Bottom CRP Installation: Structural Modeling & Placement Tool

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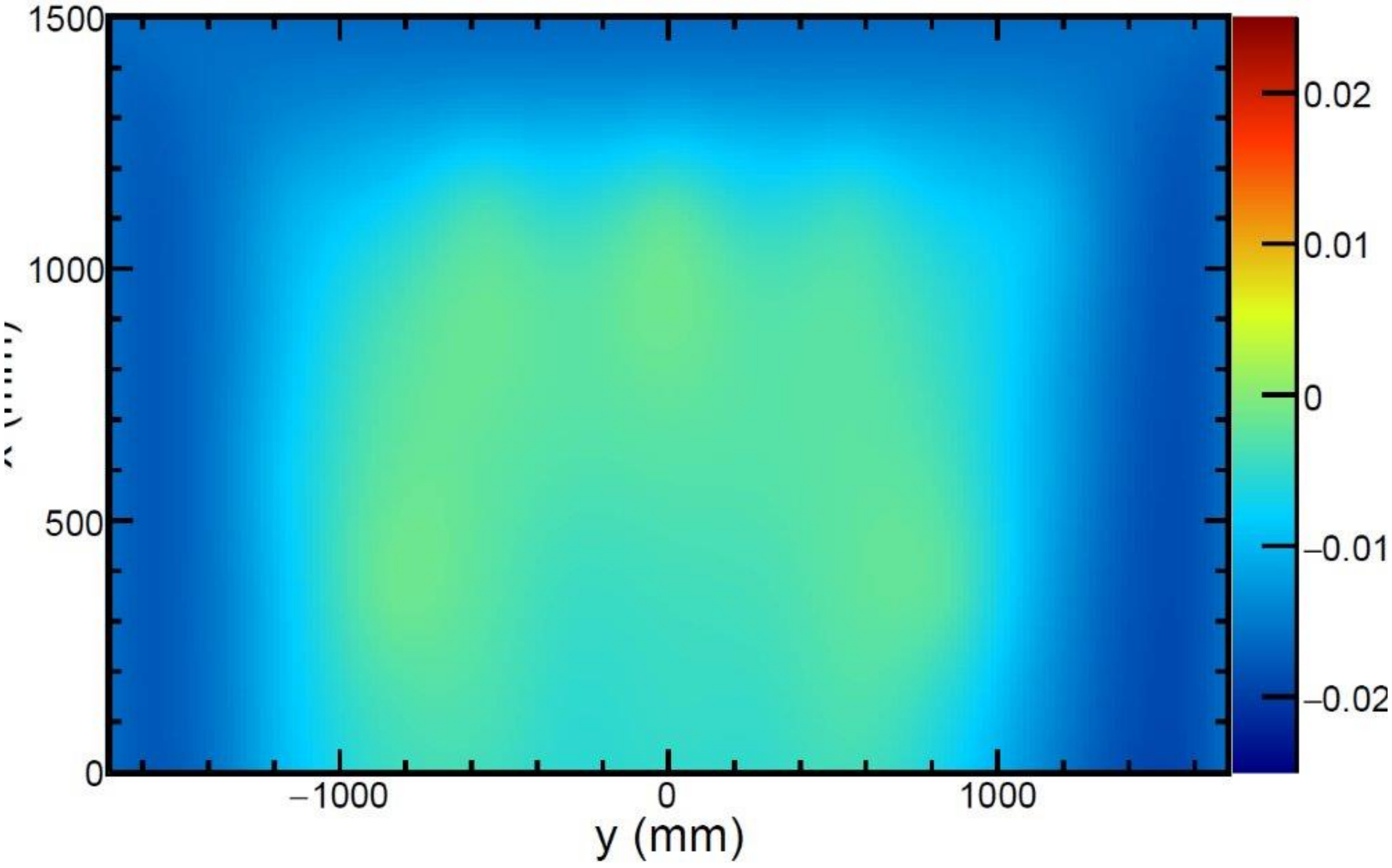
Agenda

- Mechanical Analysis of CRU installation
  - Floor Contact Modeling: looking at displacement of CRU during thermal contraction and frictional sliding on membrane floor
  - Thermal and Buoyancy modeling: looking at contraction of CRU structure and loads during LAr fill
- Positioning of CRU
  - Tool for final placement and adjustment of CRU on membrane floor

Floor Contact Model Summary

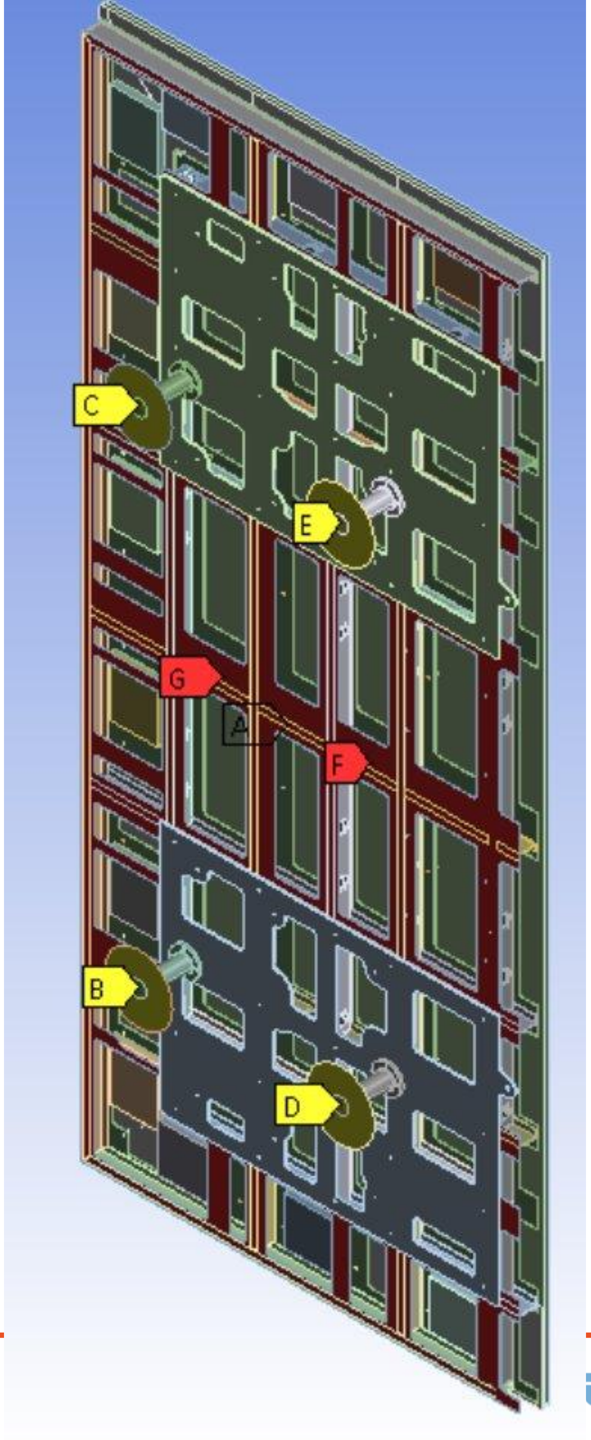
- We have implemented frictional contact between the membrane floor and the feet of the CRU.
- This will allow us to predict the stresses and any displacement or rotation of the CRU during cooldown.
- To test our boundary conditions, we ran the warm state deadweight load case with these new contacts. This is almost like what the first load case of cooldown
- The results with friction modelled are very similar to those using the fixed-frictionless support method:
- The fixed-frictionless support method is an acceptable simplification for when elastic boundary conditions are necessary.

Fixed-Frictionless Model Anode Z-Deformation – Friction Model Anode Z-Deformation

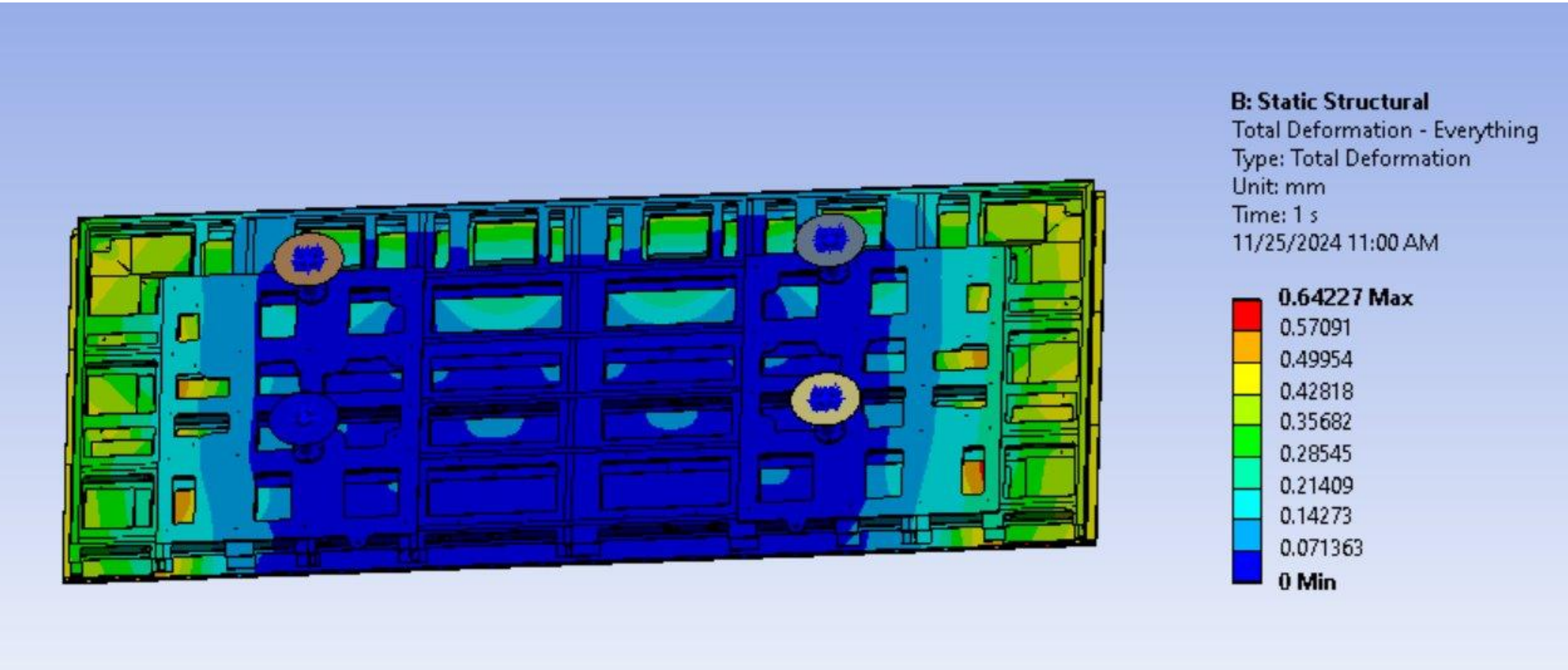


Floor Contact Model Setup

- Boundary condition representing the contact between supports and the membrane floor.
- rigid surface patches (about B, C, D, and E**)** represent the membrane floor. Remote displacements which don't allow these surfaces to move at all.
- Complex formulation of support/floor contact has frictional contact between surface patches and CRU support feet:
  - C has static friction coefficient of 0.34 representing aluminum and stainless steel.
  - B, D, and E are assigned 0.2 to represent stainless steel and stainless steel.
- A simple formulation of support/floor can also be used:
  - C is fixed condition
  - B, D, and E are frictionless contact



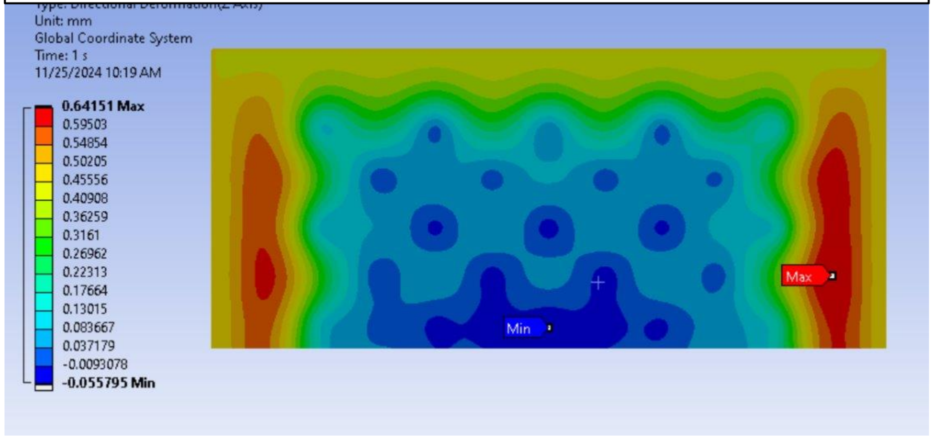
Floor Contact Model Vector Sum Deformation



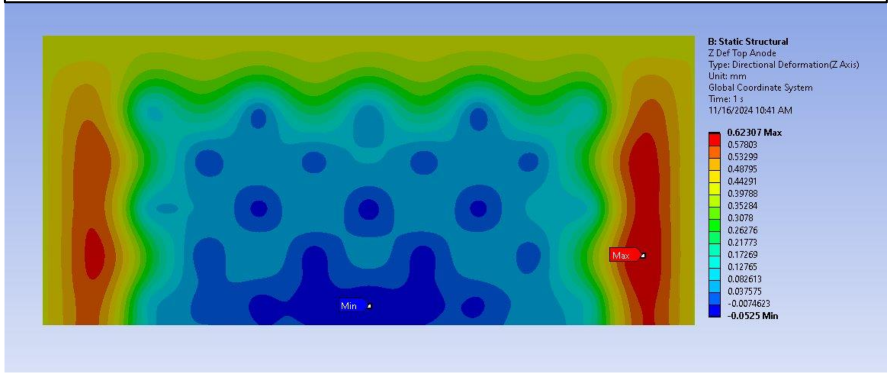
Top Anode Z-Deformation

- Note the similarity in contours and magnitude between the complex model and simplified model.
- Deflection of the CRU and anodes is the same between complex and simple formulations of the membrane floor contact BC

Complex Model:
Friction Modelled on all 4 supports



Simple Model:
Simplified support sliding Fixed-Frictionless



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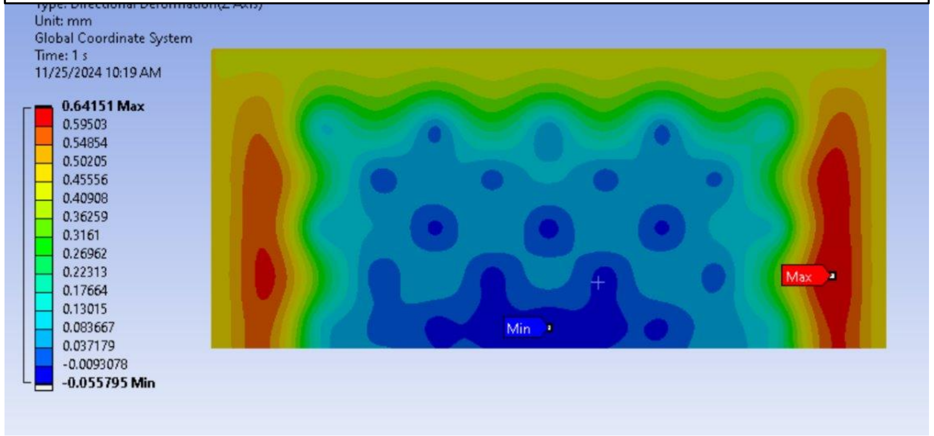
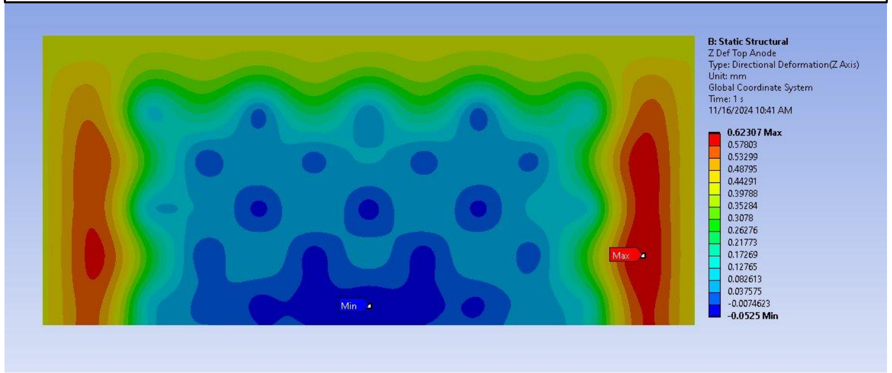


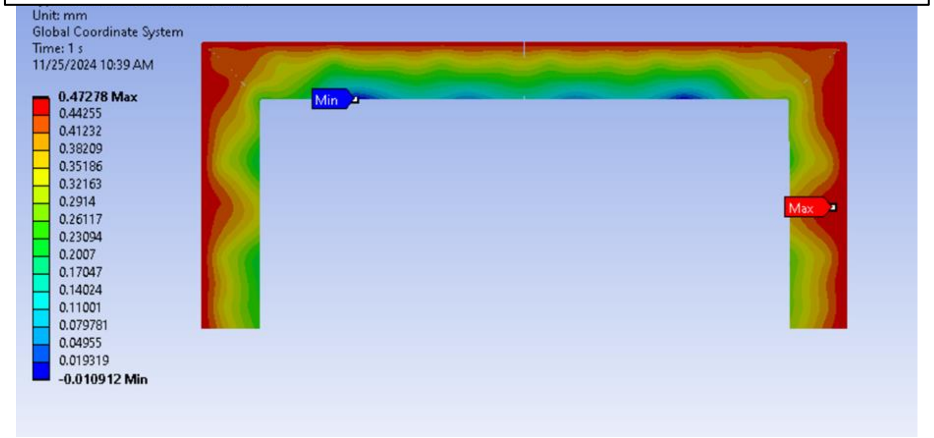
Simple Model:
Simplified support sliding Fixed-Frictionless



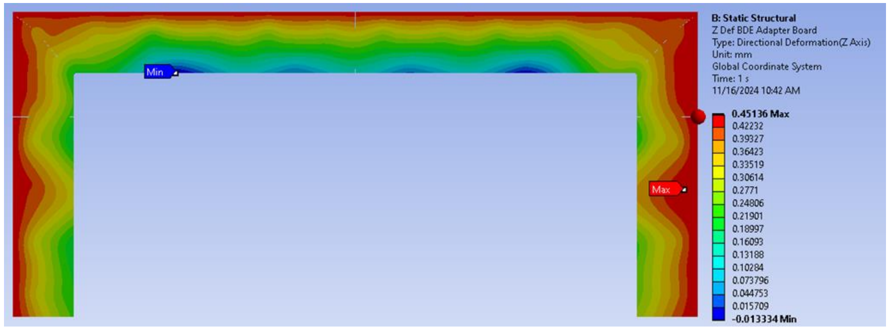
BDE Z-Deformation

- Again, the BDE Z-displacements are similar between models.

Complex Model:
Friction Modelled on all 4 supports



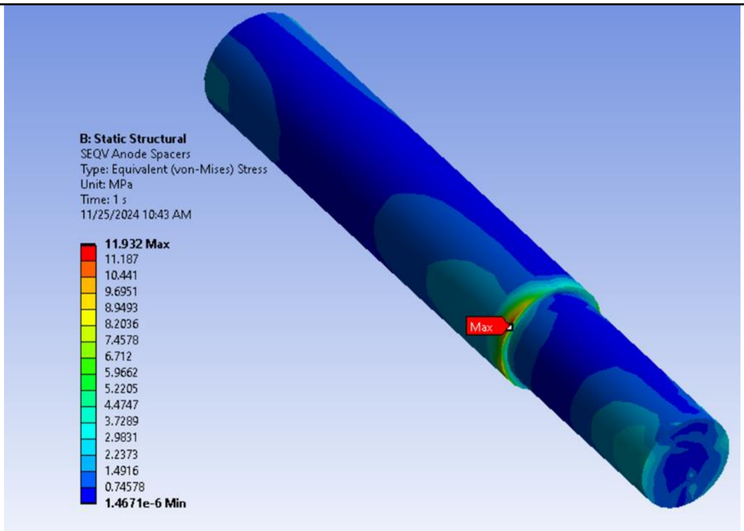
Simple Model:
Simplified support sliding Fixed-Frictionless



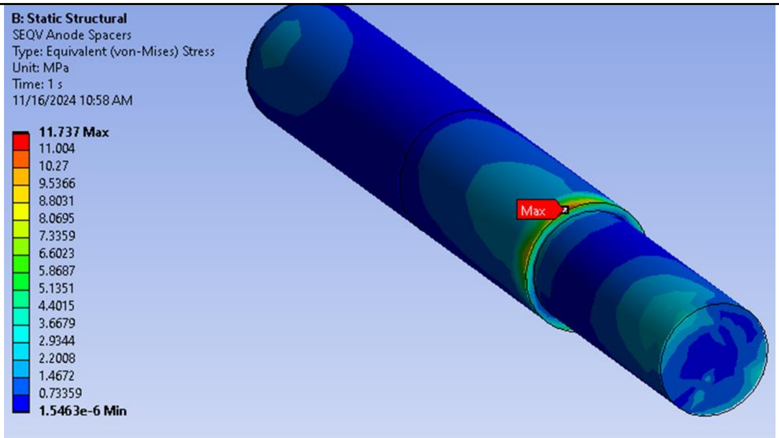
PEEK Spacer Stress

- Stresses are similar between models. 11.7-11.9 MPa peak is well within PEEK limits

Complex Model:
Friction Modelled on all 4 supports

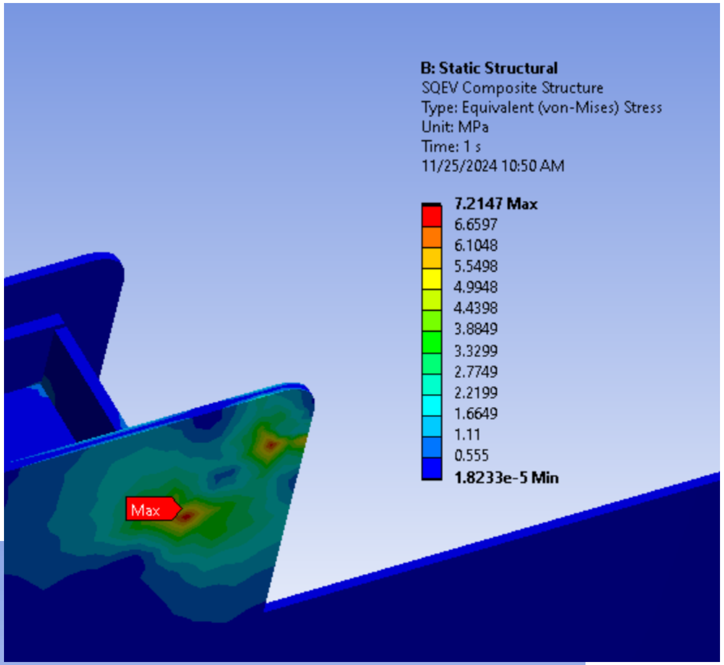


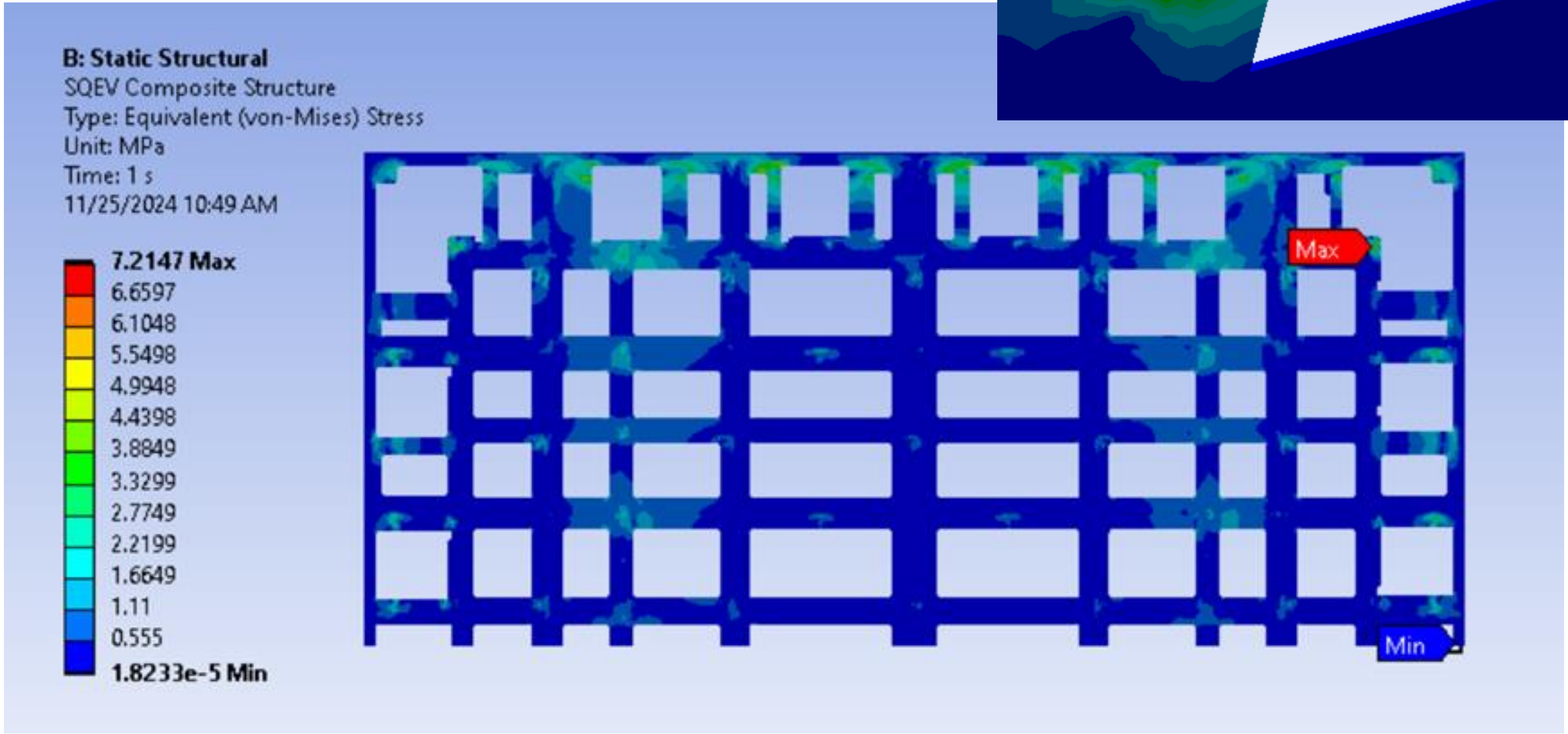
Simple Model:
Simplified support sliding Fixed-Frictionless



Composite Structure Stress

- These remain acceptable in the warm state, with a very healthy margin.
- These results will get more interesting during cooldown, but we predict that they will still be acceptable.





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  - Floor Contact Modeling: looking at displacement of CRU during thermal contraction and frictional sliding on membrane floor
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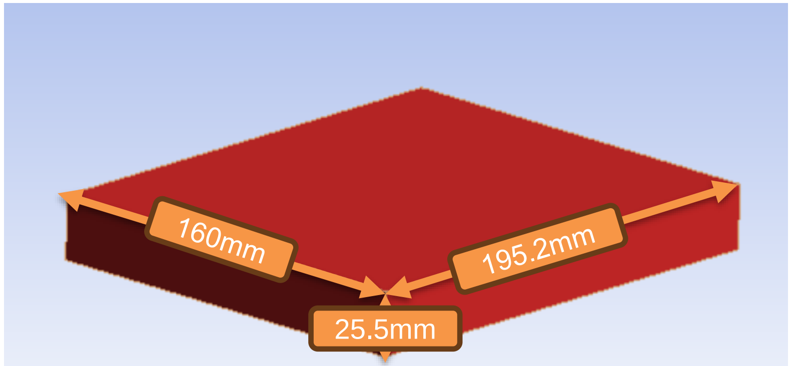
FEMB Modelling And Density

- We have been using a bounding box approach to model the FEMBs.
- Within ANSYS there is a box of solid elements with approximate footprint of the FEMB.
- The updated mass of the FEMB is 0.6kg, from Manhong.
- The real volume of the FEMB is 204,300 mm3, this is the amount of LAr which will be displaced. This is used for the body acceleration calculations.
- Our ANSYS geometry has a volume of 796,420 mm3. We will use a different density than the physical density to model the mass correctly.
- Previous ANSYS models have had the FEMBs as 0.9kg, which is 1.5x heavier than reality.
- This is could be a good thing; it provides us with margin going forward.
- Which does the group want us to use going forward?



Representation	Density Value [kg/m^3]
Physical Body Density	2937
1.5x Real Mass ANSYS Geometry	1124
Real Mass ANSYS Geometry	753.4

G10 Adapter Plate Thermal Model Physical Properties

Material	ANSYS Model Density [kg/m³]	ANSYS Model Secant Thermal Expansion Coefficient [1/K]	Poisson Ratio [-]
G10	1850	0.988635×10^{-5}	0.11
Anode Composite	804	1.32×10^{-5}	0.1543
BDE Composite	1845.5	1.32×10^{-5}	0.1543
Composite Skin	1904	1.32×10^{-5}	0.3065
Composite Beams	1845.5	1.32×10^{-5}	0.1543
PEEK	1310	5.48×10^{-5}	0.4

These are 1.2×10^{-5} with a +10% added. The FEA analysis V2 document lists the CTE of the PCBs as 1.33×10^{-5} , which do we use?

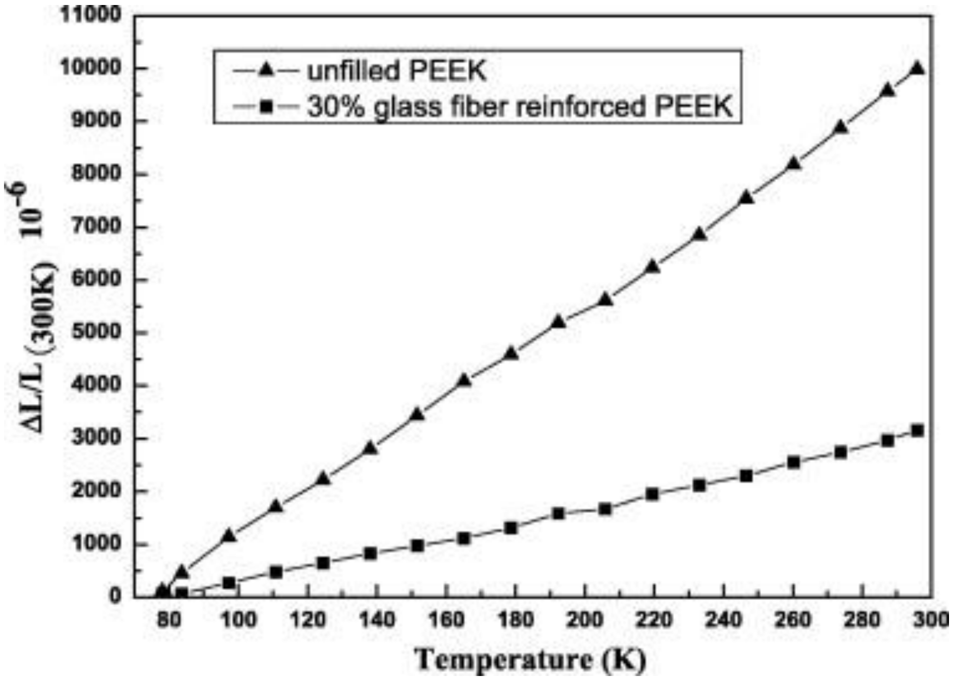
G10 Adapter Plate Thermal Model Physical Properties

Material	ANSYS Model Density [kg/m^3]	ANSYS Model Secant Thermal Expansion Coefficient [1/K]	Poisson Ratio [-]
Stainless Steel	7960	1.388×10^{-5}	0.27
Anode Composite	804	1.08×10^{-5}	0.1543
BDE Composite	1845.5	1.08×10^{-5}	0.1543
Composite Skin	1904	1.08×10^{-5}	0.3065
Composite Beams	1845.5	1.08×10^{-5}	0.1543
PEEK	1310	5.48×10^{-5}	0.4

These are 1.2×10^{-5} with a -10% added. The FEA analysis V2 document lists the CTE of the PCBs as 1.33×10^{-5} , which do we use?

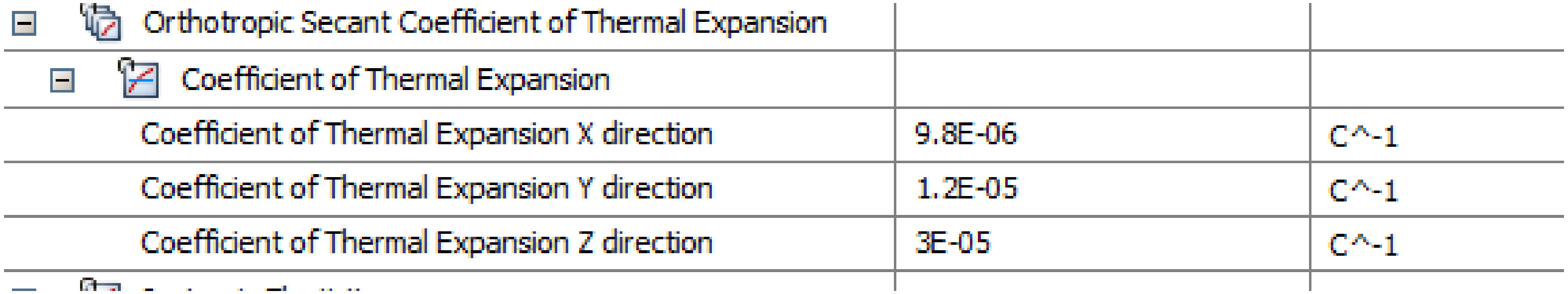
Comment About PEEK Thermal Expansion

- The value used in the CRP model and shown in the previous slides is 5.48 x 10^{-5}.
- Looking at literature, I find an estimated value of 4.57 x 10^{-5}.
  - ((10,000 – 500)/(295-87)) x 10^{-6}.
- The value of the CTE for PEEK likely does not have a large effect in our model, but I wanted to be aware



Comment About PCB

- PCB CTE is described as orthotropic, with only the Y-direction matching the values that we have been talking about.
- Is the X-direction CTE different?

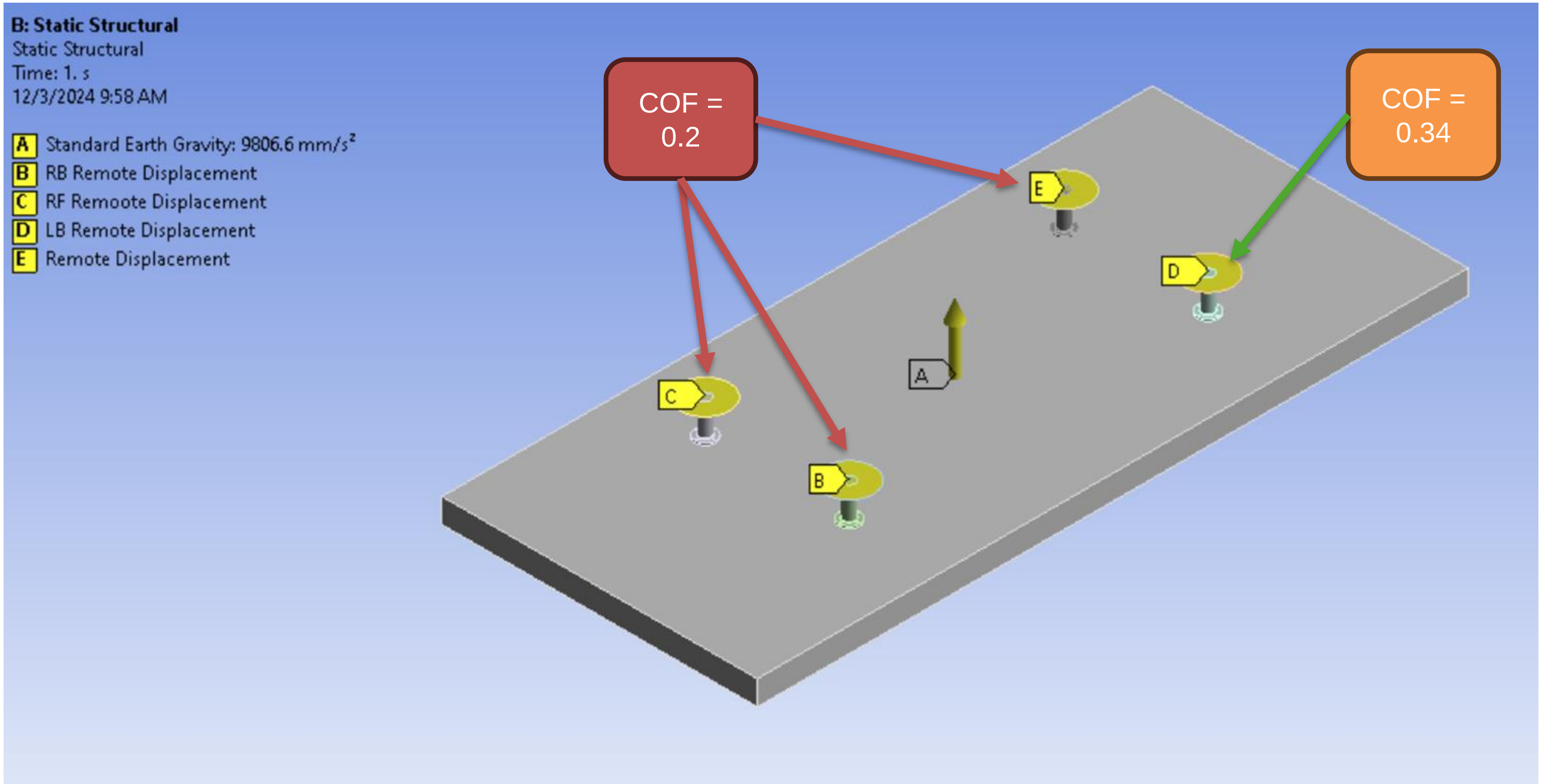


Orthotropic Secant Coefficient of Thermal Expansion		
Coefficient of Thermal Expansion		
Coefficient of Thermal Expansion X direction	9.8E-06	C^-1
Coefficient of Thermal Expansion Y direction	1.2E-05	C^-1
Coefficient of Thermal Expansion Z direction	3E-05	C^-1

Thermal Model Approach

- We have tried to take the friction model from above and apply a thermal condition.
  - This model failed to converge after thousands of iterations spanning several days of computational time.
  - Debugging this model is impractical because of the solve time.
  - This model requires a lot of iteration as it must iterate displacement due to friction and iterate through displacement due to contraction. This interaction causes long solve times and impacts convergence.
- Instead, we will break this into two different models:
  - One model will investigate the slip along the floor induced by contraction; this was done by Josh Truchon at UW for the CRP. This model will include frictional contact, but the CRU will e treated as a solid rectangular box with the appropriate mass and CTE, elastic modulus and Poisson’s ratio given to be those of the composite beams.
  - One model will investigate stresses caused by differential contraction within the structure of the CRU, this model will use elastic boundary conditions (fixed-frictionless) but include the real geometry of the CRU.

Slip During Cooldown Model



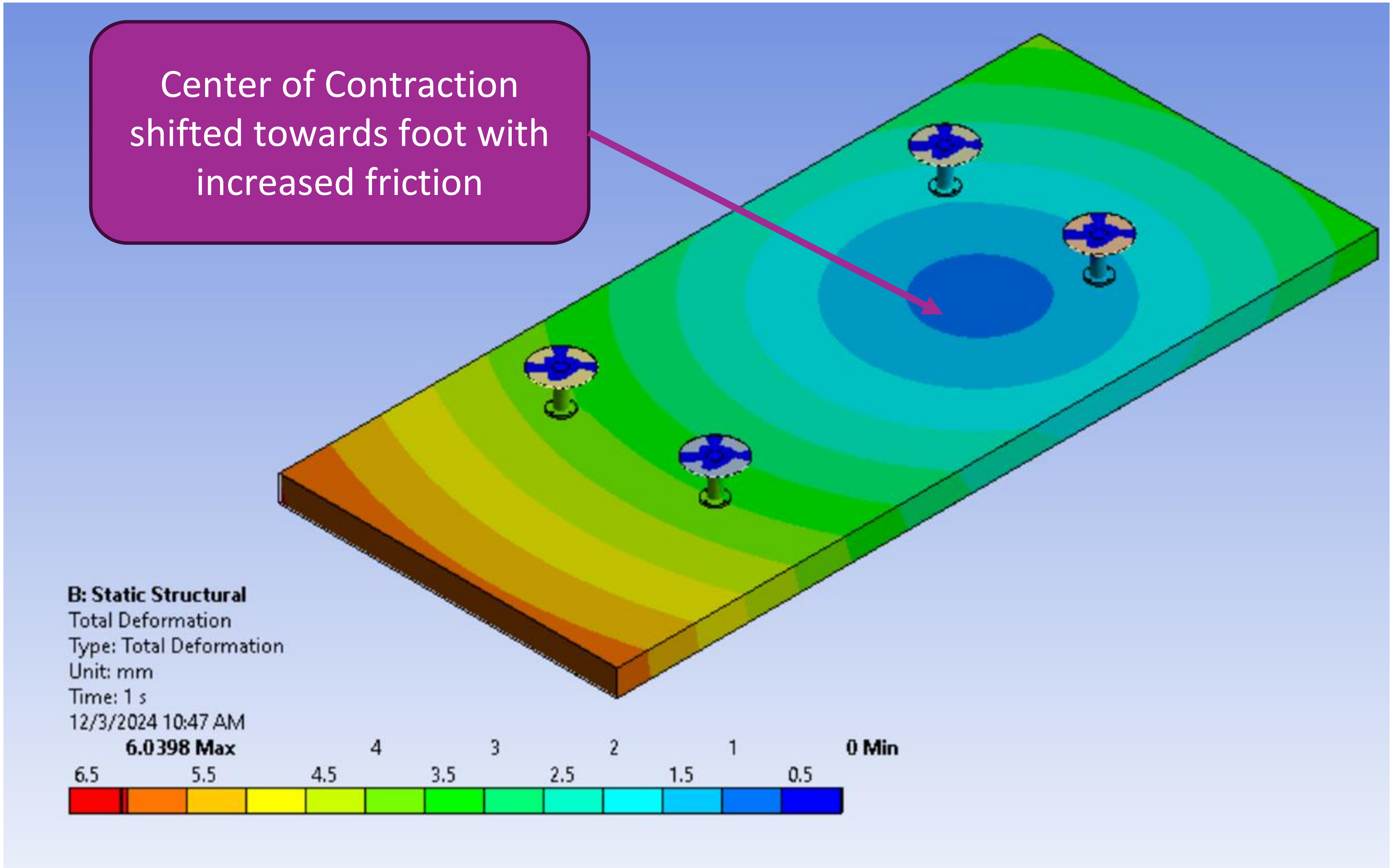
B: Static Structural
Static Structural
Time: 1. s
12/3/2024 9:58 AM

- A Standard Earth Gravity: 9806.6 mm/s²
- B RB Remote Displacement
- C RF Remoote Displacement
- D LB Remote Displacement
- E Remote Displacement

COF = 0.2

COF = 0.34

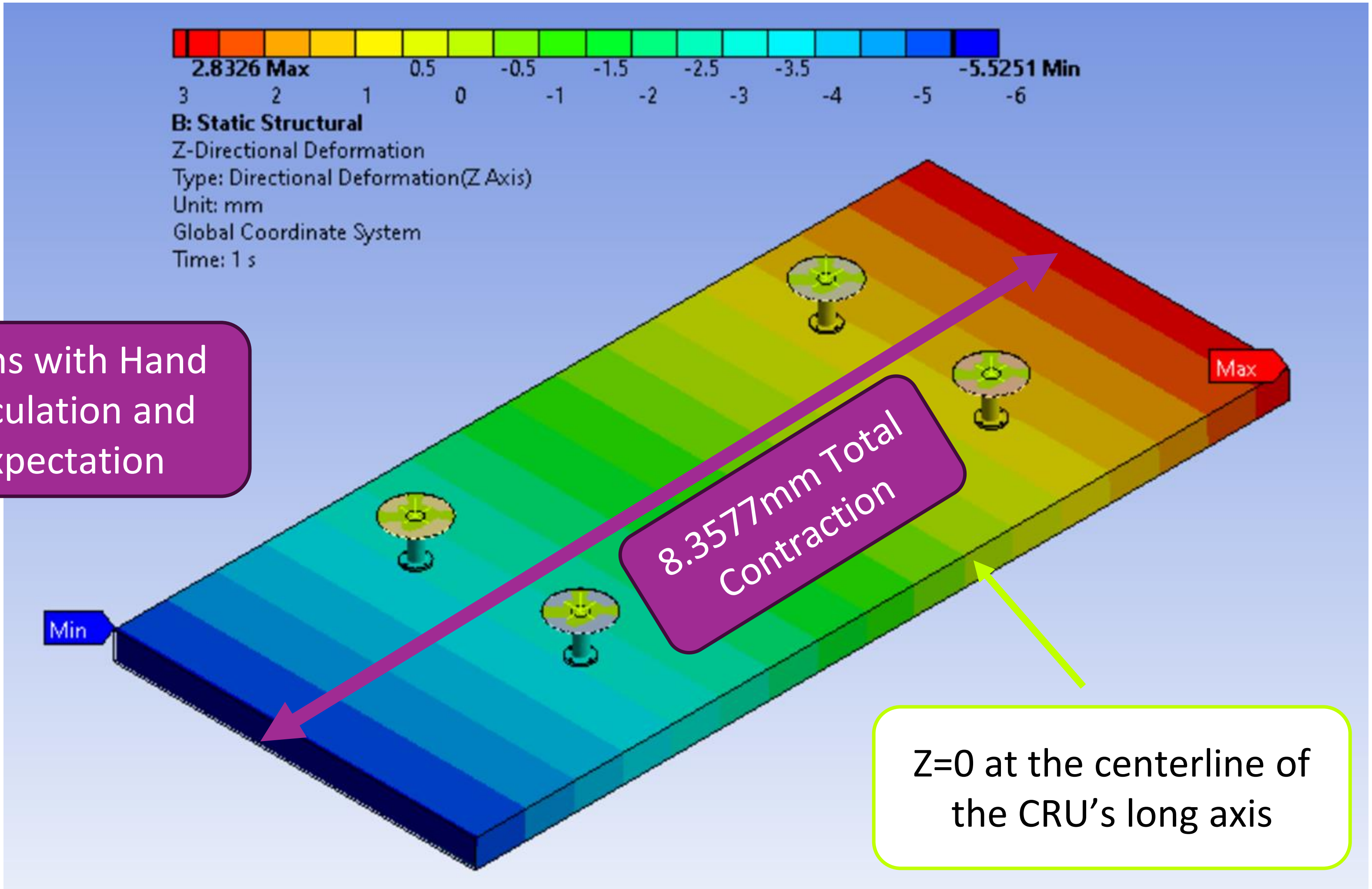
Vector Sum Deformation



Center of Contraction shifted towards foot with increased friction

B: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1 s
12/3/2024 10:47 AM

Deformation Along Long Axis



B: Static Structural
Z-Directional Deformation
Type: Directional Deformation(Z Axis)
Unit: mm
Global Coordinate System
Time: 1 s

Aligns with Hand Calculation and Expectation

8.3577mm Total Contraction

Z=0 at the centerline of the CRU's long axis

Friction Slip Model Summary

- This simple slip model behaves as expected and is likely sufficient to capture the information needed to inform design and installation procedure.
- We can extract the forces on the feet from the reactions on the floor, and input these into a stress model with the real geometry.
  - We have these but are working on making a visual.
- The reaction forces are similar in magnitude to those observed by Josh Truchon.
  - CRP Force Reaction Magnitude: 316 N
  - CRU Force Reaction Magnitude: 382 N
- We can insert the forces as remote forces in the full geometry model.

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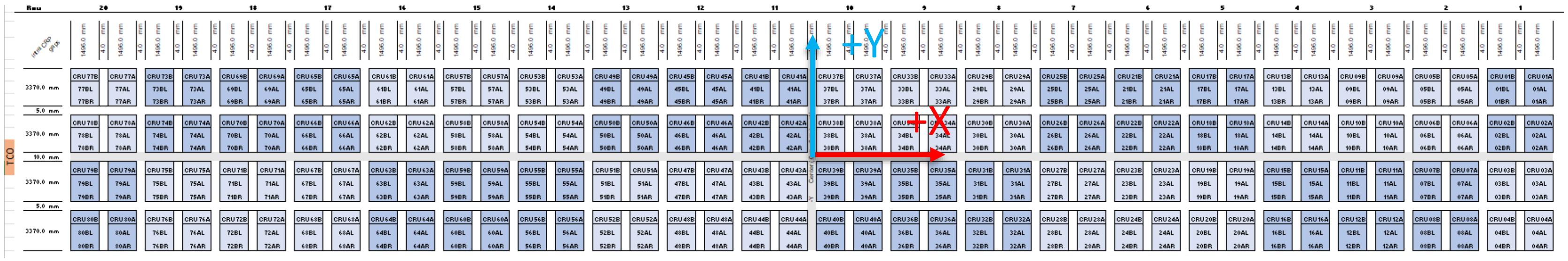
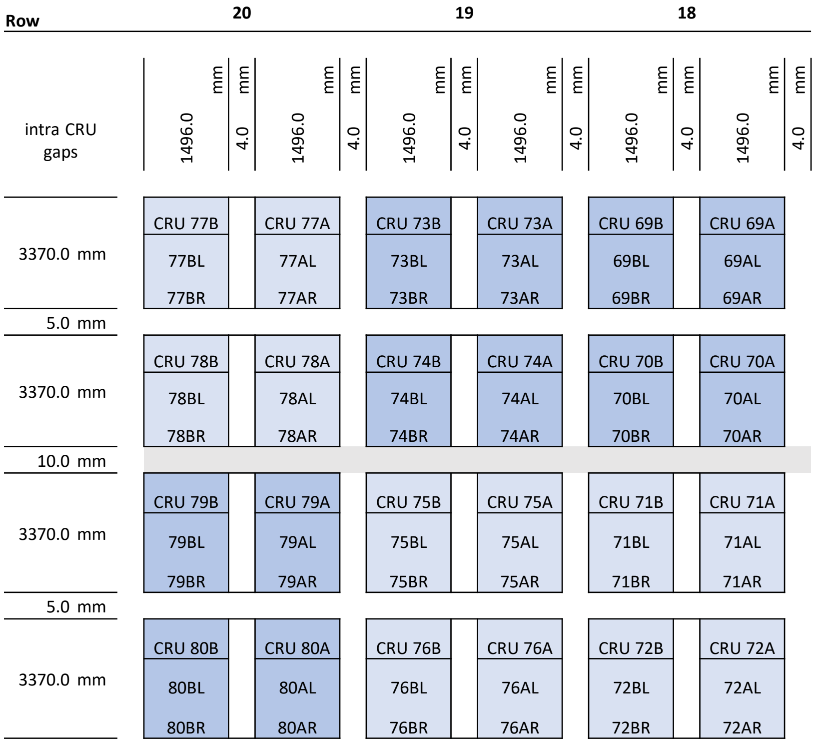
CRU positions



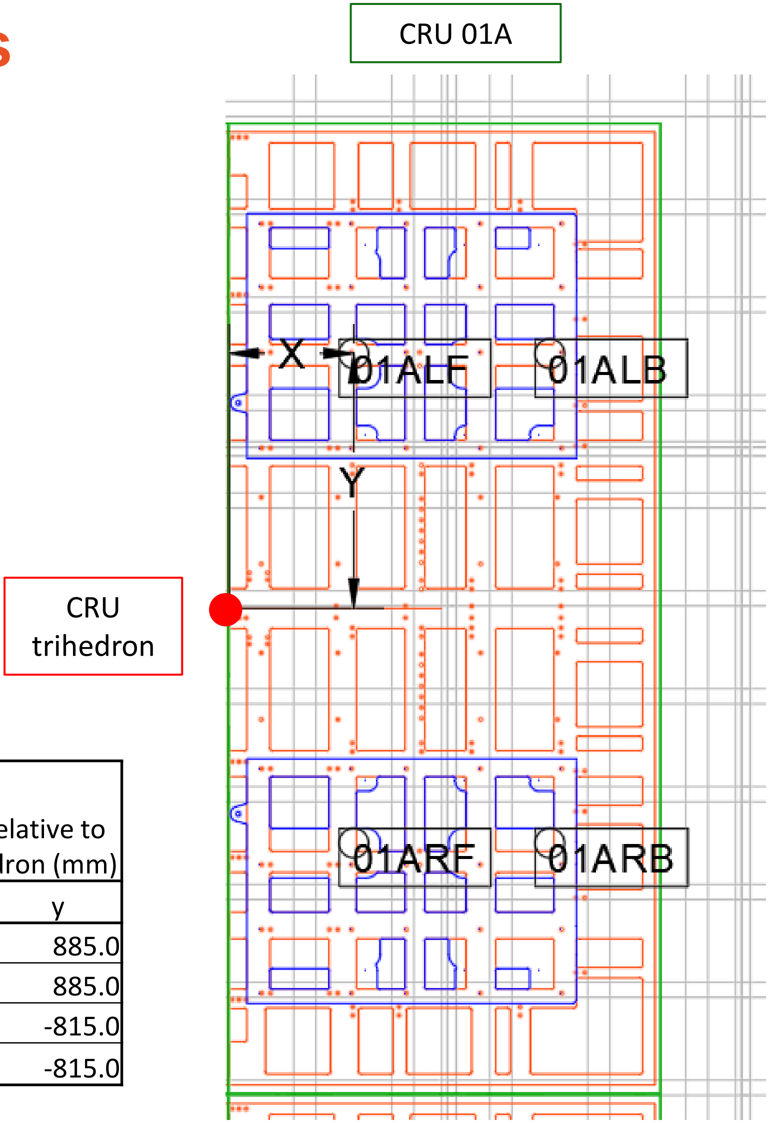
- Simplified layout of FD is provided in spreadsheet
- Cryostat membrane floor layout is taken from 3D model from FD2 CAD. Membrane floor has not changed over versions
  - FD2 – Complete 3D Assembly (Navisworks) ,
  - Doc id **2756552 v.7**, with Released status, 2023-12-18 , Adrien Parchet https://edms.cern.ch/document/2756552/7
  - Doc id **3170306 v.8**, with In Work status, 2024-10-03 , Adrien Parchet https://edms.cern.ch/document/2756552/8
- Bottom CRU layout is changed
  - 4mm spacing between CRUs in X
  - Keep spacing in Y the same as top CRP planes
  - Layout is 6 mm longer in X than top CRPs, 3 mm at each end
- CRUs are labeled and the 4 adapter plates / frames and their relative location are pictured
- Centroid (trihedral) position of CRUs are given relative to the center of the FD cryostat floor



Row	**20**				**19**				**18**			
intra CRU gaps	1496.0 mm	4.0 mm	1496.0 mm	4.0 mm	1496.0 mm	4.0 mm	1496.0 mm	4.0 mm	1496.0 mm	4.0 mm	1496.0 mm	4.0 mm
3370.0 mm	CRU 77B 77BL 77BR		CRU 77A 77AL 77AR		CRU 73B 73BL 73BR		CRU 73A 73AL 73AR		CRU 69B 69BL 69BR		CRU 69A 69AL 69AR	
5.0 mm												
3370.0 mm	CRU 78B 78BL 78BR		CRU 78A 78AL 78AR		CRU 74B 74BL 74BR		CRU 74A 74AL 74AR		CRU 70B 70BL 70BR		CRU 70A 70AL 70AR	
10.0 mm												
3370.0 mm	CRU 79B 79BL 79BR		CRU 79A 79AL 79AR		CRU 75B 75BL 75BR		CRU 75A 75AL 75AR		CRU 71B 71BL 71BR		CRU 71A 71AL 71AR	
5.0 mm												
3370.0 mm	CRU 80B 80BL 80BR		CRU 80A 80AL 80AR		CRU 76B 76BL 76BR		CRU 76A 76AL 76AR		CRU 72B 72BL 72BR		CRU 72A 72AL 72AR	

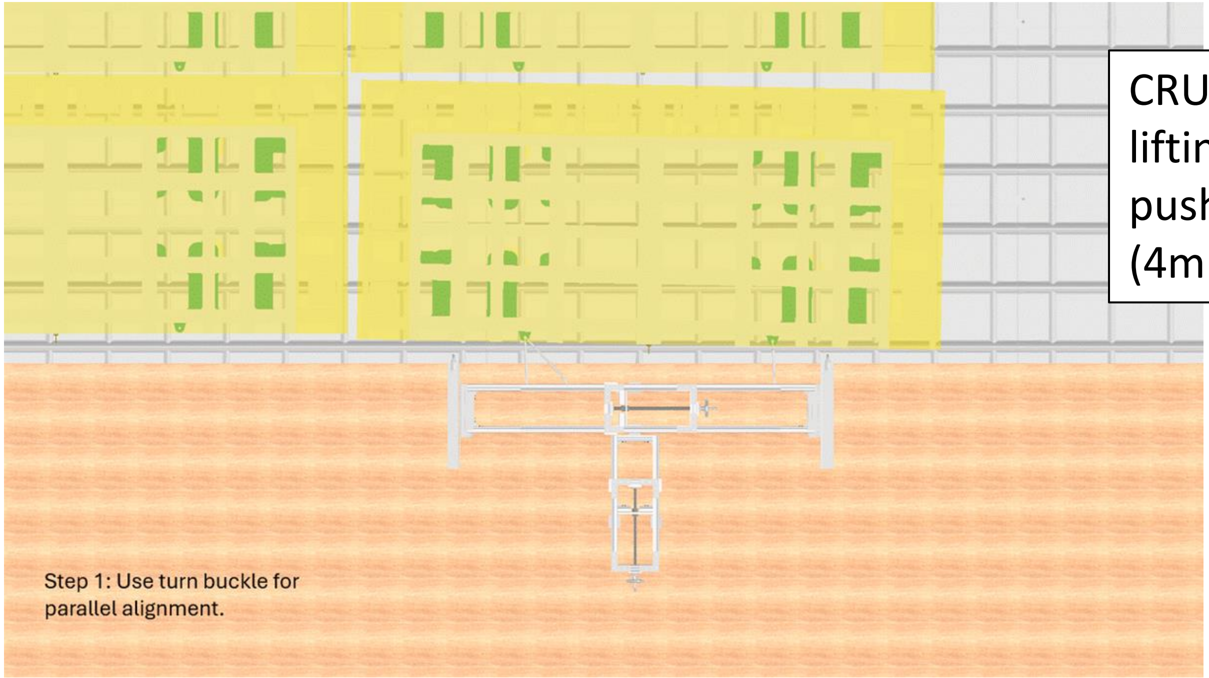
Position of Bottom supports

- CRU is positioned relative to cryostat center
  - CRU 01A trihedral location: X = 28.2955 m, Y = 5.0650,
- Each CRU has 4 supports. Described as viewed from the TCO side during install:
  - LB, left adapter plate, back support
  - LF, left adapter plate, front support
  - RB, right adapter plate, back support
  - RF, right adapter plate, front support
- Support position is given relative to the CRU trihedron.



	Position relative to CRU Trihedron (mm)	
Support	x	y
01ALB	1114.5	885.0
01ALF	432.5	885.0
01ARB	1114.5	-815.0
01ARF	432.5	-815.0

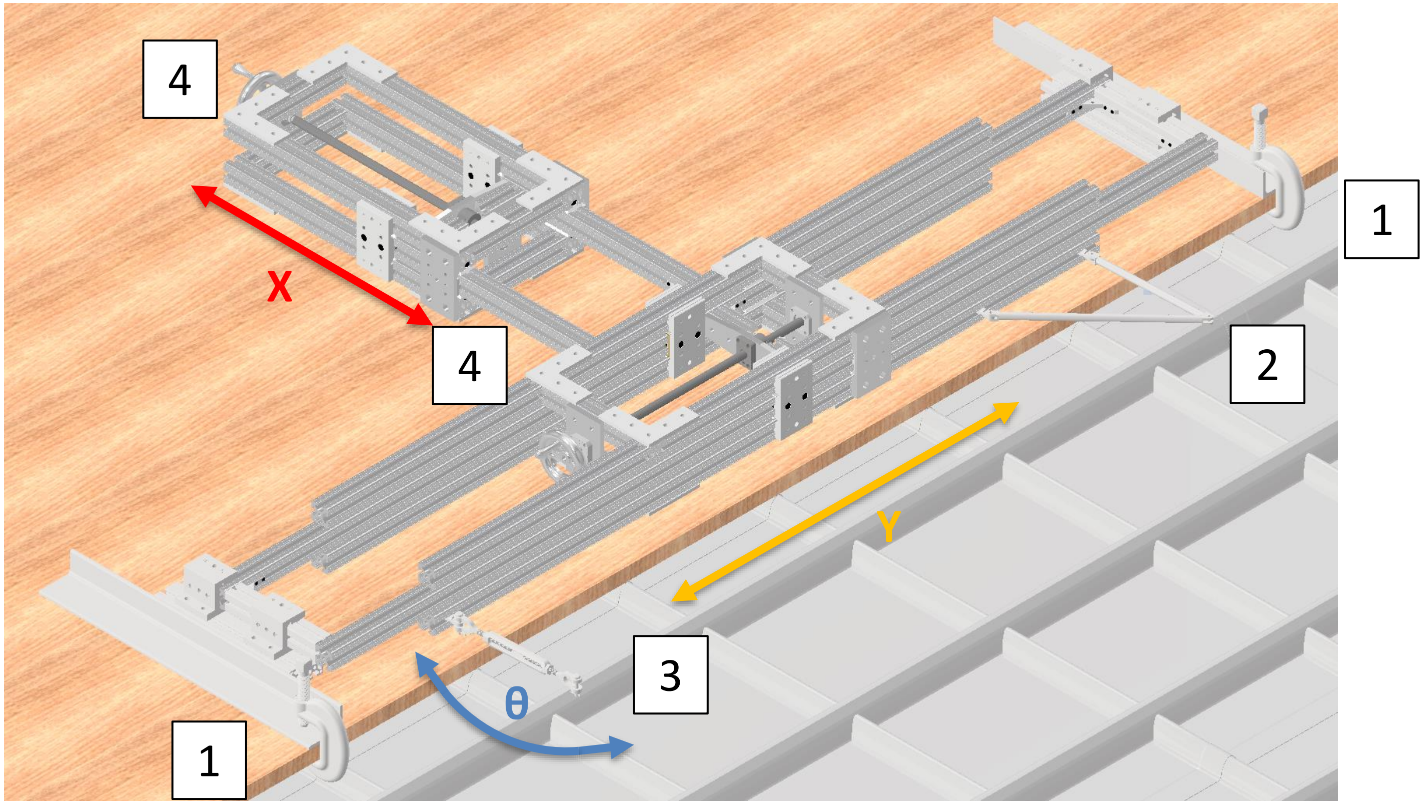
Placement Tool: Design Goals



CRU is placed on floor using lifting tools. Needs to be pushed into final position (4mm gaps to neighbors)

- Precise and reliable control of displacement for CRU.
- Ease of operation, incorporating user-friendly controls.
- As compact as possible
- Challenges include:
  - Limited space.
  - Alignment requirements.
  - Interfacing device with the wood floor.

Placement Tool: Overview and Functionality



- Extruded 8020 framework provides modularity and rigidity.
- Key components:
  1. Clamps attach the device to the wood floor.
  2. Tie rods with clevis ends connect to CRU and transfer load.
  3. Turn buckle allows rotational adjustment, to ensure CRU is parallel.
  4. Ball screws for precise linear motion in X and Y.

Placement Tool: Positioning a CRU

Step 1: Use turn buckle for parallel alignment.

- Alignment Steps:
  1. Adjust Turn buckle for rotational adjustment, ensure CRU is parallel to neighbors.
  2. Adjust Y ball screw until CRU has 4 mm gap to row behind
  3. Adjust X ball screw until CRU has 4 mm gap to neighbor CRU

Placement Tool: Next Steps

- Prototyping Phase:
  - Develop and refine the design.
  - Iterating on concepts to address linear motion in x displacement.
- Design Flexibility:
  - Exploring multiple mechanisms for linear motion.
- Prototyping and Testing:
  - Scale up testing to larger and heavier objects to ensure structural and functional reliability.
  - Push around a mock CRU