Oak Ridge National Laboratory

CV QIKR NOZZLE Extension 925 Preliminary Analysis

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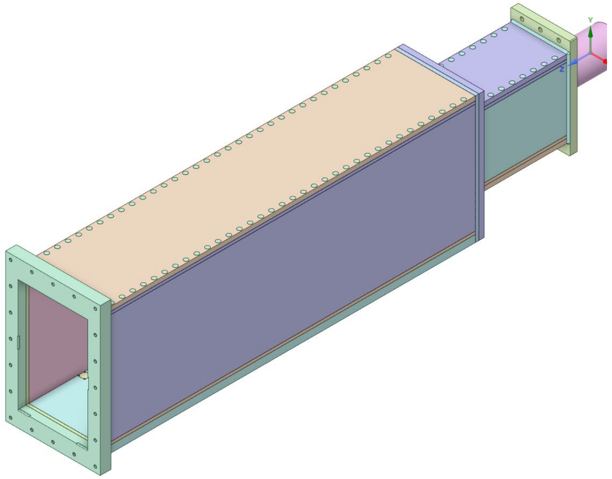
10/2/24

QIKR Nozzle with 10 mm seal welds

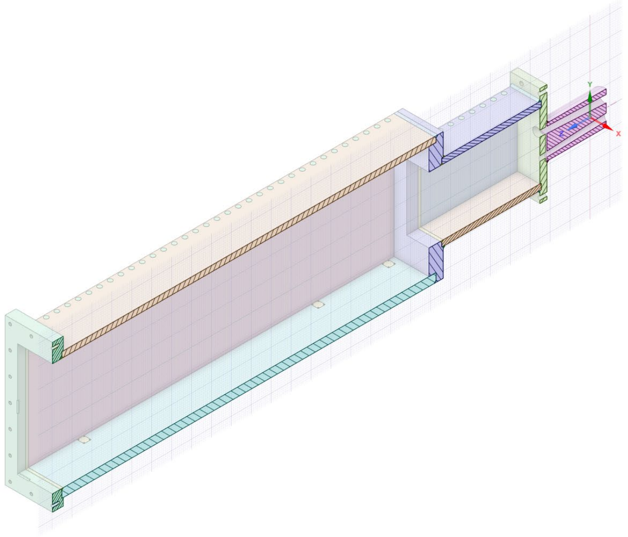
- The QIKR Nozzle model from 9/5/24 includes
  - 10 mm seal welds on the outer surfaces
  - Plate structures instead of forgings
  - Intermediate flange between front and wider rear sections
  - 12 mm bolts on 75 mm centers for side plates
  - 4 25 mm diameter bolts to attach to beltline
- Abaqus model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

SpaceClaim model from 9/5/24

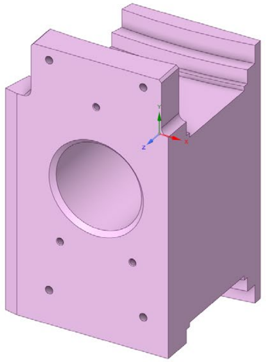
QIKR Nozzle Assembly



Section View

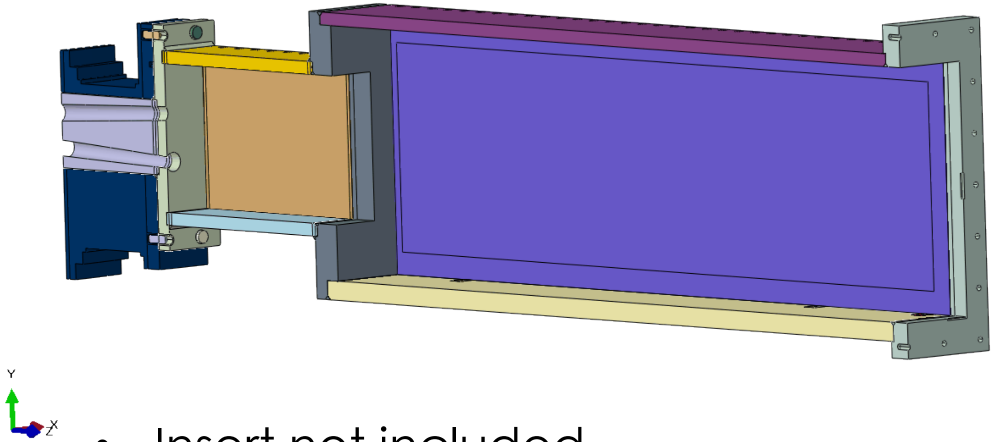


Beltline section



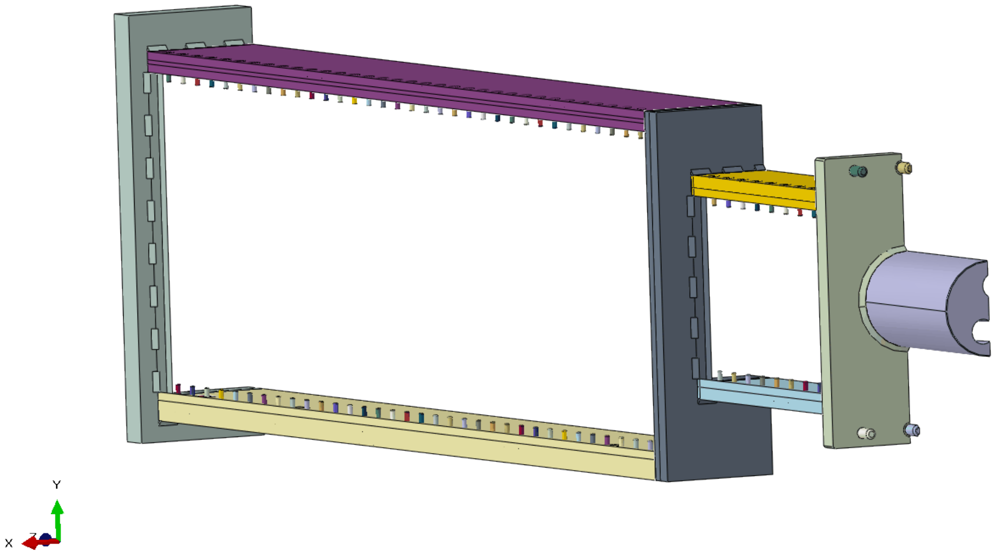
Abaqus model with all welds merged

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

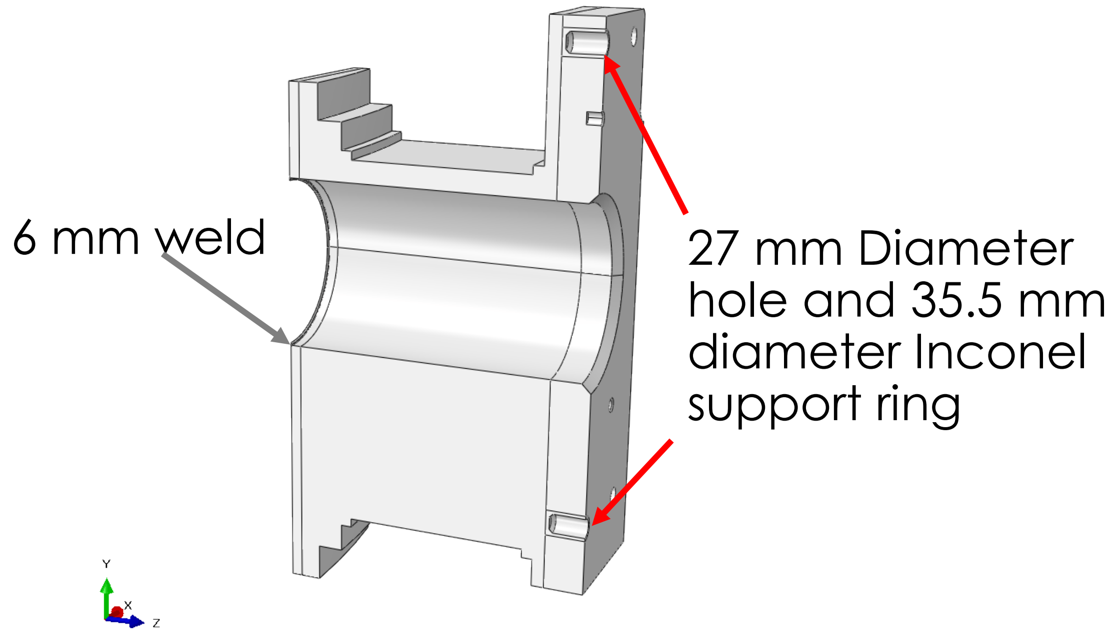
Side Plates removed to show bolting and merged welds



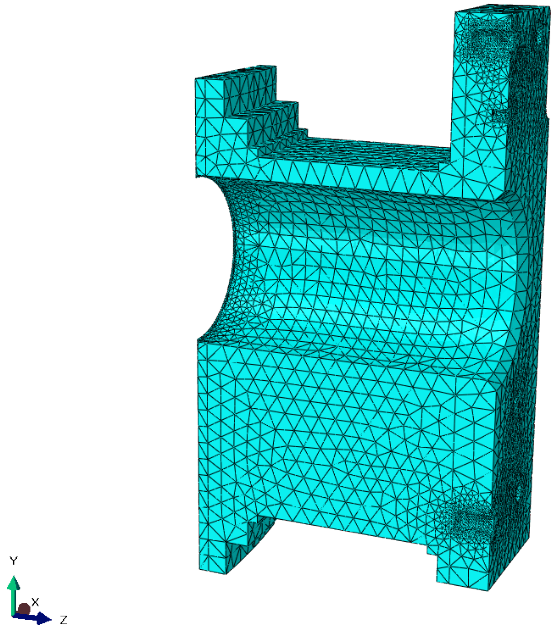
Fillet and skip welds merged with flanges and Groove welds merged with top and bottom plates in front and rear sections

Beltline Part

Beltline part

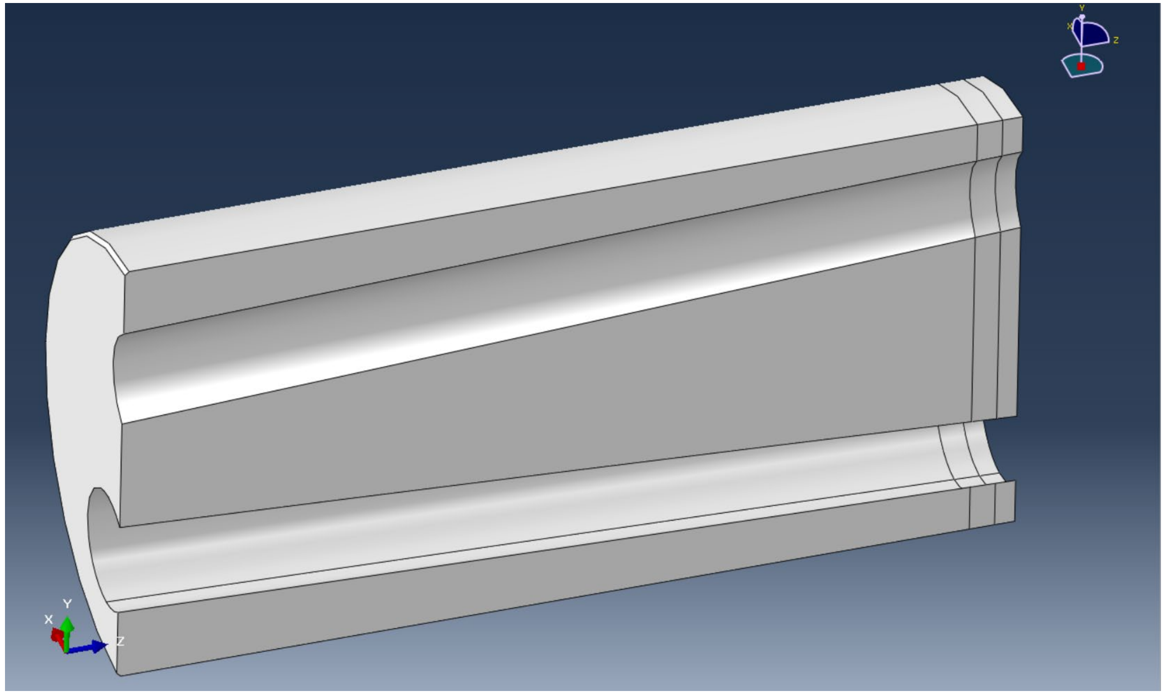


Beltline mesh with 89,403 C3D10 elements

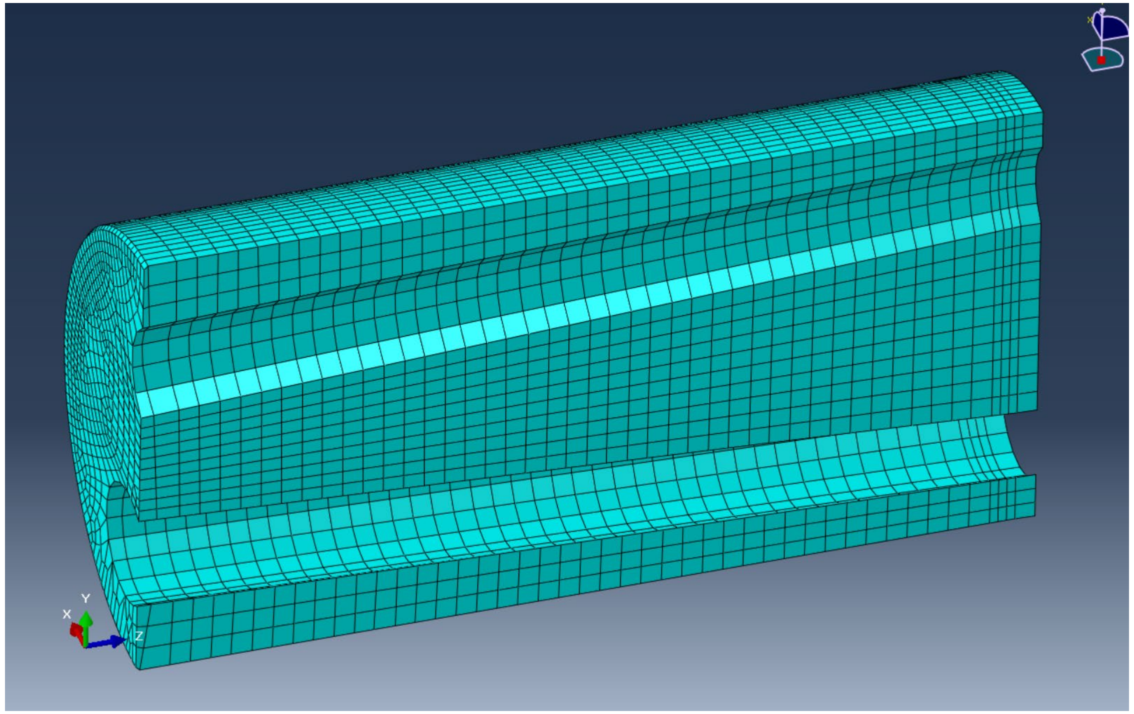


Front part

Front beam guide Part 1

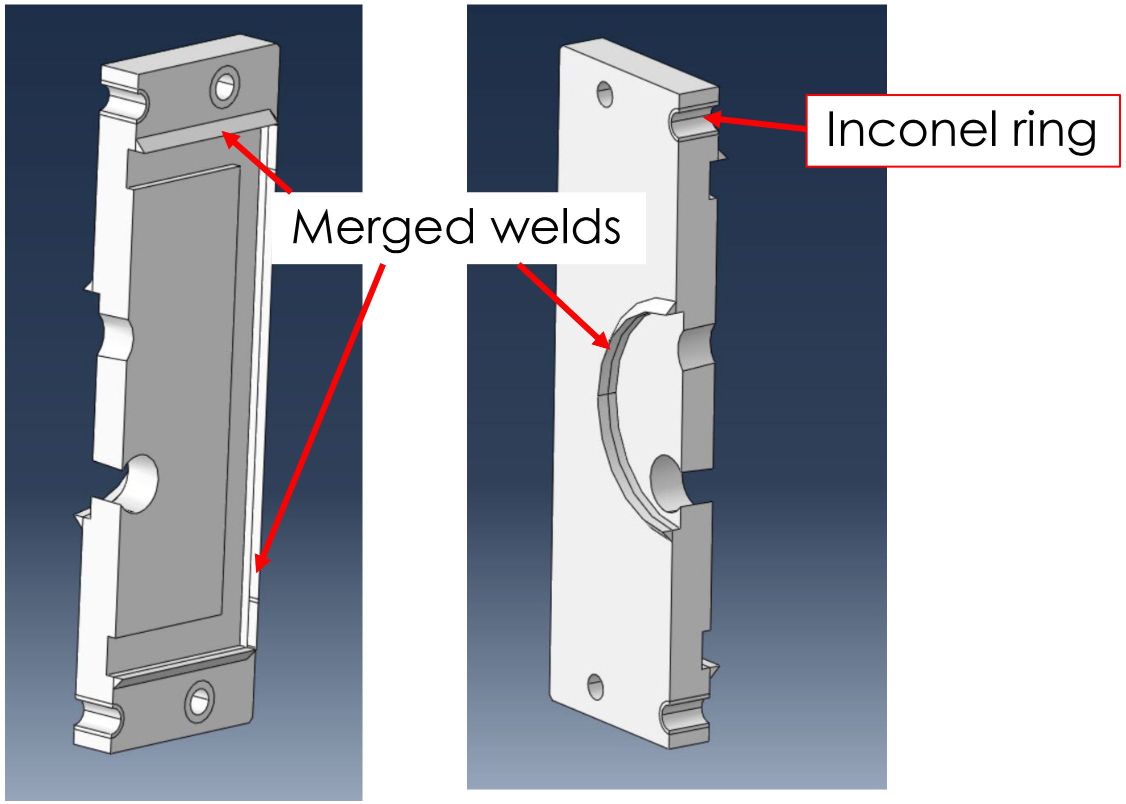


C3D8R Mesh with 22494 elements

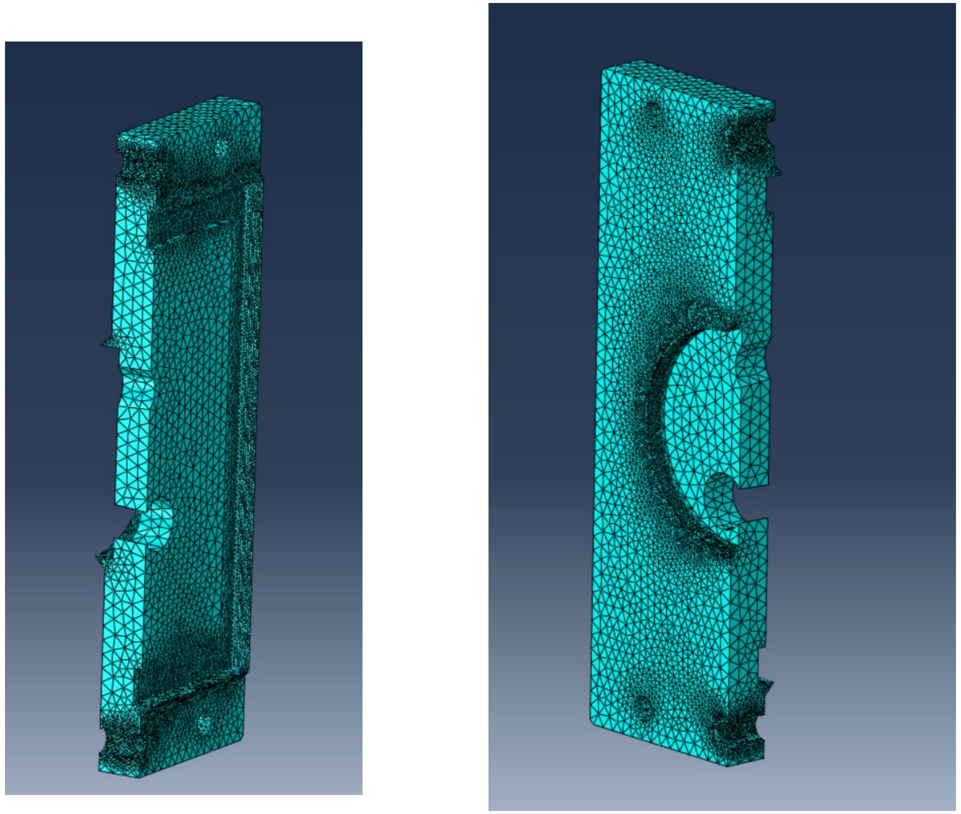


Front Flange

Front flange (R2W)



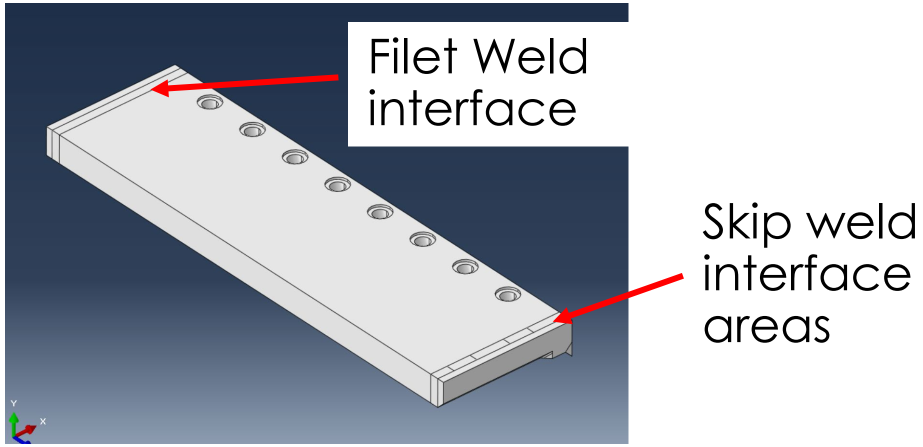
Mesh with C3D10 elements

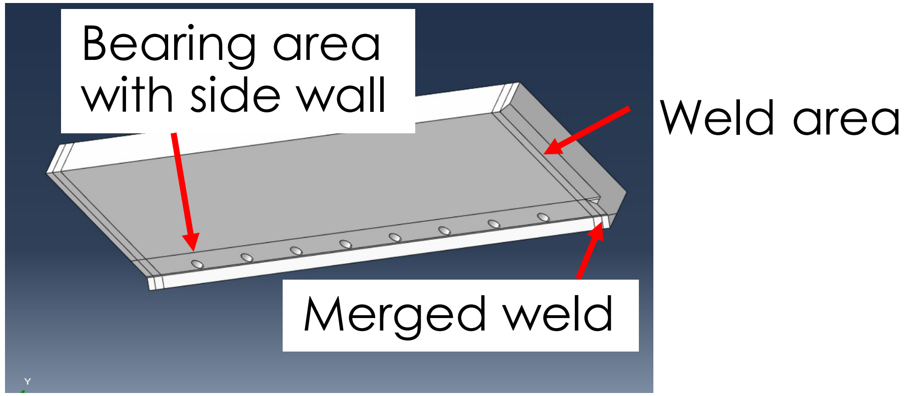


Front Section top plate

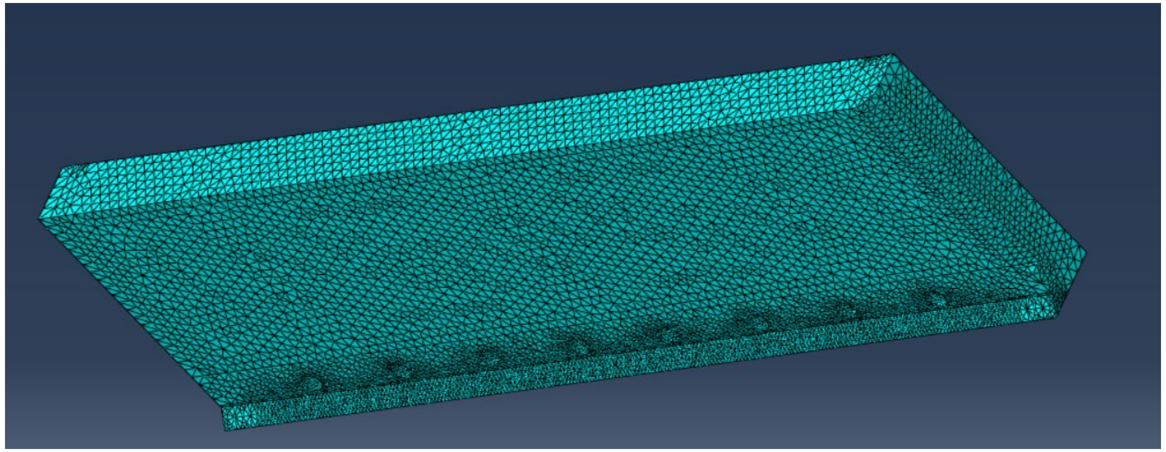
Bottom plate has similar geometry with merged weld material

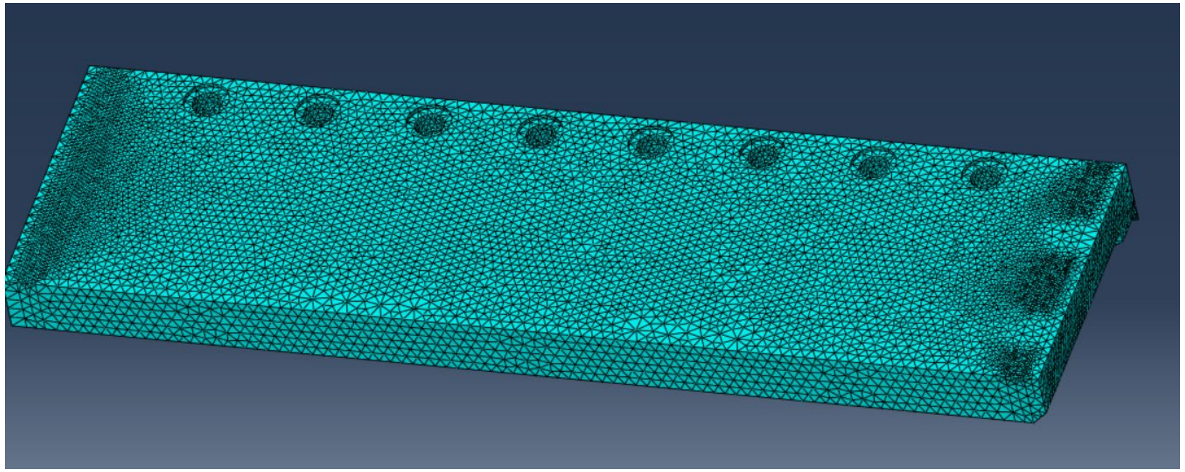
Top front plate (R3W) – bottom (R4W) similar





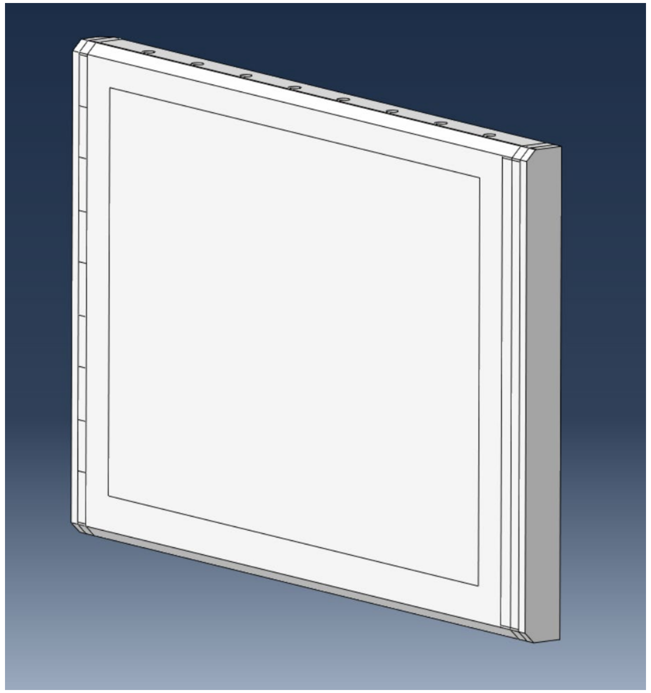
Mesh model with C3D10 elements

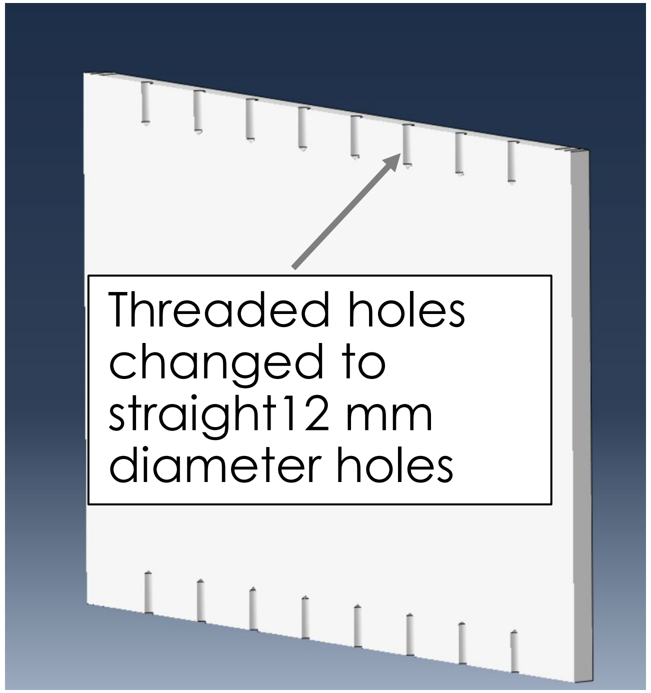




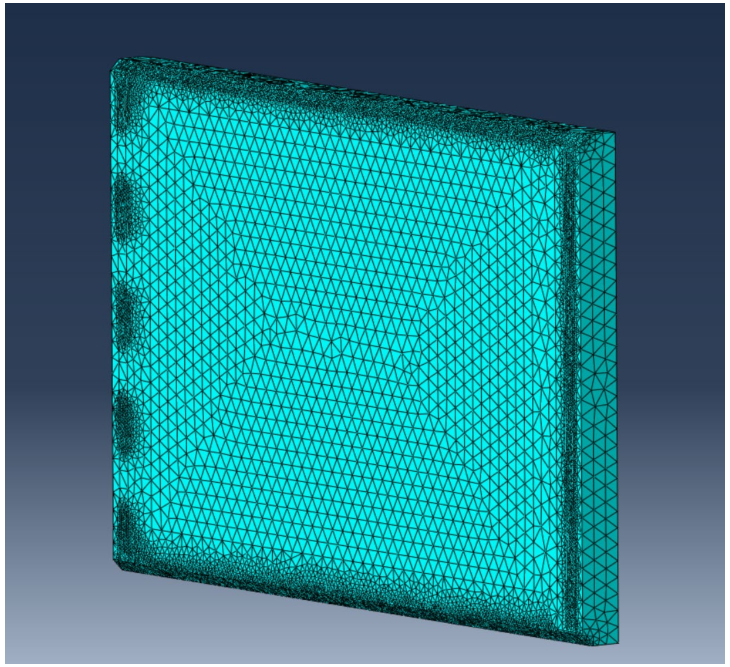
Front side Wall (R5)

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



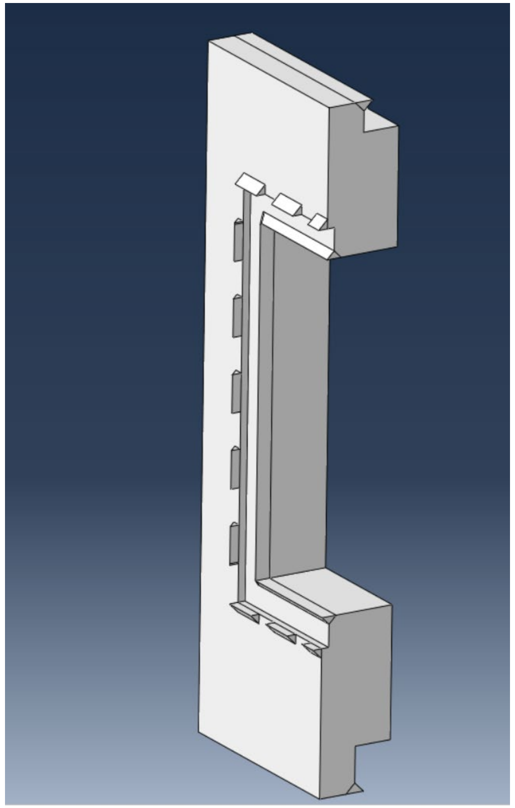


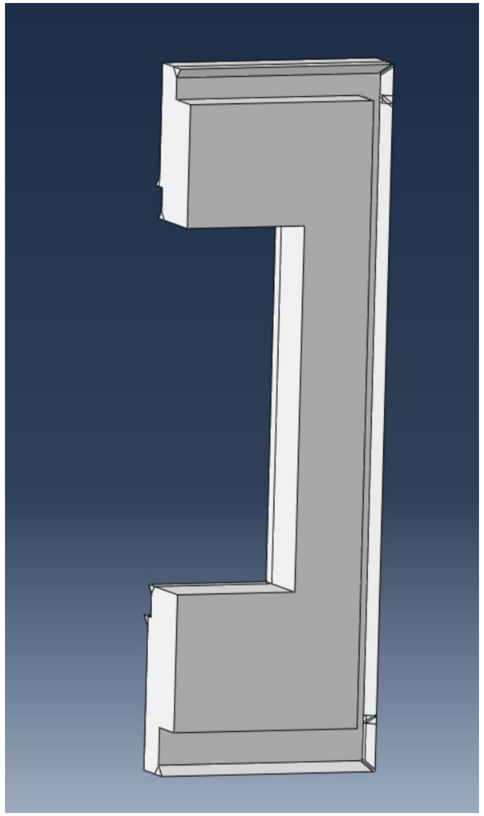
C3D10 elements with Finer mesh around weld areas



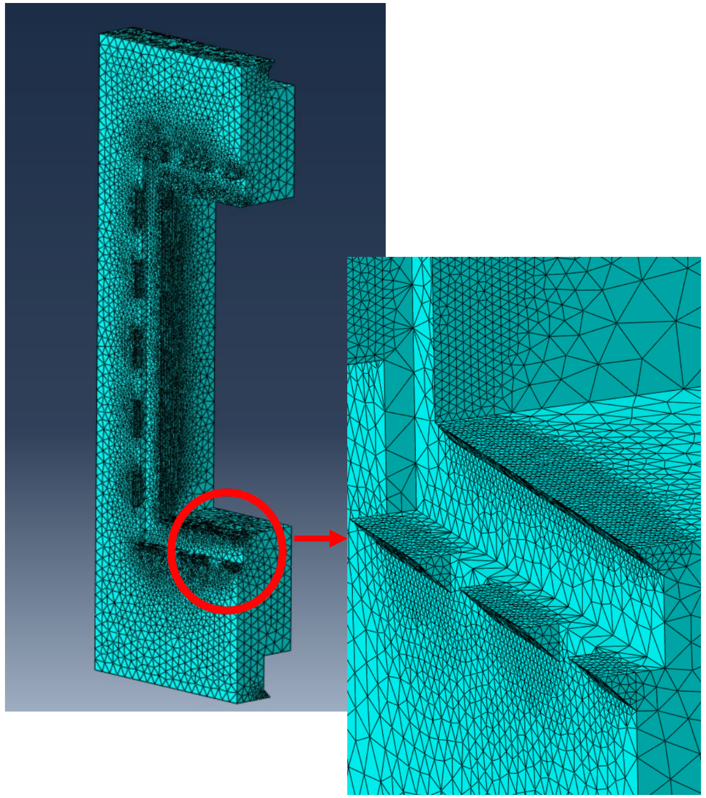
Intermediate Flange

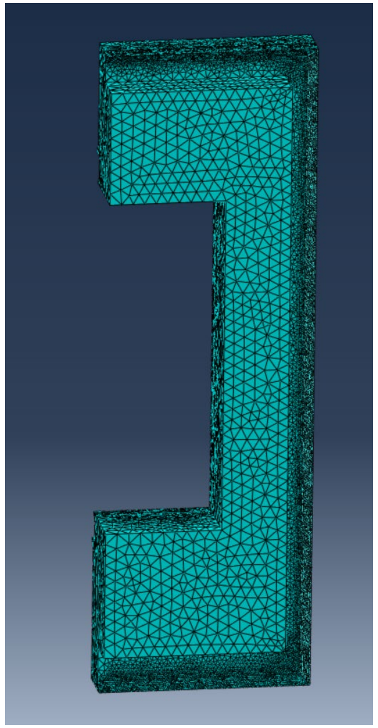
Flange (R7W) with merged fillet and skip welds





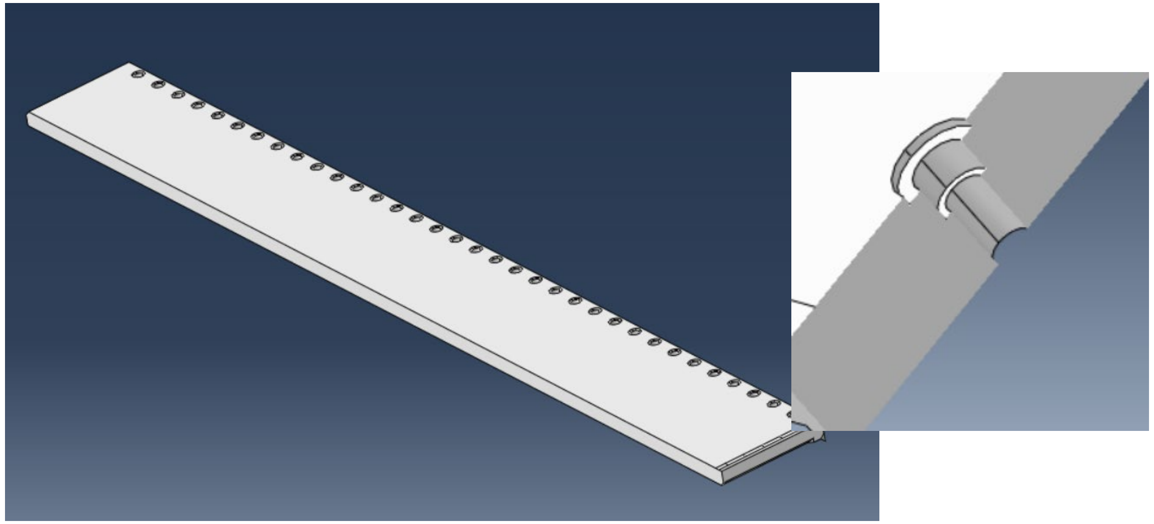
C3D10 Mesh model

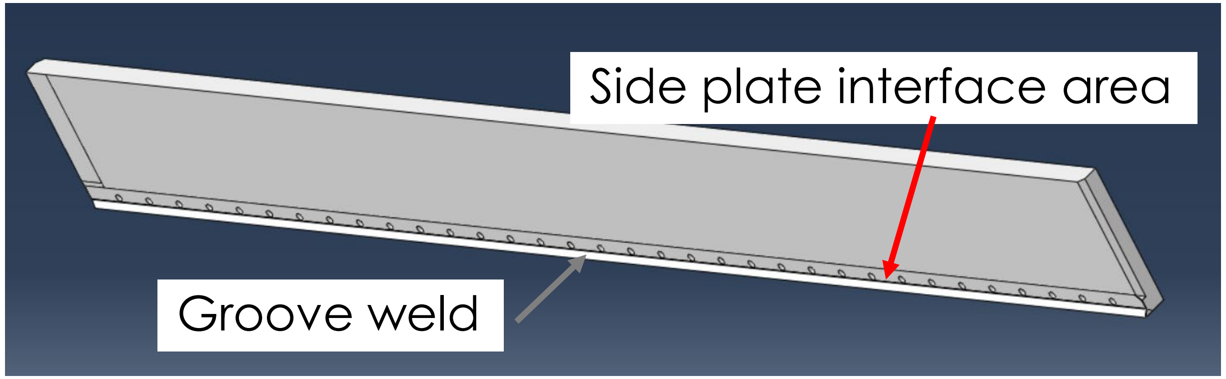




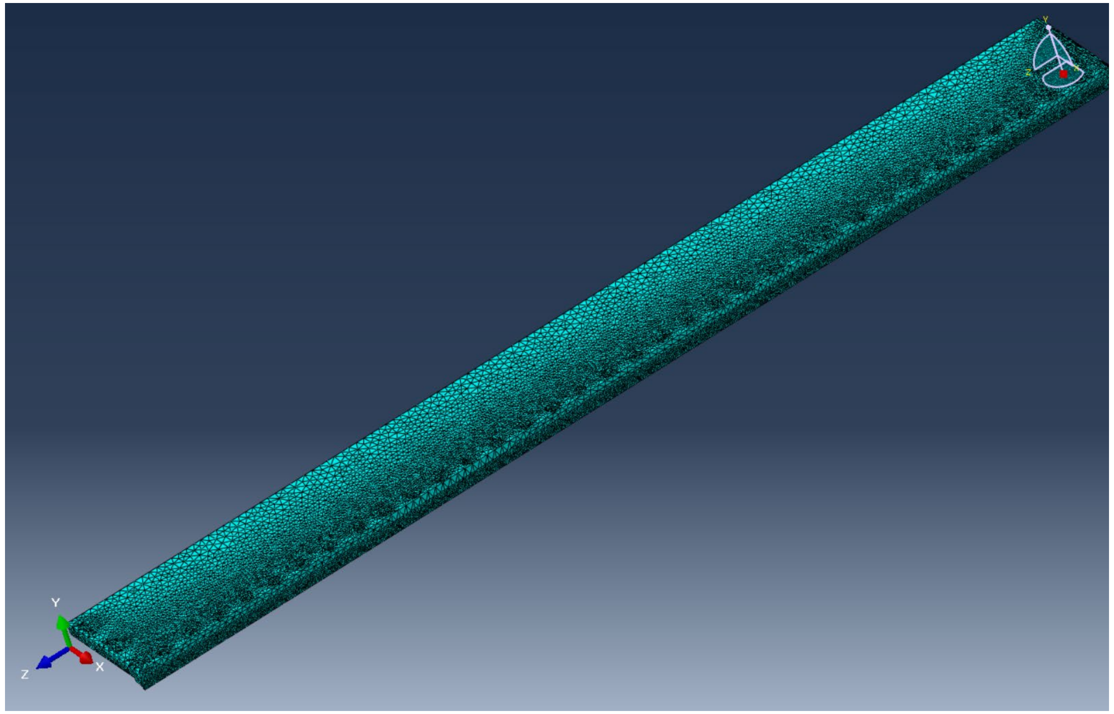
Top rear plate (R8W) with merged groove weld

Top plate



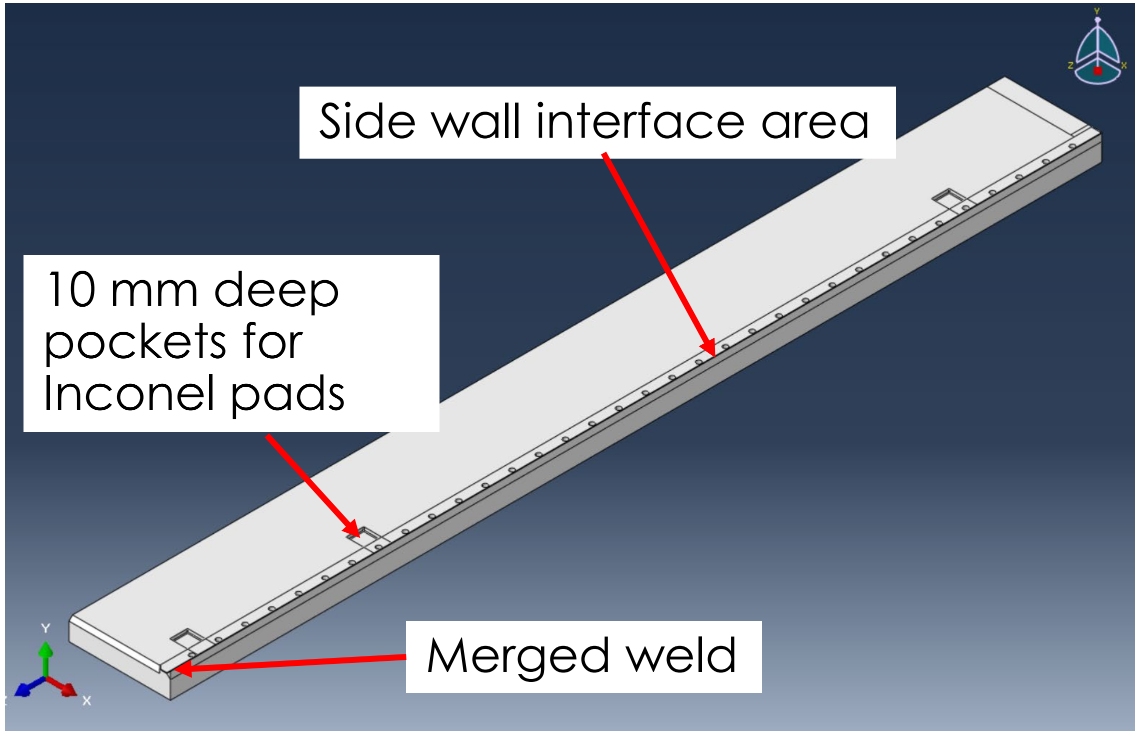


C3D10 Mesh model

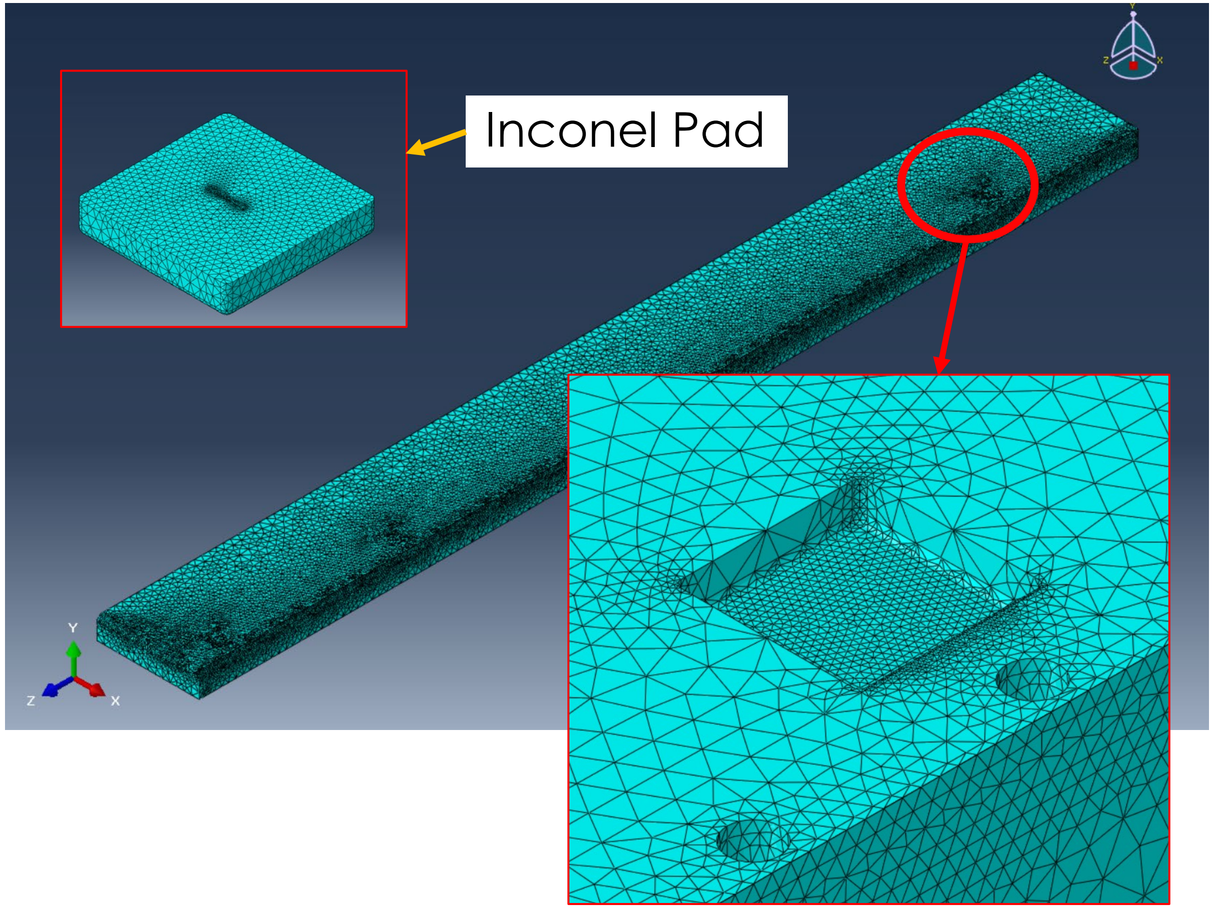


Rear Bottom plate

60 mm thick bottom plate (R9W)

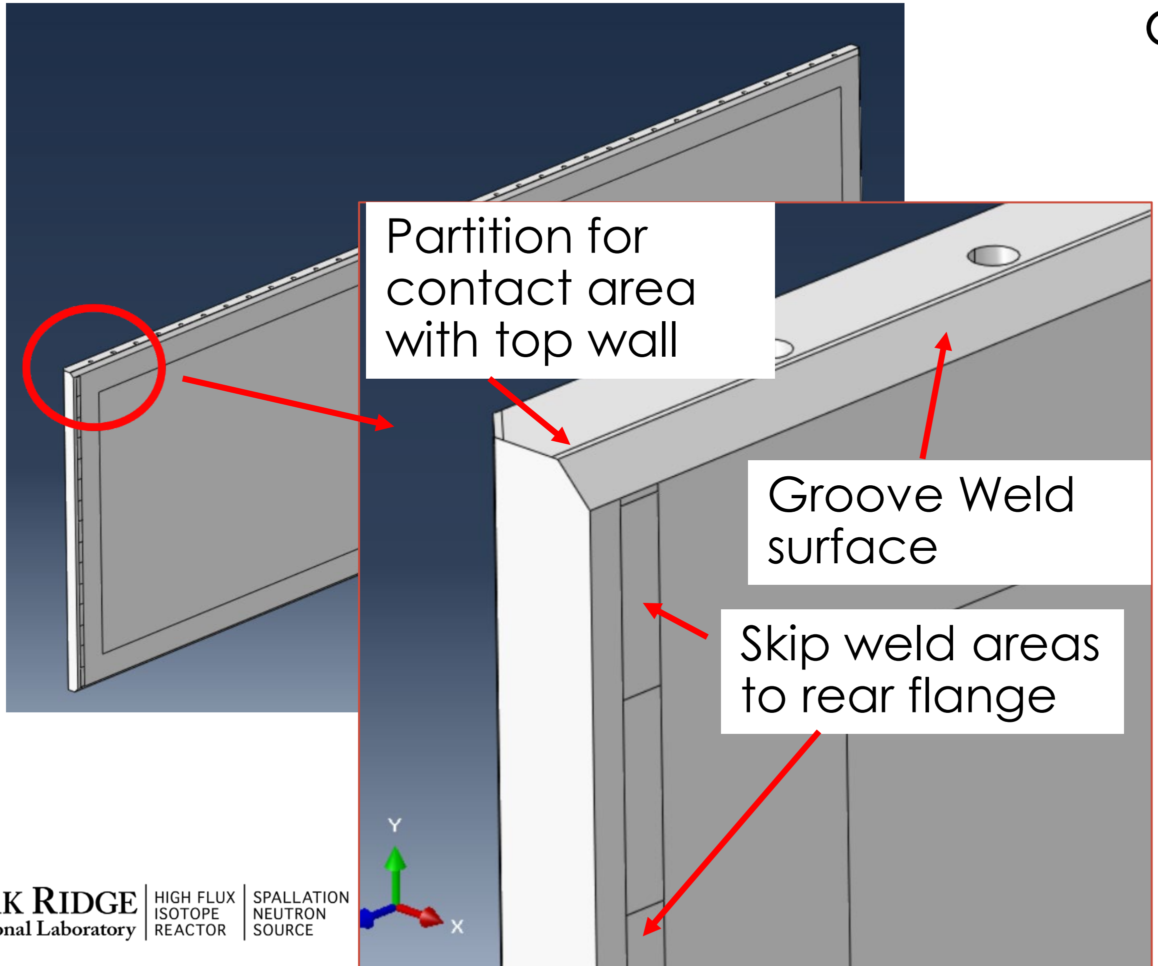


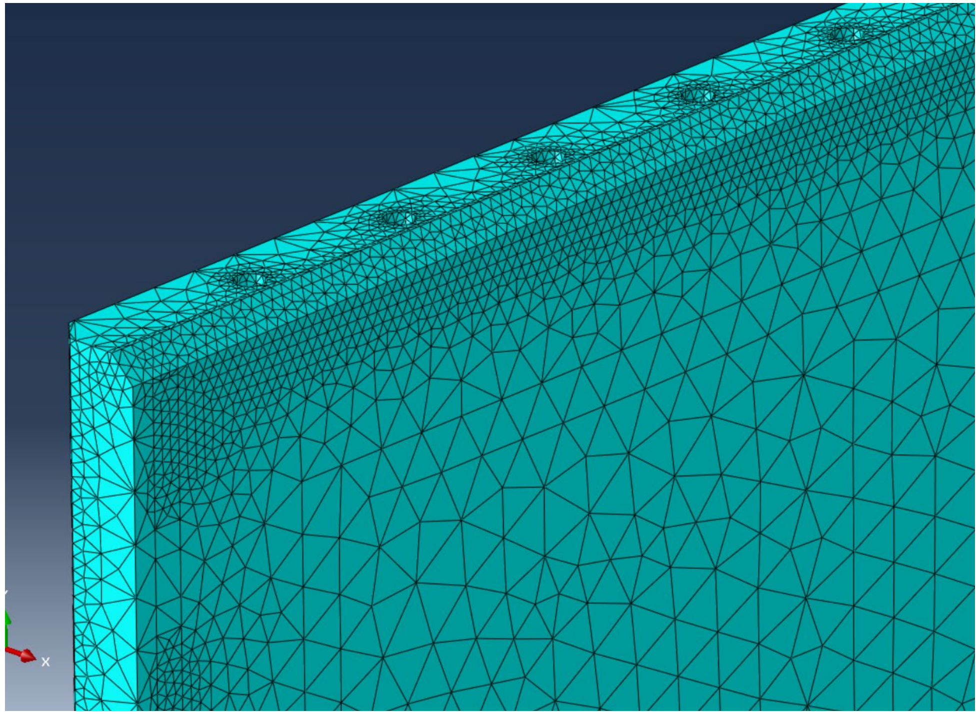
C3D10 Mesh



Rear Side Walls

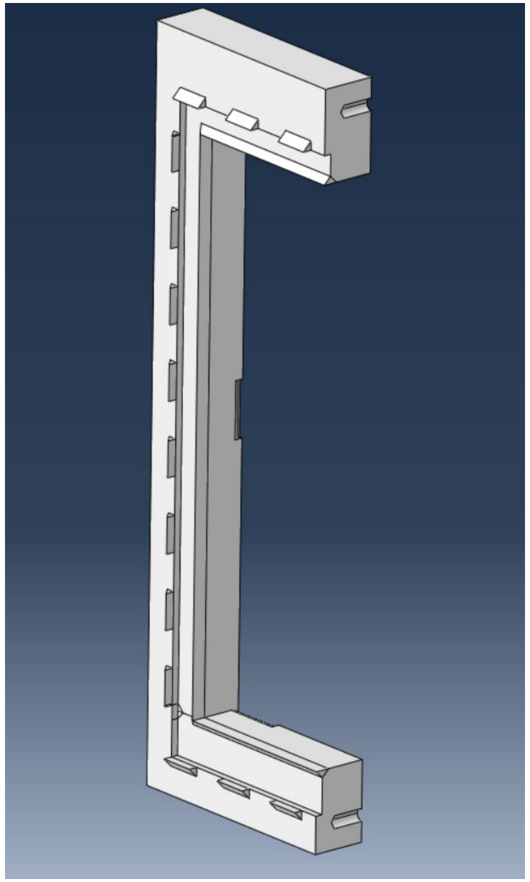
Representative C3D10 mesh with nominal 5 mm element size in weld and 20 mm in plate middle

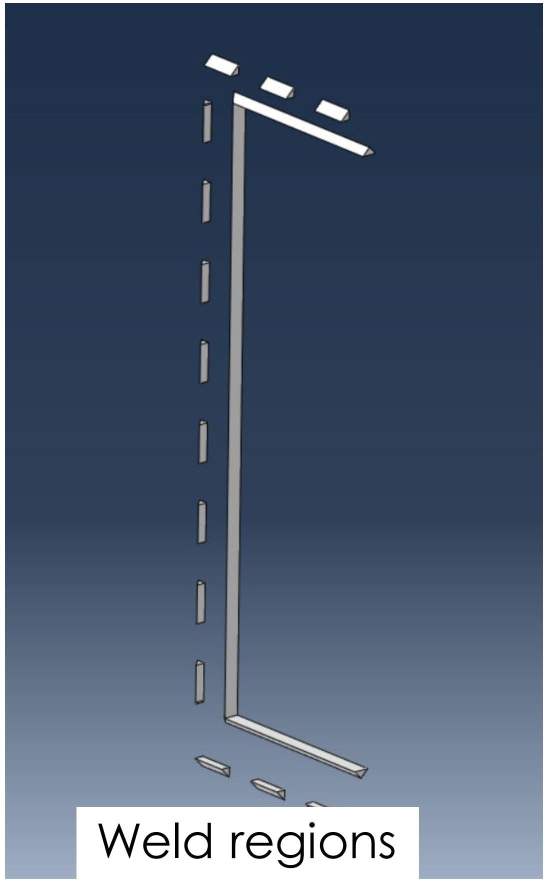




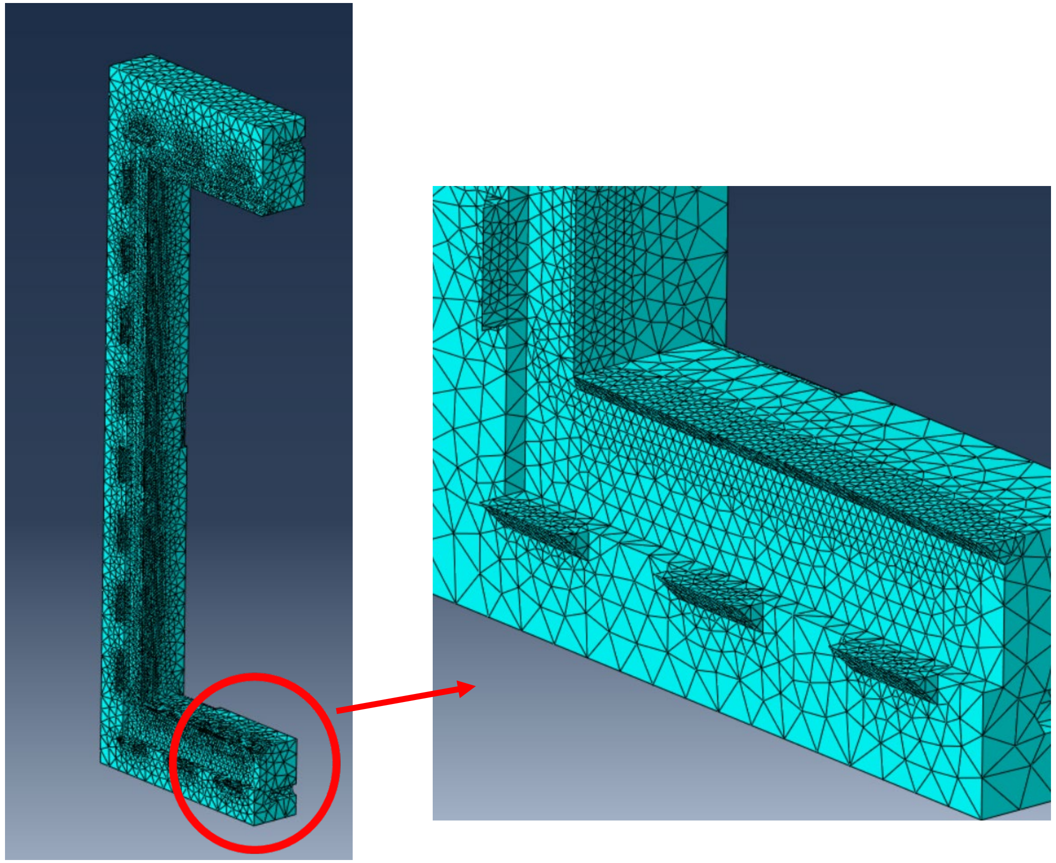
Rear Flange

Rear flange (R12W) with merged welds



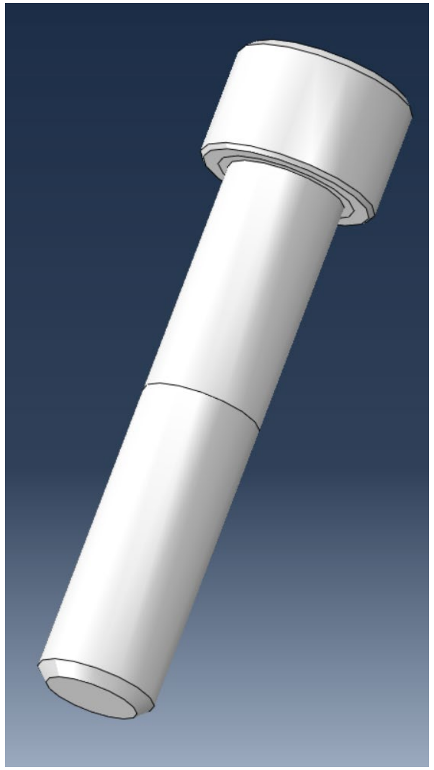


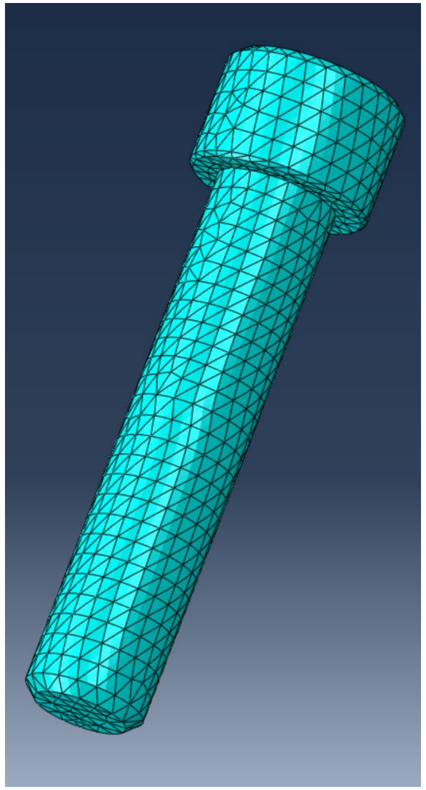
C3D10 mesh model



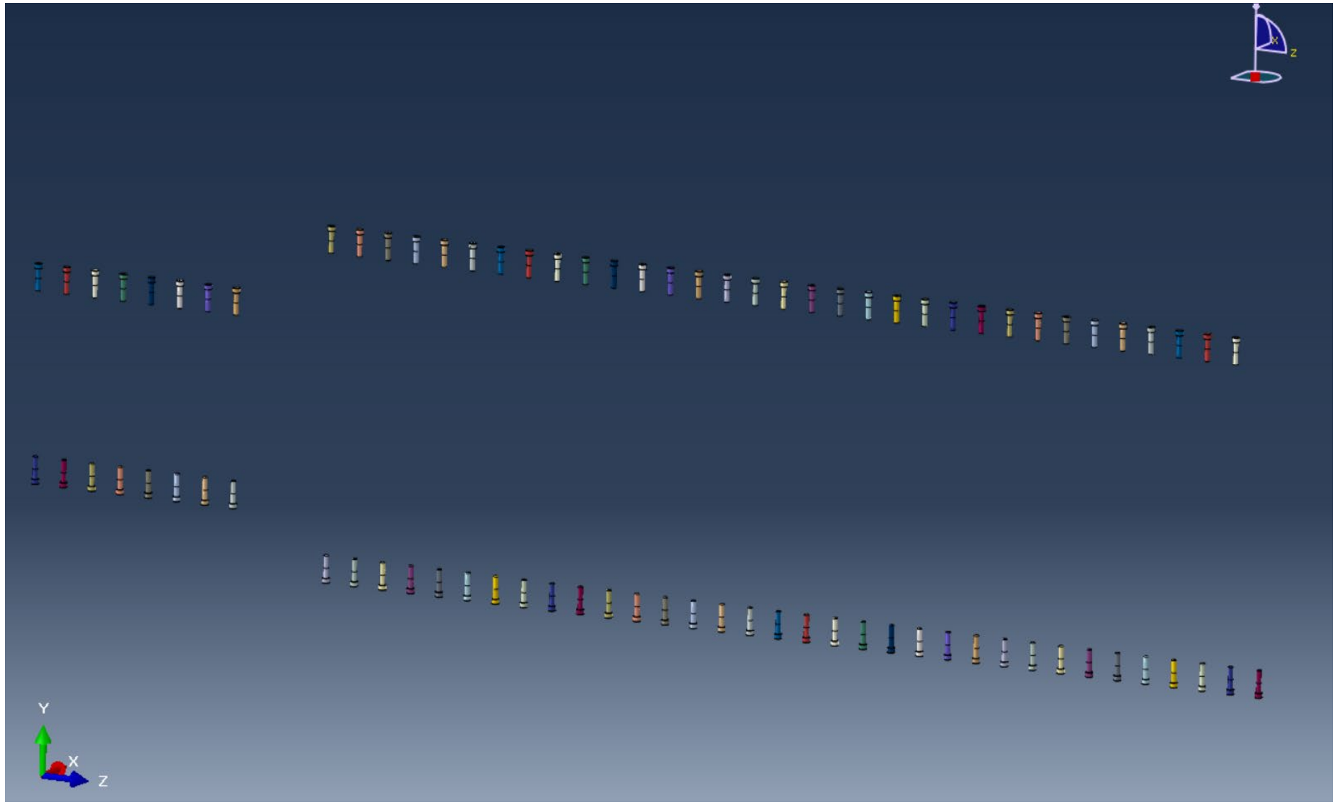
Bolts

12 mm diameter bolt



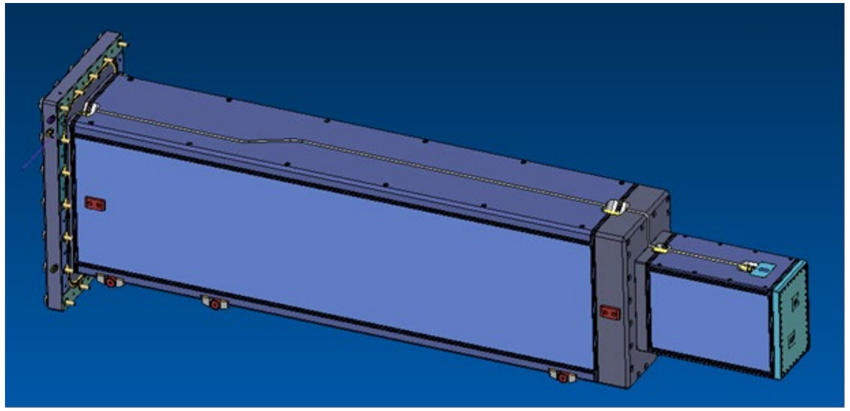


Array of 84 bolts in model

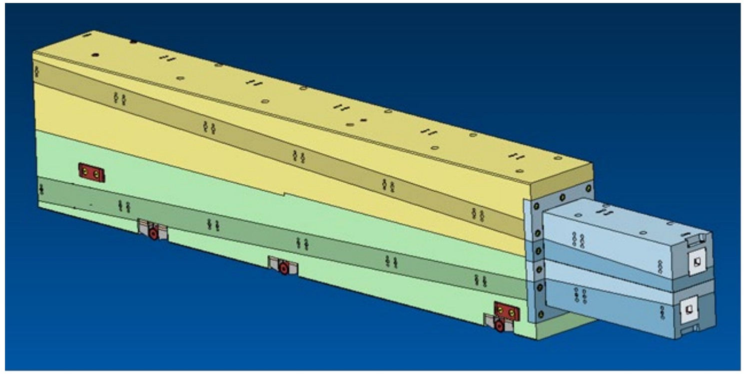


Inserts for QIKR Nozzle

7541lbs (3420.6kg)

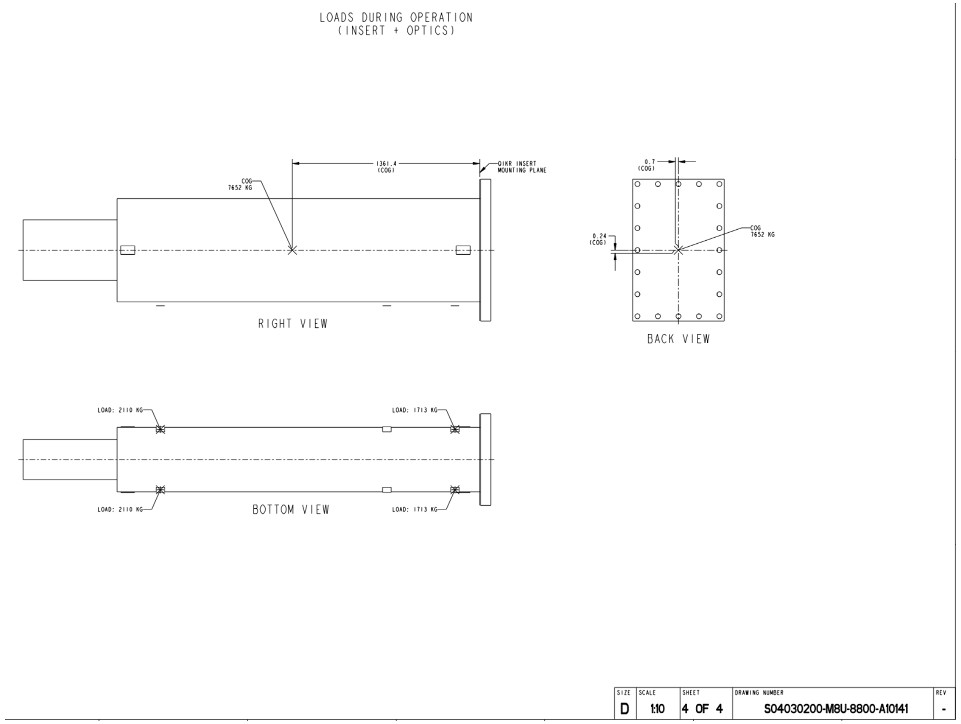


9228lbs (4185.6kg)



Wheel loads from Interface dwg

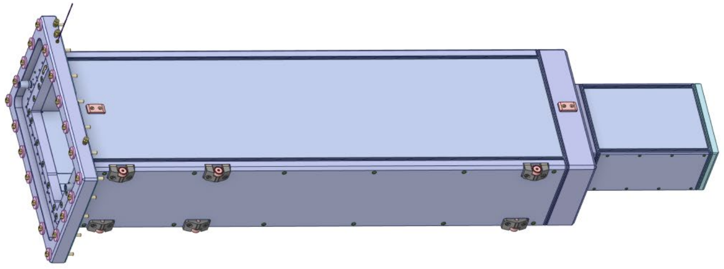
- 2110 kg front wheels
- 1713 kg rear wheels

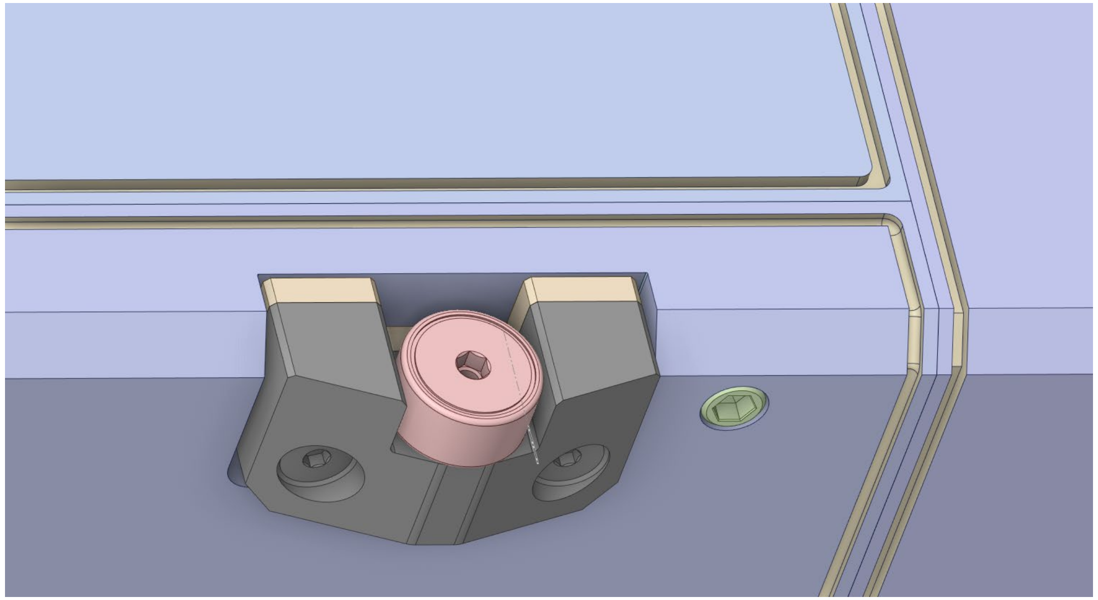


Wheel to plate contact analysis

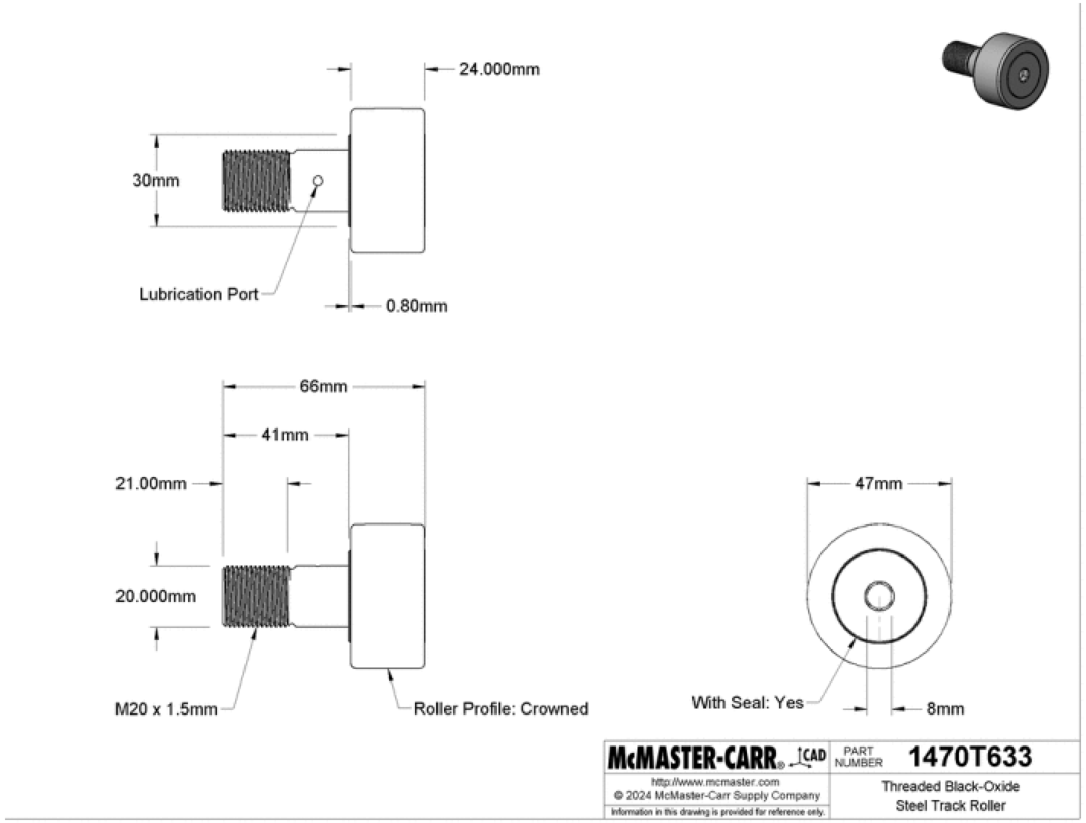
- An idealized analysis of the wheel to plate contact was made
- The intent was to find the contact stress distribution in the nozzle plate structure using a finer mesh than could be used for full assembly model
- The load on a front wheel from the mass of the insert and optics was 2110 Kg
- A quarter 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

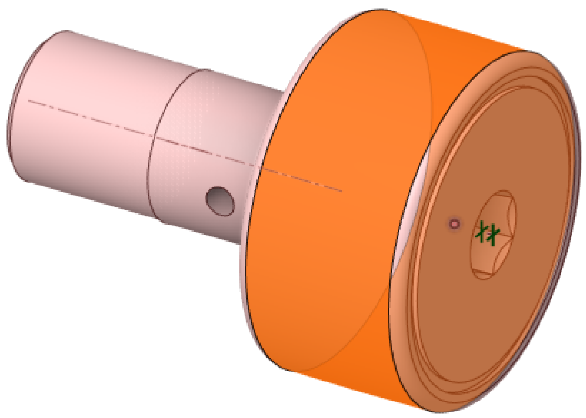
Insert SpaceClaim model





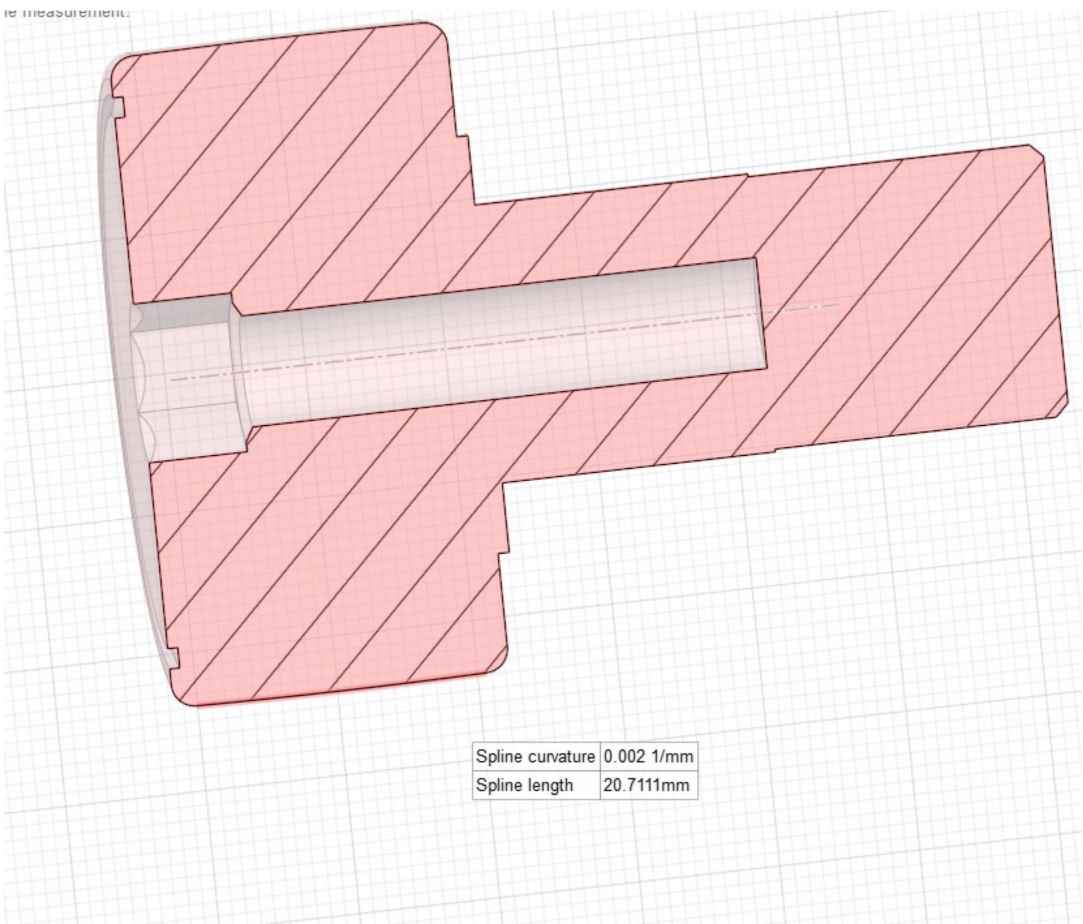
Wheel geometry with crown surface

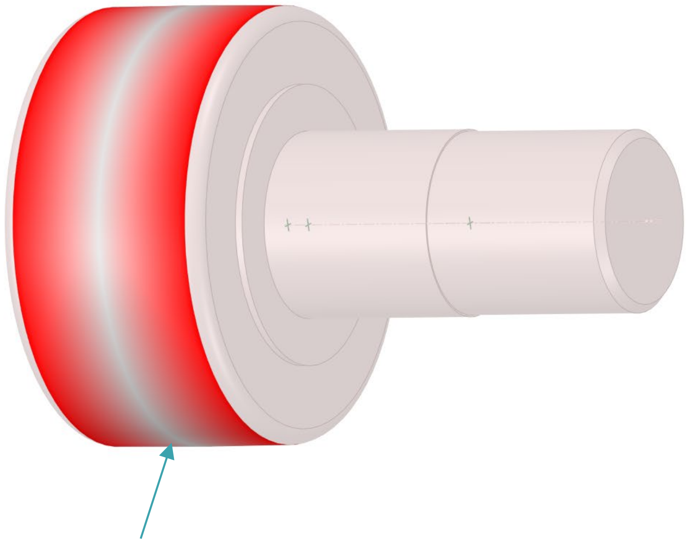




Major Diameter	0
Minor Diameter	1000mm
Fillet Radius	500mm
Area	3053.4385mm²
Perimeter	293.9622mm

Wheel cross section and curvature on contact face

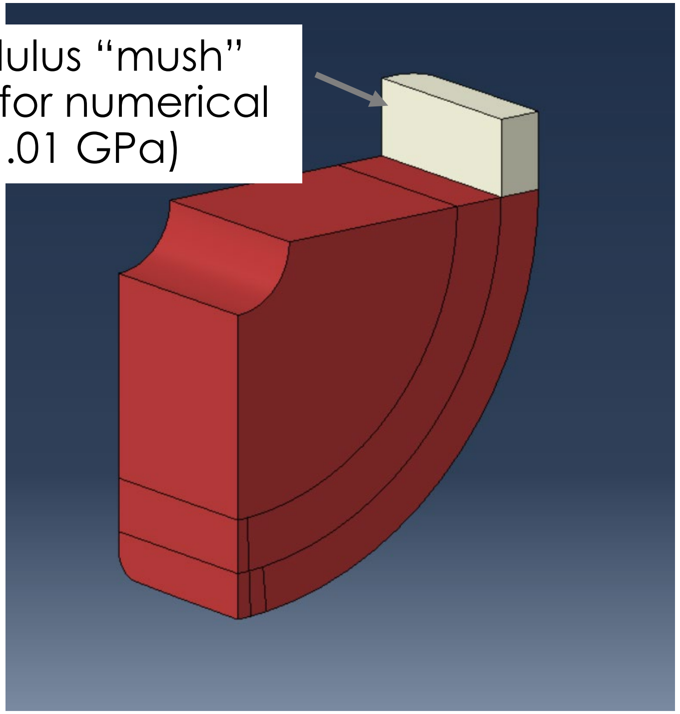




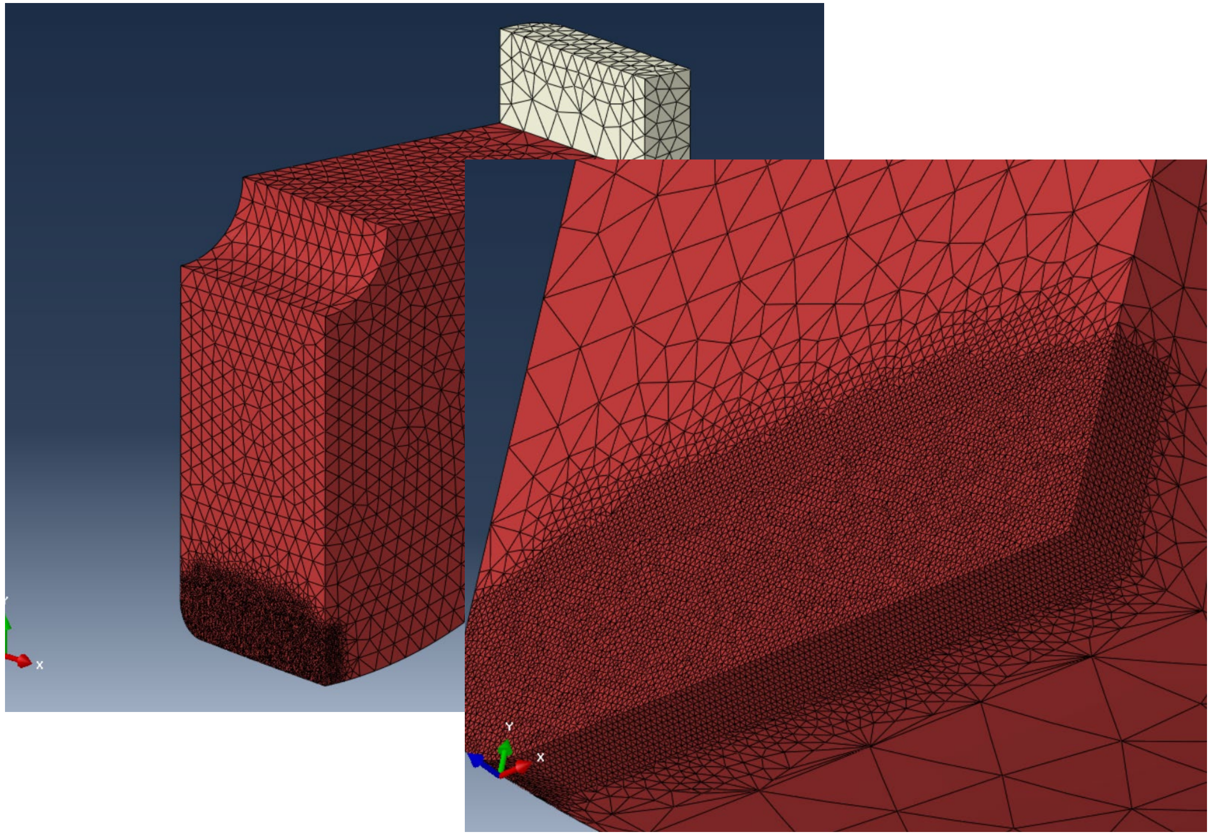
Crown radius = 500 mm

Wheel Abaqus model

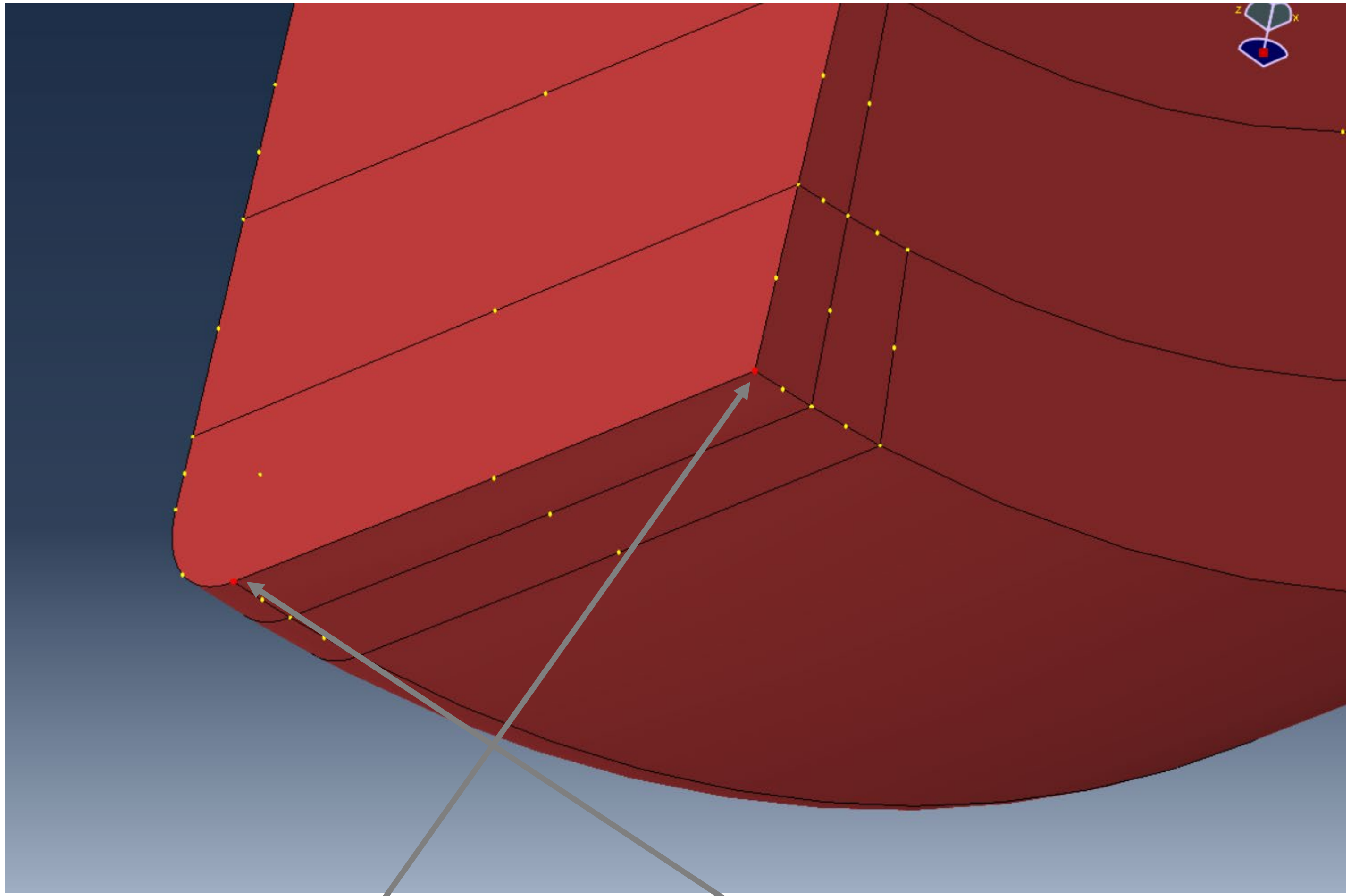
Idealized ¼ symmetry wheel model



C3D10 mesh with 0.1 mm size in contact area



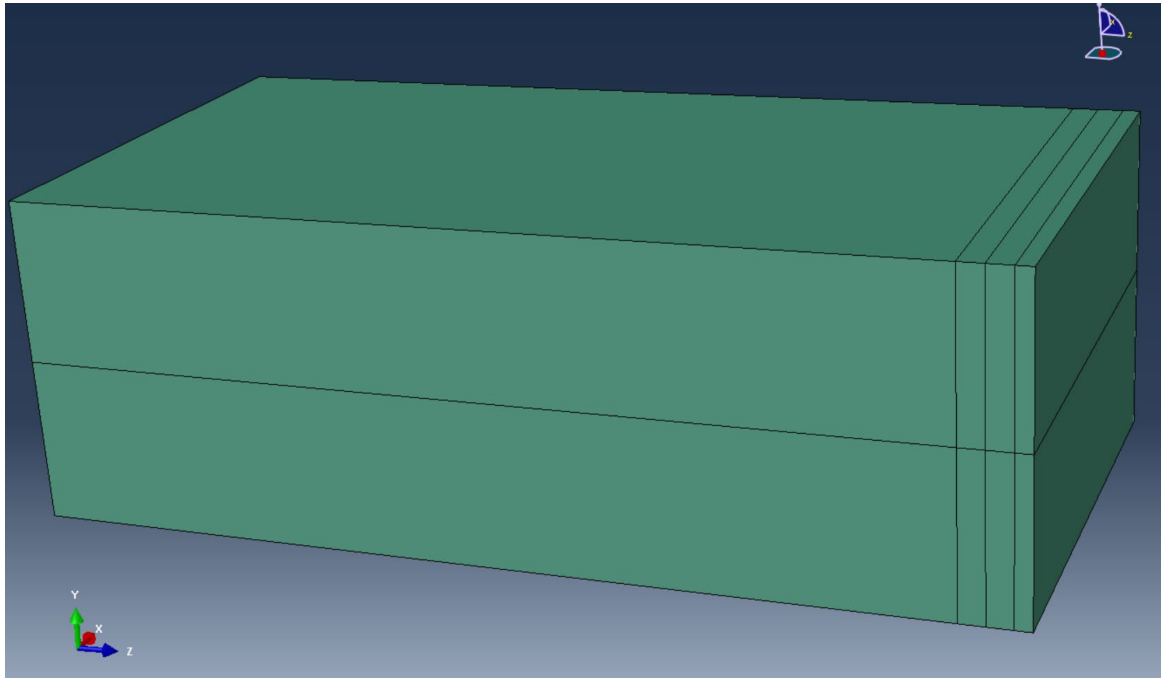
Bottom center to edge elevation change 0.107 mm



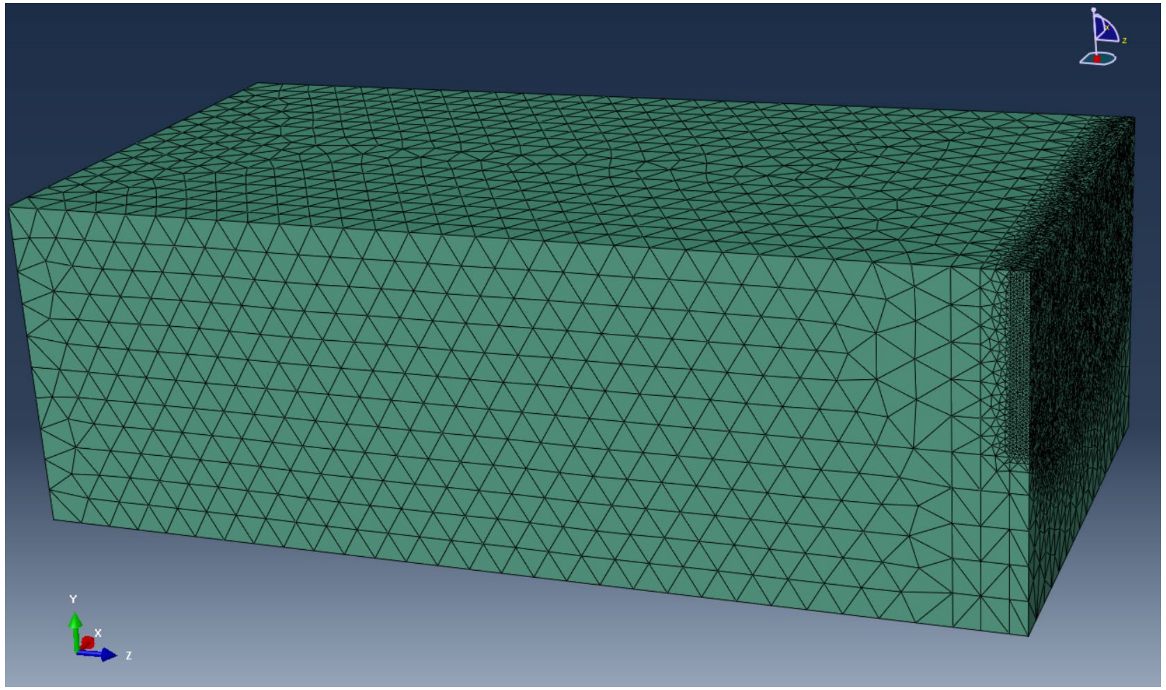
Point 1: 219.7E-03, -404.E-03, 2.84435 Point 2: 209.345E-03, -403.893E-03, 2.84435
Distance: 10.355E-03 Components: -10.355E-03, 107.E-06, 0.

10 mm thick Inconel block

Contact block 10 mm thick

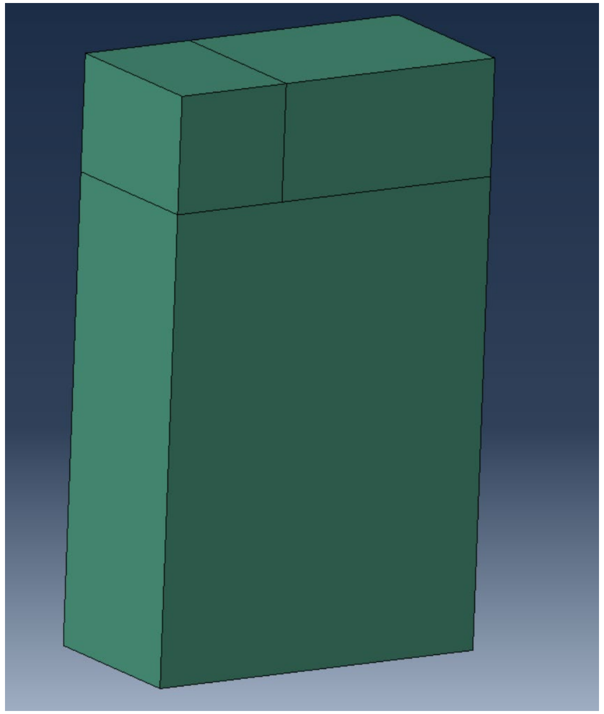


C3D10 mesh with 0.1mm spacing in contact region

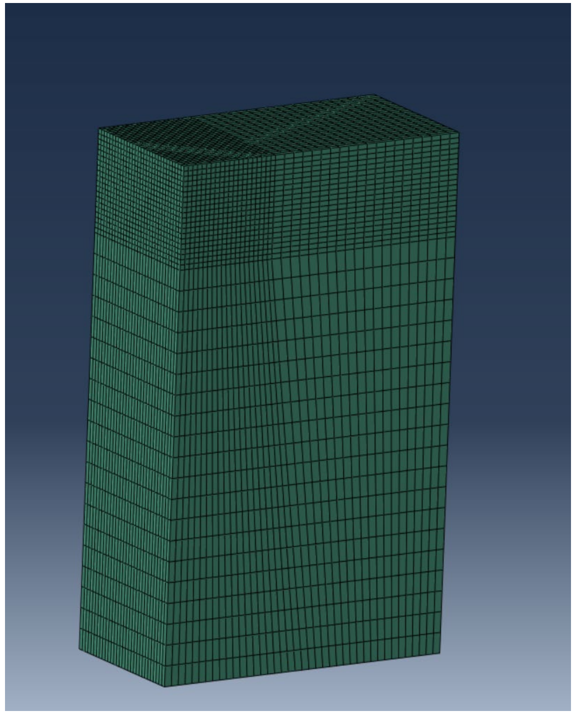


316L plate

50 mm thick 316L block

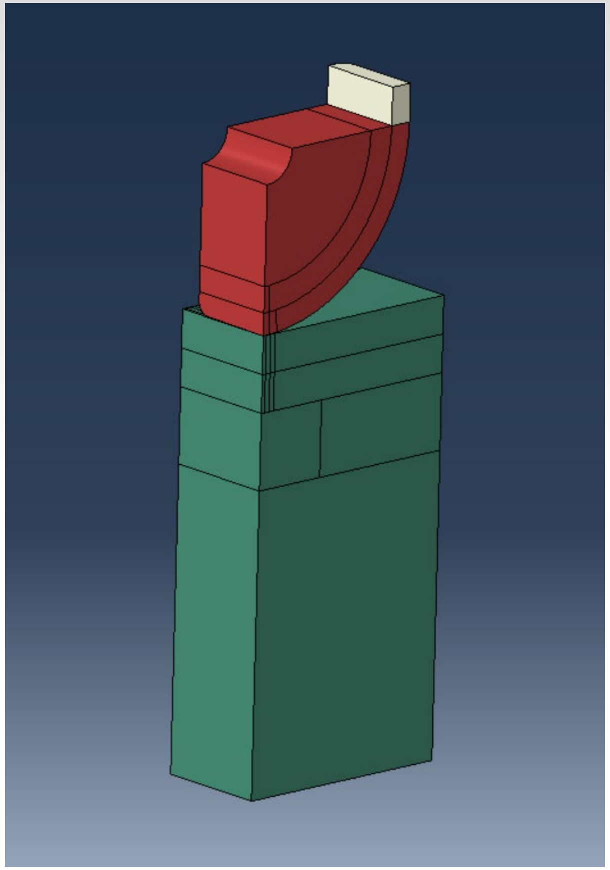


C3D8 Hex mesh

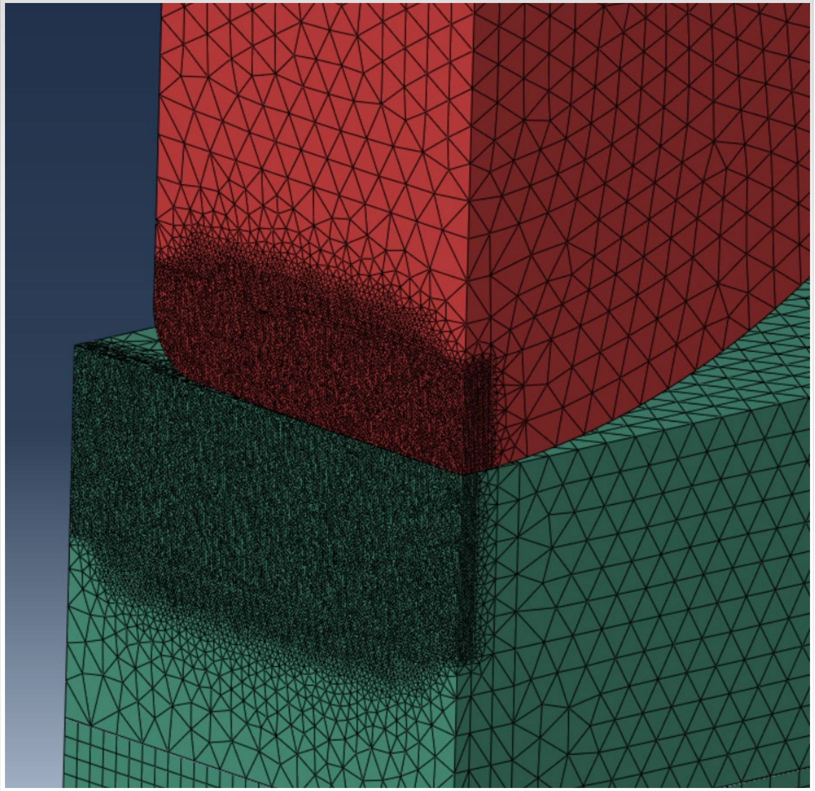


Assembly model

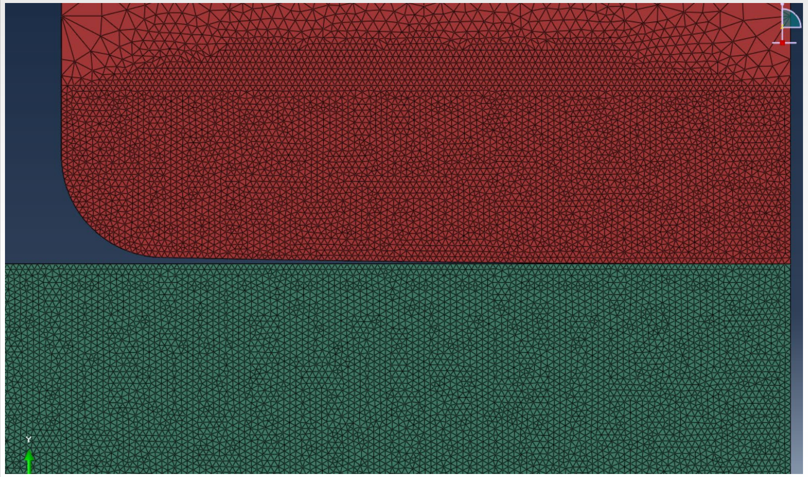
Assembly



Assembly mesh by contact zone

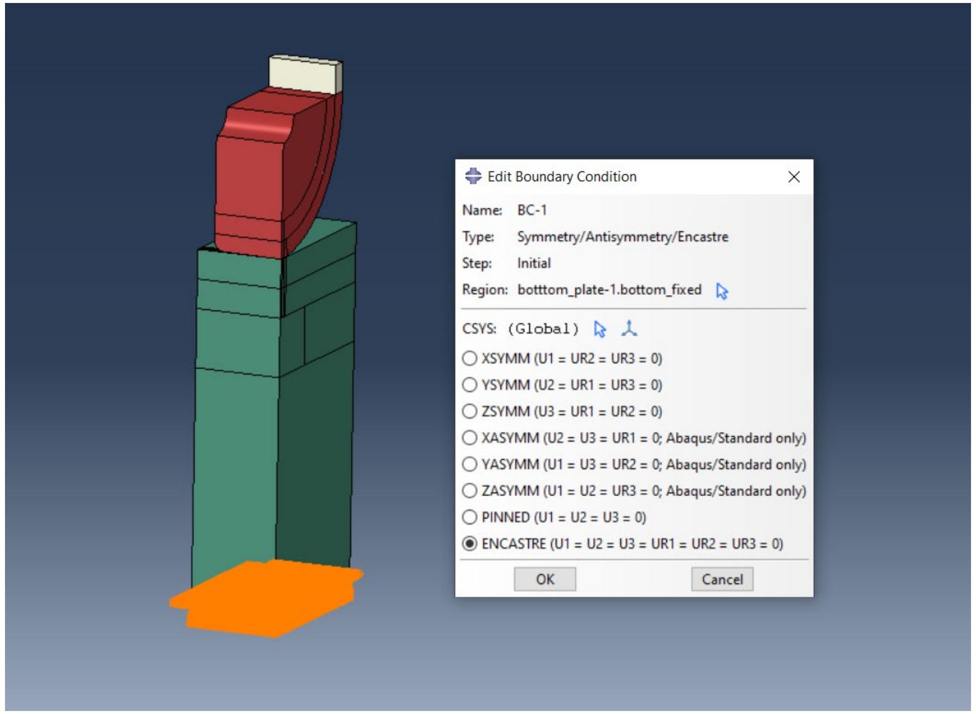


Curvature gap across width

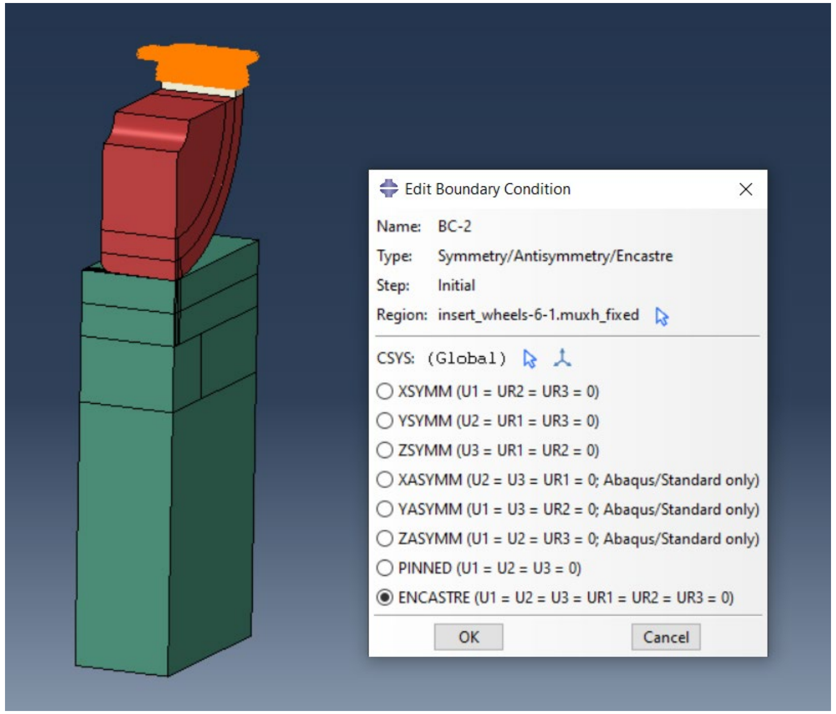


Boundary Conditions

Bottom fixed nodes

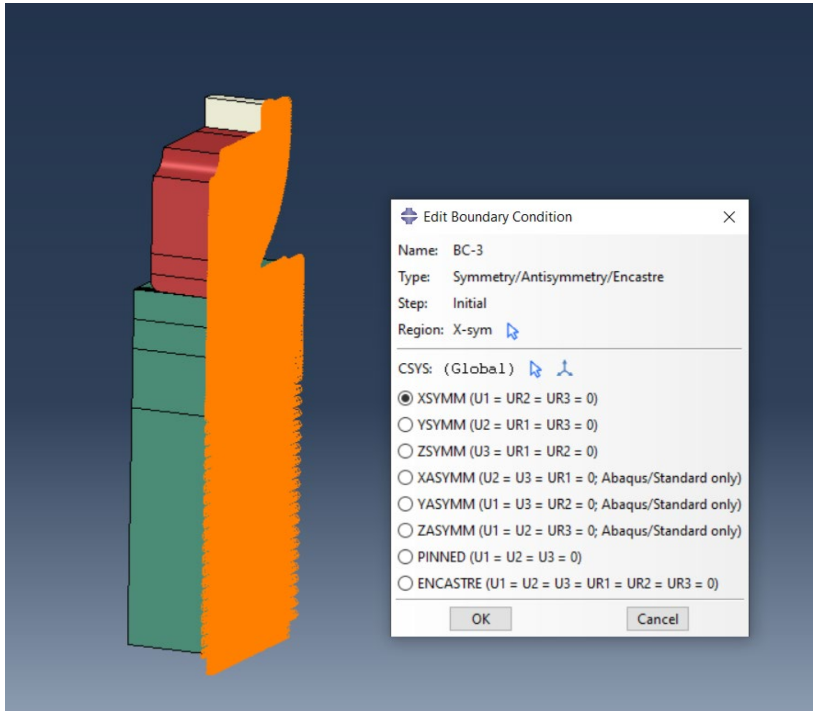


Top surface nodes of "mush" fixed to have a vertical constraint

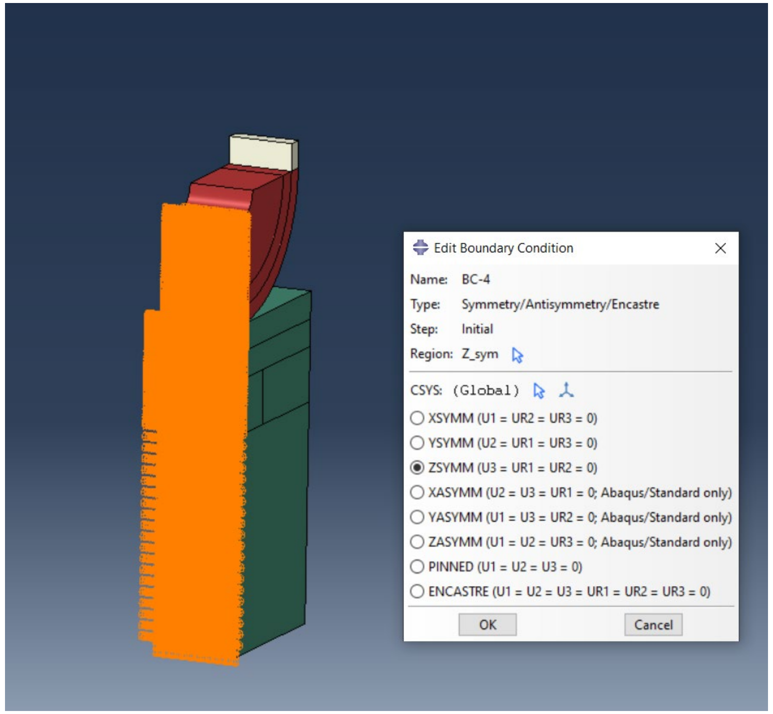


Symmetry boundary conditions

X symmetry

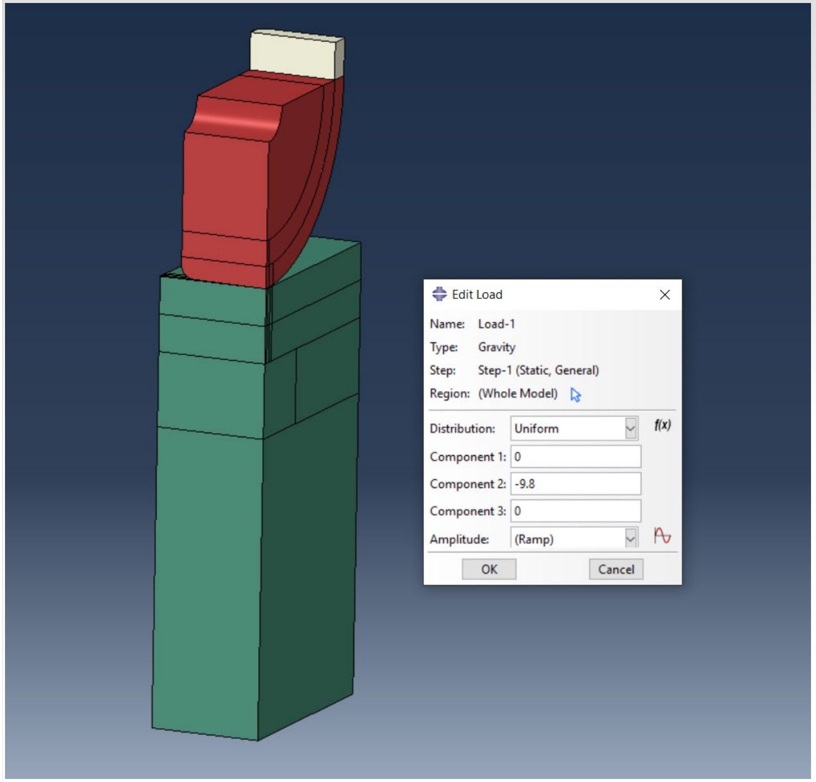


Z symmetry

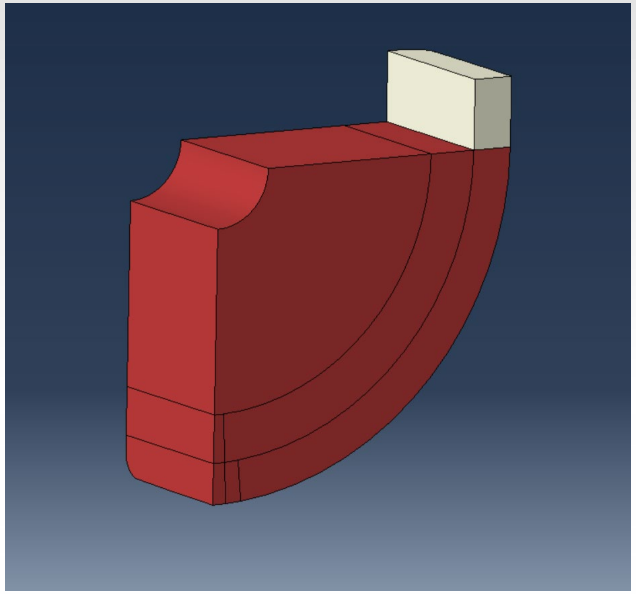


Assembly model loads and materials

Loads



¼ wheel mass 529 kg



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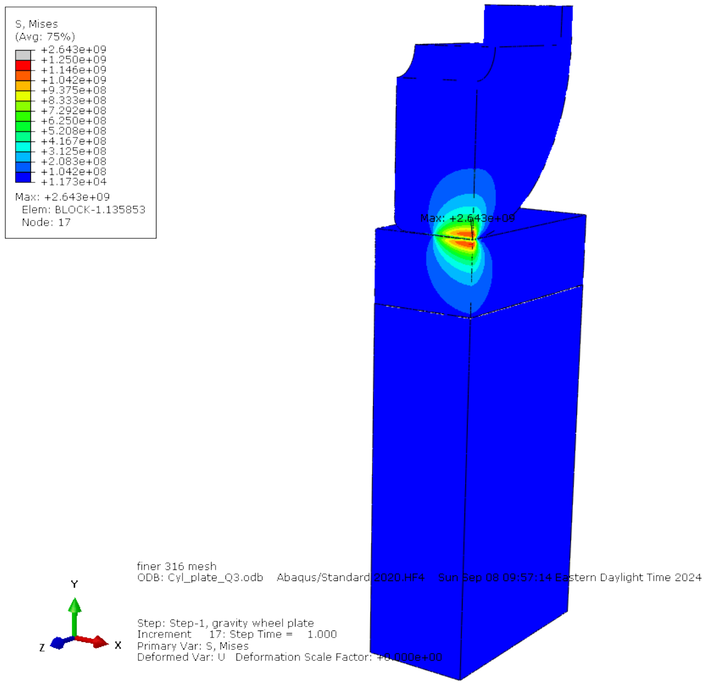
Mass properties:
  Volume: 5.18e-06
  Volume centroid: 0.214,-0.390,2.83
  Mass: 528.77
  Center of mass: 0.214,-0.391,2.83
  Moment of inertia about the center of mass (Ixx, Iyy, Izz, Ixy, Iyz, Izx): 0.0395,0.0260,0.0260,8.69e-05,0.00736,8.69e-05
```

Material input

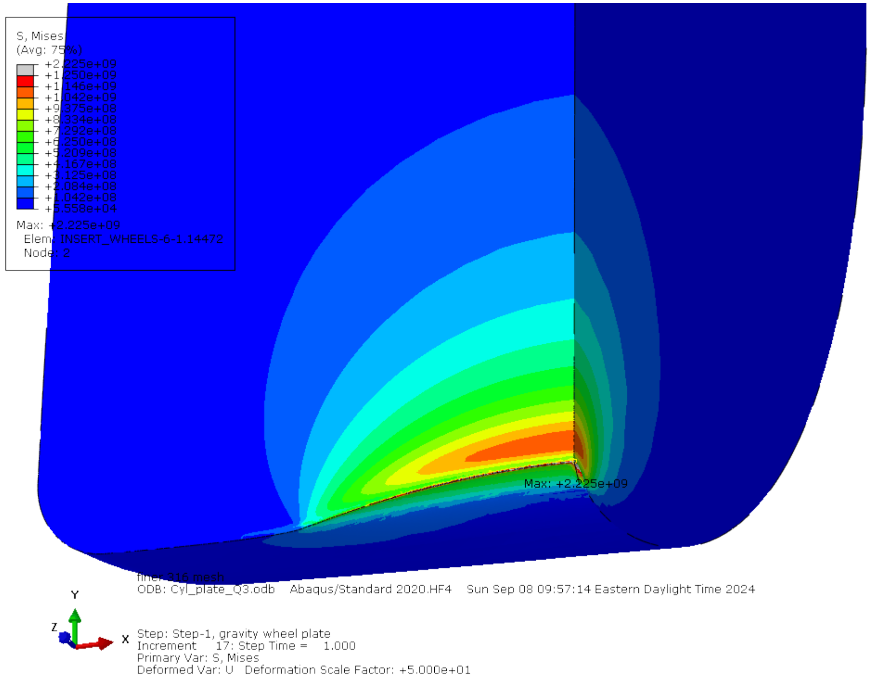
```
** MATERIALS
**
*Material, name=SS316L
*Density
8000.,
*Elastic
 2e+11, 0.292
*Material, name=mush
*Density
1.,
*Elastic
 2e+06, 0.3
*Material, name=steel_wheel
*Density
 1.055e+08,
*Elastic
 2e+11, 0.3
**
```

Assembly Von Mises Stress with 1250 MPa scale

Assembly S Mises 1250 MPa scale peak 2643 MPa

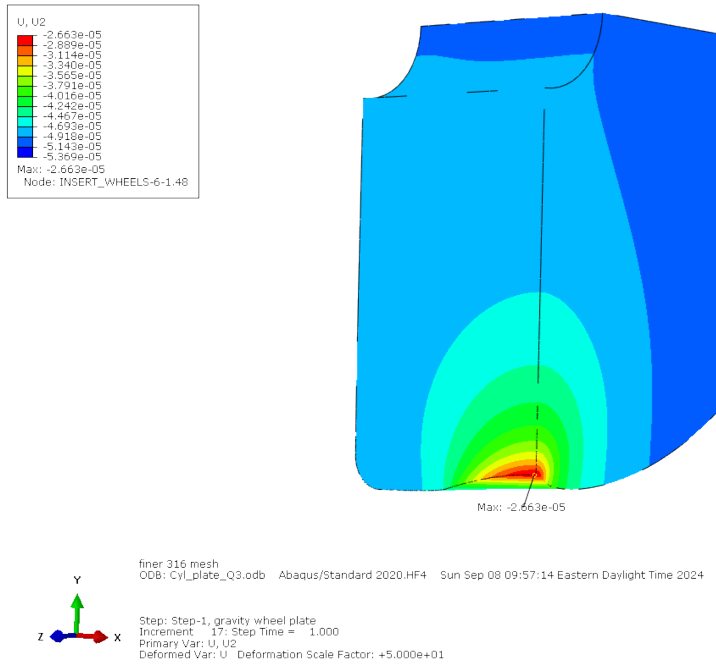


Wheel S 1250 MPa scale

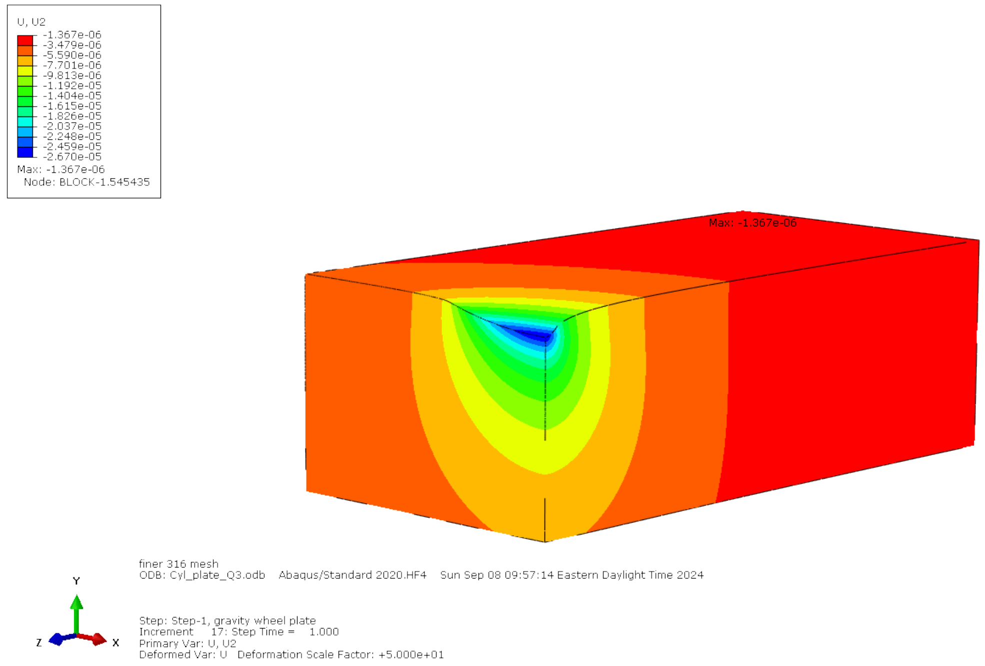


Vertical Displacements

Wheel

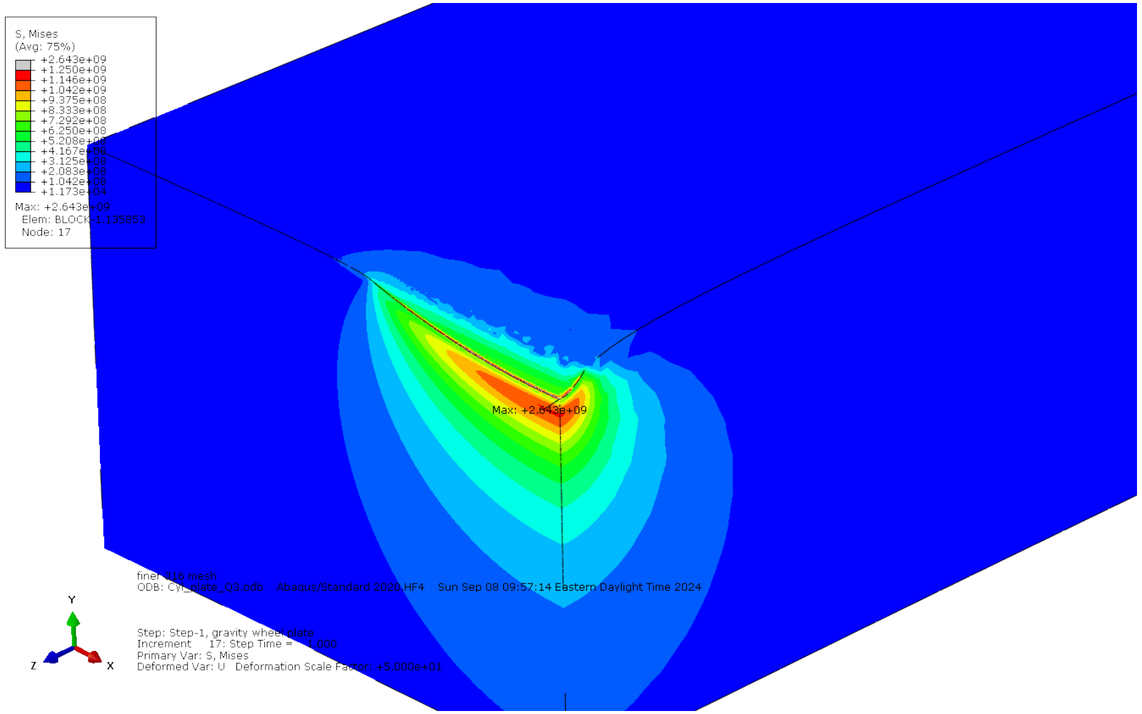


Block

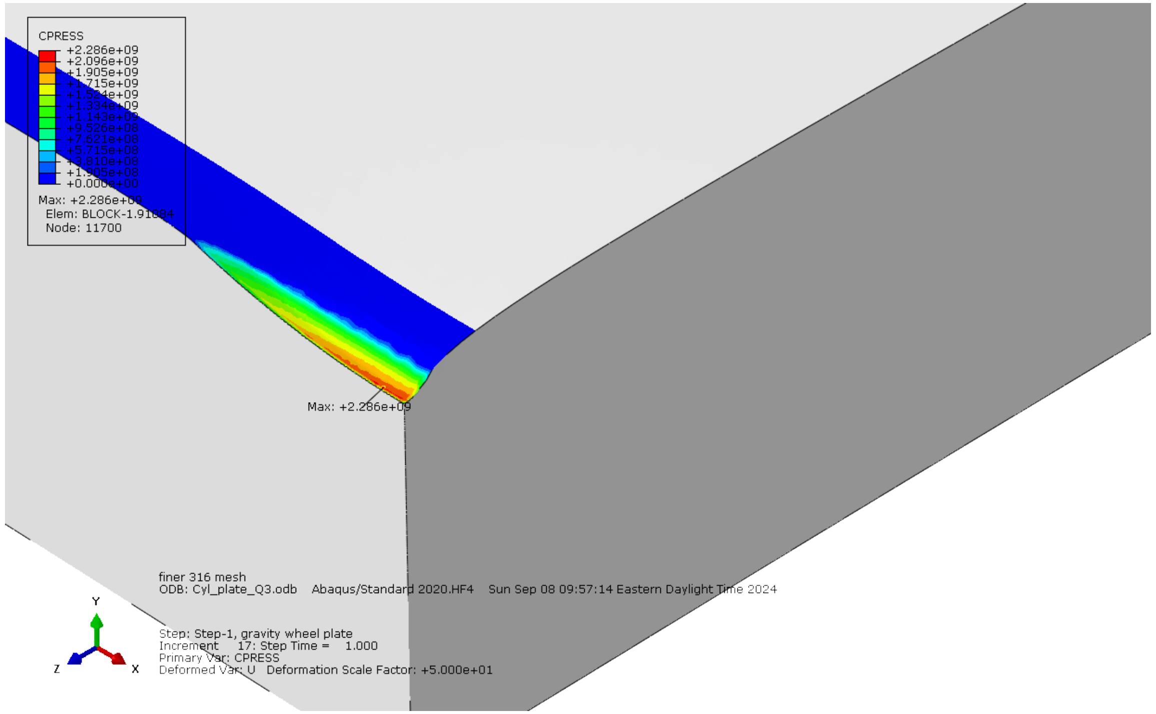


Inconel plate

S 1250 Scale 50x displacements

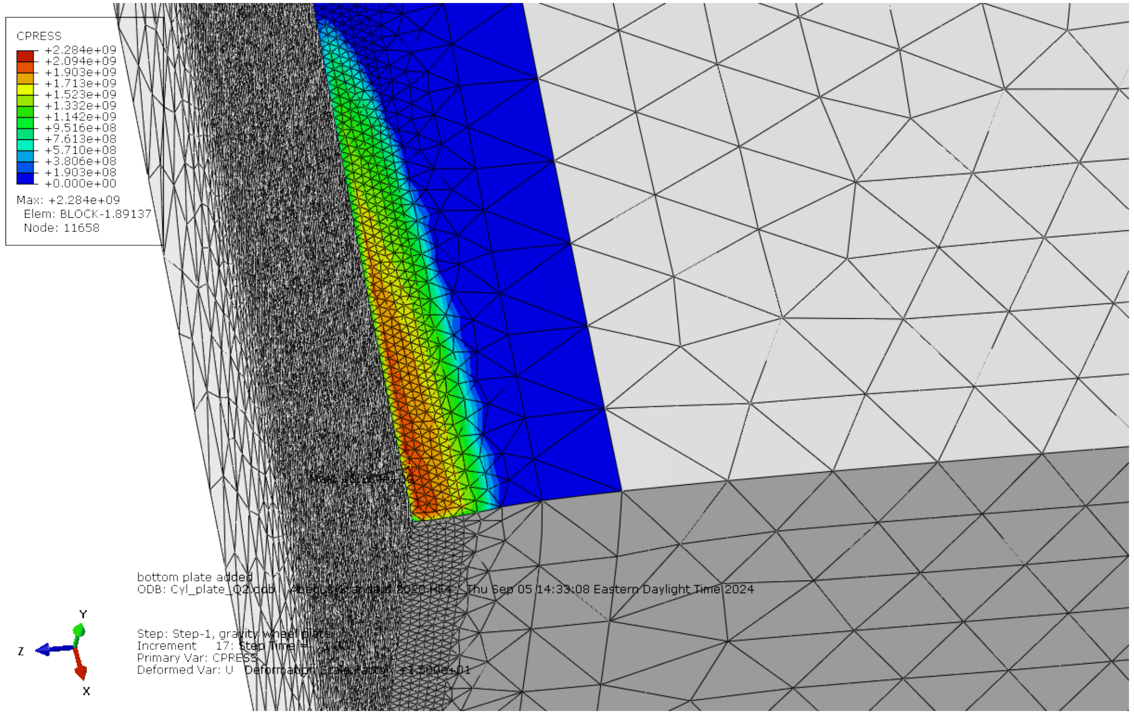


Block Contact pressure –peak 2286 MPa



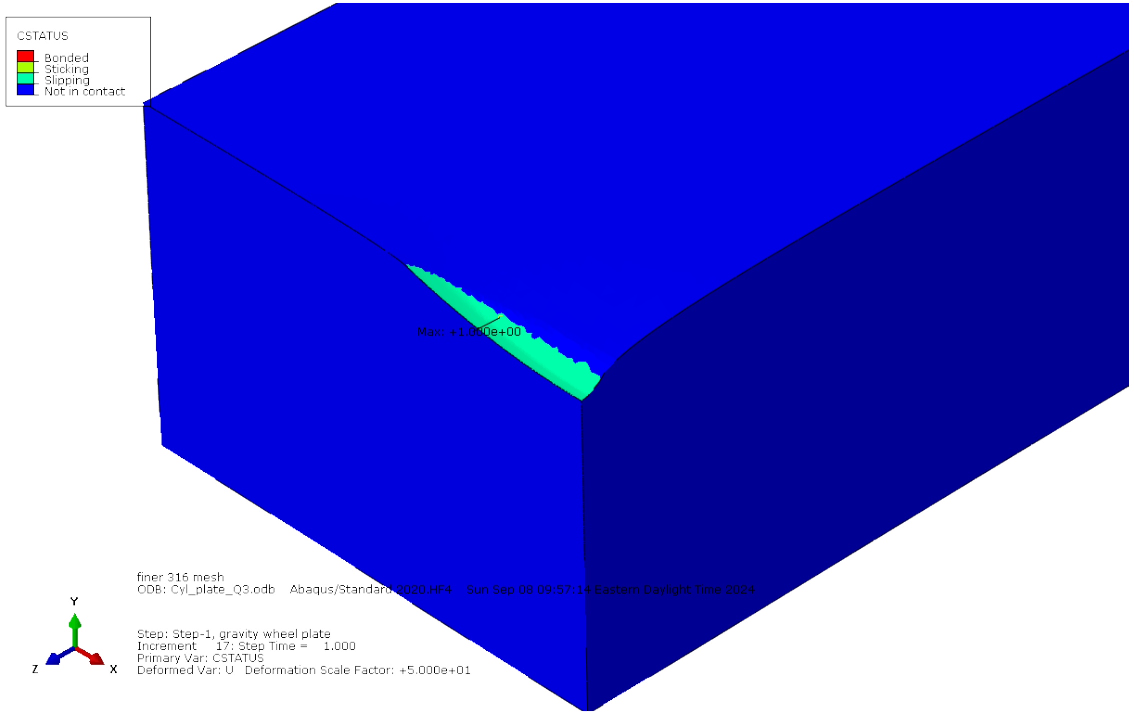
Inconel plate contact surface

Pressure with mesh shown



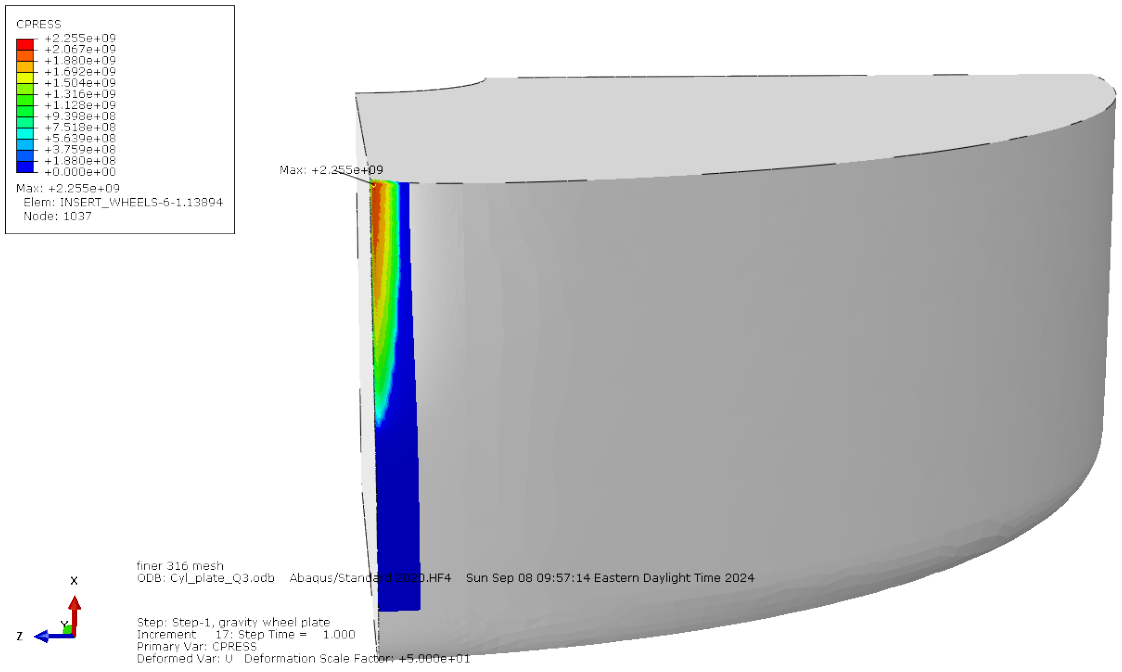
Contact area roughly .5mm x 6mm or 1mm x 12 mm for full model

Block Contact status

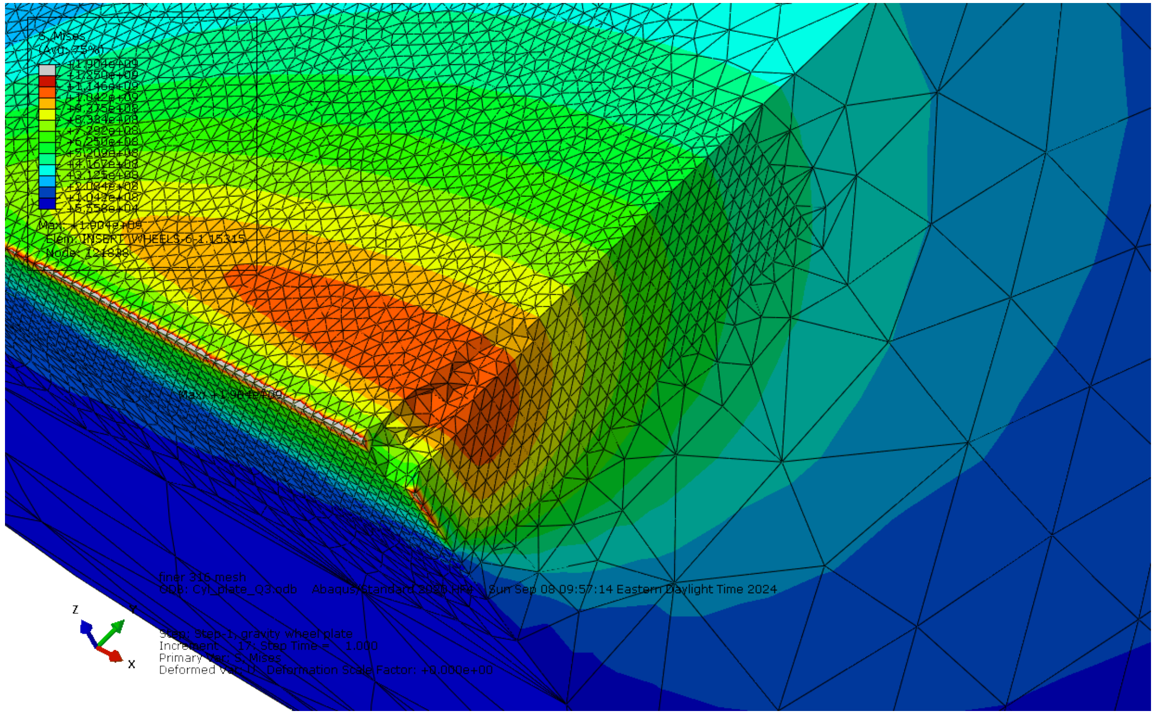


Wheel contact pressure and stress

Wheel Contact pressure

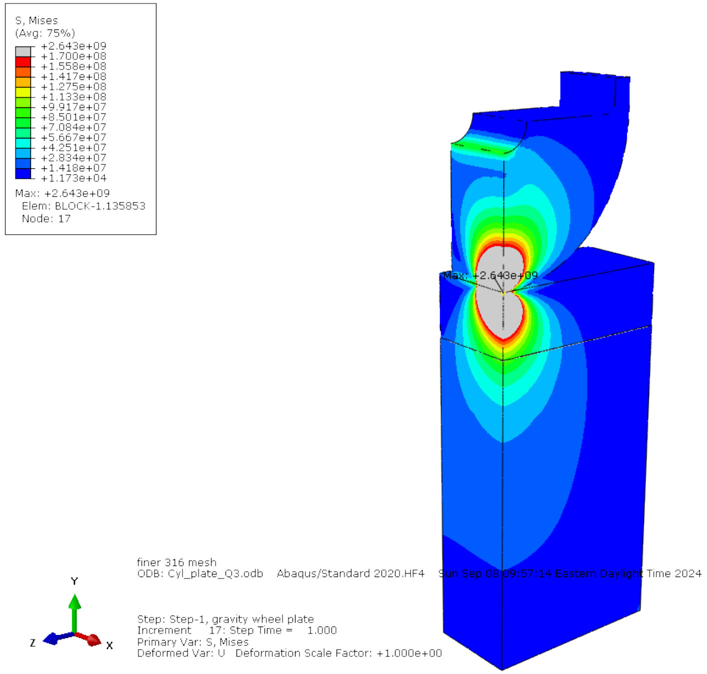


Wheel S 1250 MPa scale mesh with cut to interior

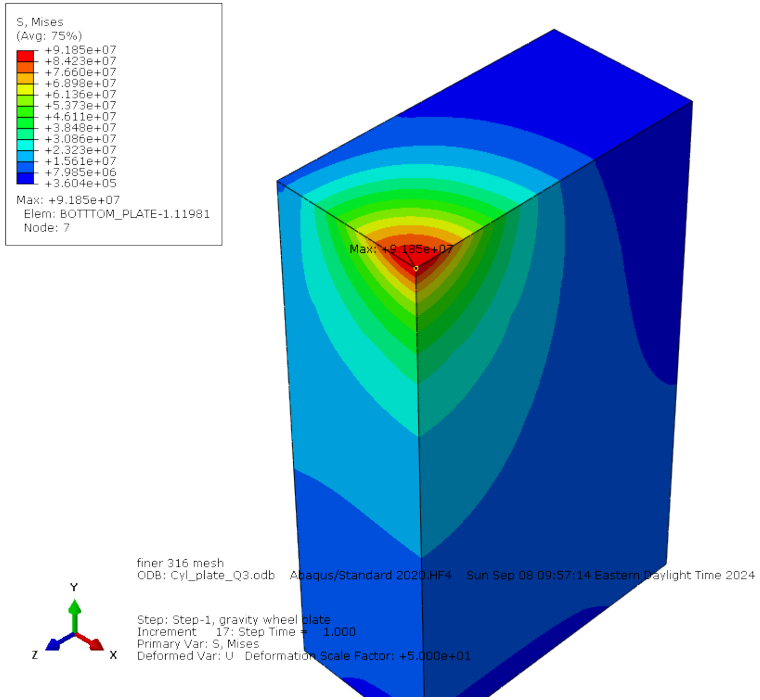


Assembly stress with 170 MPa scale

Von Mises stress 170 MPa scale



Bottom 316L section Stress peak 91 MPa

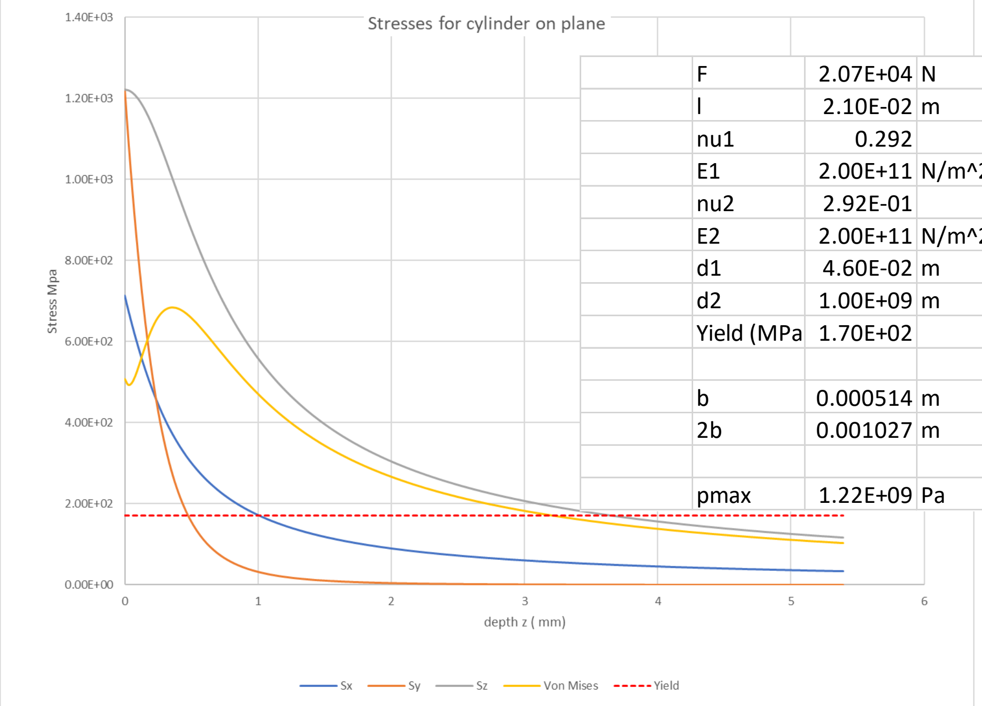


Comparison to ideal cylinder on plate

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



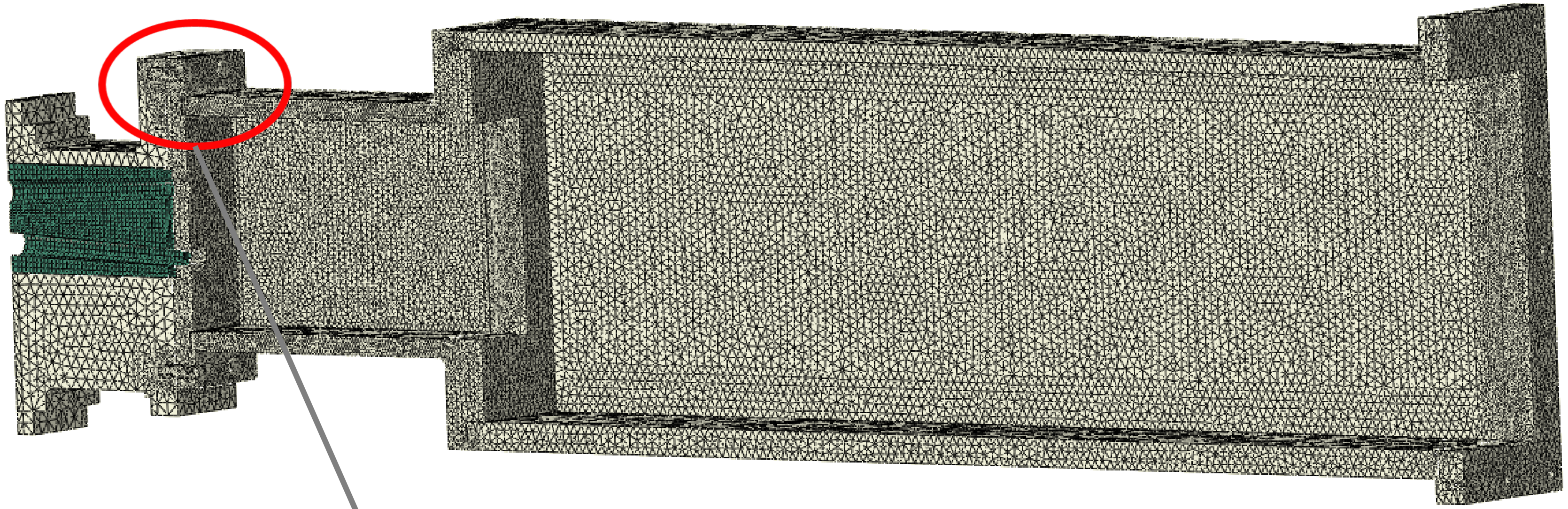
F	2.07E+04	N
l	2.10E-02	m
nu1	0.292	
E1	2.00E+11	N/m^2
nu2	2.92E-01	
E2	2.00E+11	N/m^2
d1	4.60E-02	m
d2	1.00E+09	m
Yield (MPa	1.70E+02	
b	0.000514	m
2b	0.001027	m
pmax	1.22E+09	Pa

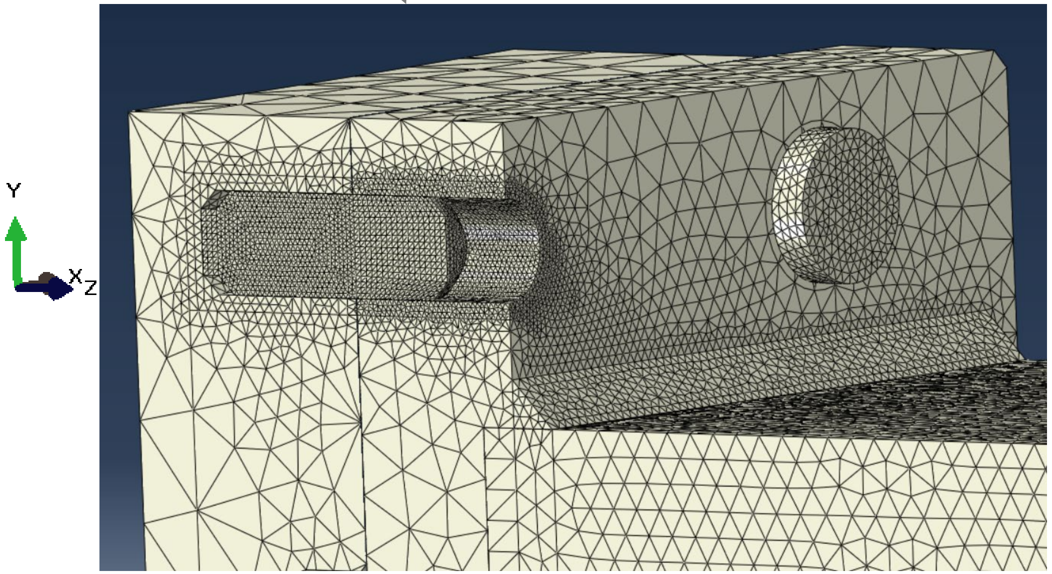
Contact model Analysis Summary

- 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**

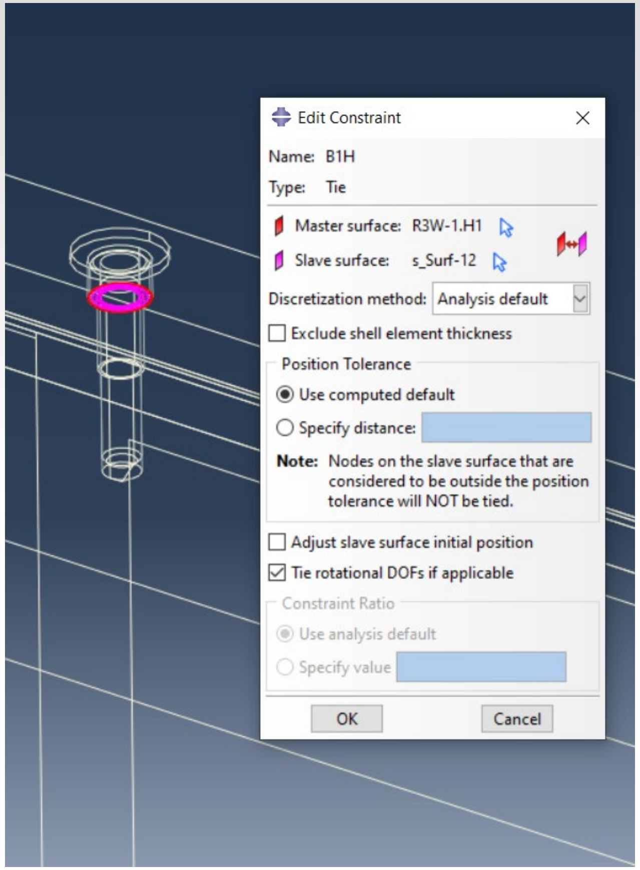




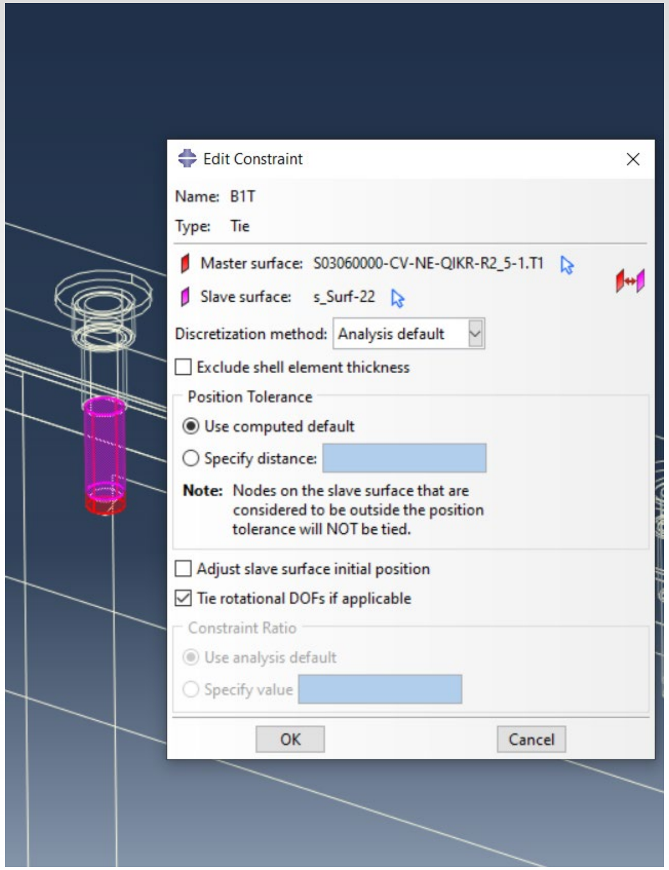
12 mm bolt Constraints -168

- 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

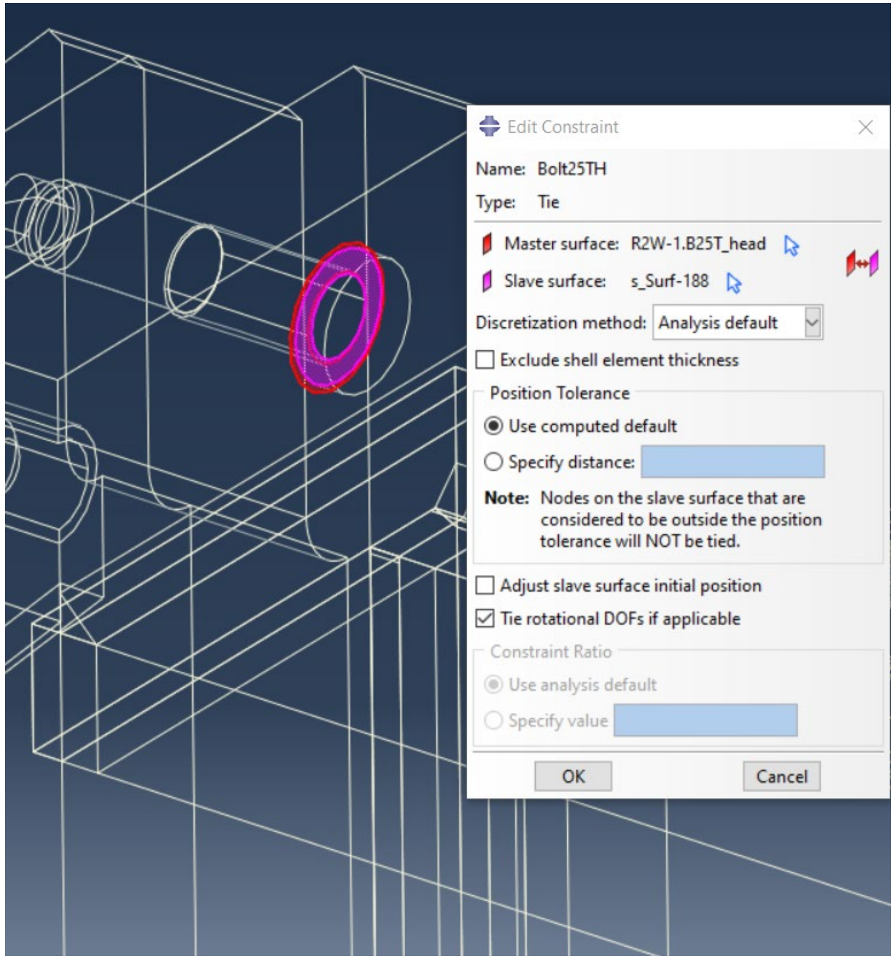


Typical threaded zone tie

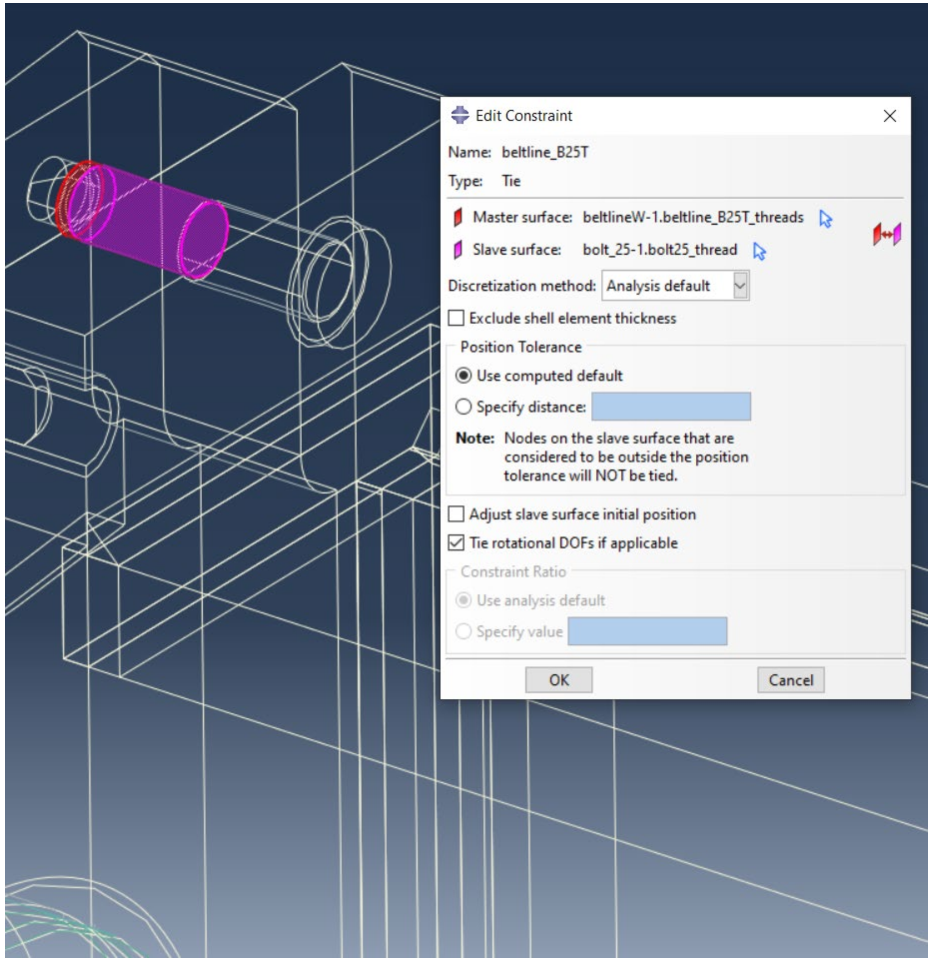


Front flange top bolt tie constraints - bottom constraints similar

Upper bolt head to flange tie

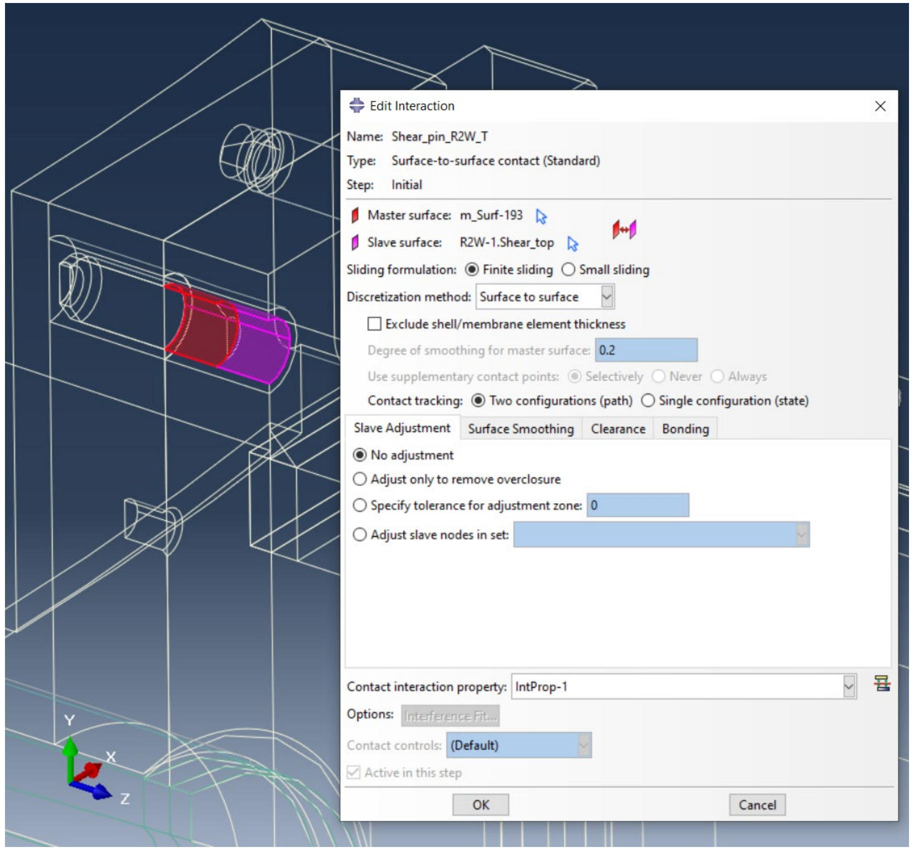


Threaded area tie to beltline

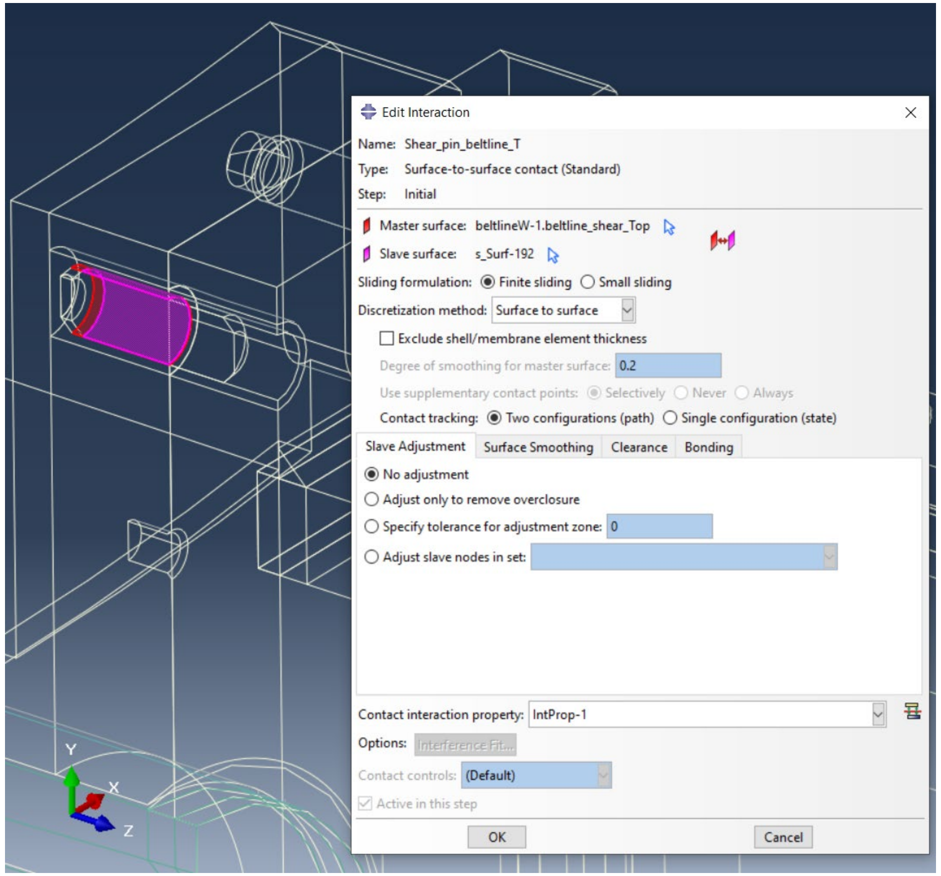


Shear Pin Surface to Surface Interactions – top shown – bottom similar

Shear Pin to Front Flange



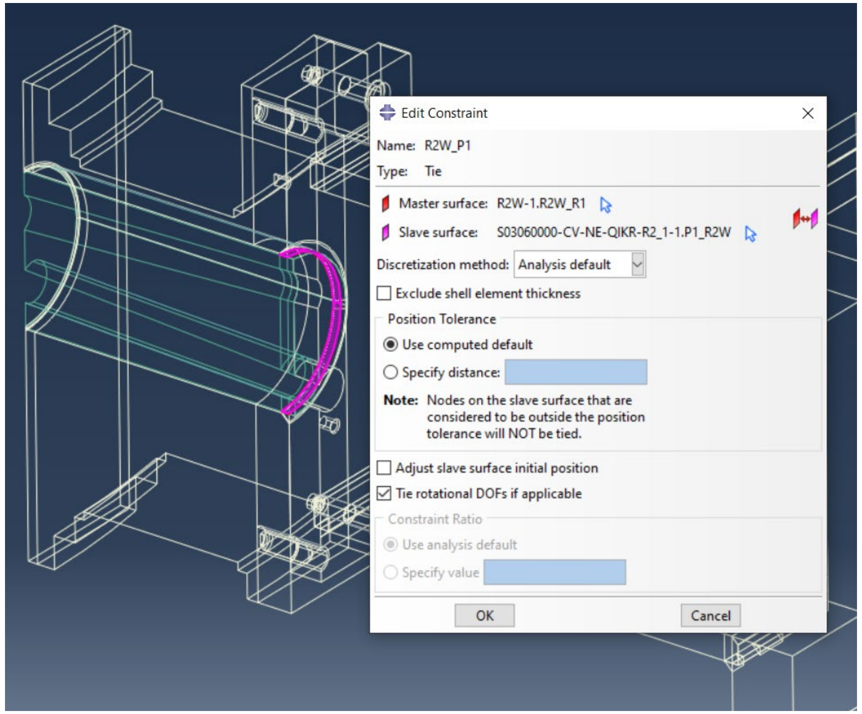
Shear Pin to Beltline



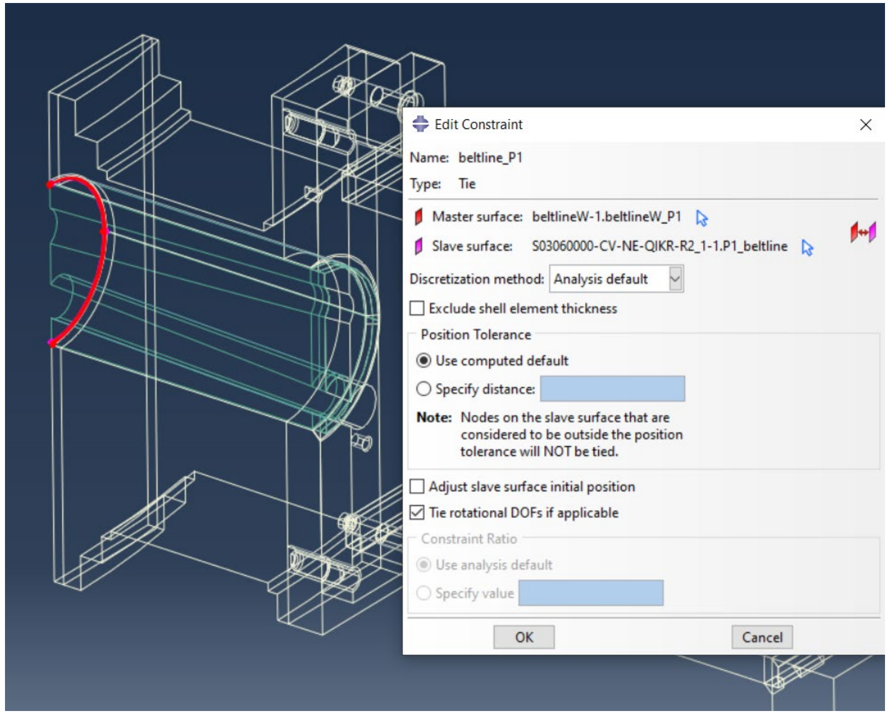
Weld Tie Constraints

Front Flange (R5W) and Beltline welds

Front Flange to Part 1

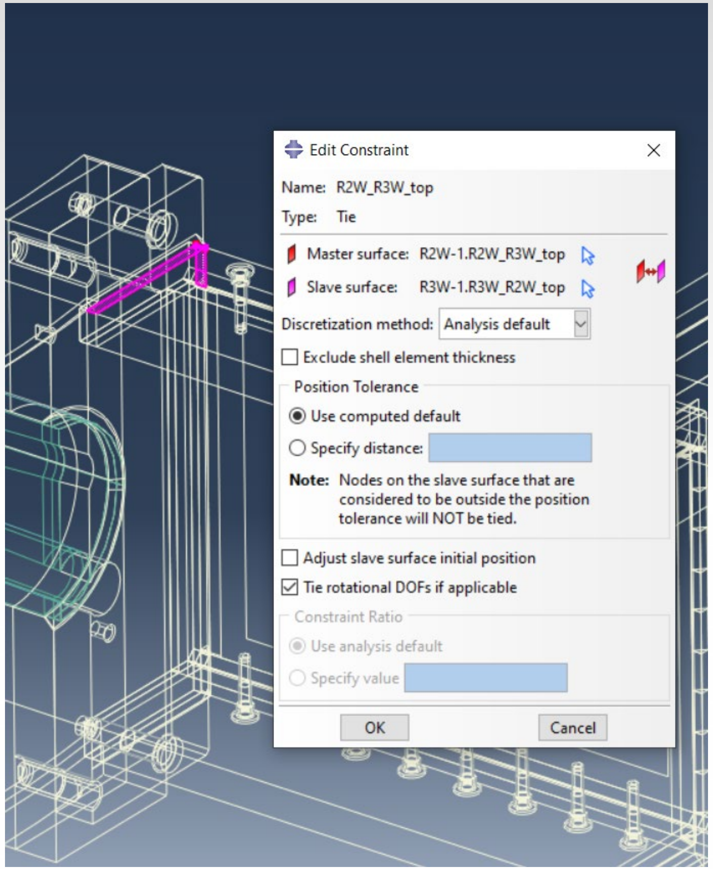


Beltline to Part 1

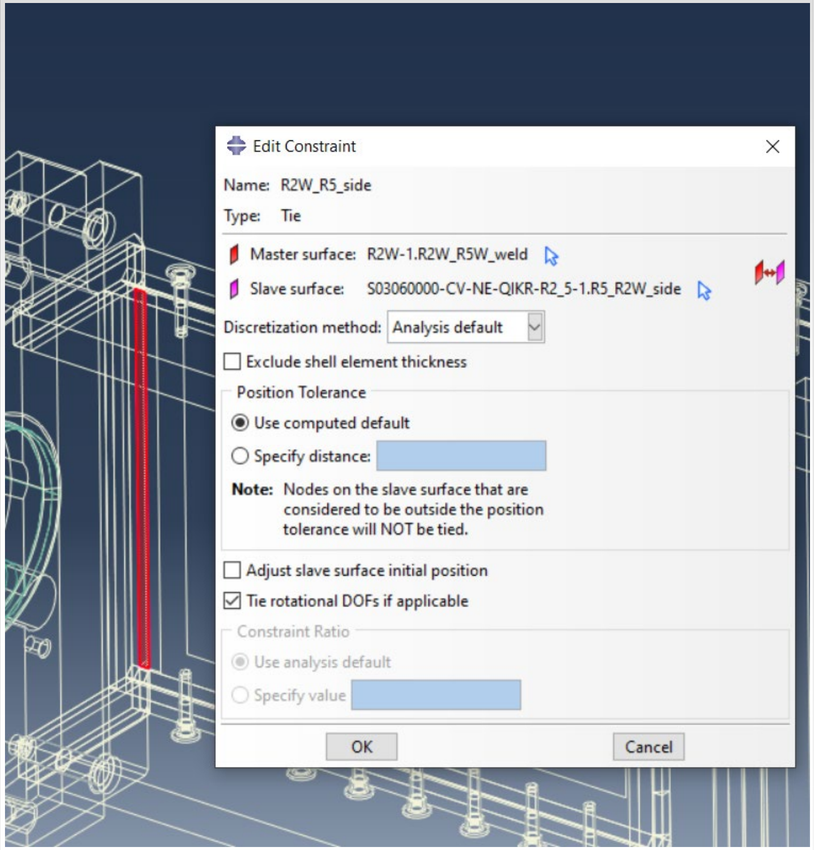


Front Flange (R2W) welds

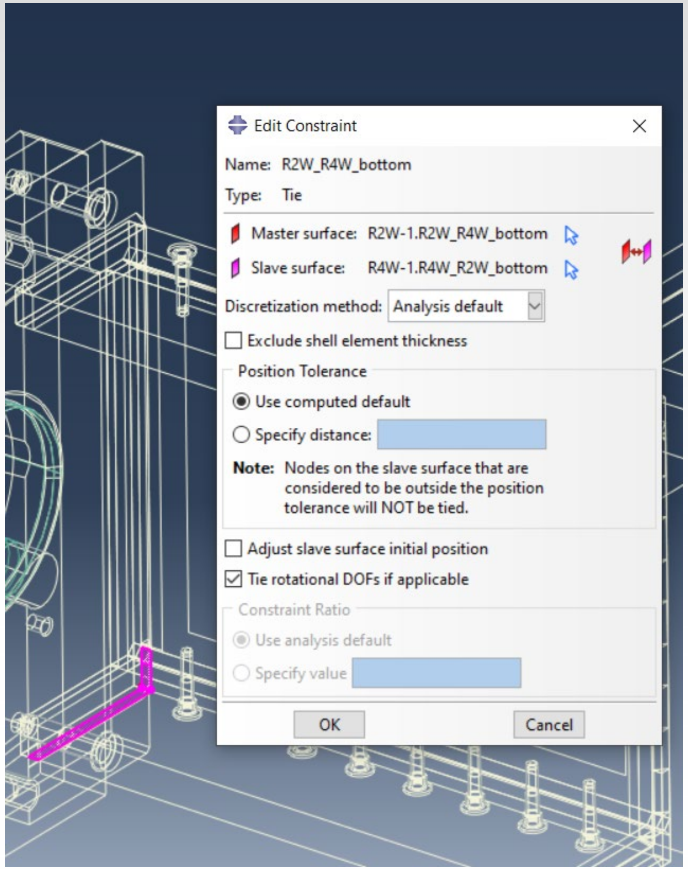
Front Flange to front top plate



Front Flange to front side plate

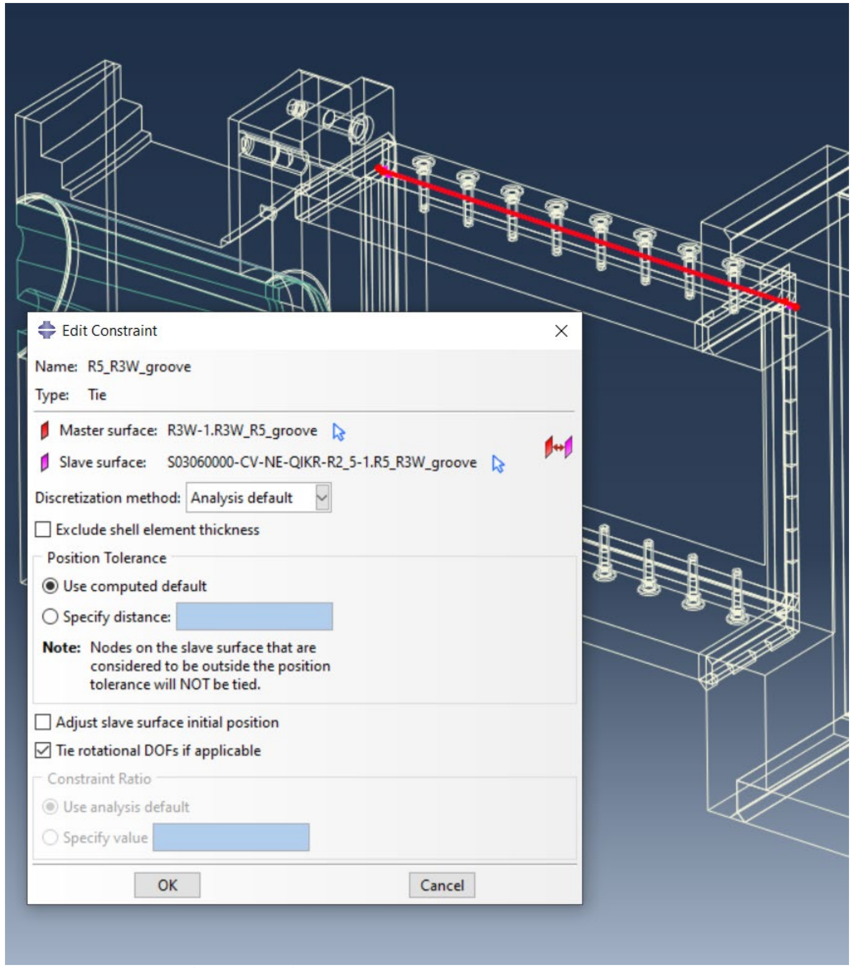


Front Flange to front bottom plate

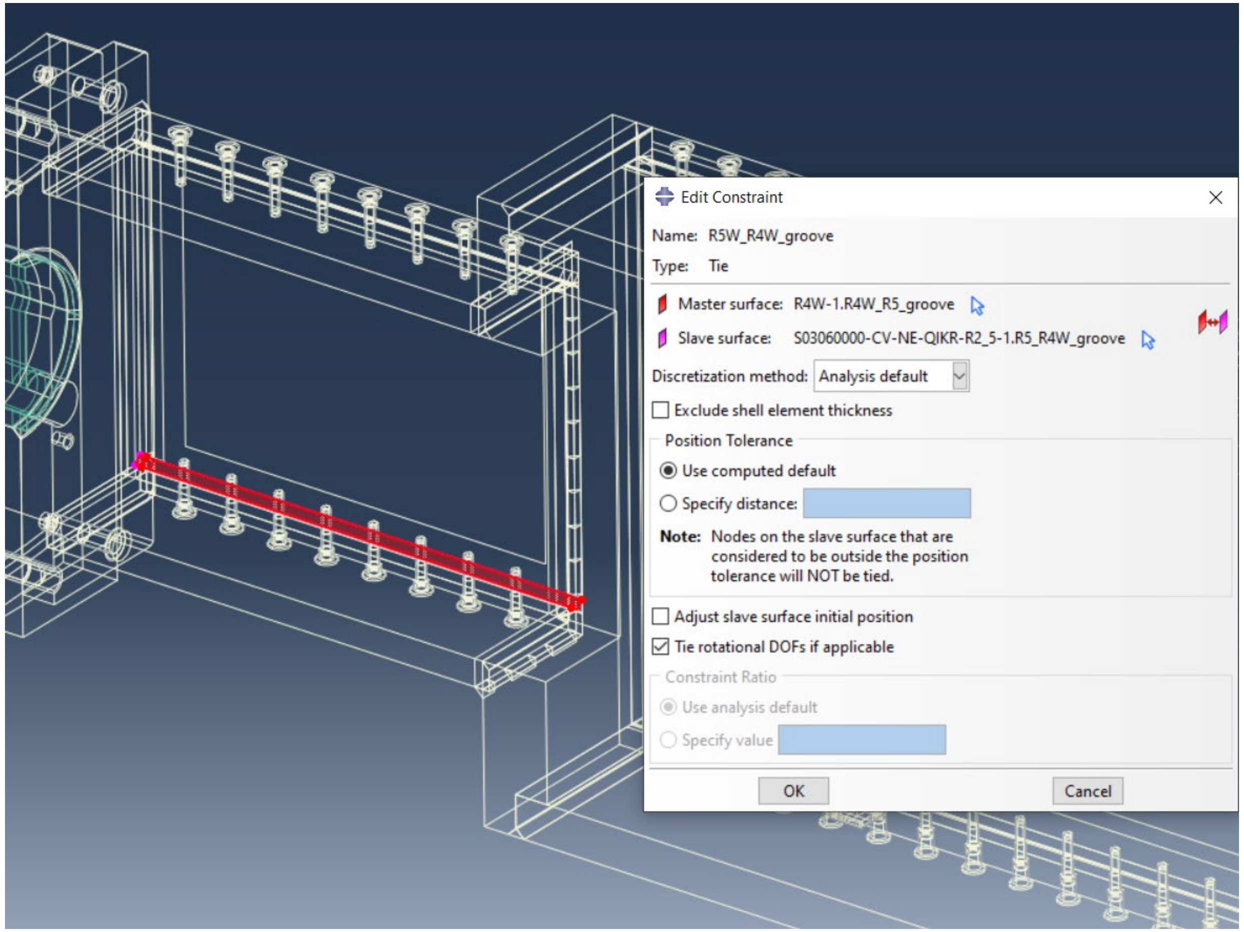


Front 10 mm Groove welds

Front top plate groove weld

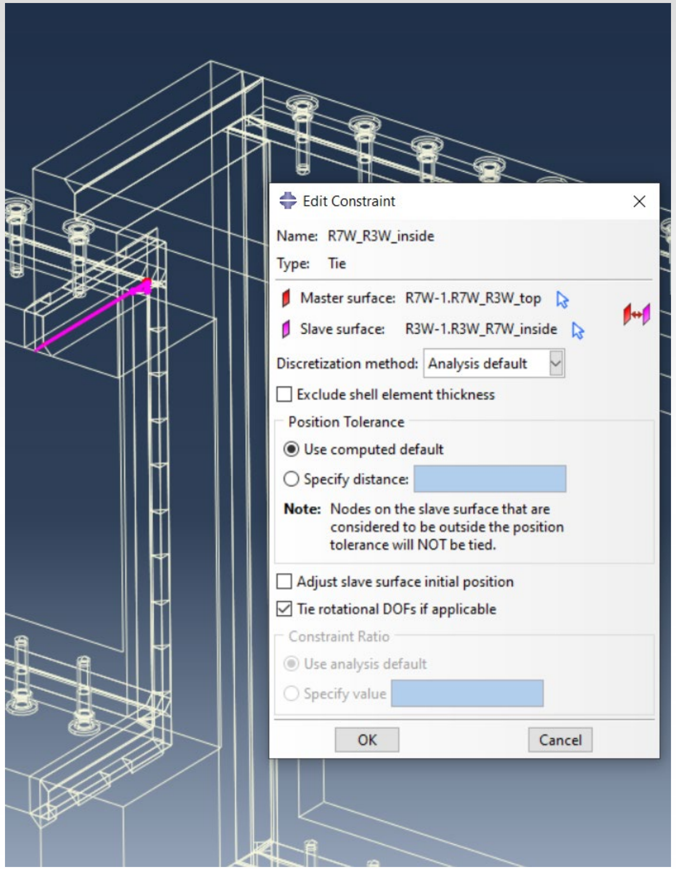


Front bottom plate groove weld

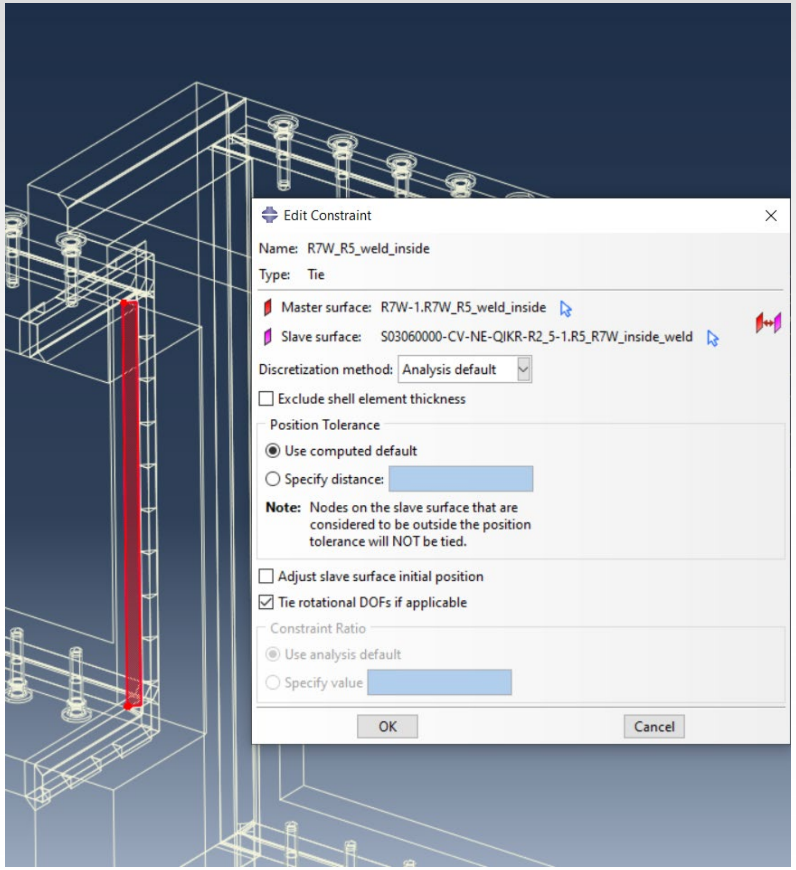


Intermediate flange (R7W) welds

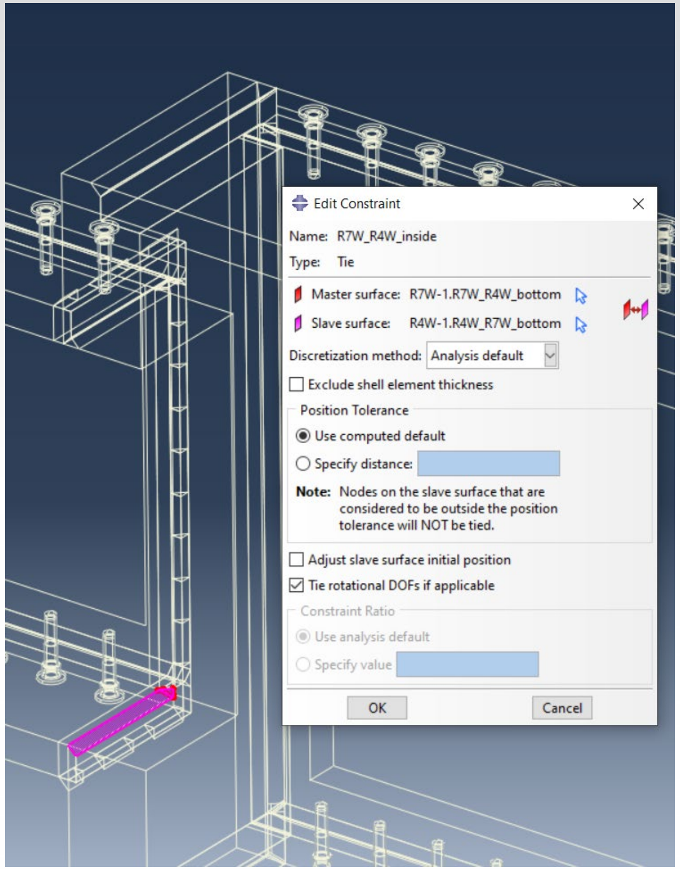
Intermediate flange to front top plate



Intermediate flange to front side plate

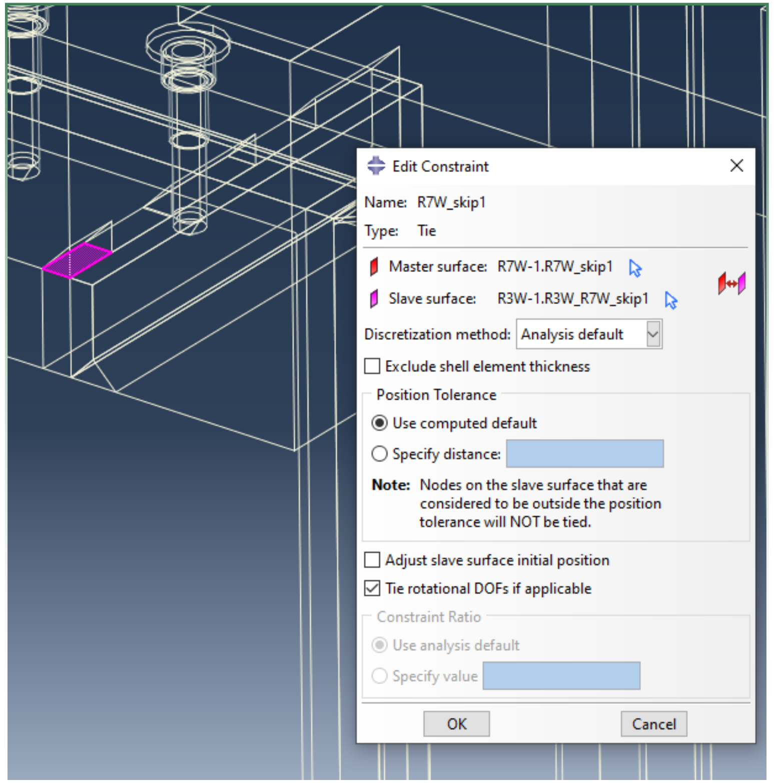


Intermediate flange to front bottom plate

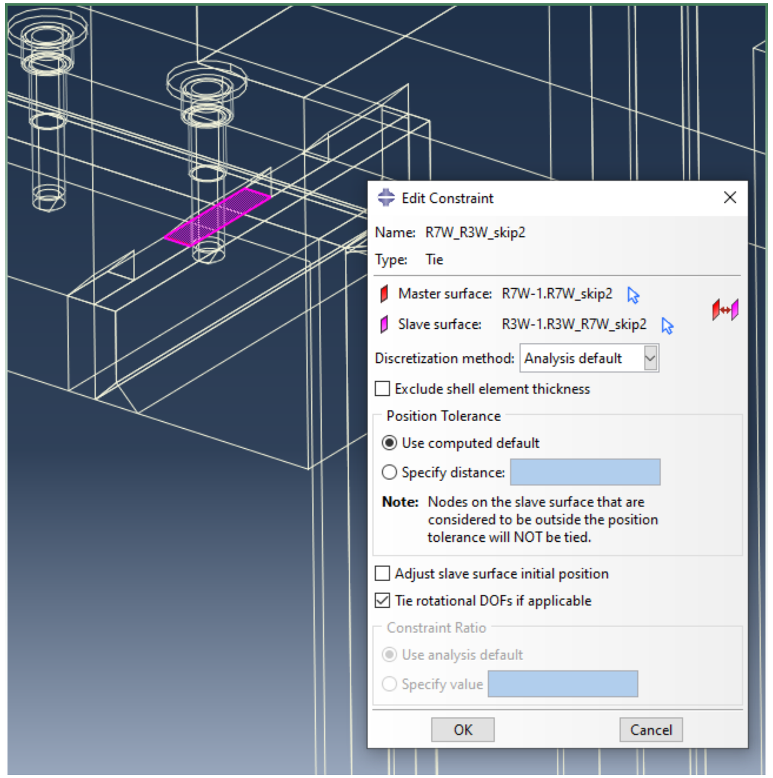


Skip weld ties around Intermediate flange – 11 total

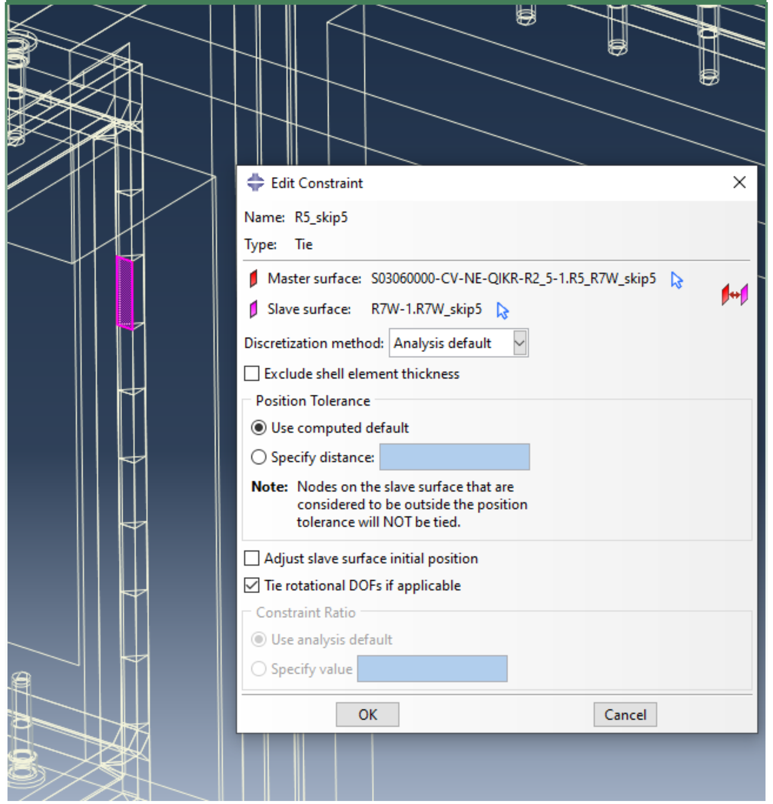
Skip weld tie to top plate



Typical skip weld tie to top or bottom plate

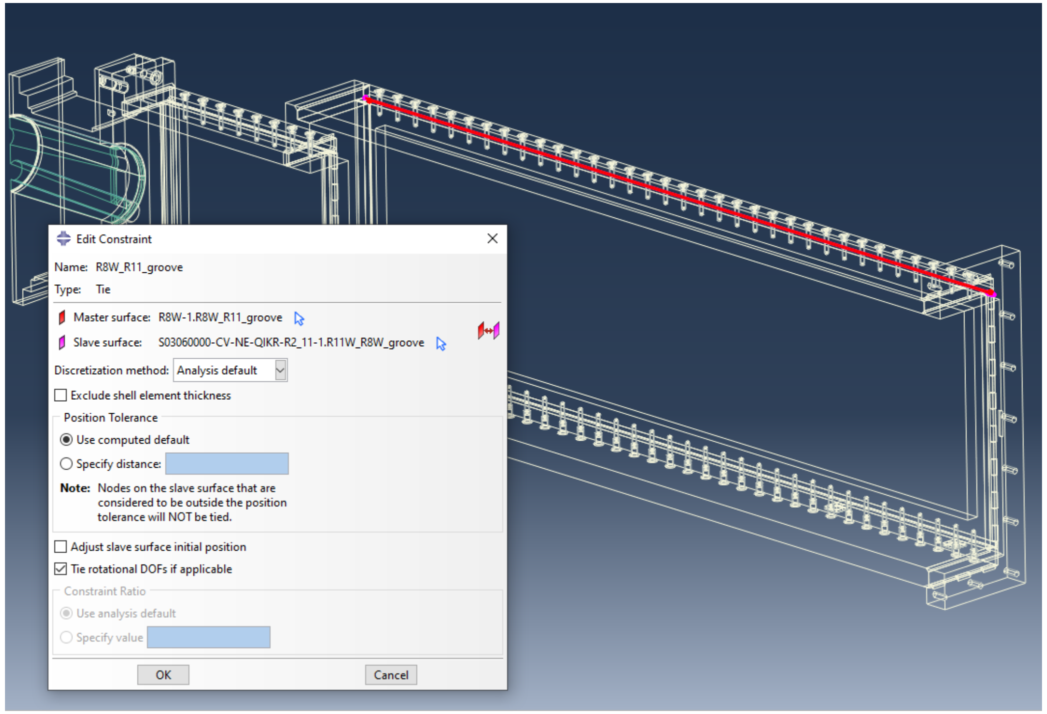


Typical Skip weld tie to front side wall

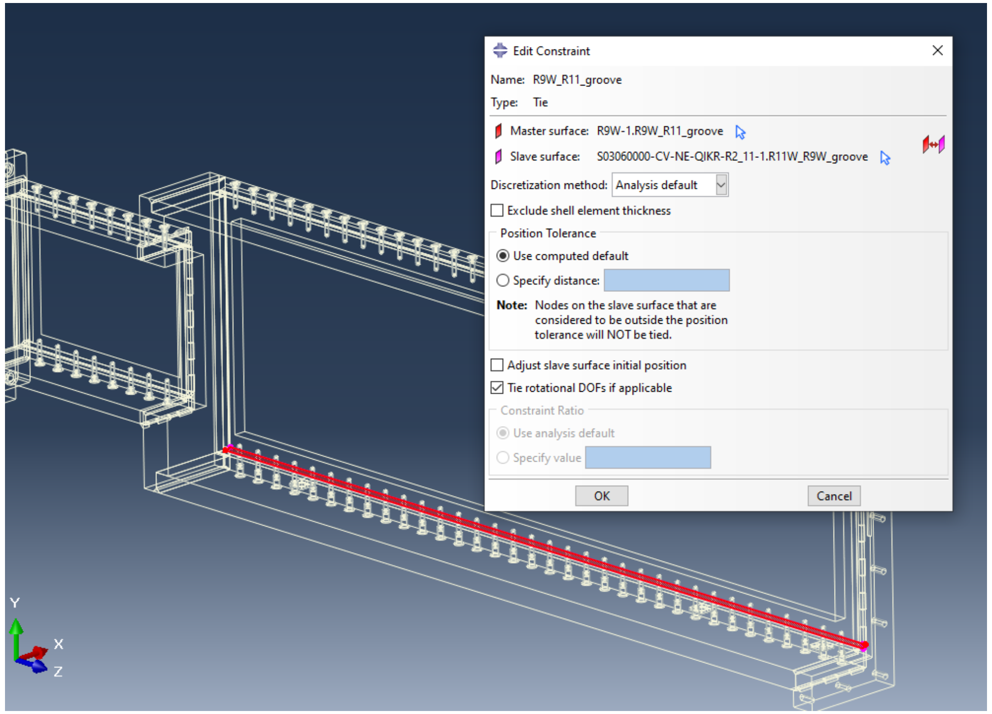


Groove Weld Tie Constraints to rear side wall

Rear Top Groove Weld

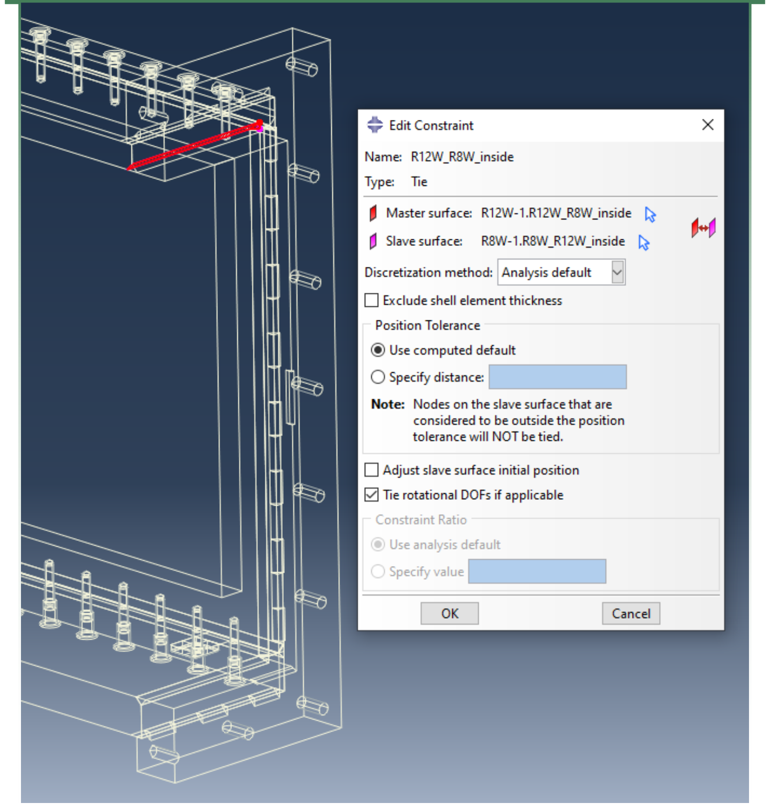


Rear Bottom Groove Weld

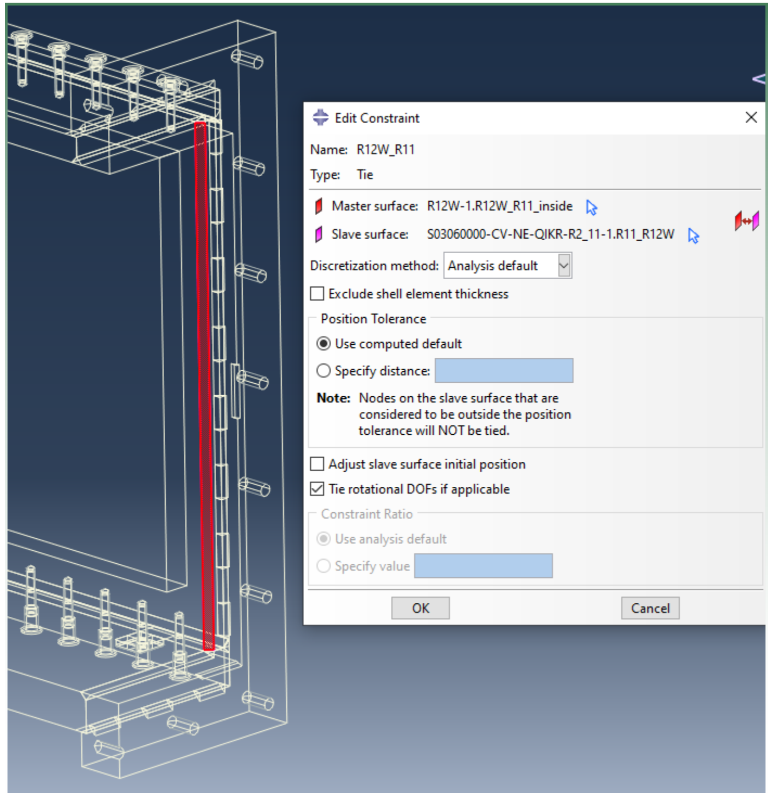


Rear Flange Weld tie constraints

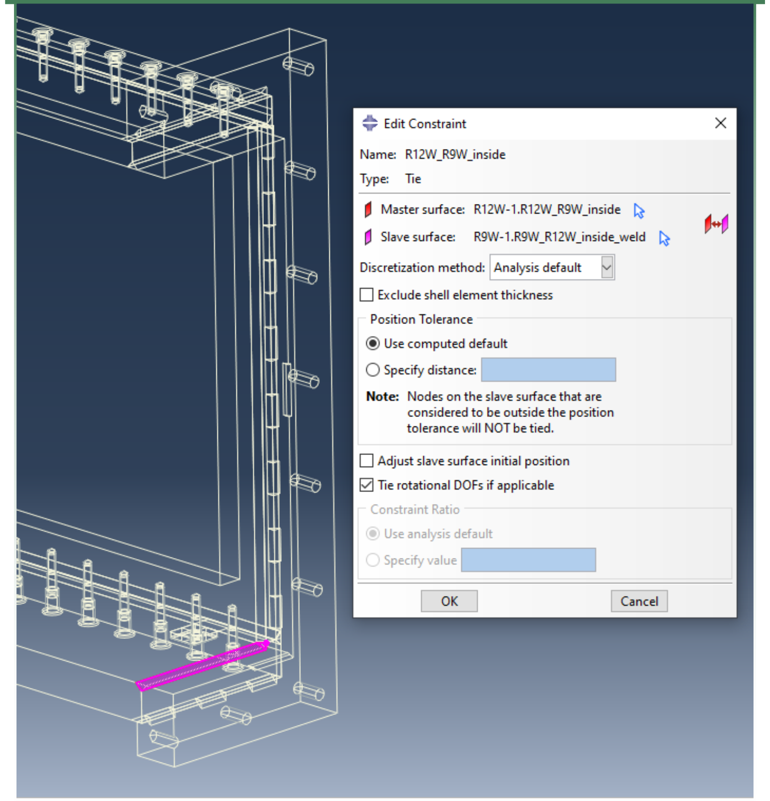
Rear Flange to top plate inside



Rear Flange to side plate

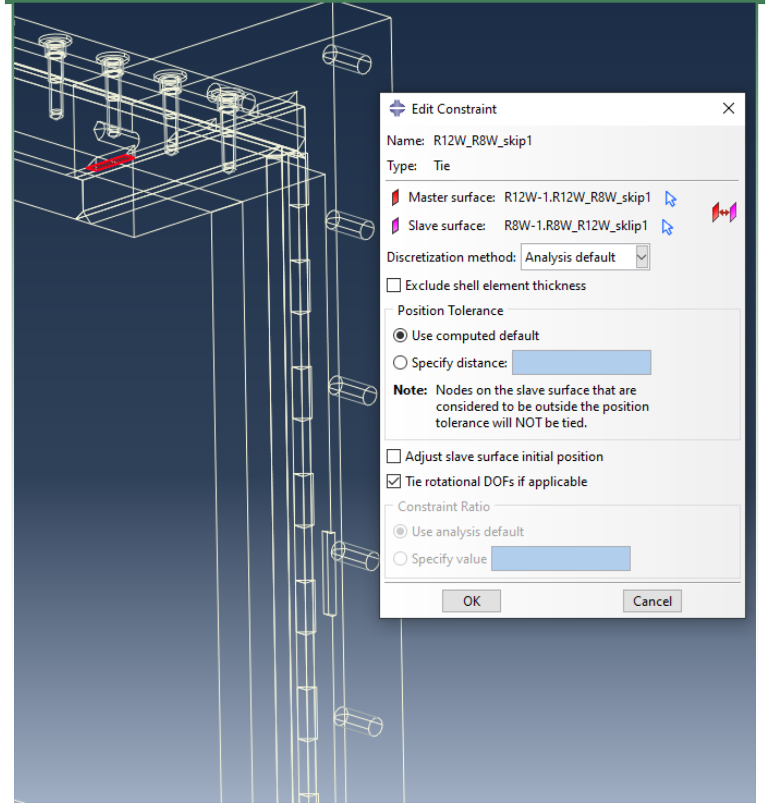


Rear Flange to bottom plate inside

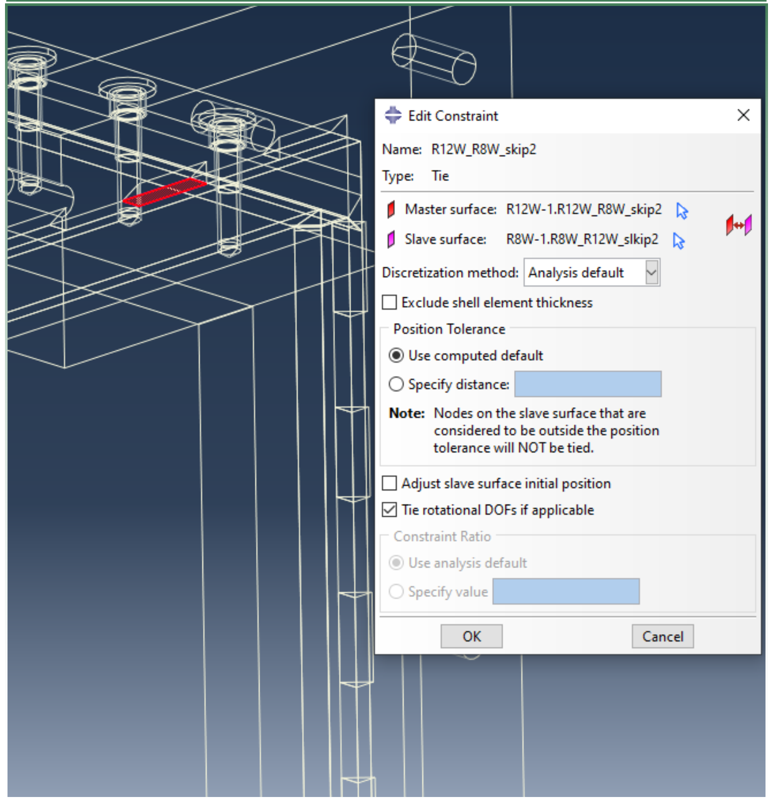


Skip weld tie constraints with rear flange – total 14

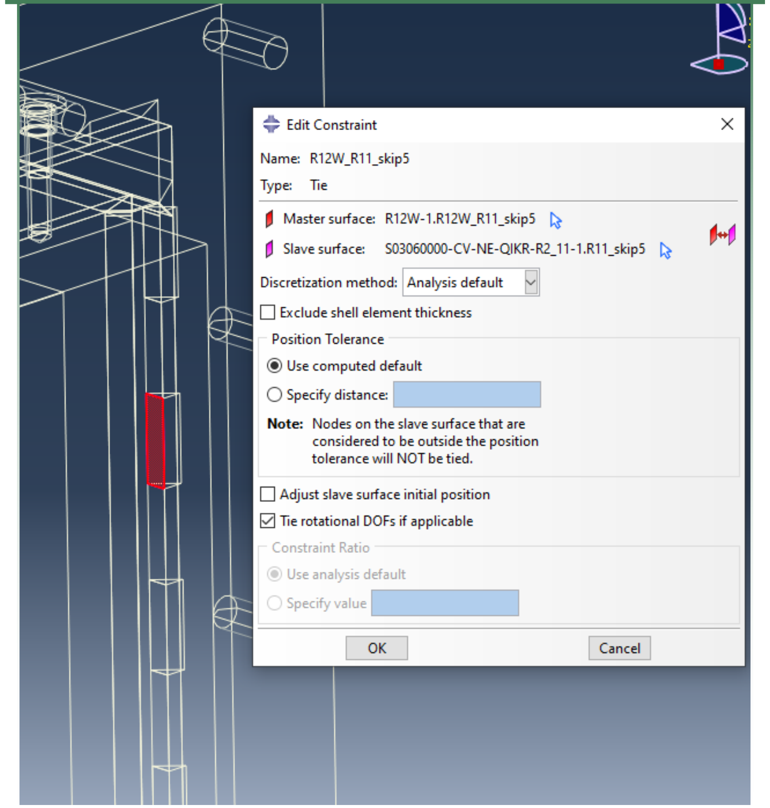
Centerline skip weld



Typical top or bottom skip weld



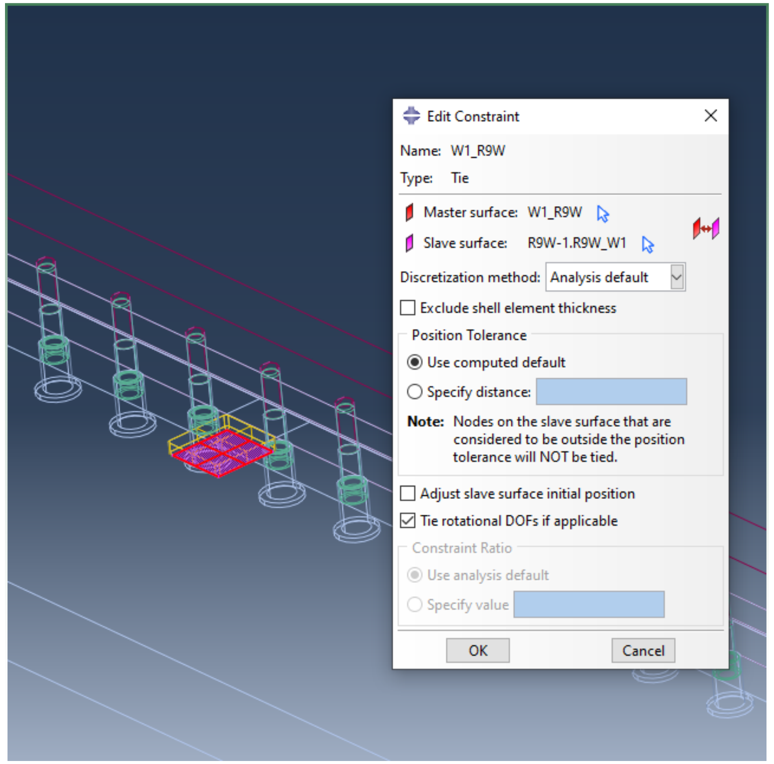
Typical side wall skip weld



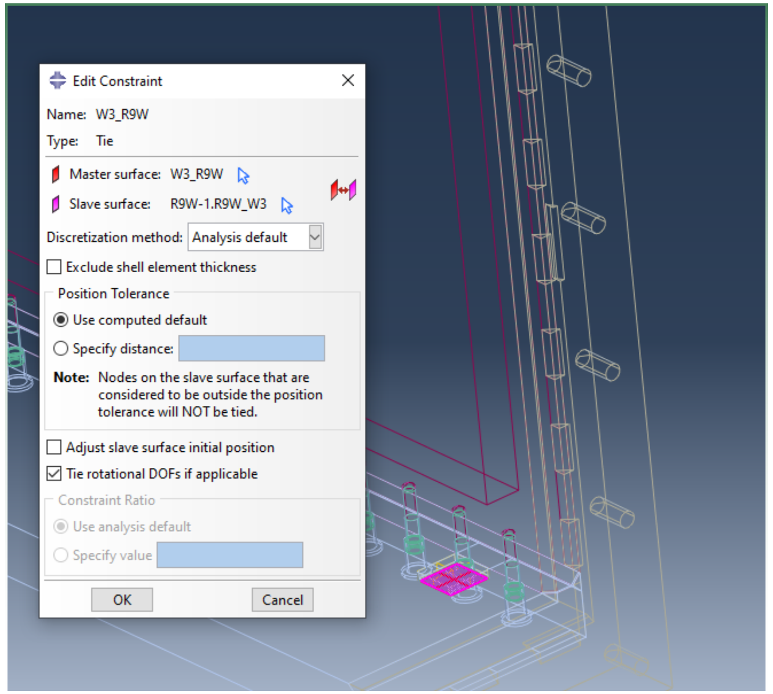
Inconel pad tie constraints to bottom plate (3 locations)

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

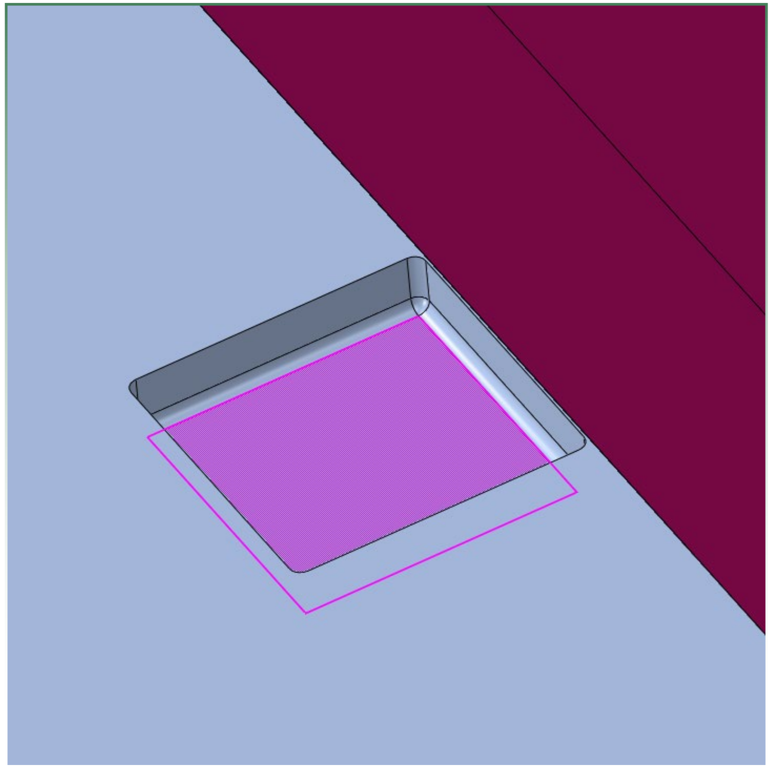
Front Wheel pad tie



Rear Wheel tie

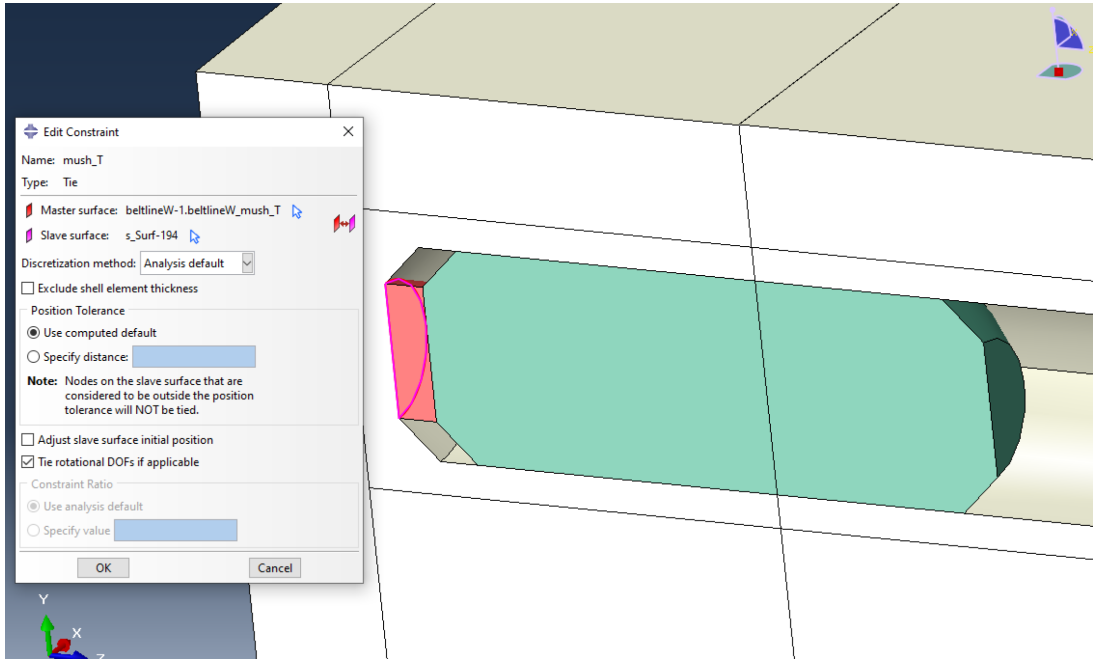


Bottom plate tied surface



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

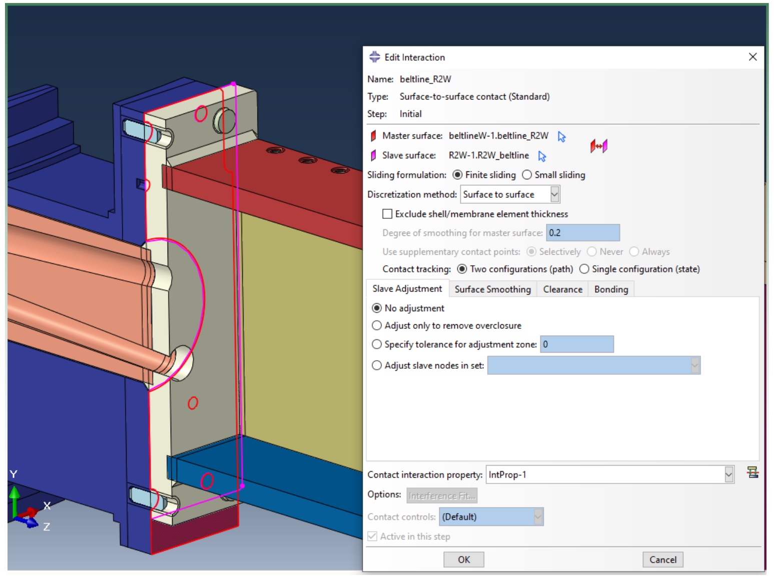


Interactions

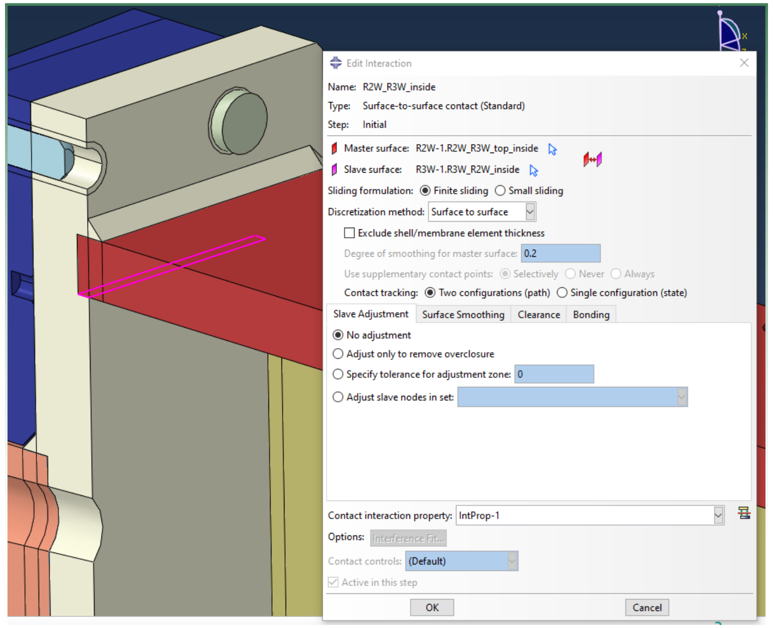
- All Hard Frictionless
- Allows separation

Interactions around front flange

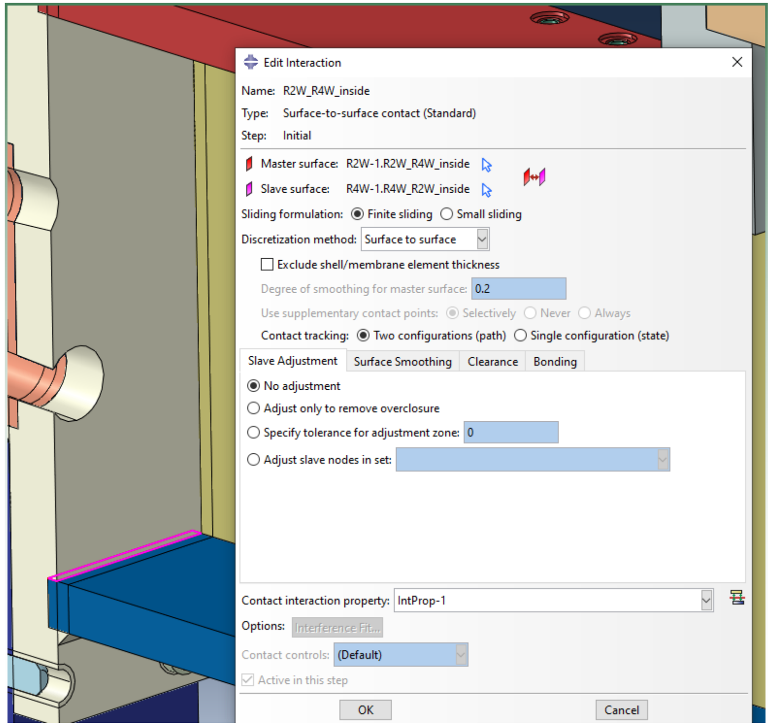
Beltline and Front Flange



Front top plate bottom inside to front flange

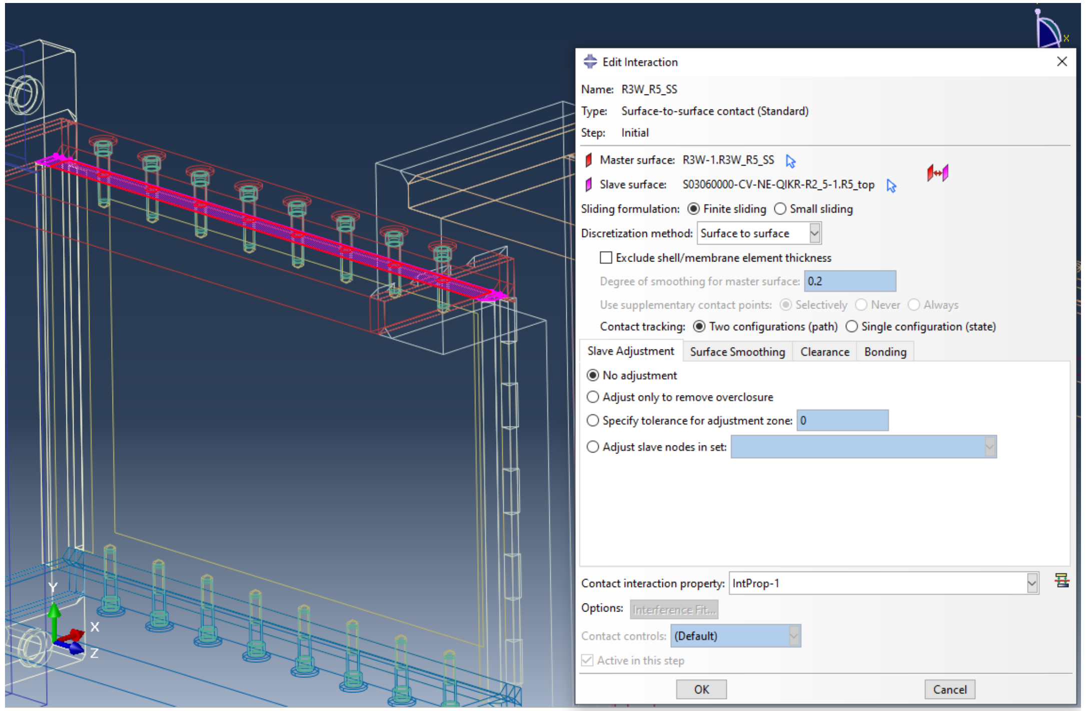


Front bottom plate top inside to front flange

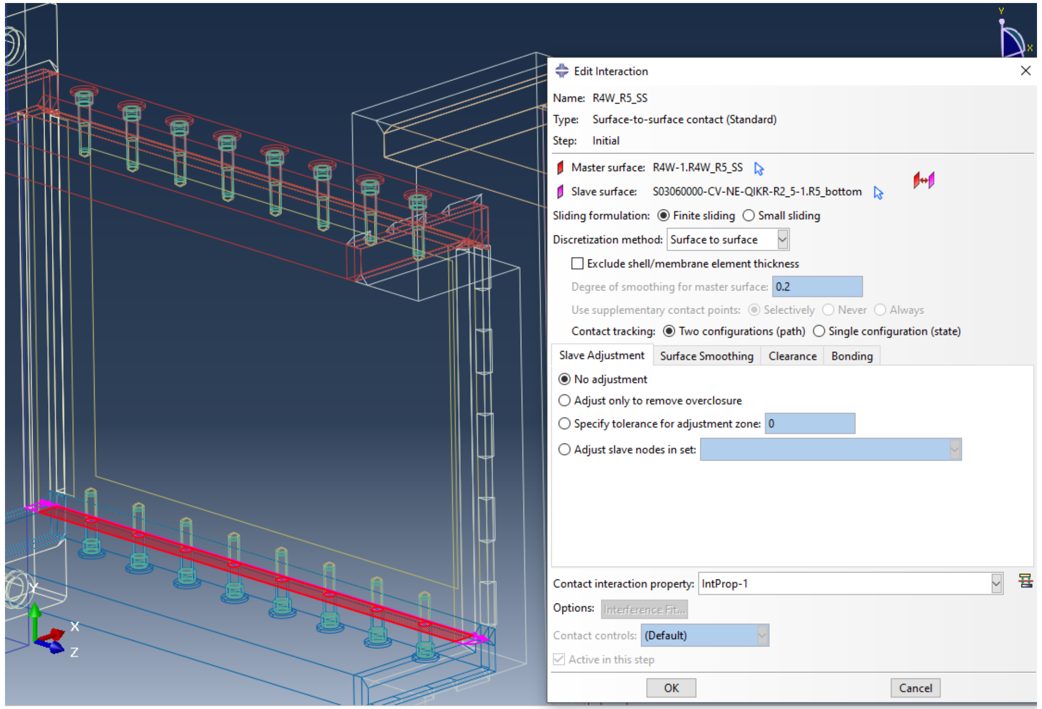


Front Side Wall interactions

Front top plate to front side all

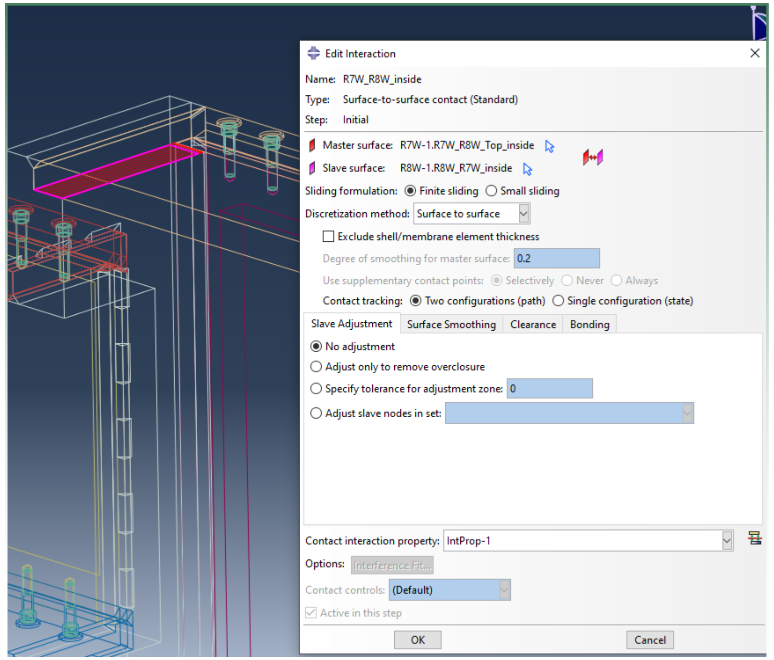


Front bottom plate to front side wall

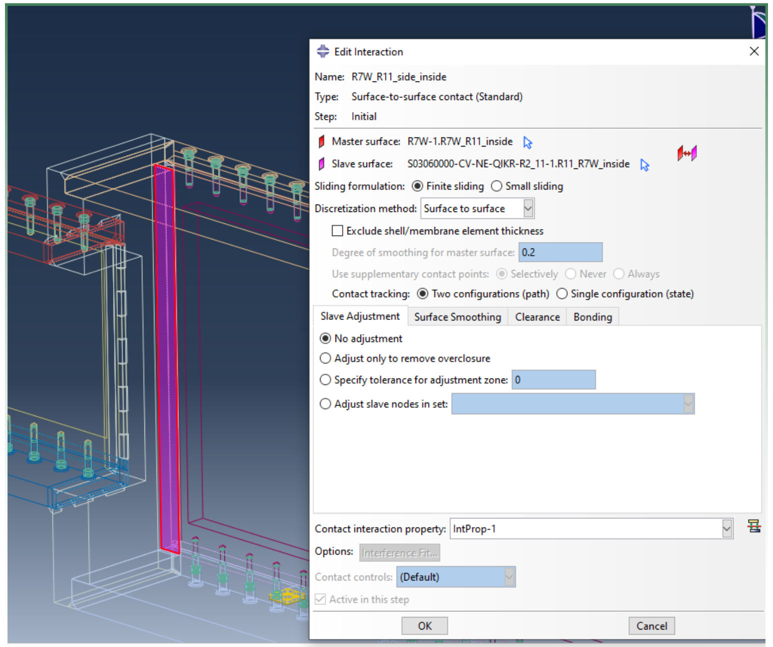


Intermediate flange interactions

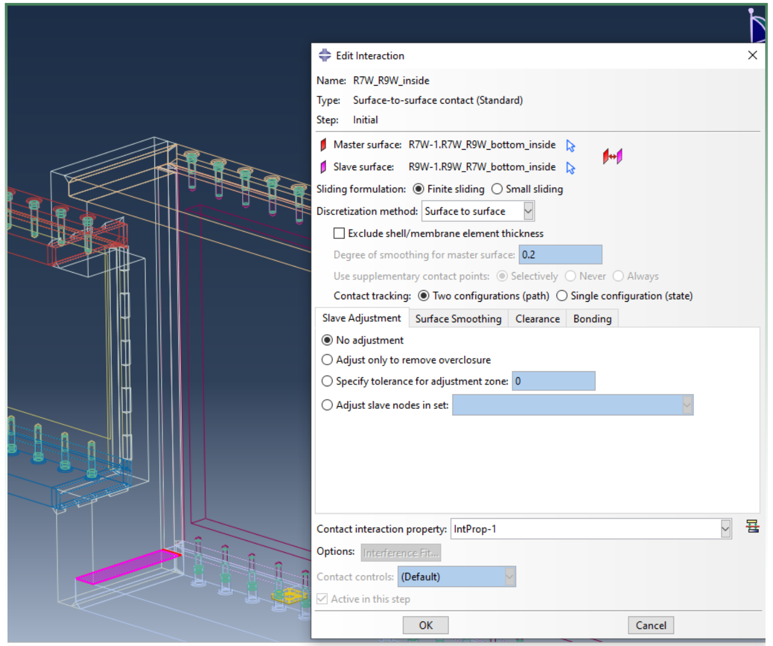
Intermediate flange to rear top plate



Intermediate flange to rear side wall

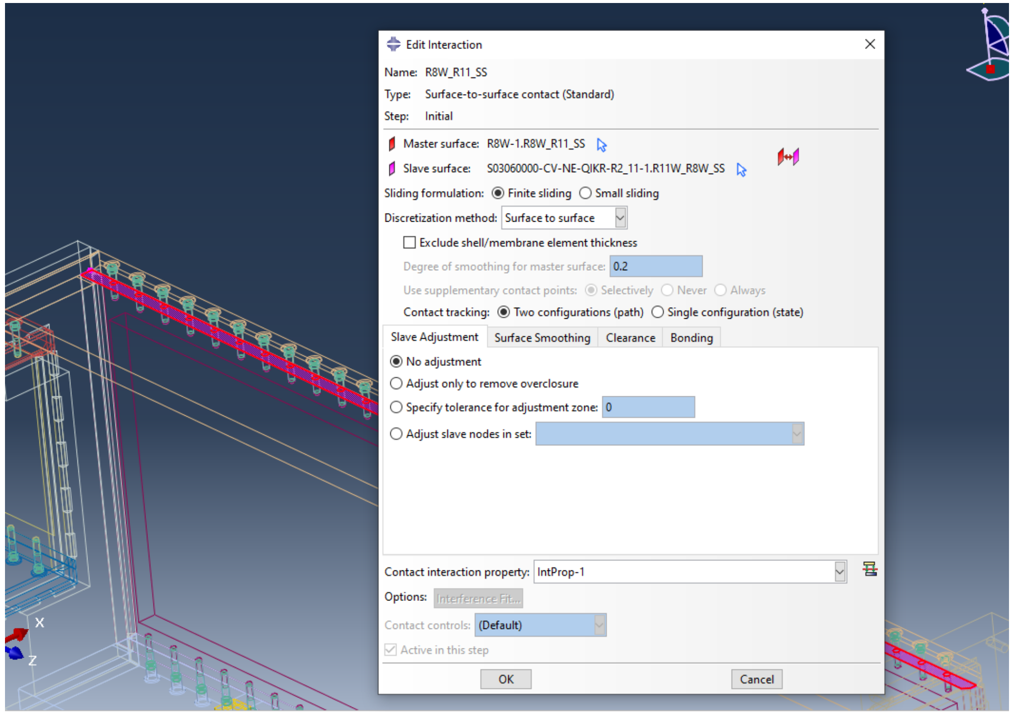


Intermediate flange to rear bottom plate

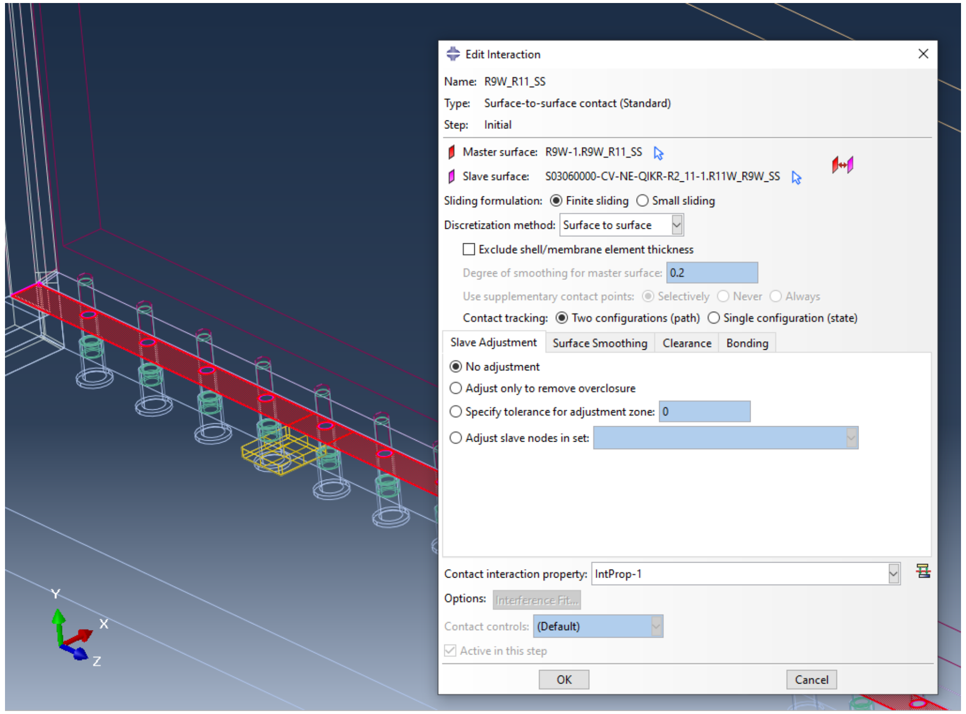


Rear side wall (R11) interactions

Rear top plate to rear side wall

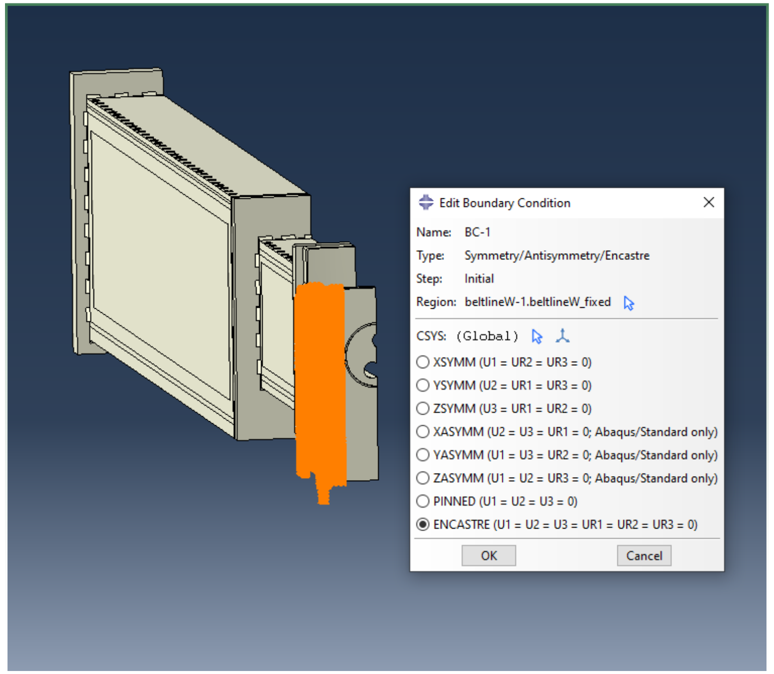


Rear bottom plate to side wall

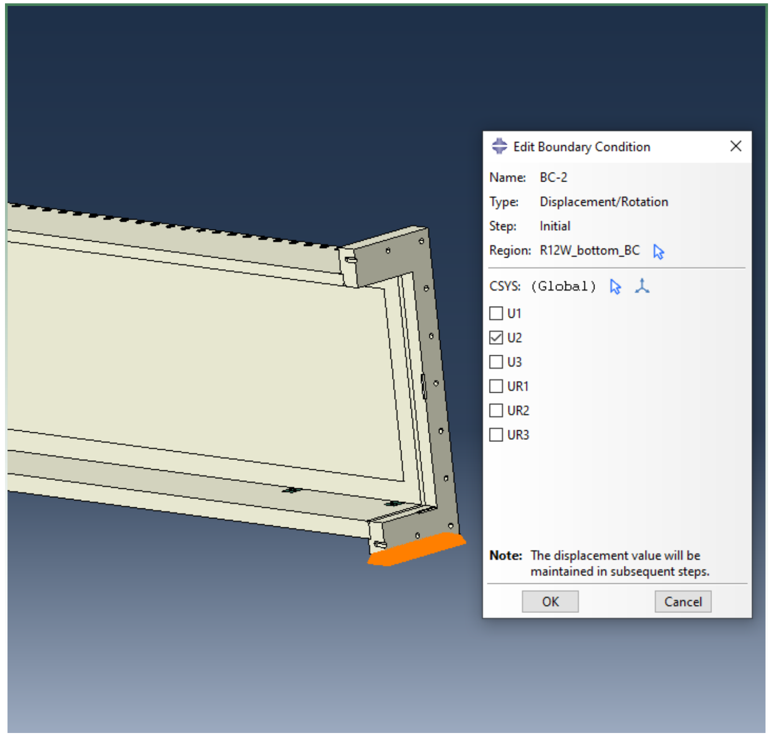


Boundary Conditions

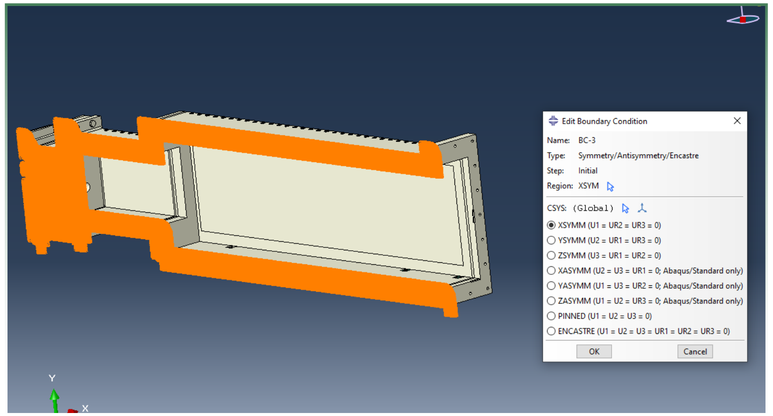
Beltline side nodes fixed



Rear flange bottom nodes restrained vertically

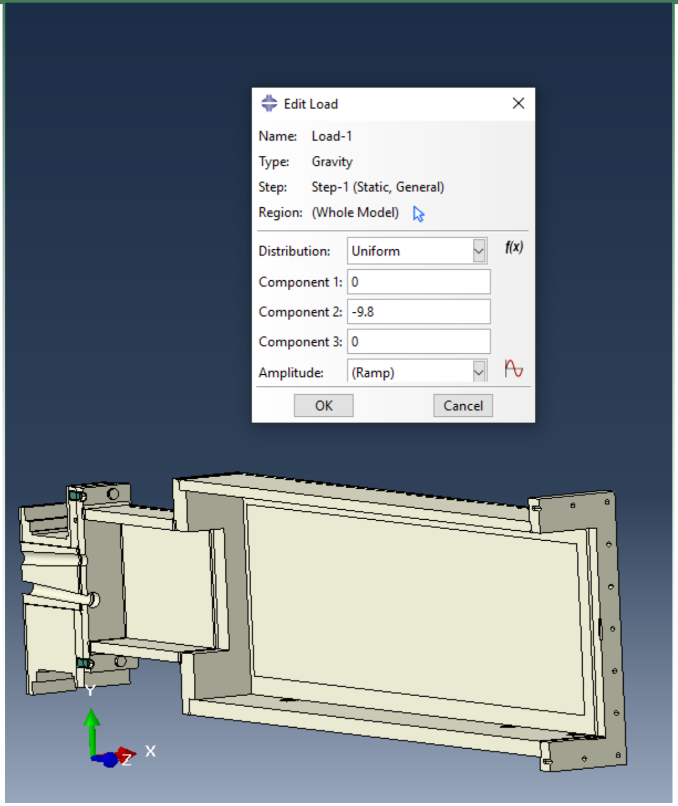


X symmetry boundary condition

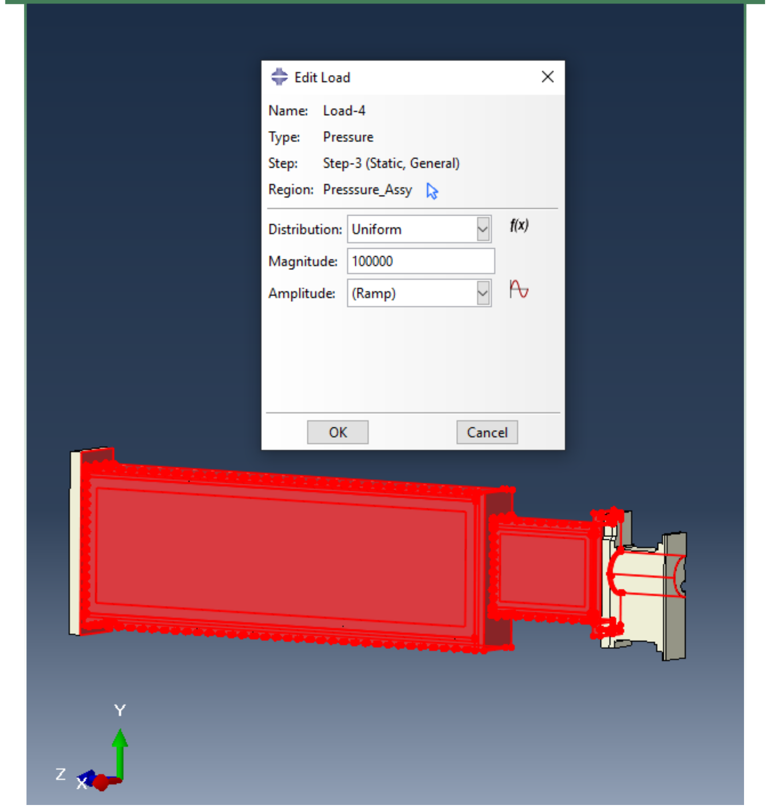


Loads

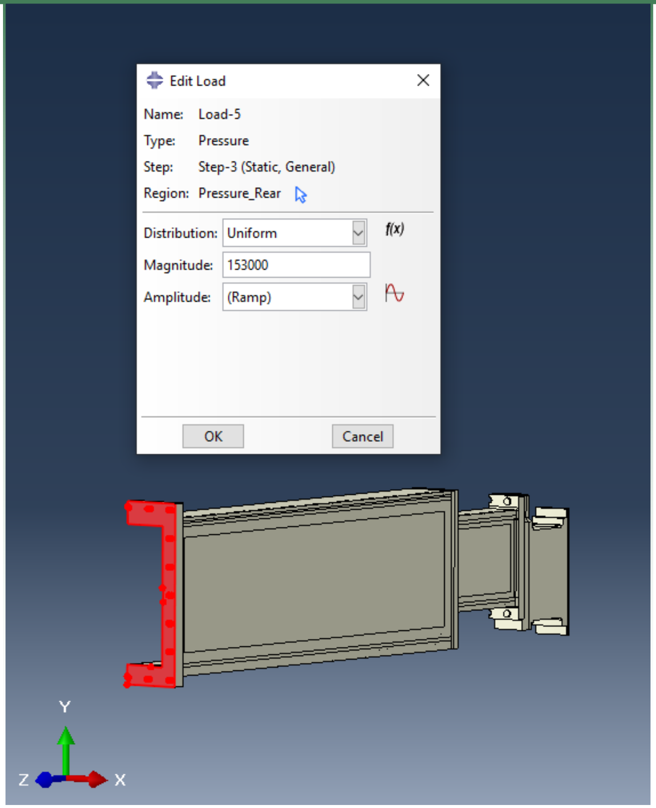
Gravity



Pressure 1 bar



Pressure equivalent on rear flange

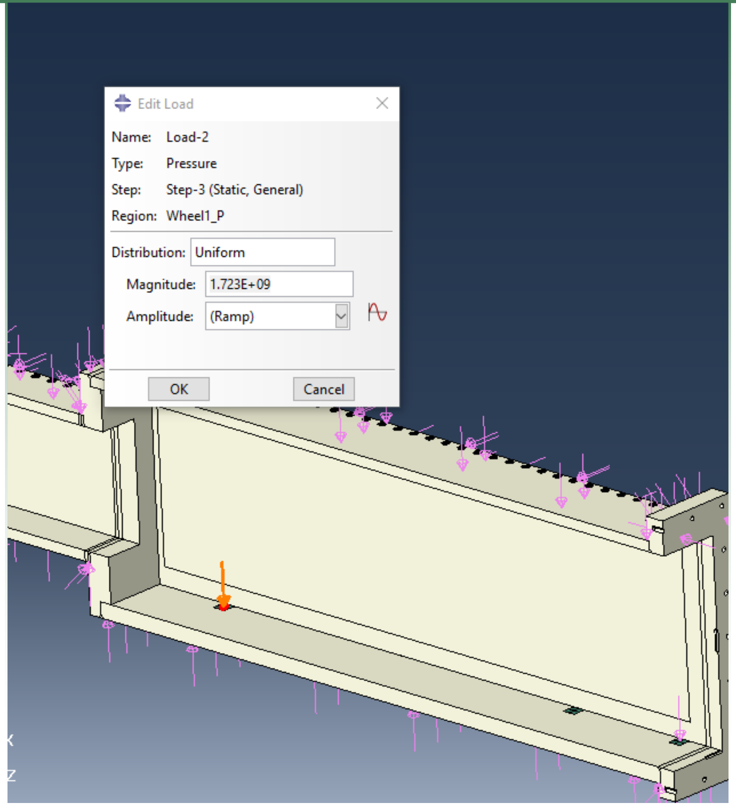


Uniform Pressure (Pa) loads from inserts on wheel pads

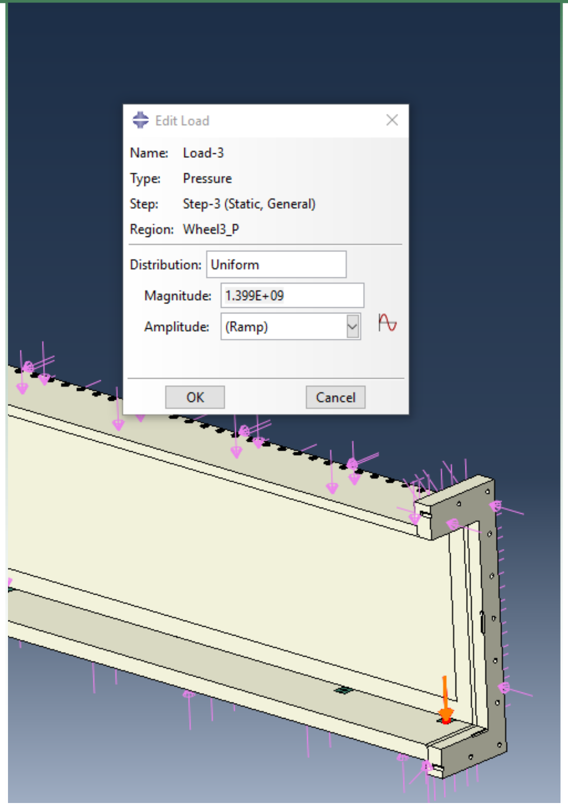
Insert load assumptions

- 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

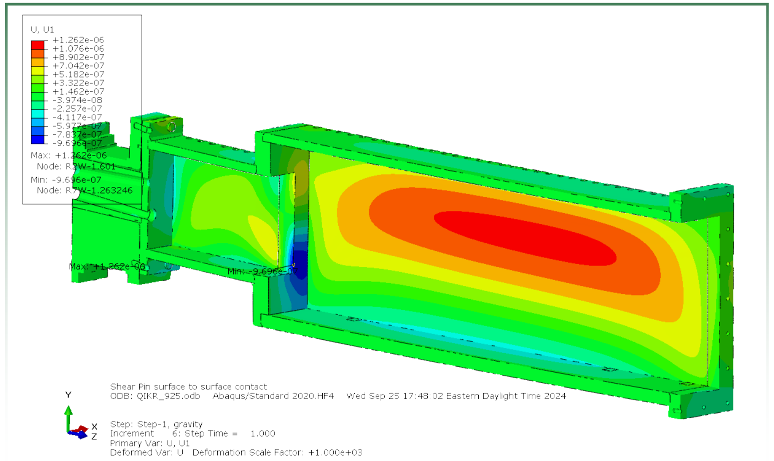


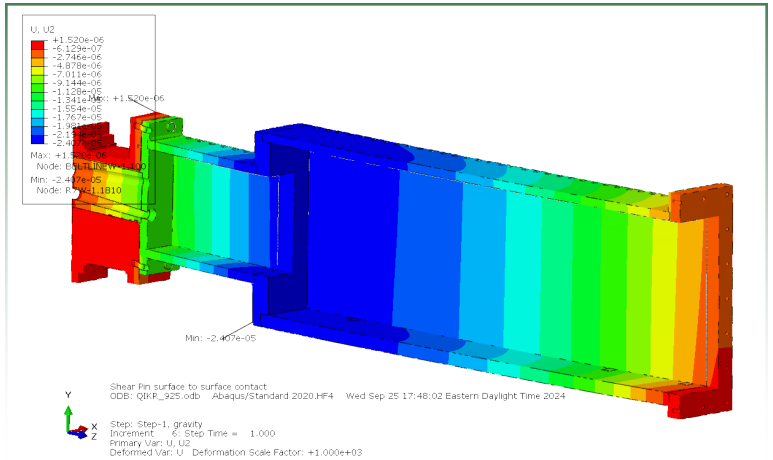
Results

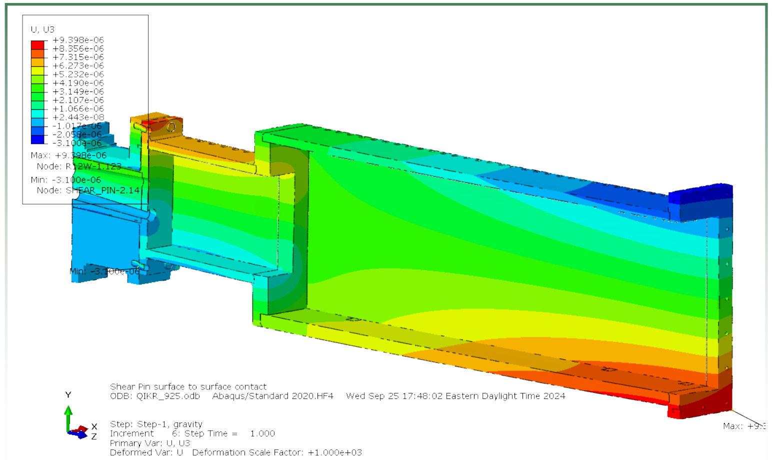
- Step 1 – gravity only load
- Step 2 – gravity and insert loads
- Step 3 – gravity, insert loads and pressure from vacuum operation

Displacements with only gravity and no inserts

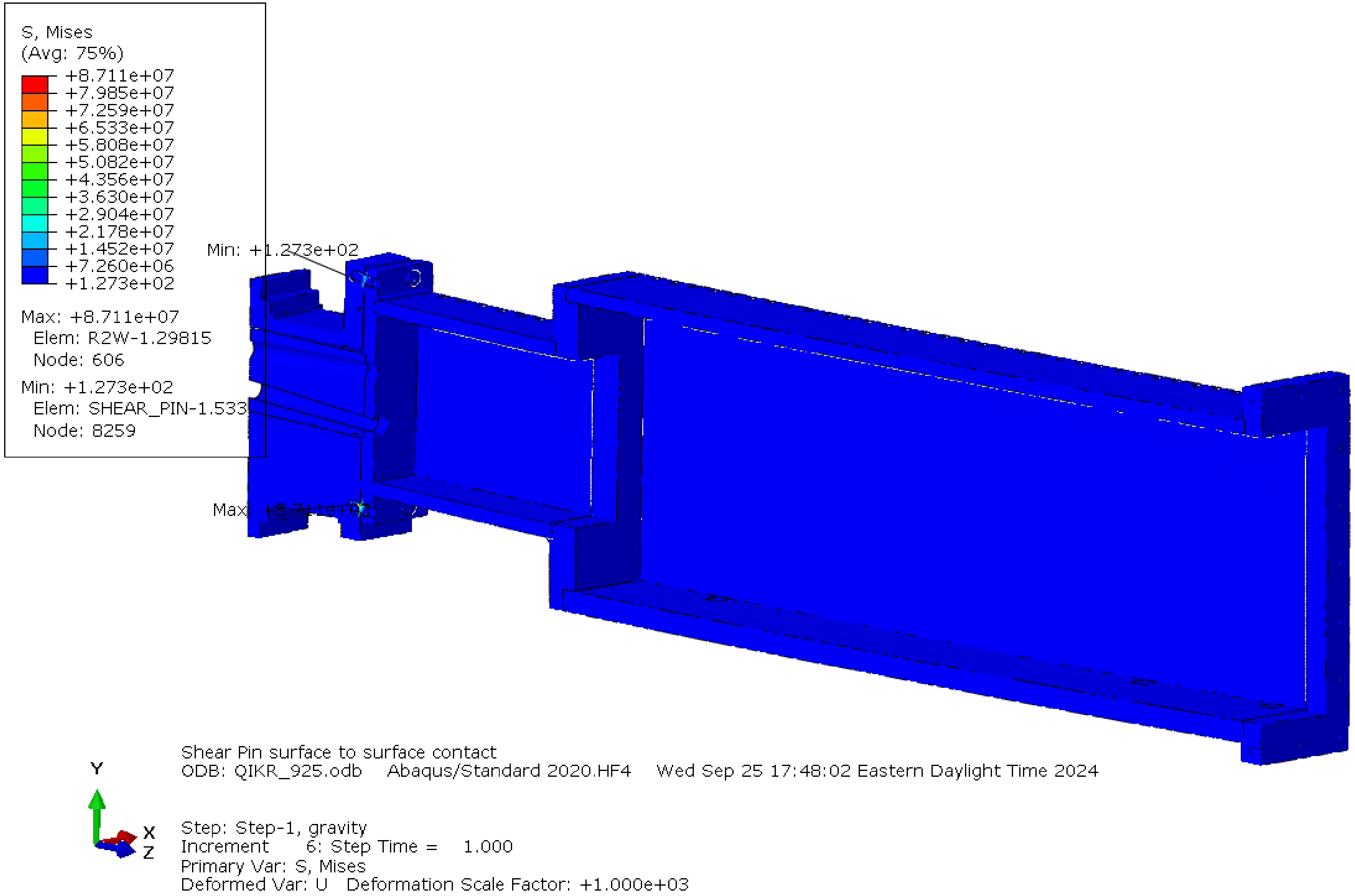
U1 (x) minimum -.01mm	U2 (y) minimum -0.025 mm	U3 (z) minimum -.03 mm







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

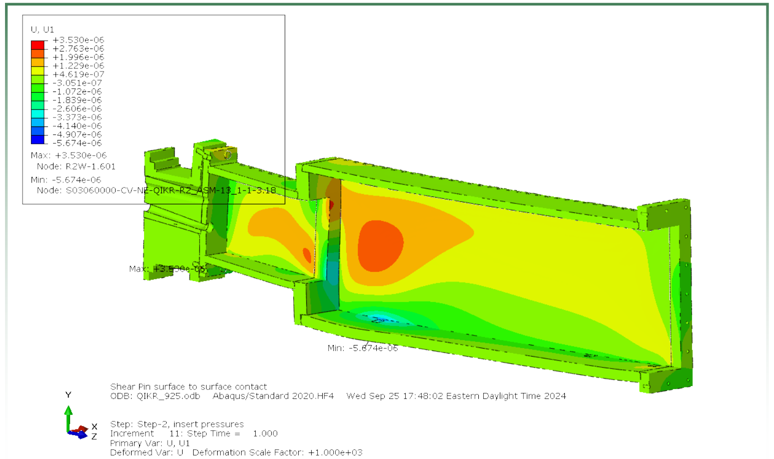


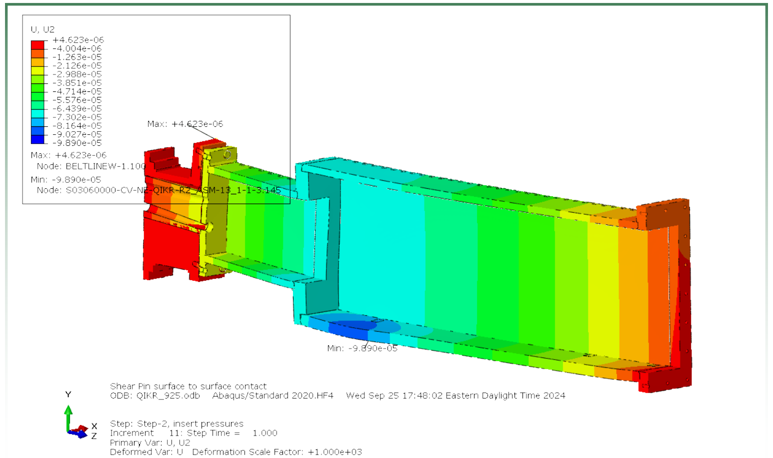
Assembly Displacement with gravity including insert loads

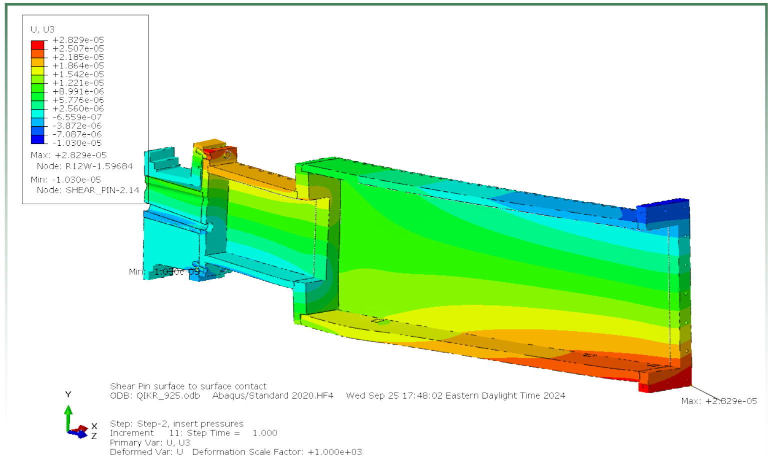
U1 (x) minimum -0.006mm

U2 (y) minimum -0.1 mm

U3 (z) minimum -0.01 mm





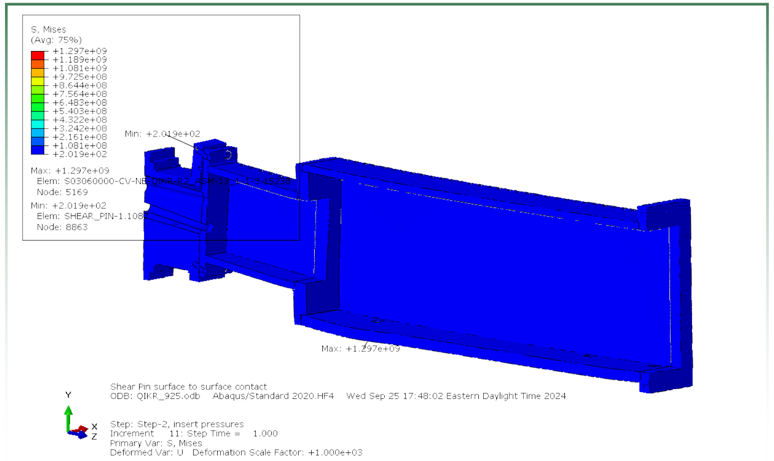


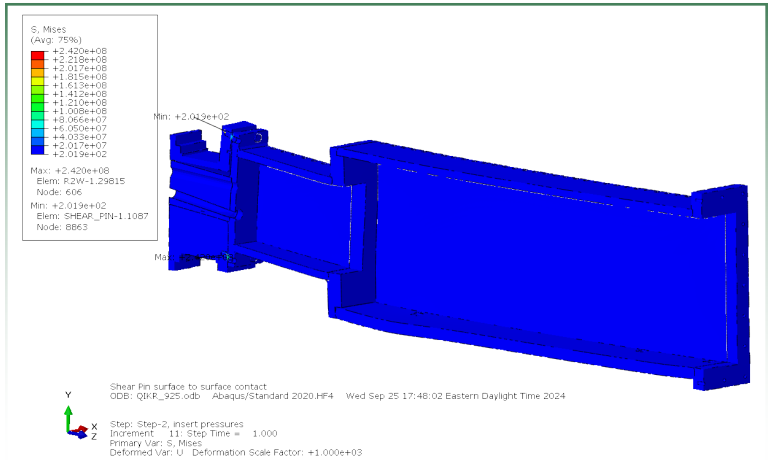
Assembly Stresses with gravity and insert loads

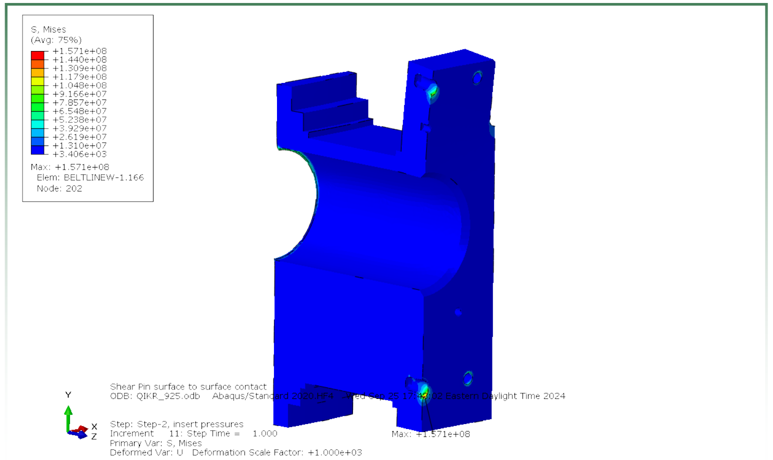
Peak 1297 MPa in Inconel Pad

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

Beltline Peak157 MPa by bottom shear pin hole

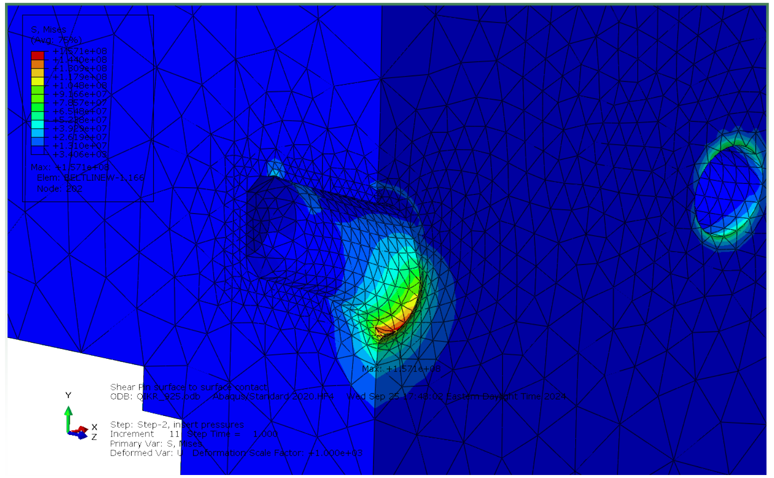




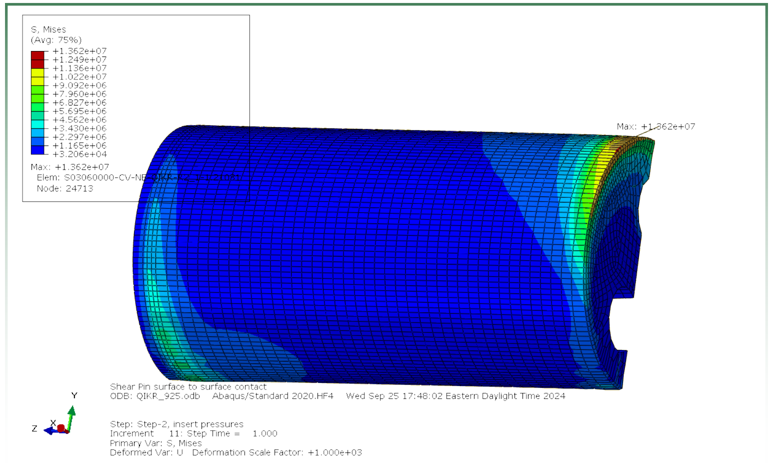


Assembly Stresses with gravity and insert loads

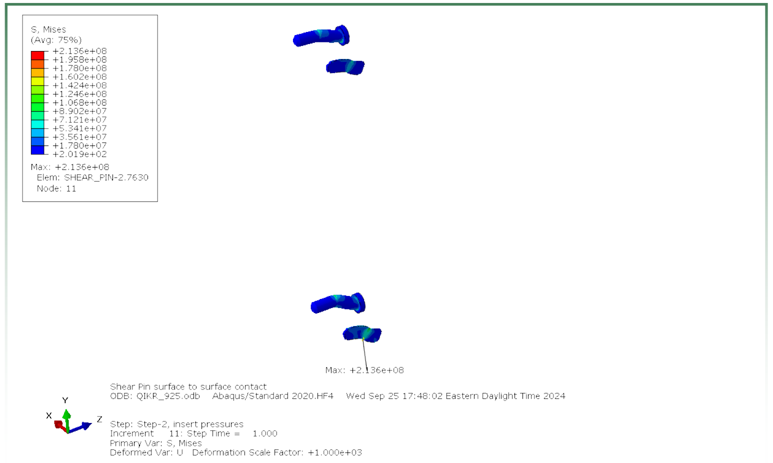
Beltline peak stress location



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

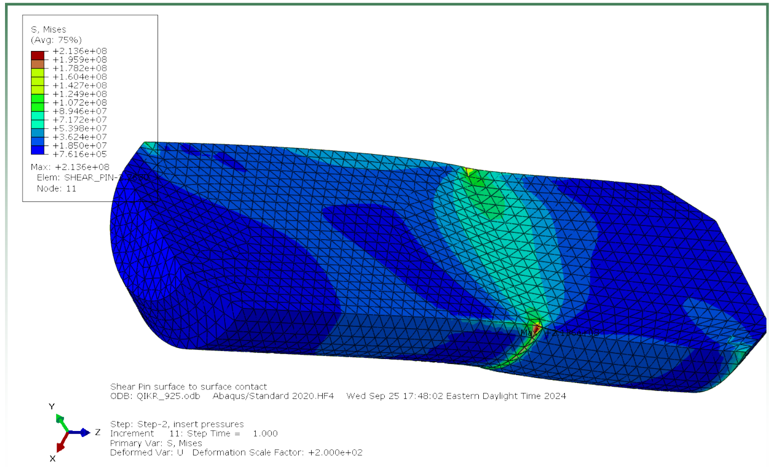


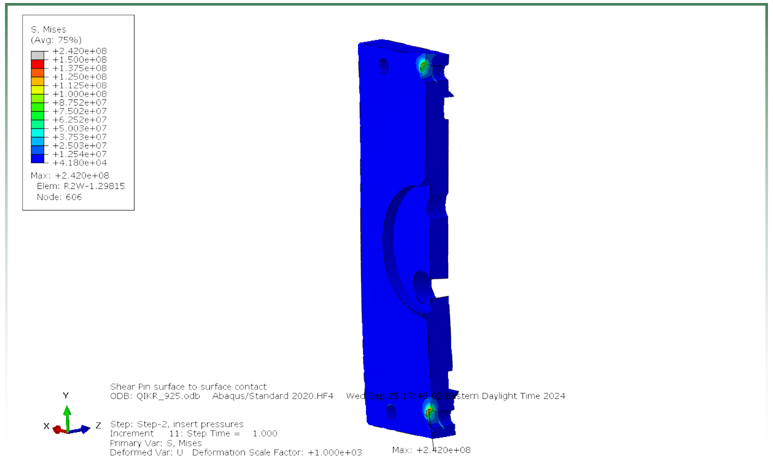
Assembly Stresses with gravity and insert loads

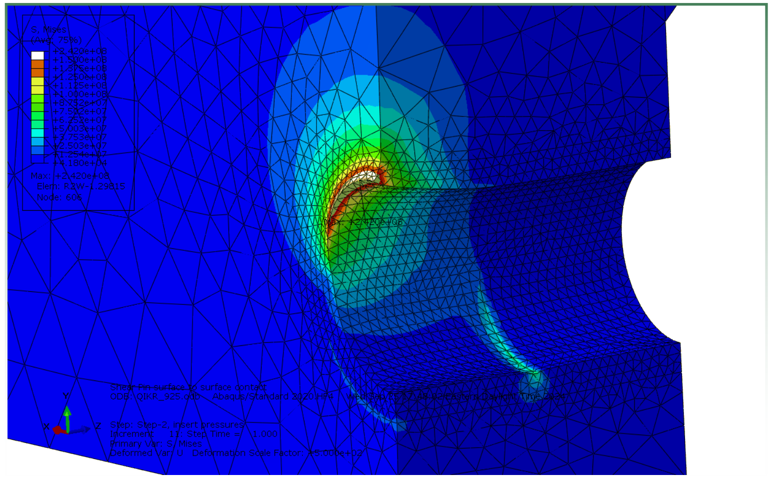
Bottom Shear Pin peak 213 MPa with mesh shown

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



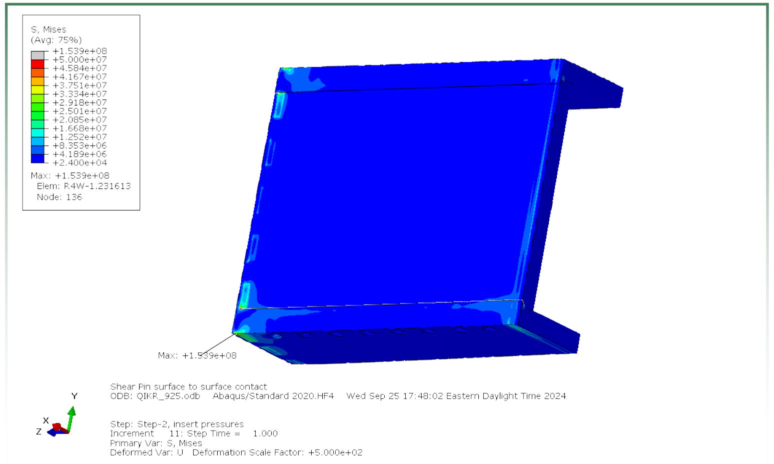




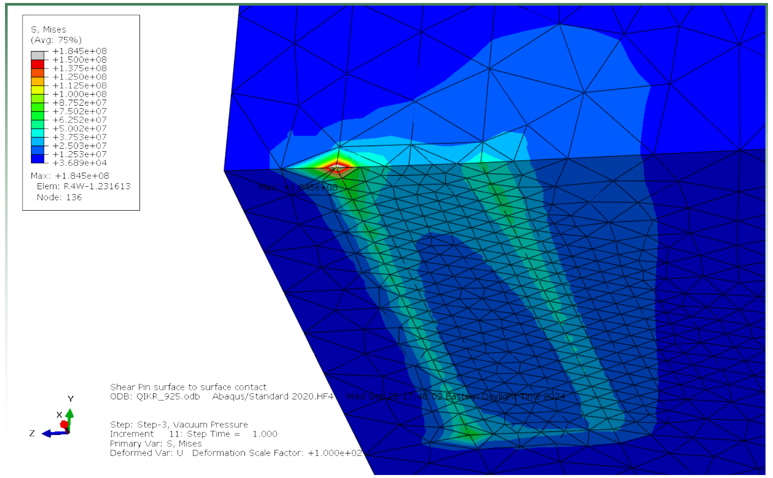
0.5 mm bearing surface offset for rear to avoid common nodes for both surfaces

Assembly Stresses with gravity and insert loads

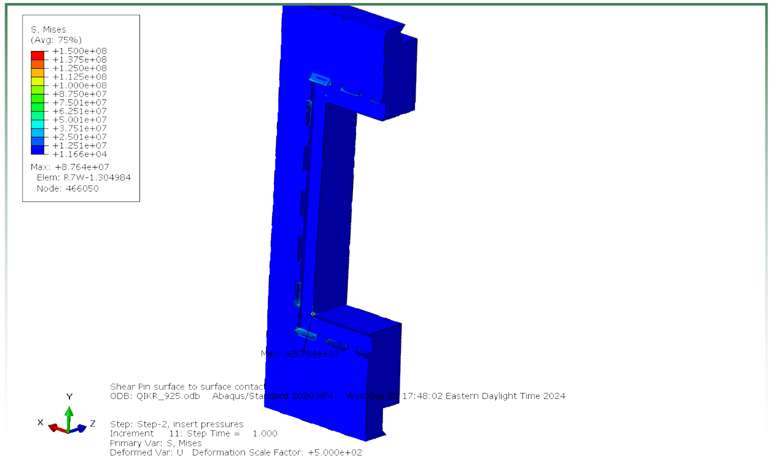
Stresses in front top, side and bottom plates – 50 MPa scale - peak 154 MPa



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



Intermediate Flange with merged welds – peak 88 MPa

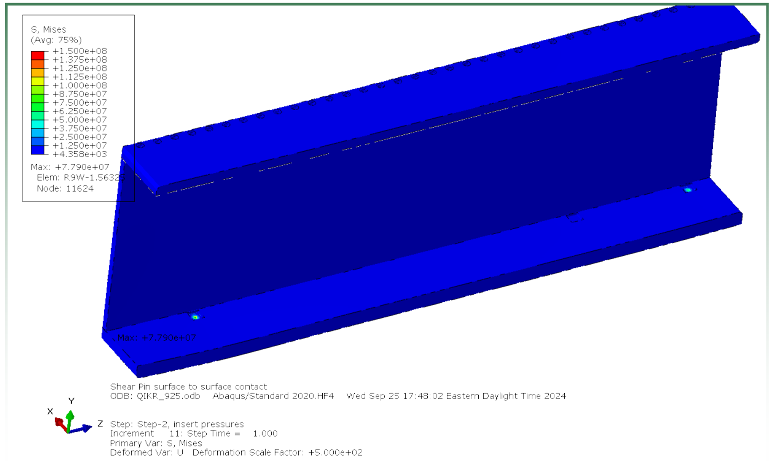


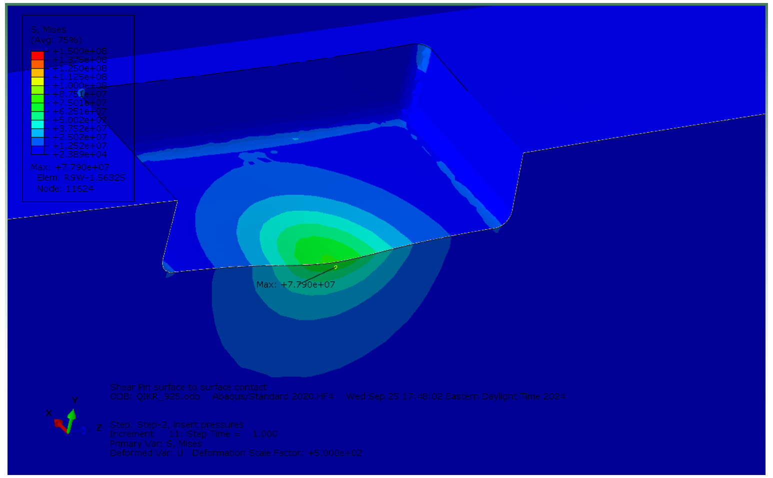
Assembly Stresses with gravity and insert loads

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

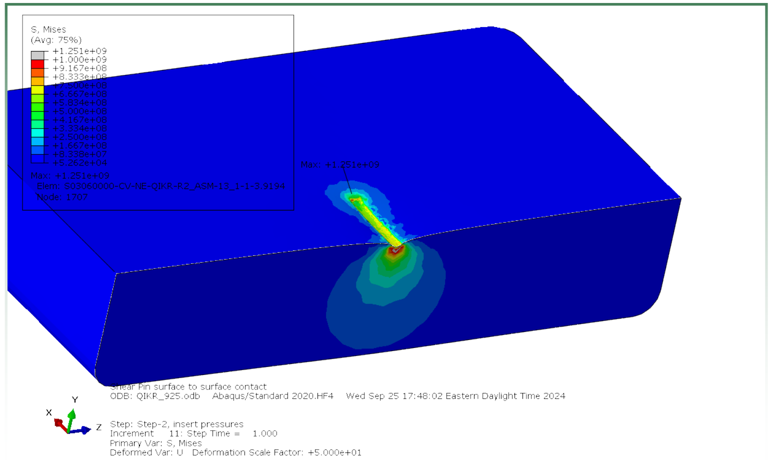
Bottom Plate stress under Inconel pad – 77 MPa peak

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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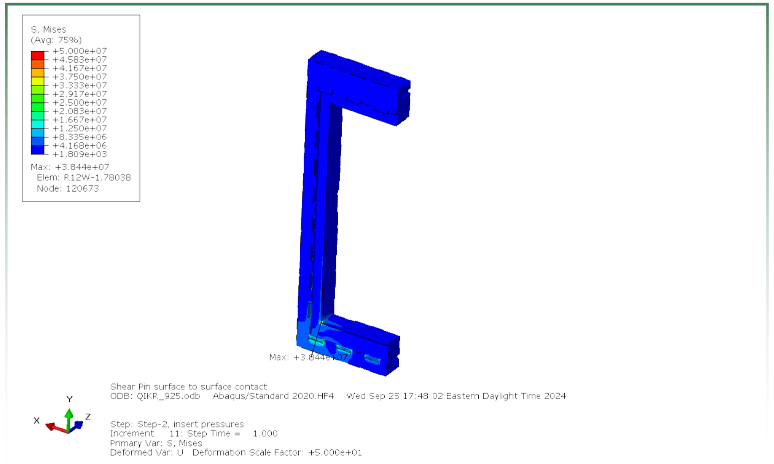
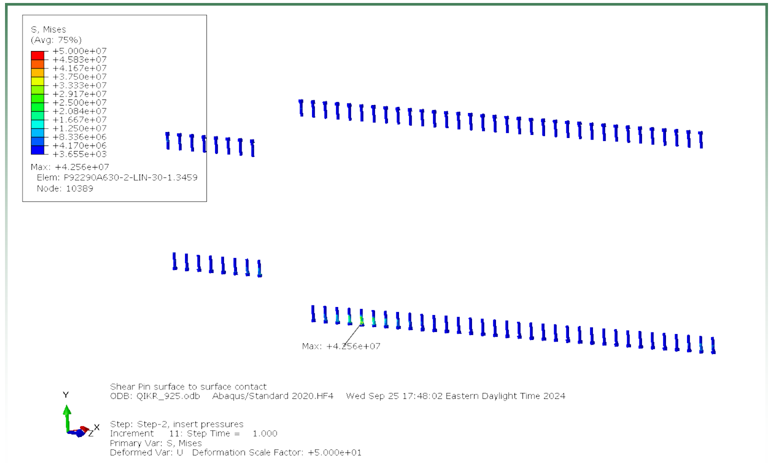
Stresses with gravity and insert loads

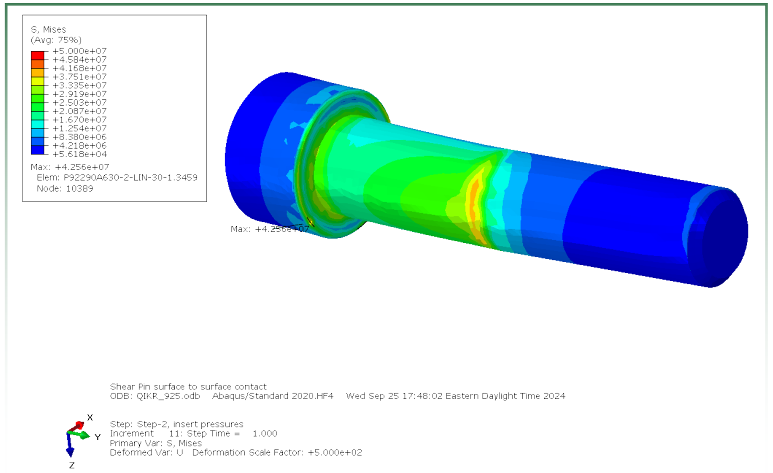
Rear Flange with merged welds peak stress 38 MPa



Peak 12 mm Bolt stress 42.6 MPa



Highest Stressed bolt – peak 42.6 MPa

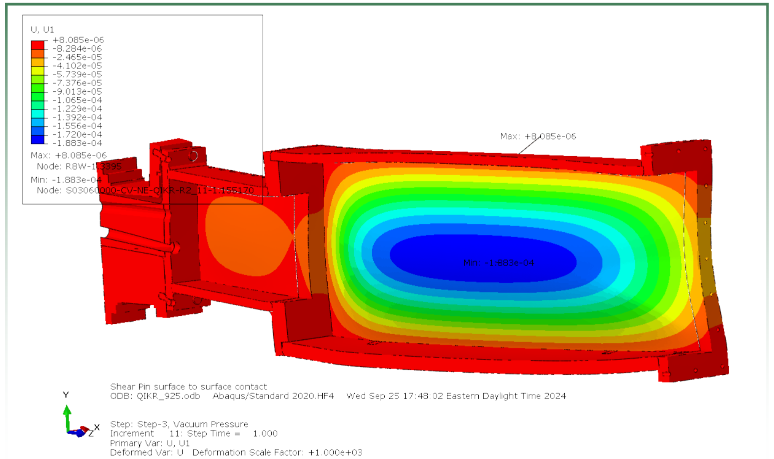


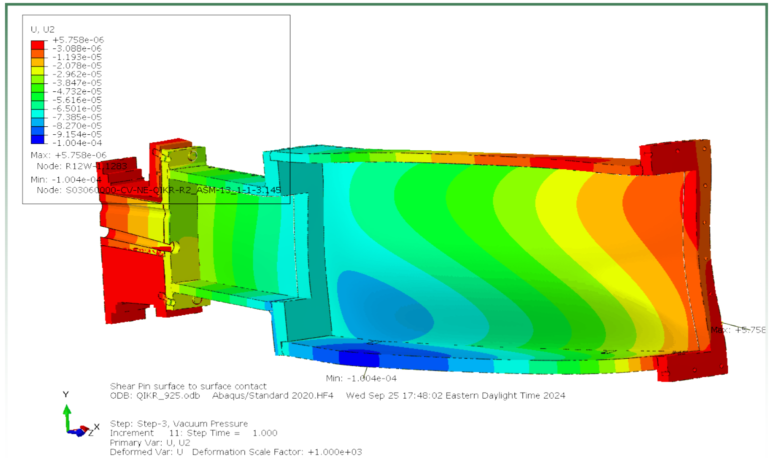
Step 3 Gravity, Insert loads and Pressure loads - displacements

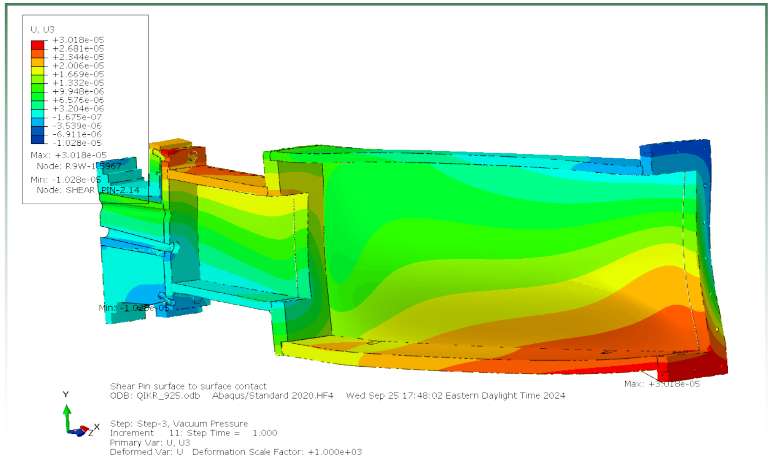
U1 minimum -0.188 mm

U2 minimum -0.10 mm

U3 minimum -0.01 mm





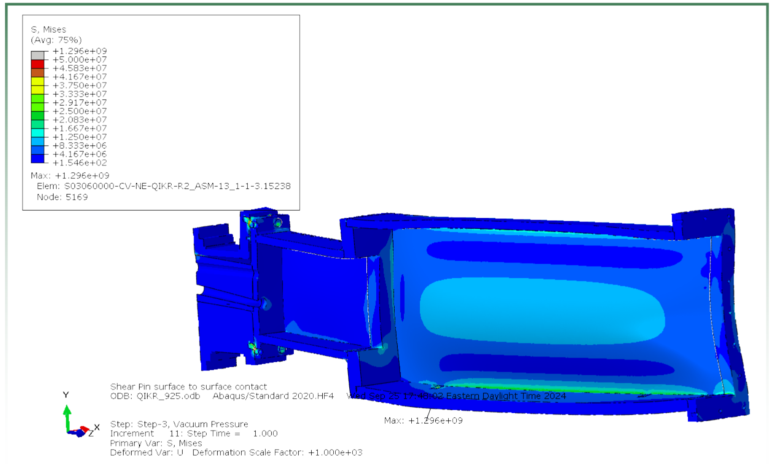


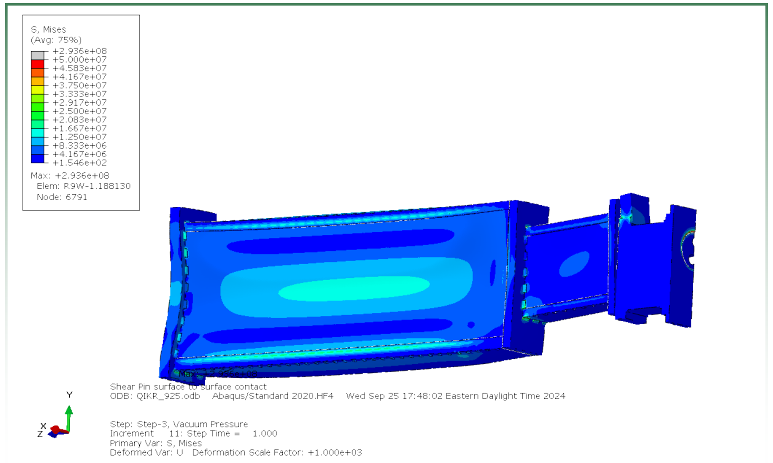
Step 3 Gravity, Insert loads and Pressure loads - Stress

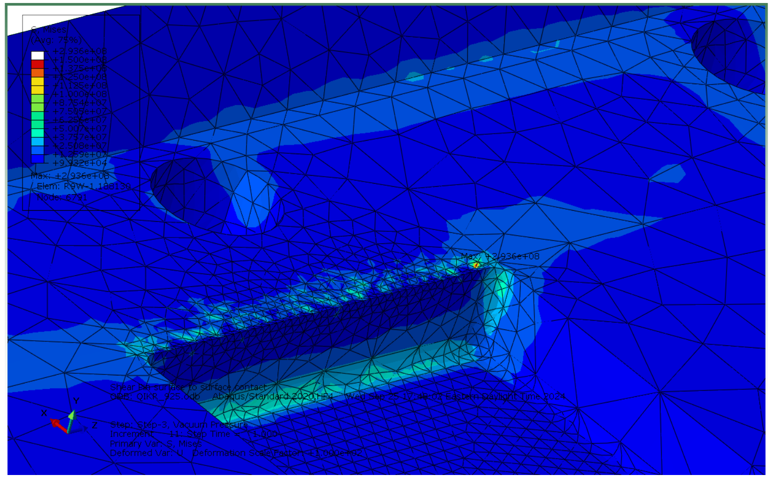
Stress 50 MPa scale peak 1292 MPa in pad

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







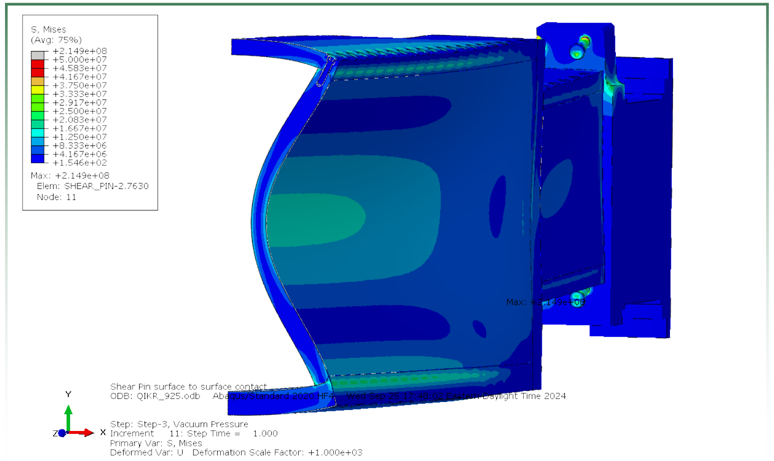
Step 3 Gravity, Insert loads and Pressure loads - Stress

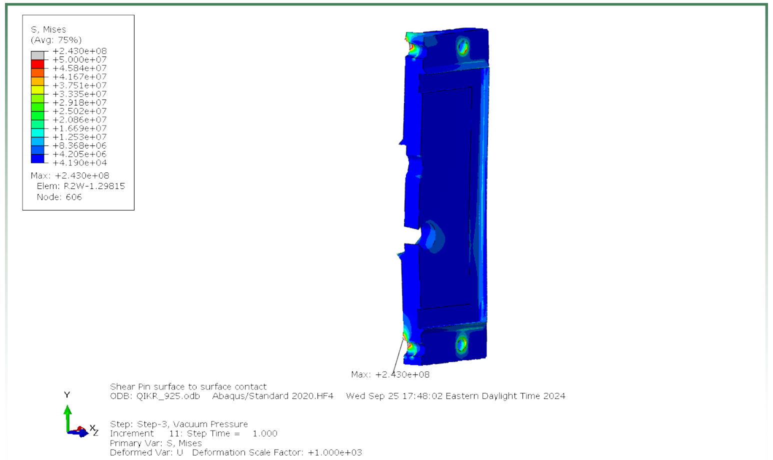
Axial cut with 50 MPa scale

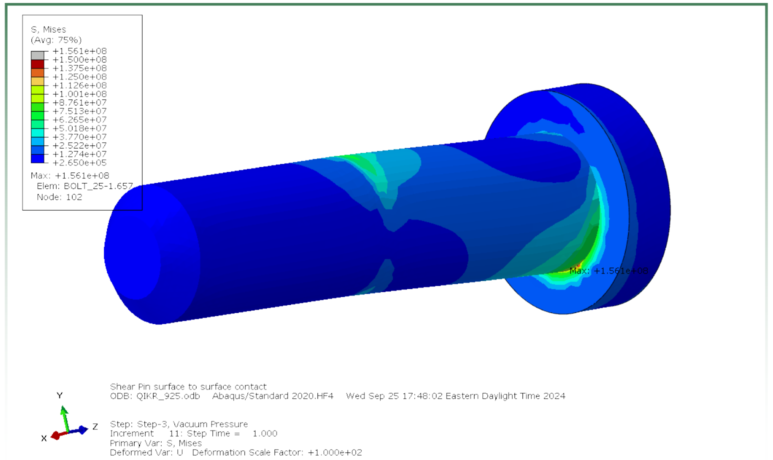
Displacement factor x1000

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

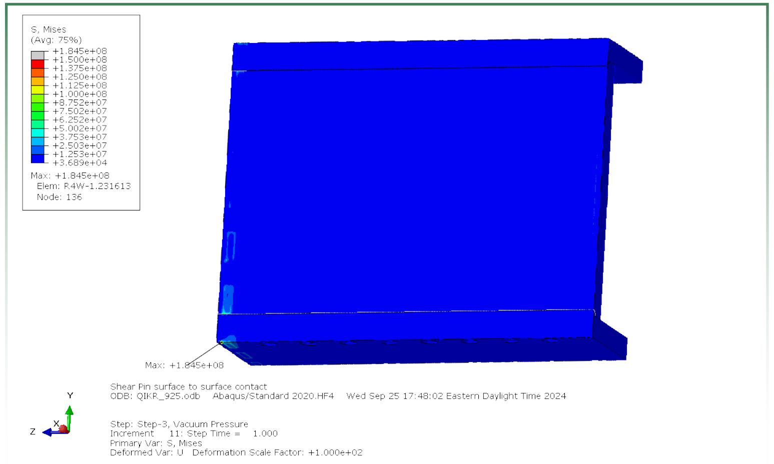




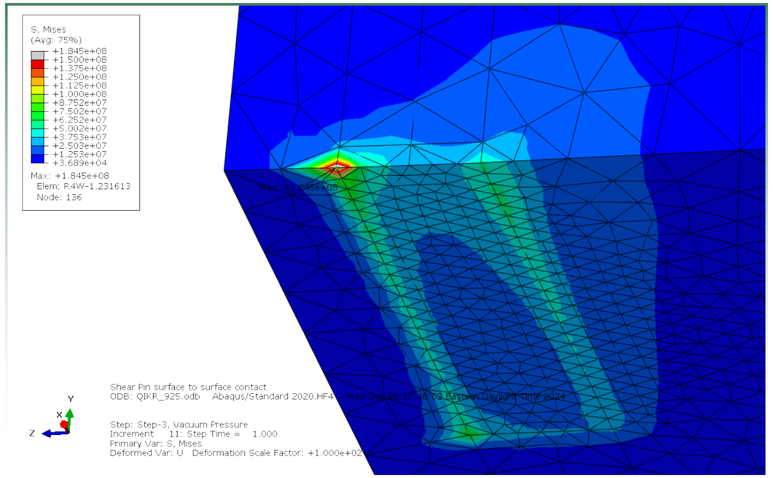


Step 3 Gravity, Insert loads and Pressure loads - Stress

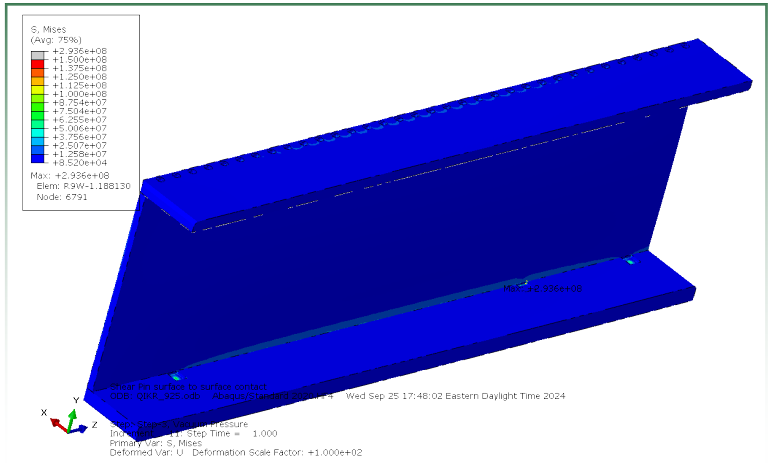
Front, side and bottom plate stress peak 184 MPa



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

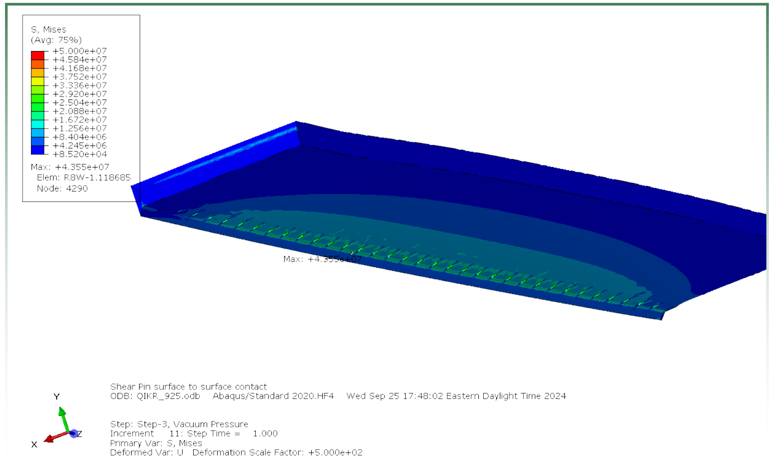


Rear Top,Side and Bottom plate stress 150 MPa scale peak 294 MPa at isolated element

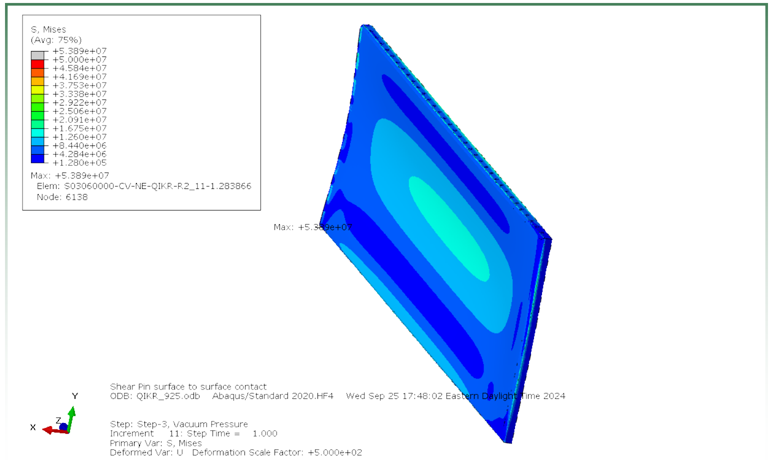


Step 3 Gravity, Insert loads and Pressure loads - Stress

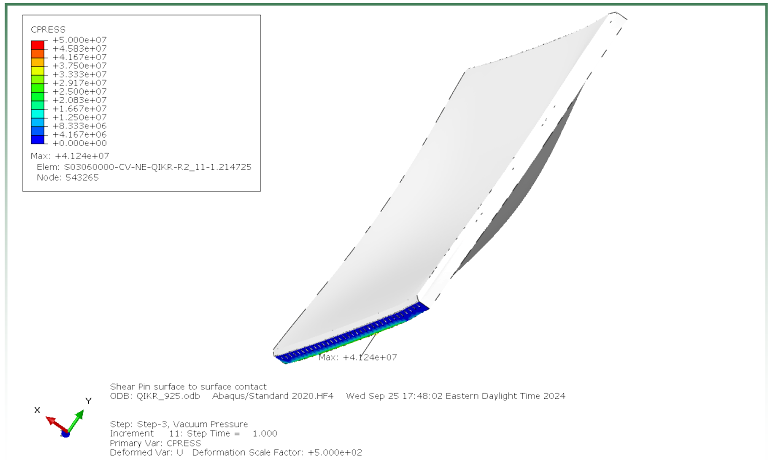
Rear Top Plate 50 Mpa scale peak 43 MPa



Rear Side Plate Stress 50 MPa scale

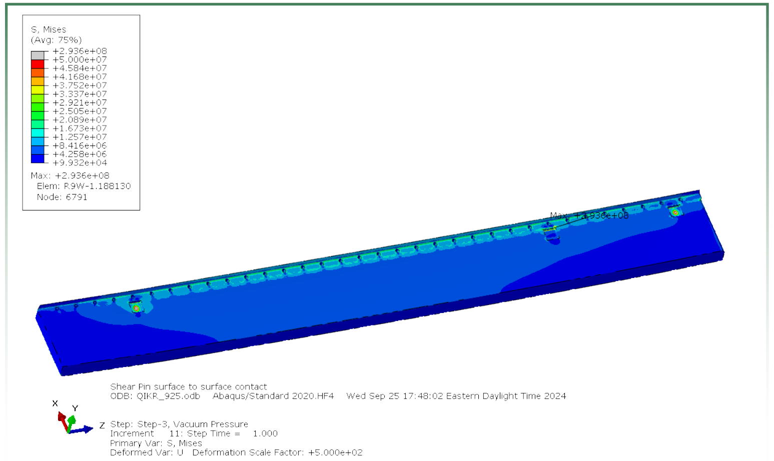


Rear Side Place Contact Pressure

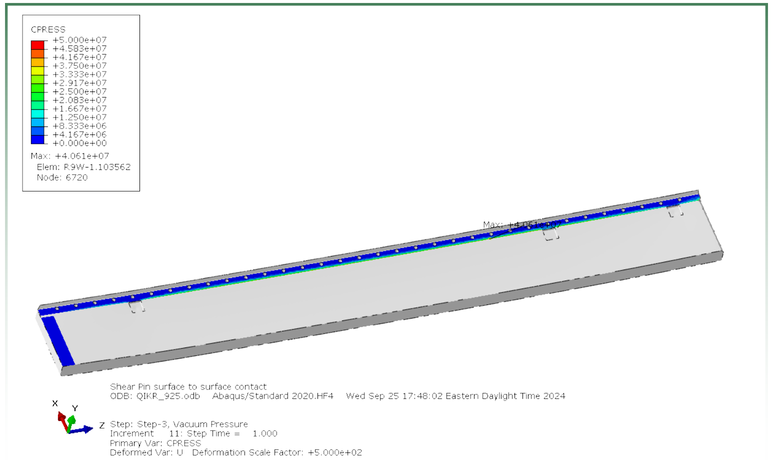


Step 3 Gravity, Insert loads and Pressure loads - Stress

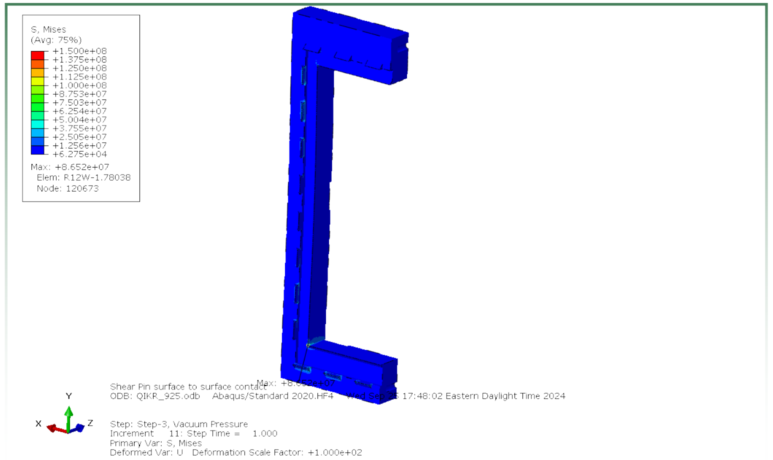
Rear Bottom plate scale 50 MPa peak 294 MPa



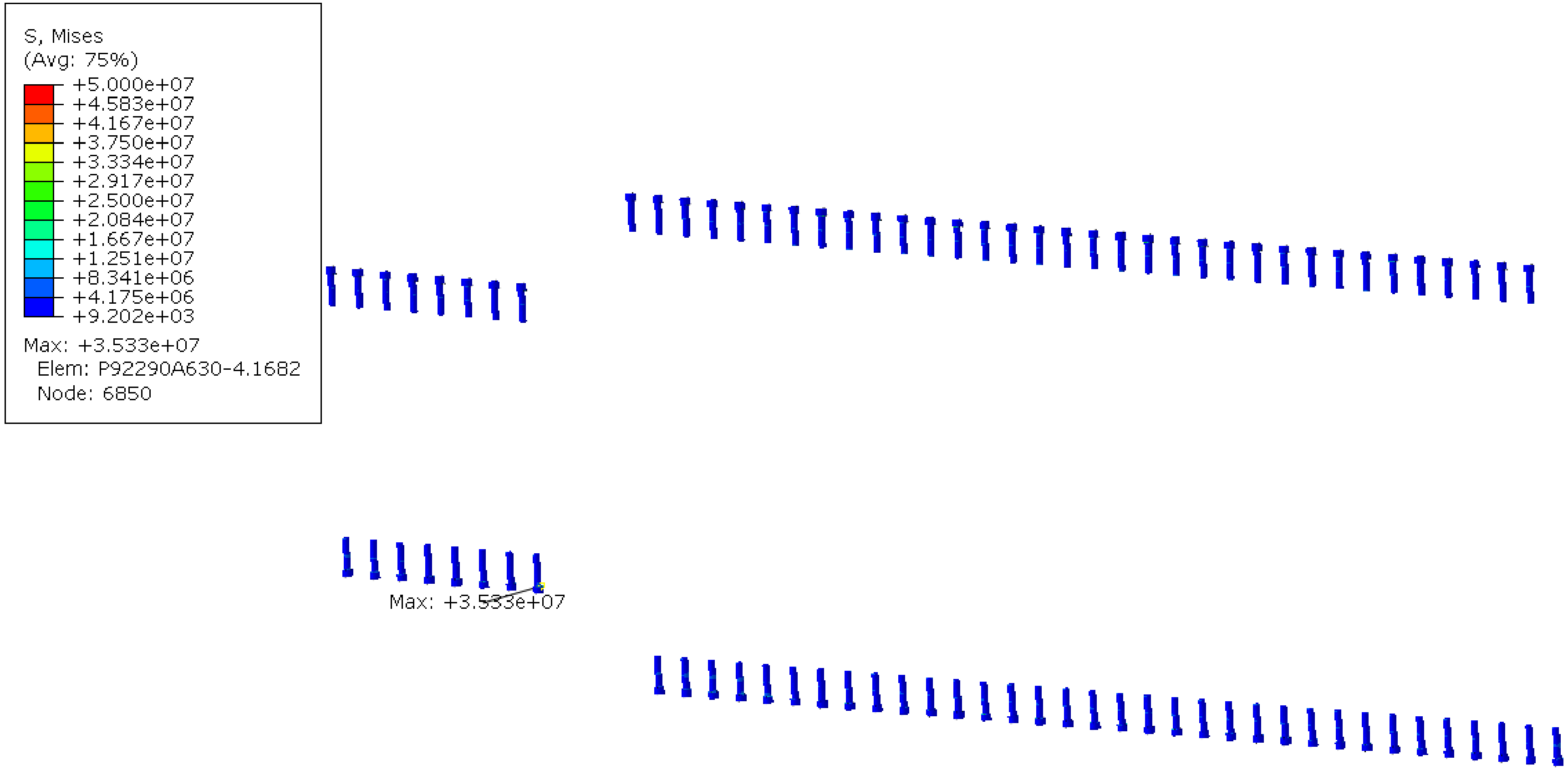
Rear Bottom Plate Contact Pressure



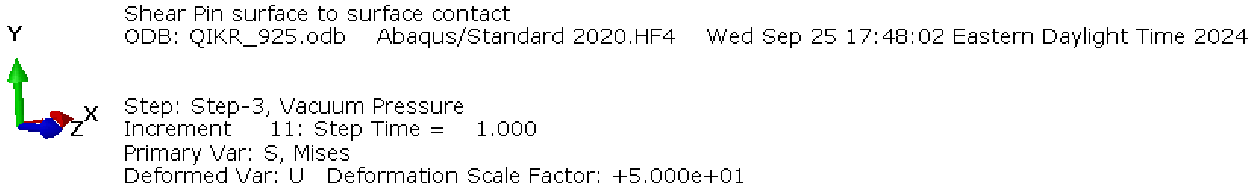
Rear Flange with merged welds 150 MPa scale peak 87 MPa



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