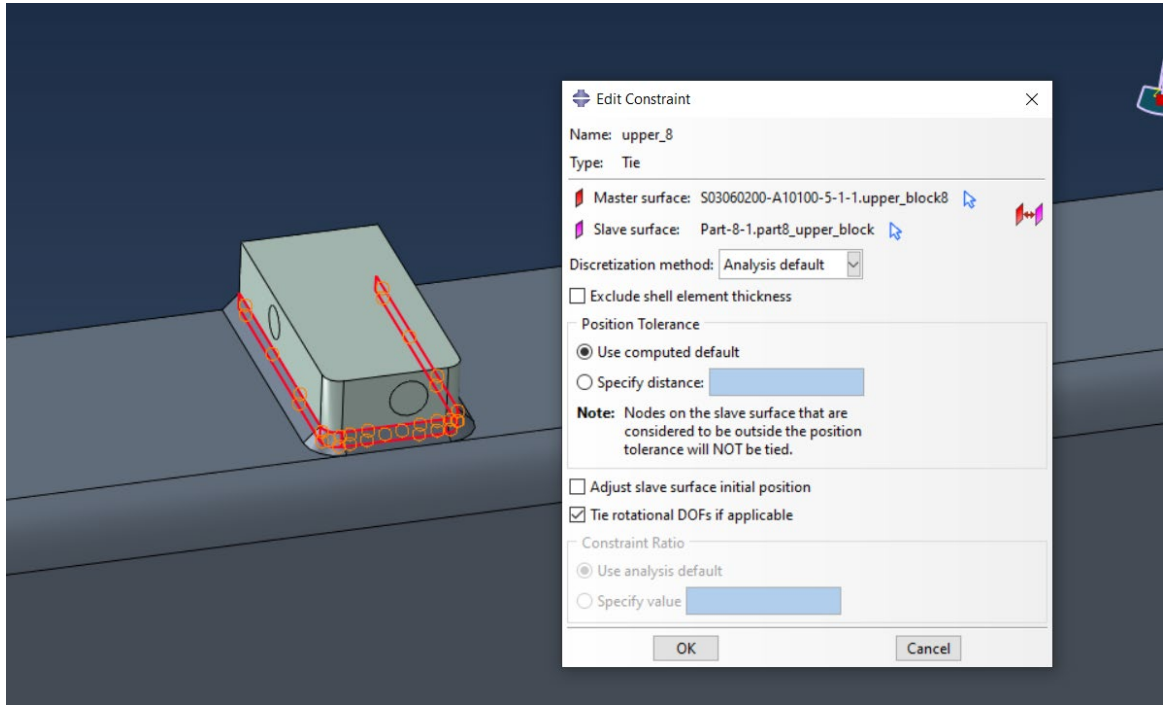
- The inner edge of the nozzle was welded to the core vessel
- The stiffness of the core vessel was simulated by fixing the nodes on the core vessel weld surface and the weld was merged with the nozzle plates in Abaqus

Fixed weld nodes

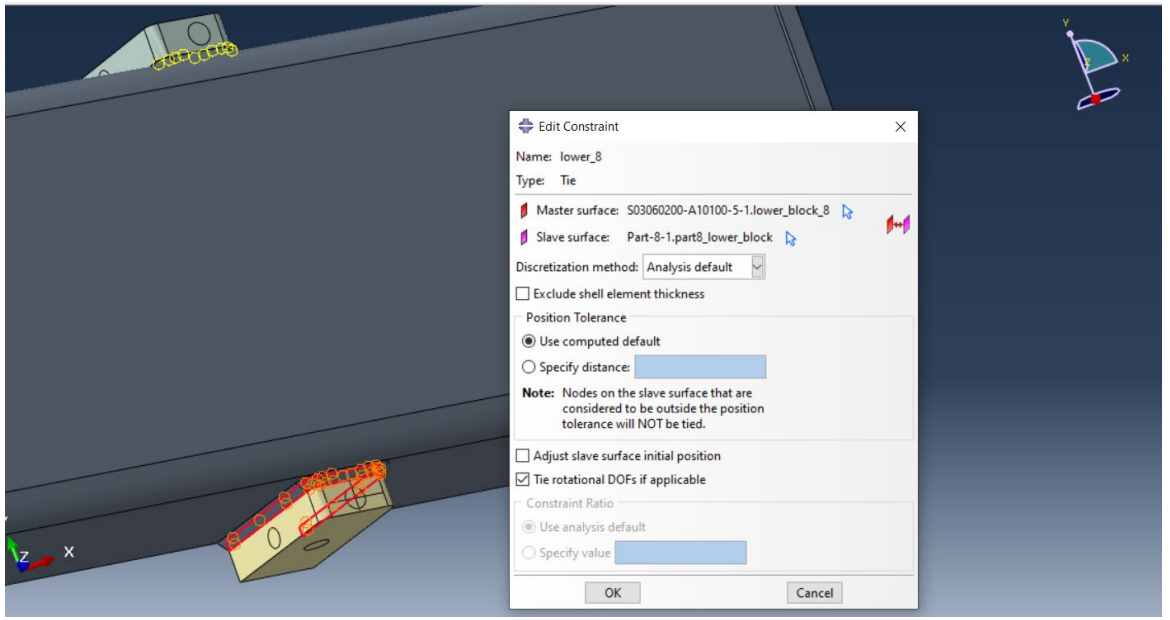


Block to nozzle welds

Weld tie for upper block



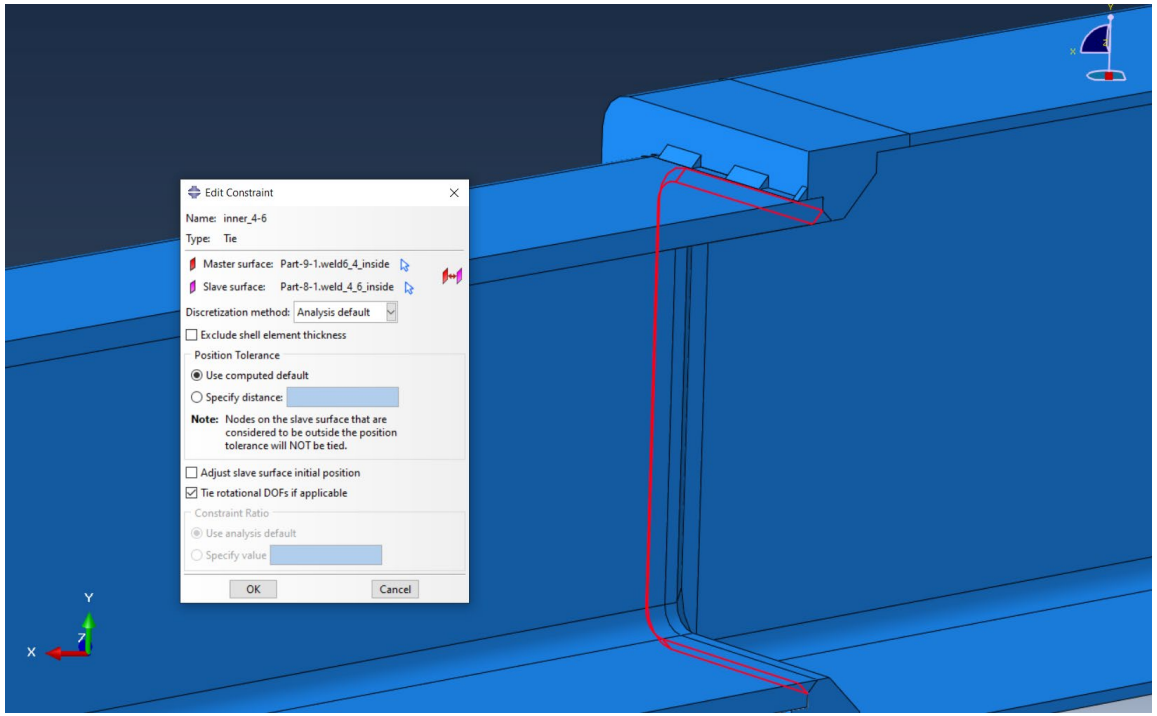
Weld tie for lower block



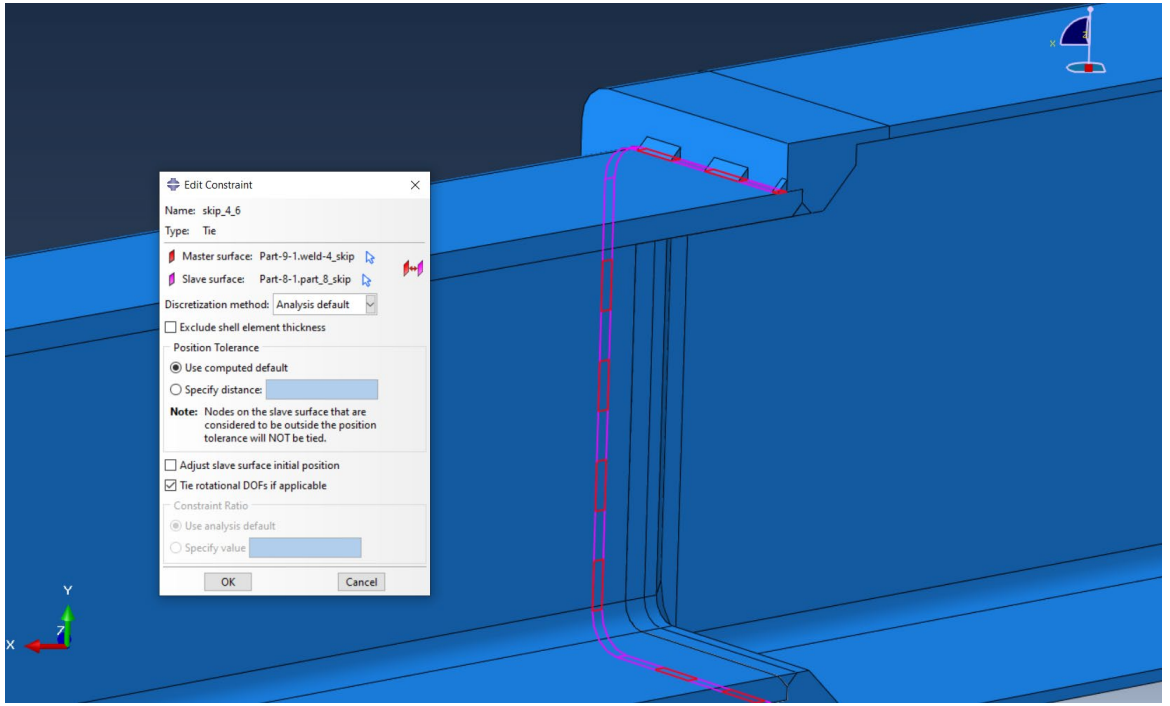
Lower block weld ties are similar

Joint between inner nozzle part and outer nozzle part

Inner to outer nozzle part tie by inner weld surface

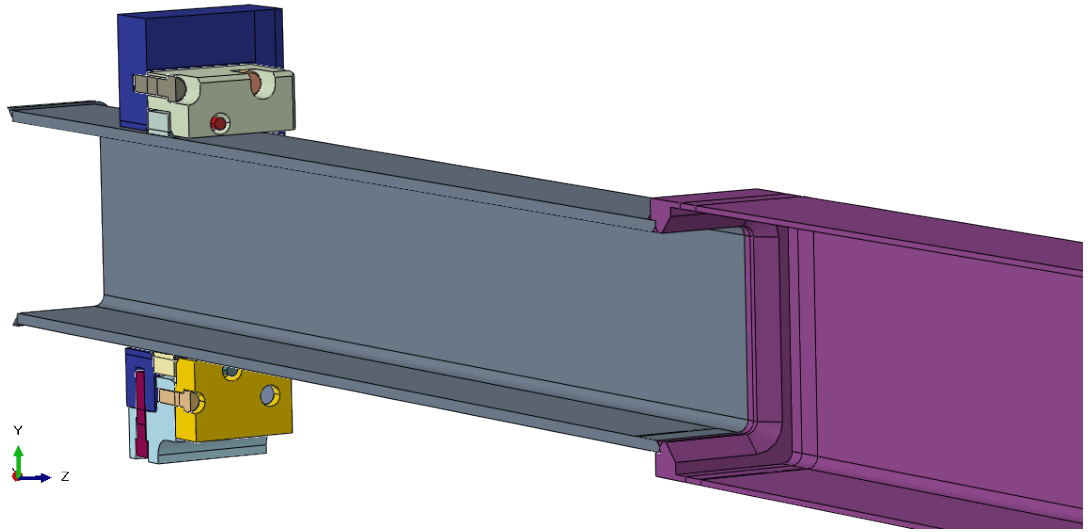


Skip welds merged with outer nozzle part and tied to inner nozzle part

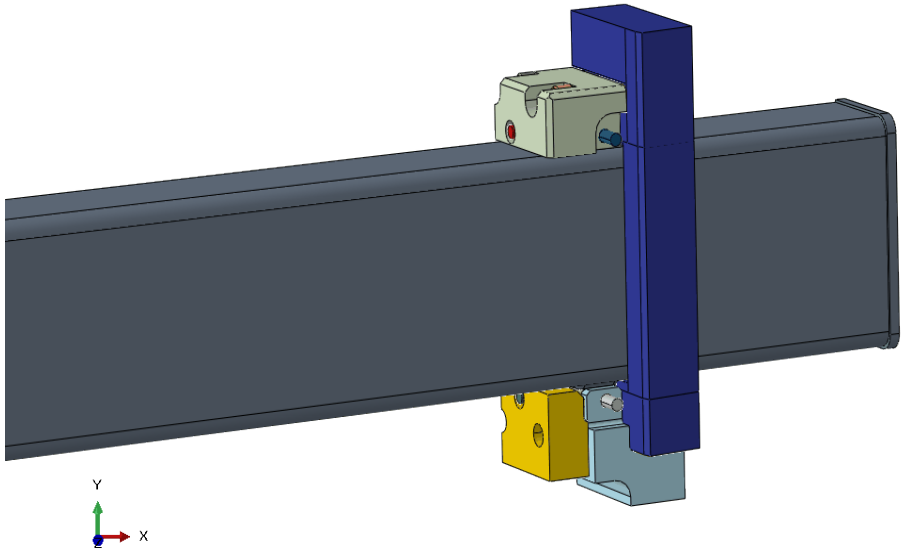


Lower Assembly

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

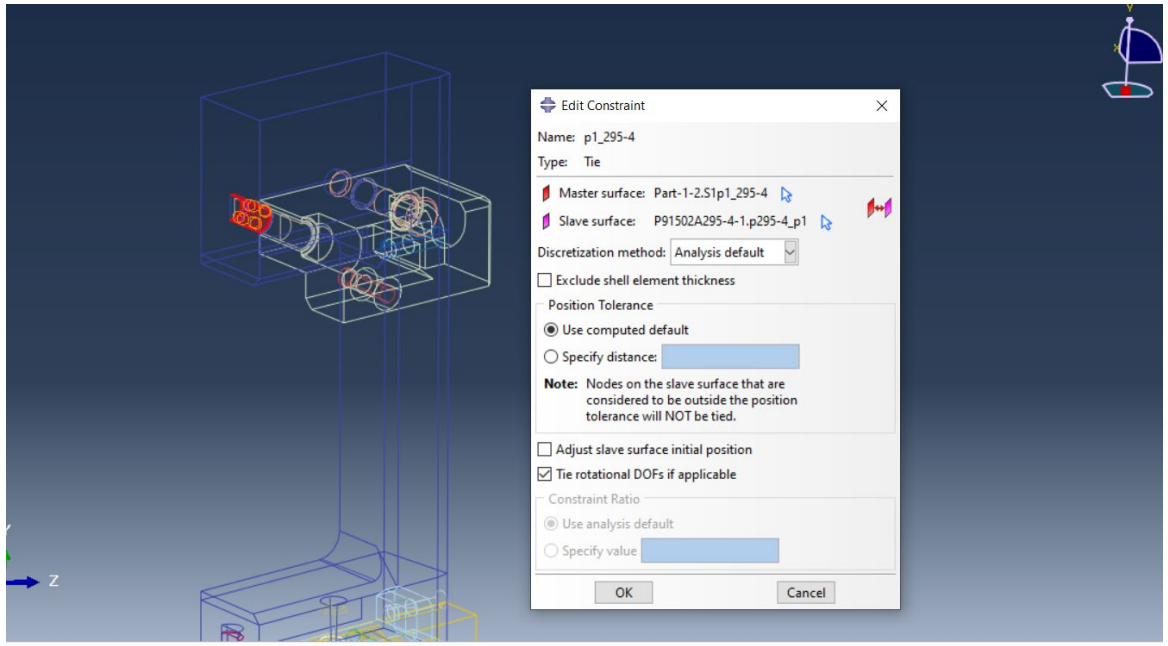


Side View of assembly

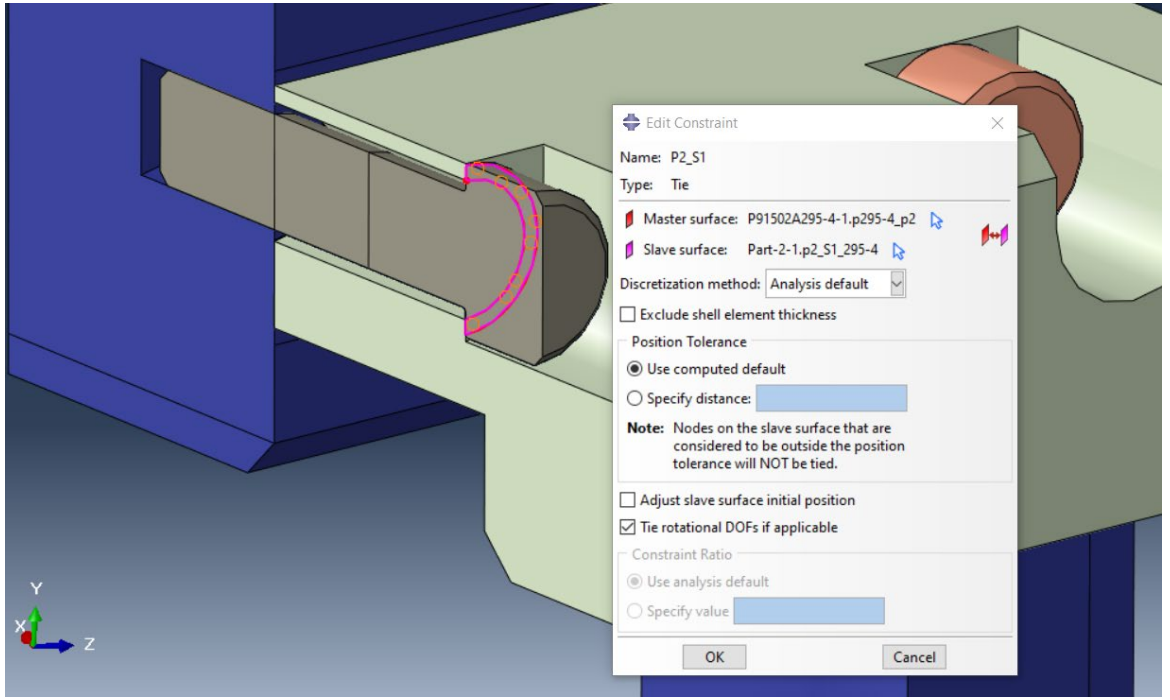


Typical bolt constraints

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



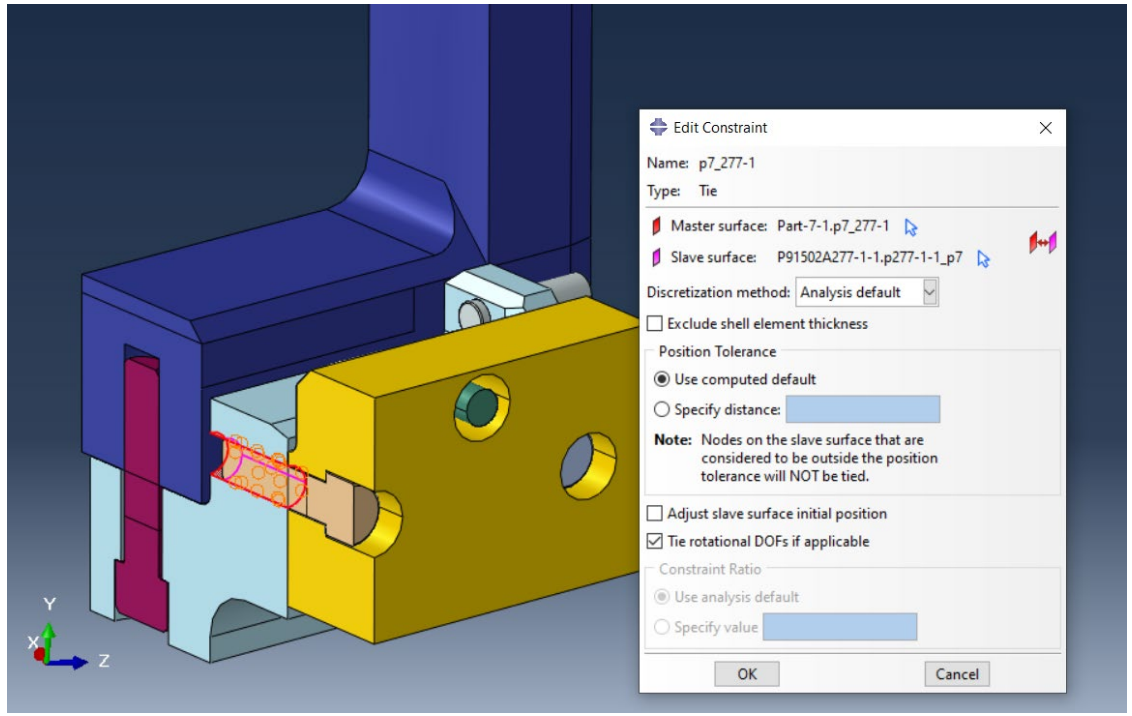
Typical constraint between bolt head and bearing surface



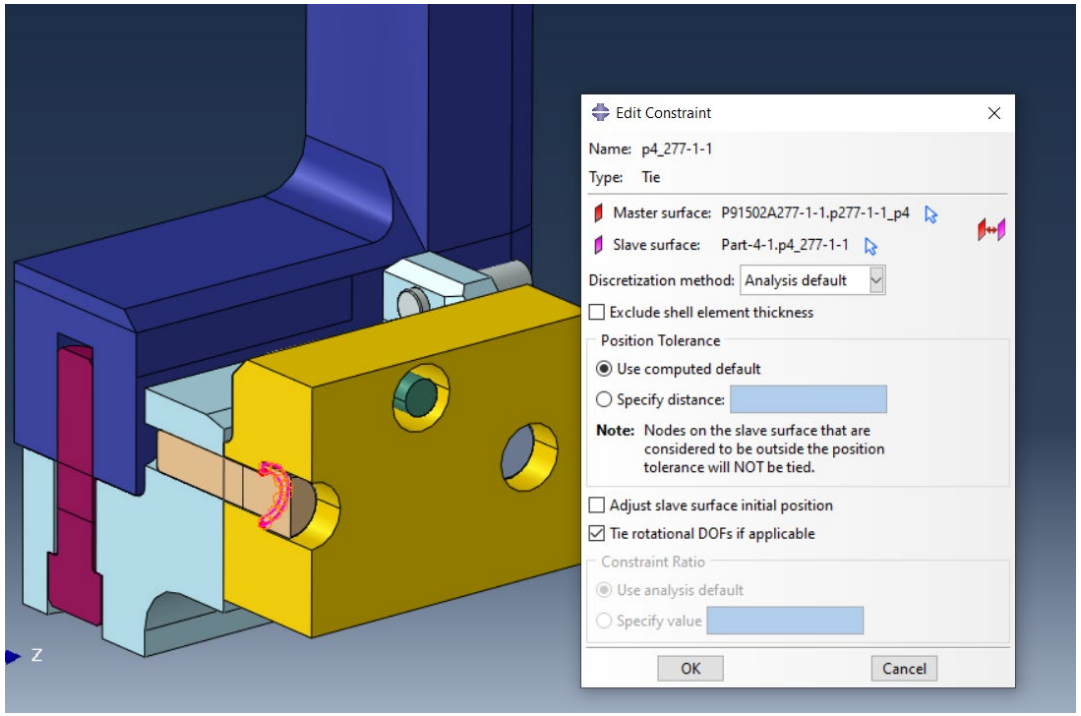
Tie constraints typical for the 4 20mm Diameter bolts into the core vessel

16 mm Diameter bolt constraints

16 mm Diameter bolt threaded region tie



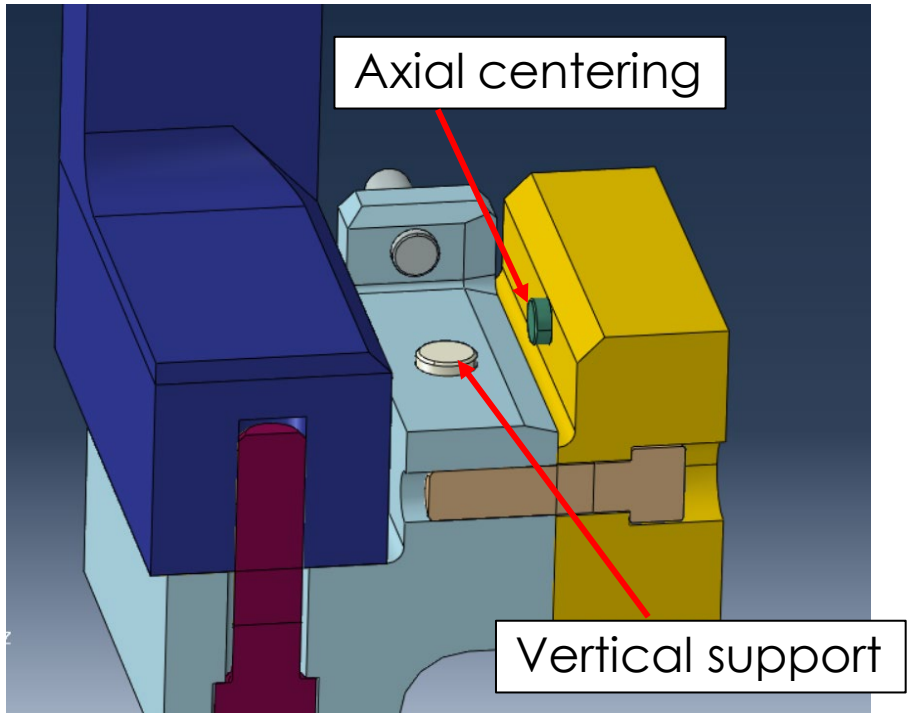
Bearing region tie for 16mm bolt



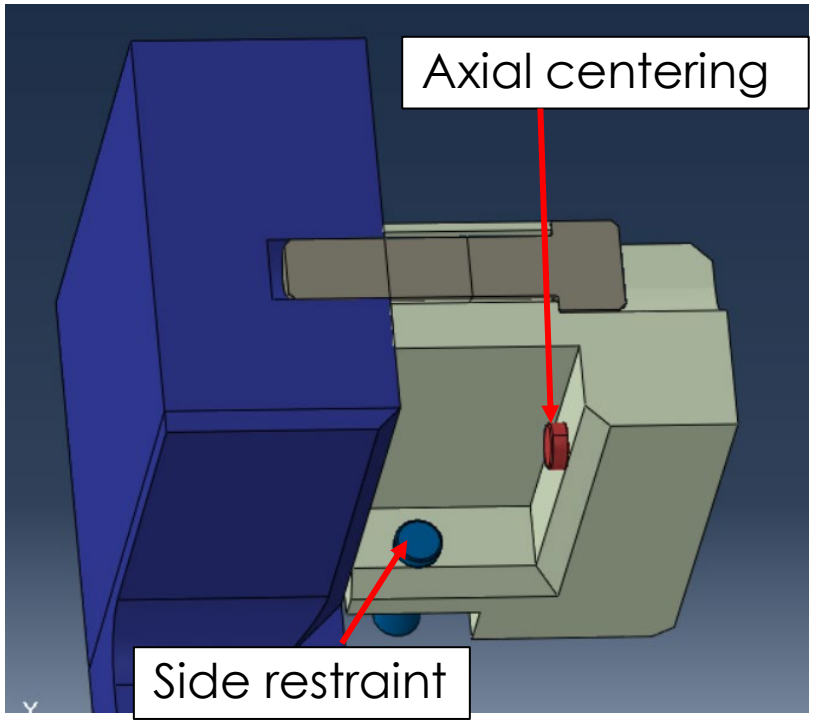
Typical for both 16 mm bolts

Restraint and centering pins

Lower support block centering pins

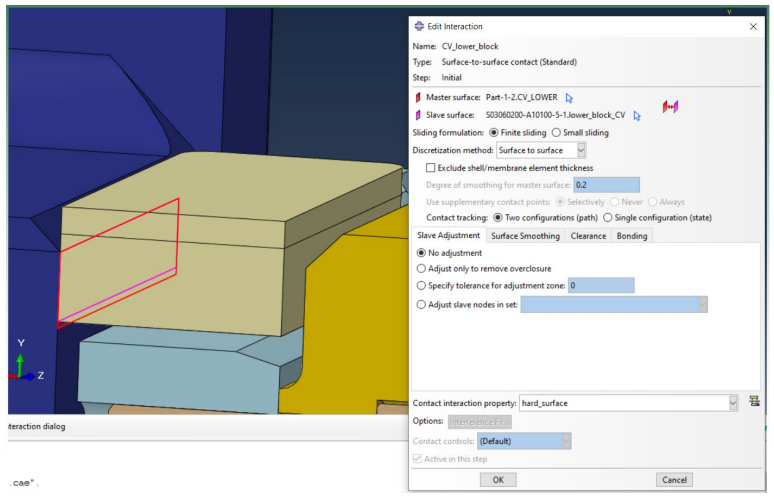


Upper Block centering pins

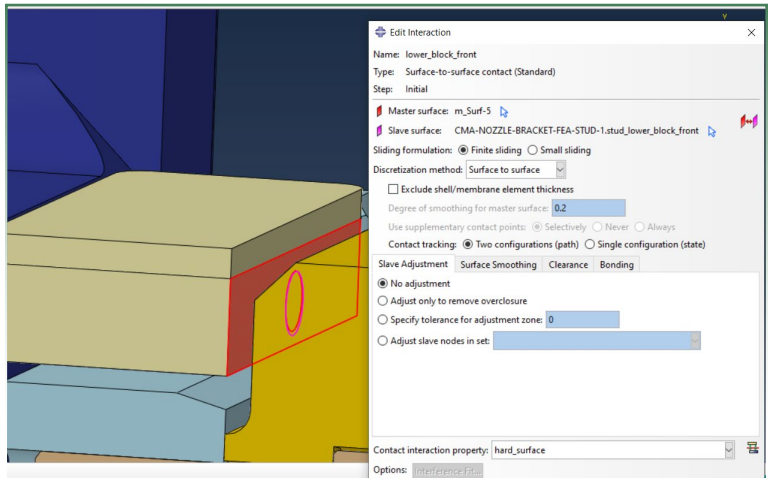


Lower support block restraints

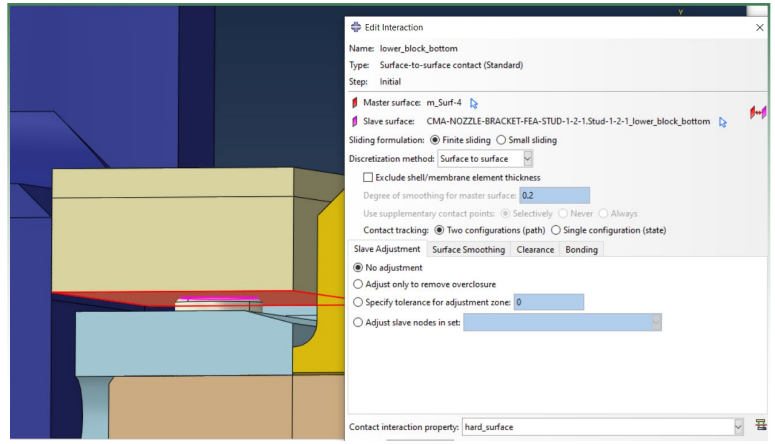
Contact between lower support block and core vessel (no friction)



Contact between lower support block and axial centering pin



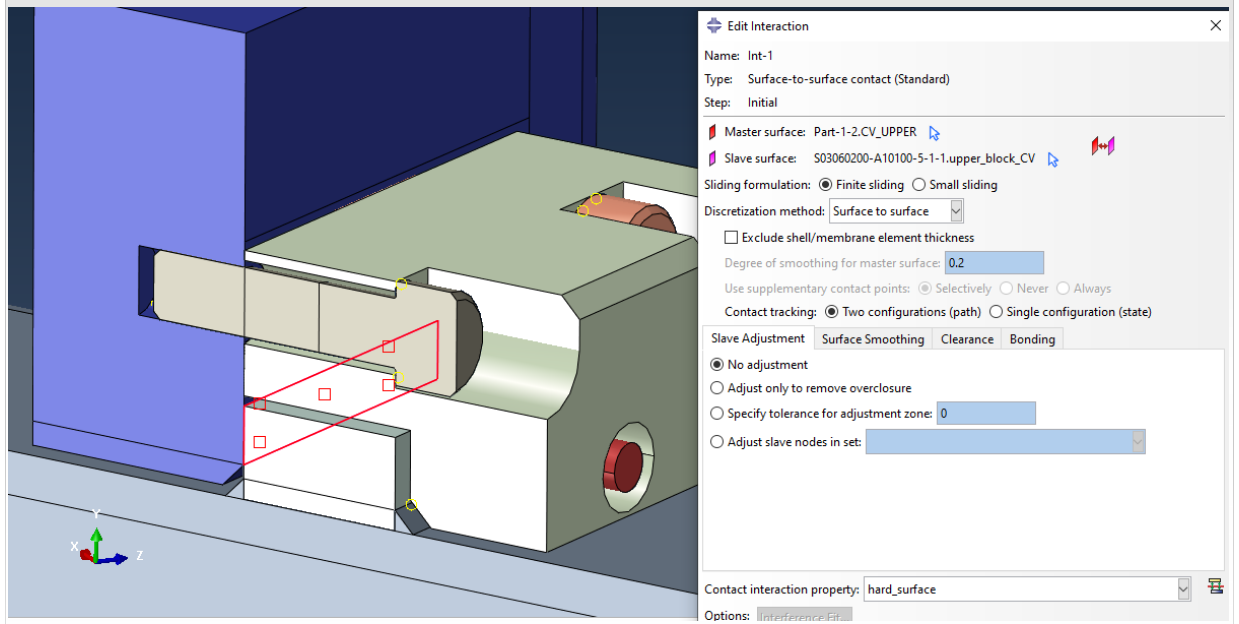
Contact between lower support block and vertical support pin



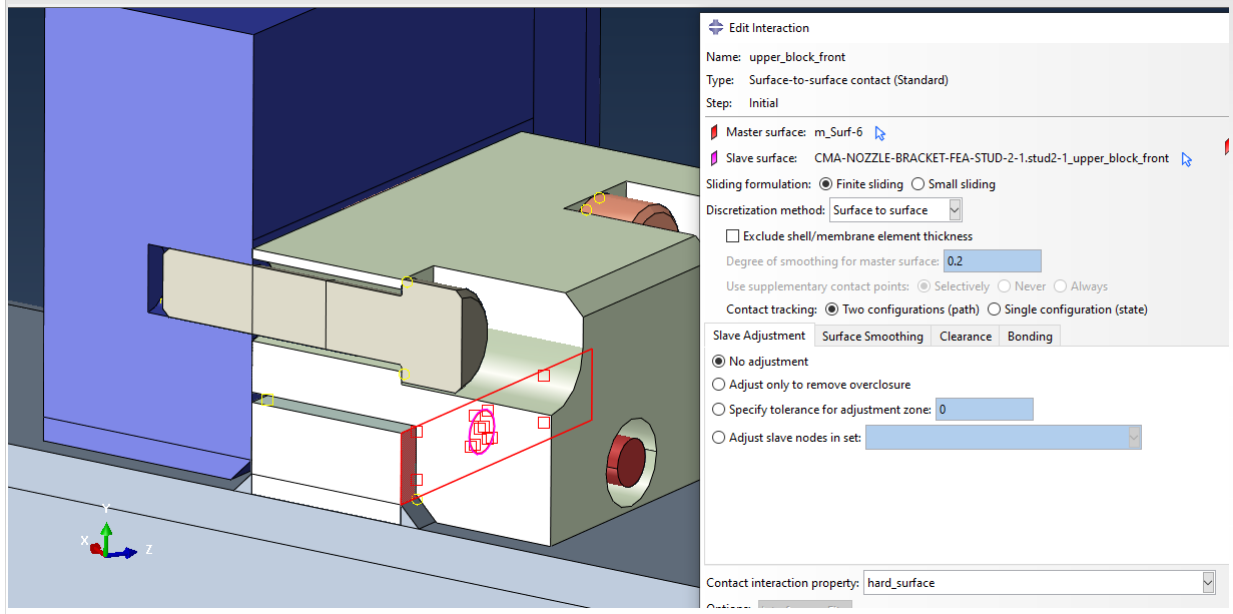
Upper block restraints are similar except without vertical pin

Upper Support block restraints

Contact upper block to core vessel



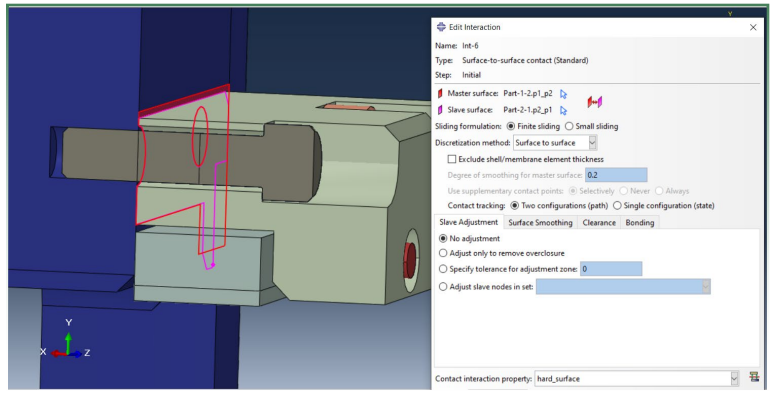
Upper block with front pin



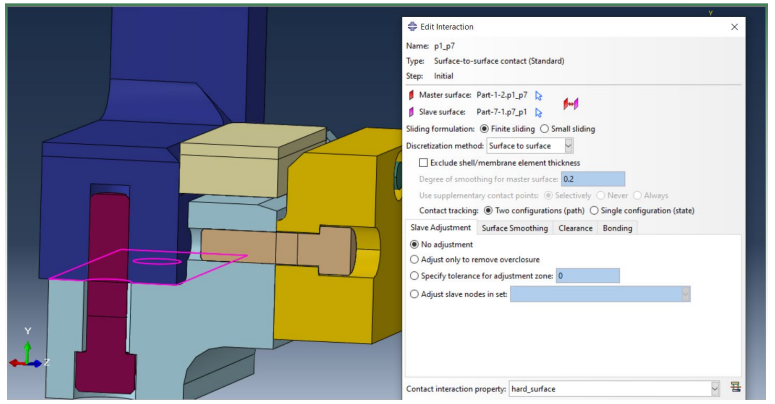
Side support pin not included because symmetry assumption keeps assembly centered

Surface to Surface part contacts

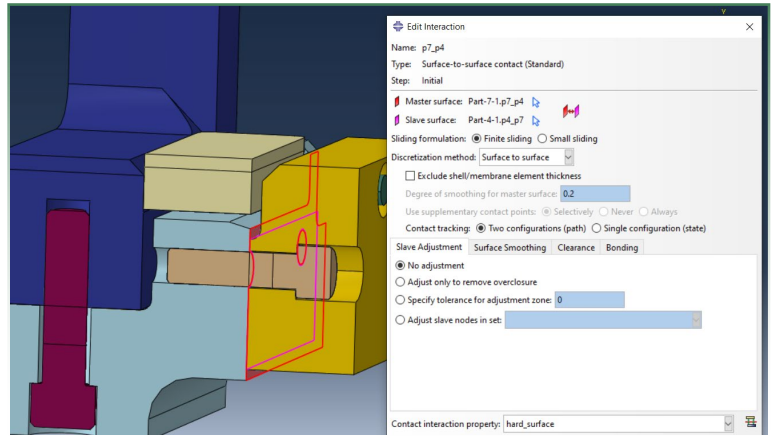
Contact Core vessel to upper bracket



Contact core vessel to lower bracket

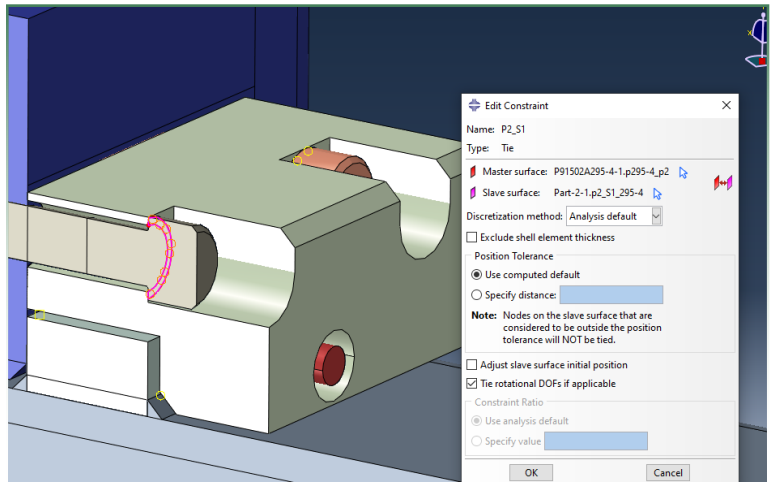


Contact lower bracket to outer lower bracket

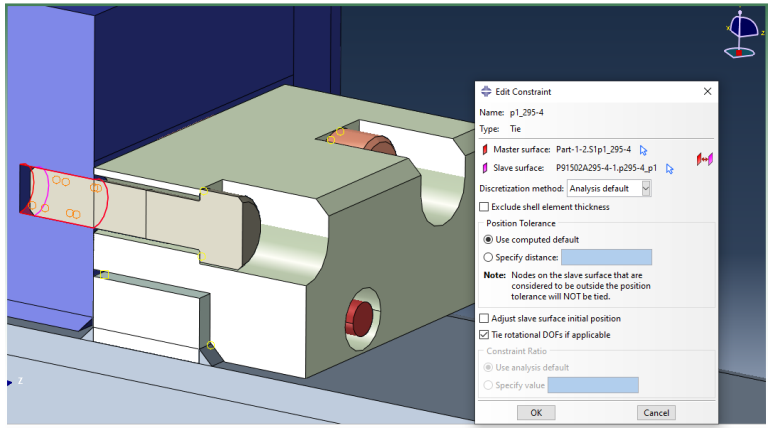


Tie Constraints

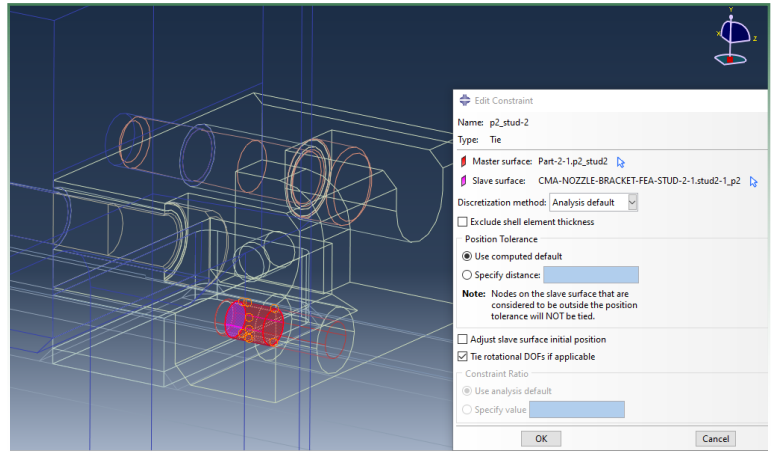
Typical tie between 20 mm bolt head and bearing surface on bracket part



Typical tie between simulated bolt thread area to core vessel

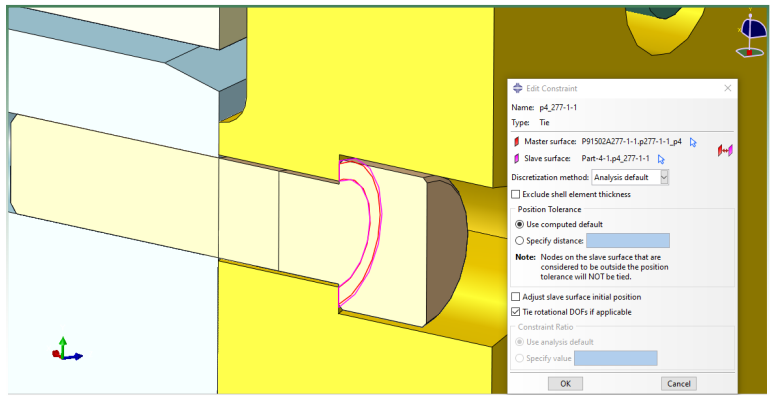


Typical tie for upper block centering pin to bracket part in threaded region

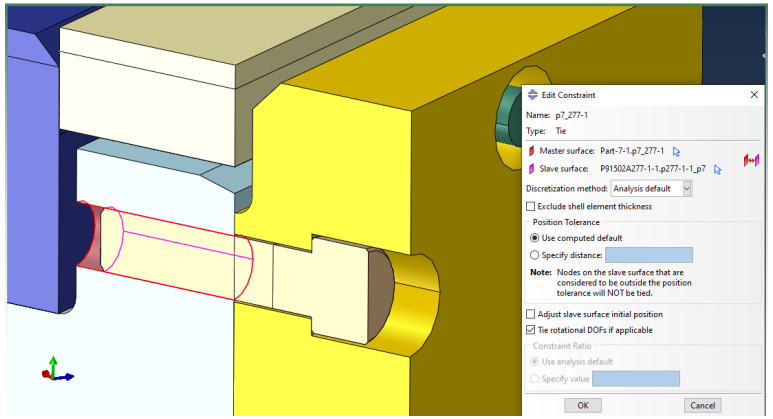


Tie Constraints on bolts and pins

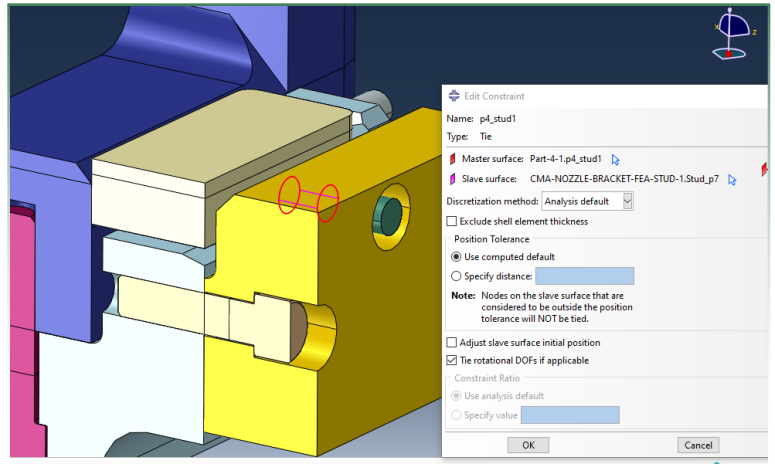
Typical 16 mm bolt head tie to bracket part



16 mm bolt tie in threaded region to bracket part

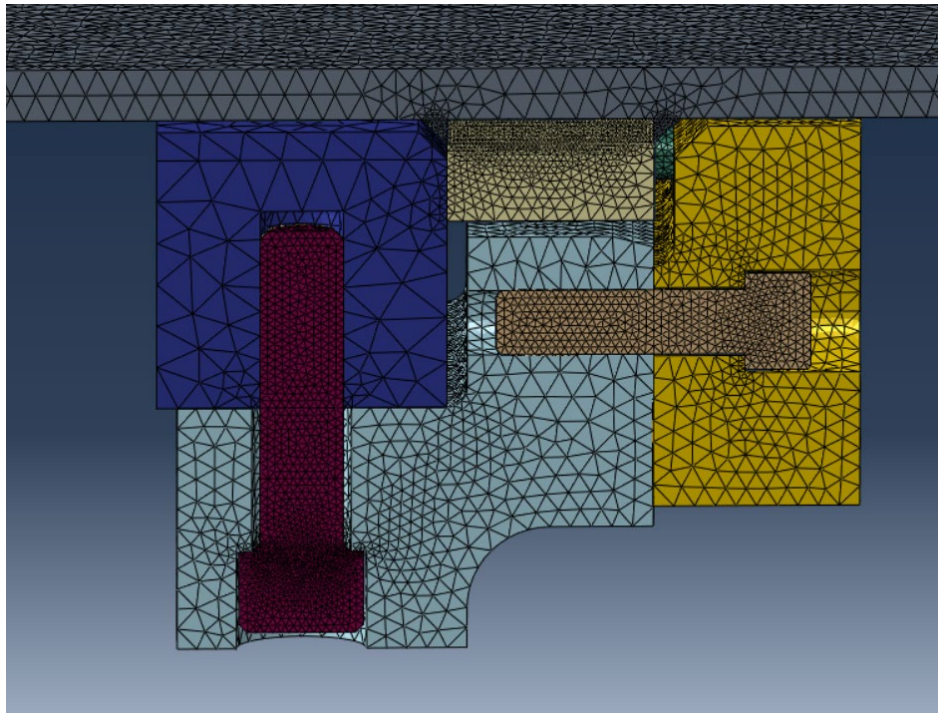


Tie lower block front pin to bracket in threaded area

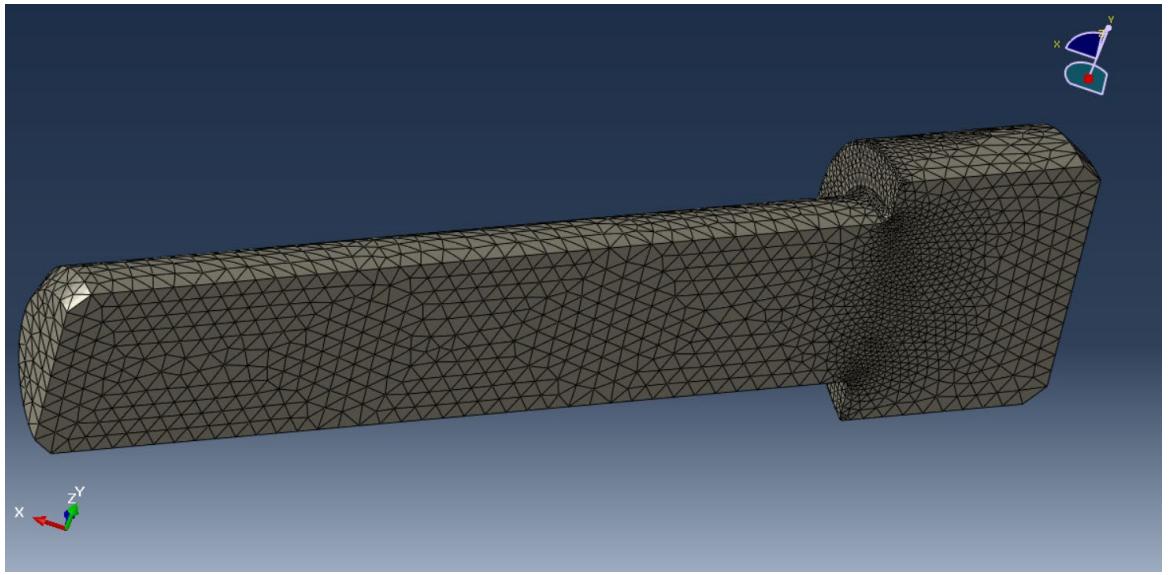


Tet Mesh around lower support bracket and typical bolt

Typical bracket and both tet mesh

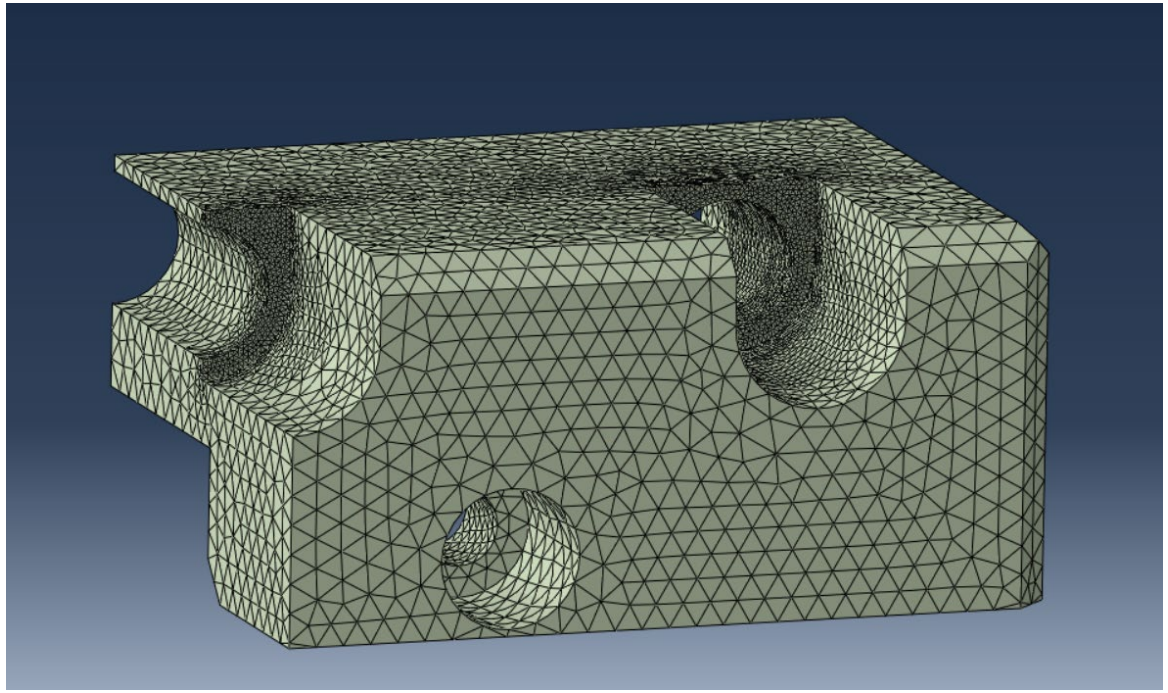


20 mm Bolt mesh

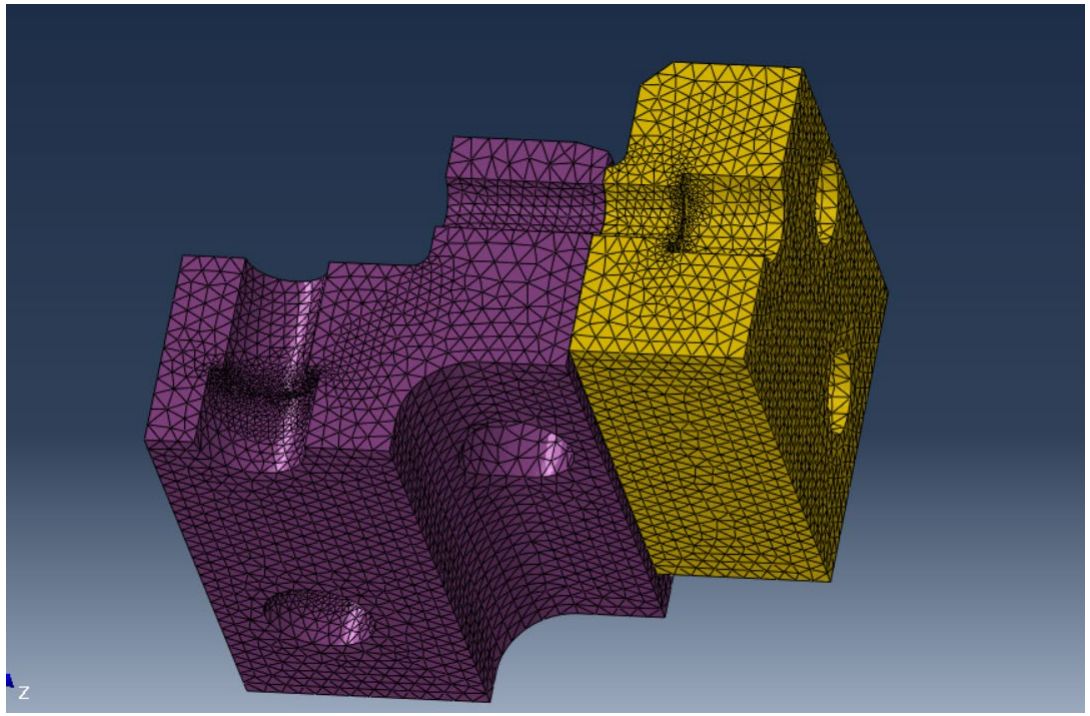


Tet Mesh for bracket parts

Upper Bracket mesh

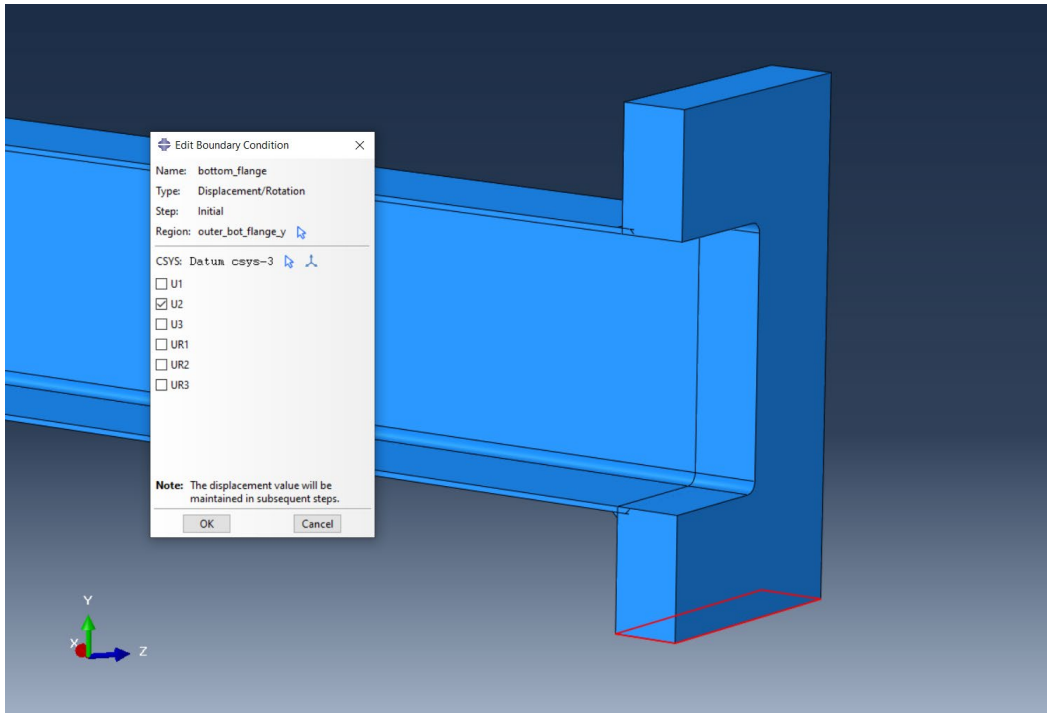


Lower Bracket part mesh

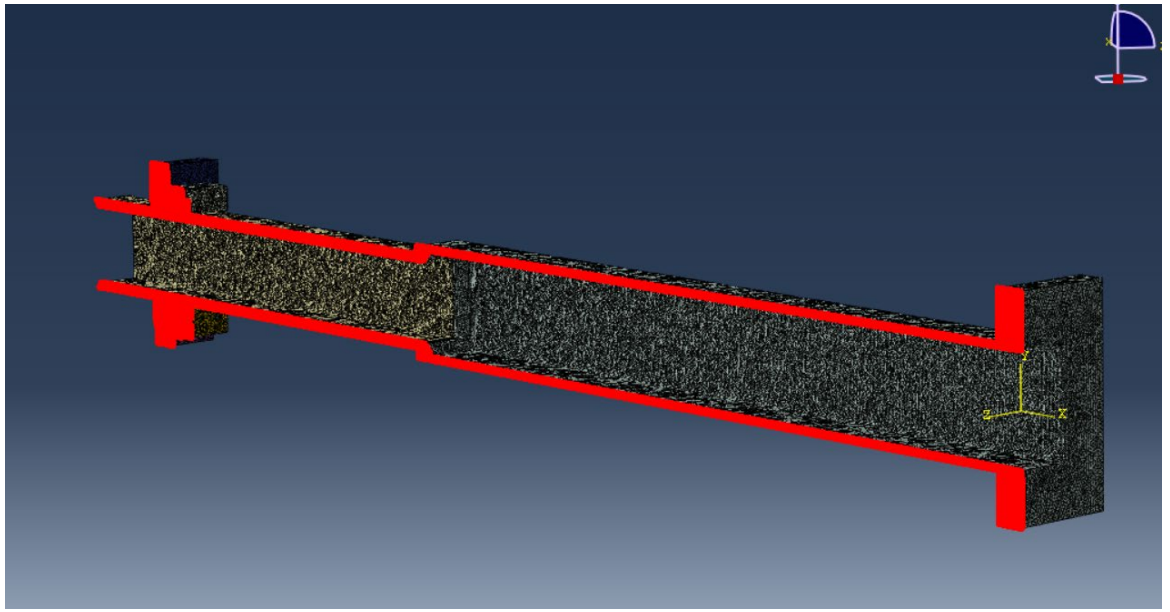


Boundary Conditions

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

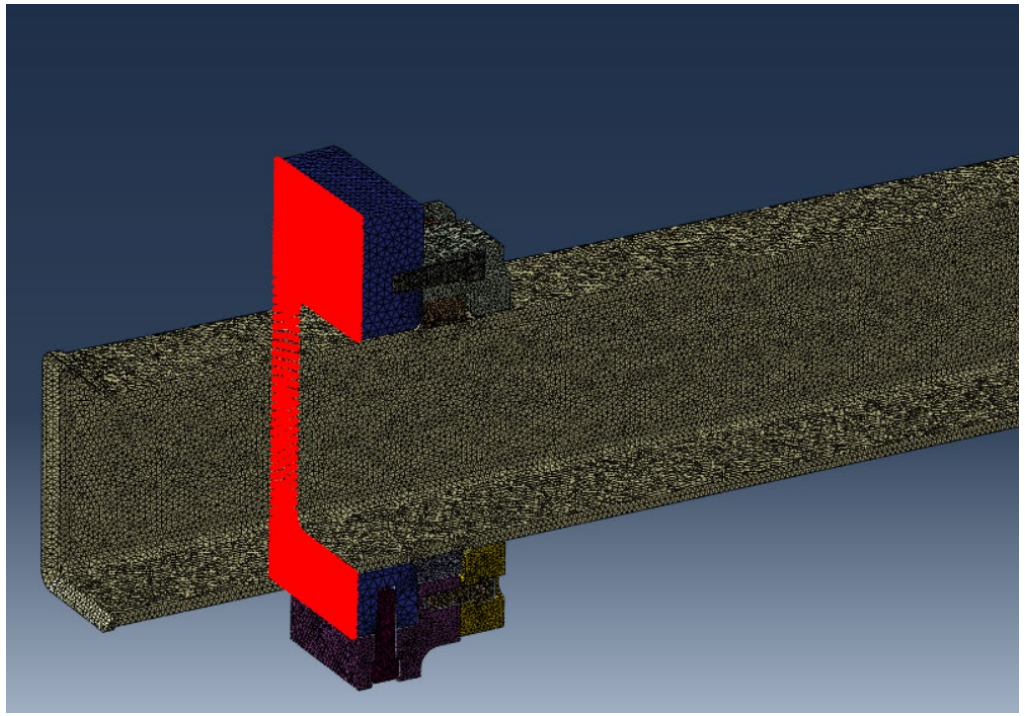


Z symmetry constraint in local coordinate system

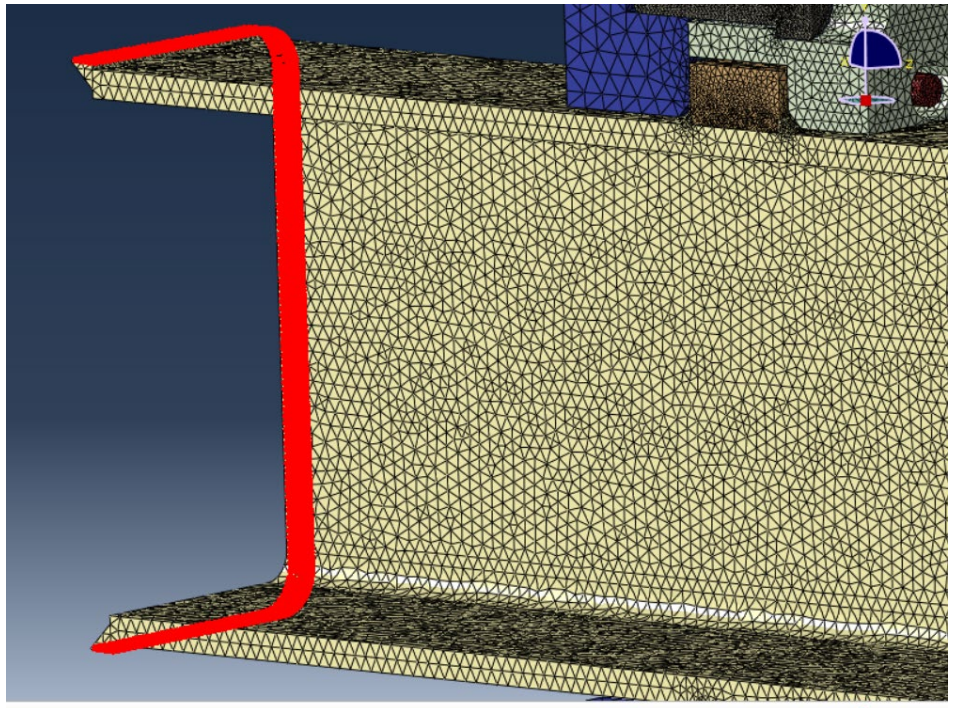


Boundary Conditions

Boundary condition fixed nodes on core vessel rear section



Boundary condition fixed nodes on weld to core vessel



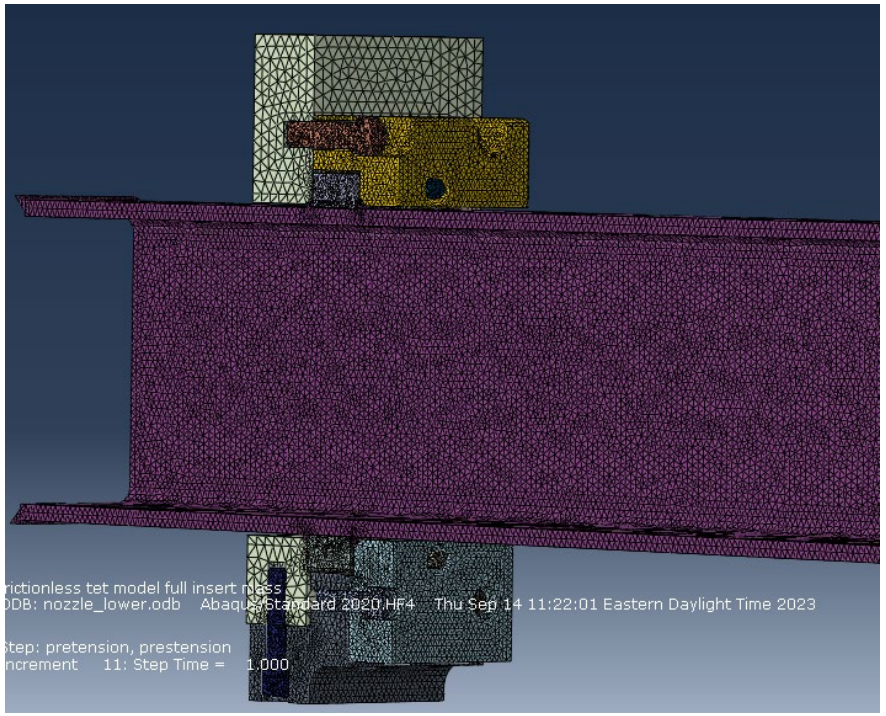
- The stiffness of the core vessel was simulated by fixing the nodes on the core vessel weld surface and the weld was merged with the nozzle plates in Abaqus

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



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

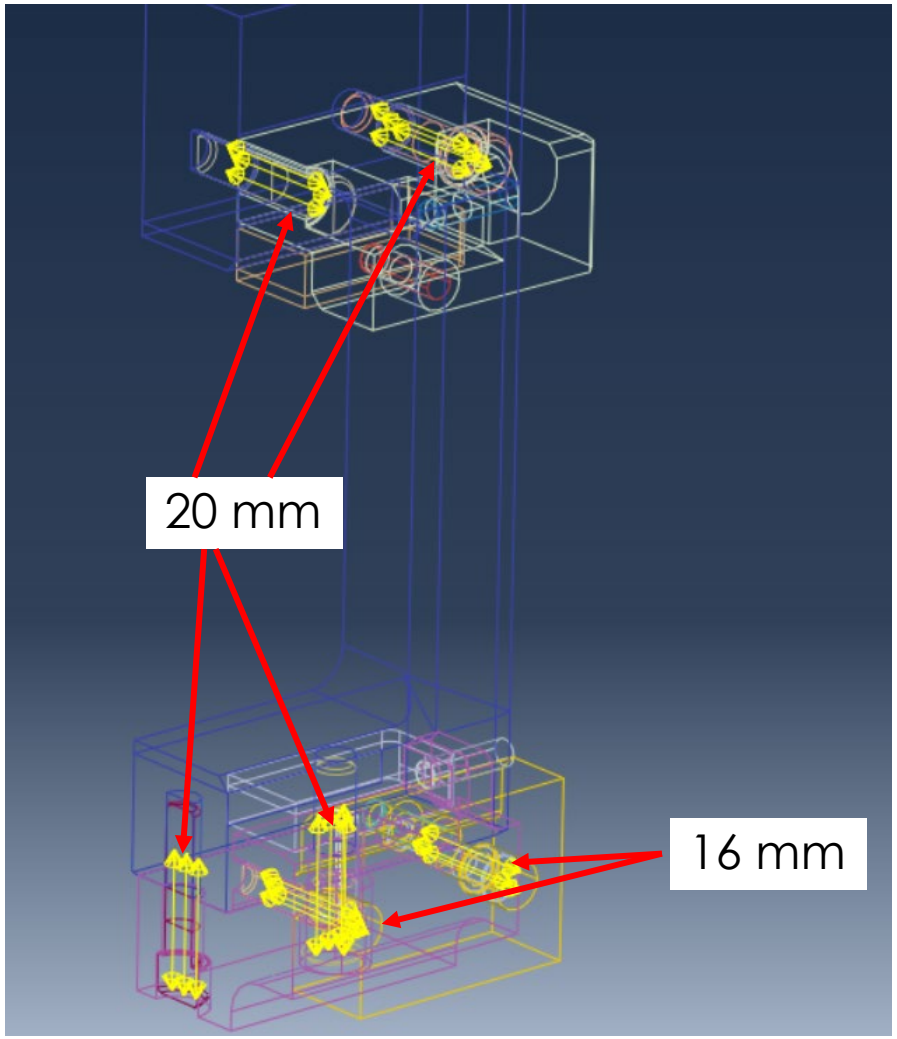
Pretension bolt loads

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

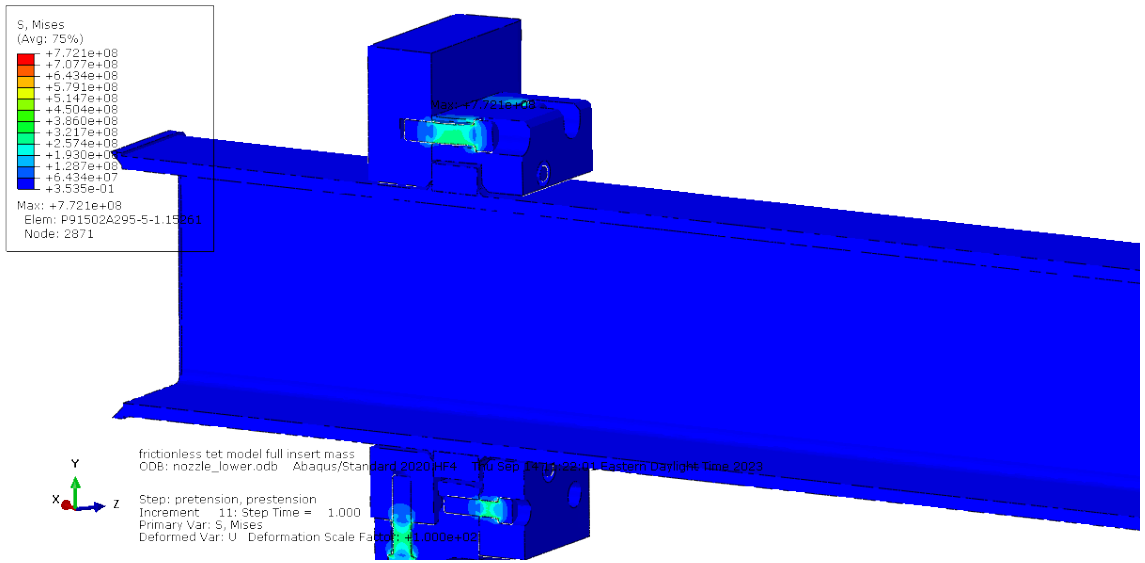
Half bolts on z symmetry plane had half the force applied

6 bolts with preload

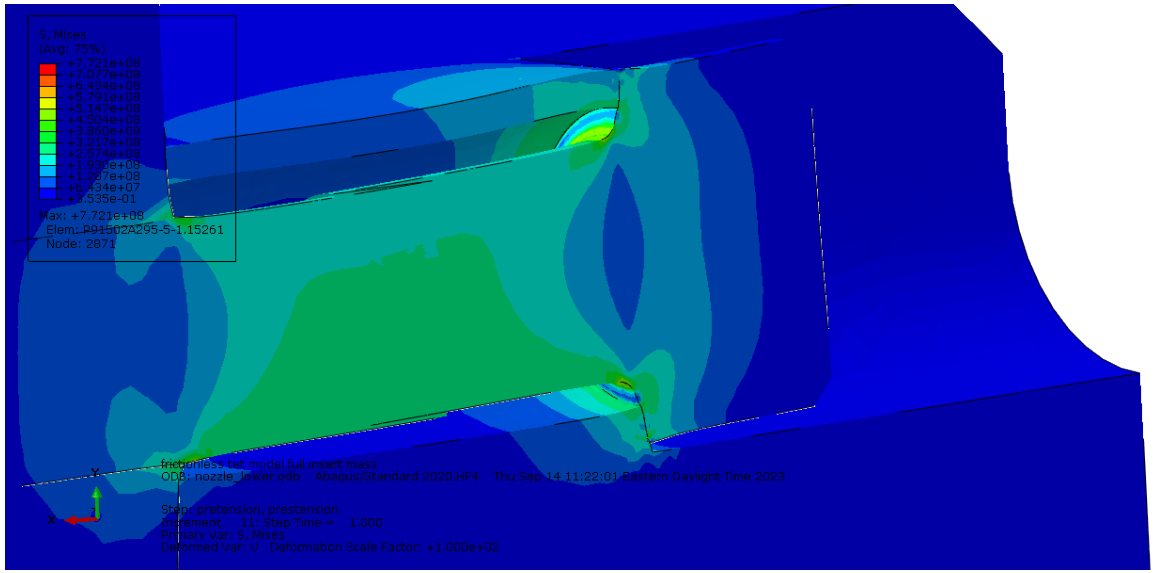


Pretension Step

S Mises

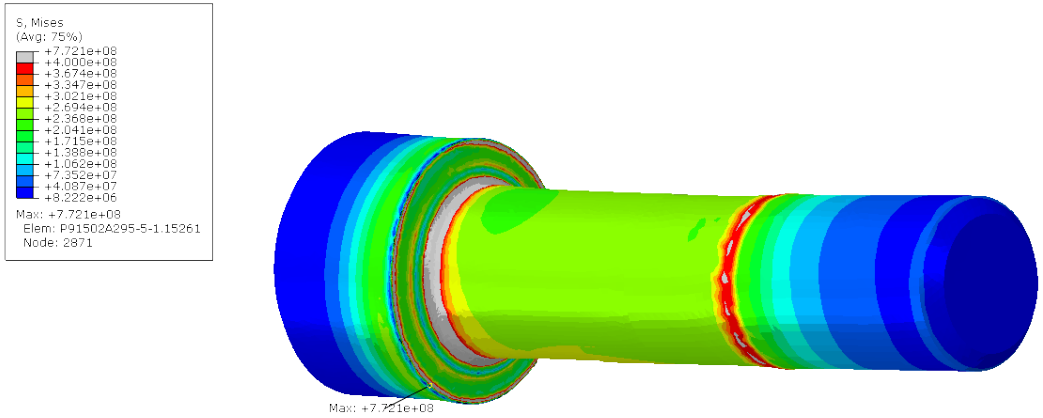


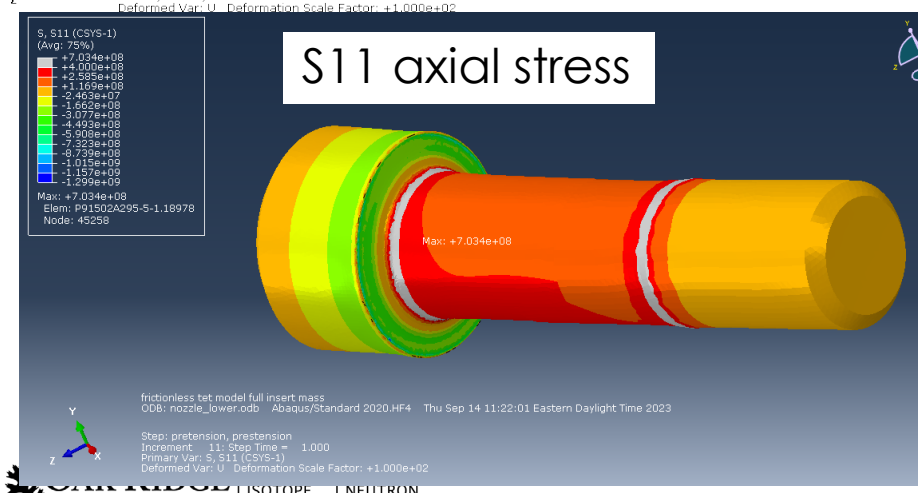
Close view



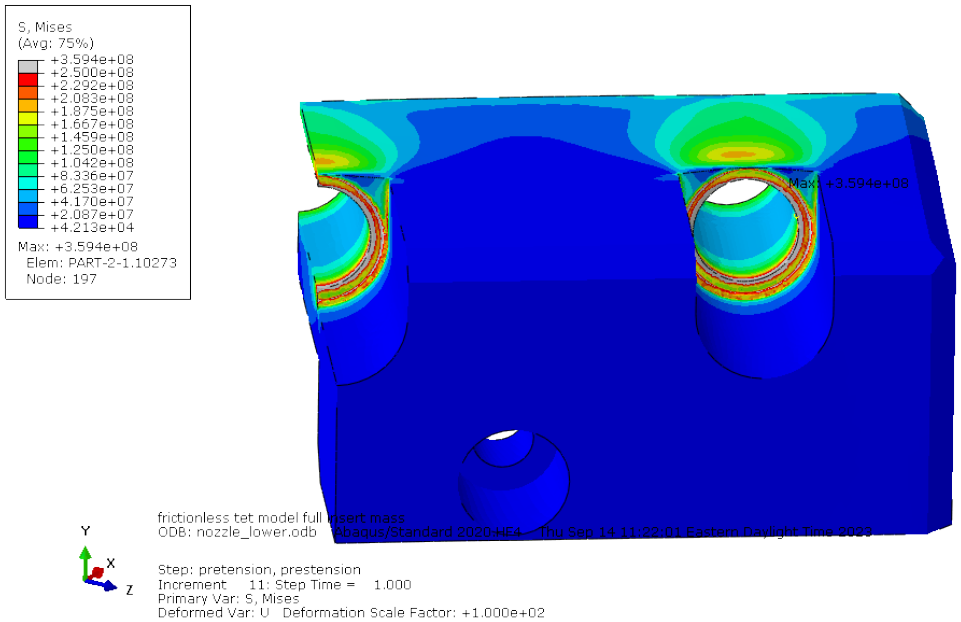
Upper bracket stresses

20 mm bolt Mises – 400 MPa bolt yield maximum scale



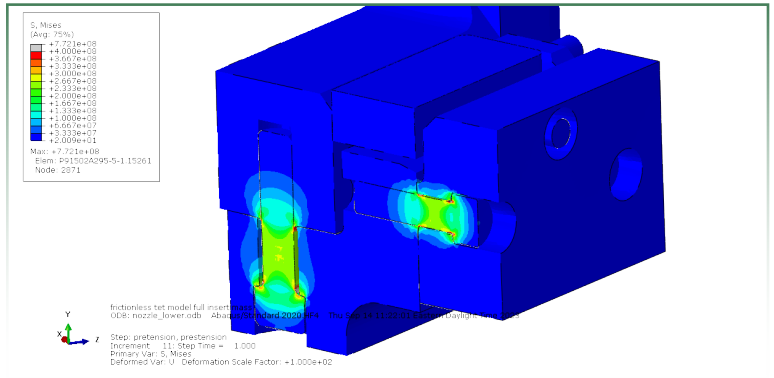


Mating upper bracket Mises stress with 250 MPa yield scale maximum

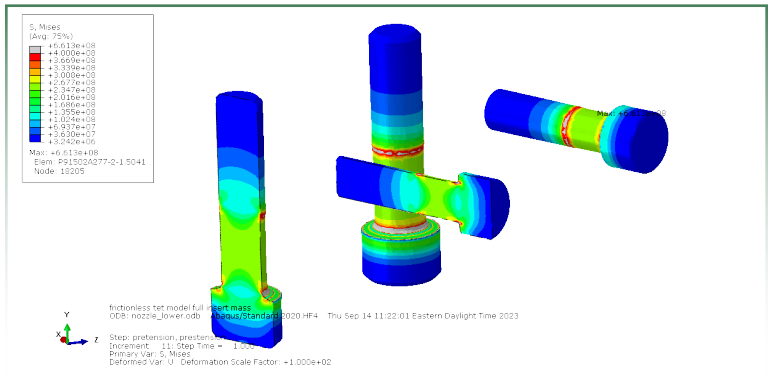


Lower Bracket Pretension Step

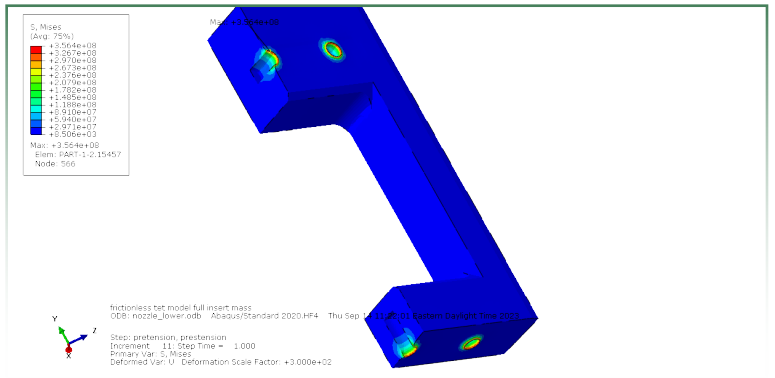
Lower Bracket Mises with 400 MPa scale maximum



Bolt Mises stress – 400 MPa scale

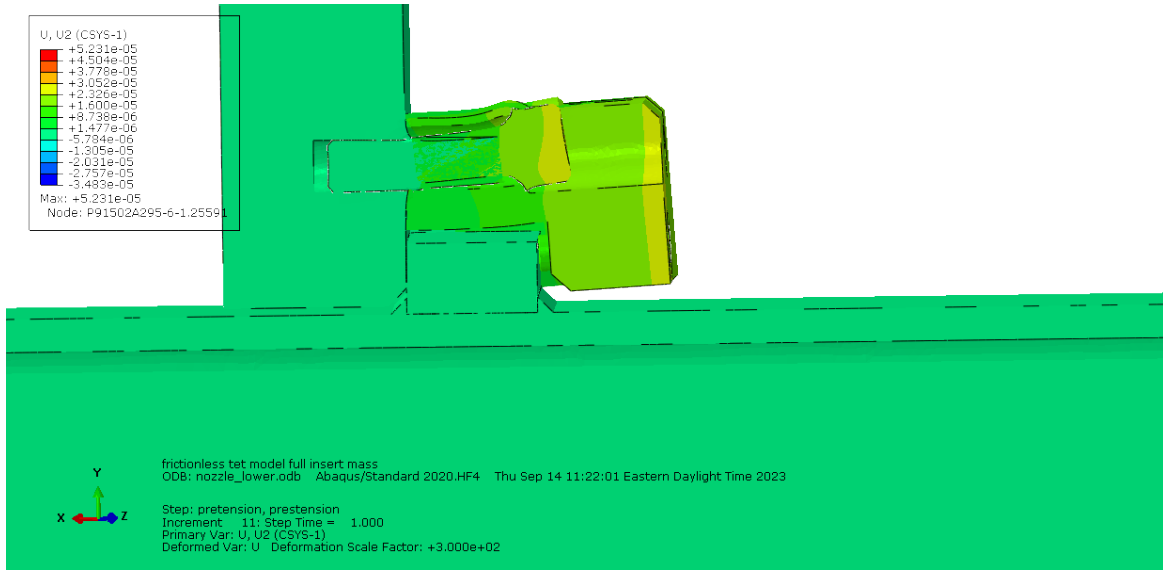


Core Vessel Mises stress

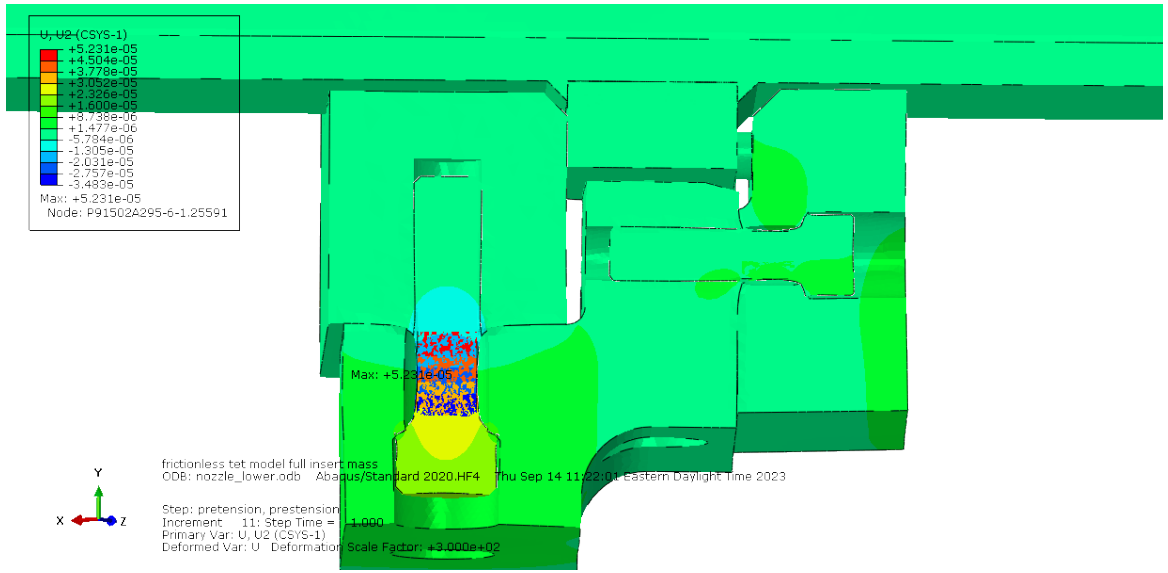


Vertical deflections due to Pretension

Vertical Displacement Upper Bracket

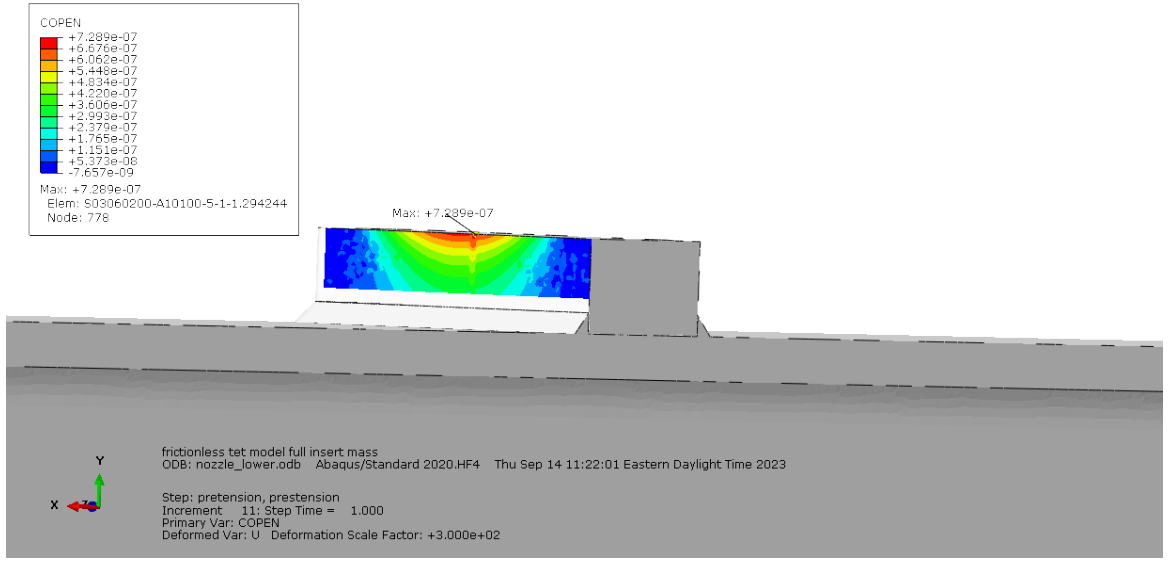


Vertical Displacement Lower Bracket

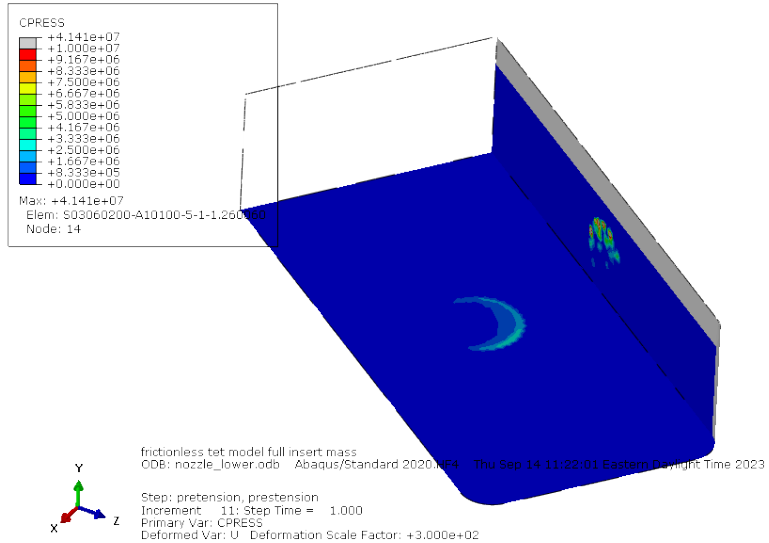


Support Blocks with gravity and pretension

Open Contact – Upper support block



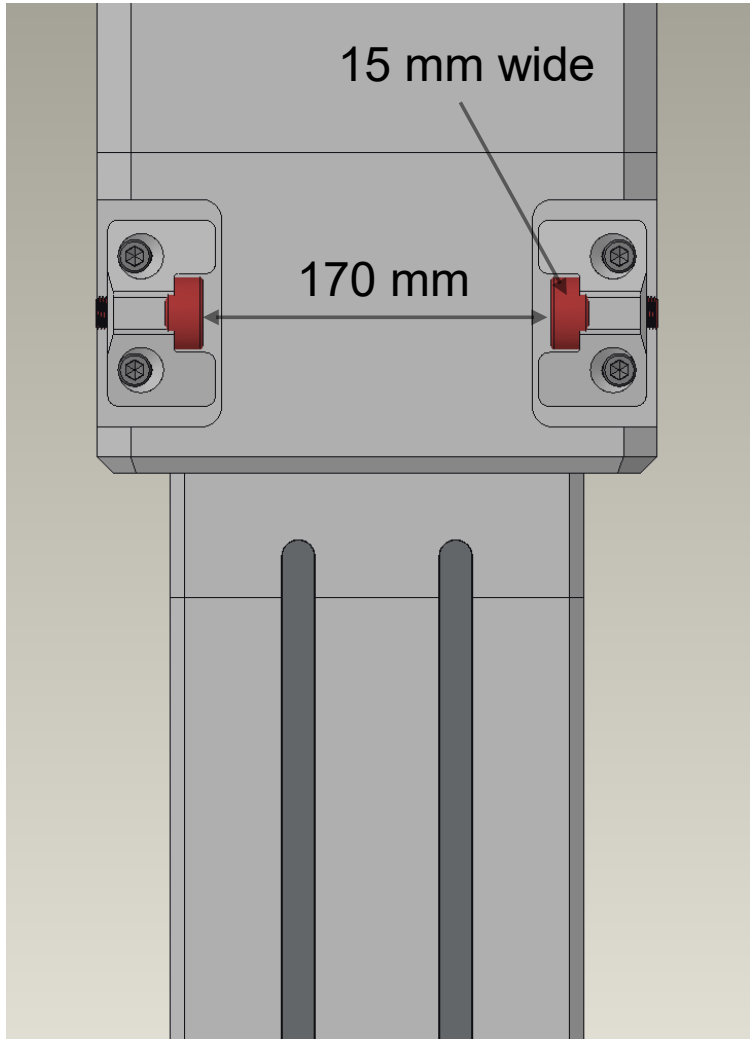
Lower support block- Contact pressure from vertical and axial pins

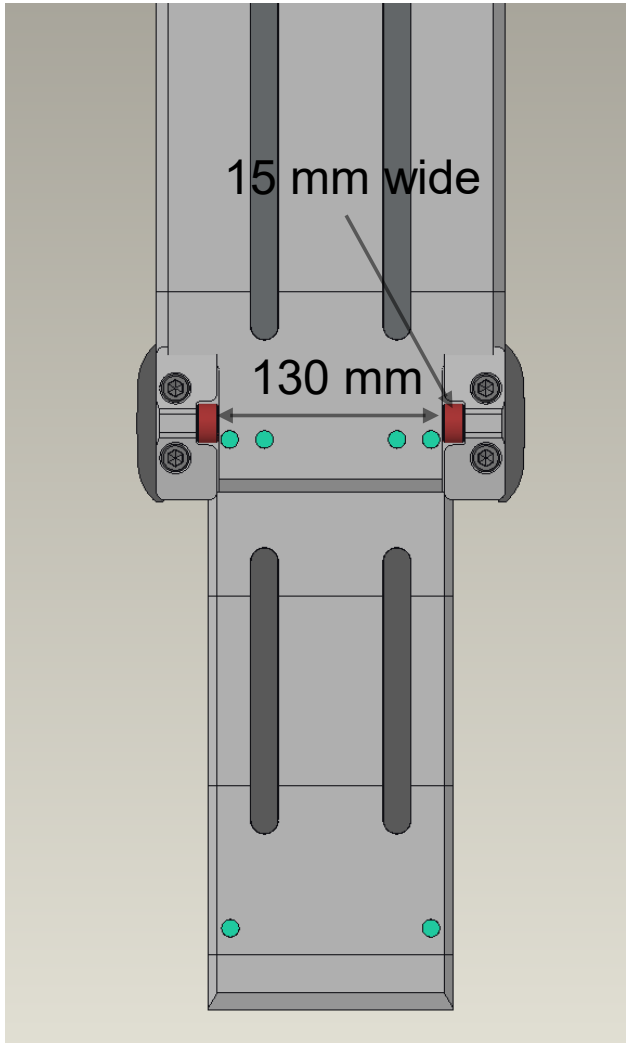


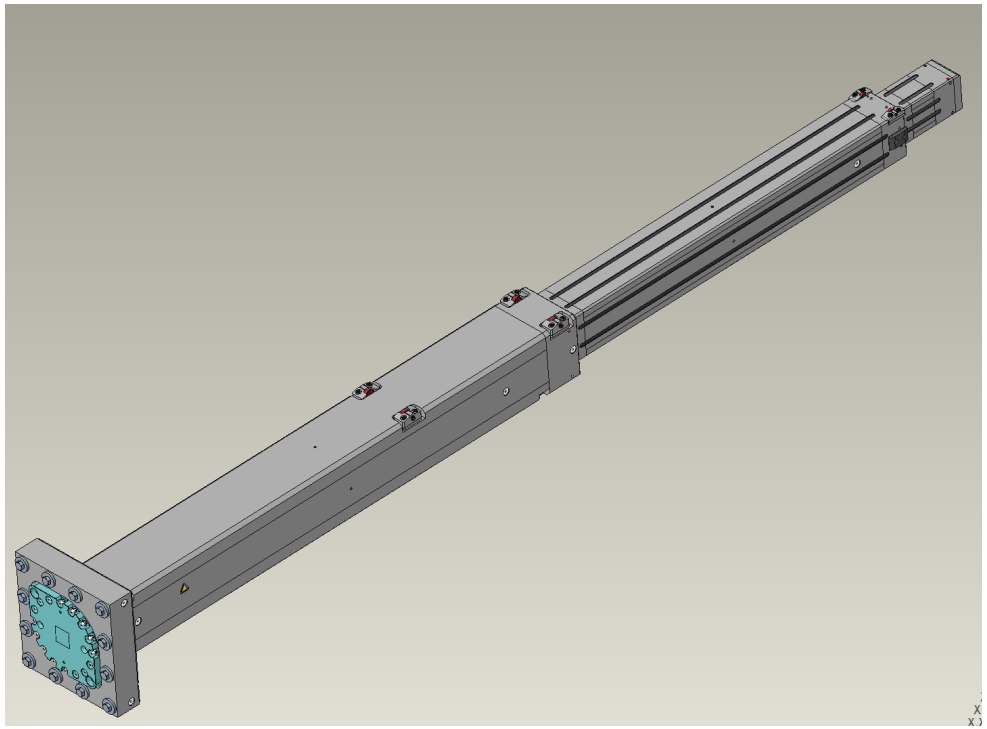
Upper block pulls away from core vessel and lower block contacts vessel and carries vertical loads

Step 2 – Gravity loads including Insert mass

Insert to be installed within nozzle







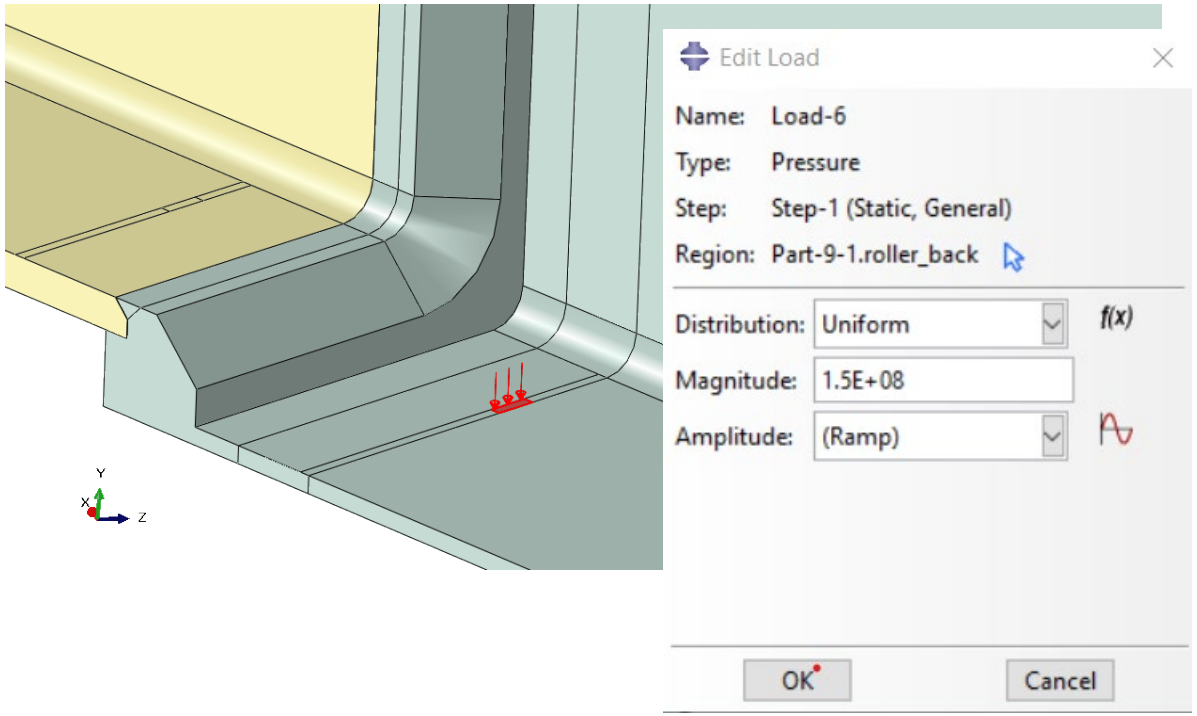
Monolith Insert Mass = 1830 kg
The red parts are wheels, so we can assume a small width contact area

Insert mass loading worst case assumption

Loading Assumption

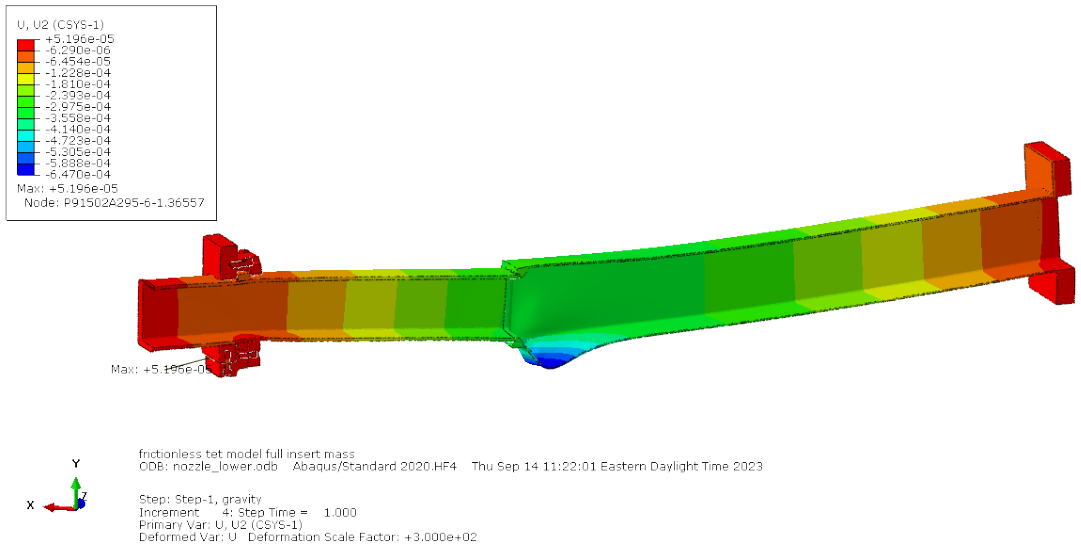
- Total mass 1830 kg
- Worst location on thinner plate
- Assume the whole mass is supported on the two wheels without accounting for an outer support
- Wheel contact area estimated at 4 mm x 15 mm
- Pressure = 1830*9.8/(2*(4e-3*15e-3)
  =149.5 MPa

Roller Pressure on back nozzle section

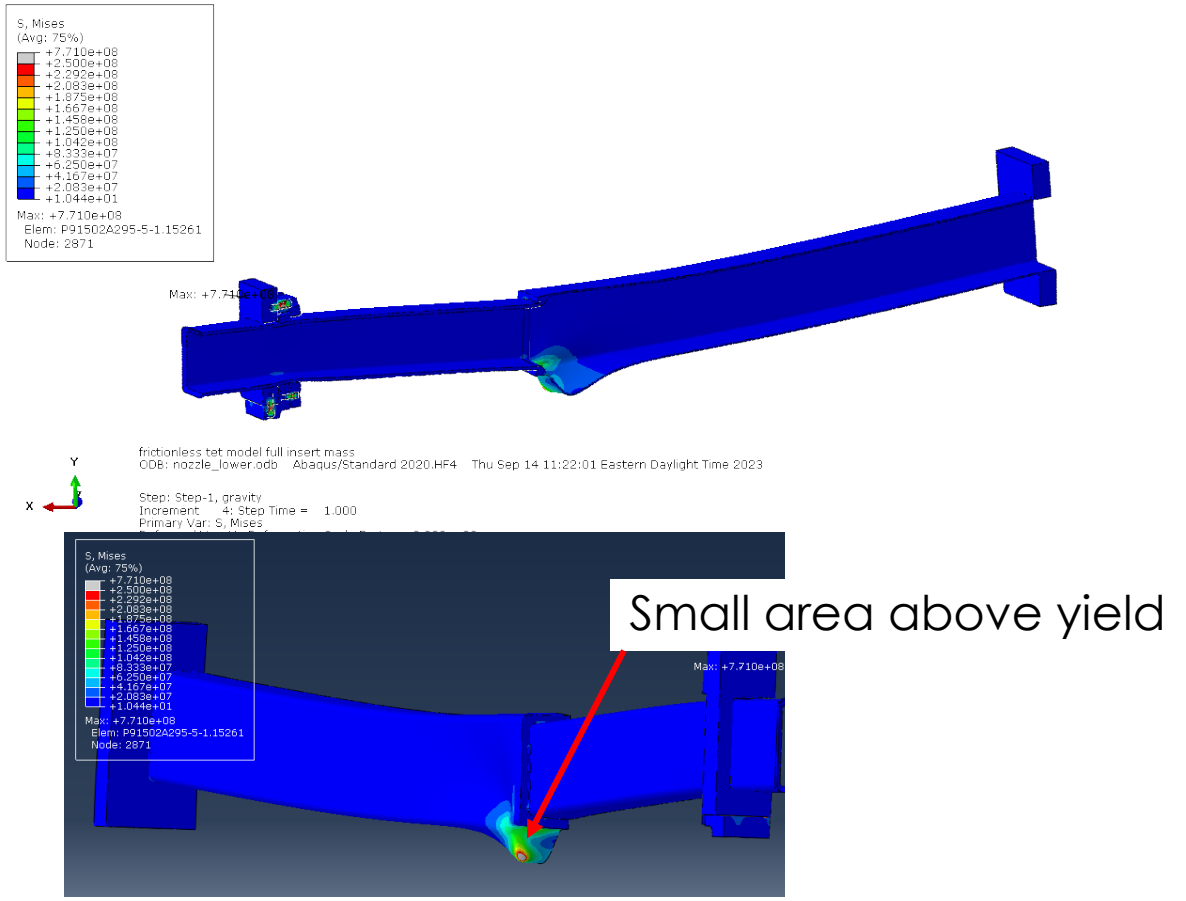


Step 1 Gravity including Insert total mas

Vertical deflection – peak .6 mm under insert support wheel



Mises stress – 250 MPa scale maximum

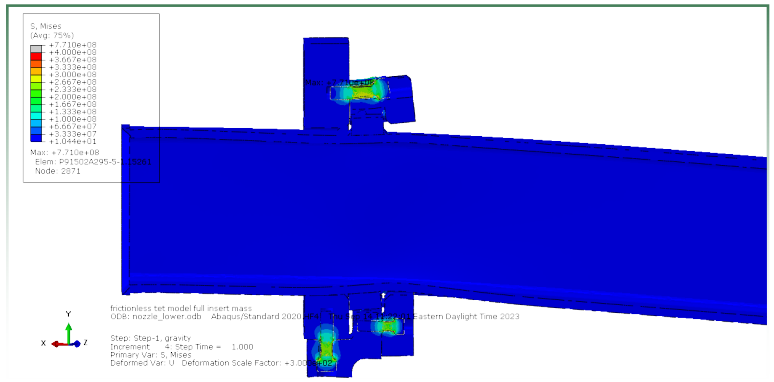


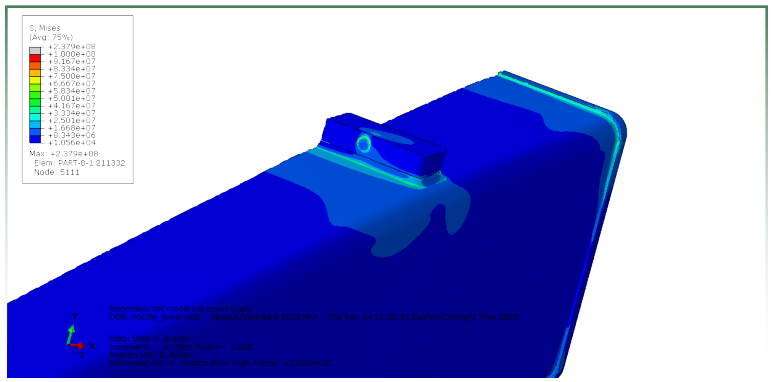
Step 1 stresses

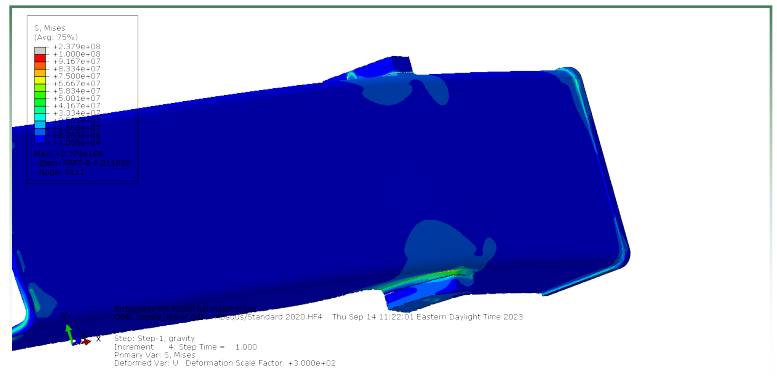
Bolts stresses similar to preloading but bracket vertical deflections increased

S Mises 100 MPa scale showing low weld stresses

Lower support block welds peak ~ 120 MPa

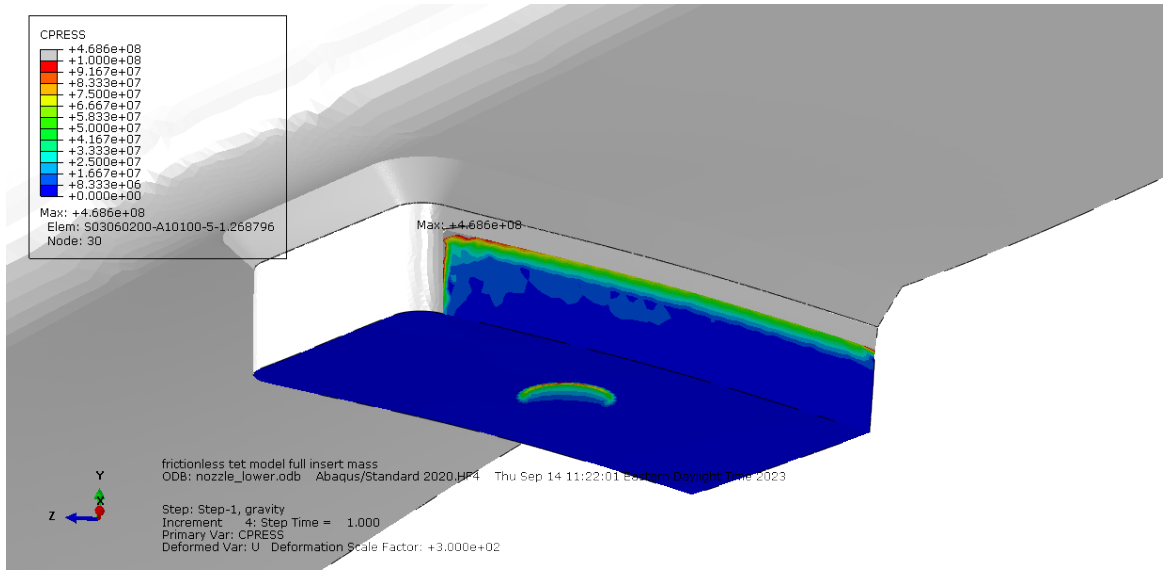




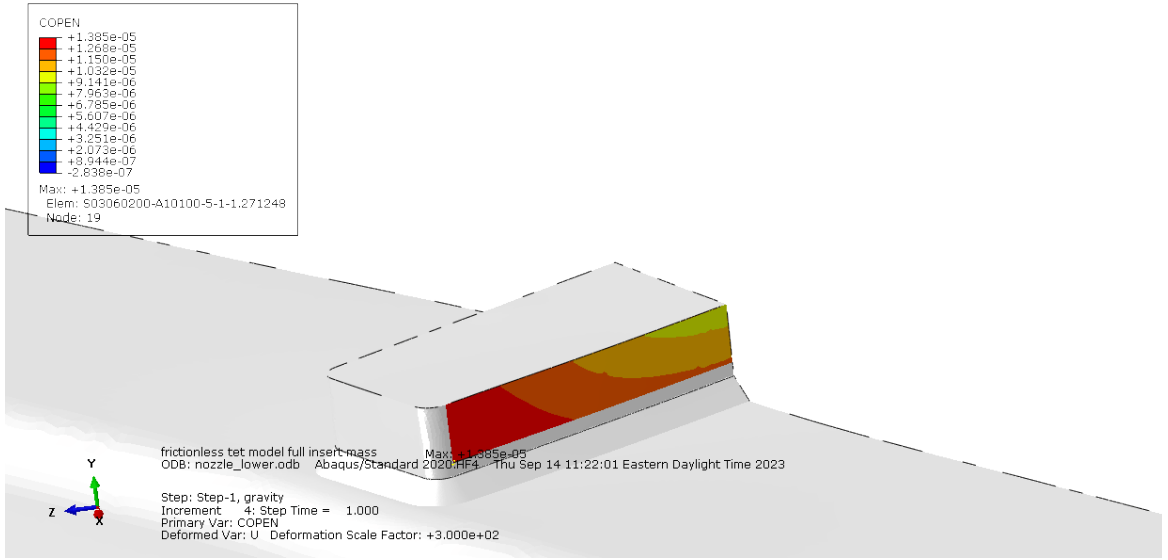


Step 1 Support Blocks

Contact pressure between lower support block and core vessel



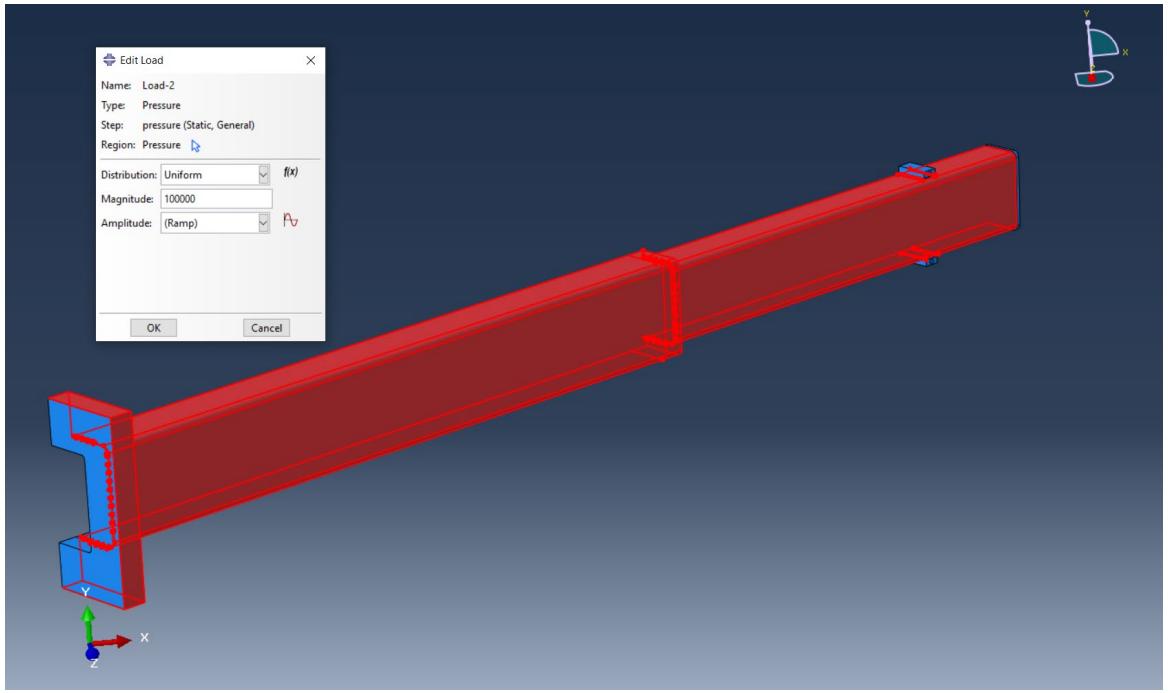
Open Contact area on upper support block – no contact on Core vessel



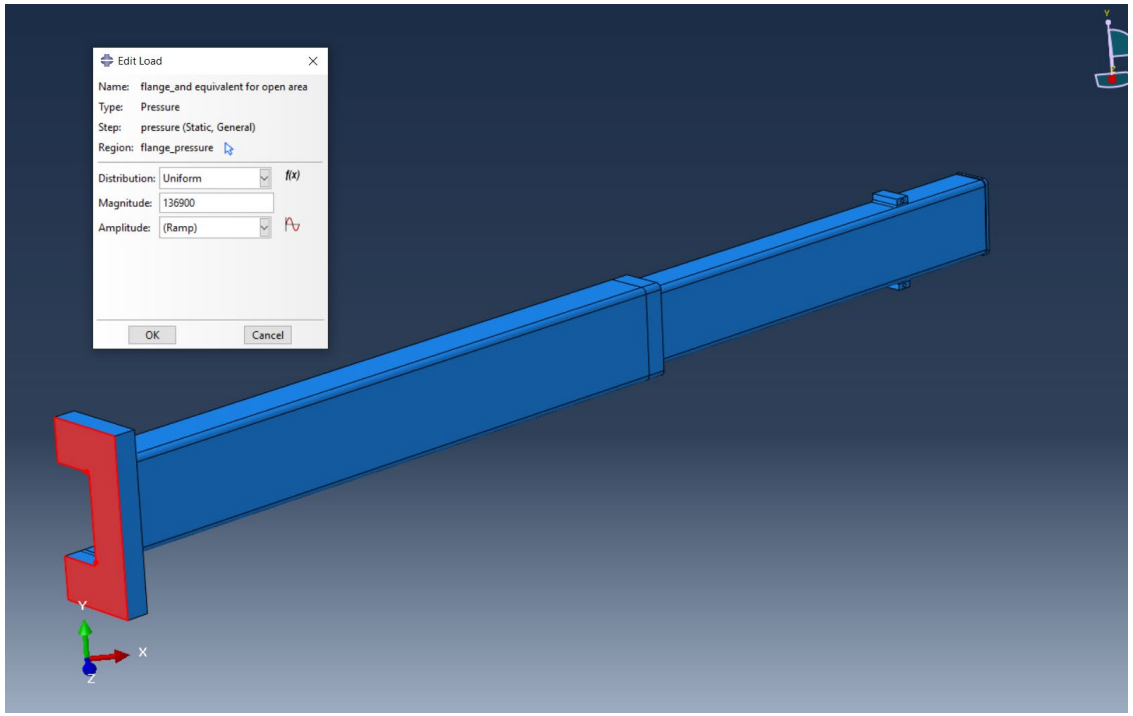
Step 2 – Gravity without insert mass, vacuum pressure and bolt preloads

Pressure Loads

External Pressure

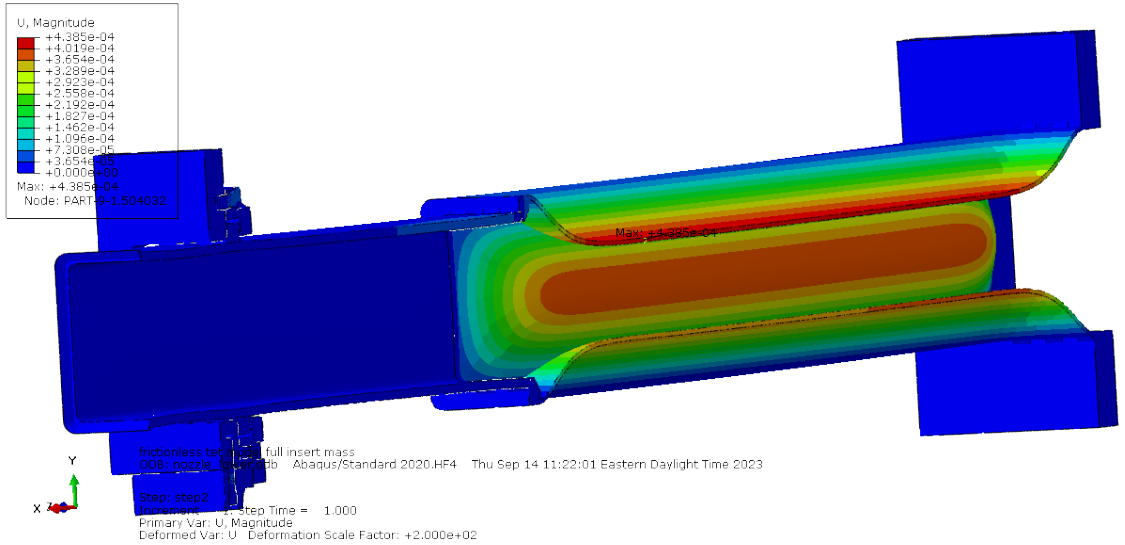


Flange pressure increased to account for 1 bar on open area

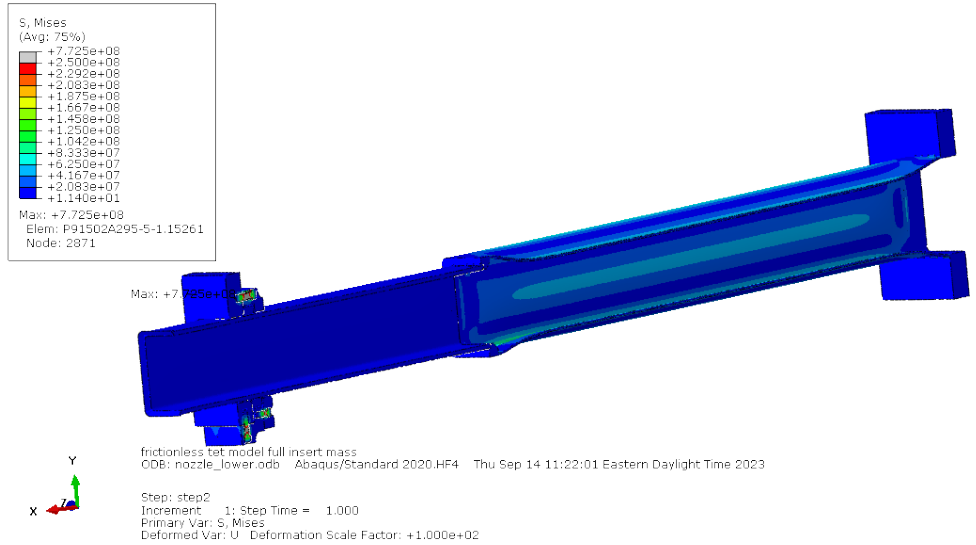


Lower Nozzle Step 2

Displacement magnitude

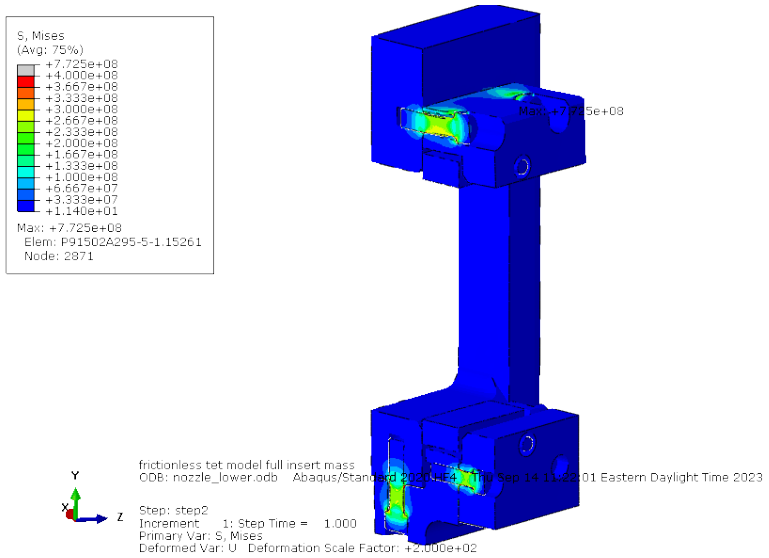


S Mises – 250 MPa Scale

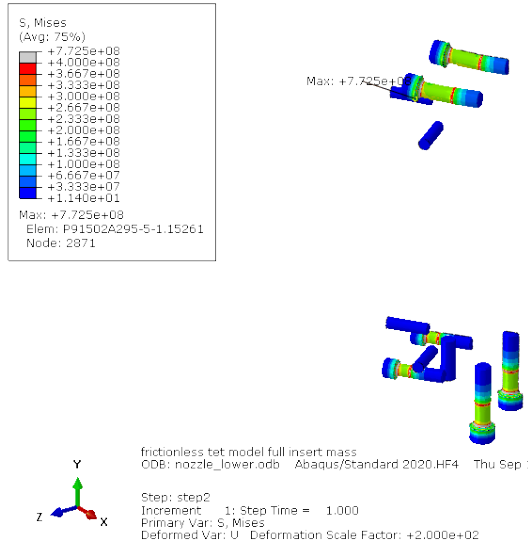


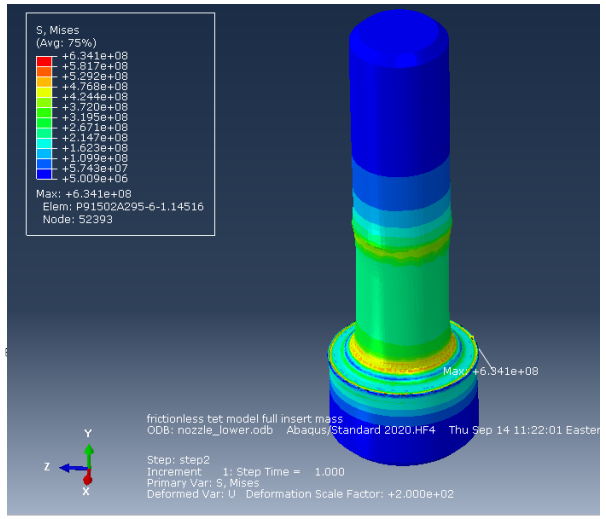
Step 2 stresses

Bolt and brackets S Mises 400 MPa scale



Bolt Mises Stress 400 MPa scale

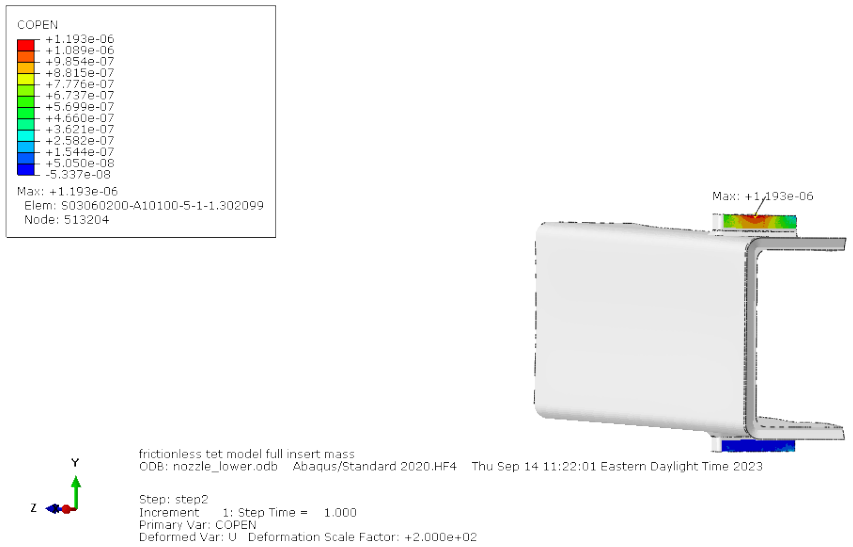




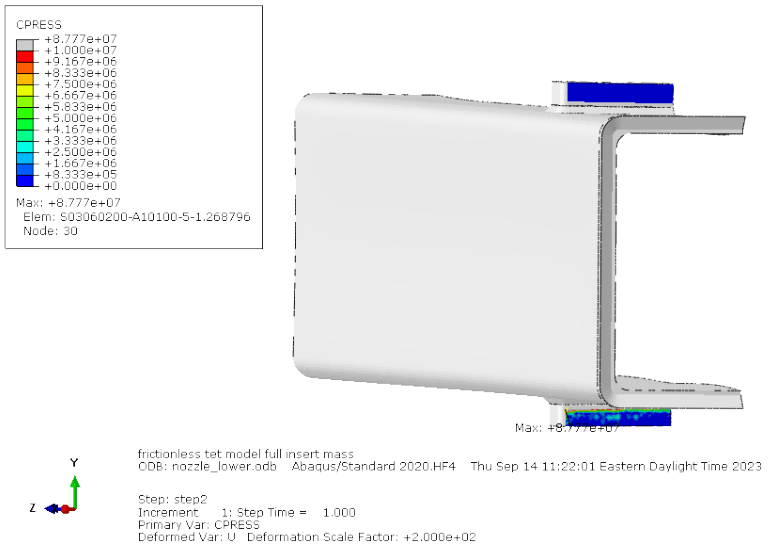
Lower 20 mm bolt
Peak near head ~ 450 MPa

Step 2 Support Blocks contact conditions

Upper block not in contact with core vessel



Contact pressure on lower block

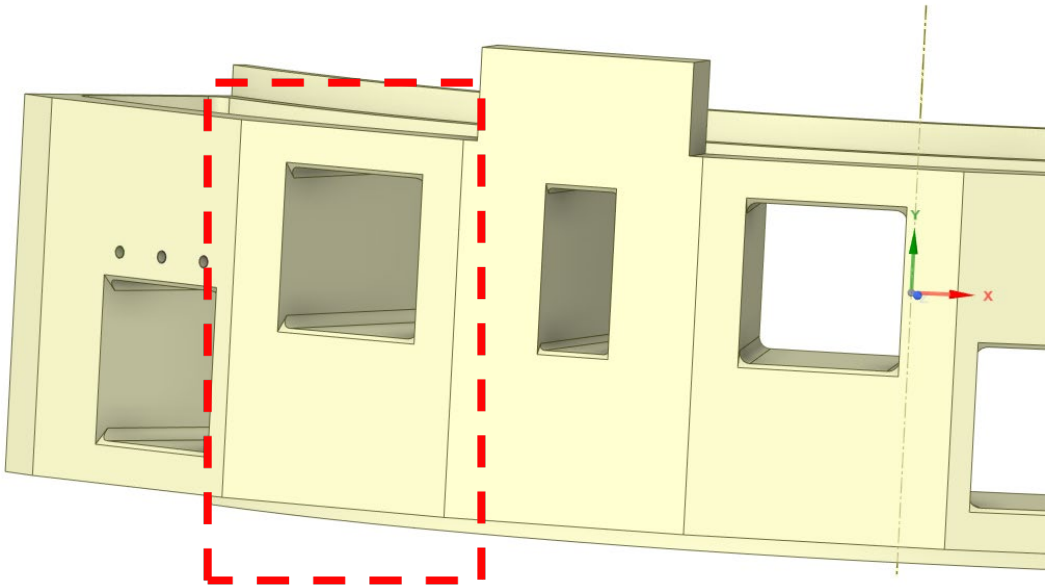


Summary for lower nozzle assembly

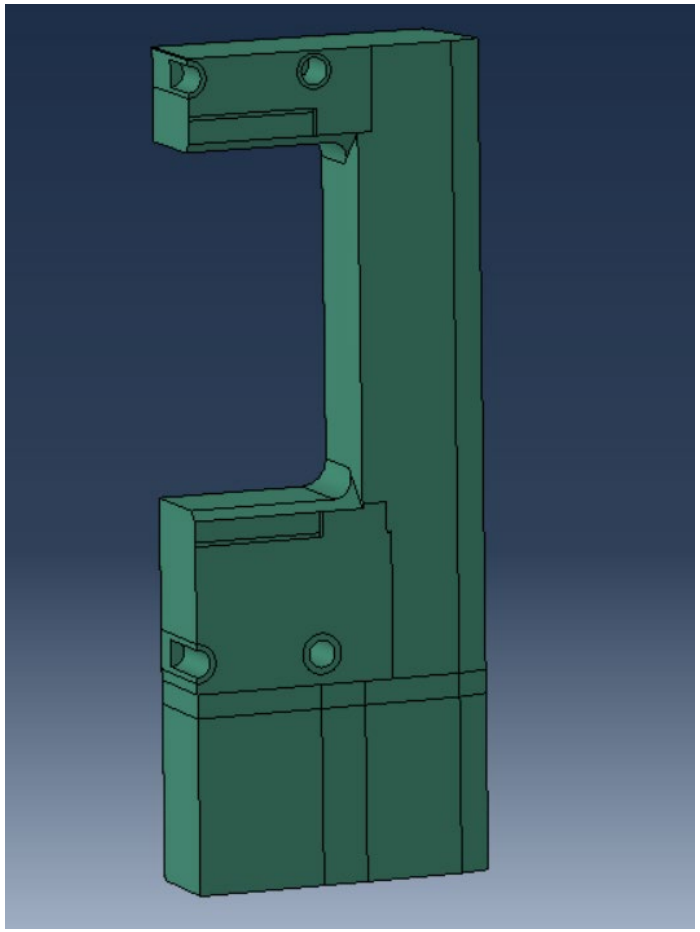
- Preloads on bolts are approximately 60% of proof loads but do show small zones of yielding around base of head and by core vessel tie
- Bracket parts show some local yielding around edges adjacent to bolt bearing areas and at start of ties simulating threads
- Upper support bracket does not contact 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

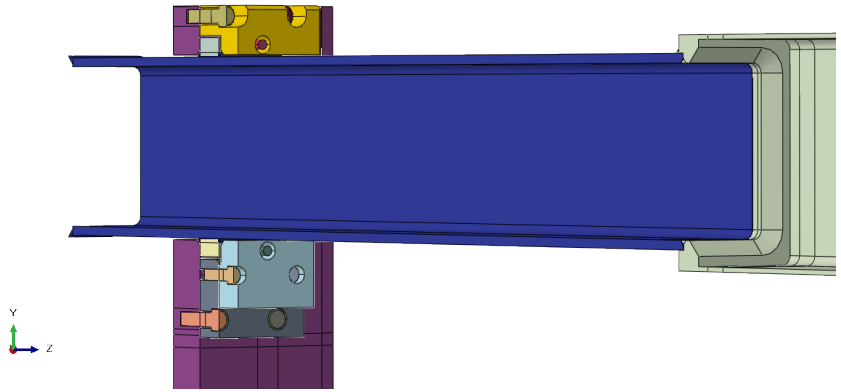


Half symmetry model of upper port

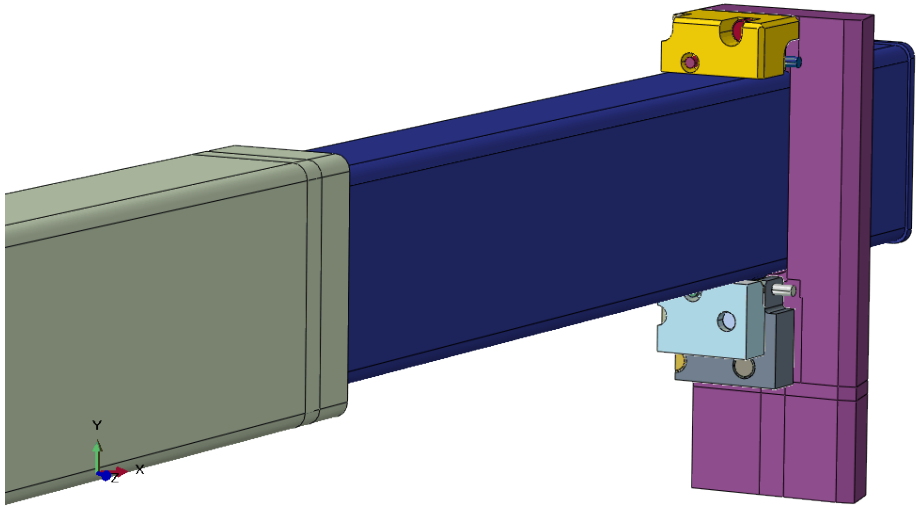


Upper Nozzle Assembly with Brackets

Half Symmetry model

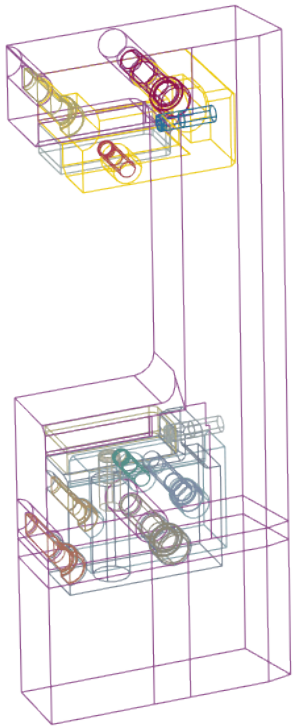


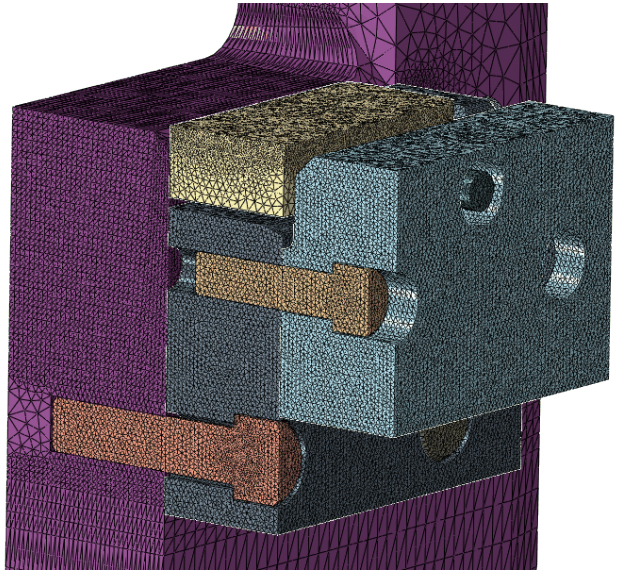
Side view

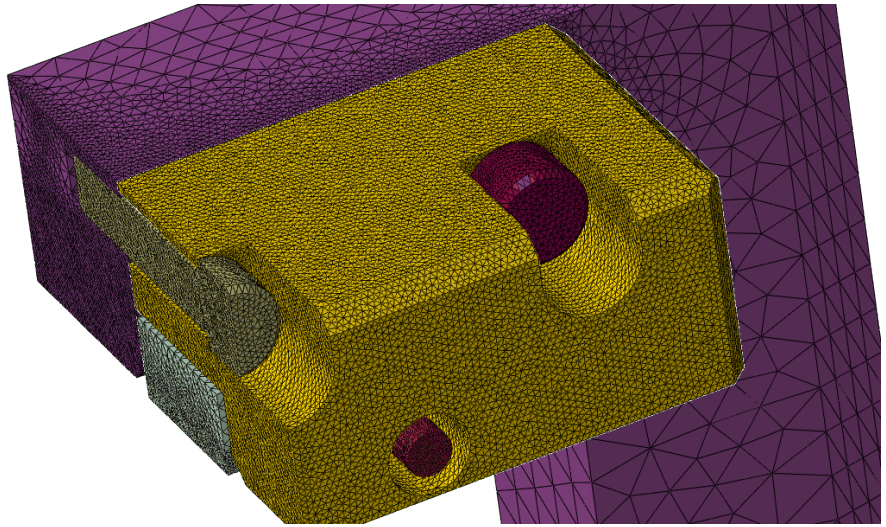


Lower Bracket simplified compared to lower assembly and bolts horizontally into core vessel instead of on bottom otherwise similar constraints and contacts

Upper Nozzle Assembly brackets and mesh examples

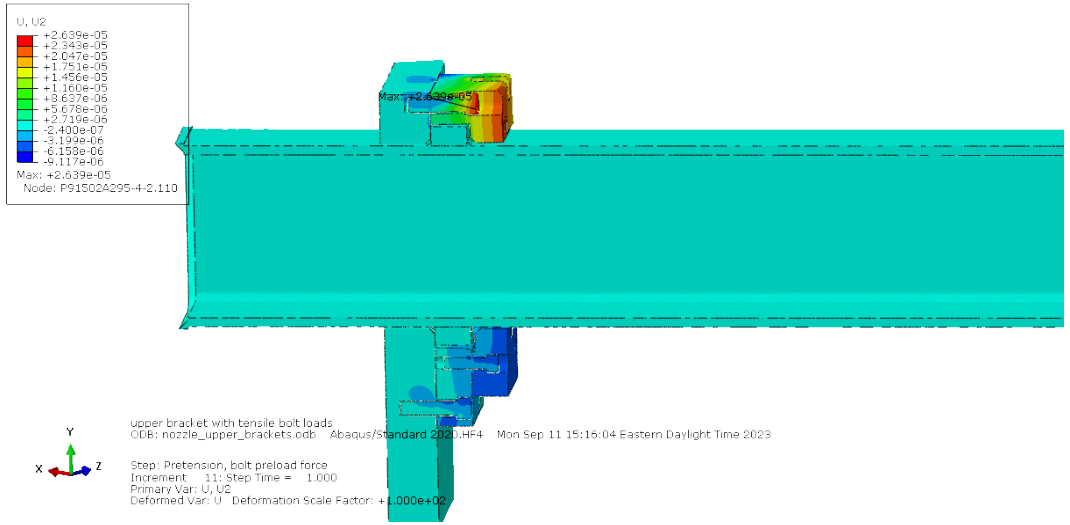




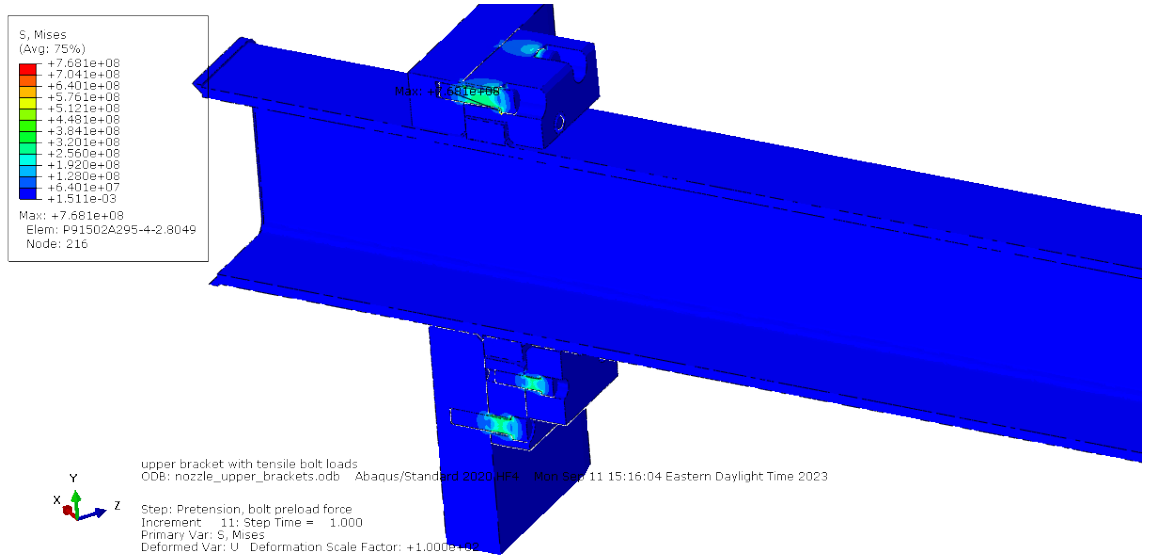


Upper nozzle Prestress step

Vertical Displacement



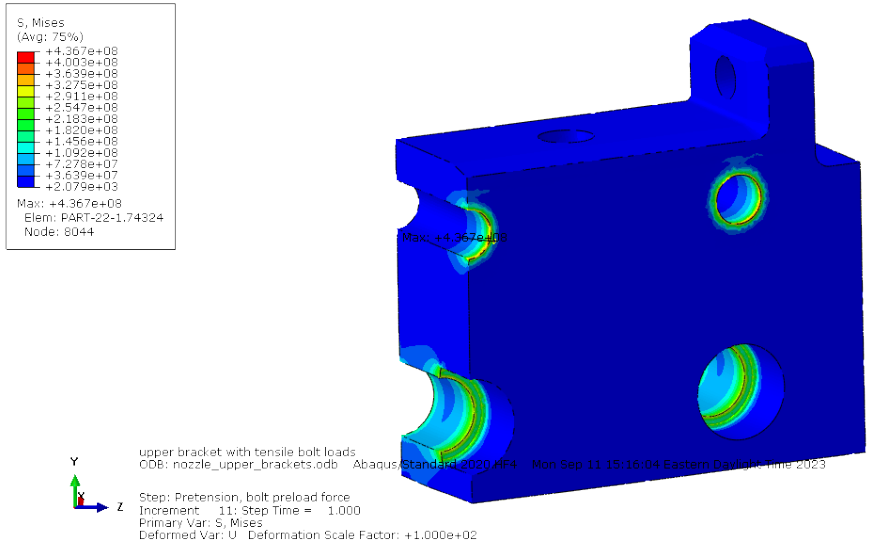
S Mises



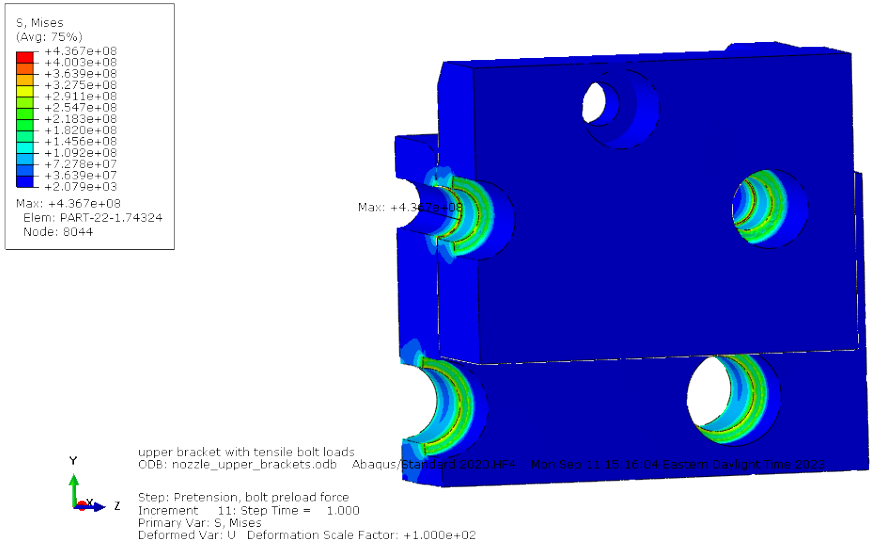
Bolt stresses similar to Lower Nozzle results

Upper nozzle, lower bracket parts pretension S

Lower bracket inner part S

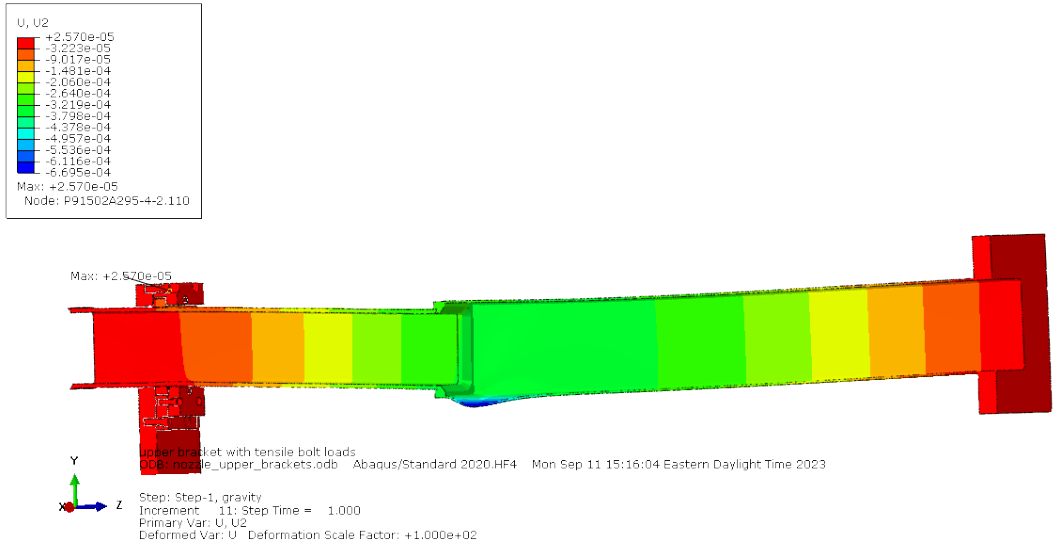


Lower bracket inner and outer parts S Mises

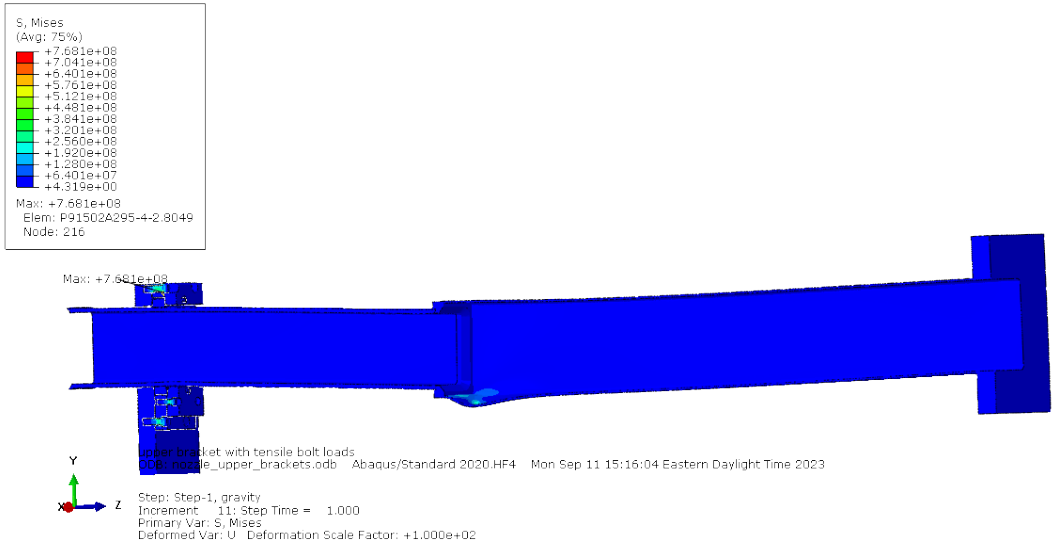


Upper Nozzle Step 1

Vertical Displacement

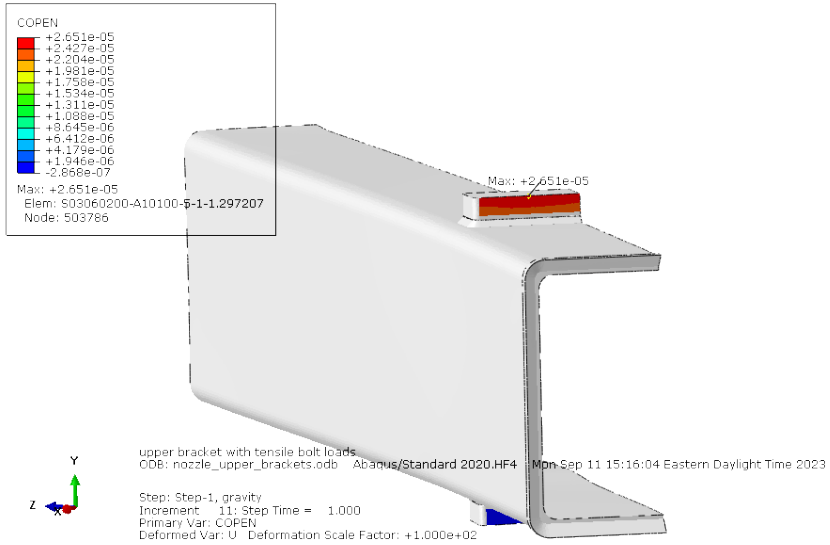


S Mises

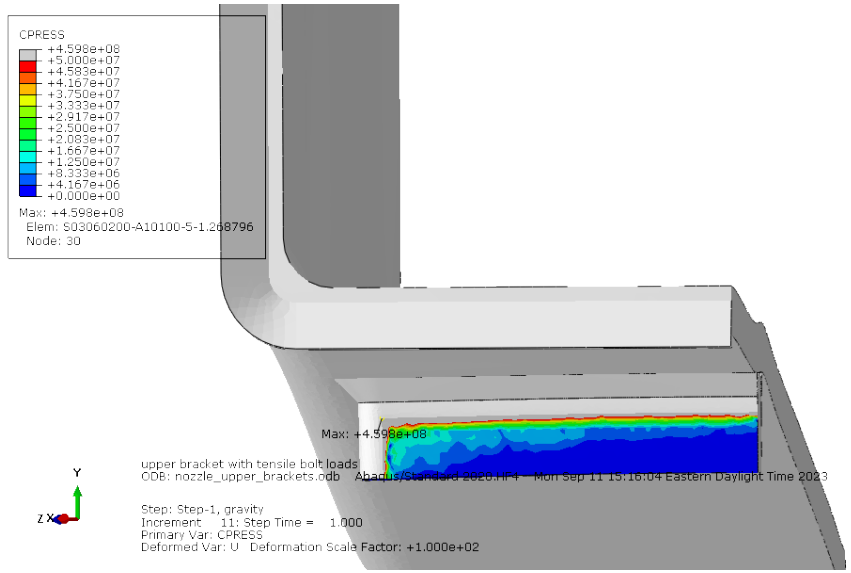


Upper nozzle STEP1 support block contact conditions

COPEN



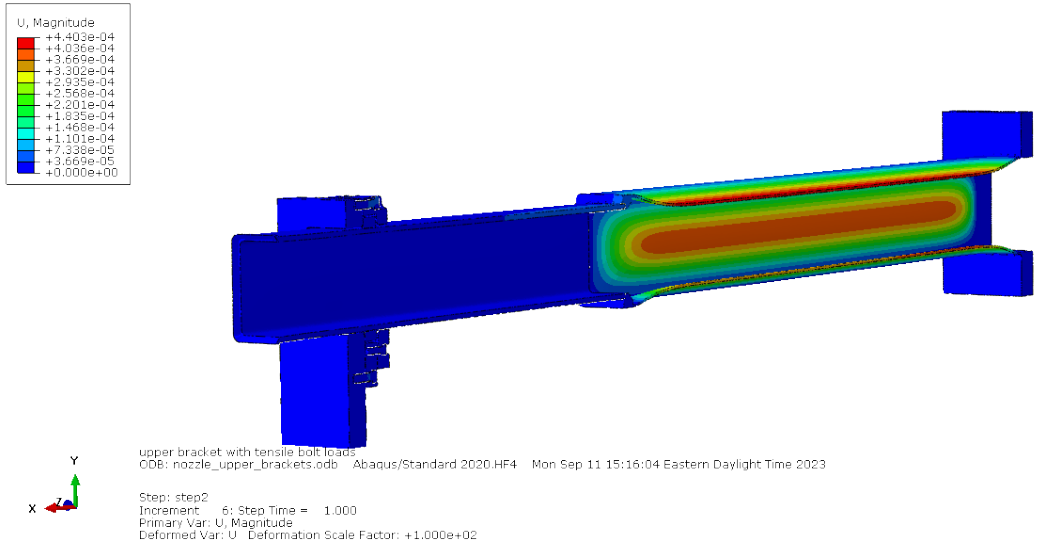
CPRESS



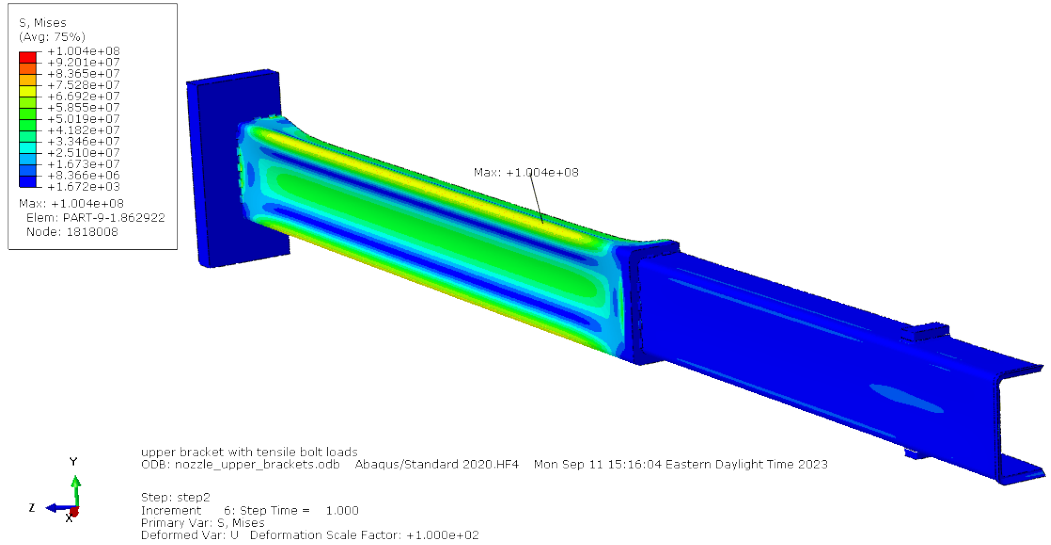
Similar to lower nozzle assembly - the upper blocks pulls away from core vessel and the lower block has pressure distribution with core vessel

Step 2 – normal operation

Displacement

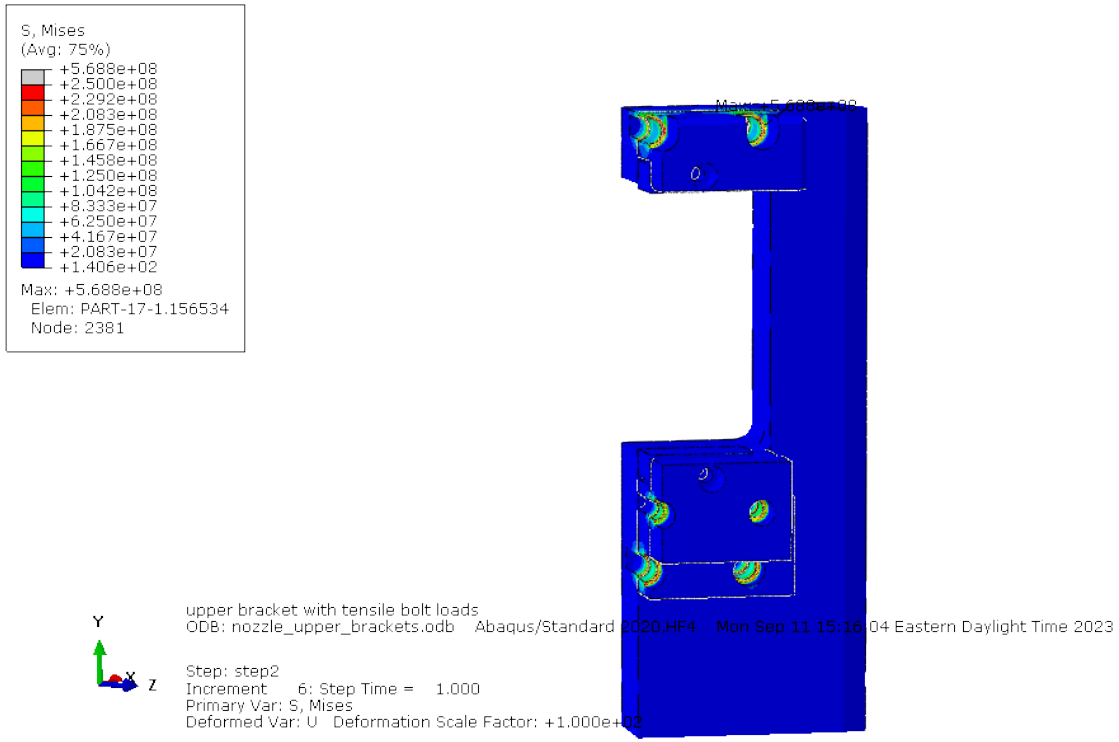


Nozzle parts S Mises

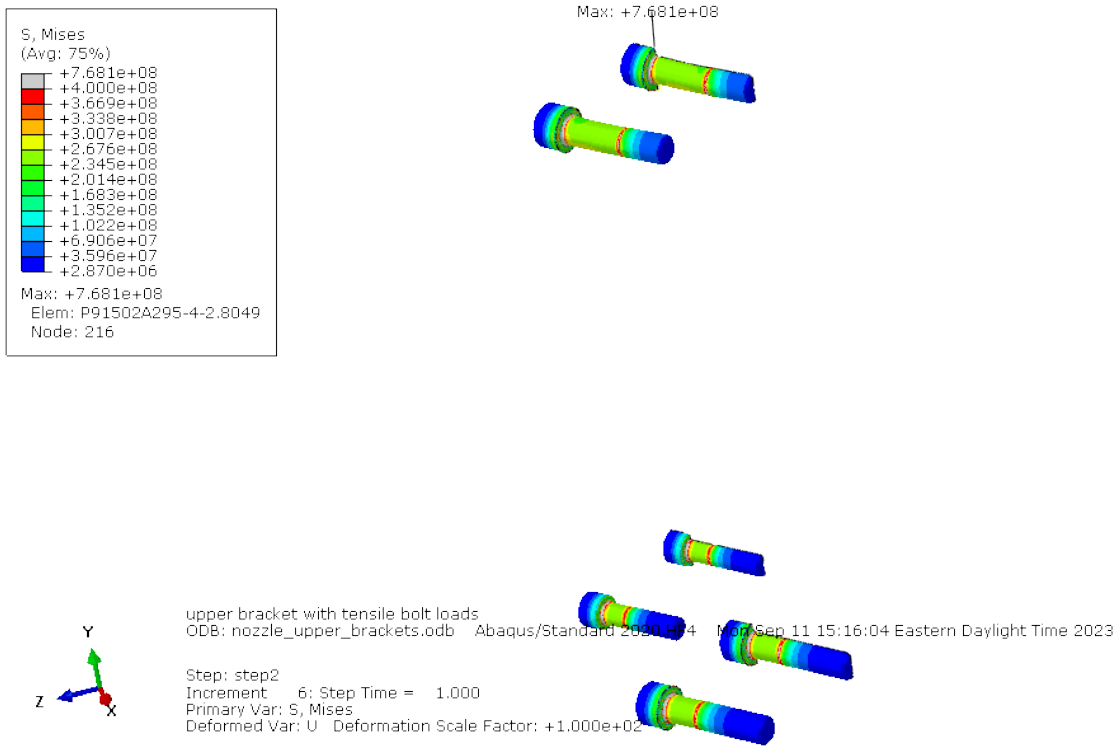


Step 2 Stresses

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