Bottom CRU Installation Mechanical Analysis

November 21st, 2024

Agenda

1. Resolution to local stiffness behavior of adapter plate models.
   - Review of issues presented last week.
   - Presentation of updated adapter plate results (304 Stainless Steel).
   - Presentation of updated adapter plate results (G10).
2. Unistrut Model progress.
3. Thermal Model Parameters Overview
4. Buoyancy Effects
5. FD Clearances below bottom CRU

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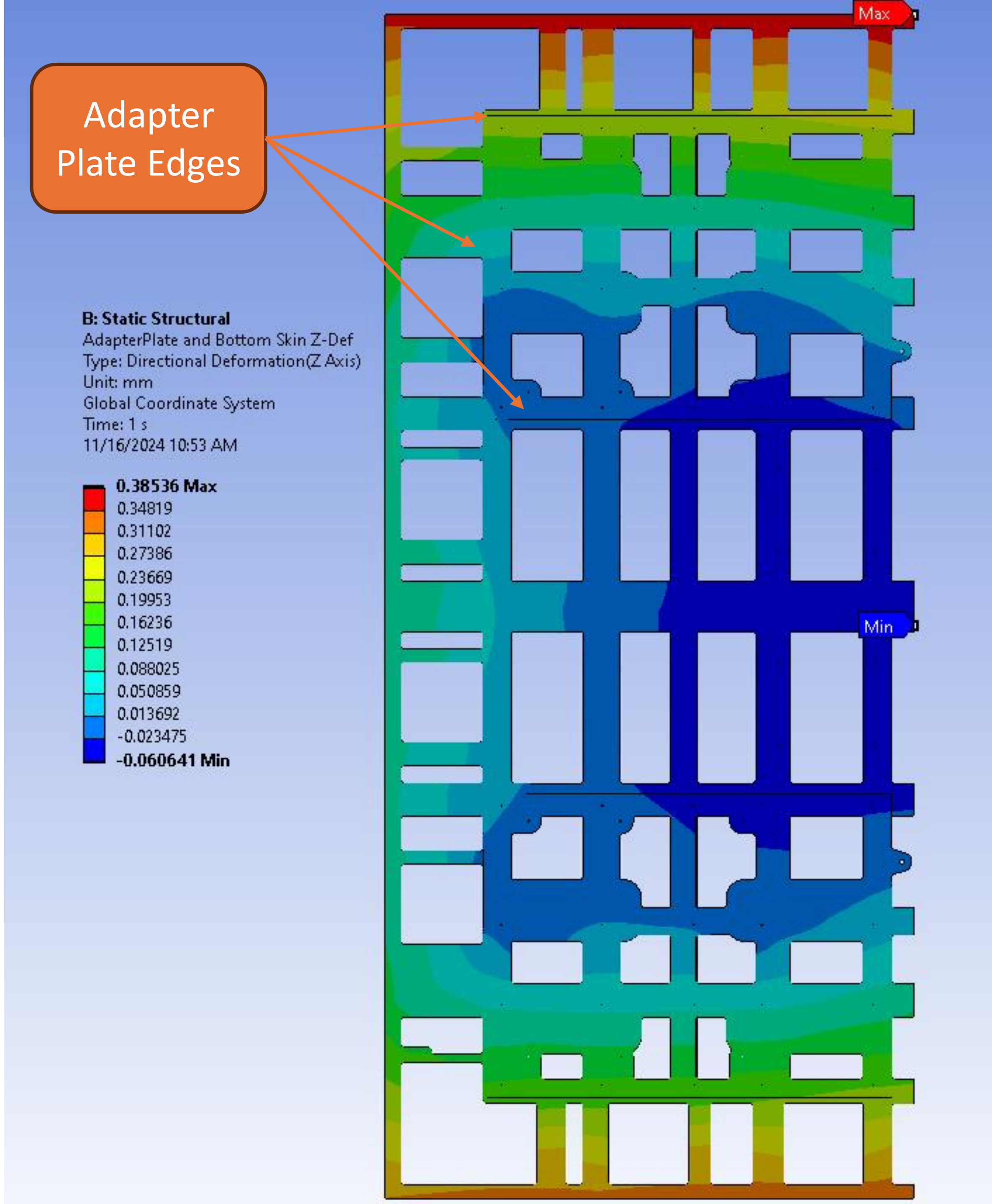
Summary of Revised Adapter Plate Model

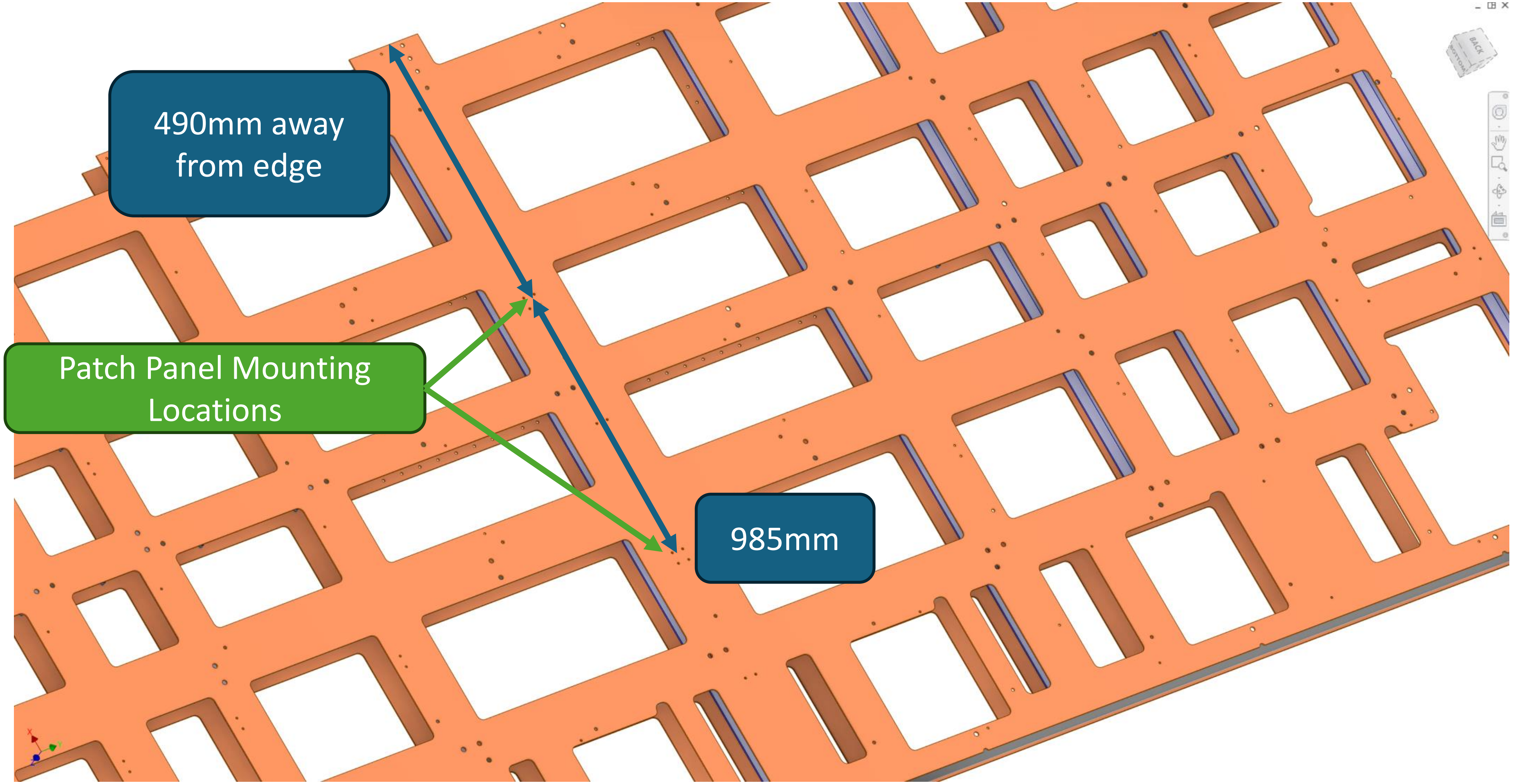
- Previously the adapter plates and supports had some ill-constrained contact regions that were causing increased deformation in the structure.
- The structure was essentially only supported by the fixed foot, so the structure was bending downwards radially outward from this foot.
- Additionally, only the adapter plate with the fixed foot on it was providing any support from the underside of the CRU.
  - This made adapter plate stiffness appear much more important than reality.
  - This is why the stainless-steel adapter plate showed tangibly lower deformation before.
- We have resolved those issues and have seen the deformation decrease dramatically.
  - Adapter Plates are Bonded to the Composite Skin (for fair comparison with the only running Unistrut model)
  - Now there is less than one millimeter of deformation in the anodes.
  - Both G10 and stainless steel perform essentially identically in this load case.
- Patch panel loads have been implemented, and the results depict those loads.

Resolved Behavior

- Both of these regions had contacts which lost their references during a geometry update.
- The load was not transmitted from the upper adapter plate to the top left foot.
- Load was not transferred at all to the bottom adapter plate.
- The structure is now much stiffer, and the behavior is more symmetric.
- The following slides show results with these contacts repaired.

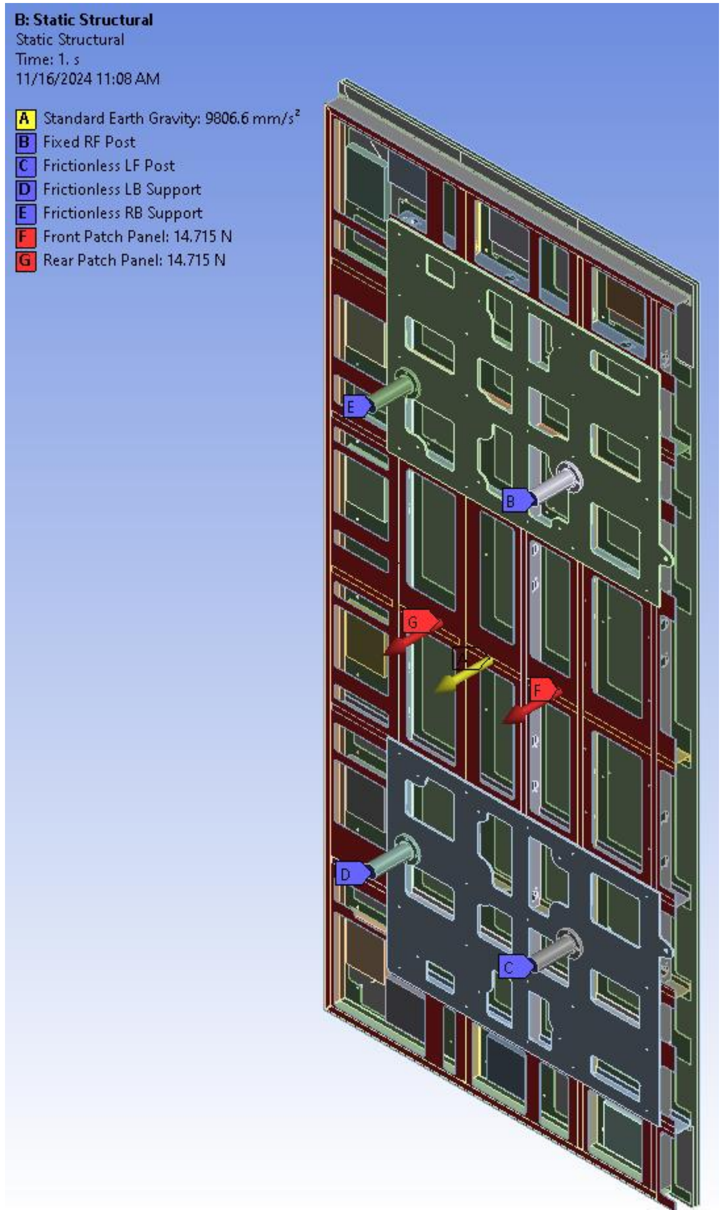


Patch Panel Loading: Geometry



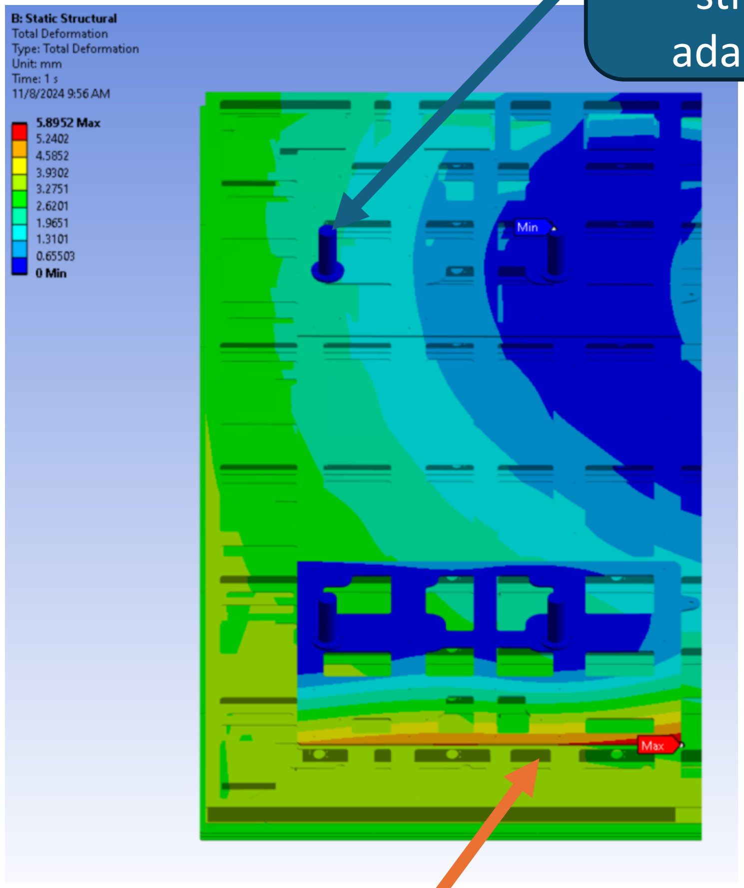
Patch Panel Loading: Applied Force

- Force applied to a deformable remote point attached to the bottom CRU skin.
- Chose a remote point so that it is node independent and to handle any changes in geometry better.
- Patch panel mass is estimated to be 1.5kg each.



Local Stiffness in the CRU Model

- Last week we discussed the view on the right.
- There are two things in this image which we investigated.
- The foot on the top left corner does not displace with the adapter plate properly.
- The adapter plate on the bottom does not displace with the CRU structure.
- Causes for both issues have been identified, and fixes implemented.



This foot should displace with the structure + adapter plate

This adapter plate's displacements should match the structure's.

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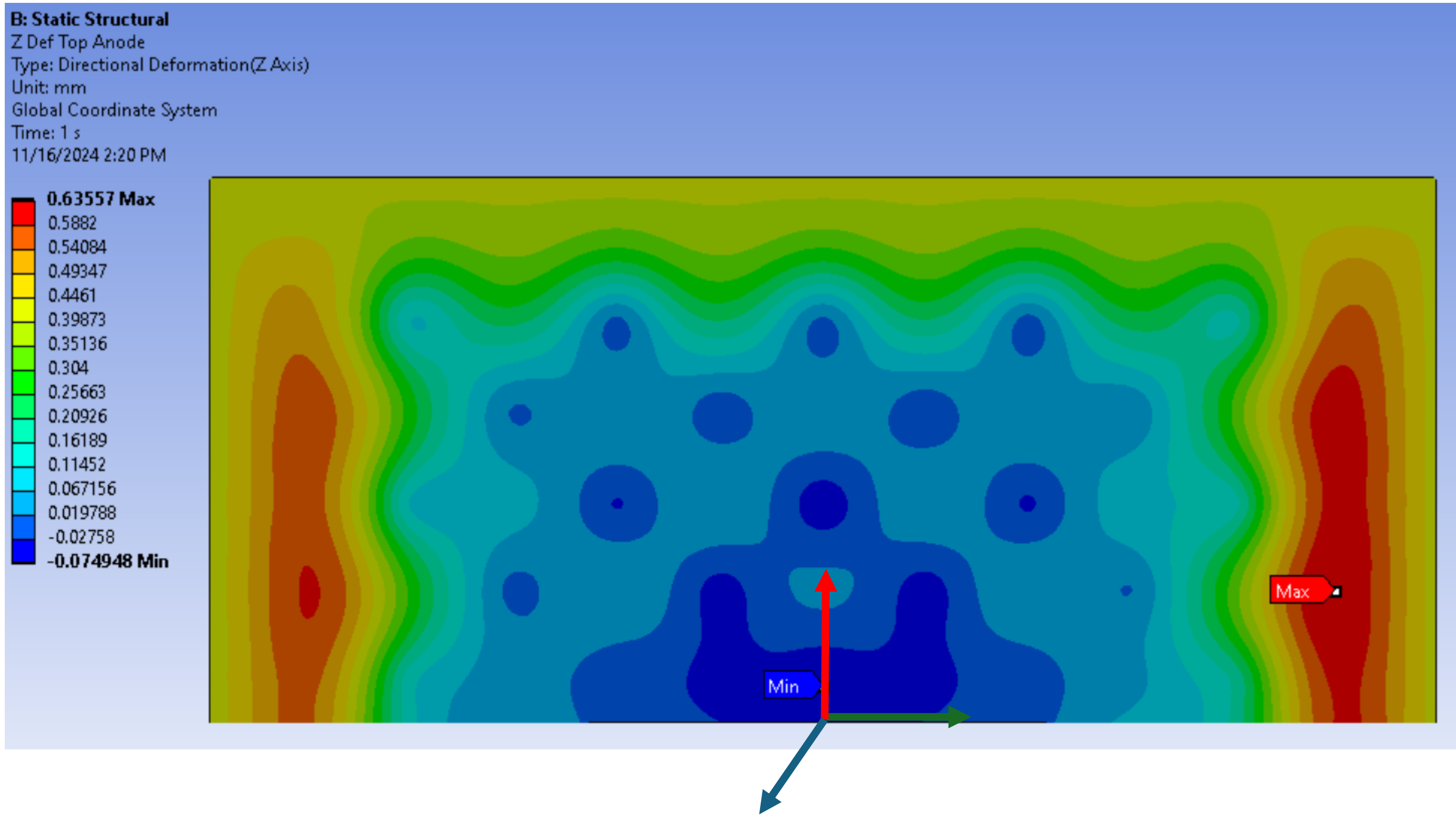
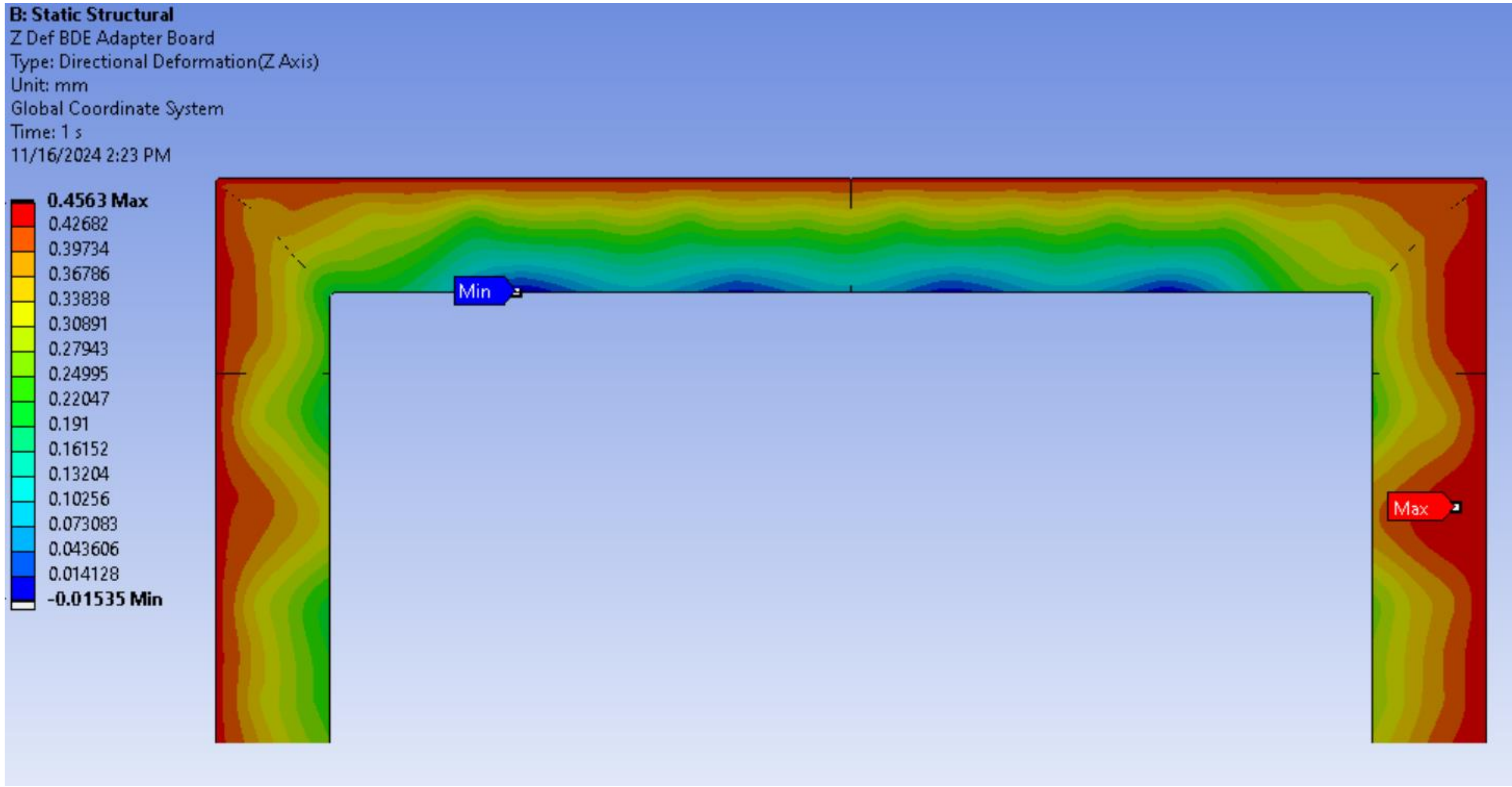
Stainless Steel Adapter Plate: Anode Z Deformation

- About 6x lower maximum Z displacement!
- The shape of the deformations makes good sense
  - Edges with FEMBs displace the most.
  - Circular regions of local stiffness around the PEEK spacers
- Note that the area in the middle (Y=0) is actually moving upwards, this is due to the concave down shape caused by the FEMB weights.



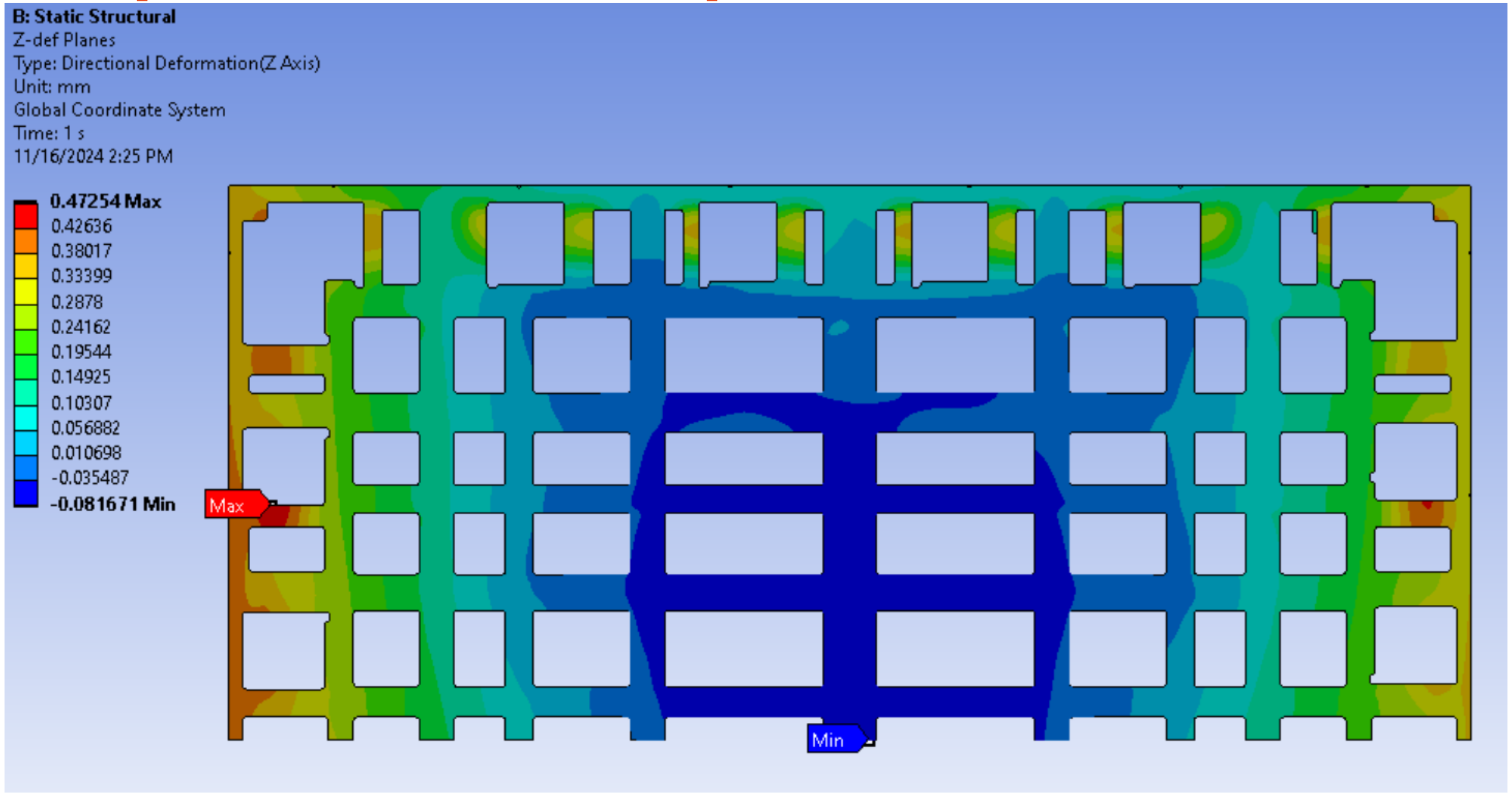
Stainless Steel Adapter Plate: BDE Z Deformation

- The BDE board displaces less than the anodes now.
  - I think this is because the BDE causes PEEK spacers to bend, and that displacement is magnified at the ends of the spacers.
- The BDE board displacement magnitude is similar to that of the structure.



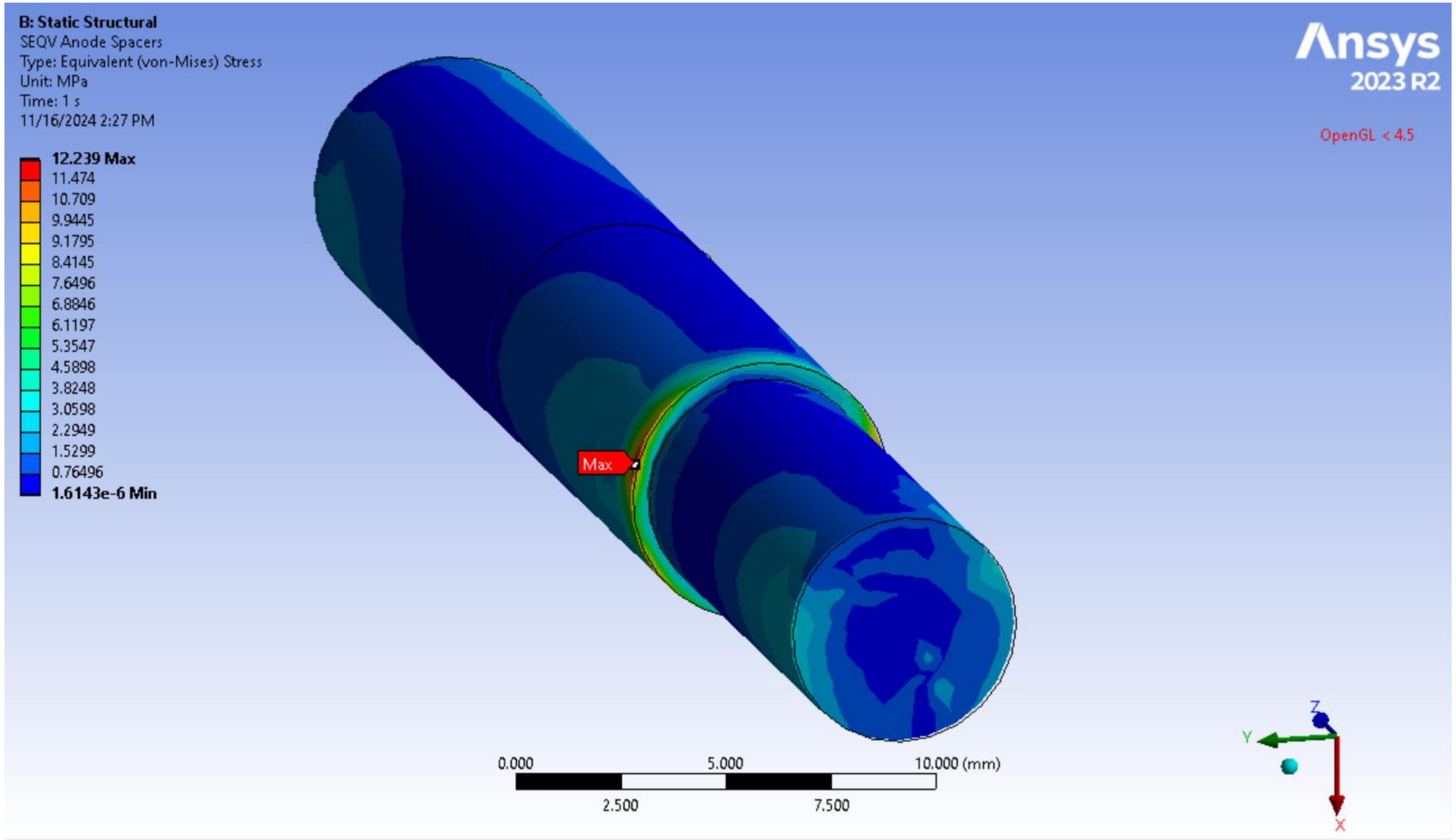
Stainless Steel Adapter Plate: Composite Structure Z Deformation

- The structure shows roughly symmetric displacement.



Stainless Steel Adapter Plate: PEEK Spacer Stress

- Maximum stress now much more comparable to the LAPP CRP model.
  - CRP ~ 16 MPa
  - CRU ~ 12 MPa
- This is now essentially equivalent to the results using the beam approximation.



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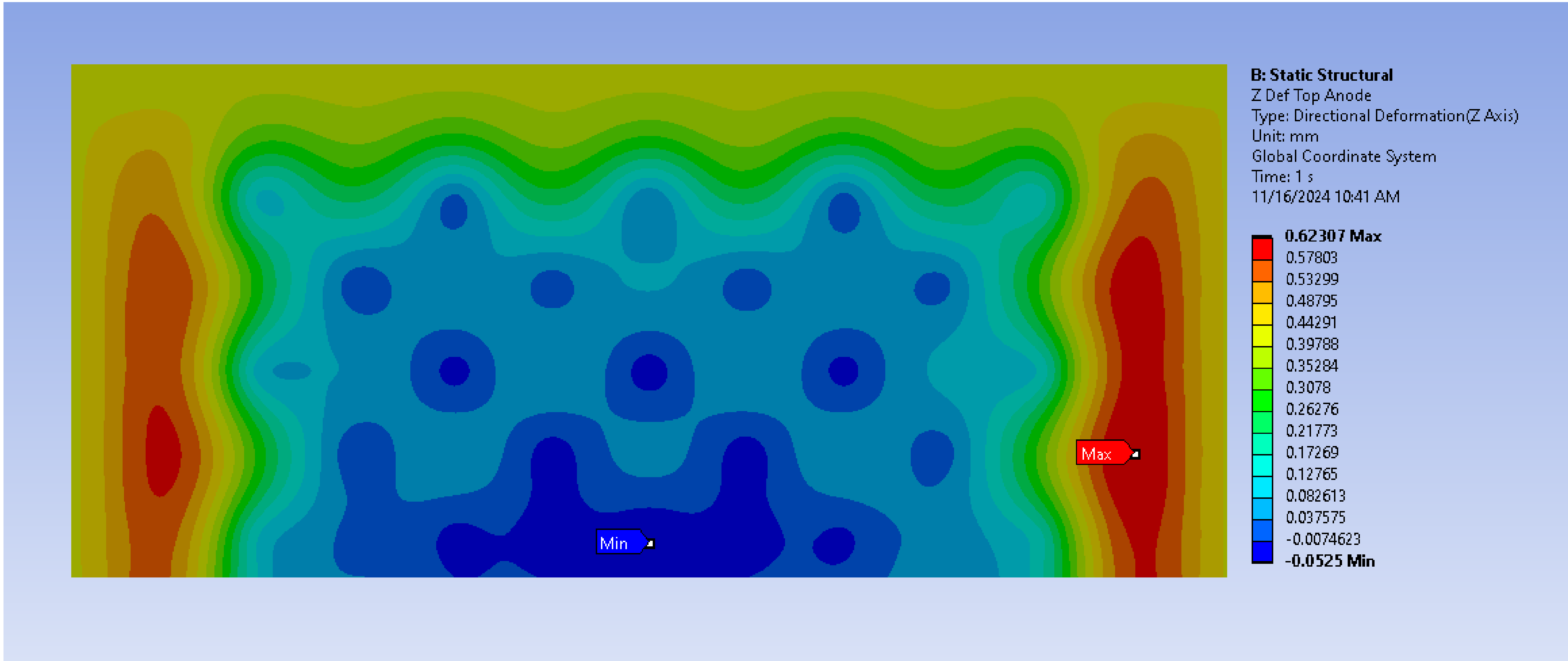
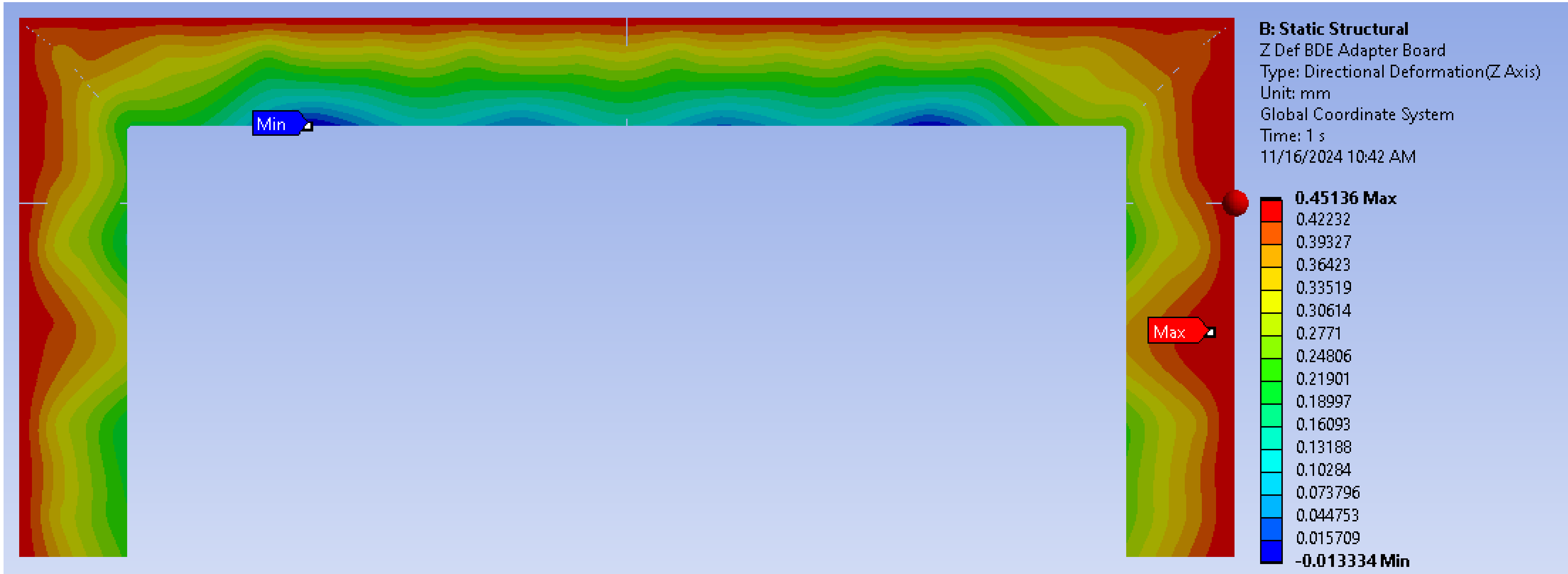
G10 Composite Adapter Plate: Anode Z Deformation

- Essentially identical performance to stainless steel.
  - 0.015mm less Z deformation



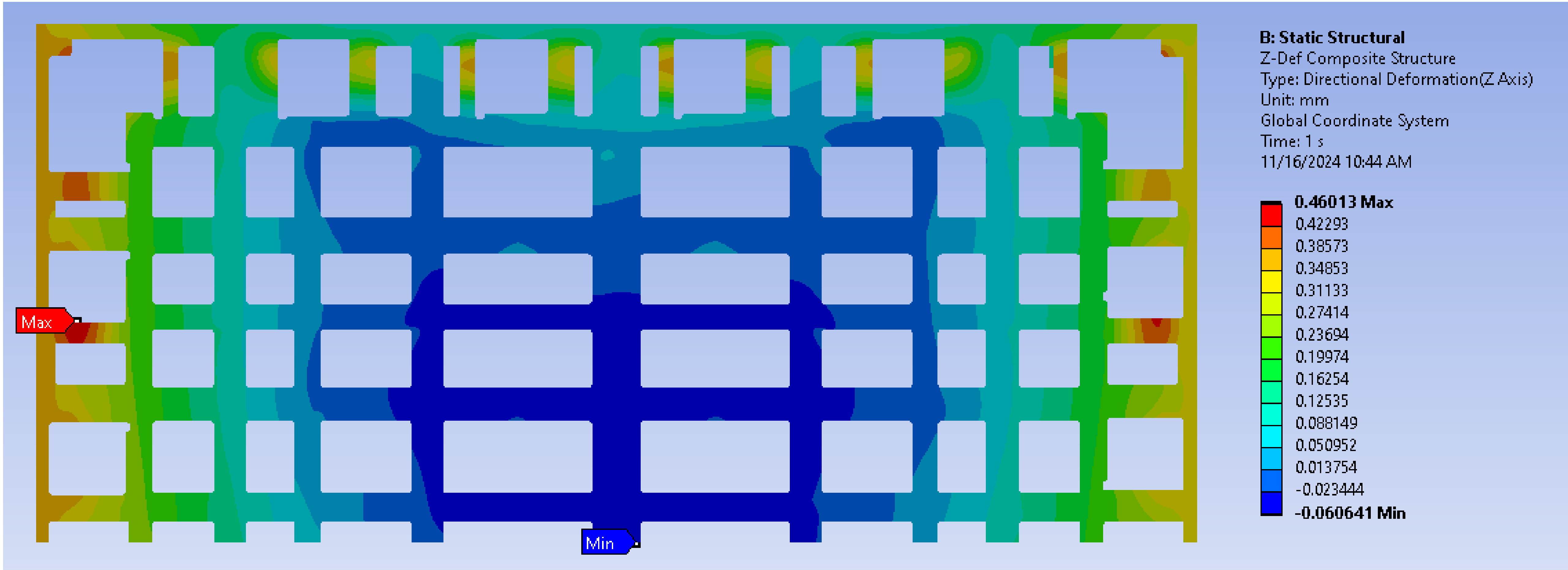
G10 Composite Adapter Plate: BDE Z Deformation

- Again, essentially identical performance to stainless.
  - 0.00494mm less deformation than stainless



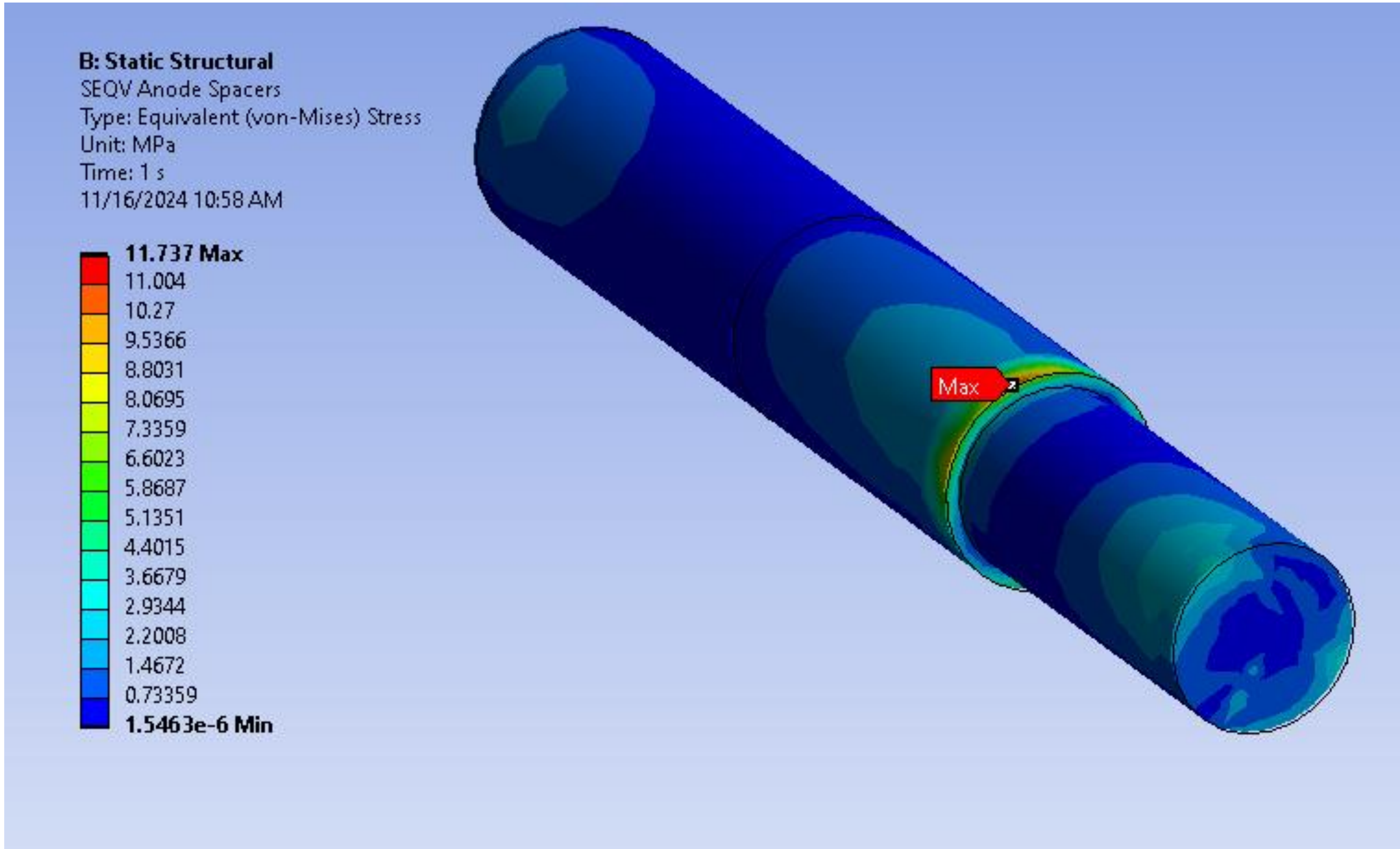
G10 Composite Adapter Plate: Composite Structure Z-Deformation

- Same story again…
  - 0.0124mm less deformation than stainless



G10 Composite Adapter Plate: PEEK Spacer von Mises Stress

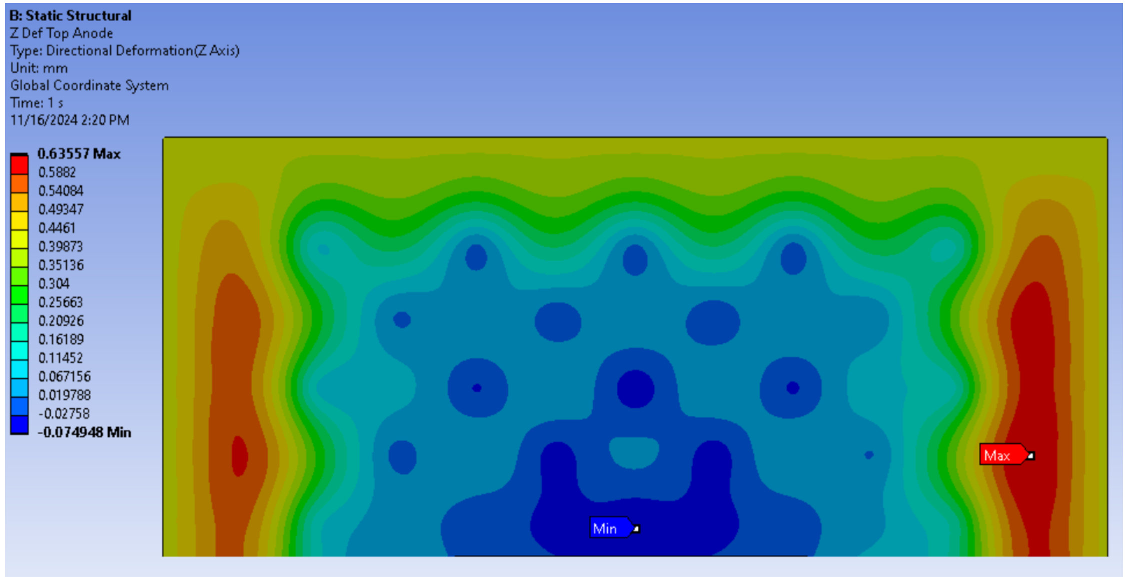
- You get the picture by now
  - About 0.5 MPa less peak stress.



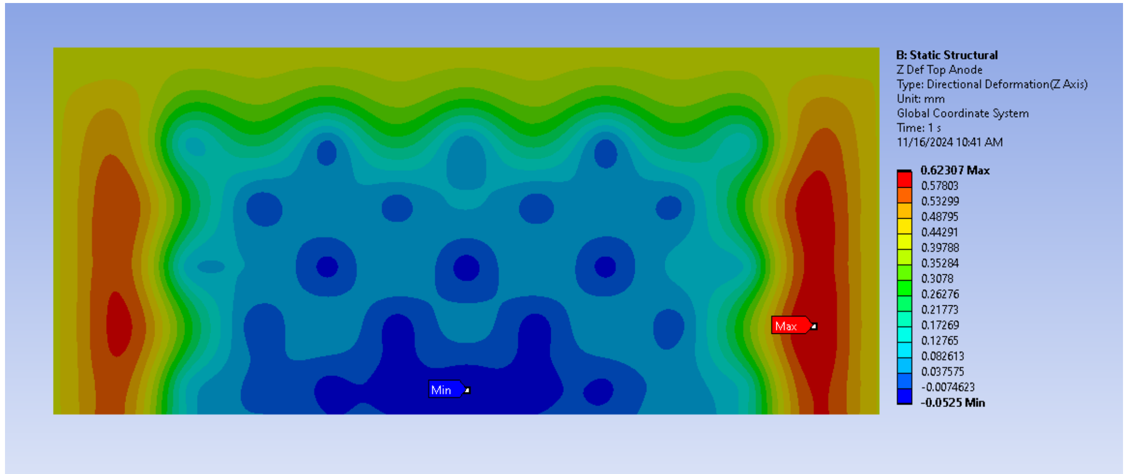
Adapter Plate Material Comparison Summary

- The two materials perform essentially identically.
- Patch panel loads have been added, and their impacts are very small on the overall structure.
- The following slides show the contour plots side by side for both materials.

Anode Z Deformation Direct Comparison

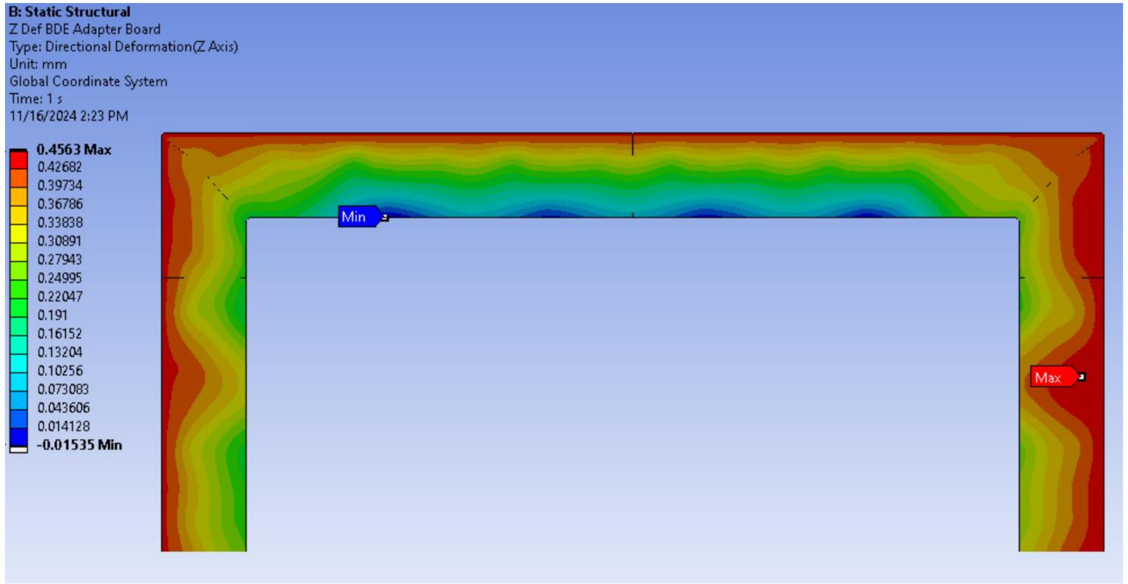


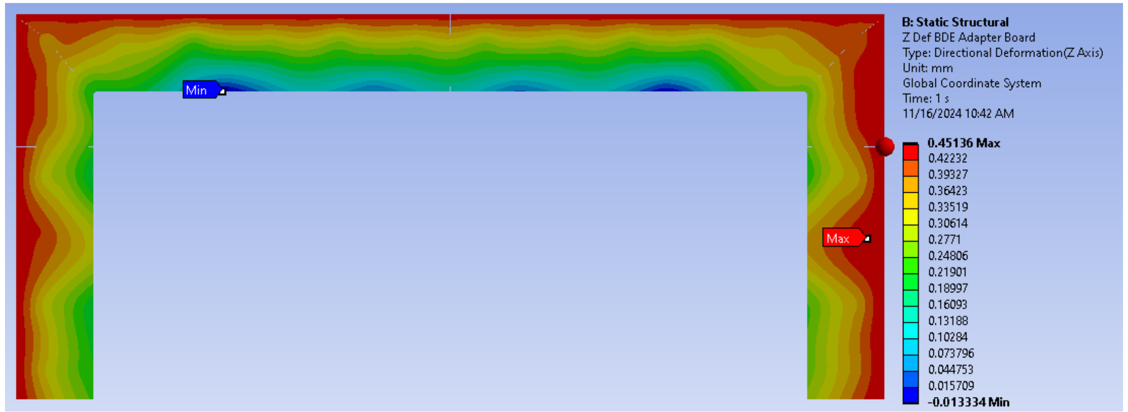
Stainless Steel Adapter Plate



G10 Adapter Plate

BDE Z-Deformation Direct Comparison

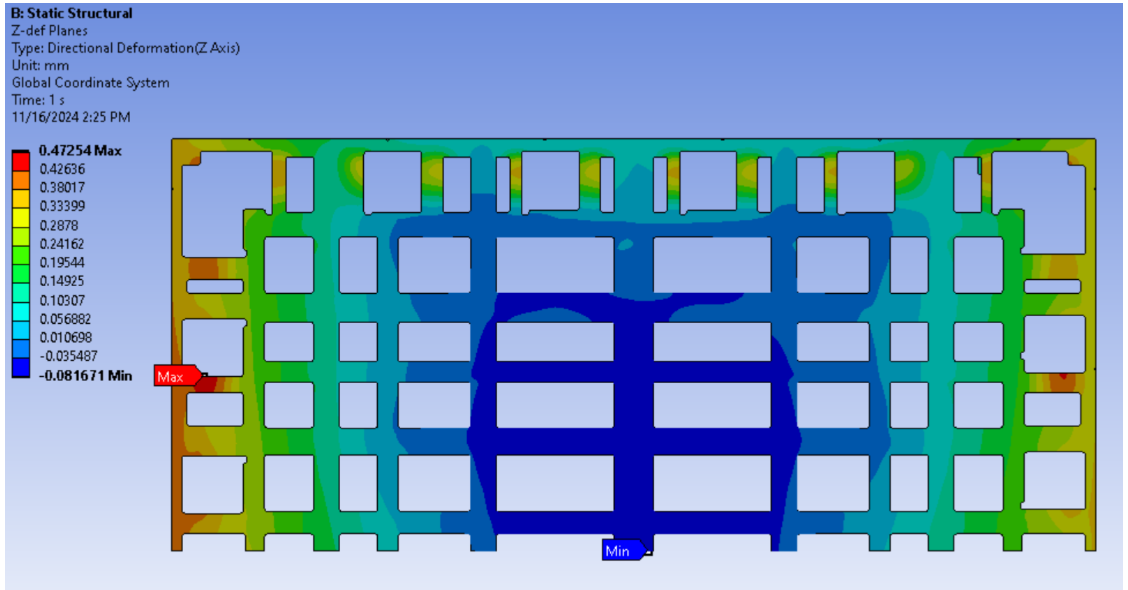


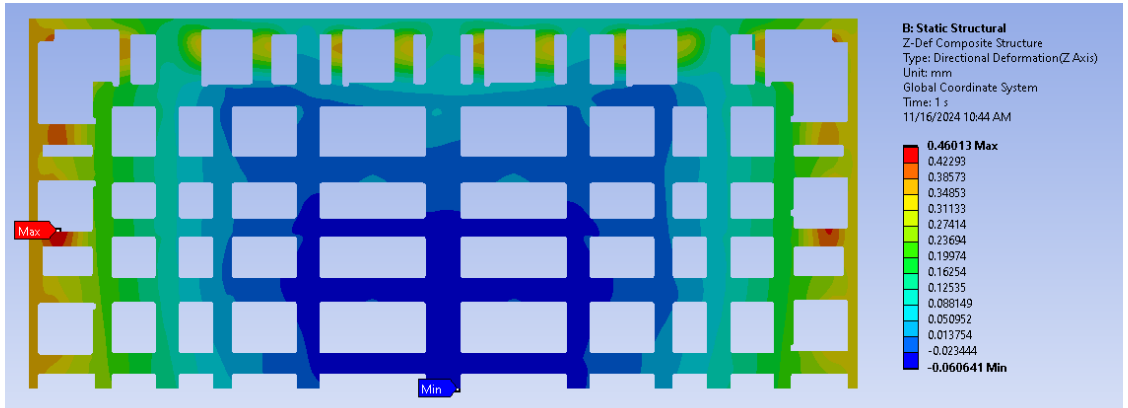


Stainless Steel Adapter Plate

G10 Adapter Plate

Composite Structure Z-Deformation Direct Comparison

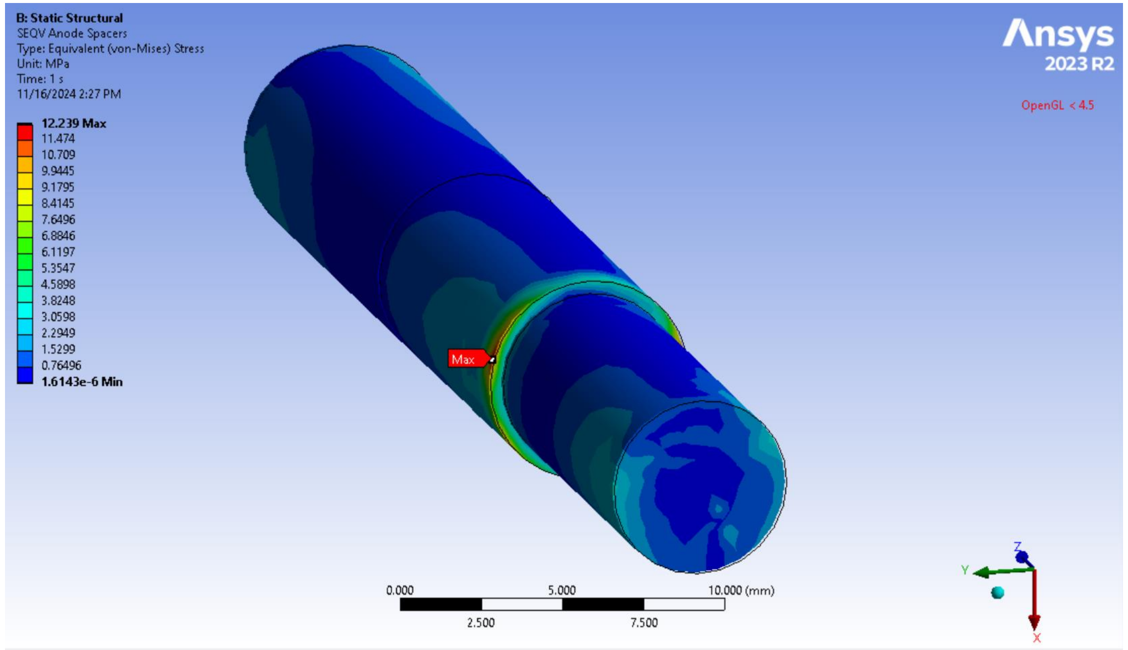


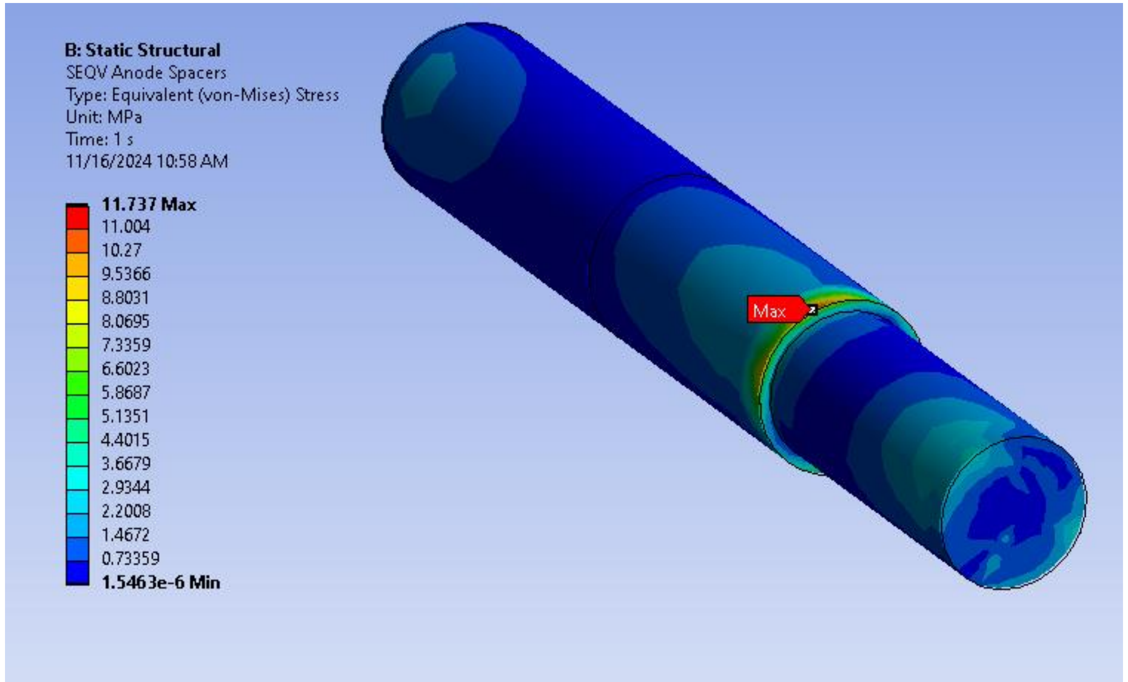


Stainless Steel Adapter Plate

G10 Adapter Plate

Anode Spacer Stress Direct Comparison





Stainless Steel Adapter Plate

G10 Adapter Plate

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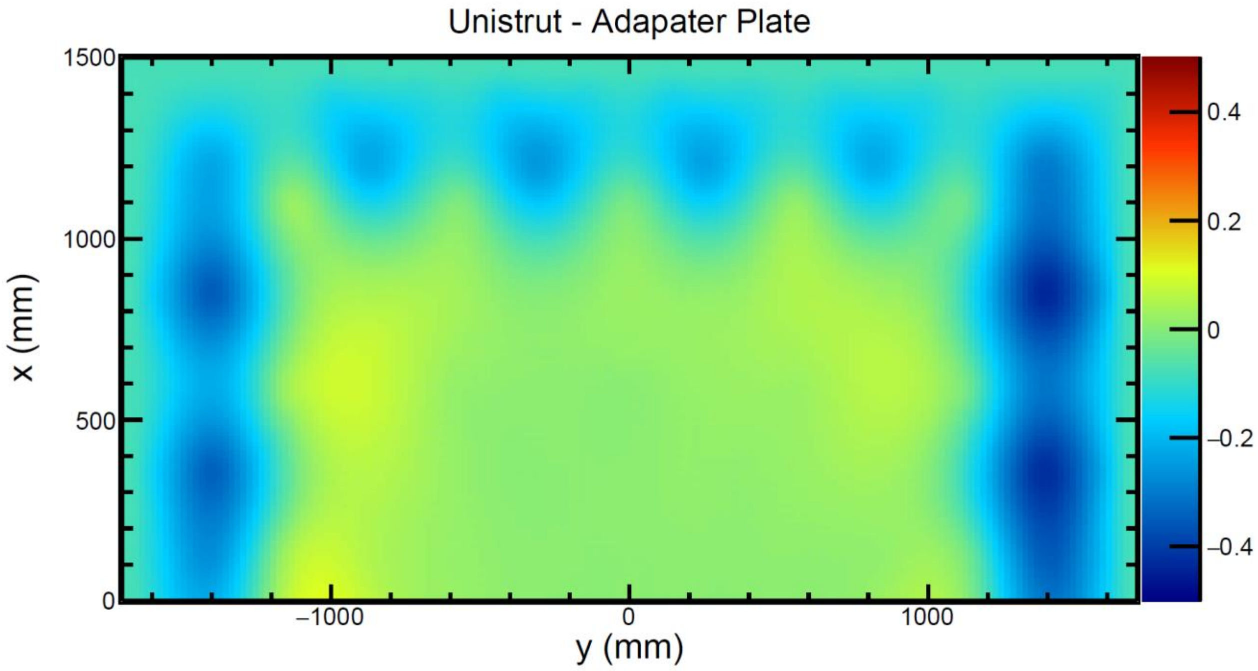
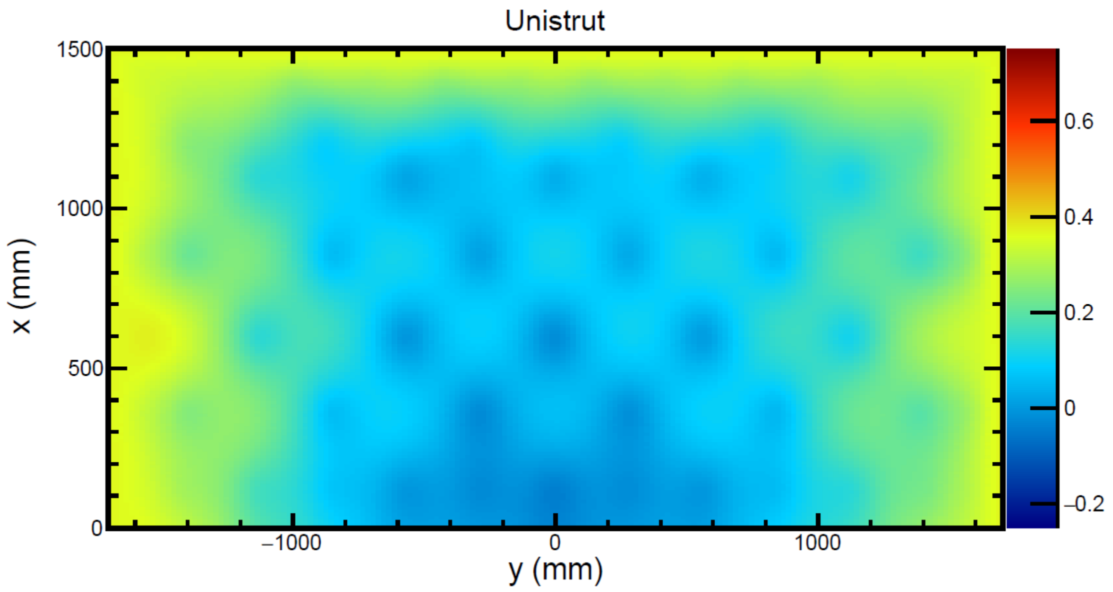
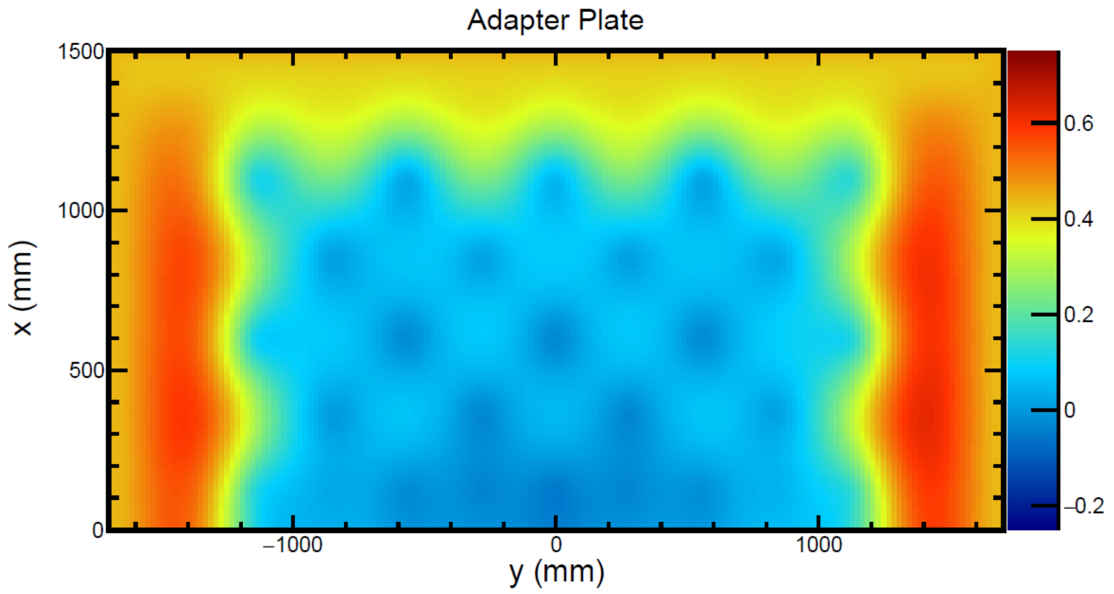
Summary of Comparison with Unistrut Model Results

- The right shows the difference in Z displacement of the top anode plane between the Unistrut and G10 Adapter Plate.
- The contours show the values of $\Delta z_U - \Delta z_{G10}$. A positive value means that the Unistrut deforms more than the adapter plate.
- From the results we can see that the two perform similarly. Maximum difference is 0.4mm, which is within tolerance. Unistrut is less stiff in the center, and stiffer around the edges.
- The edges of the Adapter plate deform slightly more; (0.63mm vs 0.38mm).
- The requirement is that the deformation is >1mm at cold conditions. Both solutions satisfy this requirement.
- Other factors will drive the decision.





Unistrut
1500
1000
500
0
x (mm)
−1000
0
1000
y (mm)
0.6
0.4
0.2
0
−0.2



Adapter Plate
1500
1000
500
0
x (mm)
−1000
0
1000
y (mm)
0.6
0.4
0.2
0
−0.2

Factors to Consider for Unistrut vs Adapter Plate

- Assembly time and cost.
  - Adapter plates are attached to the composite structure at the CRP factory. Technicians install feet underground. Any issues are caught and checked at the factory.
  - Unistrut is attached to the composite structure, feet are installed, adjusted, and set underground. This adds significant labor underground. Any issues are encountered during installation.
- Clearance to the membrane floor and cables.
- Material cost.
  - Unistrut profiles, plates, channel nuts, are approximately $1,100.
  - G10 sheet is $330. Can spend over $700 on machining before costs level out.
  - AISI 304 sheet is $660 each. Can spend $440 on machining before costs level out.
- Engineering resources for flipping.
  - Adapter plates and flipping tool are already designed to integrate.
  - Need to develop a method to attach the flipping tool to the Unistrut frame.

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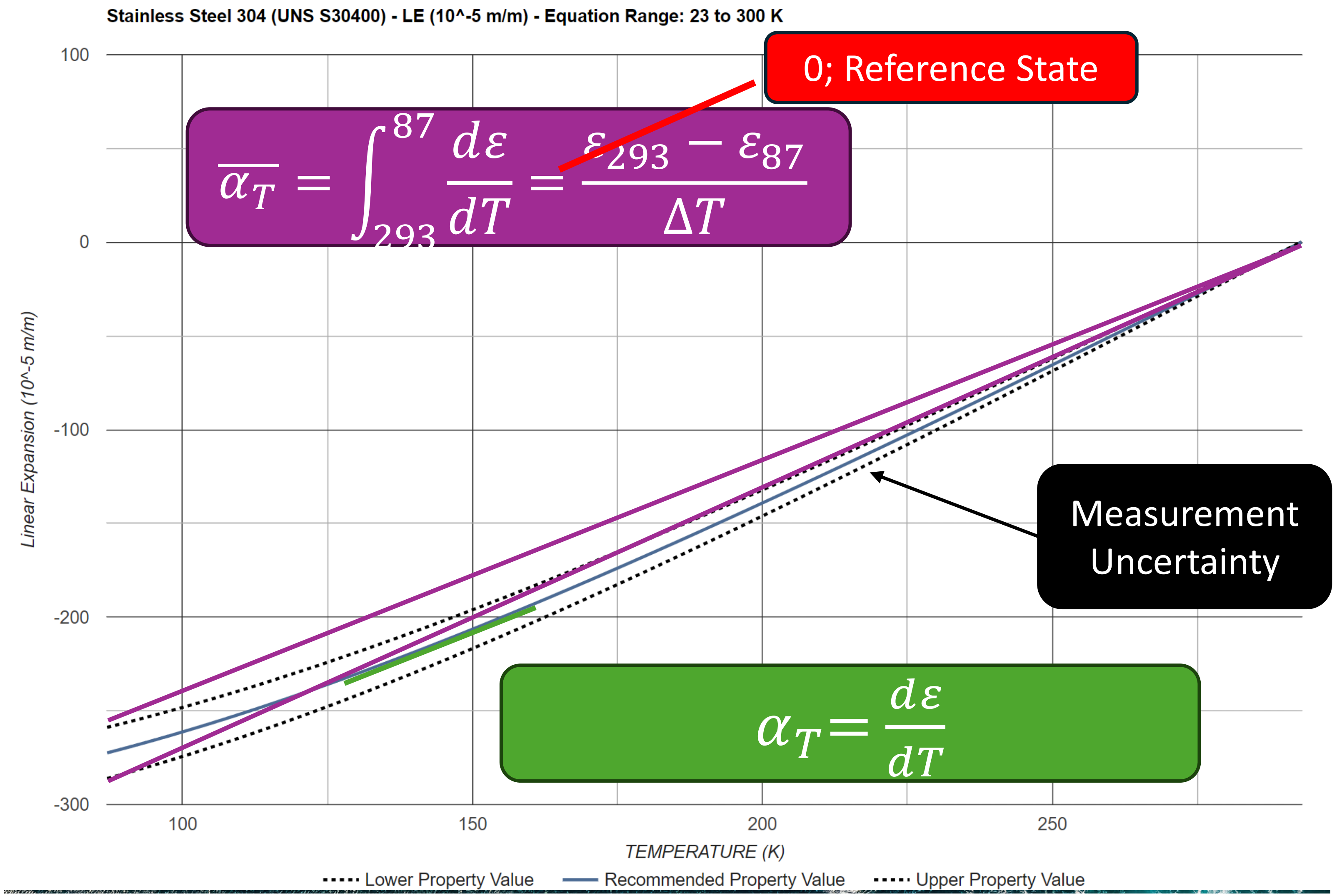
Summary of Thermal Model

- The model has three load steps; Warm, cold but not submerged; cold and submerged.
- We will model the frictional effects of the feet on the floor:
  - Test data from Josh Truchon at UW for various materials on stainless steel.
  - One foot will have much higher coefficient of friction (aluminum foot pad), the rest will be lower (stainless steel footpad).
  - This controls the contraction direction. We will model any resulting loads from this.
- The materials will have their CTE modelled as an average across their temperature range.
- The CTE of the CRU and adapter plate materials has some uncertainty; we will run the worst cases.

How CTE is applied

- To the right shows the strain caused by cooling stainless steel from 293K to 87K.
- The CTE at each temperature is the tangent line.
- Since we are running a model where we step between two temperatures, the linear average is suitable.
- This average is input into ANSYS as the CTE



CTE Data Table

Material	Minimum CTE (Long Direction)	Mean CTE (Long Direction)	Maximum CTE (Long Direction)
CRU Composite (10% Uncertainty Applied)	1.08e-5	1.2e-5	1.32e-5
304 Stainless Steel	1.25614e-5	1.32226e-5	1.38836e-5
G10CR Composite	0.988635e-5	1.008816e-5	1.028990e-5

- Above are the values for the different materials.
- We will test combinations of these values; there are 8 possible.

- CRU Max – 304 Max
- CRU Max – 304 Min
- CRU Min – 304 Max (-0.6606mm)
- CRU Min – 304 Min
- CRU Max – G10 Max
- CRU Max – G10 Min (+0.7099mm)
- CRU Min – G10 Max
- CRU Min – G10 Min

Largest Difference in CTE for each material

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Body Accelerations Applied to Different Components

- What is the true volume of the anodes?
- Added FEMB body acceleration based on information from BNL.

Material	Equivalent Body Accel [m/s^2]	In terms of g
Skin	2.61	0.2661
Beams	2.382	0.2429
BDE	2.382	0.2429
Anodes	2.38	0.2427
Spacers	-0.6553	-0.06662
G10	2.4	0.2447
AISI 304	8.108	0.8267
FEMB	5.141	0.5242

Point Loads Applied to the Model

- The cables are managed within the composite structure now.
- How to apply these loads?

Component	Force (Warm) [N]	Force (Cold) [N]
Patch Panel	14.71	8.592
FEMB Cables	3.085	0.6284

Wrap Up

- G10 Adapter Plates, Stainless Steel Adapter Plates, and a Unistrut frame all provide acceptable anode deformations.
  - These are less than the original CRP model predicted.
  - These are easily accounted for by adjusting the supports relative to neighboring CRUs and are likely less than the deformation of the membrane floor itself.
- Unistrut has several disadvantages including cost, installation effort, and increased engineering effort.
- Worst cases for thermal contraction have been identified, and the differential contraction quantified.
- The buoyancy loads have been calculated for the submerged portion.
- Friction effects have been implemented for the thermal model.

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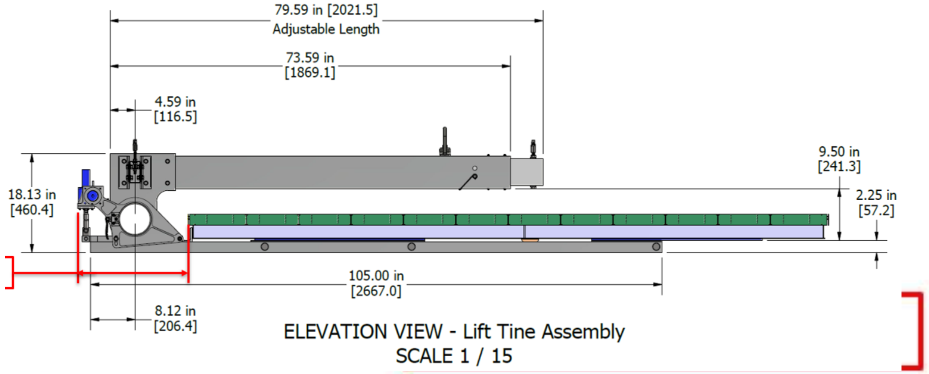
Items that need clearance below the CRP/CRU

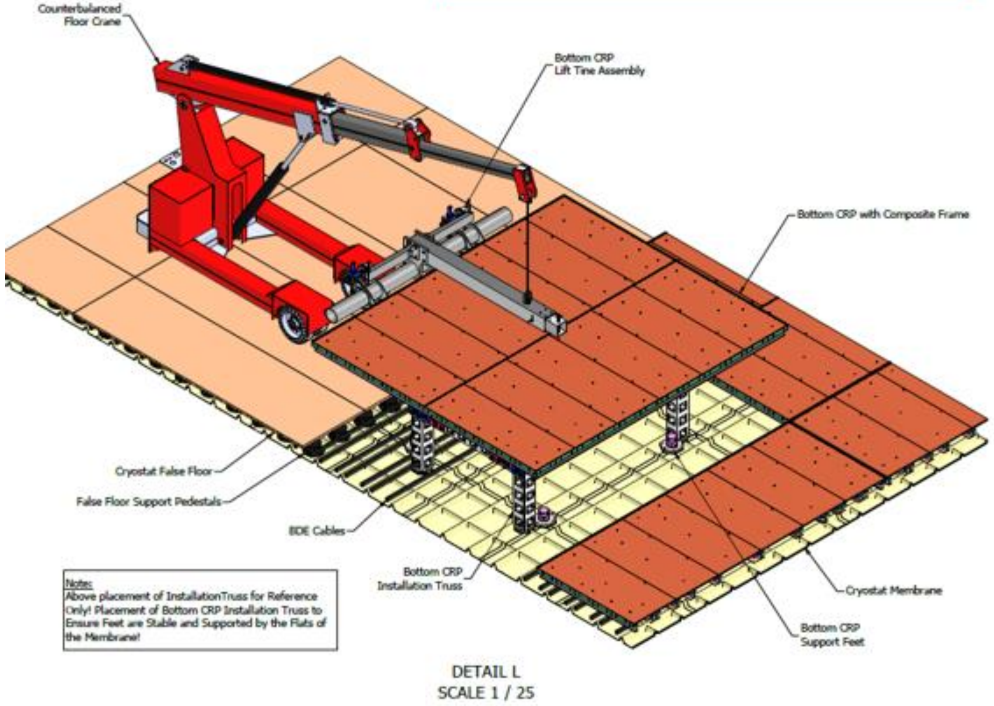
Bottom CRU supports (add together)

- Tines for lifting system:
  - 82.1 mm of clearance needed (57.2 mm thick tines + 24.9 mm deflection under load)
- Connection to bottom support feet
  - 6.35 mm for adapter plate OR
  - 47.3 mm for Unistrut frame & hardware

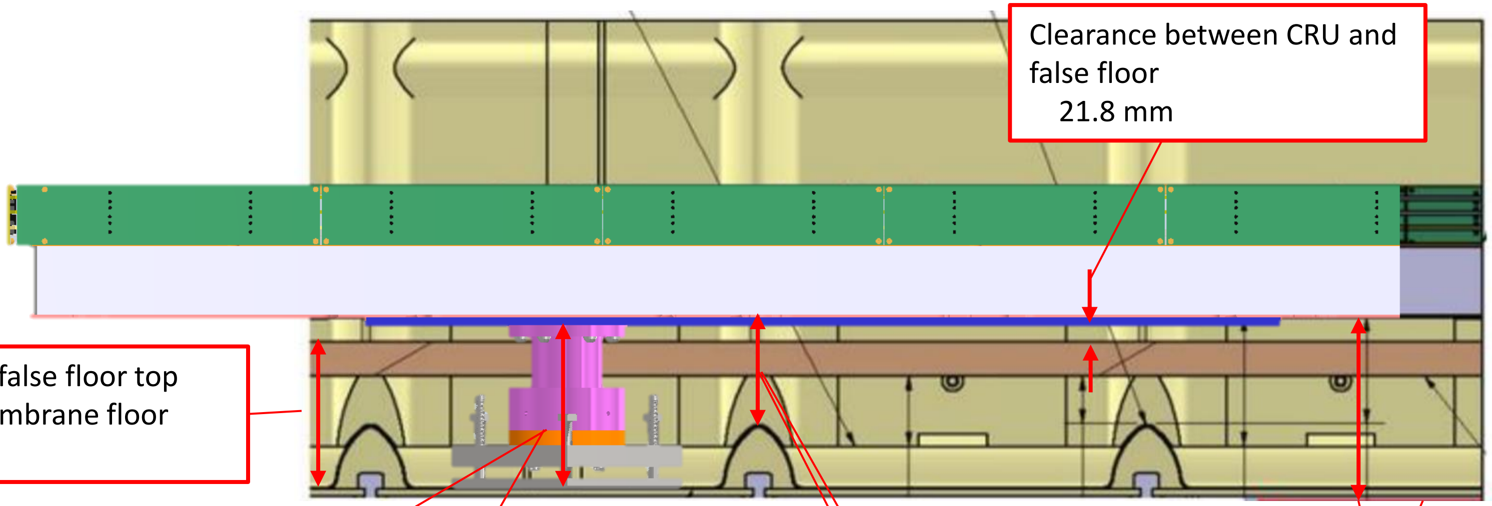
Electronics (separately)

- BDE Cable bundles running across floor from neighboring CRUs:
  - 40 mm diameter running over membrane corrugations
- BDE Patch panel:
  - Xx mm needed for tool access





Clearances in Original FD Bottom Layout



Clearance between CRU and false floor
21.8 mm

Height of false floor top above membrane floor
128.1 mm

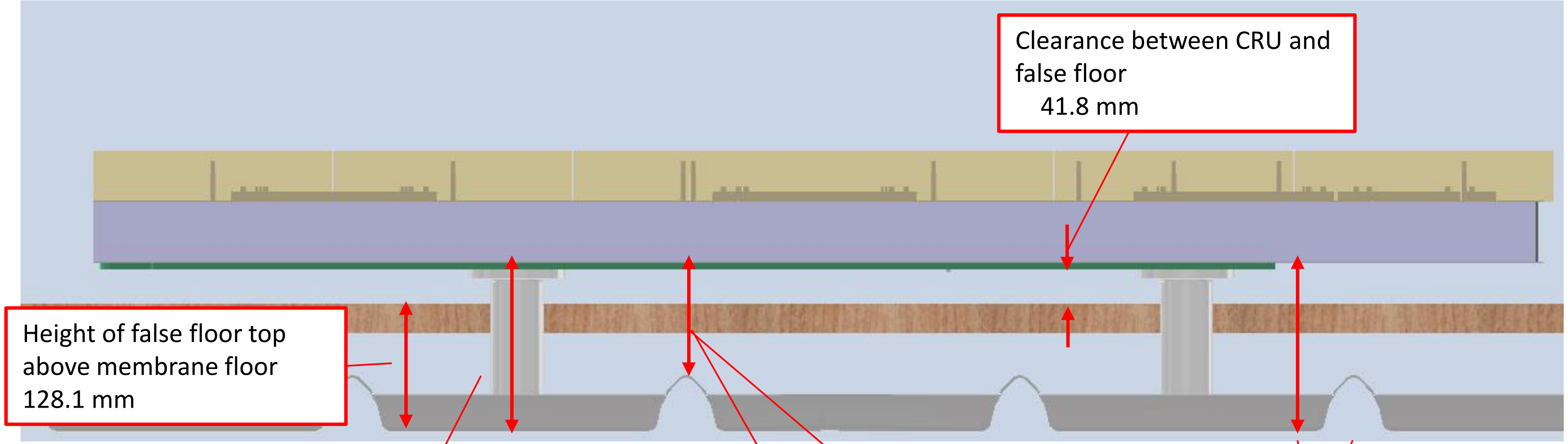
Height of bottom supports + adapter plate
143.55 mm
+ 6.35 mm

Clearance between bottom of CRU and:

- Knuckle (estimated 70 mm tall (not modeled in CAD)
  79.90 mm
- Cross Membrane Corrugation (54.25 mm tall)
  95.65 mm
- Membrane Corrugation (36.00 mm tall)
  113.90 mm

Clearance between CRU structure and membrane floor
149.9 mm

New FD Bottom Layout (up 20mm)



Clearance between CRU and false floor
41.8 mm

Height of false floor top above membrane floor
128.1 mm

Height of bottom supports + adapter plate
163.55 mm
+ 6.35 mm

Clearance between bottom of CRU and:
- Knuckle (estimated 70 mm tall (not modeled in CAD)
  99.90 mm
- Cross Membrane Corrugation (54.25 mm tall)
  115.65 mm
- Membrane Corrugation (36.00 mm tall)
  133.90 mm

Clearance between CRU structure and membrane floor
169.9 mm