OAK RIDGE National Laboratory

August 2026

Target Assembly Structural Analysis

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U.S. DEPARTMENT of ENERGY

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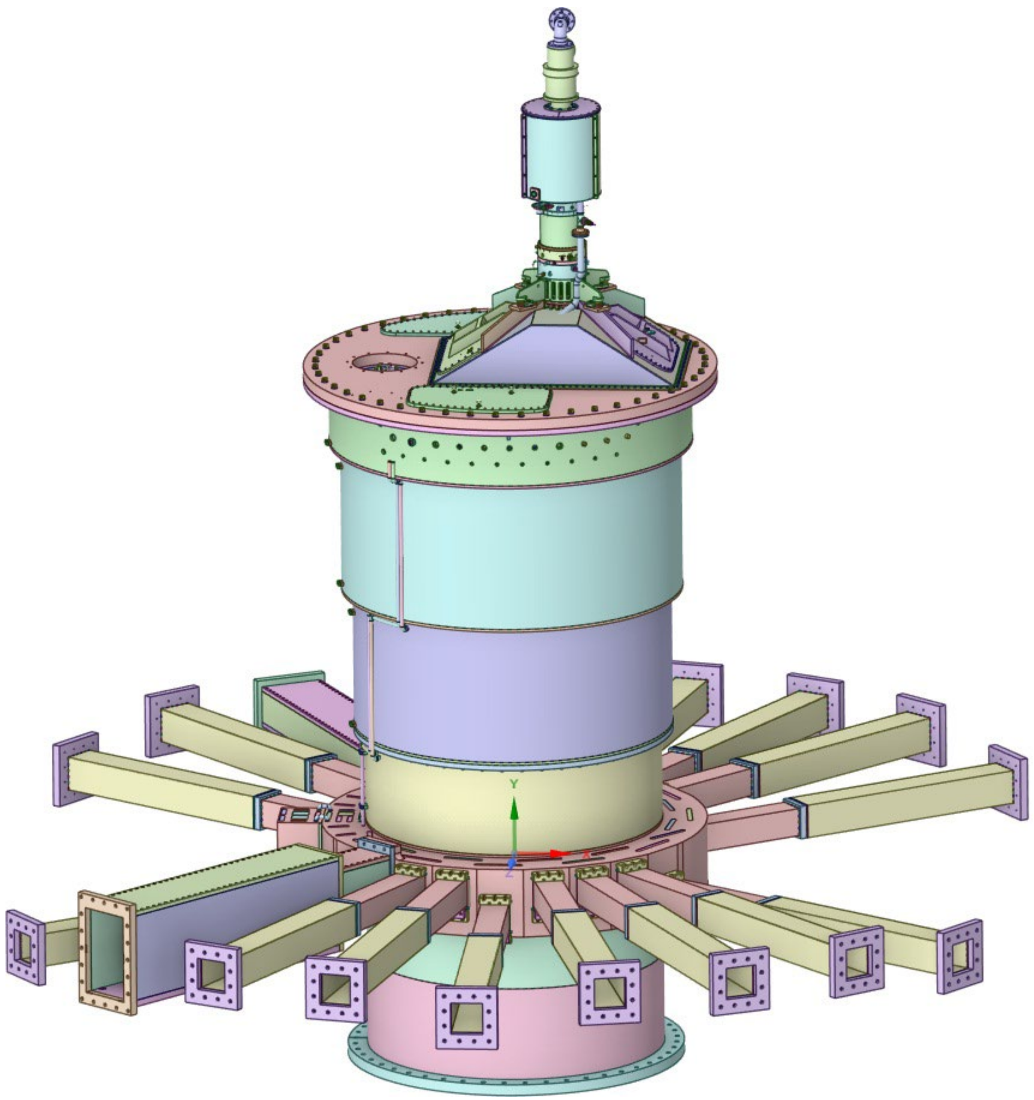
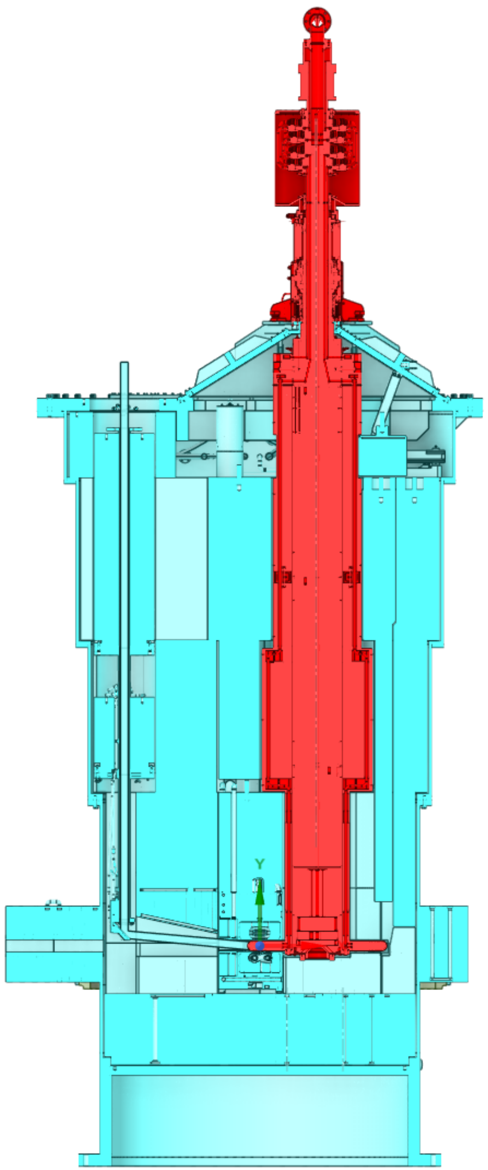
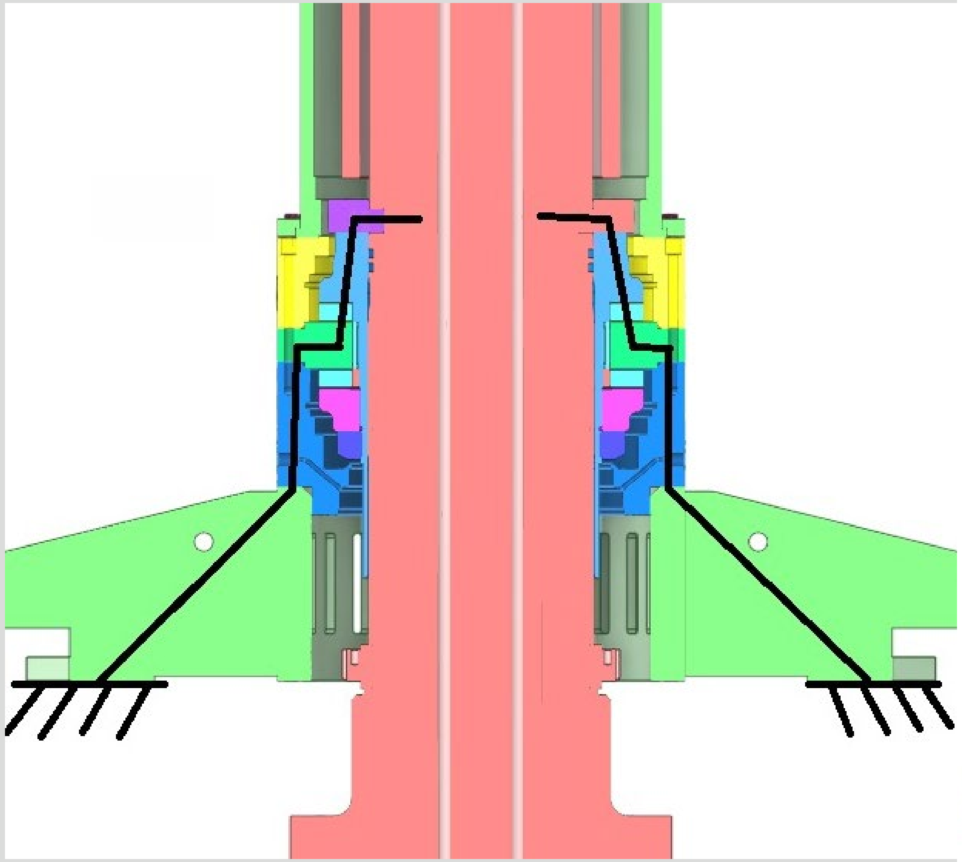
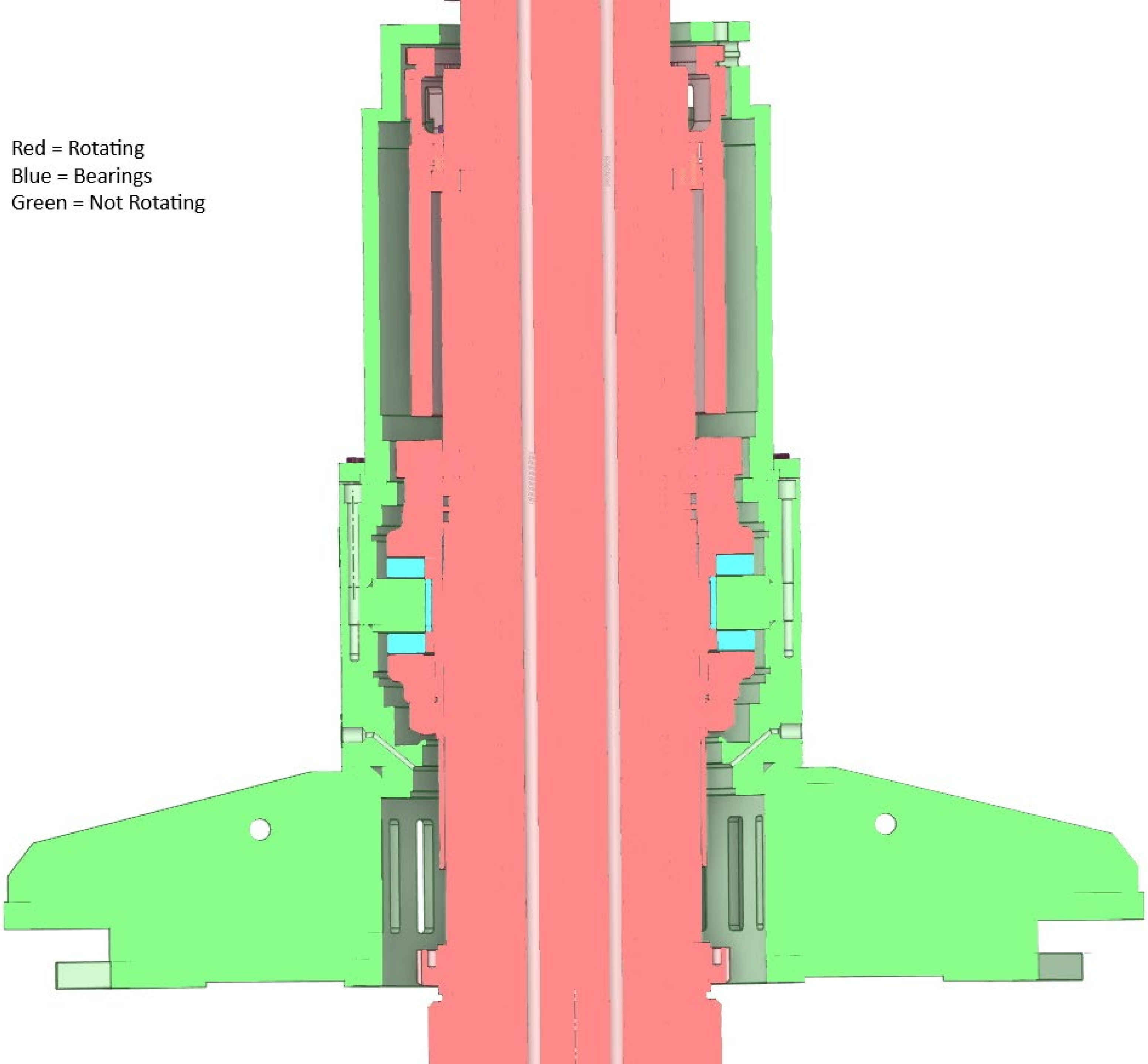




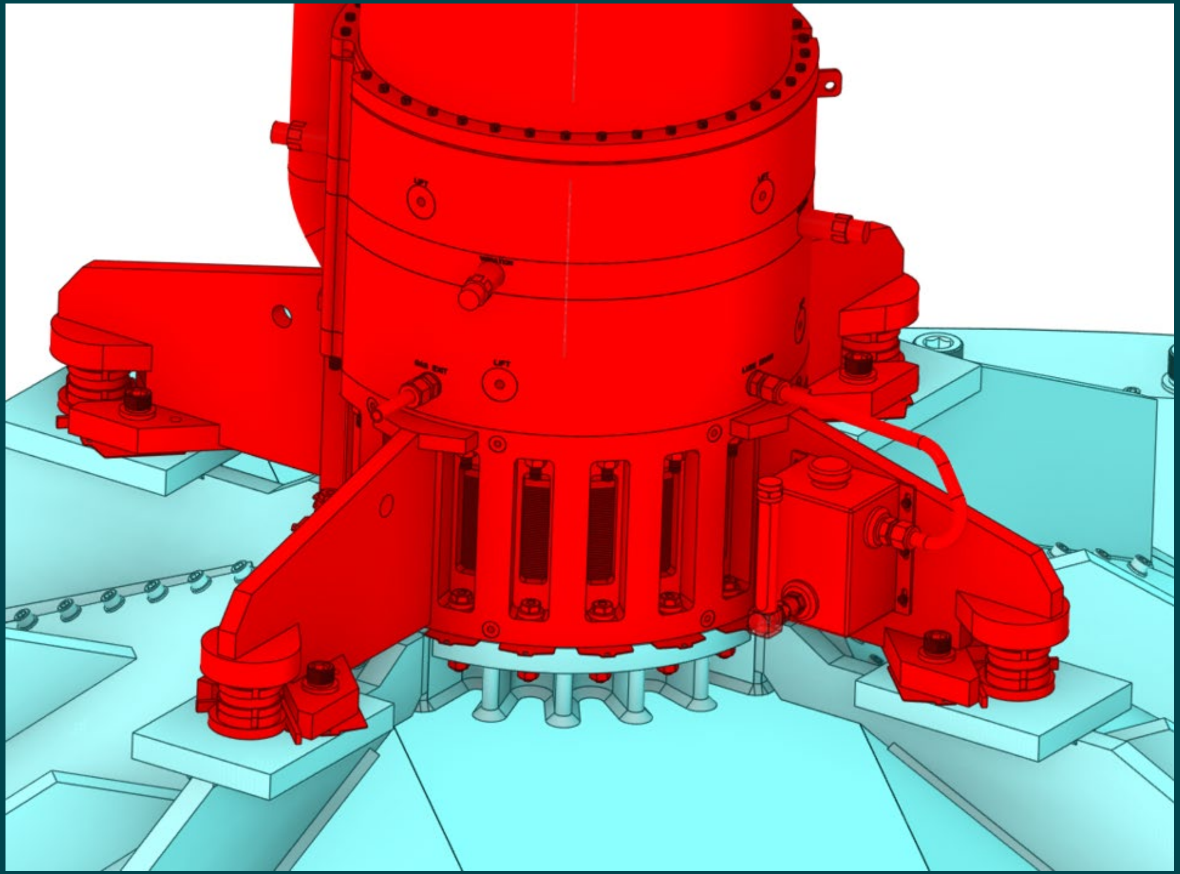
Rotating Components and Load Path

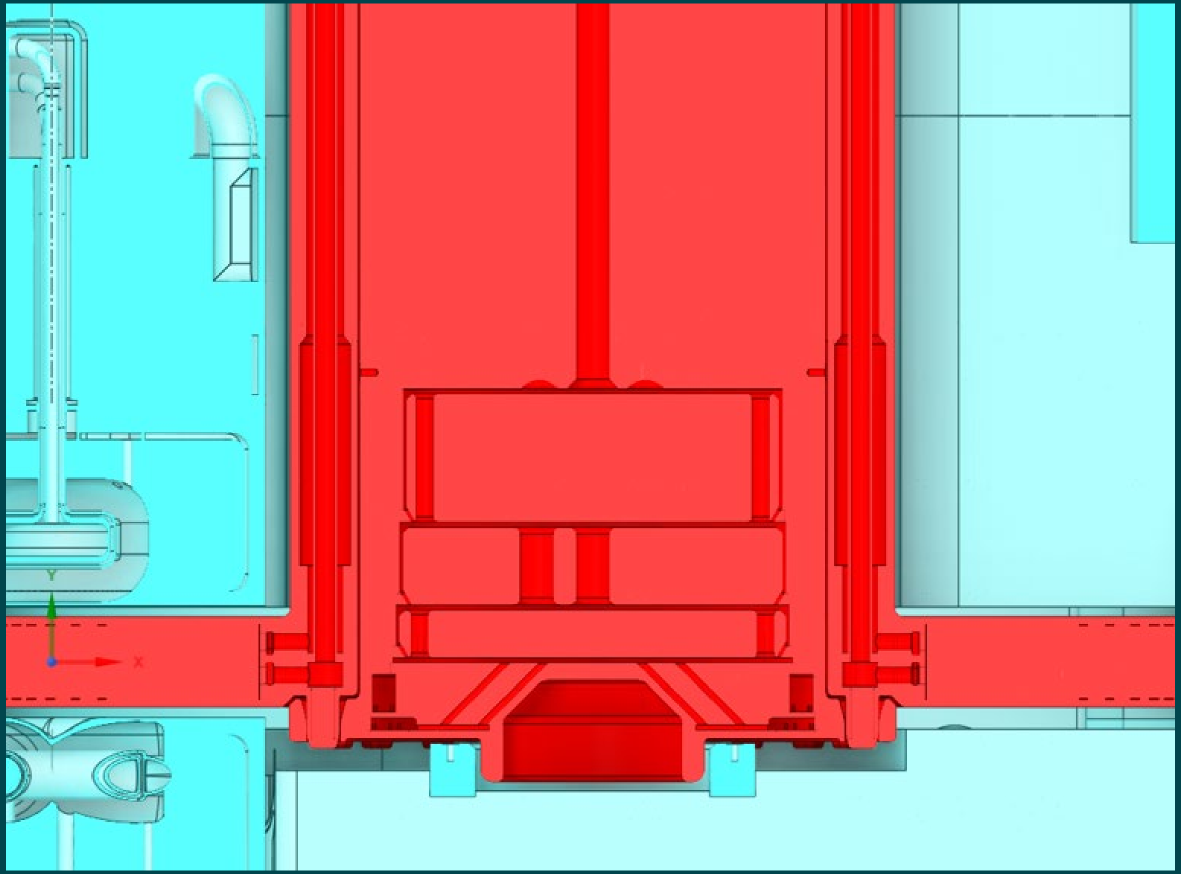


Red = Rotating
Blue = Bearings
Green = Not Rotating

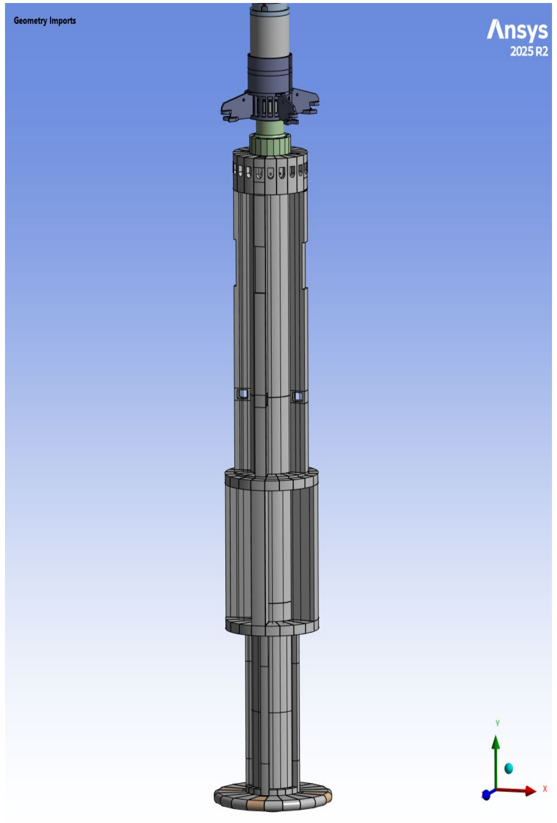


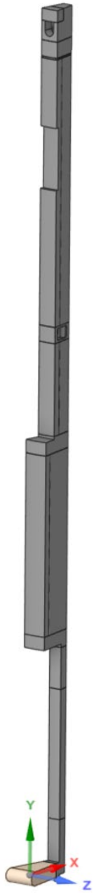
Main Interface Points with Core Vessel and MRA

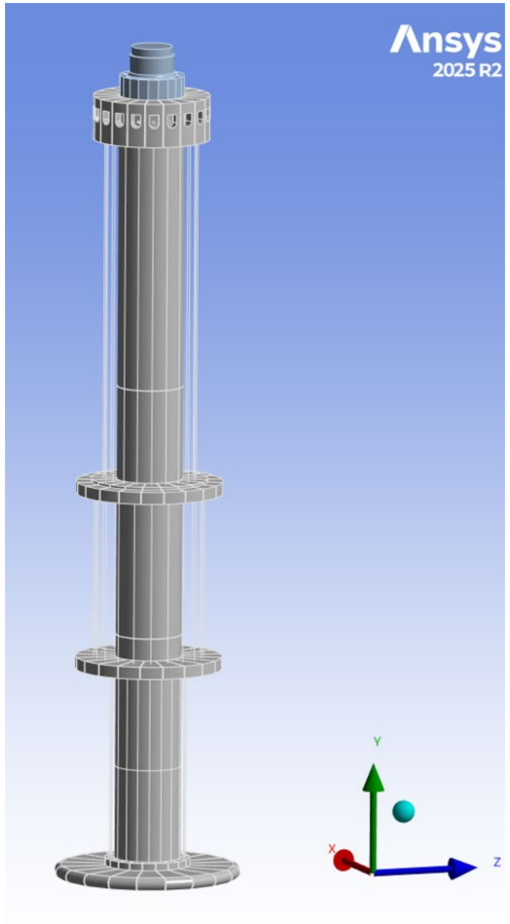


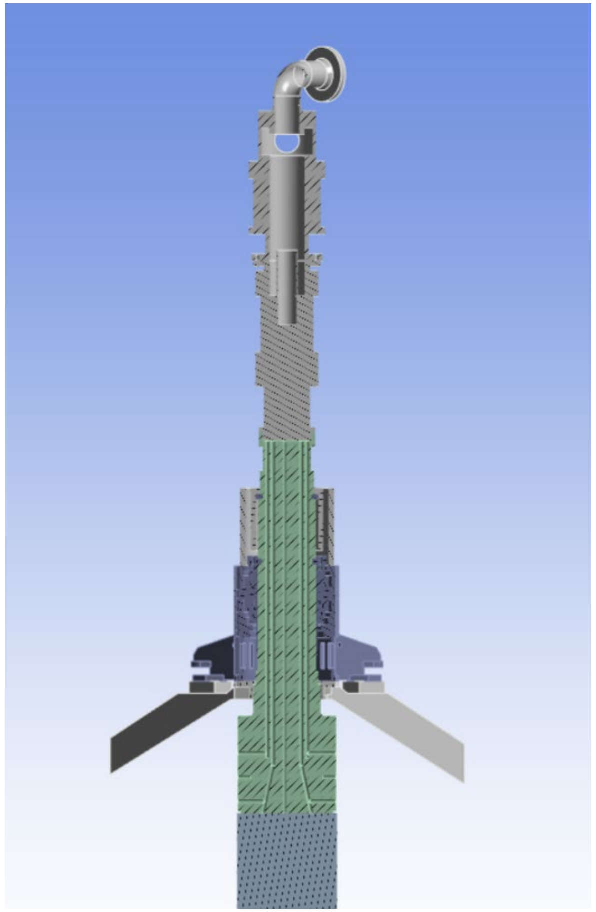


Target Analysis Models



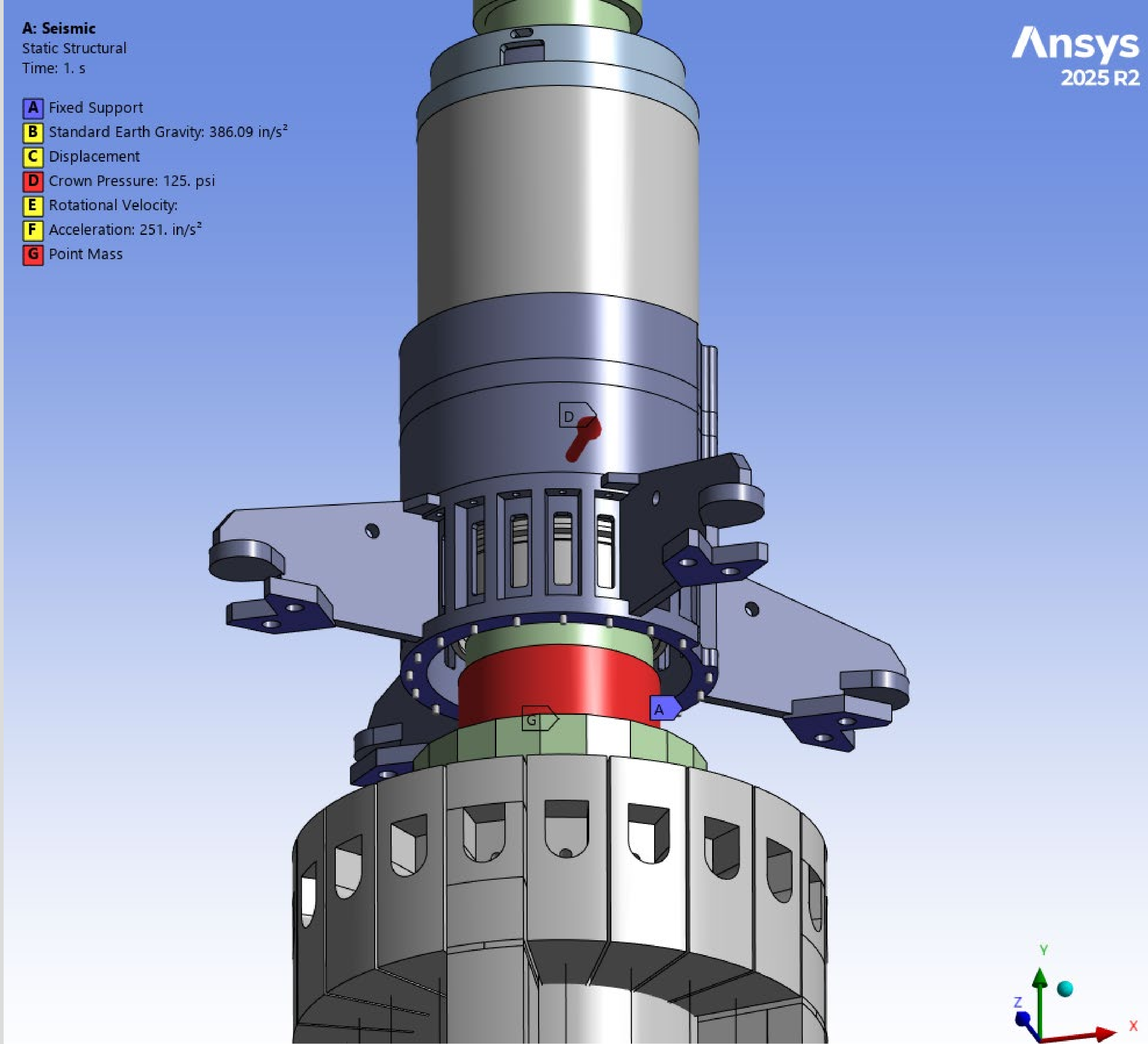






Deflection Requirements

- Uses full Target model
- Linear material properties
- Unfactored Seismic Load
- Assume worst case of combined loads
- No fasteners



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Operation Deflections

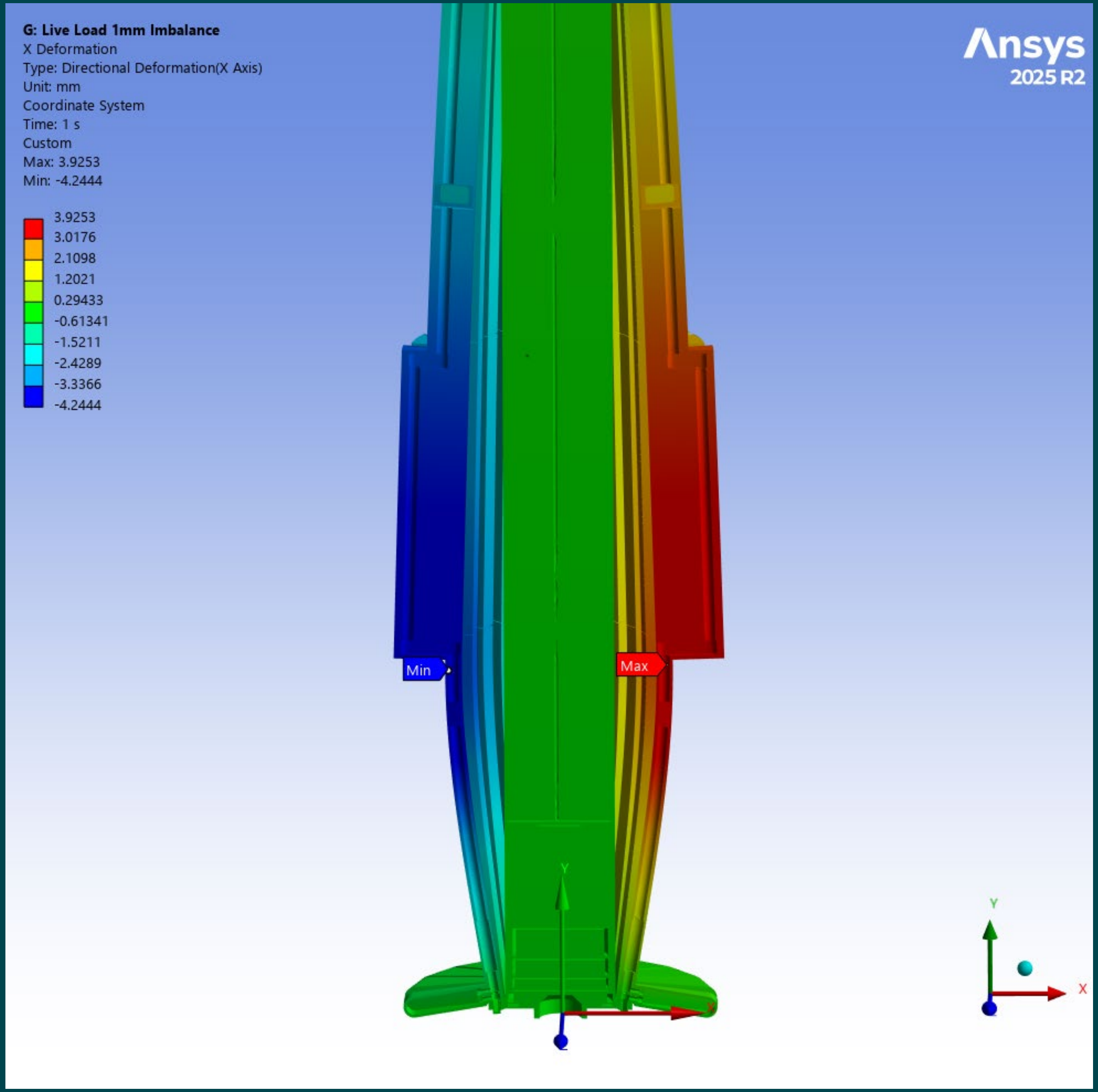
Normal operations include the worst-case combinations of:

L - Live loads (imbalance target rotation)

P - Operational pressures (Core Vessel and component operating pressures) and pressure testing (MAWP)

T - Operating thermal loads (beam on, cooling water)

Requirement < +/-4.5mm
X Deformation (mm)
-4.2424
-0.1736
-0.1719
3.9250



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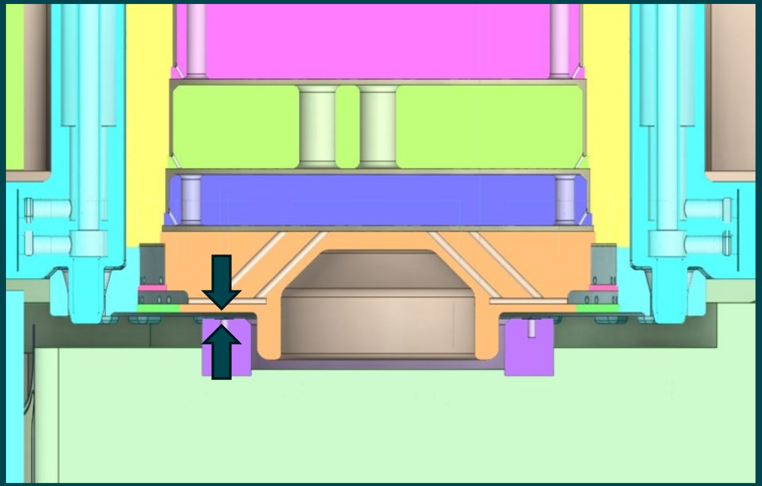
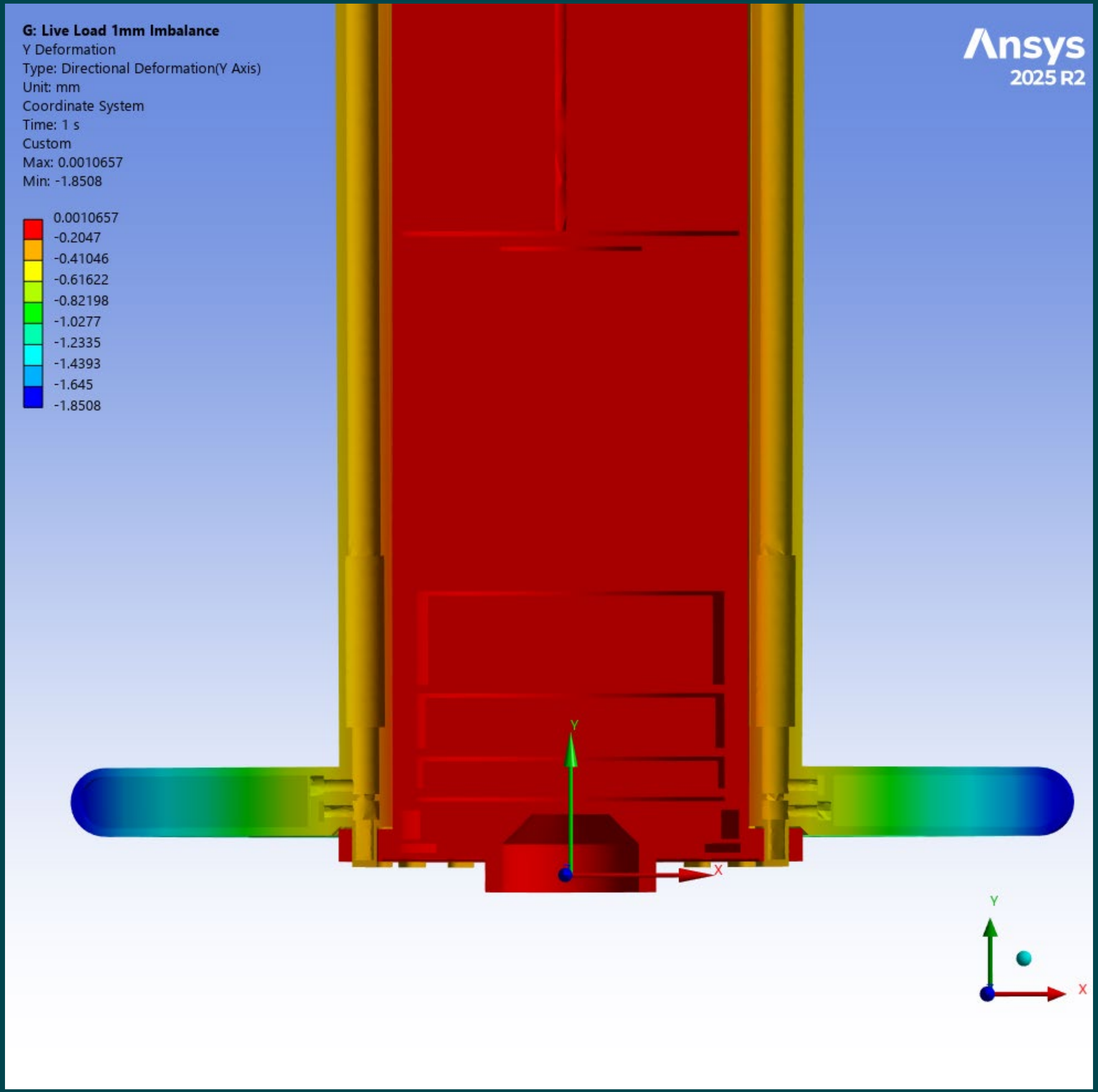
Target Vertical Deflection

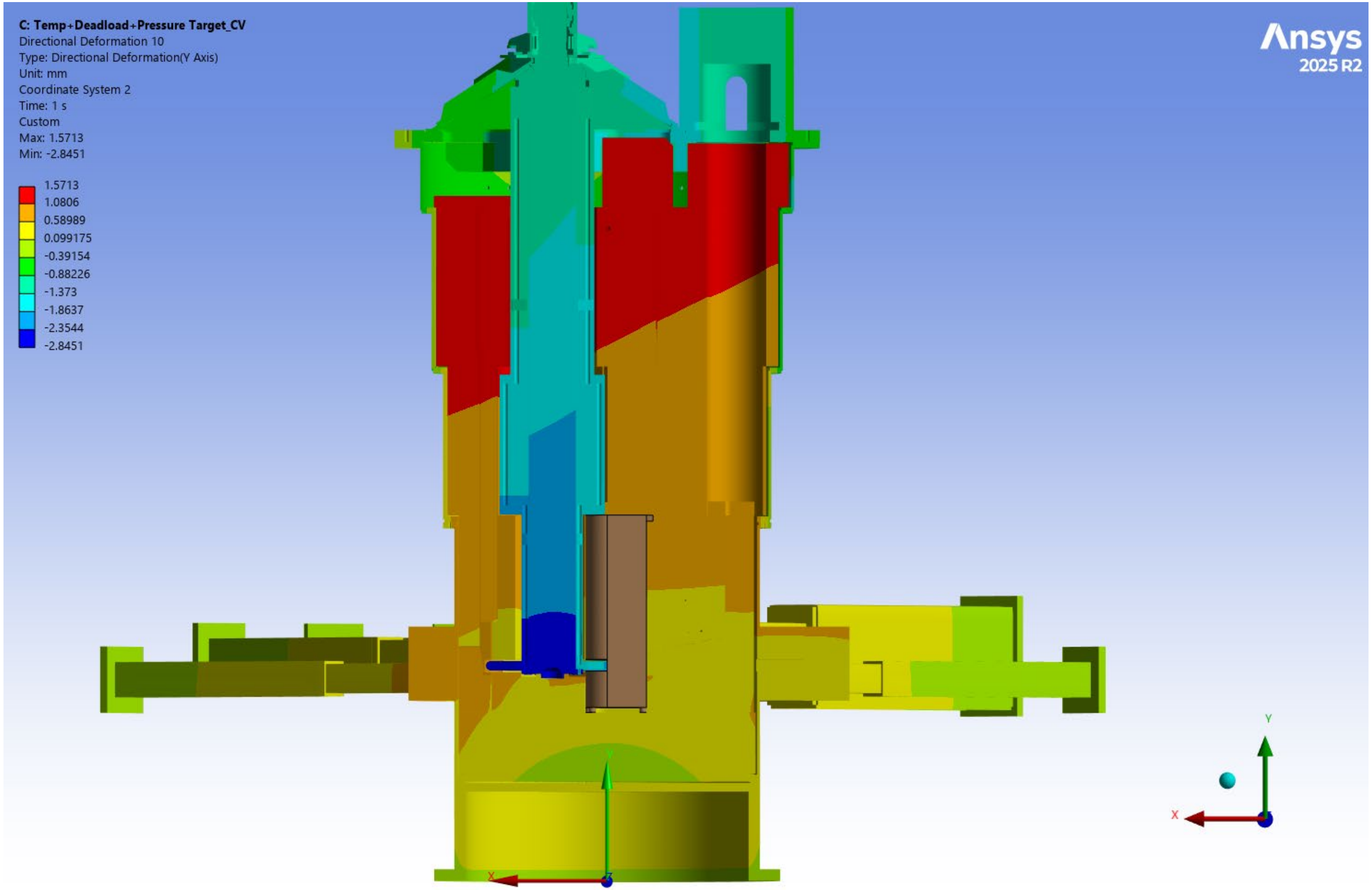
- Shaft vertical deflection is relatively small without the CV lid
- Most of the ‘foot’ movement is from the lower part of the Segment deforming.





Overall Deflection: Operational

- Target and CV Shell vs Shield Stack



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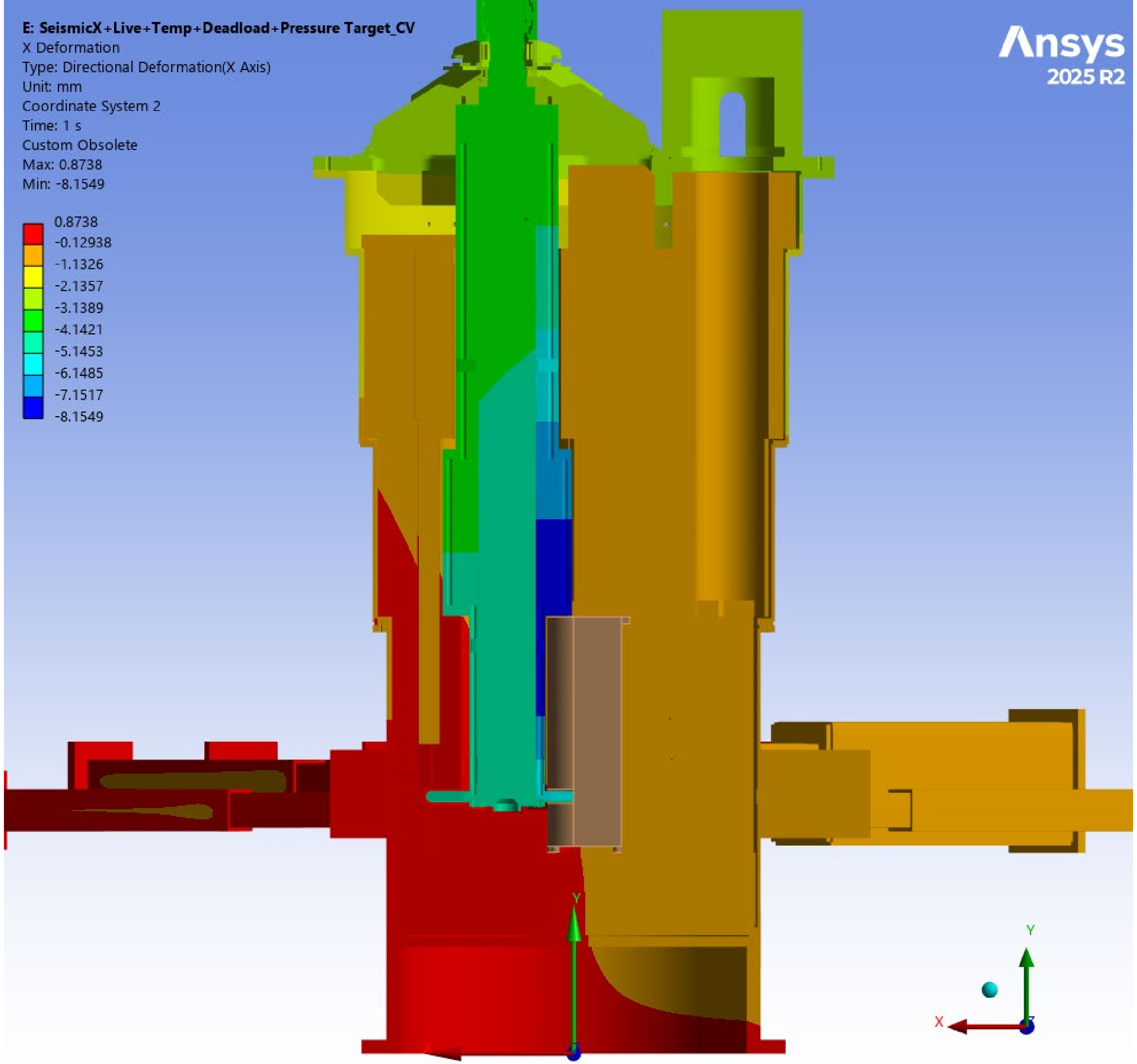
Overall Deflection: Seismic



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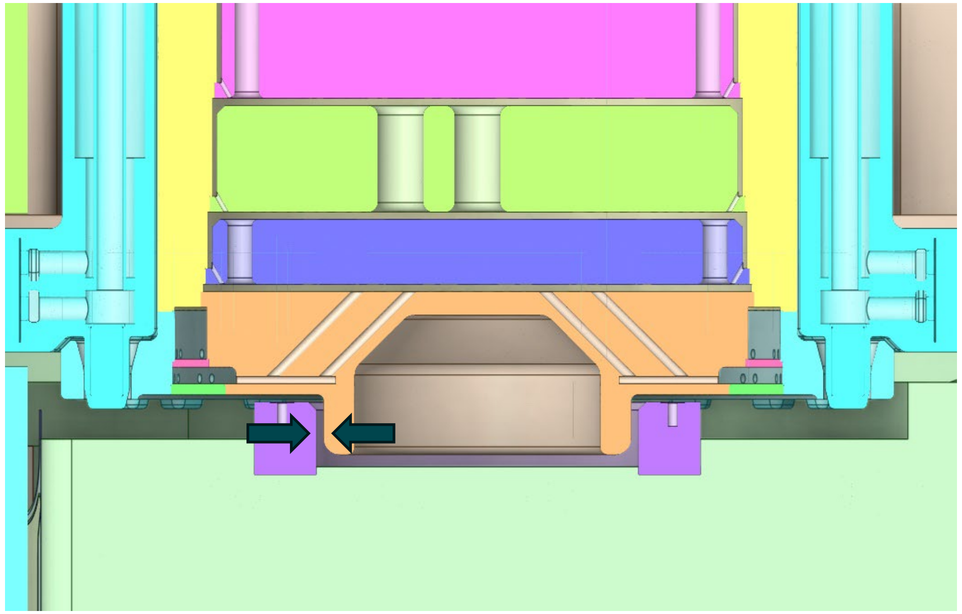
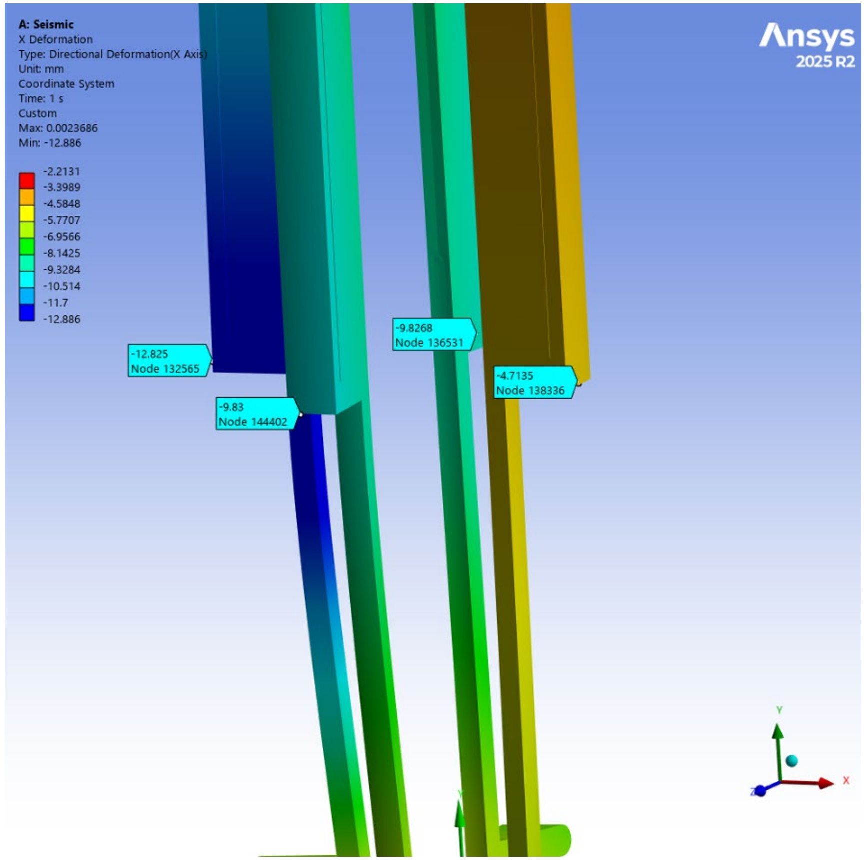
Requirement < 7mm Relative						
Node ID	X	Y	Z		Total X Deformation (mm)	Relative X Deformation (mm)
132565	-145.219	1315.054	-6.34533		-12.825	-6.825
136531	357.1438	1297.65	-516.46		-9.8268	-3.8268
138336	886.4183	1290.18	-14.1274		-4.7135	1.2865
144402	357.1024	1297.641	516.4323		-9.83	-3.83

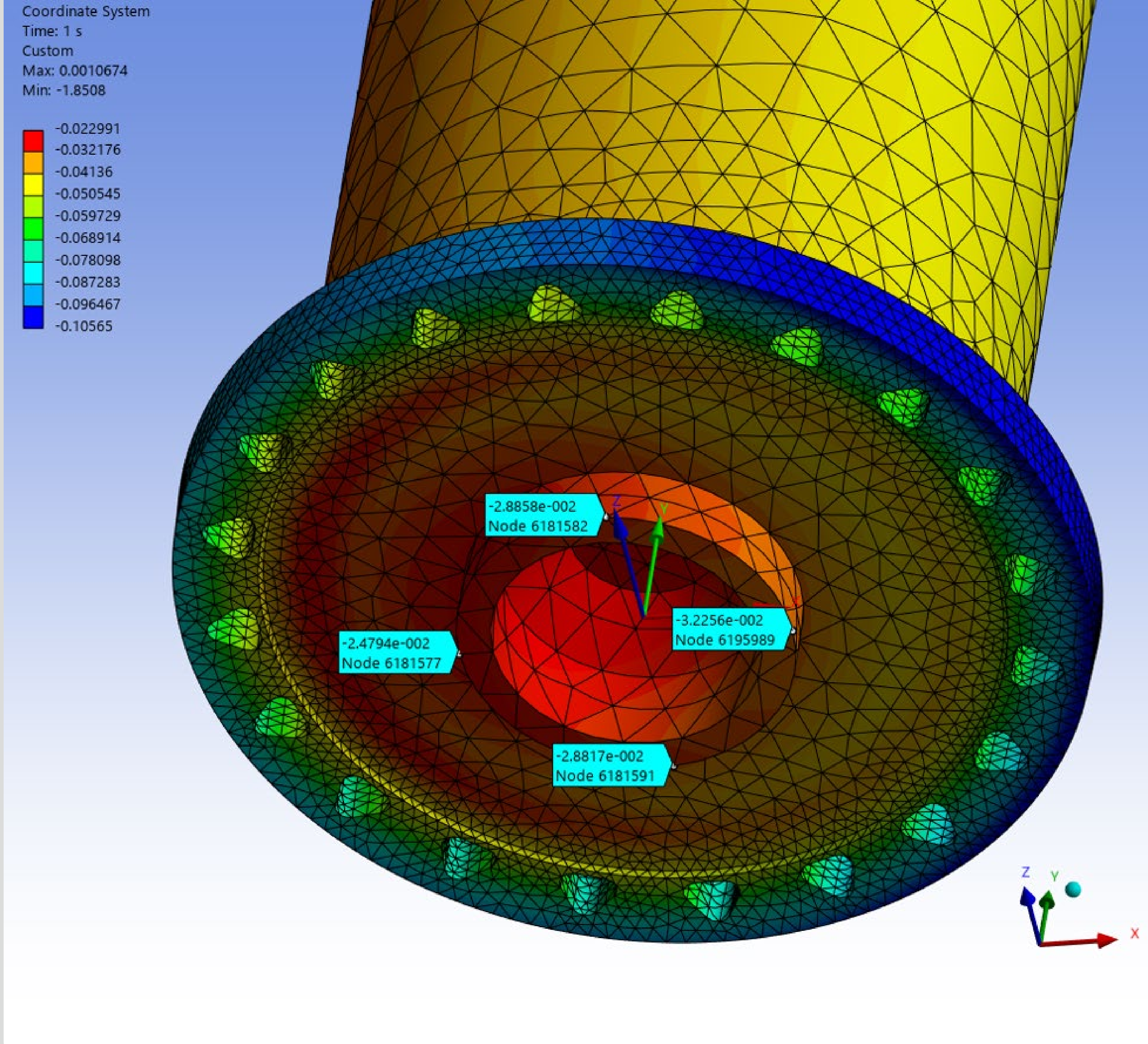
Mid Segment Seismic Deflection Requirement





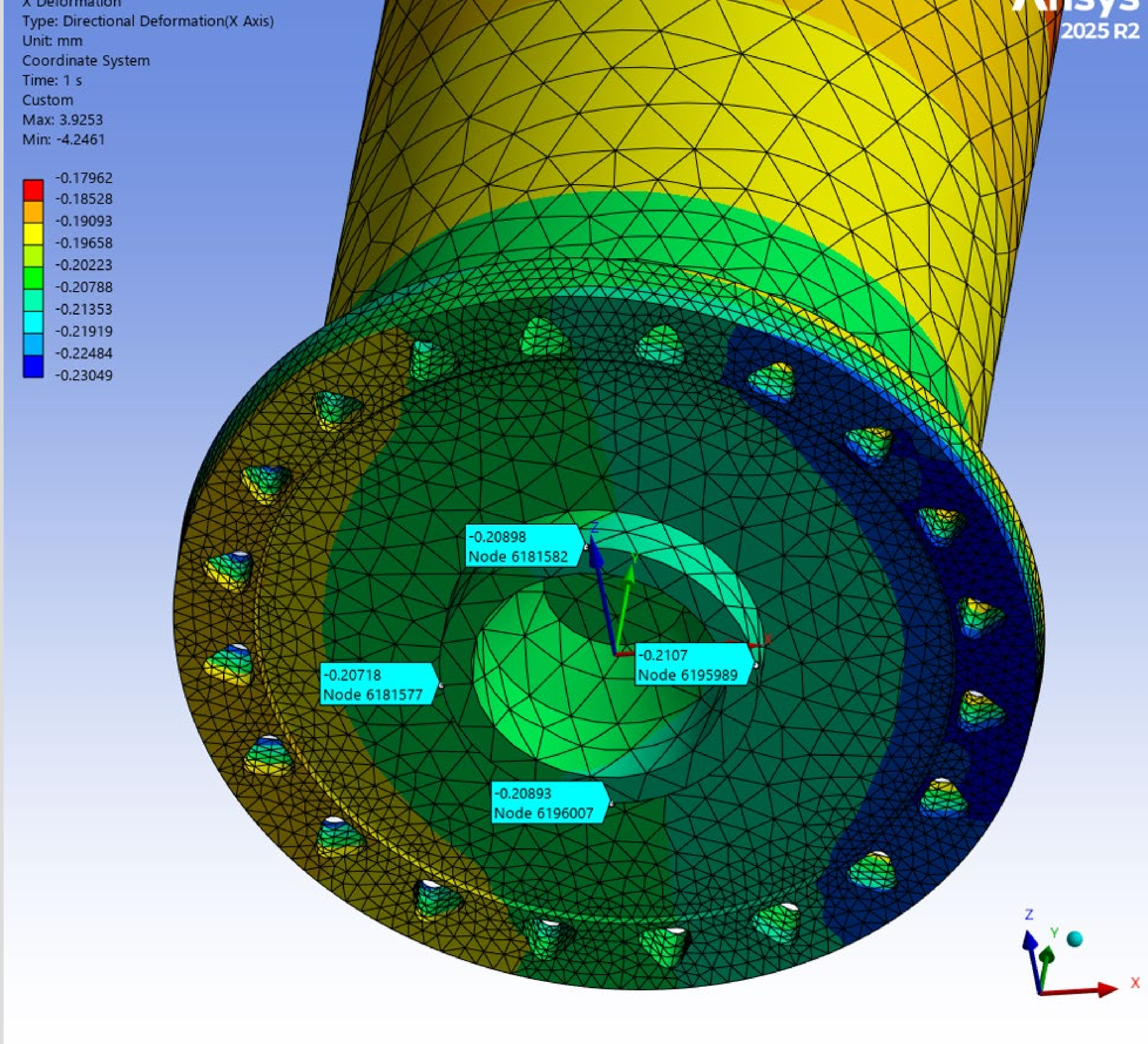
Snubber Vertical Deflection, Operational

Requirement < -2mm
Y Deformation (mm)
-0.0323
-0.0248
-0.0289
-0.0288



Snubber Radial Deflection, Operational

Requirement < +/-0.5mm
X Deformation (mm)
-0.2090
-0.2089
-0.2072
-0.2107



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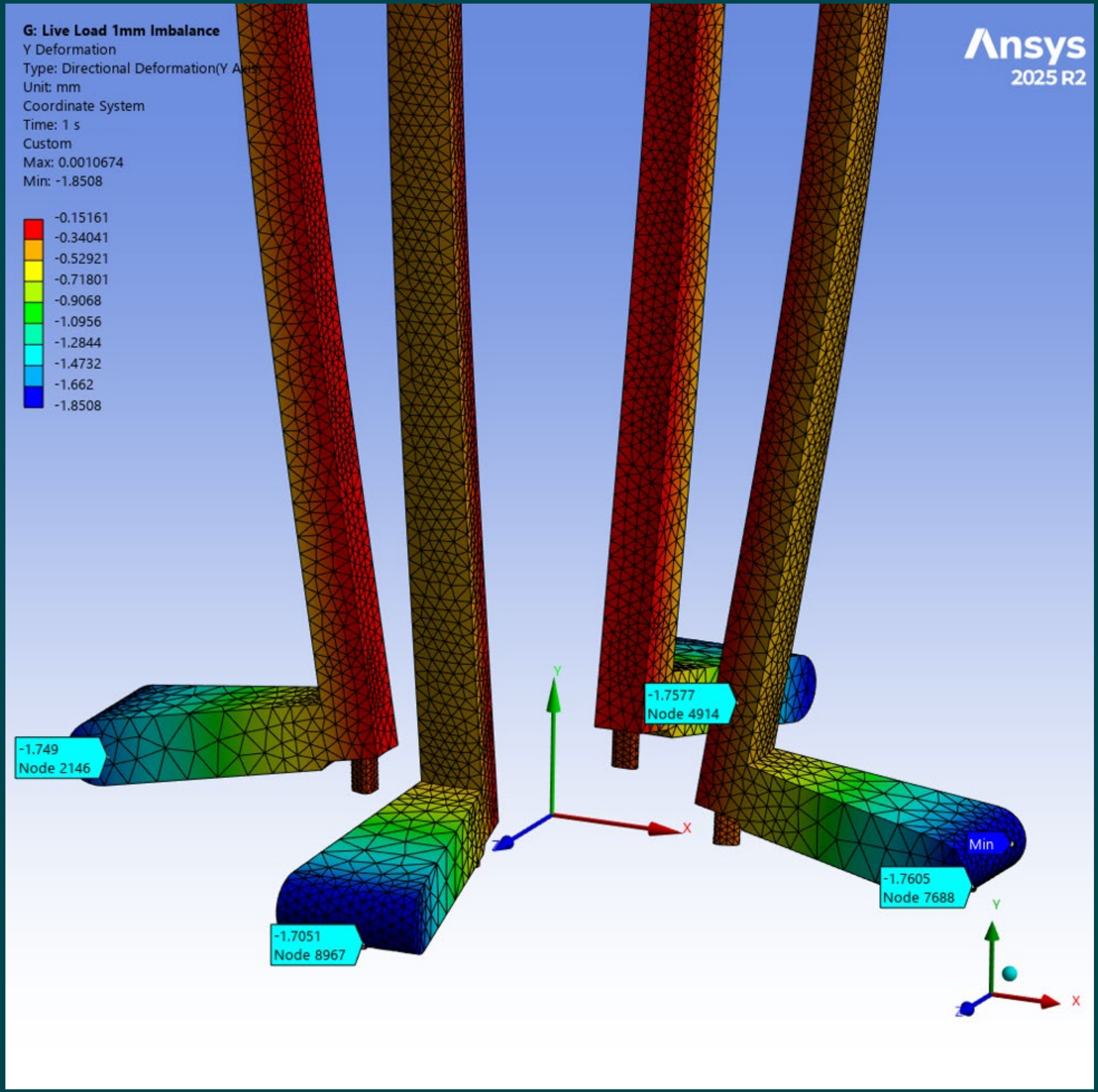
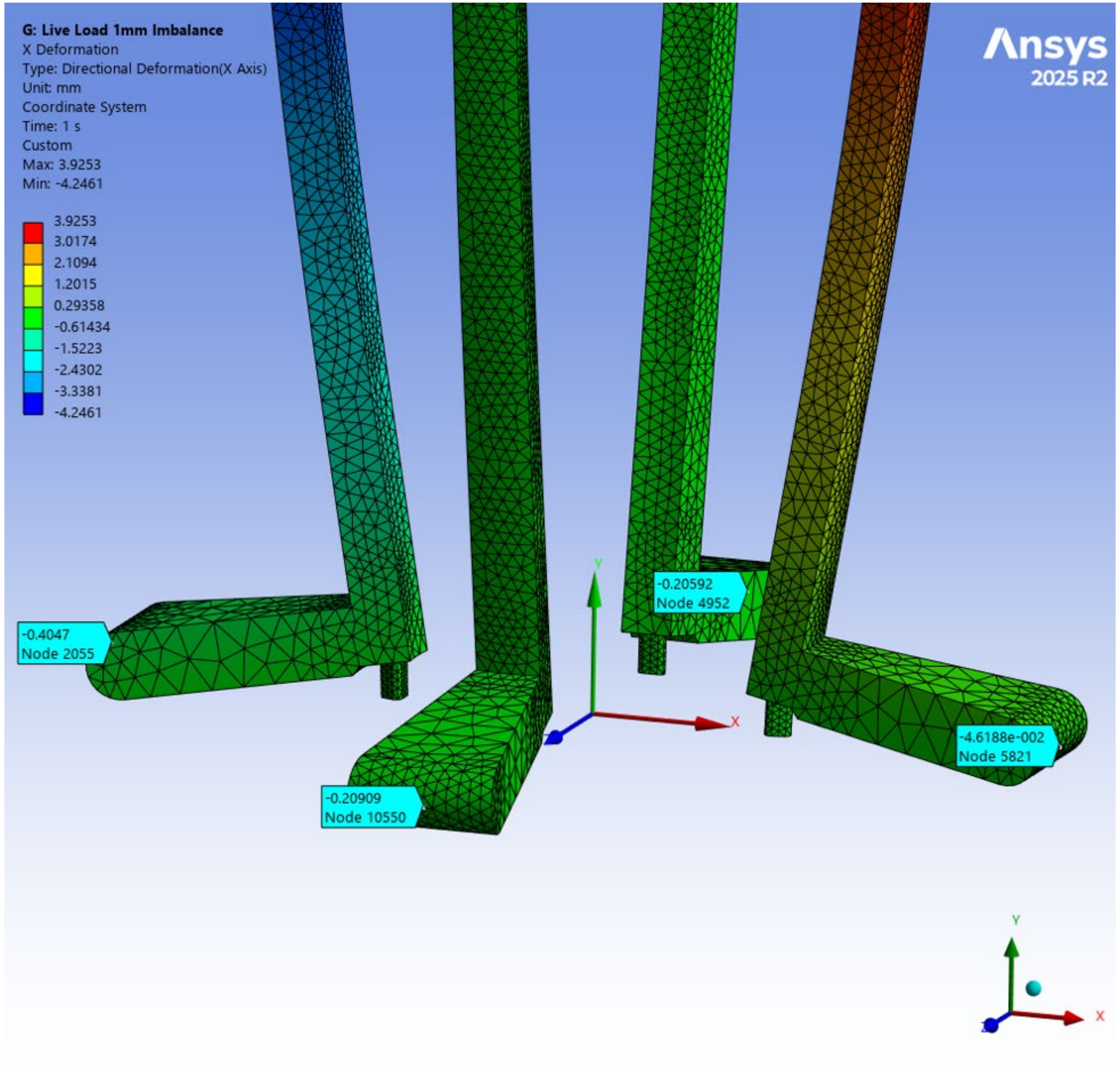
Segment Foot Vertical Deflection, Operational

Requirement < -3.25mm
Y Deformation (mm)
-1.7051
-1.7605
-1.7577
-1.749



Segment Foot Radial Deflection, Operational

Requirement < 0.5mm
X Deformation (mm)
-0.4047
-0.2091
-0.0462
-0.2059



Segment Analysis: ASME Section VIII,DIV 2

- Elastic Plastic Analysis, Table 5.5
    - Plastic Collapse
    - Local Failure

- Elastic Analysis, Table 5.3
    - Fastener Loads
    - Plastic Ratcheting

- Fatigue Analysis, Table 5.3
    - Cyclic Loads

- 316L Stainless Steel

Table 5.5
Load Case Combinations and Load Factors for an Elastic–Plastic Analysis

Criteria	Required Factored Load Combinations
Design Conditions	
Global	(1) $\beta(P + P_s + D)$ (2) $0.88\beta(P + P_S + D + T) + 1.13\beta L + 0.36\beta S_S$ (3) $0.88\beta(P + P_S + D) + 1.13\beta S_s + 0.71\beta L$ or $0.36\beta W$ (4) $0.88\beta(P + P_S + D) + 0.71\beta W + 0.71\beta L + 0.36\beta S_S$ (5) $0.88\beta(P + P_S + D) + 0.71\beta E + 0.71\beta L + 0.14\beta S_S$
Local	$1.7(P + P_S + D)$
Serviceability	Per User's Design Specification, if applicable; see 5.2.4.3(b)
Test Condition	
Global	$\frac{\beta}{1.5} \times \frac{1}{\beta_T}\left(P_T + P_S + D + 0.6W_{pt}\right)$
Serviceability	Per User's Design Specification, if applicable

GENERAL NOTES:
(a) The parameters used in the Design Load Combination column are defined in Table 5.2.
(b) See 5.2.4.3 for descriptions of global and serviceability criteria.
(c) S is the allowable membrane stress at the design temperature.
(d) S_T is the allowable membrane stress at the pressure test temperature.
(e) Loads listed herein shall be considered to act in the combinations described above; whichever produces the most unfavorable effect in the component being considered. Effects of one or more loads not acting shall be considered.

Table 5.3
Load Case Combinations and Allowable Stresses for an Elastic Analysis

	Stress Assessment and Allowable Stress [Note (2)]				
	General Primary Membrane	Local Primary Membrane	Local Primary Membrane Plus Bending	Range of Primary Plus Secondary	Range of Primary Plus Secondary Plus Peak
Load Combinations [Note (1)]	P_m	P_L	$P_L + P_b$	$P_L + P_b + Q$	$P_L + P_b + Q + F$
Design					
(1) $P + P_s + D$					
(2) $P + P_s + D + L$					
(3) $P + P_s + D + L + T$					
(4) $P + P_s + D + S_s$					
(5) $0.6D + (0.6W$ or $0.7E)$ [Note (3)]					
(6) $\Omega_p P + P_s + D + (0.6W$ or $0.7E)$ [Note (4)]	S	S_{PL}	S_{PL}	Not applicable	
(7) $\Omega_p P + P_s + D + 0.75(L + T) + 0.75S_s$ [Note (4)]					
(8) $\Omega_p P + P_s + D + 0.75(0.6W$ or $0.7E) + 0.75L + 0.75S_s$ [Note (4)]					
(9) Other design load combinations as defined in the User's Design Specification					

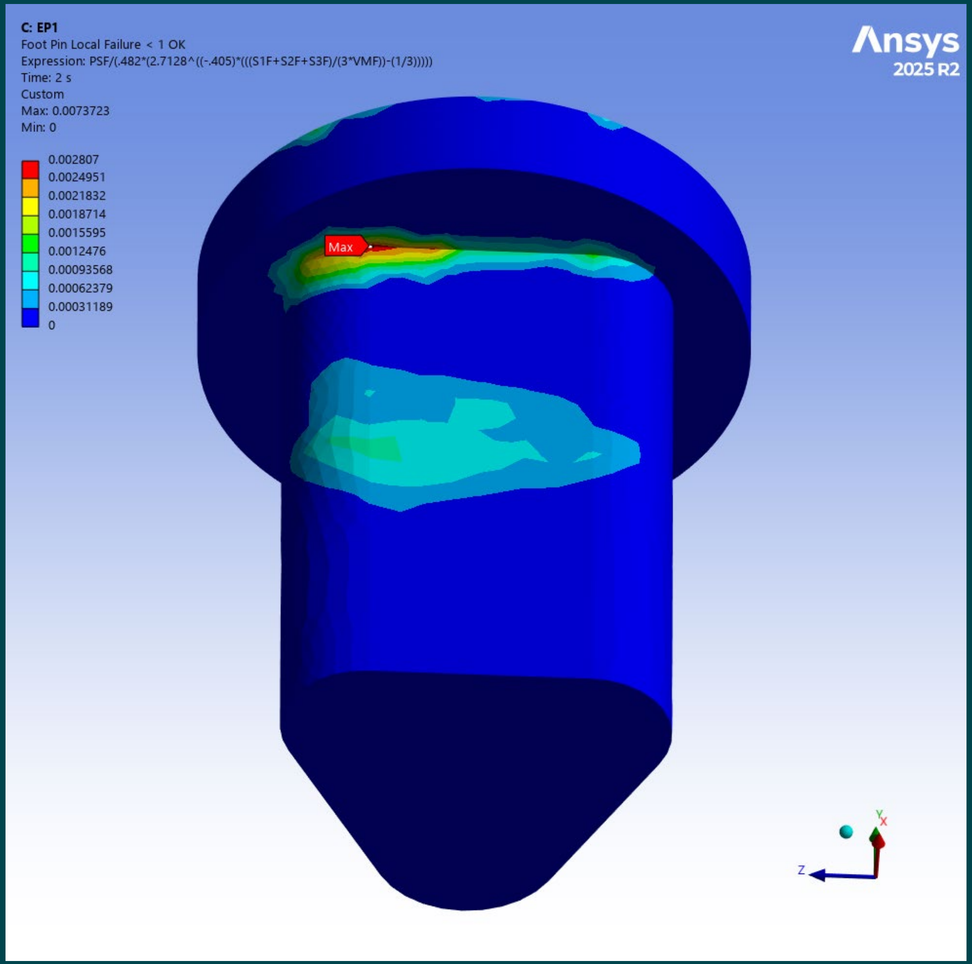
Acceptance Criteria: Elastic Plastic Loads

Local Failure: The Limiting Triaxial Strain is compared to the Equivalent Plastic Strain (no cold work strain)

$$\varepsilon_L = \varepsilon_{Lu} \cdot \exp\left[-\left(\frac{\alpha_{sl}}{1+m_2}\right)\left(\left\{\frac{(\sigma_1+\sigma_2+\sigma_3)}{3\sigma_e}\right\}-\frac{1}{3}\right)\right]$$

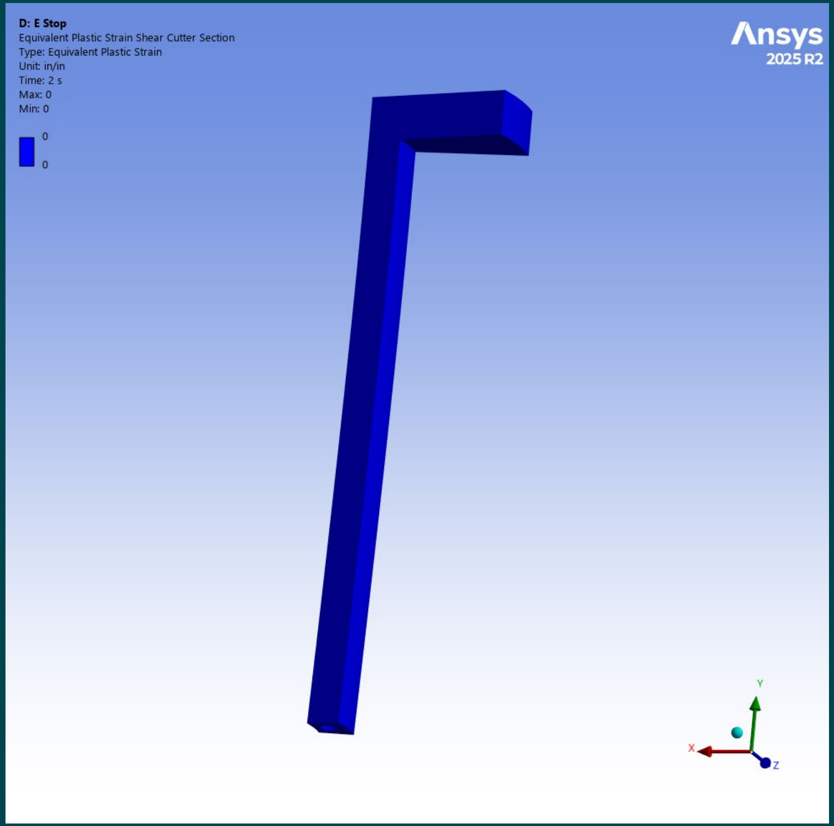
$$\varepsilon_{peq} + \varepsilon_{cf} \le \varepsilon_L$$

Plastic Collapse: Solution must converge



Acceptance Criteria: Elastic Loads

Plastic Ratcheting: Using a perfectly plastic stress strain curve, if no plastic strain occurs then ratcheting does not occur.



Fastener Loads are handled with structural methods.

$$\left[\frac{T_a}{(R_n/\Omega)_t}\right]^2 + \left[\frac{V_a}{(R_n/\Omega)_v}\right]^2 \le 1$$

Acceptance Criteria: Cyclic Loads

Cycles:

$$t_{year} := 5000 \cdot hr$$

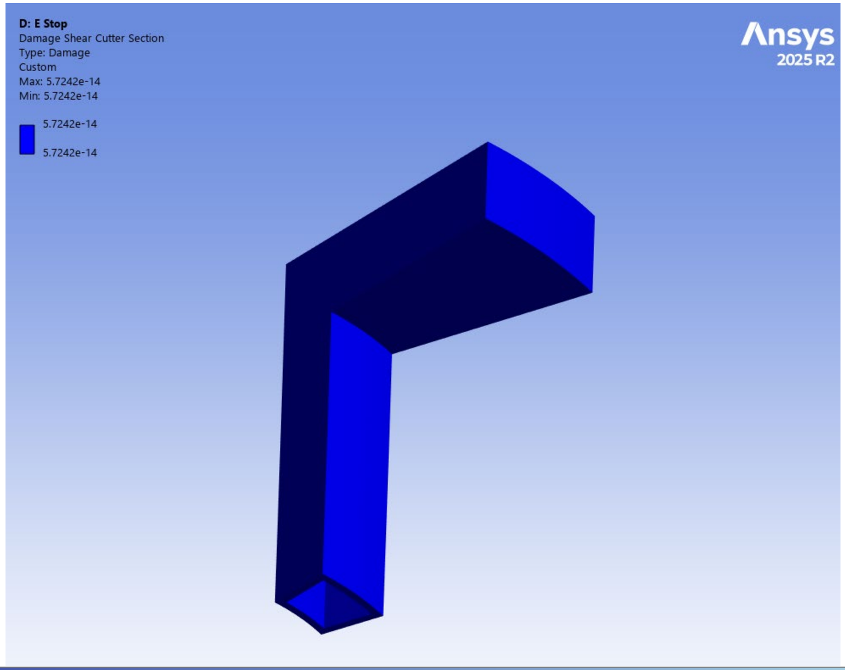
$$v_{rpm} := 45 \cdot rpm = \left(2.7 \cdot 10^{3}\right) \frac{rev}{hr}$$

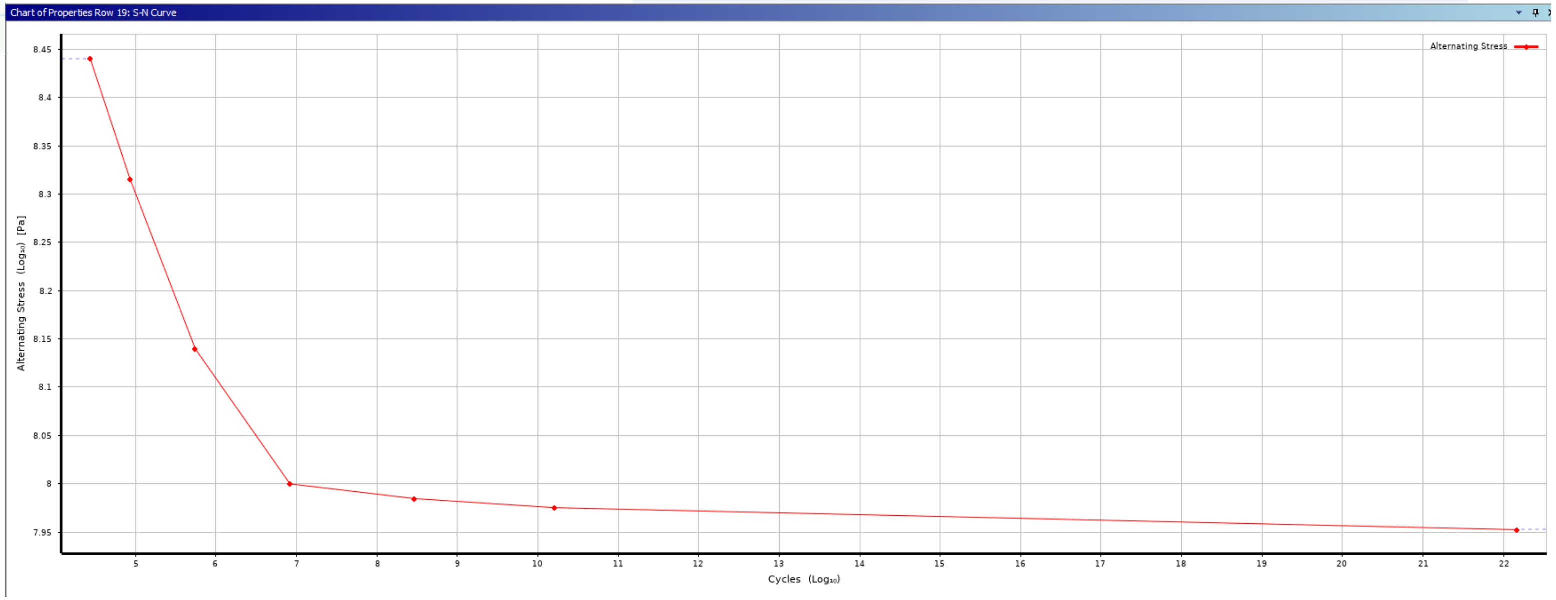
$$years_{segment} := 10 \qquad years_{LoF} := 40$$

$$Segment := \left(t_{year} \cdot years_{segment}\right) \cdot v_{rpm} = 8.5 \cdot 10^{8}$$

$$LoF := \left(t_{year} \cdot years_{LoF}\right) \cdot v_{rpm} = 3.4 \cdot 10^{9}$$

Damage < 1





Load Parameters: Seismic Coefficient

13.3 SEISMIC DEMANDS ON NONSTRUCTURAL COMPONENTS

13.3.1 Seismic Design Force

13.3.1.1 Horizontal Force. The horizontal seismic design force (F_p) shall be applied at the component's center of gravity and distributed relative to the component's mass distribution and shall be determined in accordance with Eq. (13.3-1):

$$F_p = \frac{0.4 a_p S_{DS} W_p}{\left(\frac{R_p}{I_p}\right)}\left(1 + 2\frac{z}{h}\right) \qquad (13.3\text{-}1)$$

F_p is not required to be taken as greater than

$$F_p = 1.6 S_{DS} I_p W_p \qquad (13.3\text{-}2)$$

and F_p shall not be taken as less than

$$F_p = 0.3 S_{DS} I_p W_p \qquad (13.3\text{-}3)$$

where

F_p = seismic design force;
S_{DS} = spectral acceleration, short period, as determined from Section 11.4.5;
a_p = component amplification factor that varies from 1.00 to 2.50 (select appropriate value from Table 13.5-1 or 13.6-1);
I_p = component Importance Factor that varies from 1.00 to 1.50 (see Section 13.1.3);
W_p = component operating weight;
R_p = component response modification factor that varies from 1.00 to 12 (select appropriate value from Table 13.5-1 or 13.6-1);
z = height in structure of point of attachment of component with respect to the base. For items at or below the base, z shall be taken as 0. The value of z/h need not exceed 1.0; and
h = average roof height of structure with respect to the base.

$S_{DS} := .453$	Hazard Tool
$a_p := 1.0$	Rigid Attachment
$W_p := 42000\ lbf$	Model Properties
$I_p := 1.5$	Nuclear Safety Based
$R_p := 1.25$	Response Modification
$z := 1$	Height factors set to 1.0, the component is attached at the top of the roof (CV).
$h := 1$	

$$F_p := \frac{.4 \cdot a_p \cdot S_{DS}}{\left(\frac{R_p}{I_p}\right)} \cdot \left(1 + 2 \cdot \frac{z}{h}\right) = 0.65$$

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Load Parameters: E Stop Acceleration (part of Live load)

Time to stop using full motor torque

$$T := 2400 \cdot N \cdot m$$

$$I := 1560381200 \cdot kg \cdot mm^2$$

$$a := \frac{T}{I} = 1.538 \ \frac{1}{s^2}$$

$$v := 45 \cdot rpm$$

$$t := \frac{v}{a} = 3.1 \ s$$

Use 1 second emergency stop for conservatism and 10 seconds for regular stop

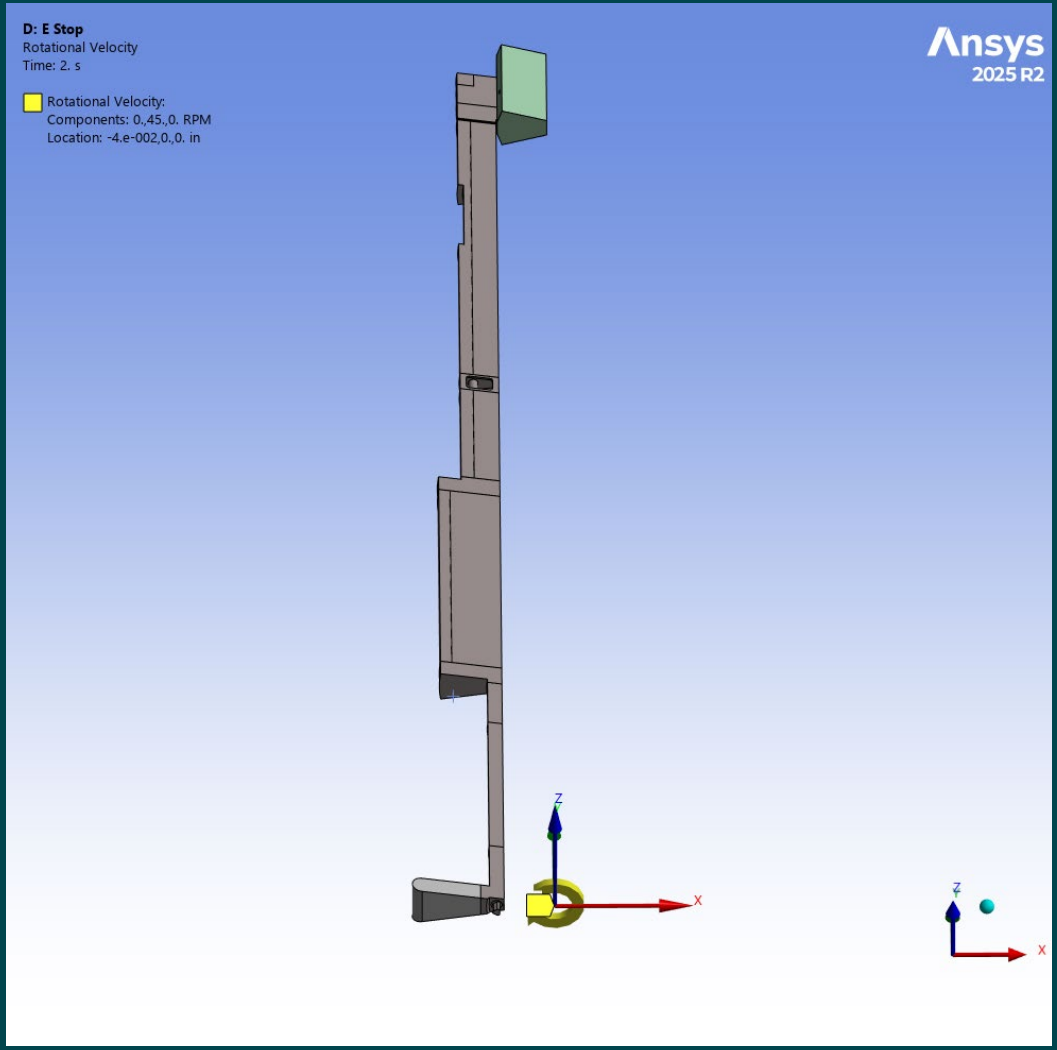
$$v := 45 \cdot rpm$$

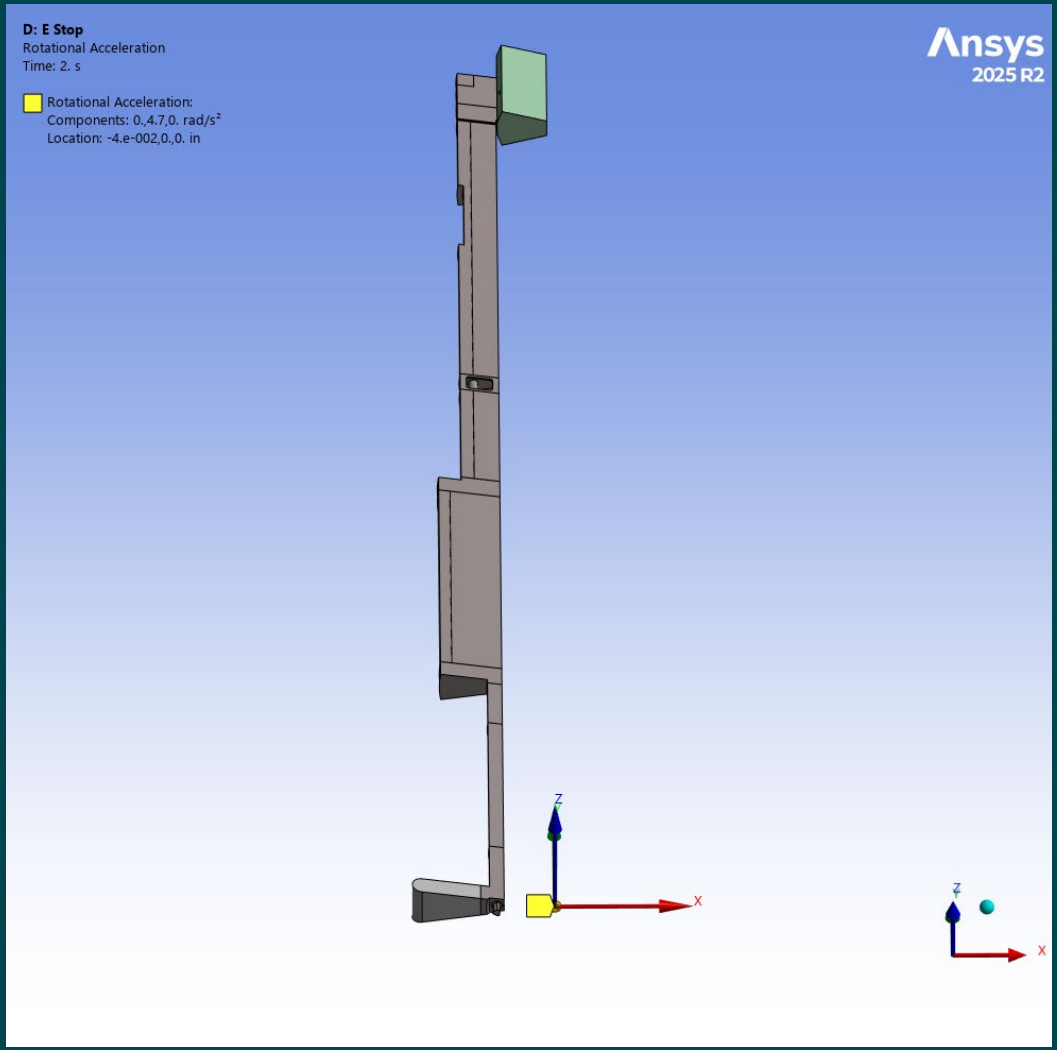
$$t_1 := 1 \ s \qquad t_{10} := 10 \ s$$

$$a_1 := \frac{v}{t_1} = 4.71 \ \frac{1}{s^2}$$

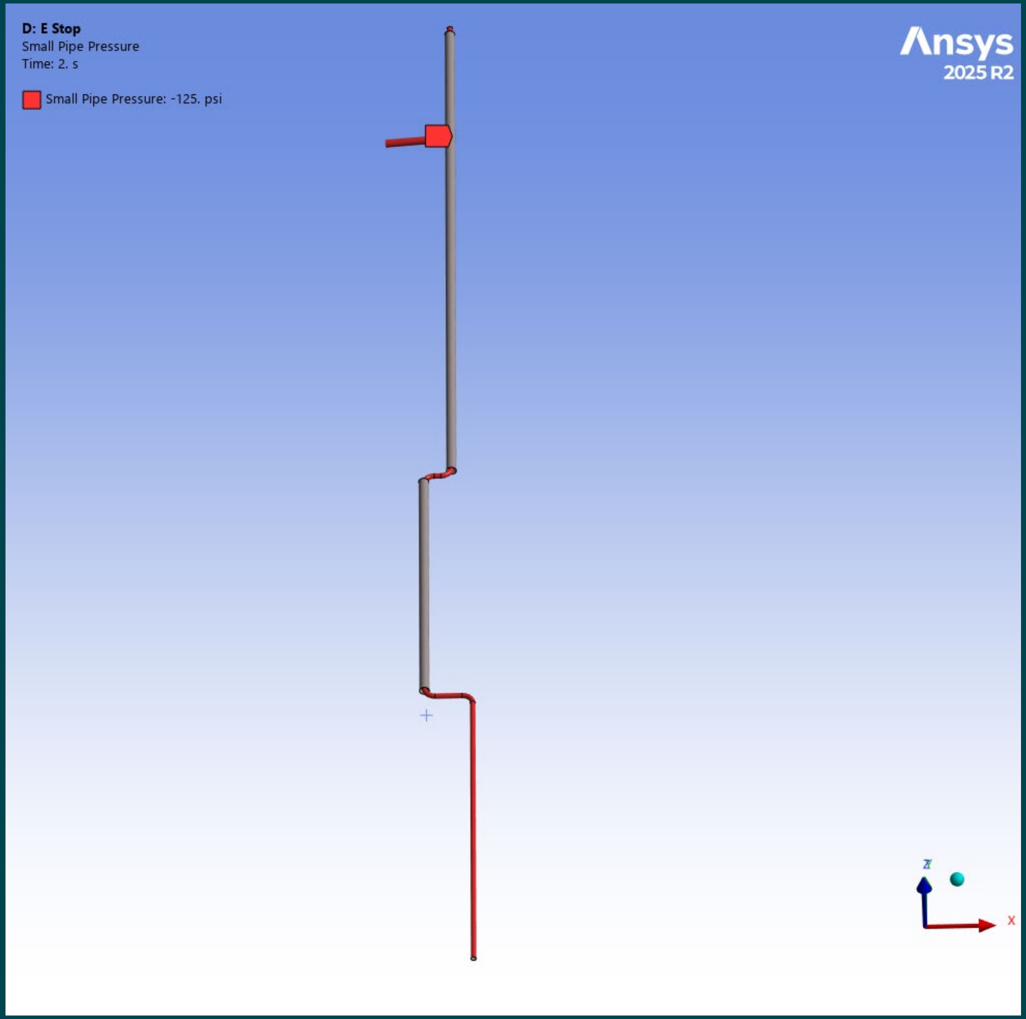
$$a_{10} := \frac{v}{t_{10}} = 0.47 \ \frac{1}{s^2}$$

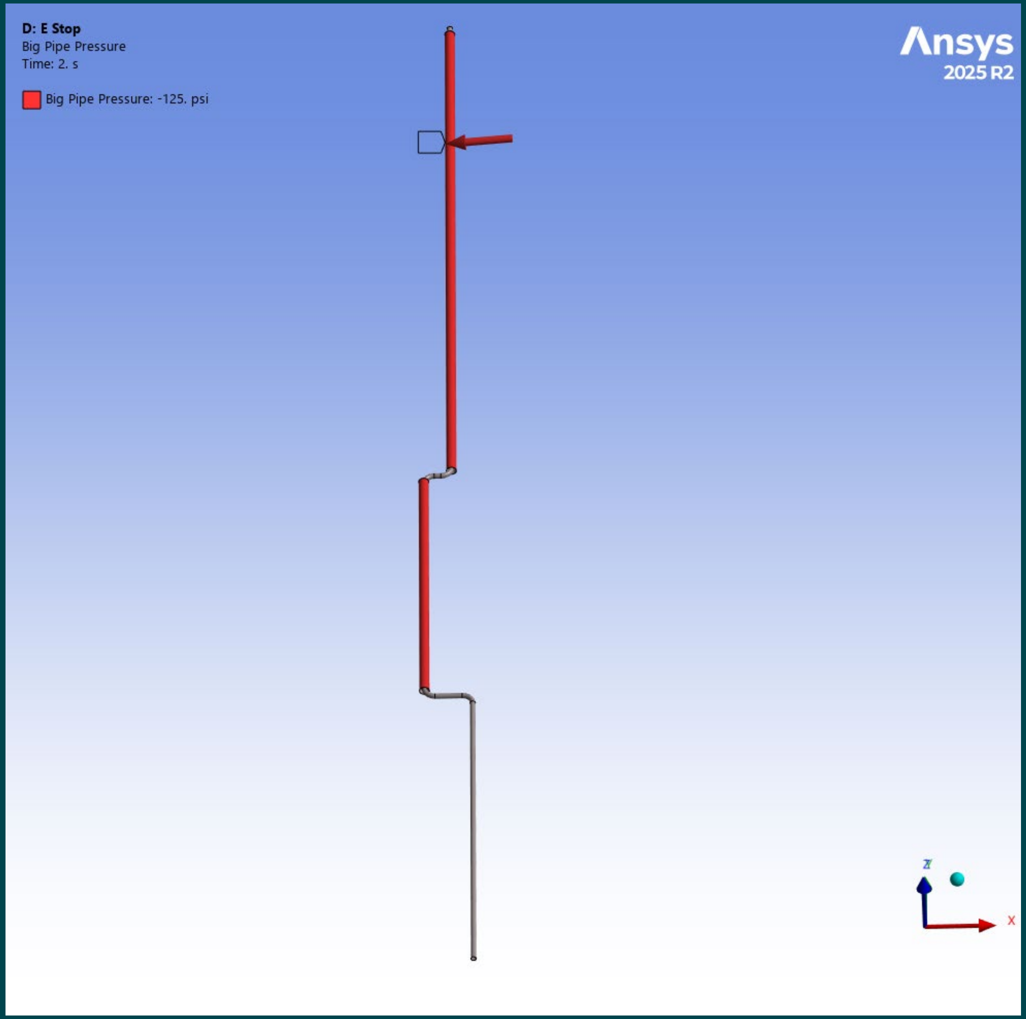
Load Parameters: Live Loads



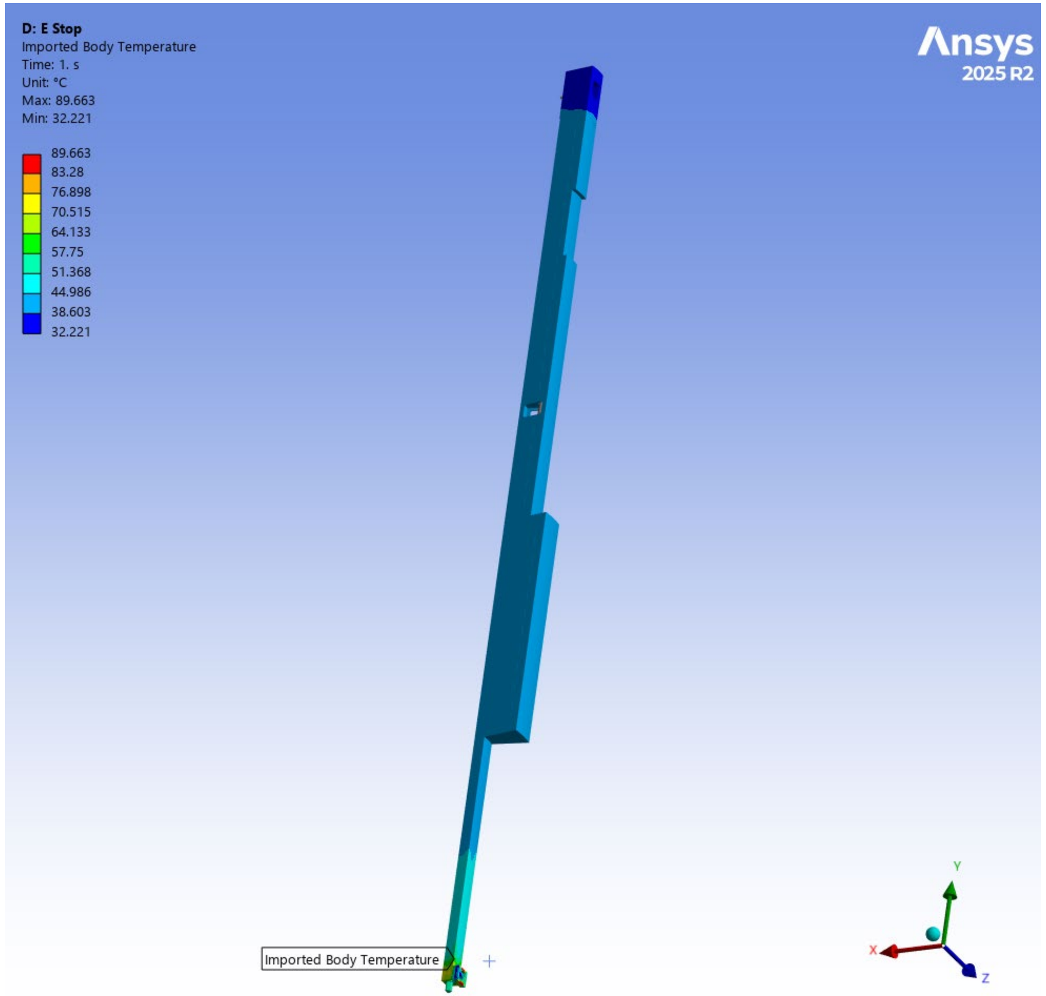


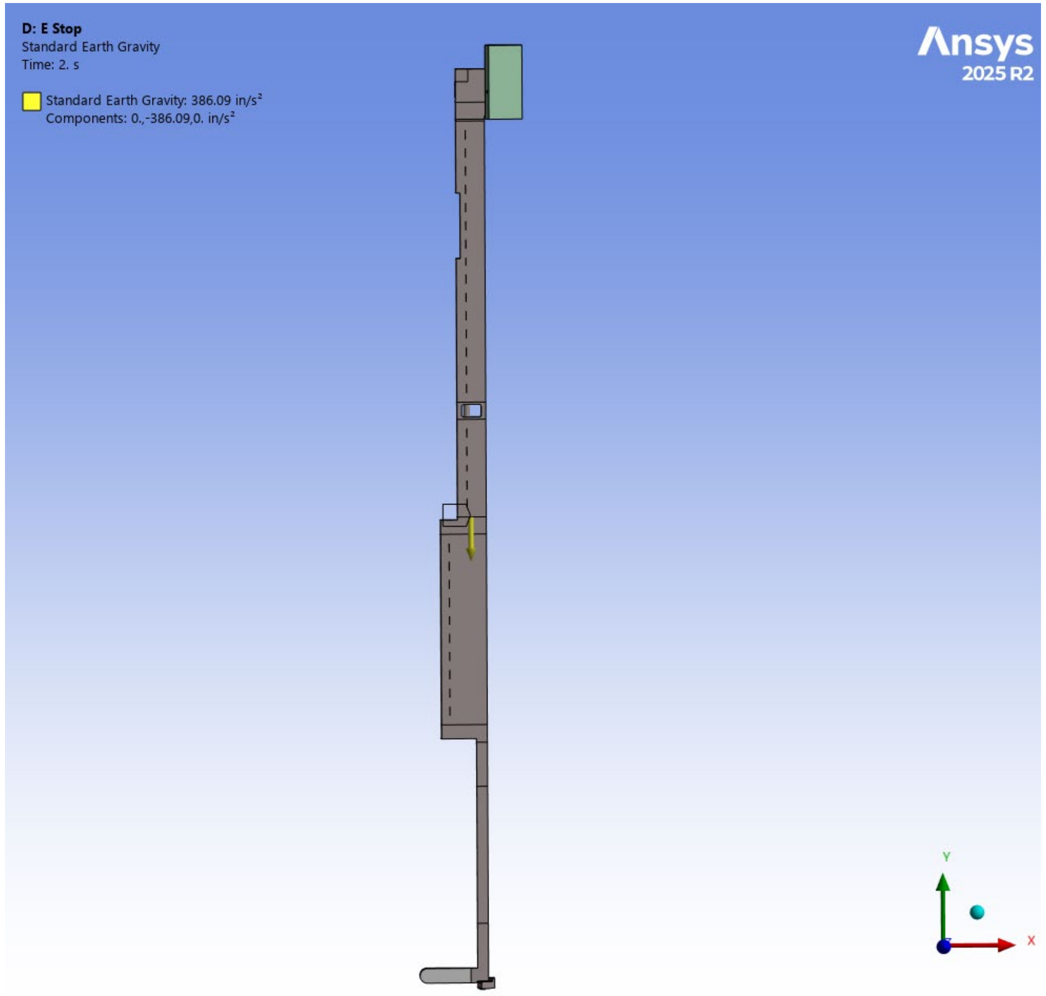
Load Parameters: MAWP





Load Parameters: Temperature and Deadload





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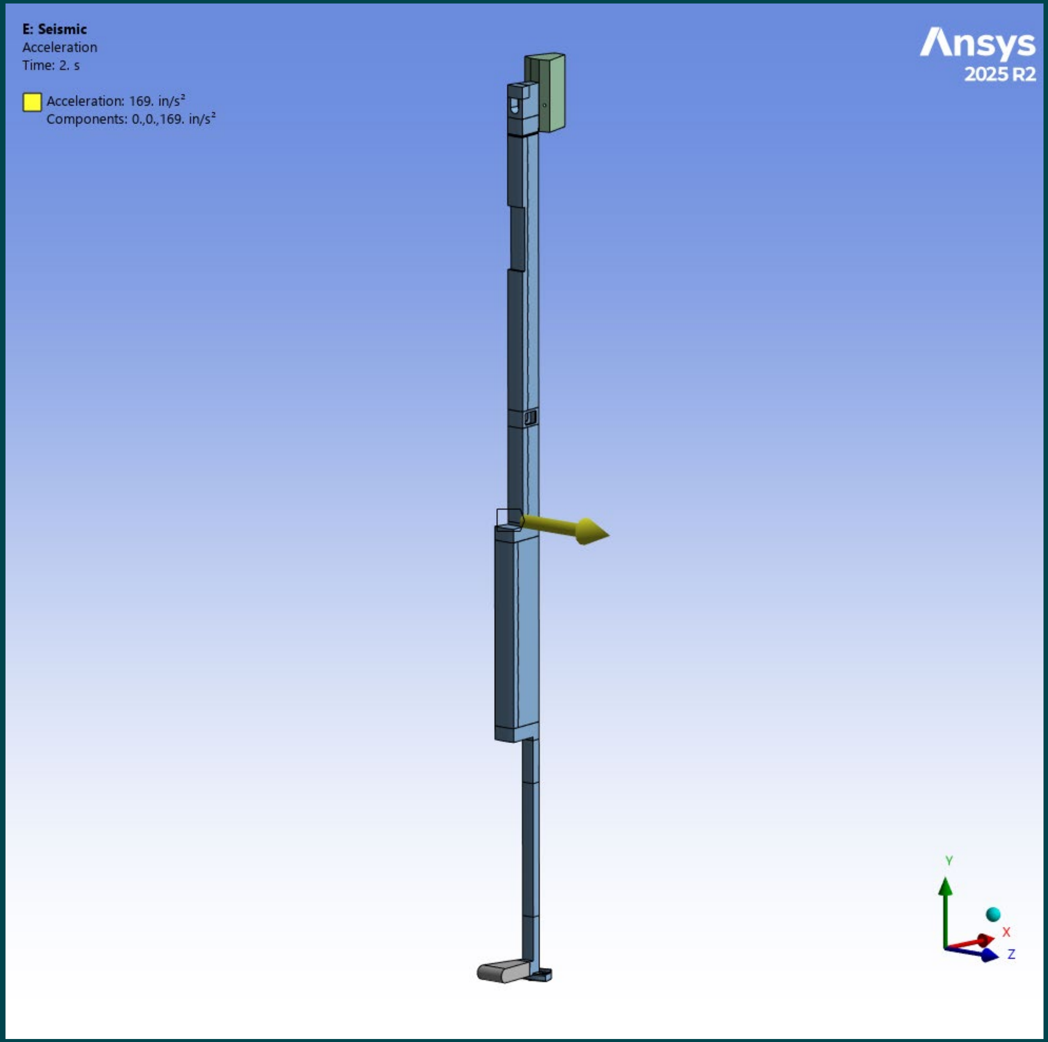
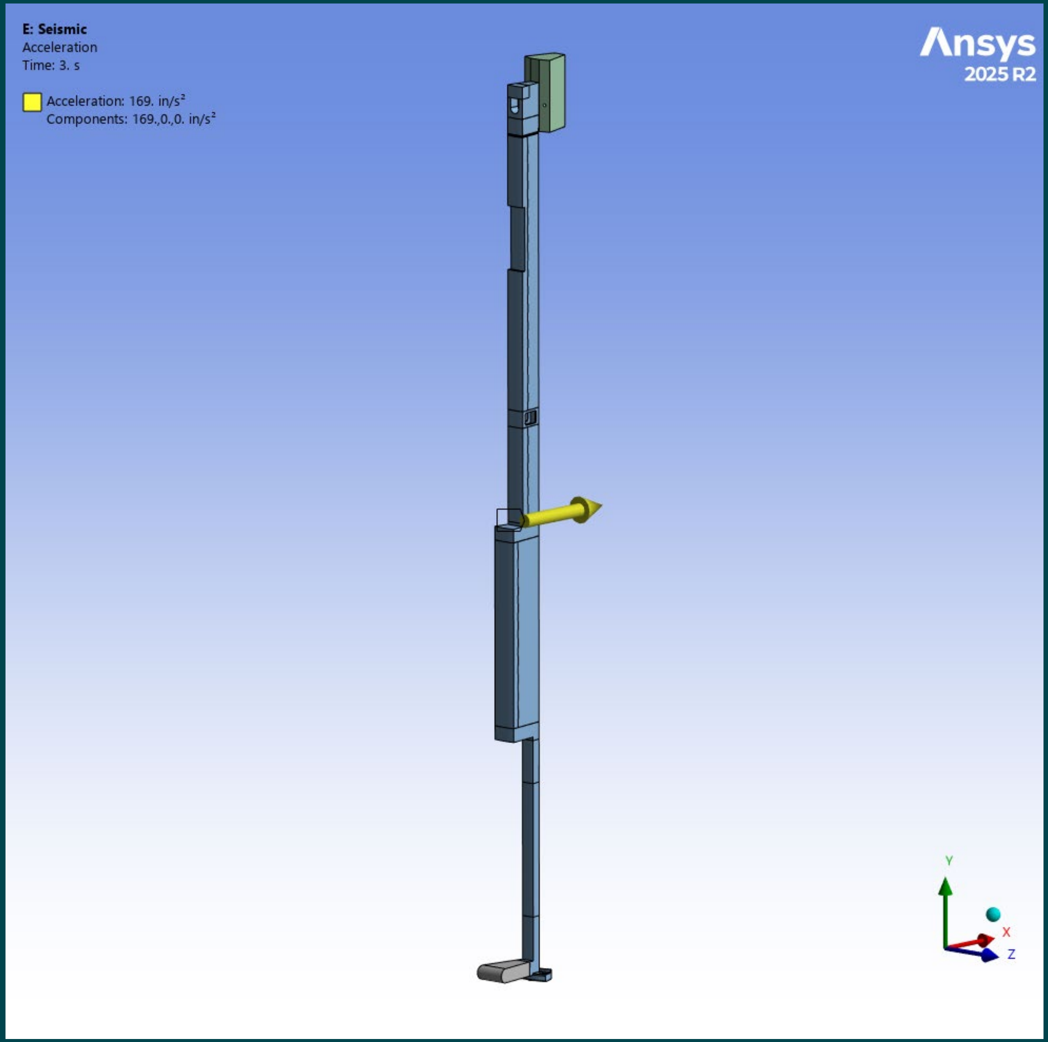
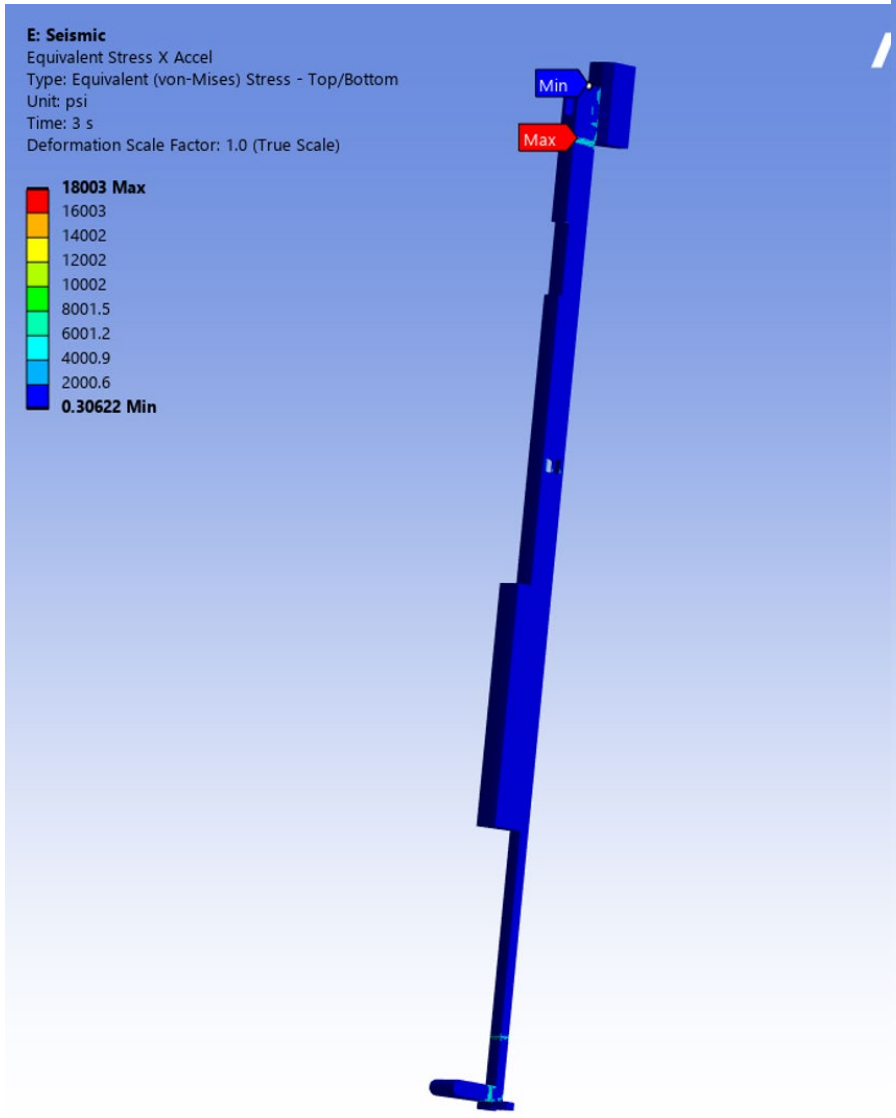
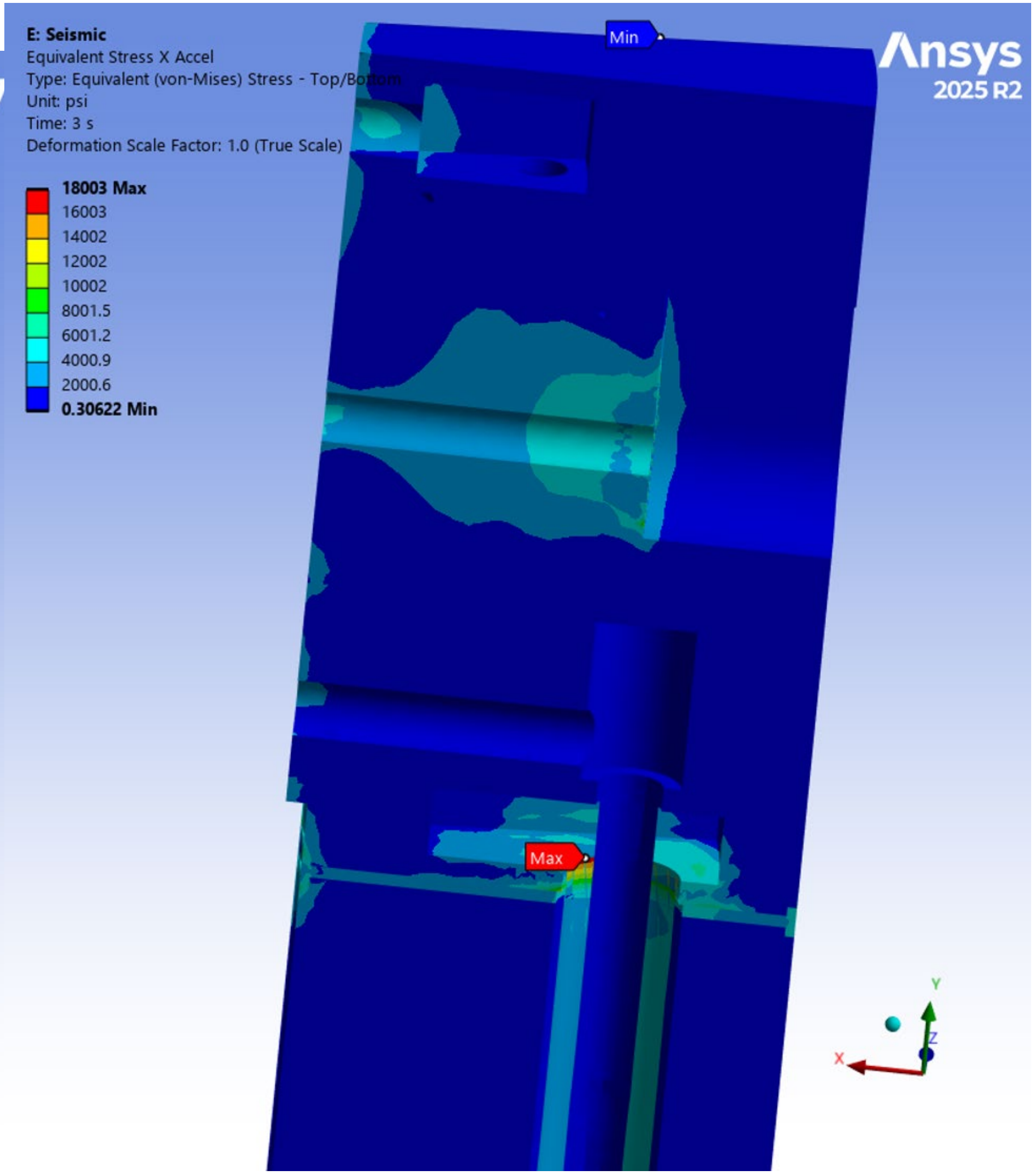
Load Parameters: Seismic (Two directions)



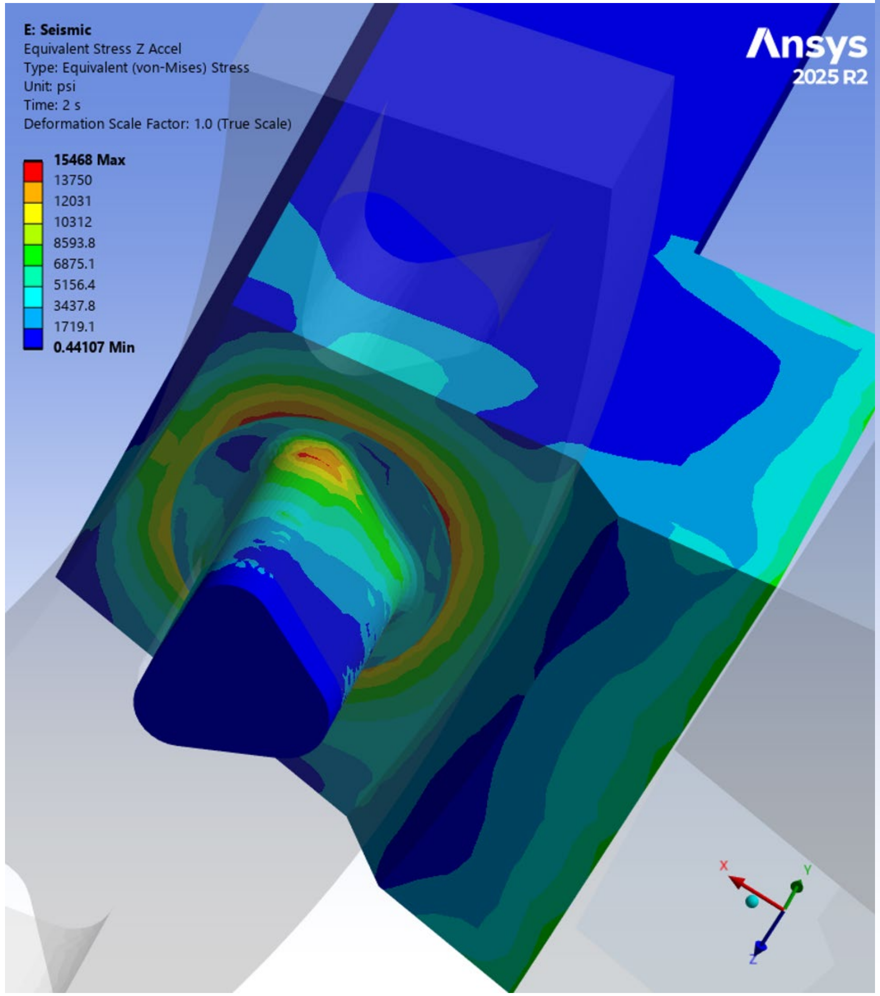


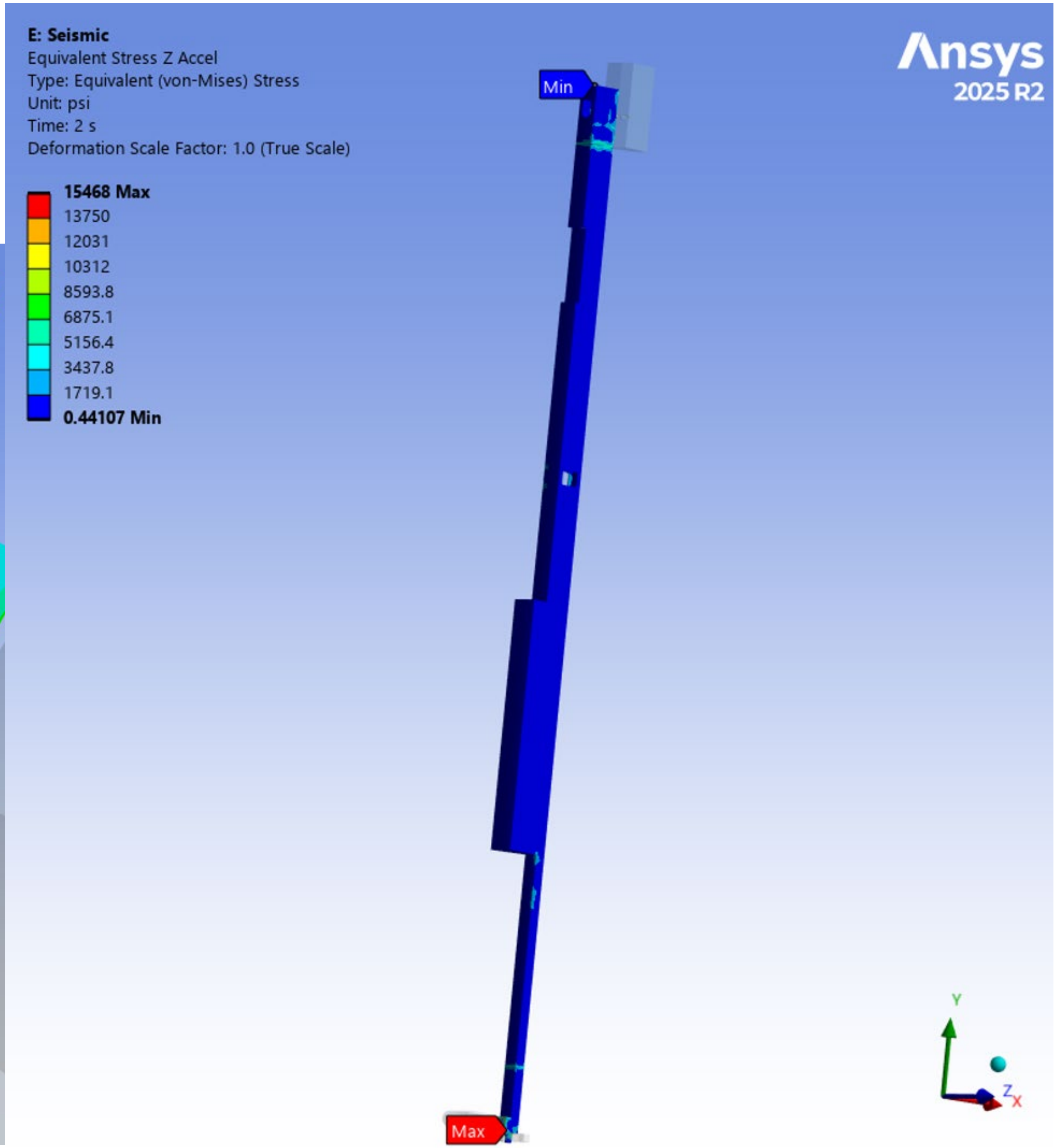
Segment Equivalent Stress: Seismic X



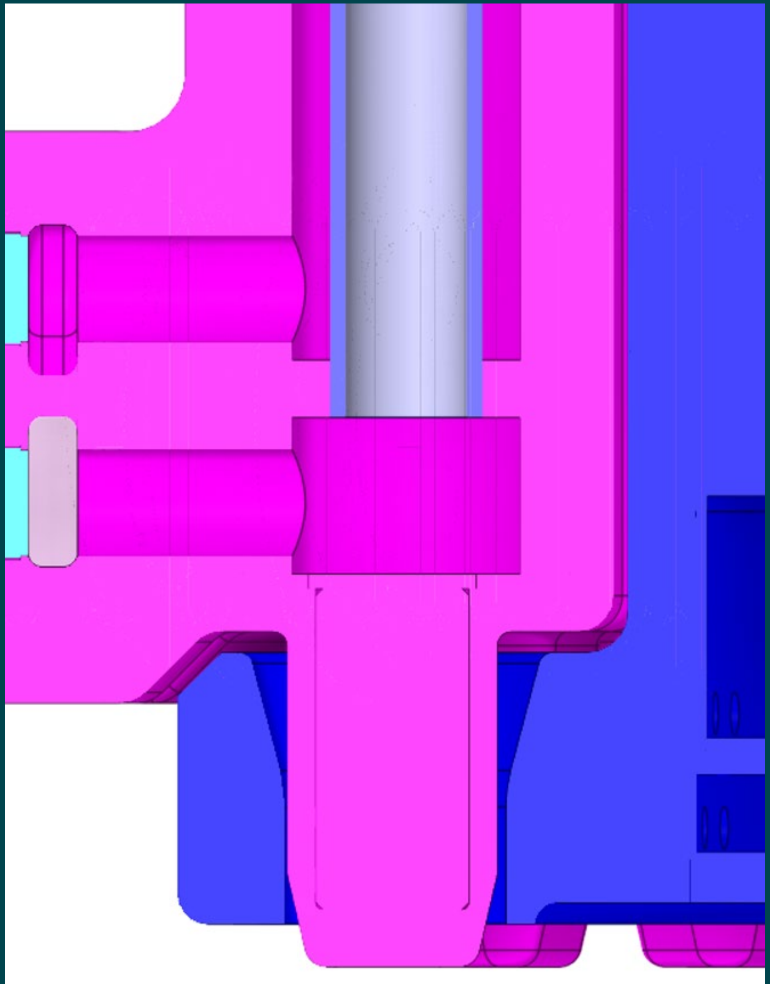


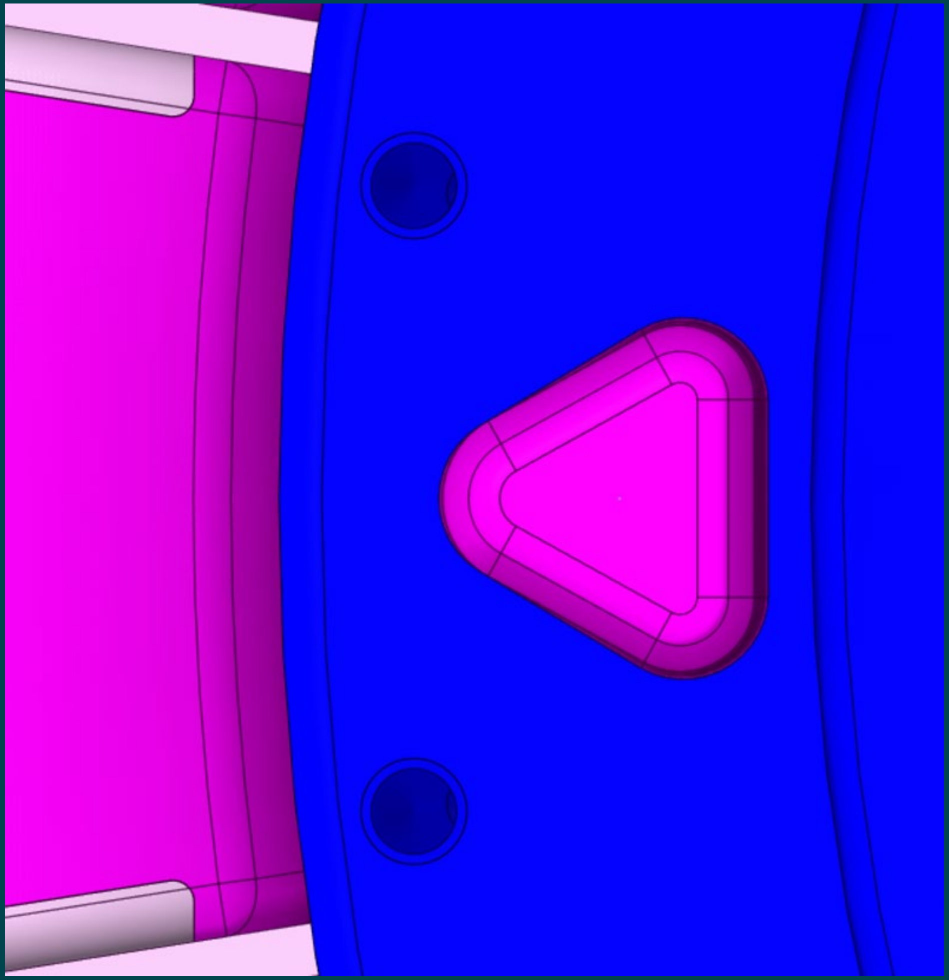
Segment Equivalent Stress: Seismic Z



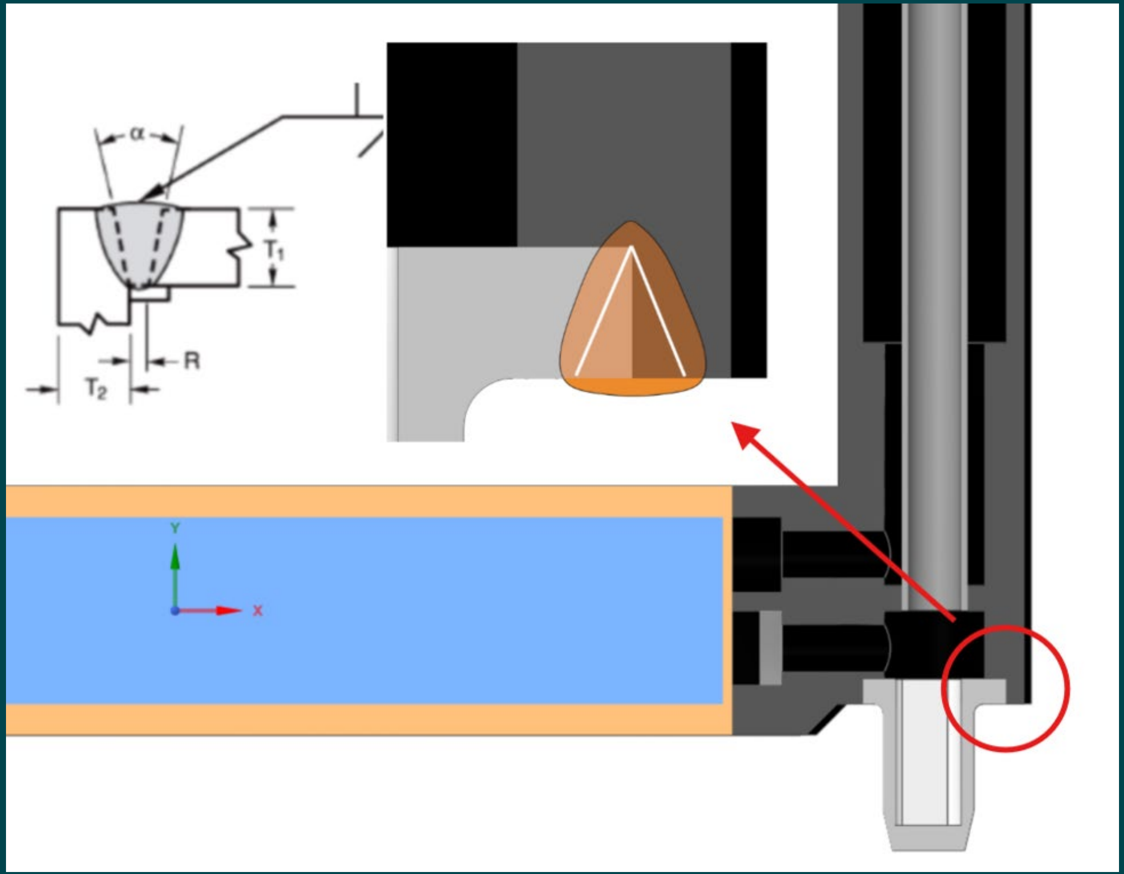


Segment Foot Pin





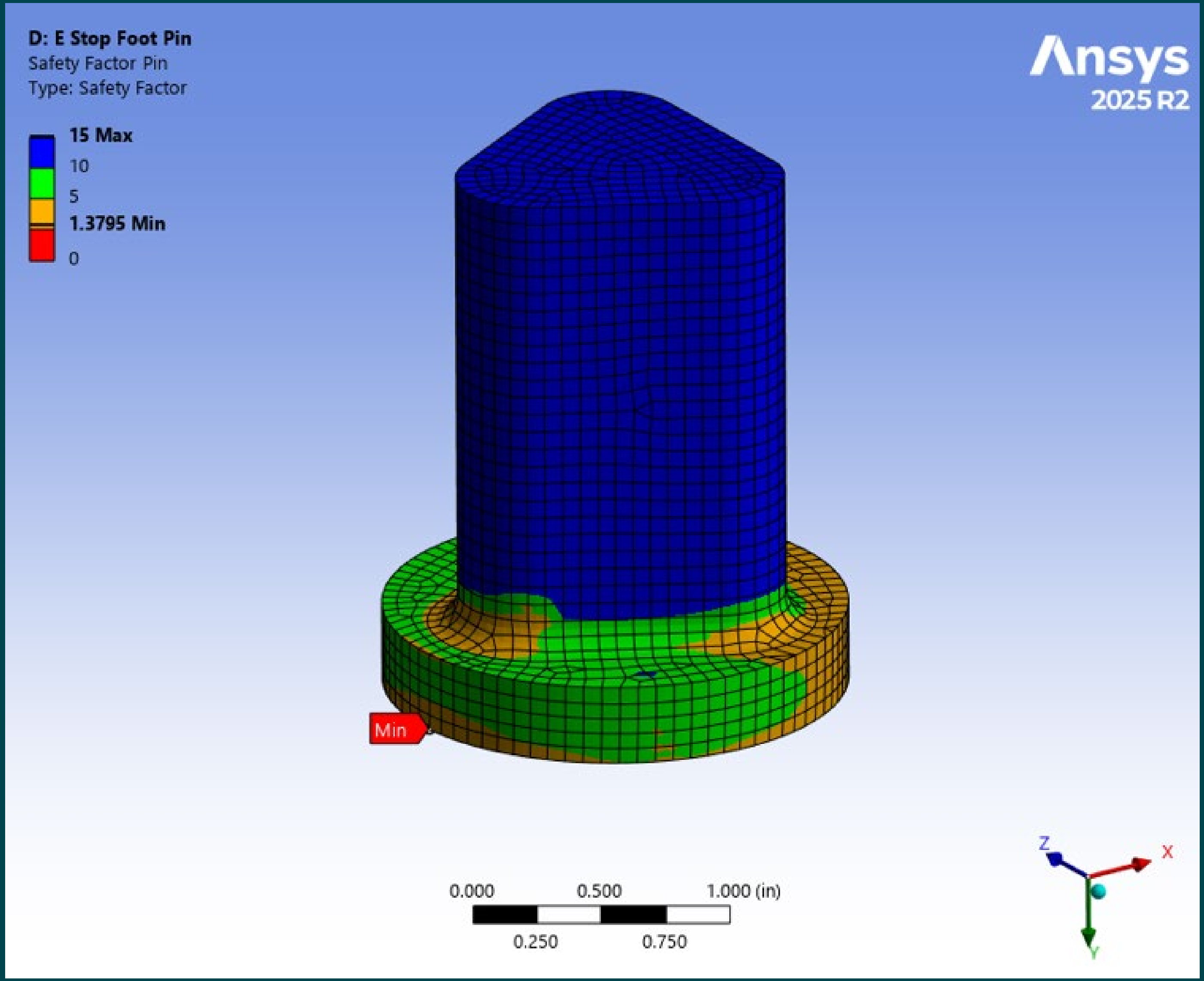
Segment Welds



- All Segment welds joints are ‘stepped’ which is similar to having a backing strip and no exposed weld root.
- This set up is like a prequalified CJP weld example from AWS (far left image).
- All welds are to be smoothed and polished during fabrication.
- Allows for the use of the same fatigue curves as the parent material.

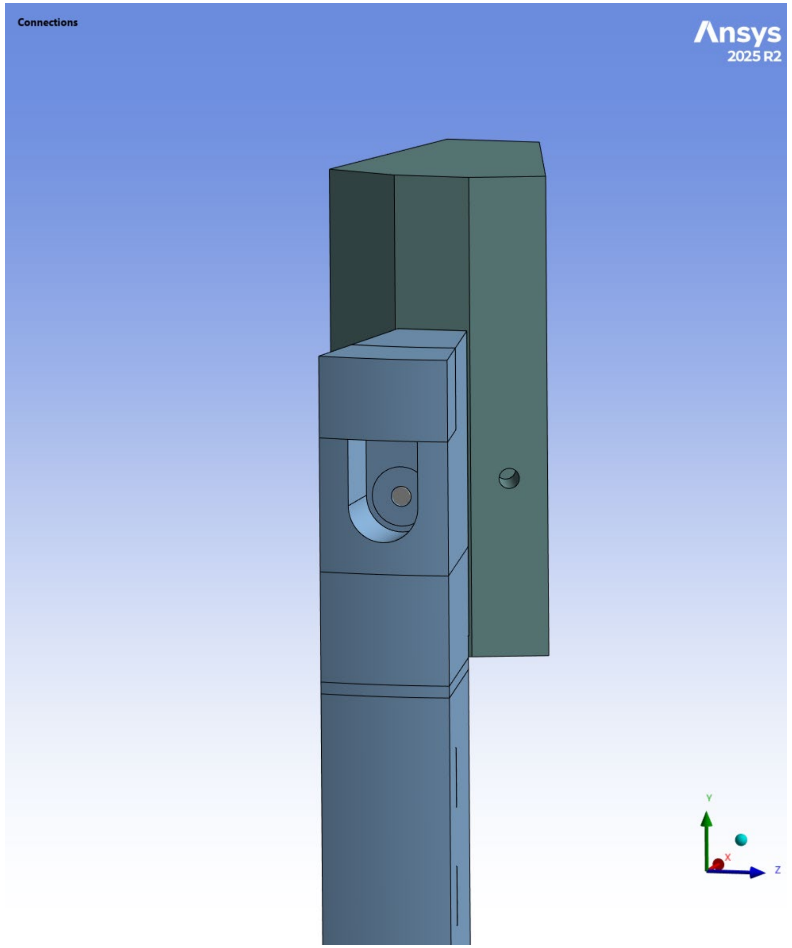
Segment Foot Pin

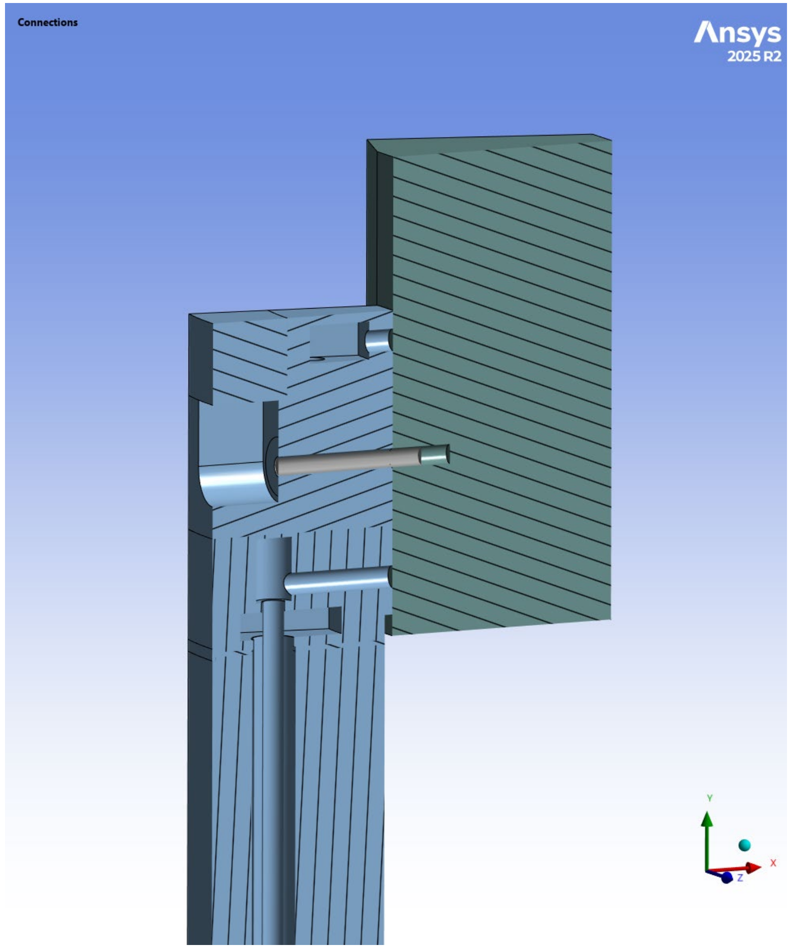
- Cyclic Safety Factor



Segment Bolt Connection

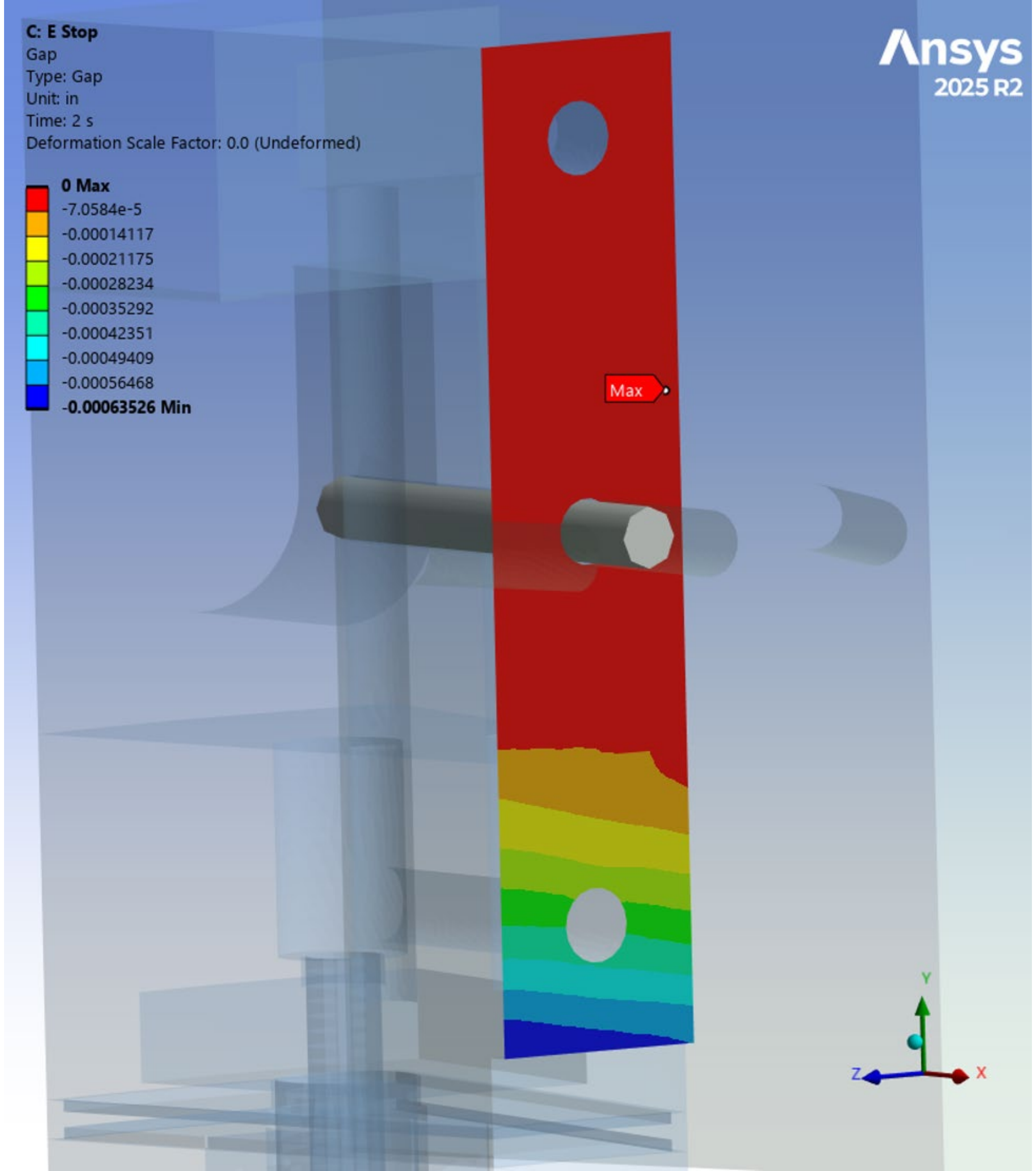
- M16 Inconel 718 Bolt
- Preload applied



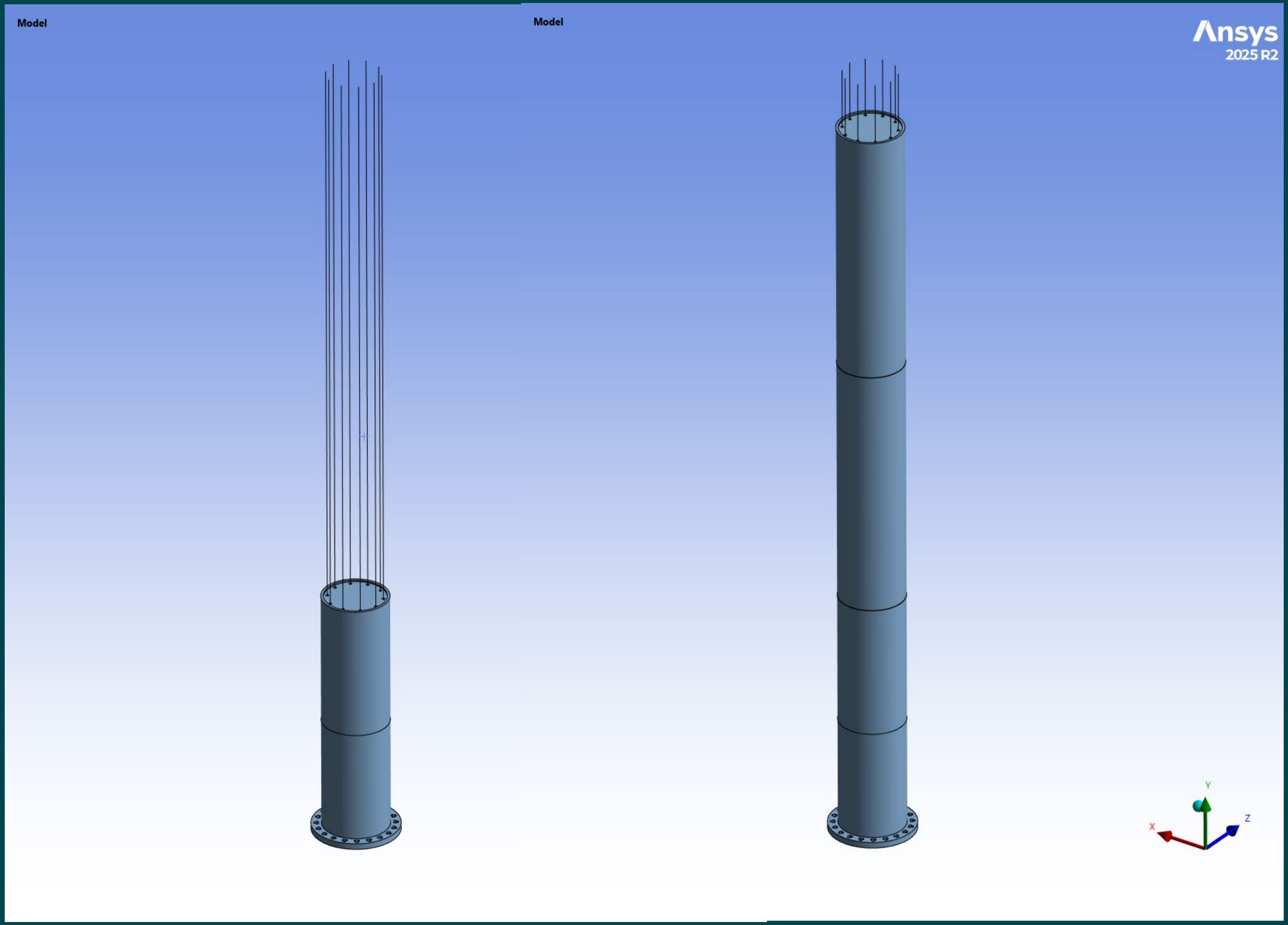


Segment Bolt Interface

- A contact plot of how the centripetal force (operational) causes the lower portion of the surface to pull away.



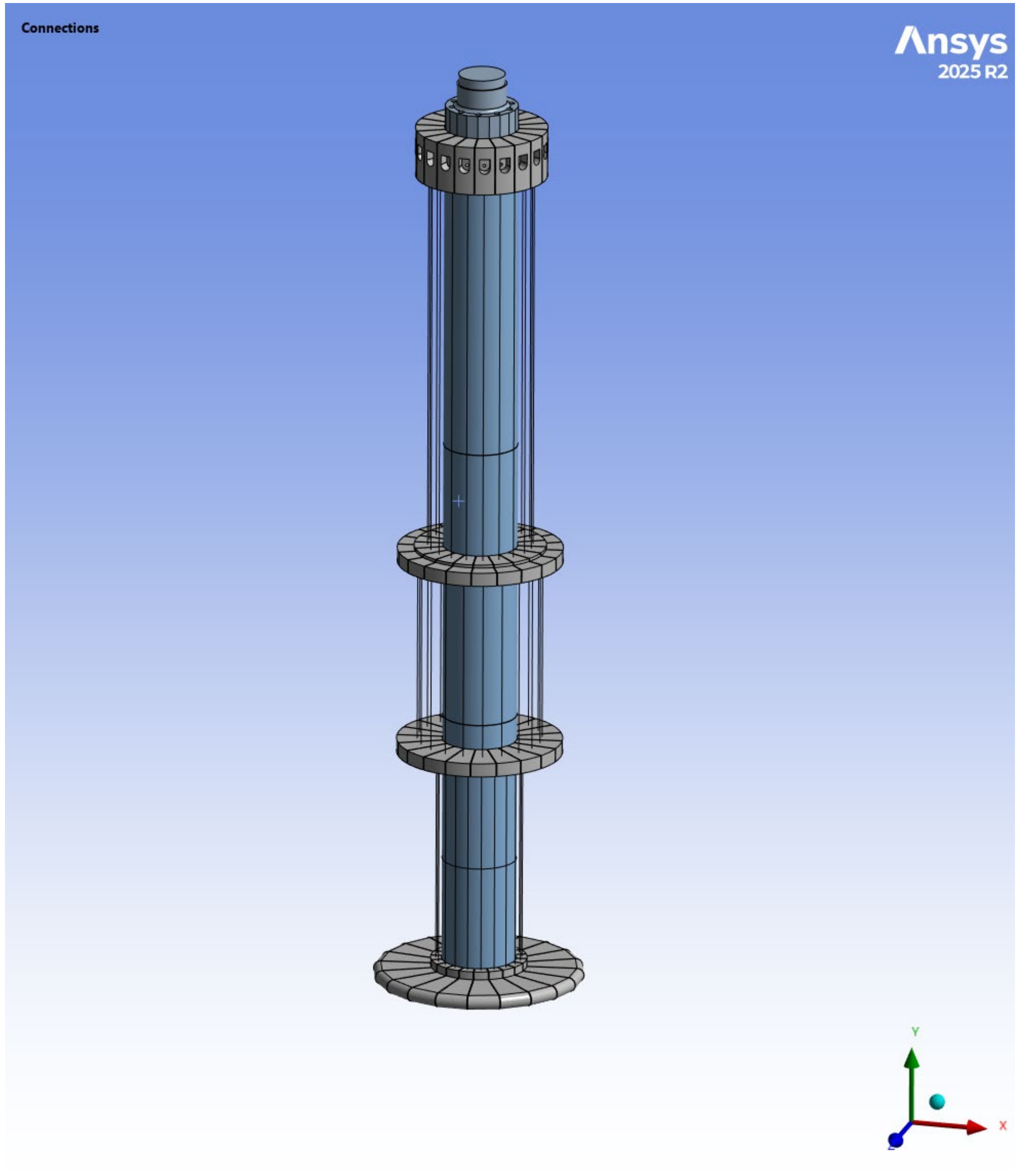
Shaft and Tie Rod Analysis



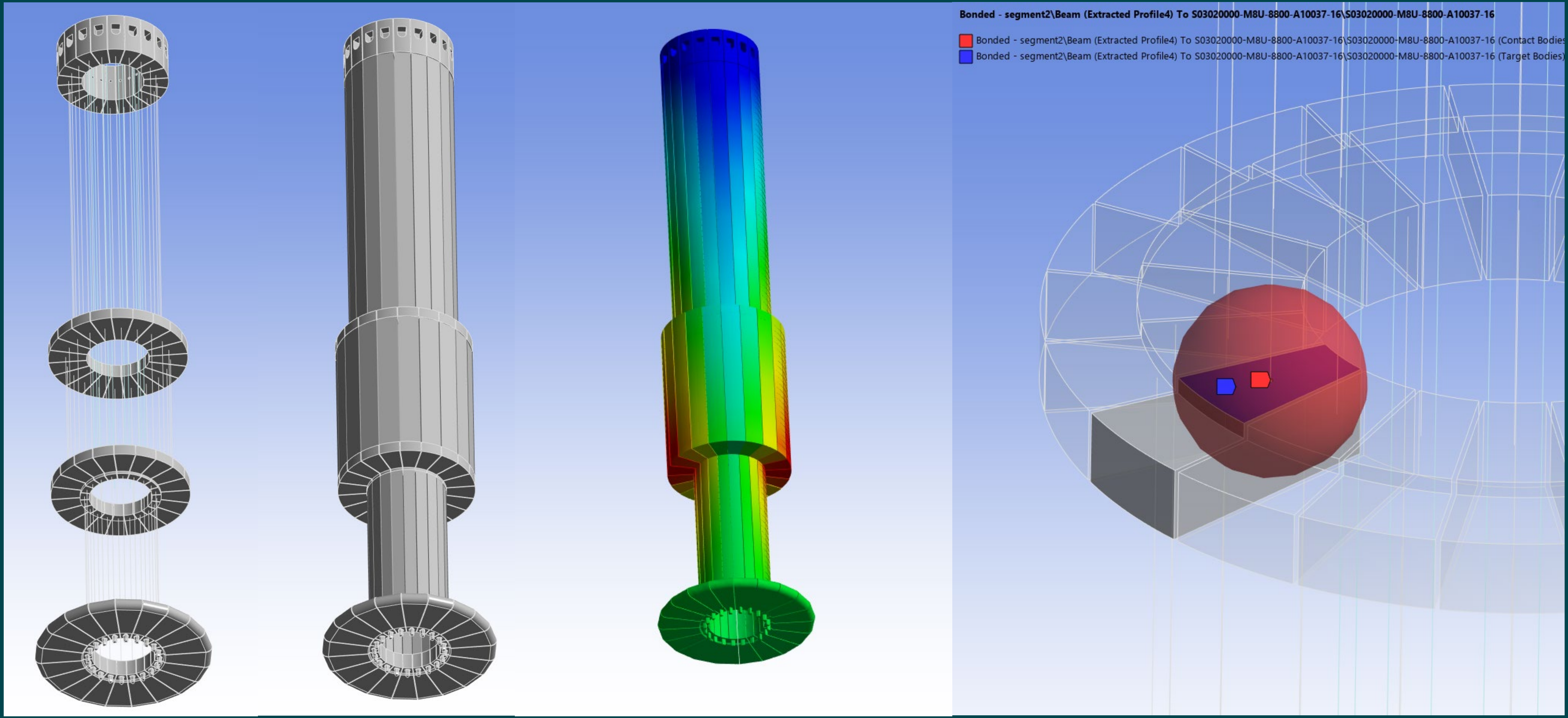
- Main focus is to check Tie Rod strength
- Verify no separation at the Shaft joints
- Inconel 718 Tie Rods
- 316L Stainless components
- Same ASME requirements

Connections:

- Shaft Interfaces have contact interfaces that allow separation
- Beam elements are used for the Tie Rods
- Simplified Segments are used



Simplified Segments



Applied Loads:

Time Step 1:

- Tie Rod Preload (24000lbf)
- Gravity

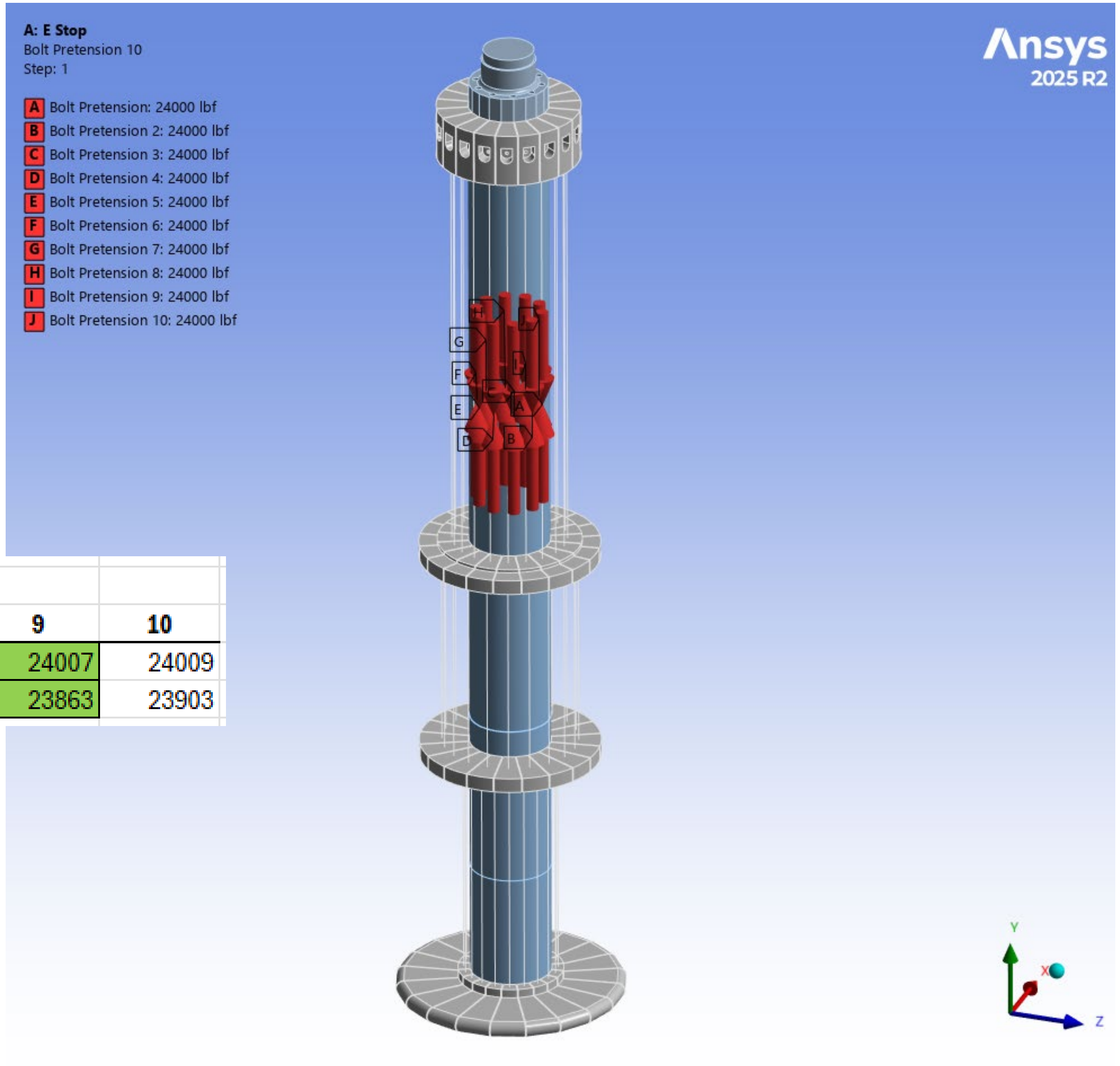
Time Step 2:

- Preload Locked
- Gravity
- Temperature
- Pressure
- Rotation
- Seismic*
- Displacement*

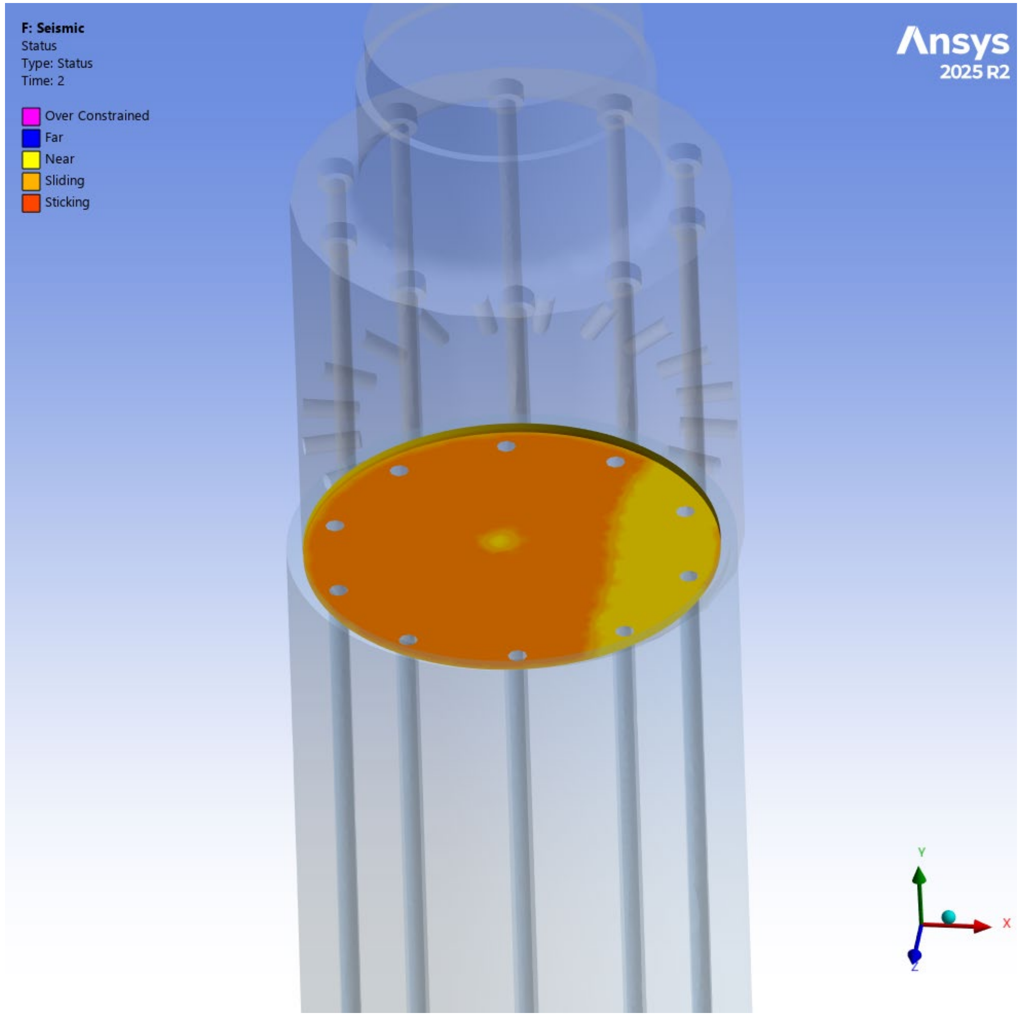
Tie Rod Preload

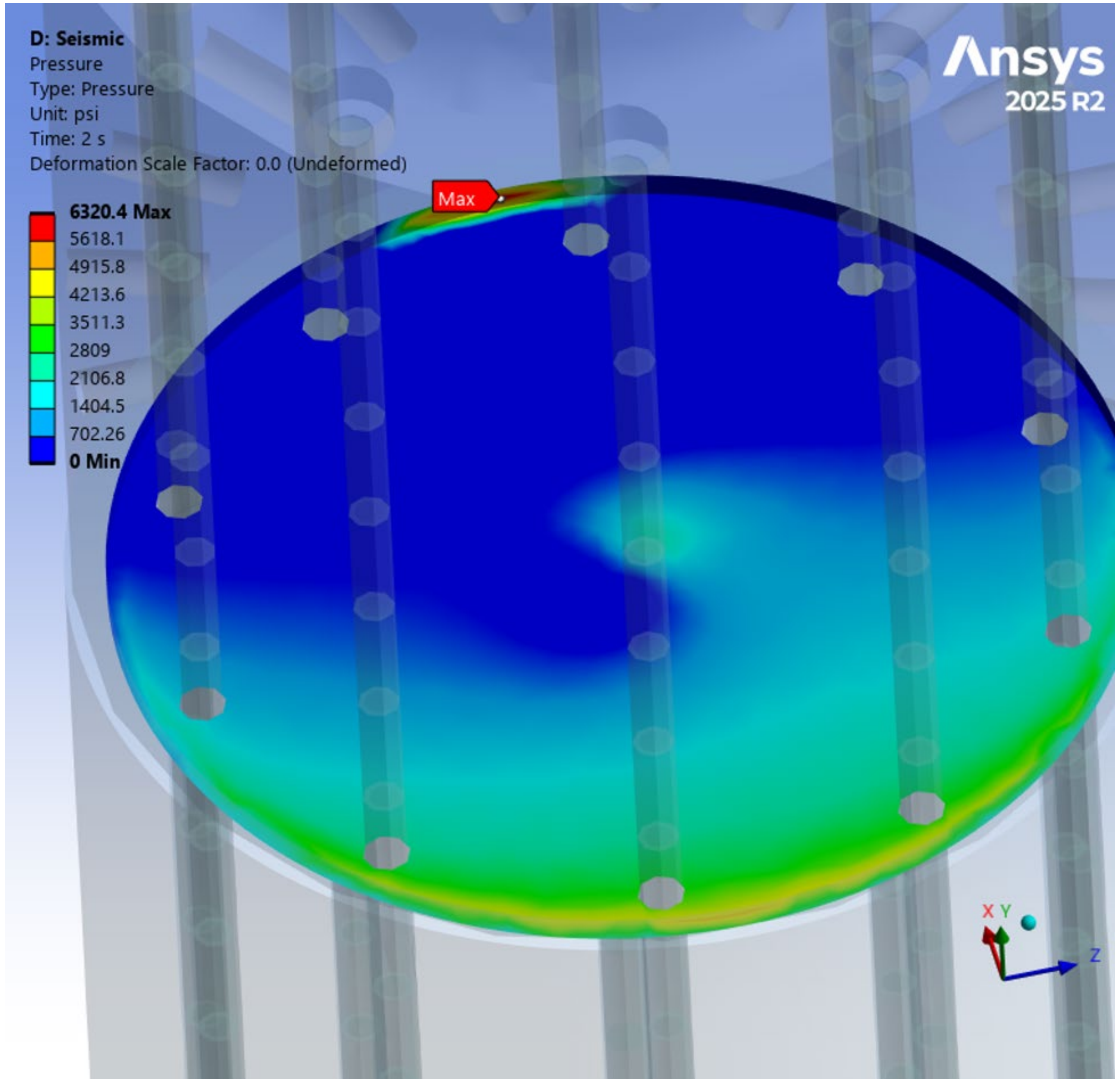
Compare Operational to Seismic Preload Values (lbf)

			-X					+X		
	1	2	3	4	5	6	7	8	9	10
Operational	24010	24010	24008	24006	24004	24003	24003	24005	24007	24009
Seismic	23981	24068	24129	24143	24103	24025	23938	23877	23863	23903



Shaft Contact Status





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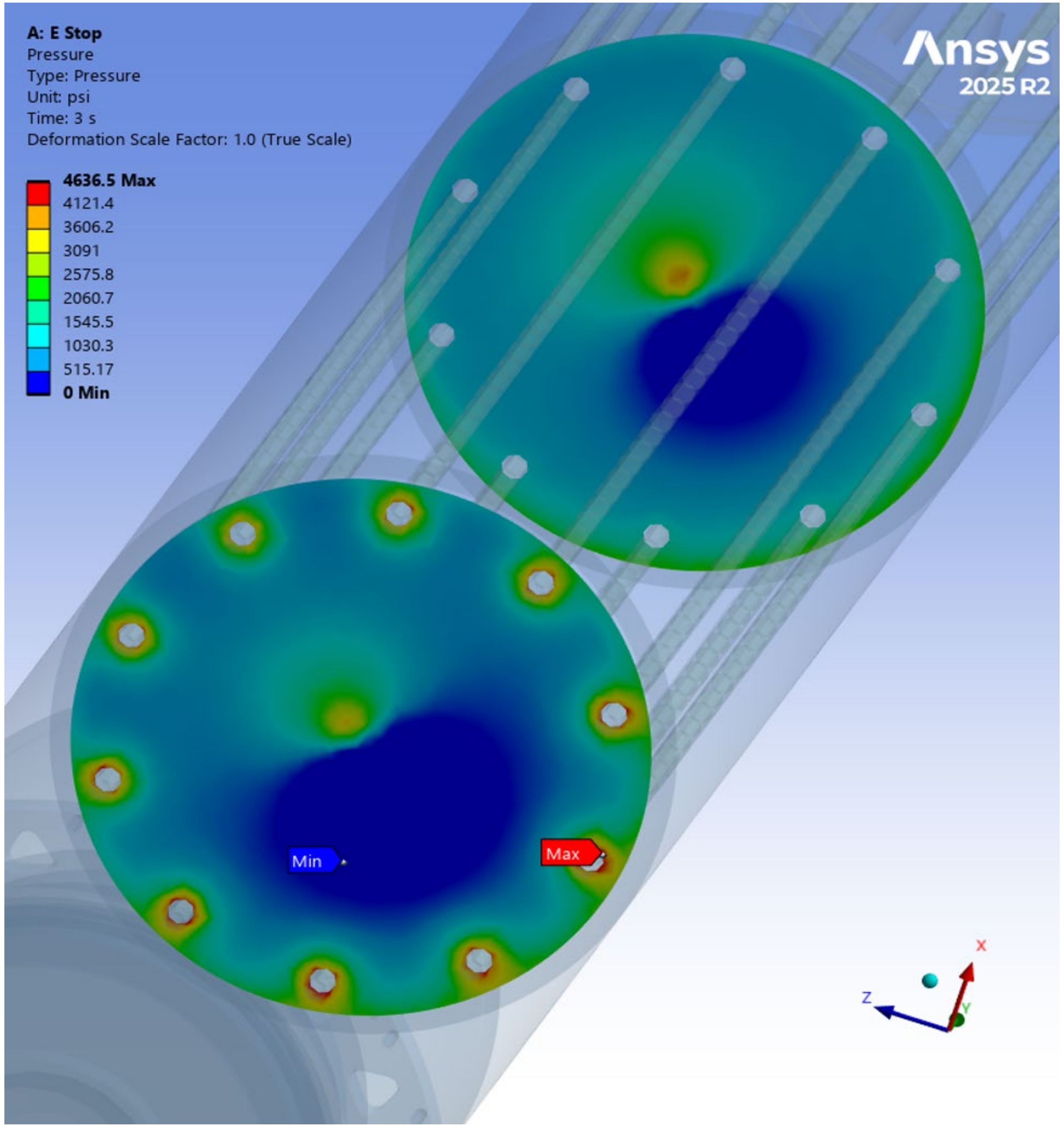
Shaft Contact Continued

- Lower Shaft Interfaces

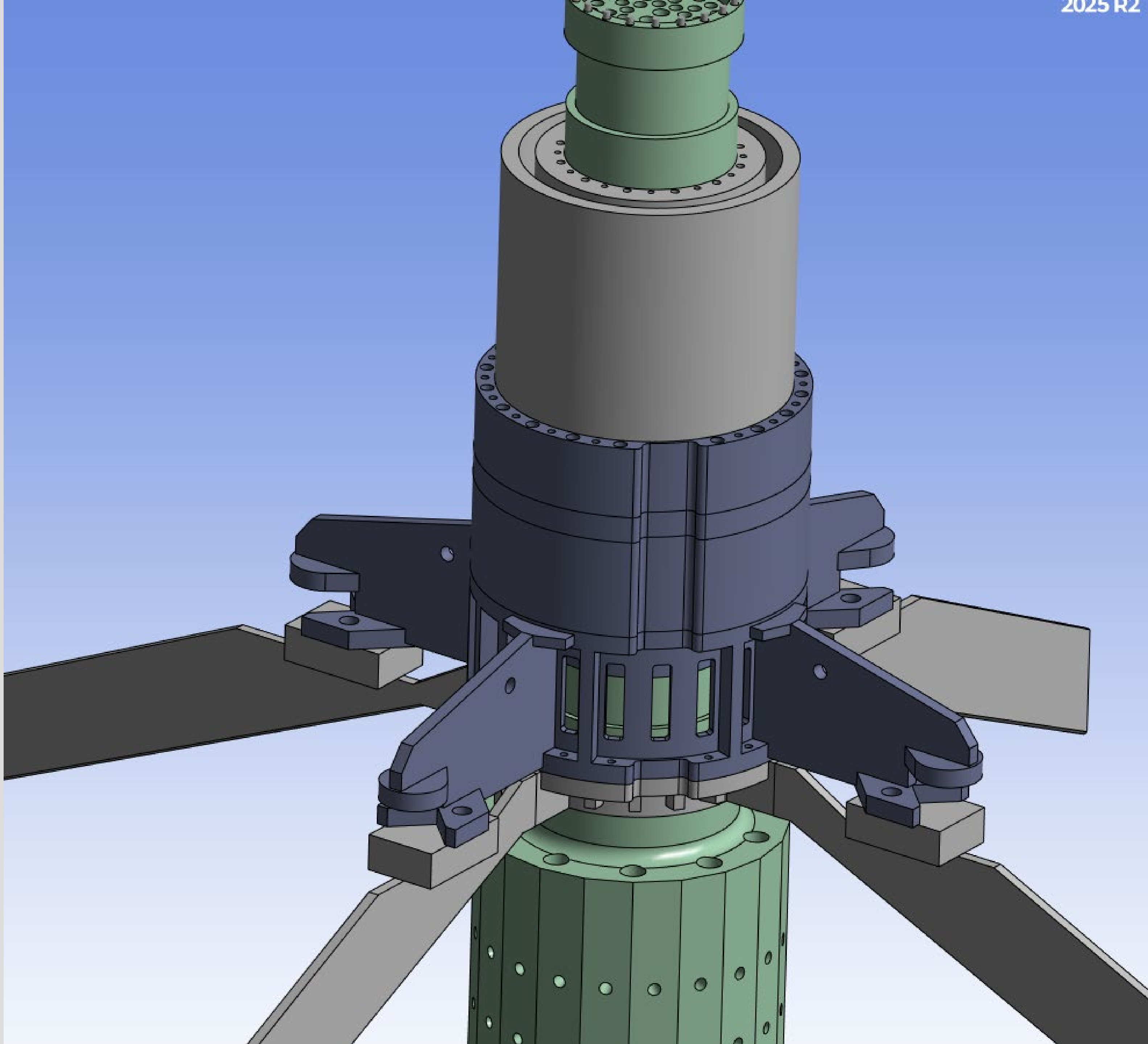


Crown and Drive Assembly

Analysis of Drive components

Contains most of the fasteners

No Temperature loads used



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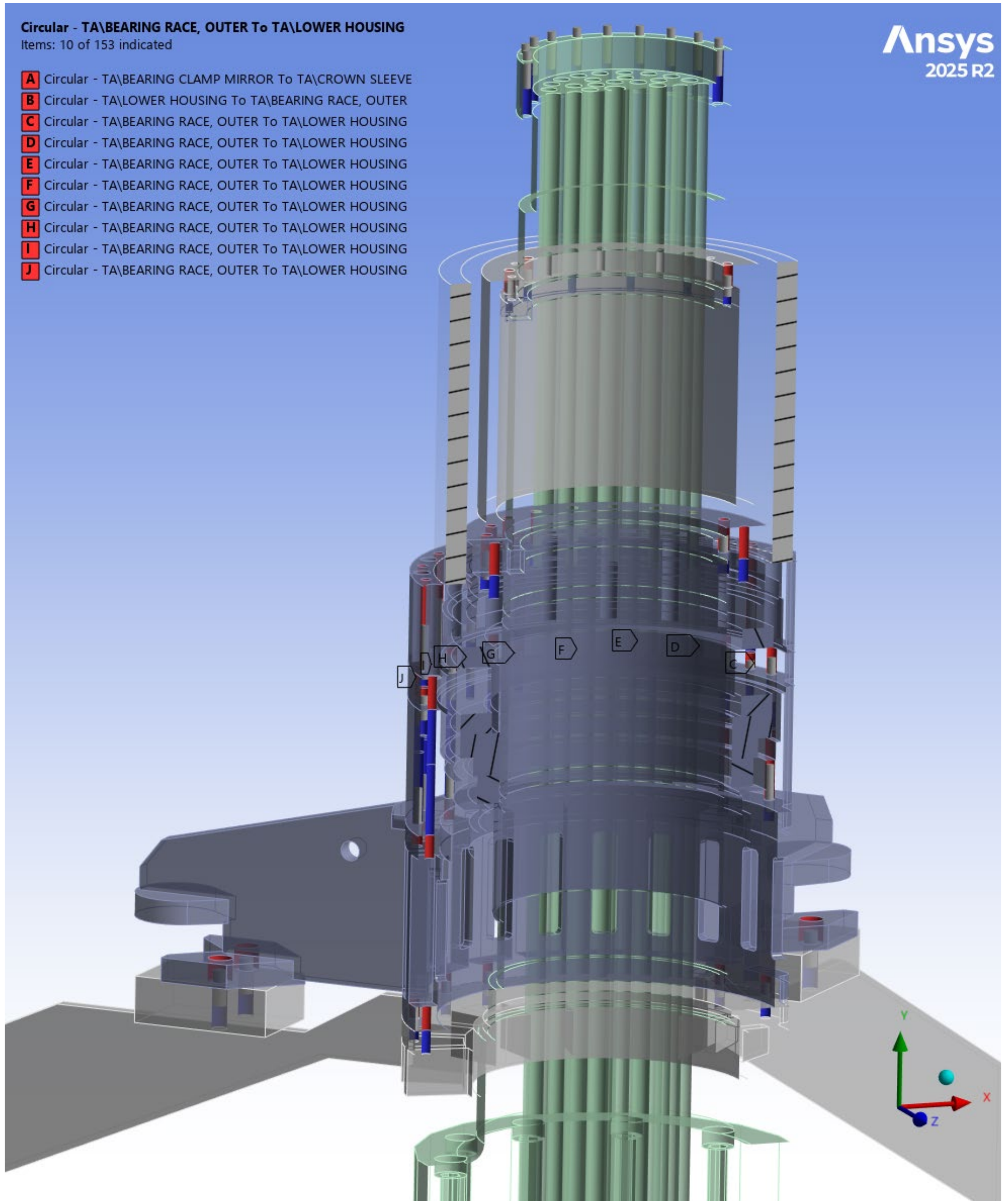
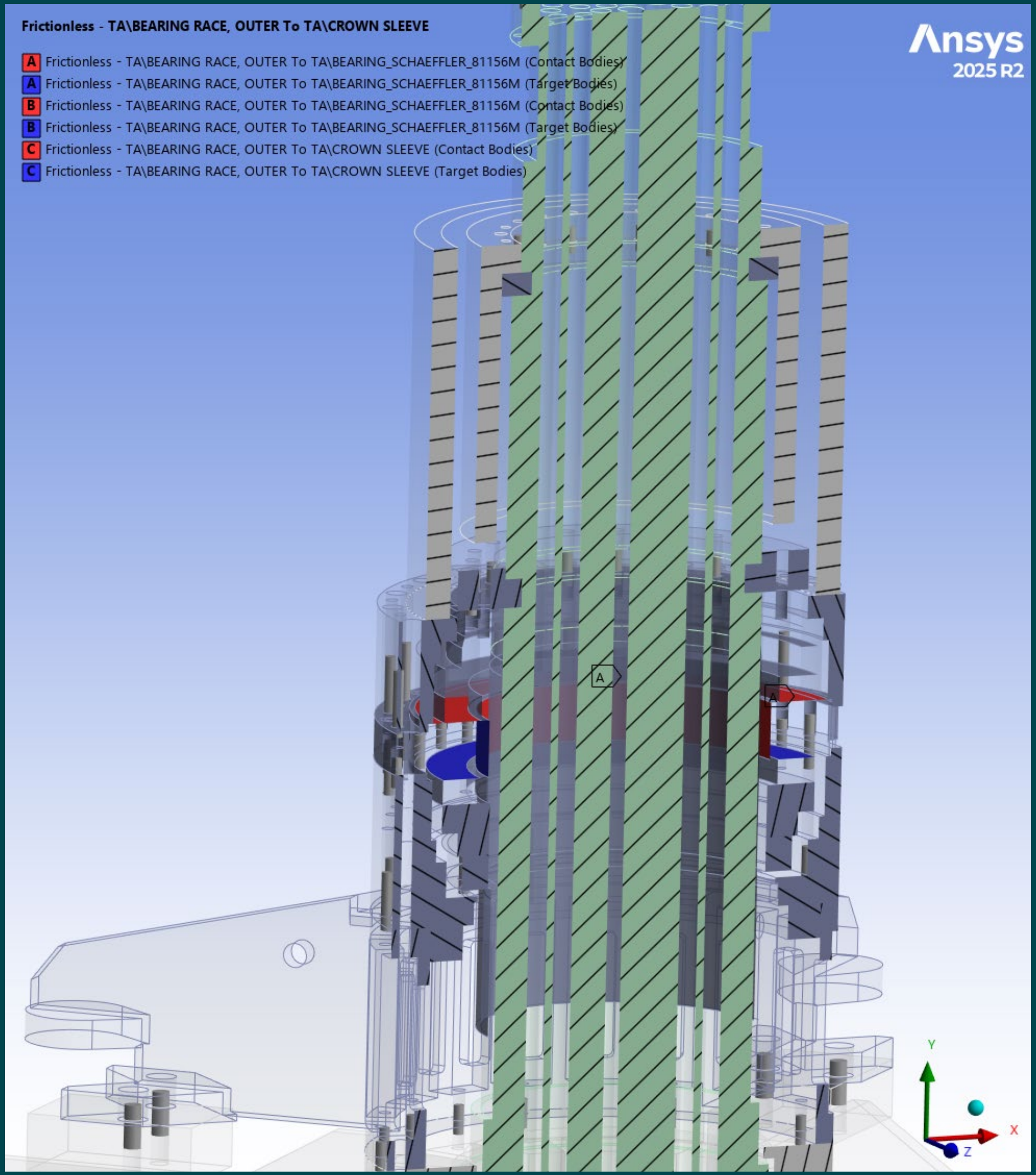
Fasteners

- All fasteners are beam connections
- No pretention used
- All fastener joints have a frictionless interface

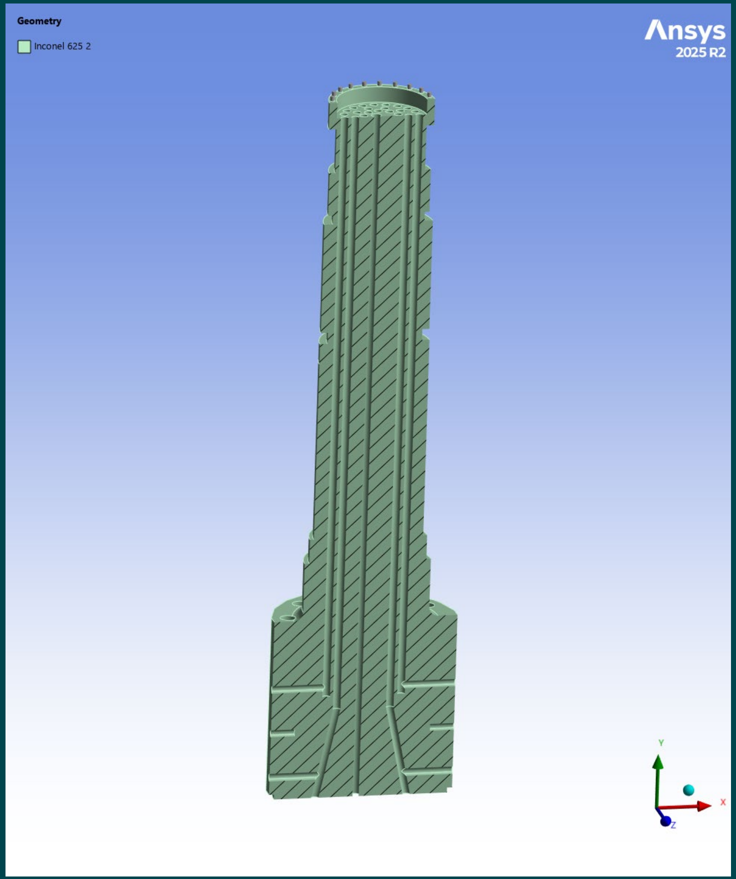


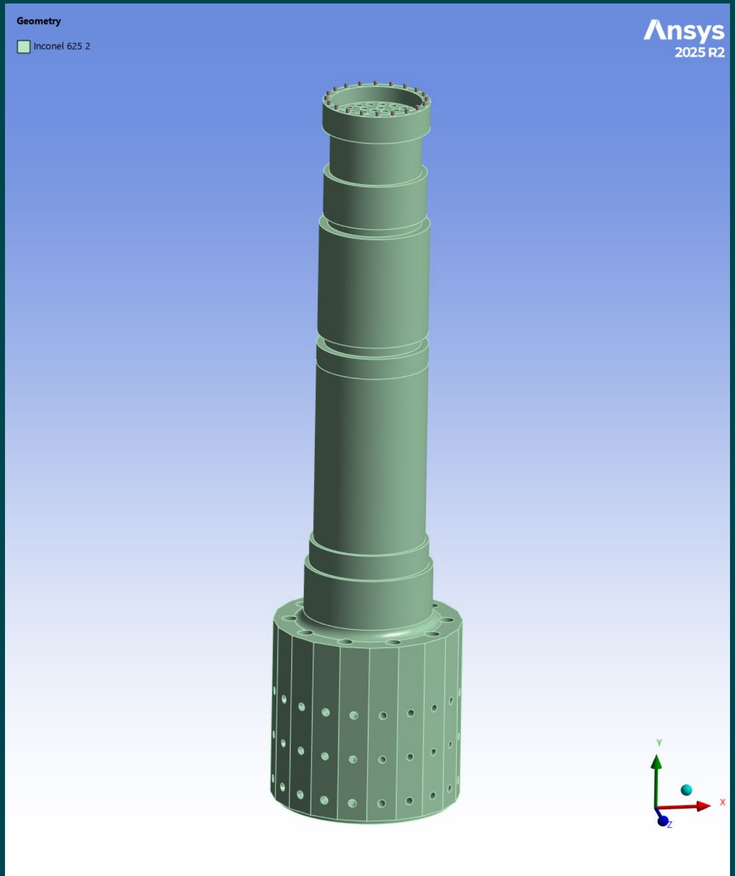
Bearing Interface

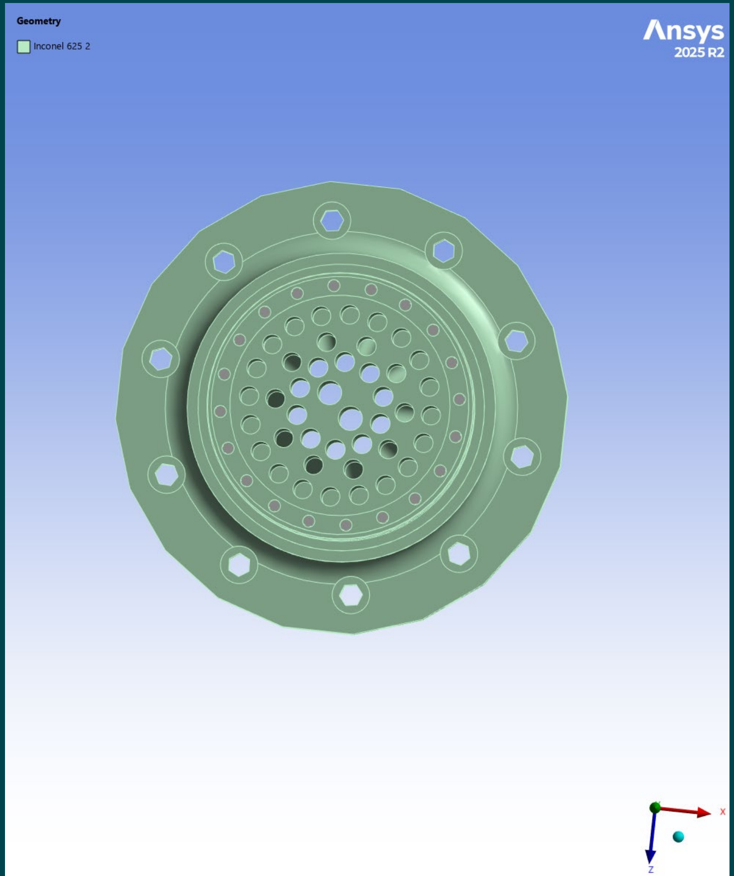
- Bearing surfaces are modeled as Frictionless



Crown

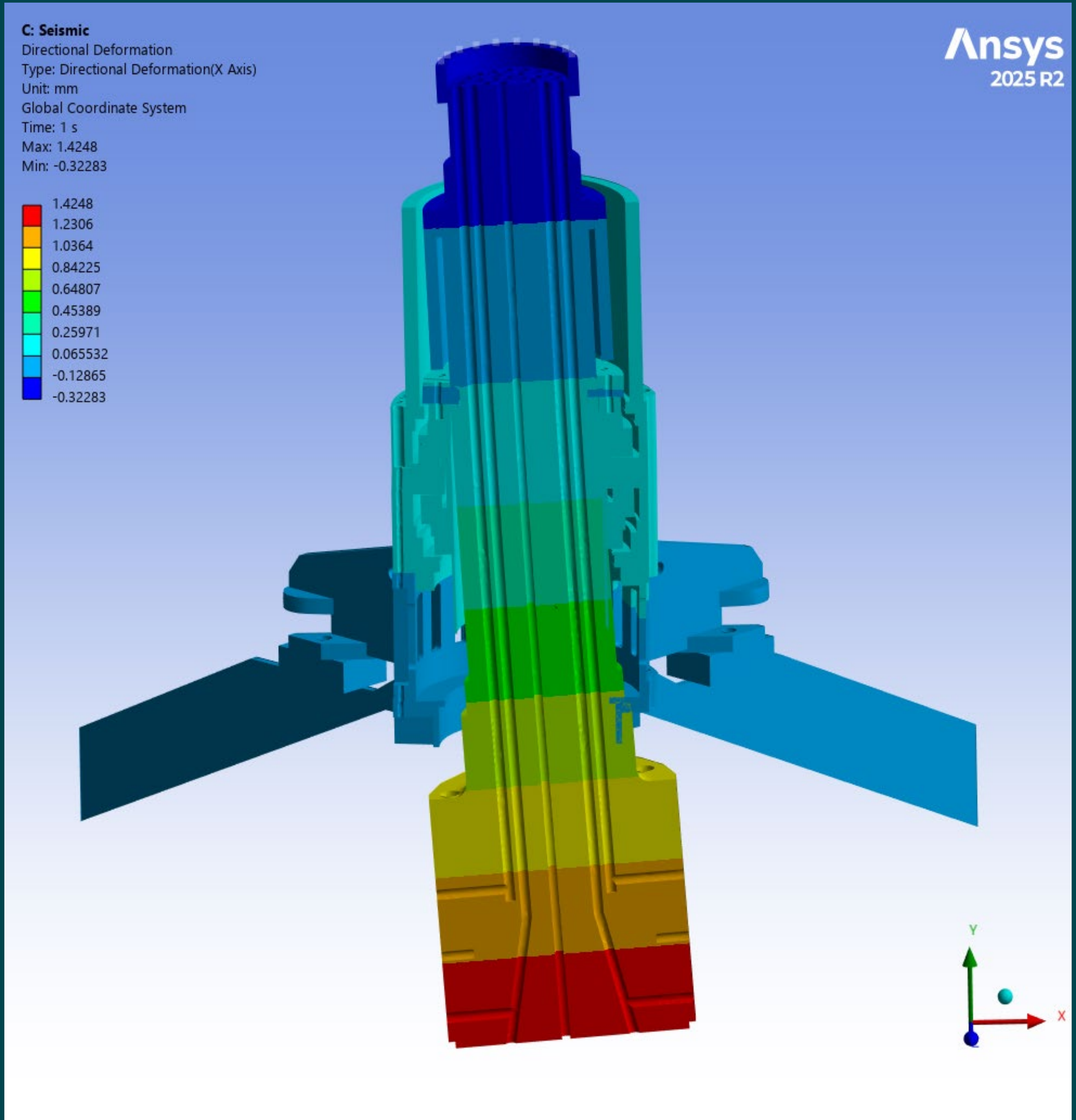

Geometry
Inconel 625 2
Ansys
2025 R2


Geometry
Inconel 625 2
Ansys
2025 R2


Geometry
Inconel 625 2
Ansys
2025 R2

Crown Deflection: Seismic

- X Deflection



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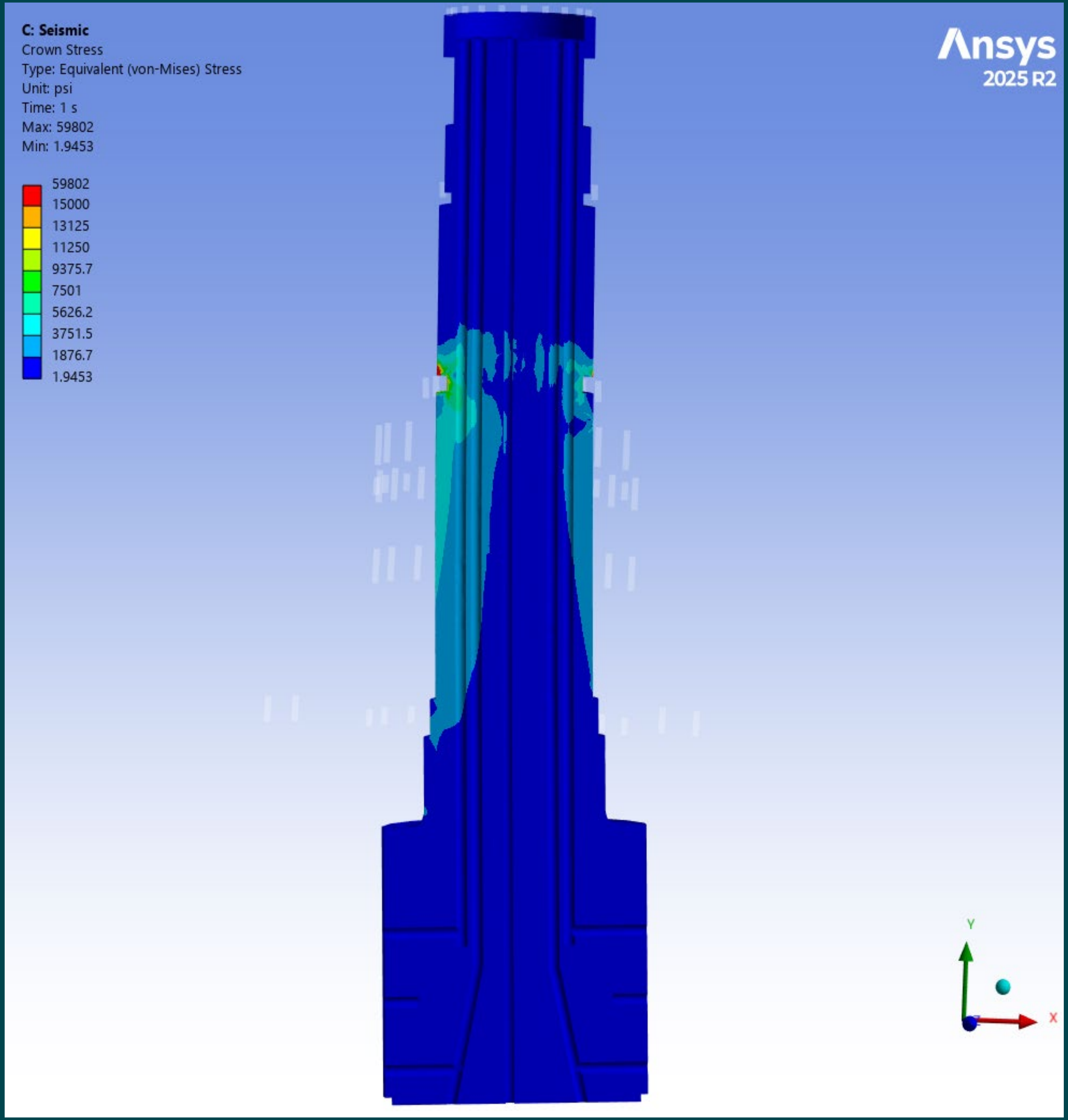
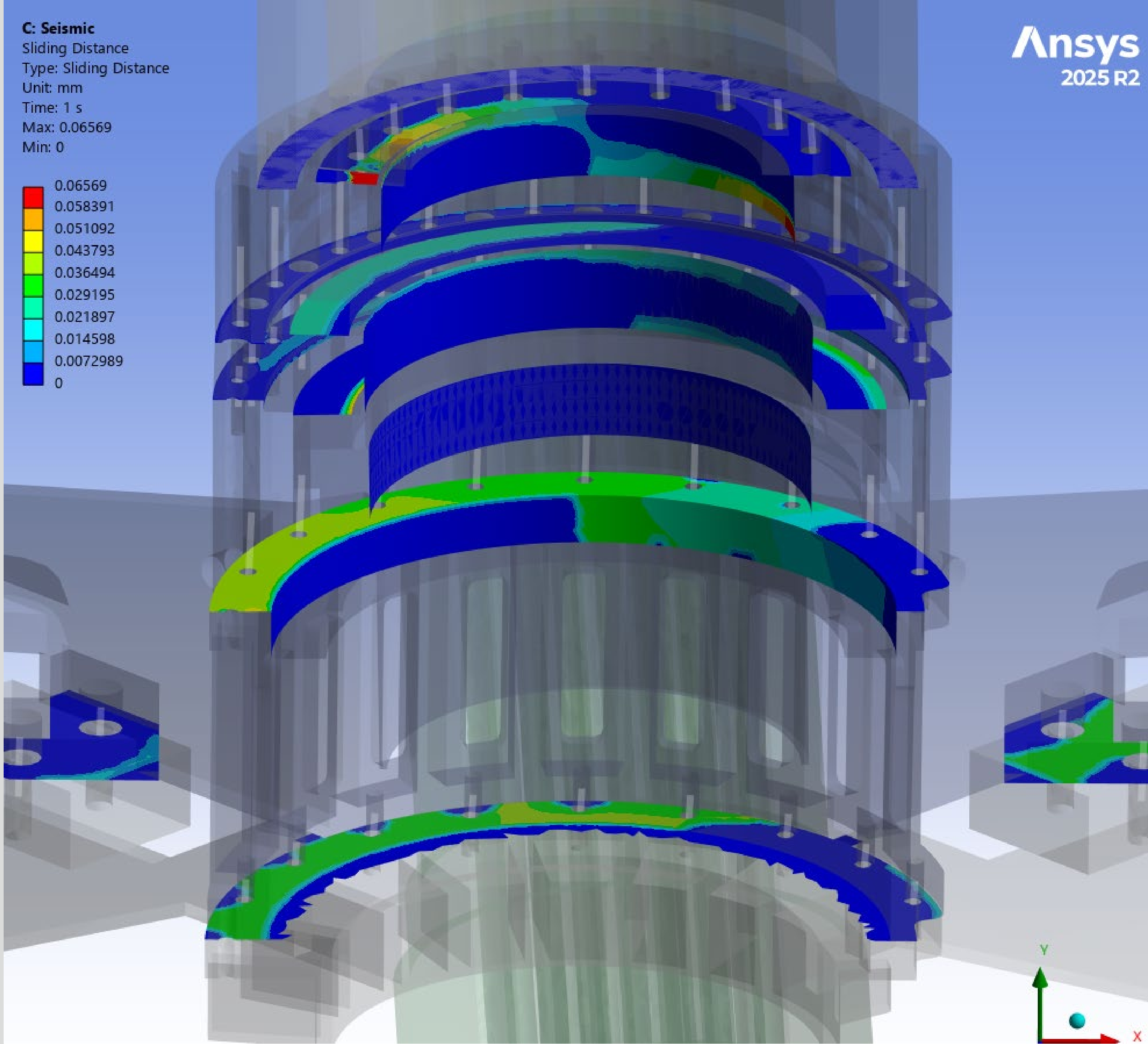
Crown Stress: Seismic

- Equivalent Stress



Contact Sliding: Seismic

- The stepped joints in the housing take most of the shear force and imparts very little to the fasteners.



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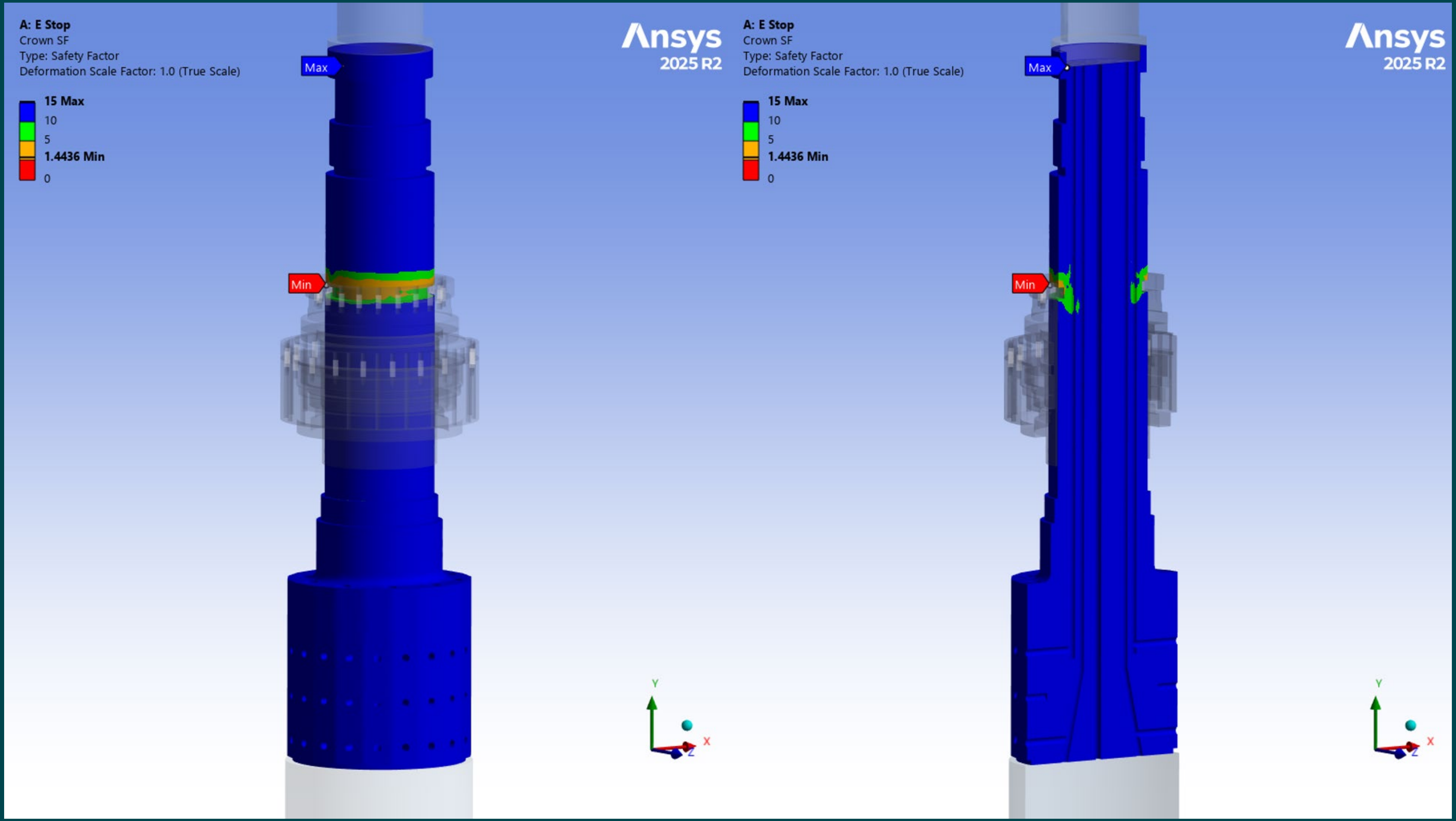
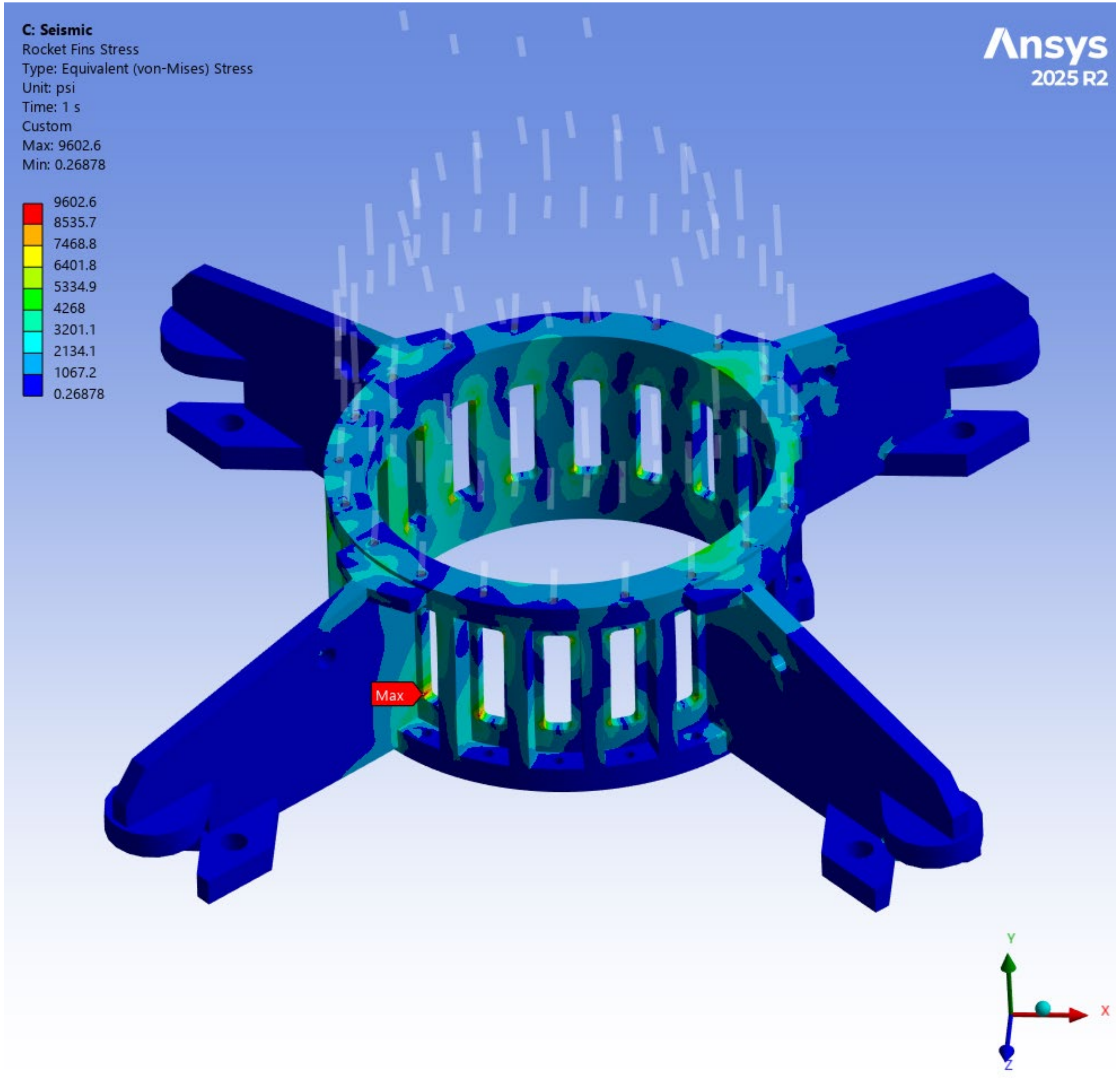
Crown Cyclic Load Results

- Fatigue
  Safety Factor



Rocket Fins: Seismic

- Equivalent Stress



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Fastener Calcs

Tension and Shear

Example Calculation for Sleeve Fasteners

Allowable Tensile
$F_n := 113\ ksi$

Allowable Shear
$F_v := 68\ ksi$

$d := 10\ mm$

M10 x 1.5 Bolt

$A_b := \frac{\pi}{4} \cdot d^2 = 0.122\ in^2$

$\Omega := 2.0$

$R_n := F_n \cdot A_b = 13756\ lbf$

$T_a := 401\ lbf$

$R_v := F_v \cdot A_b = 8278\ lbf$

$V_a := 128\ lbf$

$$\left(\frac{T_a}{\left(\frac{R_n}{\Omega}\right)}\right)^2 + \left(\frac{V_a}{\left(\frac{R_v}{\Omega}\right)}\right)^2 = 0.004$$

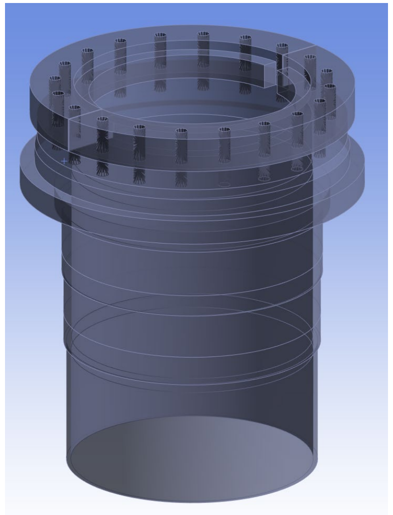
Thread Pullout

Crown Sleeve

$$P_{Sleeve} := \frac{\pi \cdot d_{M10} \cdot L_{e\_Sleeve} \cdot F_{su\_100CrMo73}}{3} = 22638\ lbf$$

$T_a := 401\ lbf$

$$\frac{T_a}{P_{Sleeve}} = 0.018$$



Fatigue

Allowable Fatigue

$F_f := 38\ ksi$

Applied Stress

$$F_a := \frac{T_a}{A_b} = 3294\ psi$$

Fatigue Margin

$$\frac{F_a}{F_f} = 0.09$$

Questions