Sealing Stresses and Deformations
-SECA CTP-

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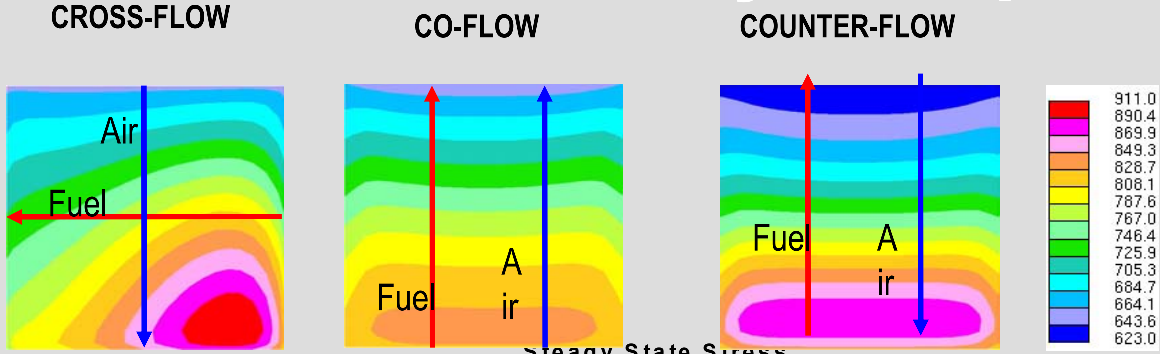
Critical questions

- What are the PEN stresses as a function of boundary stiffness during steady state or transient conditions?
- What are the cell edge displacements as a function of PEN stresses?
- What are the effects of stack B.C.s on stresses?
- What is the state of stress and displacement in the seal area?
- How does a dead load distributes throughout the stack, especially sealing areas?

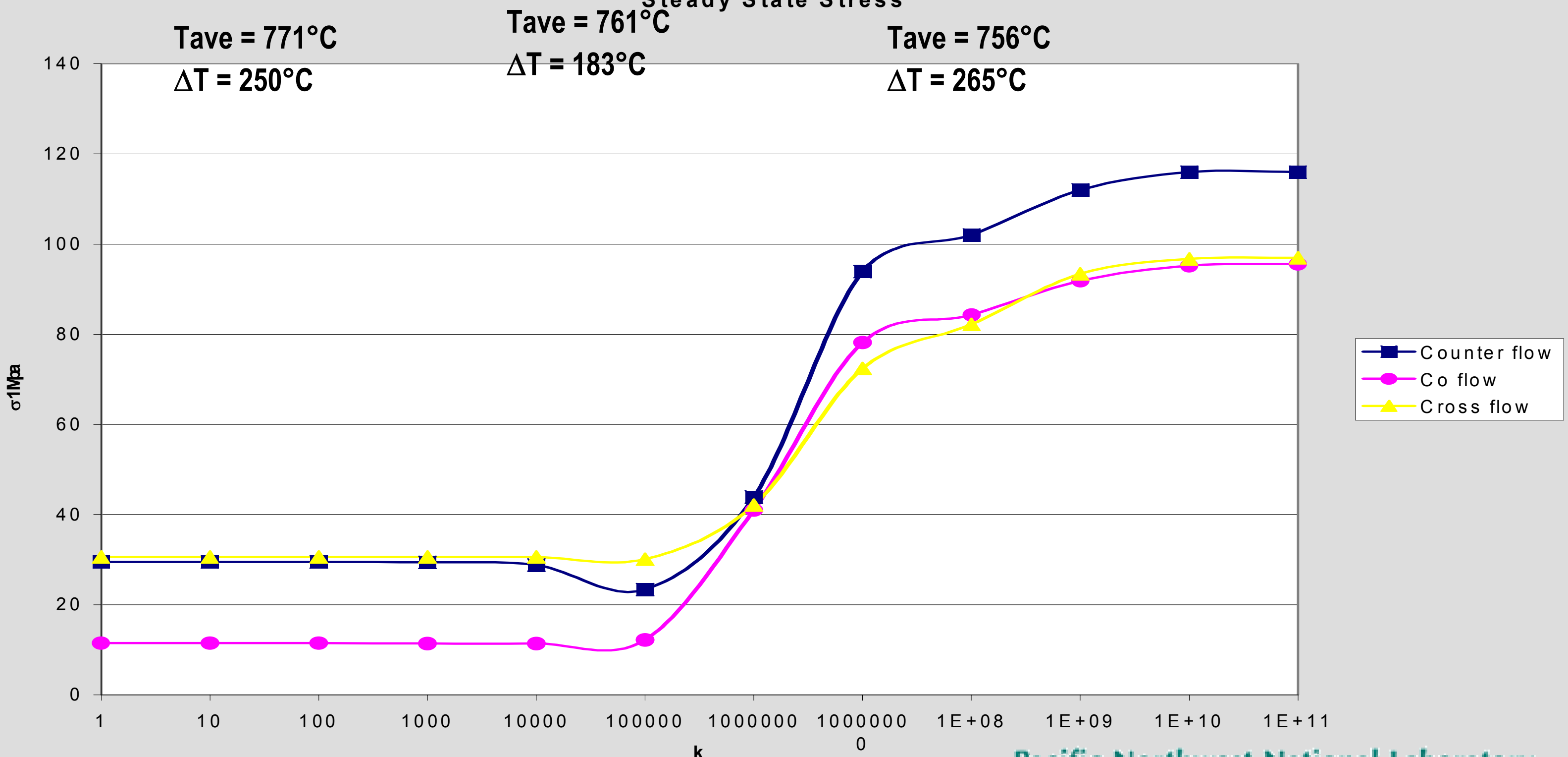
PEN Stresses during Steady State as a function of Boundary Compliance



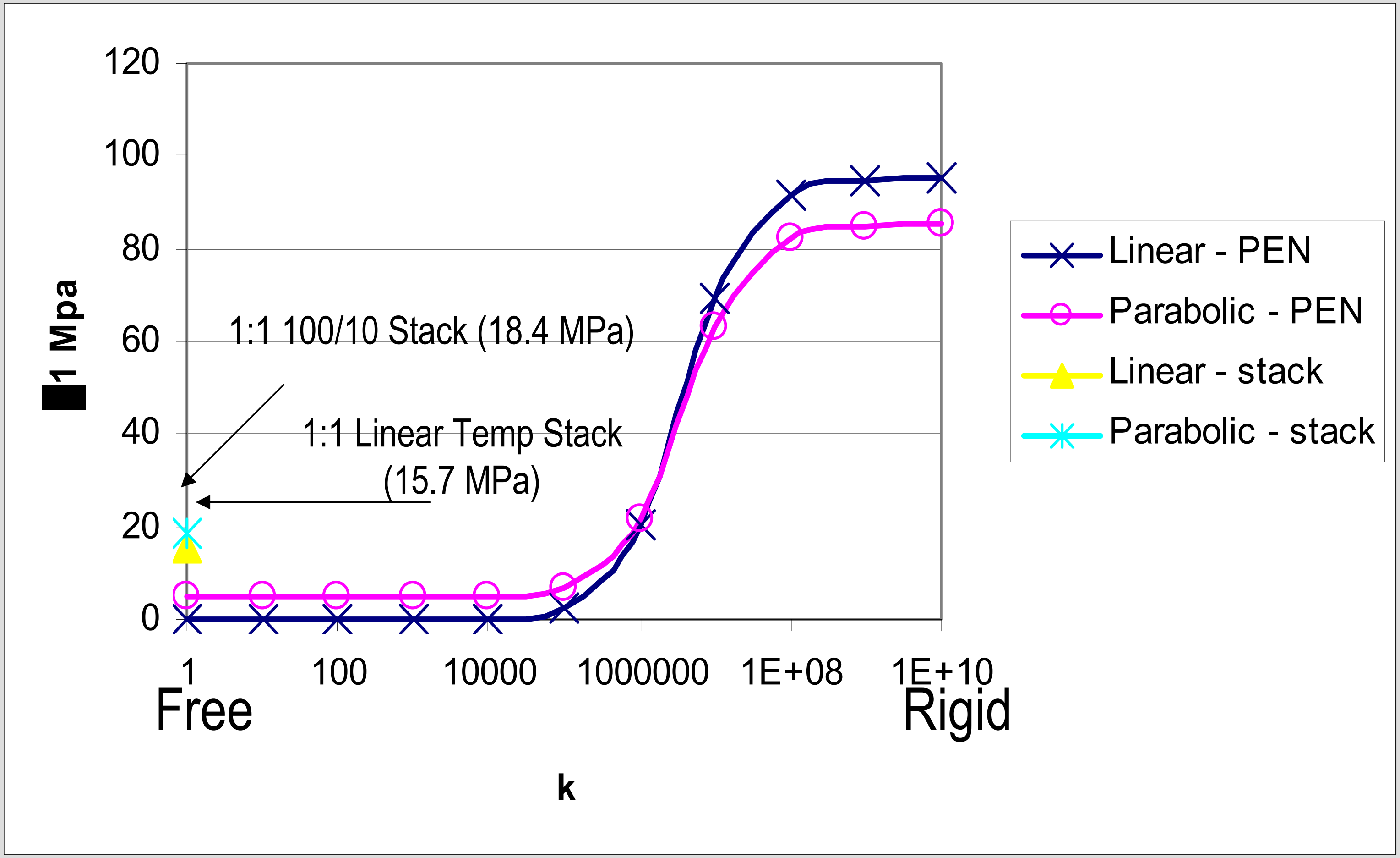
Tave = 771°C
ΔT = 250°C

Tave = 761°C
ΔT = 183°C

Tave = 756°C
ΔT = 265°C



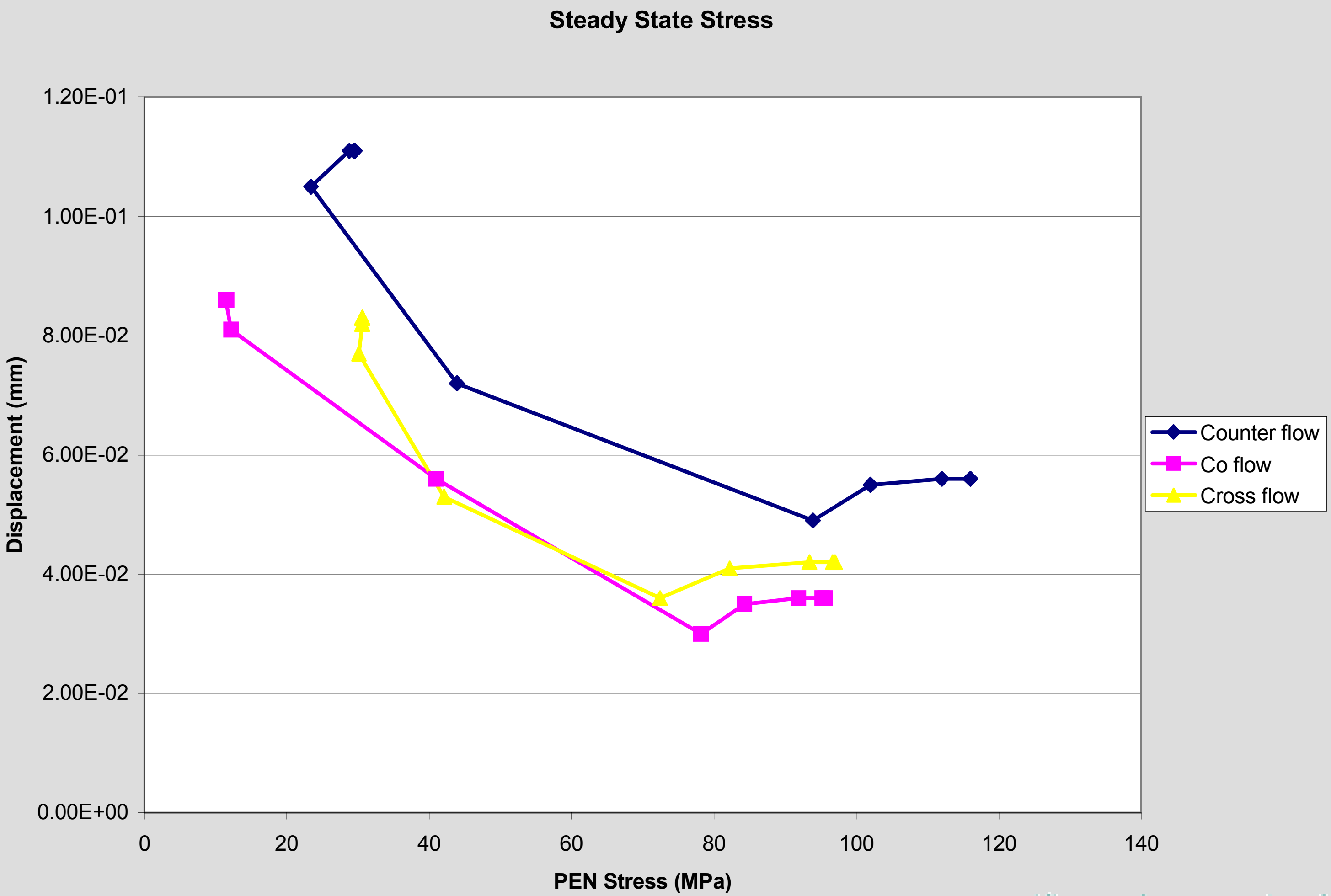
PEN Stresses during Transient State as a function of Boundary Compliance



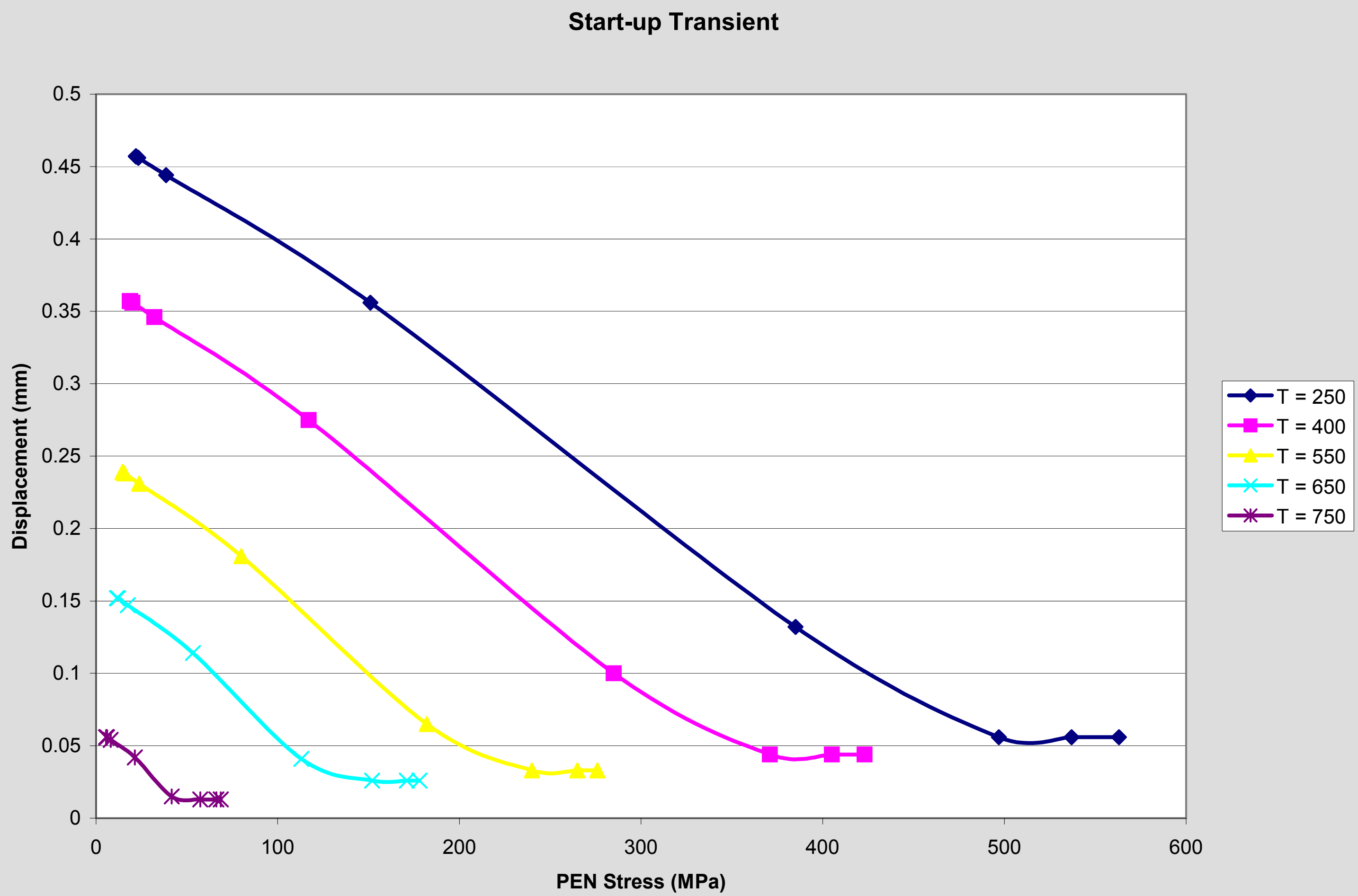
Pure Shear and Axial Loading

	E (GPa)	nu	G (GPa)	K/L Shear	K/L Axial	K shear	K axial
YSZ	175	0.3	67.30769	1.7E+12	7.0E+09	1E+10	4E+07
Steel	120	0.3	46.15385	1.2E+12	4.8E+09	7E+09	3E+07
Glass	9	0.3	3.461538	8.7E+10	3.6E+08	5E+08	2E+06
Nylon	1.7	0.3	0.653846	1.6E+10	6.8E+07	1E+08	4E+05
Rubber	0.002	0.3	0.000769	1.9E+07	8.0E+04	1E+05	5E+02

Cell Edge Displacement During Steady State

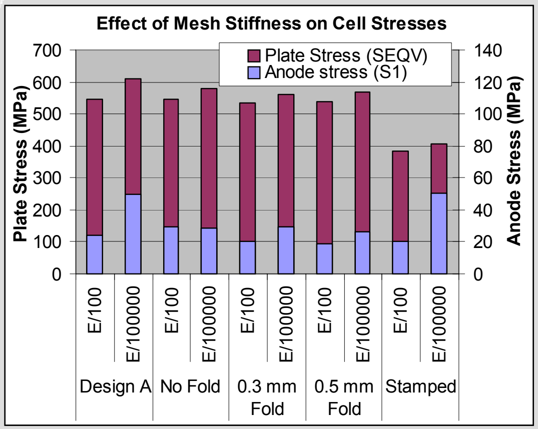


Cell Edge Displacement During Transient Loading



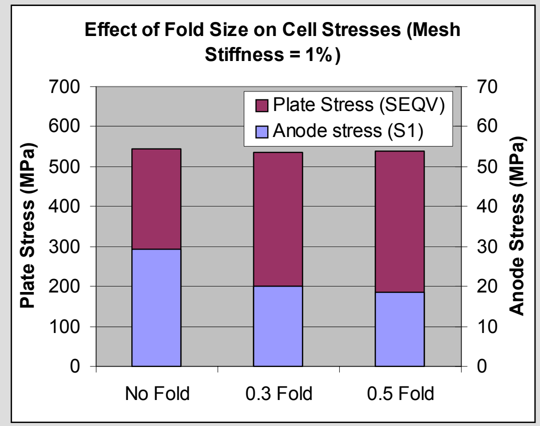
Thermal-Structural Stress Analysis: Influence of Design Variables on Cell Stresses

Mesh Stiffness



A more compliant mesh material generally increased the stresses in both the anode and the plate.

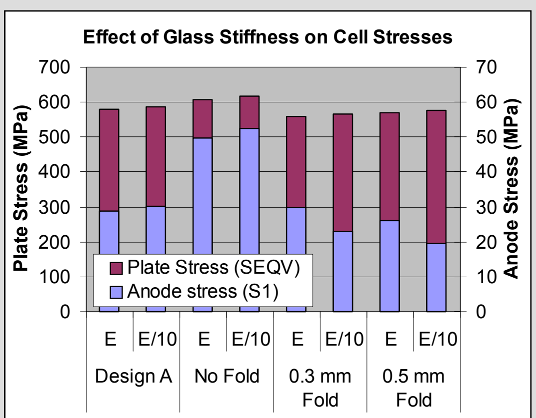
Fold Size (rigid+compliance in fold)



Addition of fold reduced the anode stress significantly and the plate stresses slightly.

(Note: Fold reduces the active area of PEN)

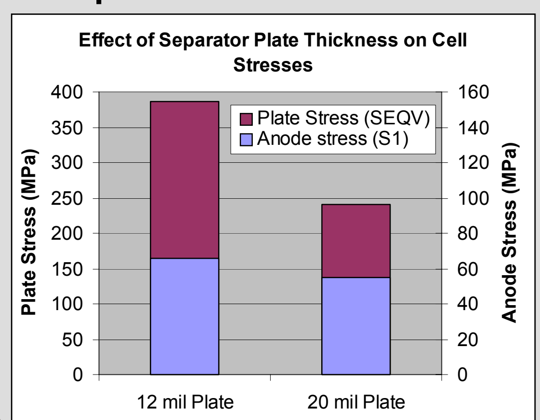
Glass Stiffness



Reduced stiffness for the glass increased plate stresses.

Reduced glass stiffness also reduced anode stress in designs w/ a fold, but increased anode stress in designs w/o a fold.

Separator Plate Thickness

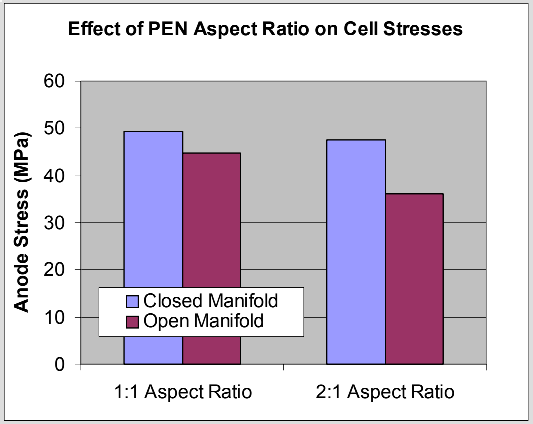


A thicker separator plate decreased the stresses in both the anode and the plate.

(Note: Thicker plate gives slower thermal response for start-up)

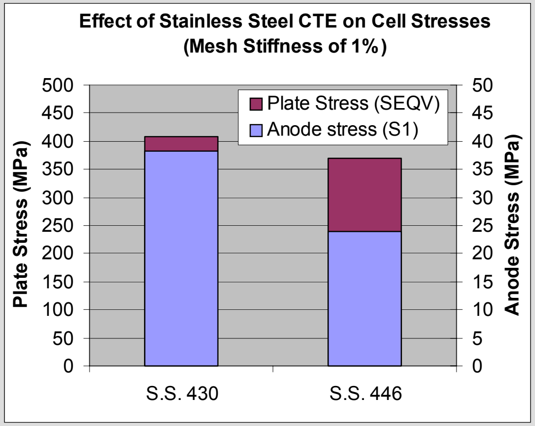
Thermal-Structural Stress Analysis: Influence of Design Variables on Cell Stresses

PEN Aspect Ratio



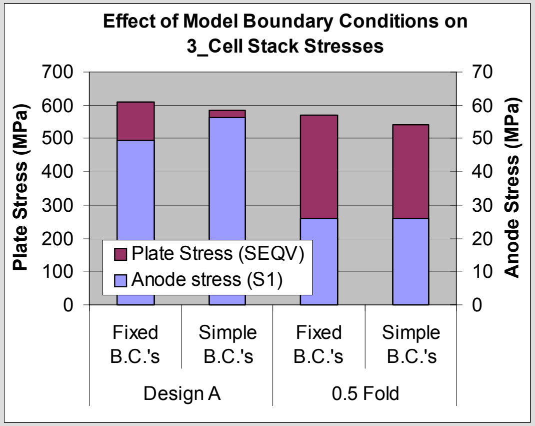
A rectangular PEN had lower stresses than a square PEN during start-up.

CTE



Lower coefficient of thermal expansion (CTE) for 446 stainless steel significantly reduced anode and plate stresses.

Model B.C.'s



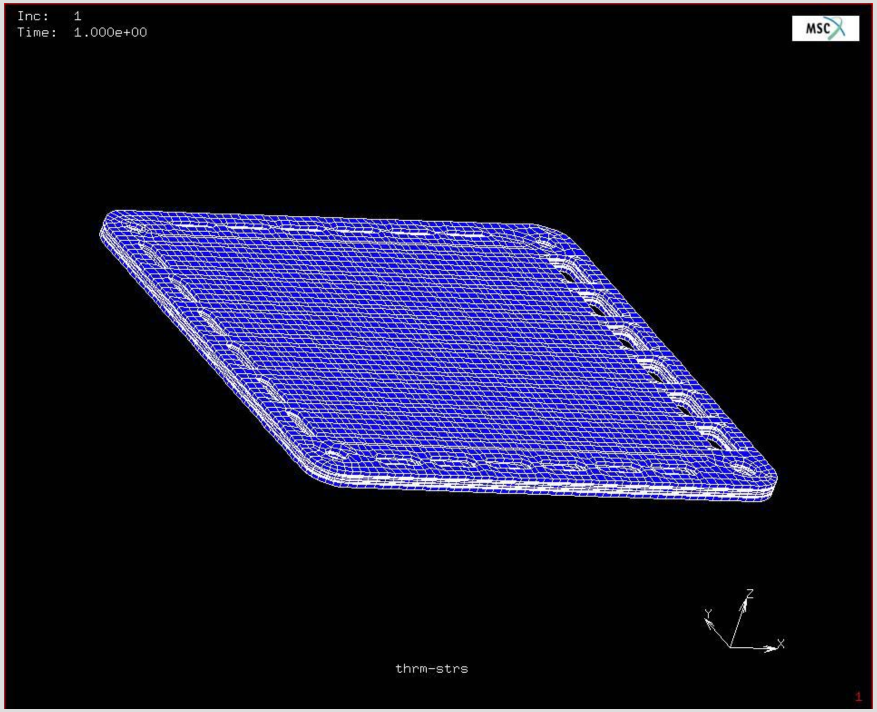
The stack stiffness can be accounted for with boundary conditions. The effect of the model B.C.'s on stresses was found to be dependent on the cell design.

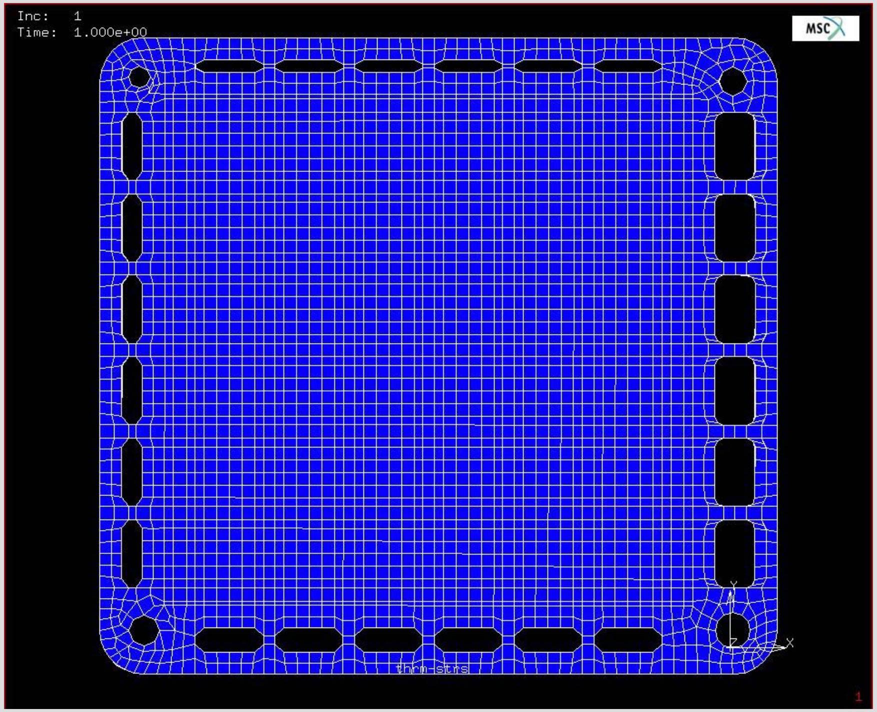
Results 3-Stack Simulations

		Anode $\sigma 1$ MPa	SS σeqv MPa
1% (A)	Bottom	24	370
	Top	22	547
0.001% (D)	Bottom	49.6	313
	Top	32.4	609
0.001% (E)	Bottom	56.4	410
Simple BC	Top	33.8	585
0.001% (F)	Bottom	52.5	326
10% glass	Top	28.9	617

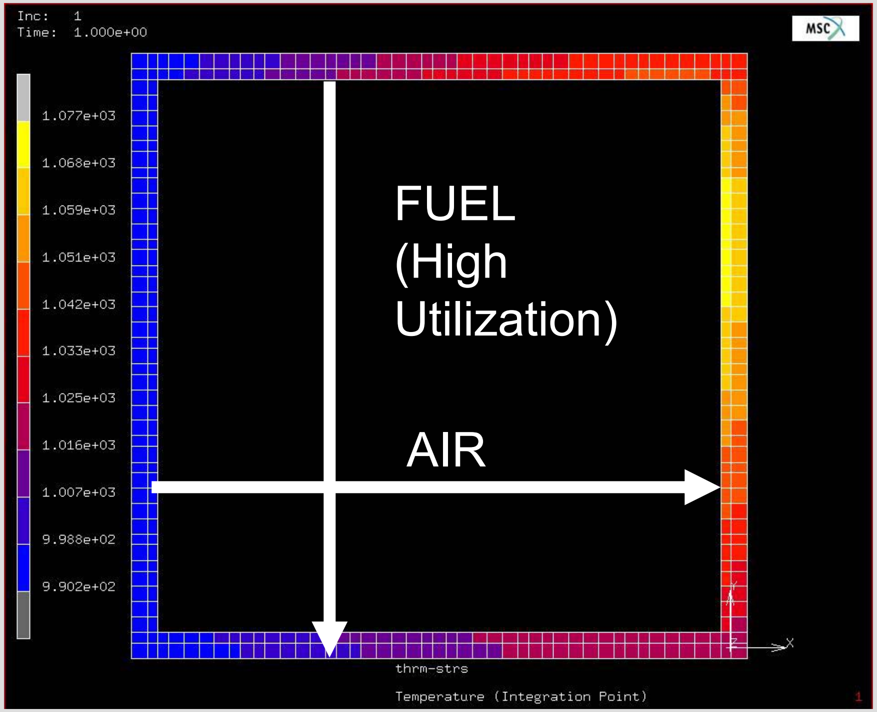
- Will the stack survive thermal stresses? (based on stress/strength failure criteria)
- What is the effect of out of plane stiffness?
- Will softer glass reduce stresses?
- How do the B.C.'s change stress profiles?

1- Cell Stack (Picture Frame)

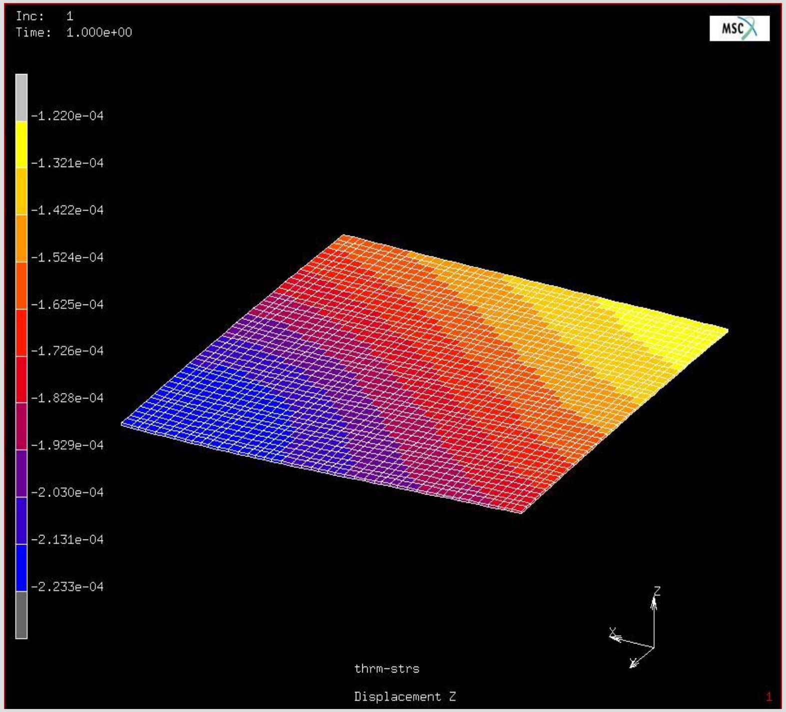




Seal Temperature Profile and PEN out-Plane Deformation

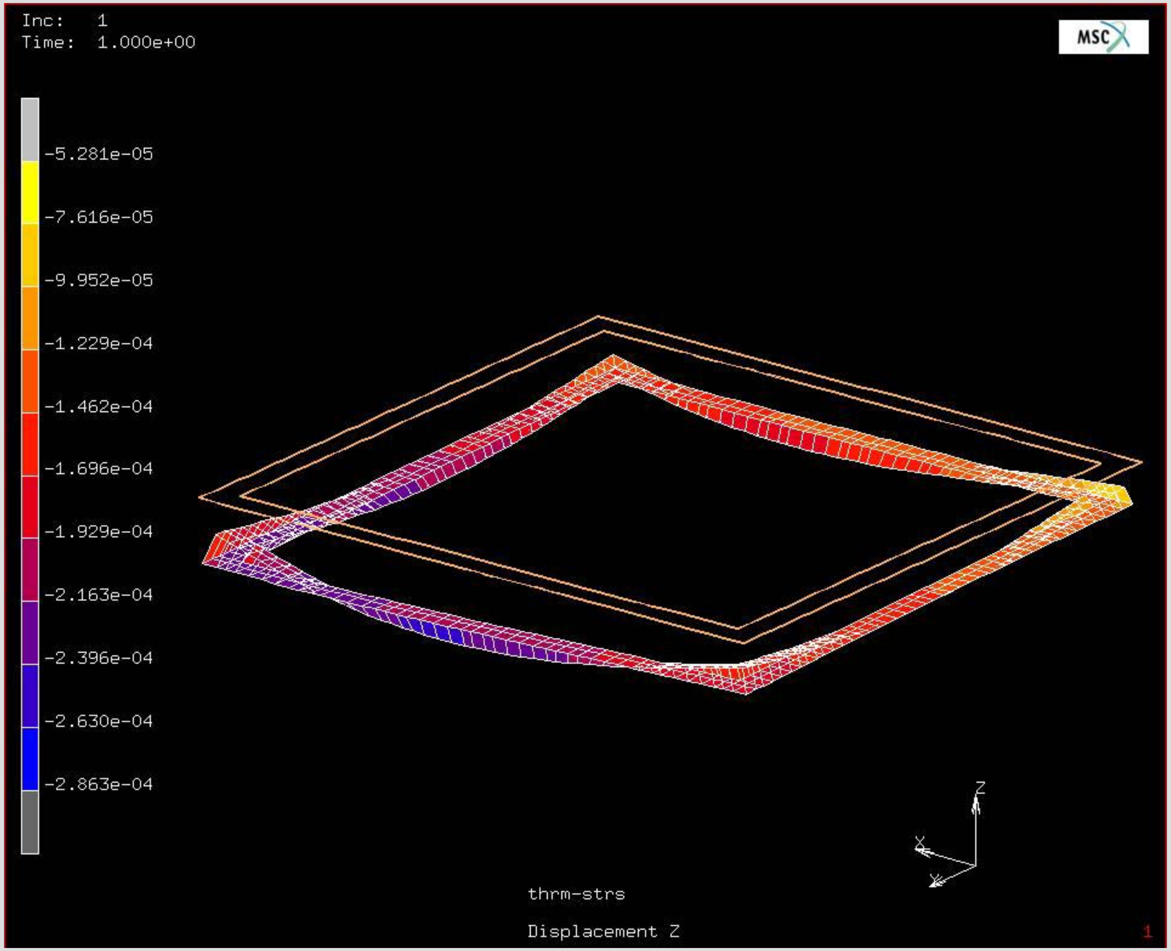


Seal Temperature



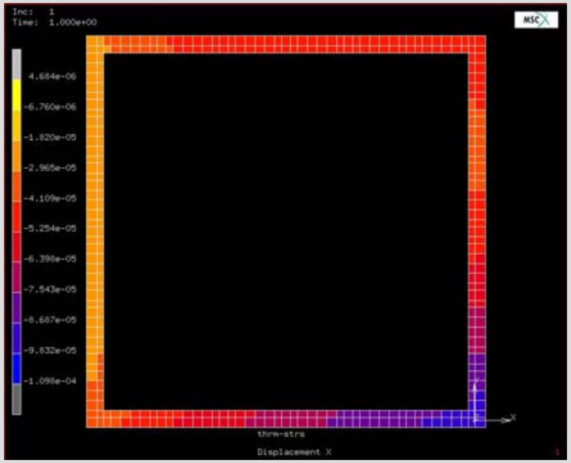
PEN UZ
Deformation

Seal Deformations

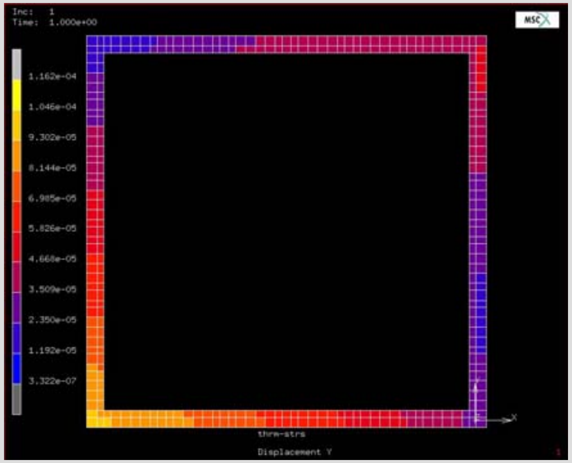


Displacement Components in Seal

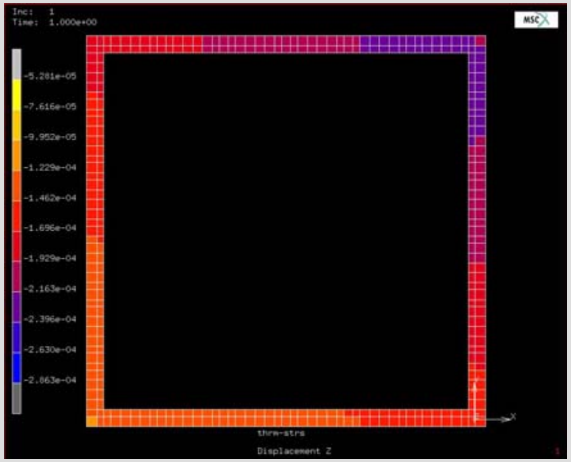
UX



UY

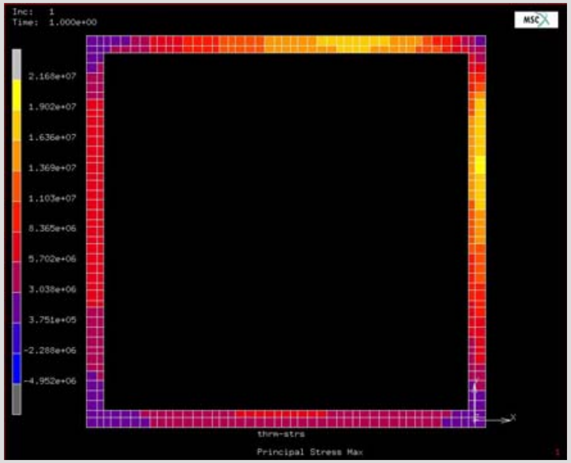


UZ

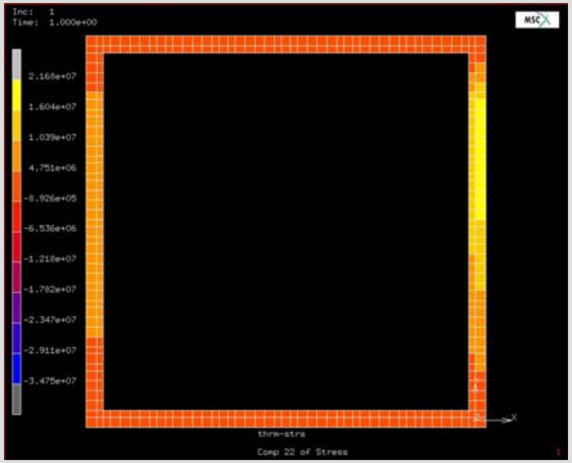


Seal – Principal Stresses

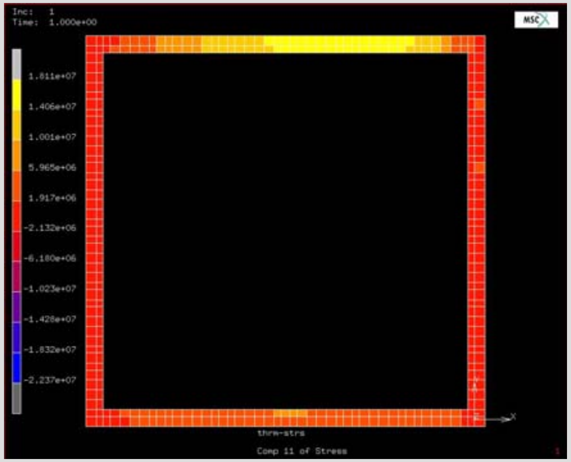
SMAX



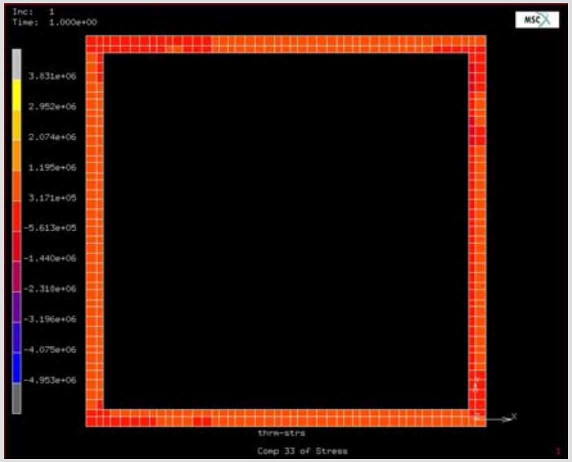
SY/S22



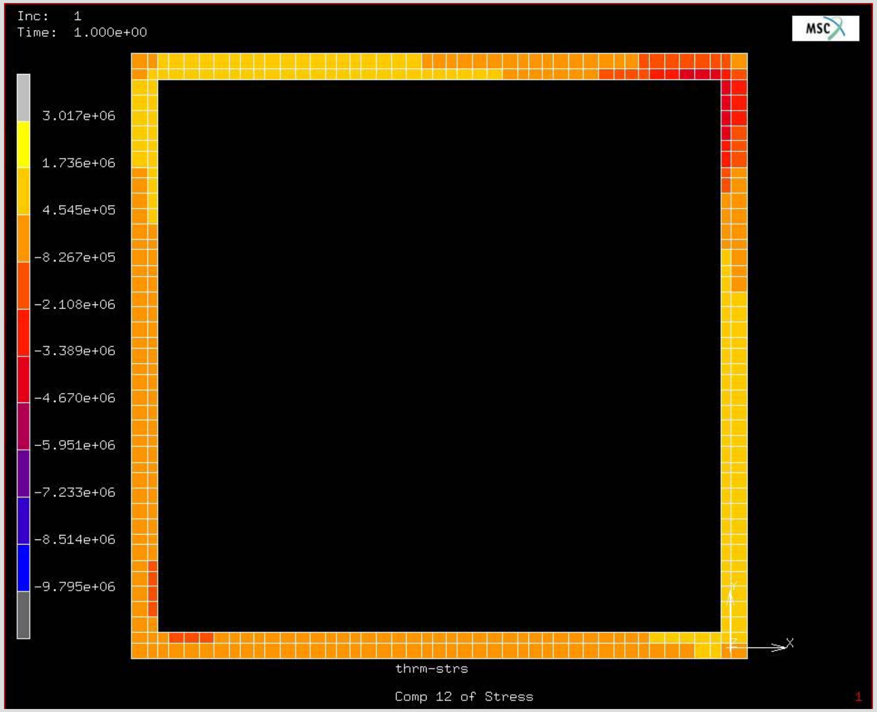
SX/S11



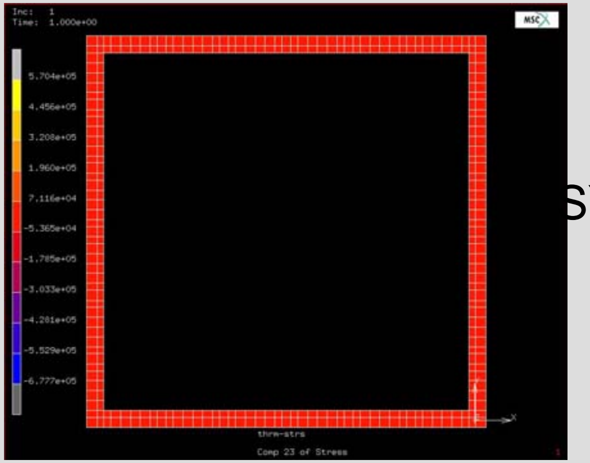
SZ/S33



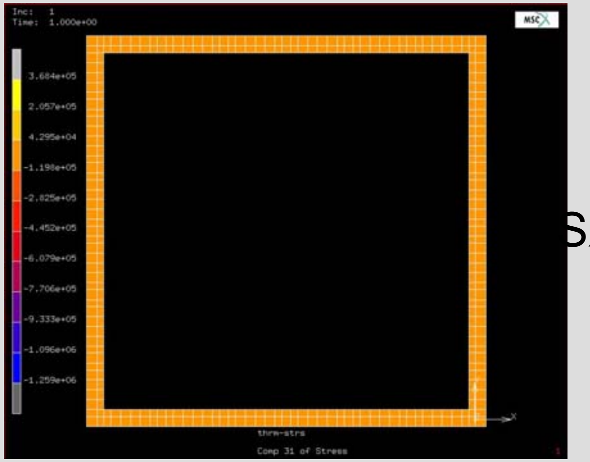
Seal- Shear Stresses



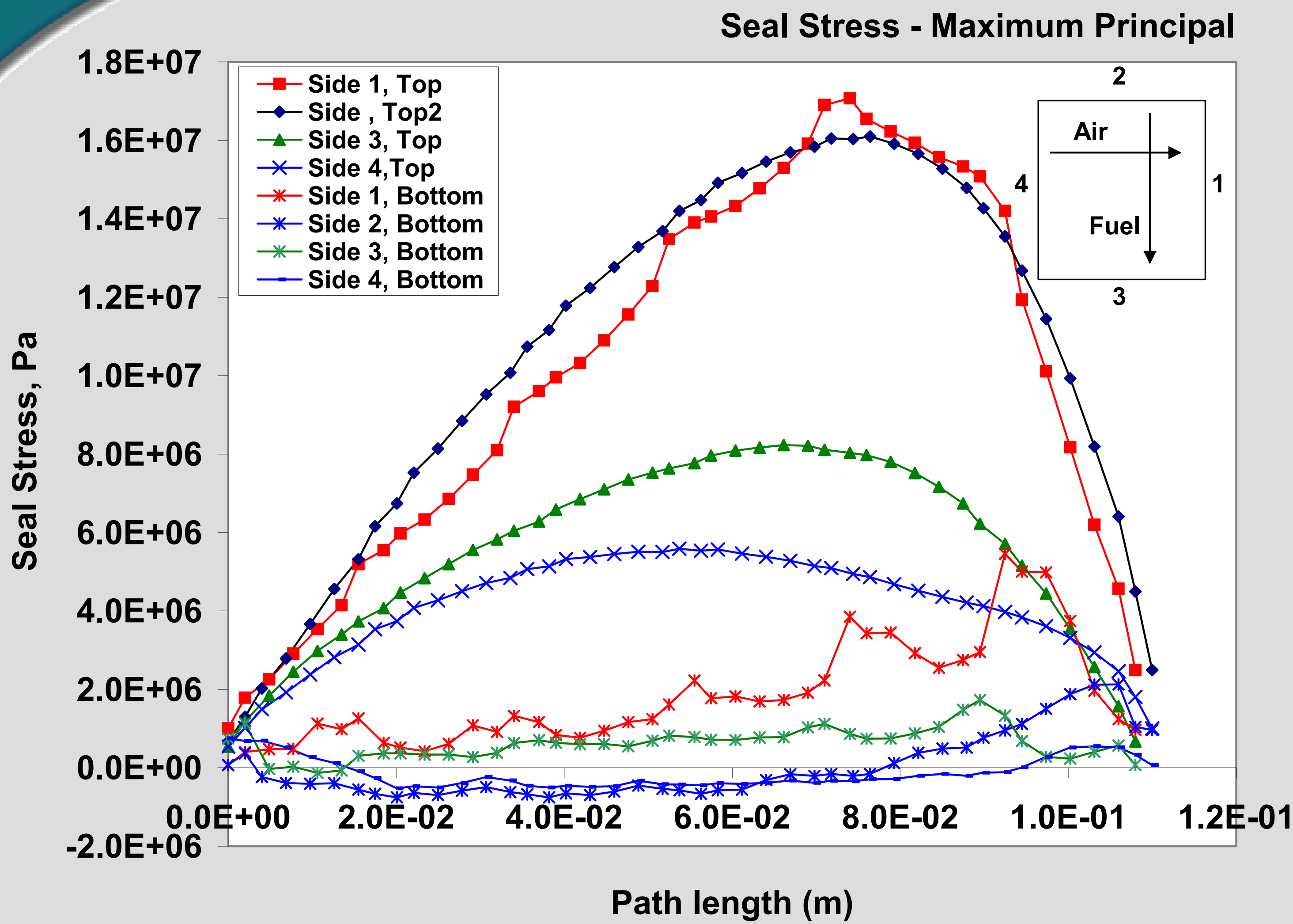
SXY/S12



SYZ/S23

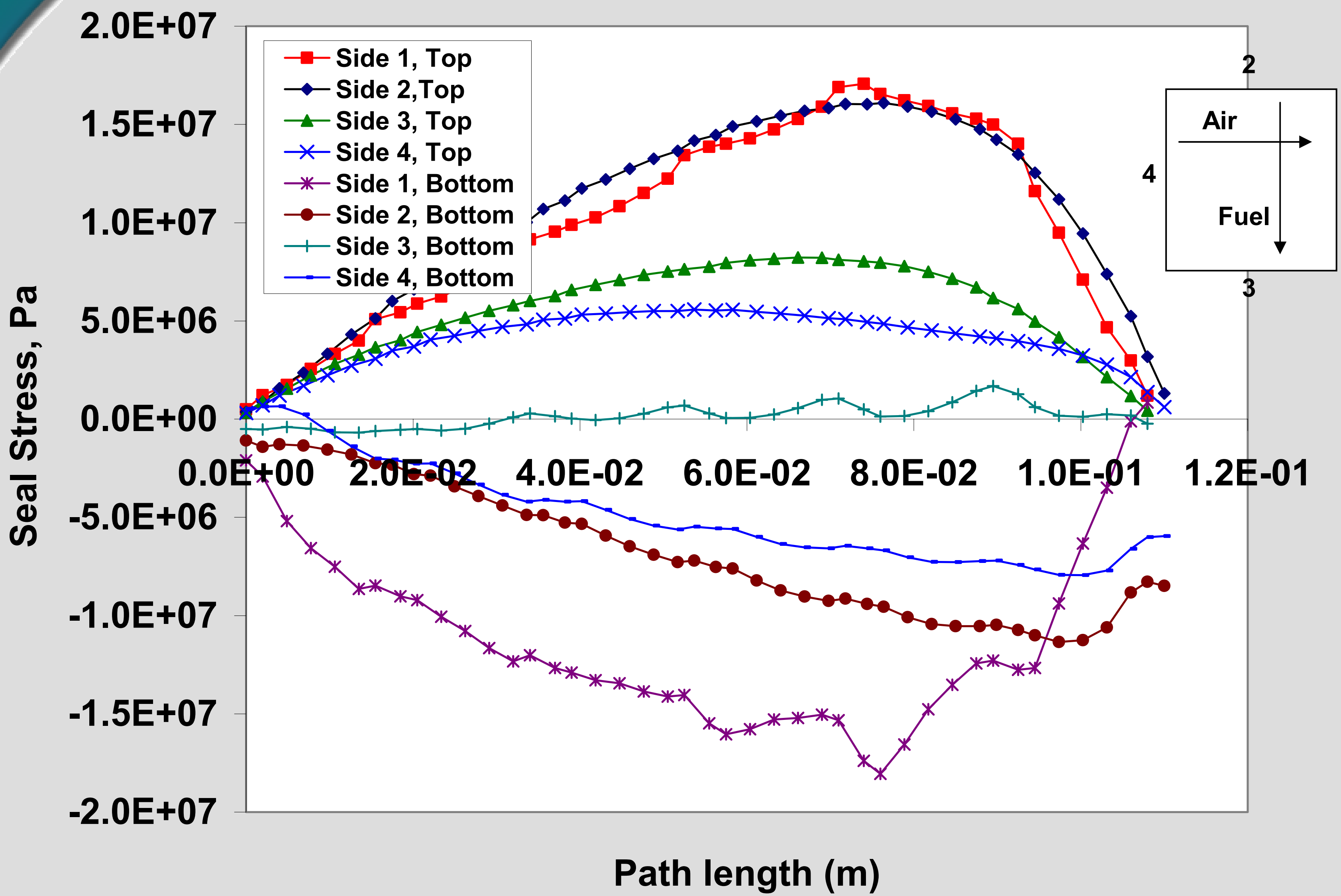


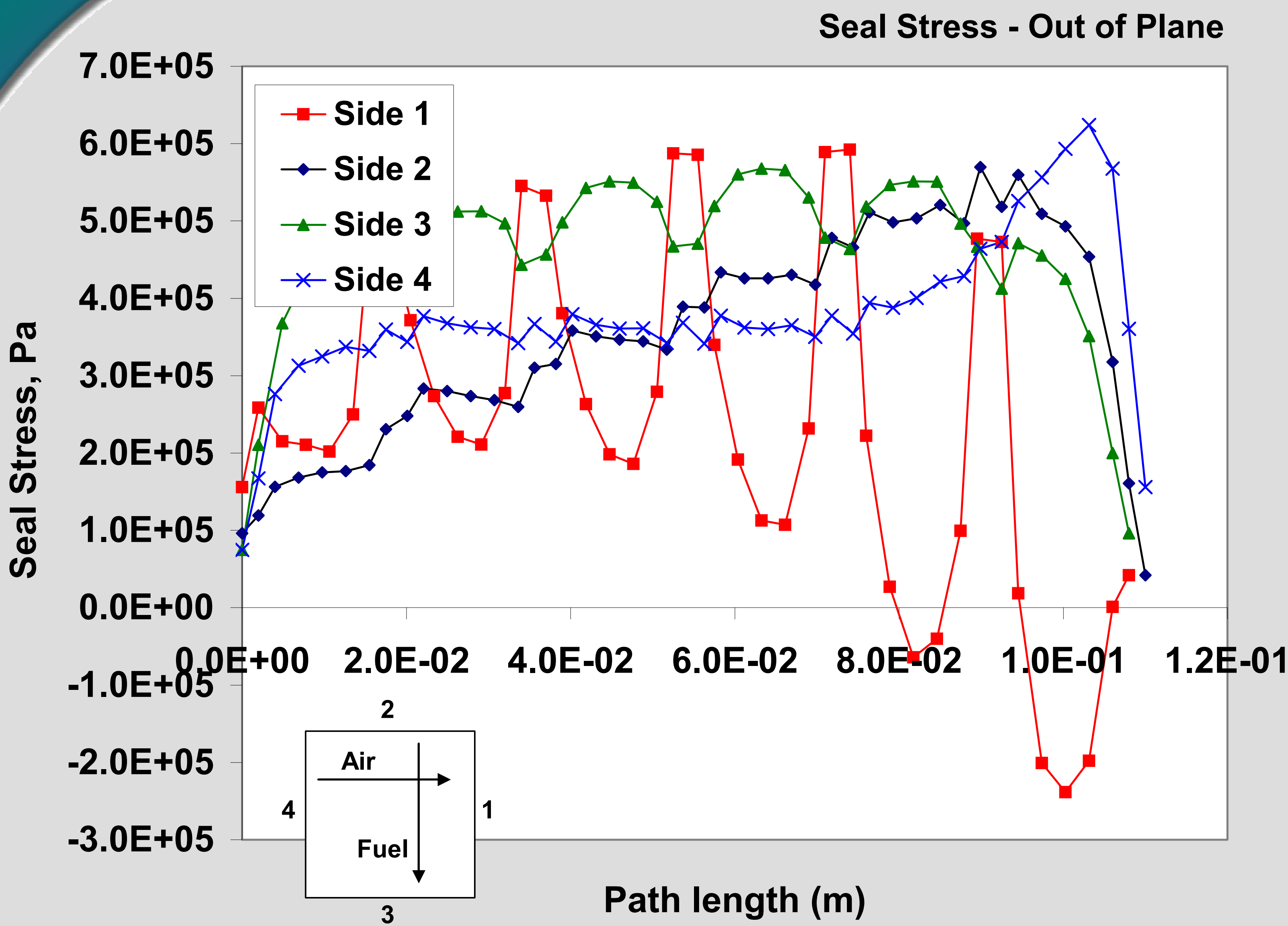
SXZ/S31



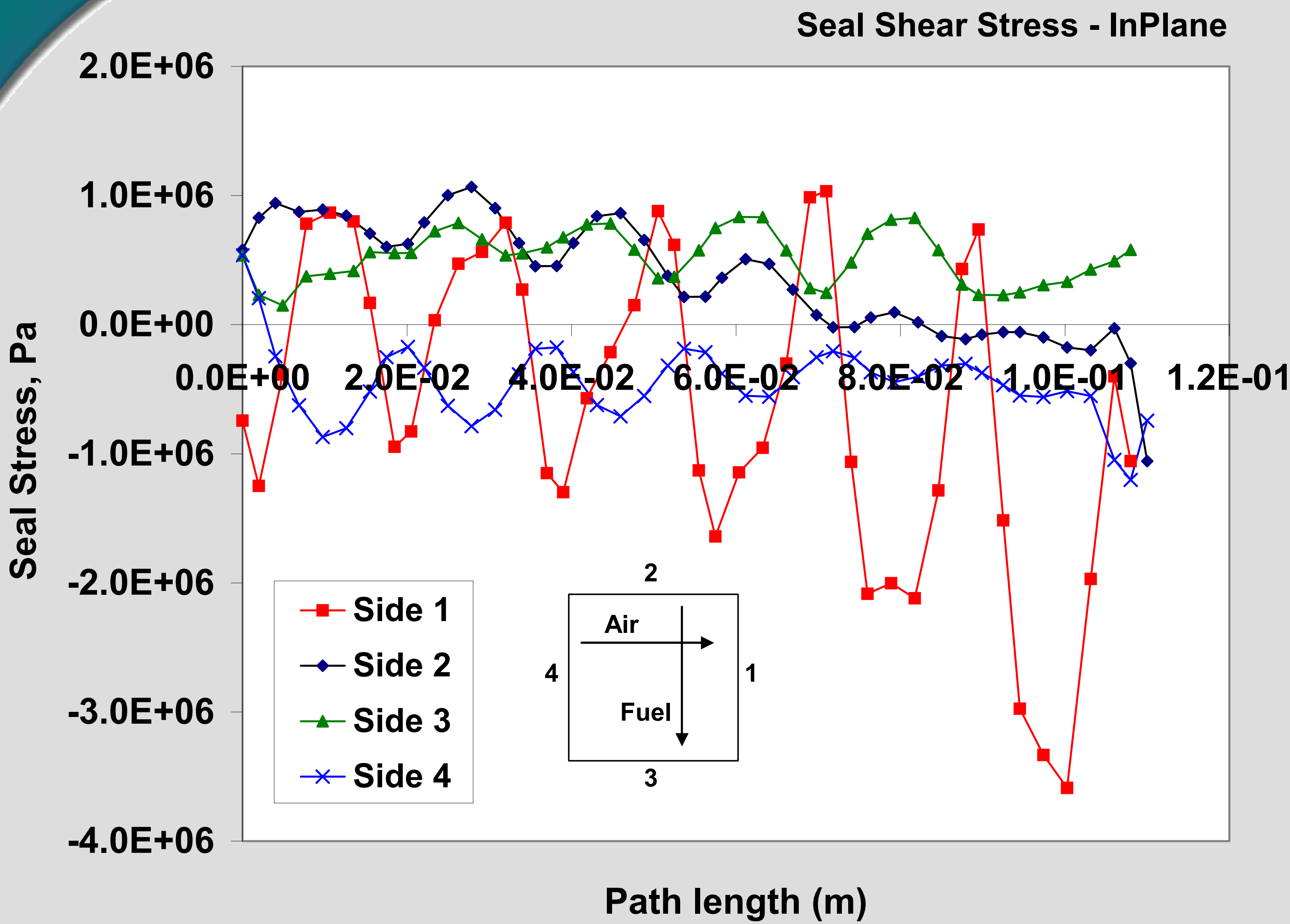
Max principal much larger on one side than other- bending dominated. 17 Mpa max. Caveat- This is only a 1 cell model with simple support, much more flexible than stuck to a manifold.

Seal Stress - Parallel to PEN Edge



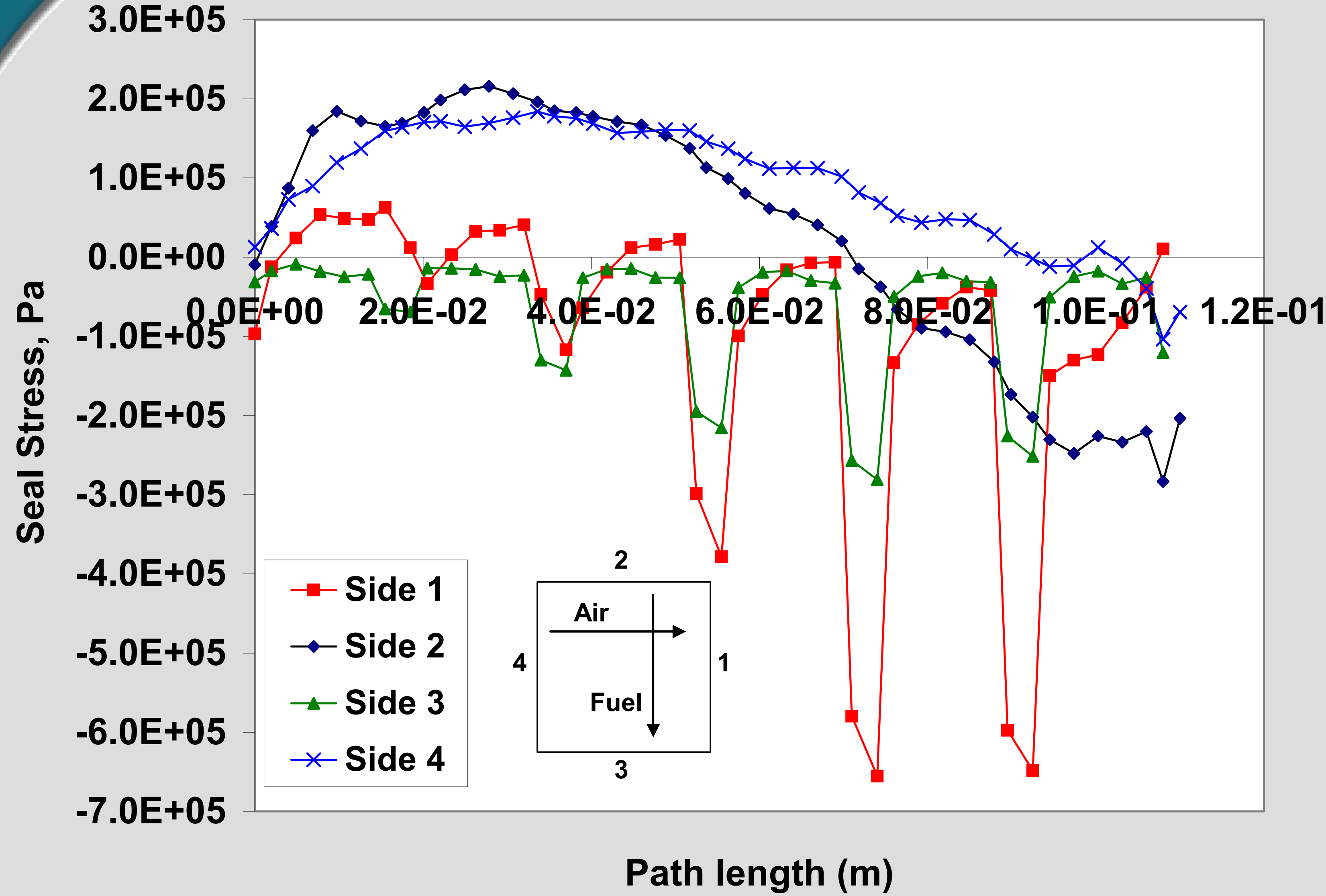


Seal Stress - Out of Plane
Seal Stress, Pa
7.0E+05
6.0E+05
5.0E+05
4.0E+05
3.0E+05
2.0E+05
1.0E+05
0.0E+00
-1.0E+05
-2.0E+05
-3.0E+05
0.0E+00
2.0E-02
4.0E-02
6.0E-02
8.0E-02
1.0E-01
1.2E-01
Path length (m)
Side 1
Side 2
Side 3
Side 4
2
Air
4
1
Fuel
3

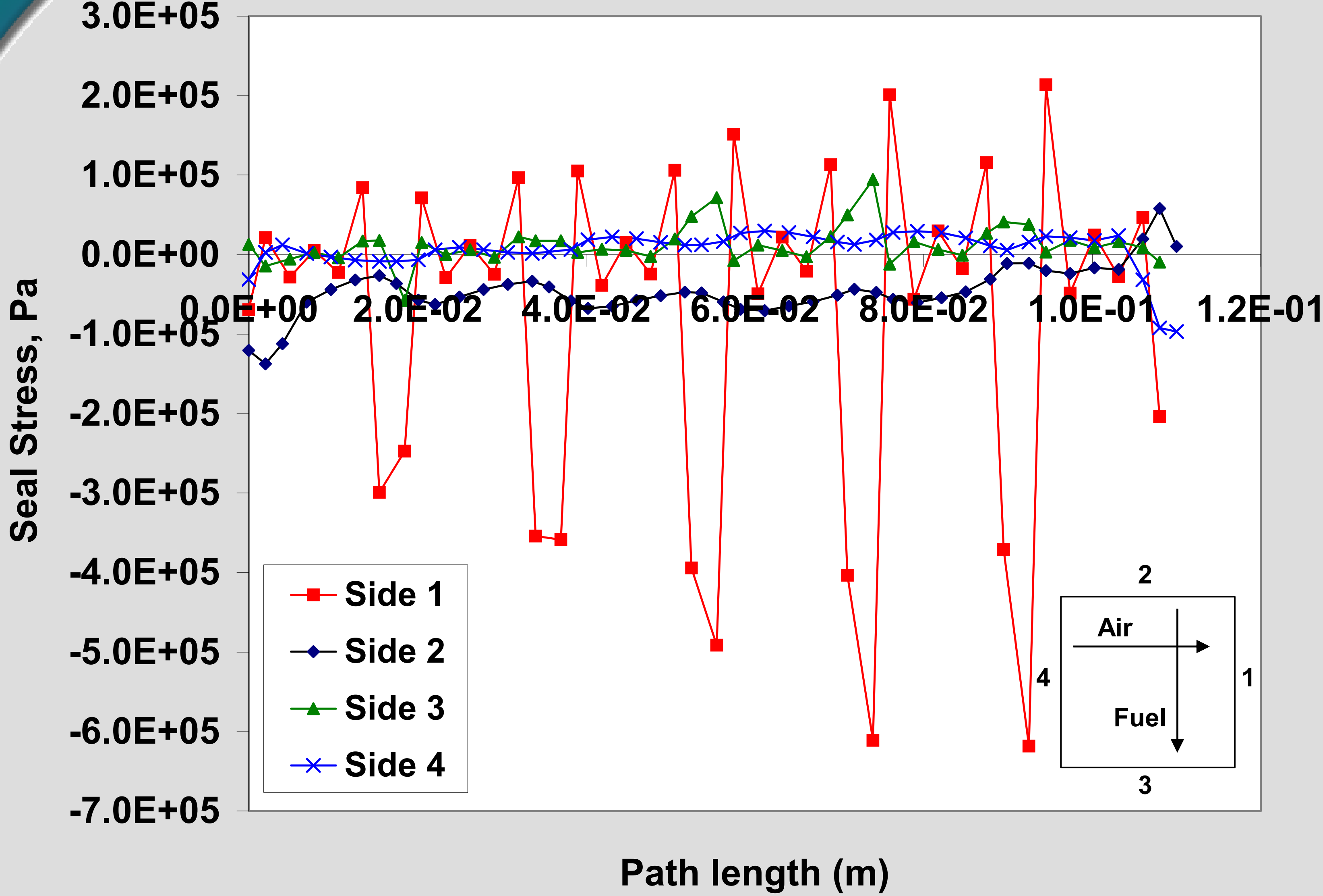


Seal Shear Stress - InPlane
2.0E+06
1.0E+06
0.0E+00
-1.0E+06
-2.0E+06
-3.0E+06
-4.0E+06
Seal Stress, Pa
0.0E+00
2.0E-02
4.0E-02
6.0E-02
8.0E-02
1.0E-01
1.2E-01
Path length (m)
Side 1
Side 2
Side 3
Side 4
2
Air
4
1
Fuel
3

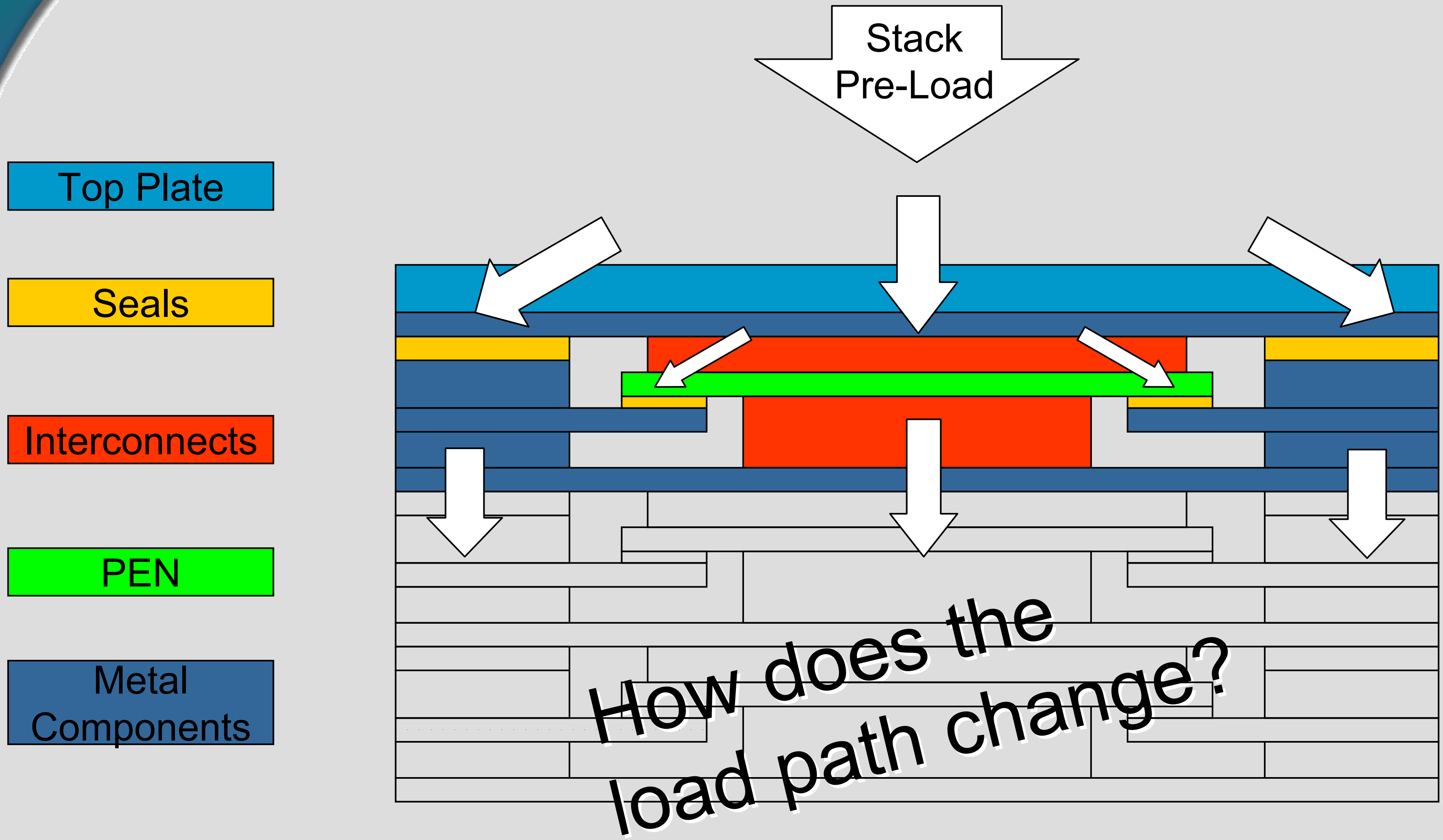
Seal Shear Stress - Tangent to PEN Edge



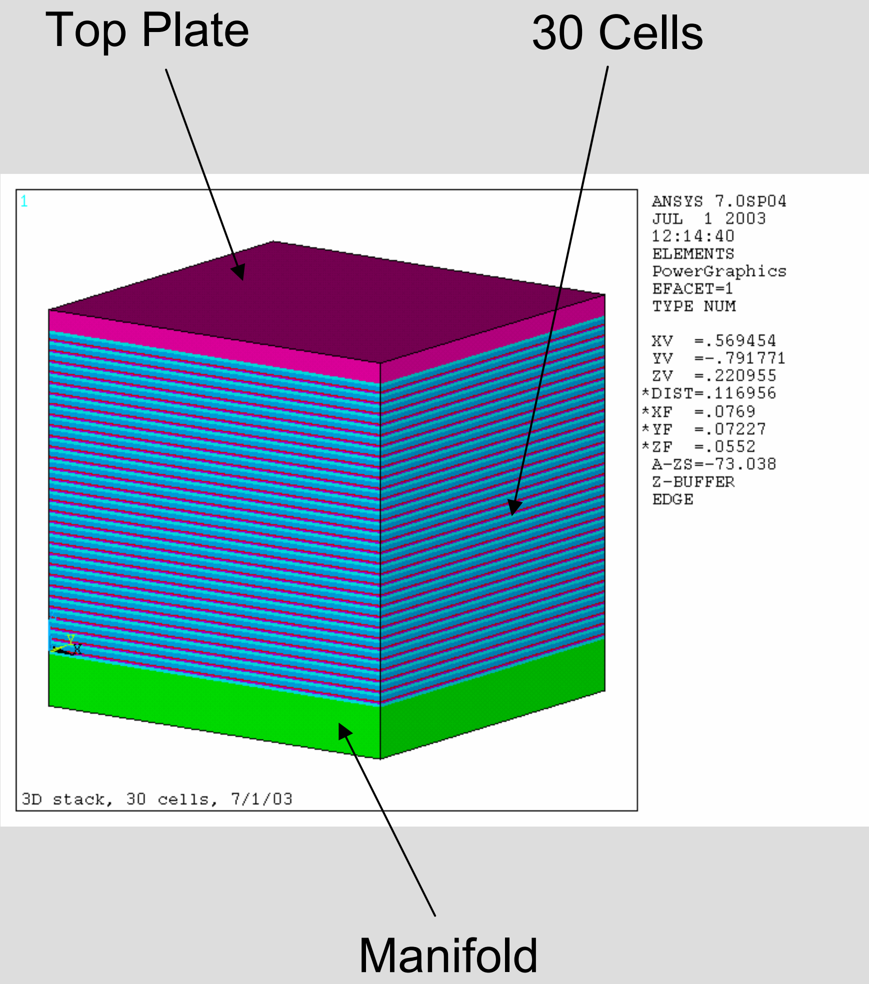
Seal Shear Stress - Normal to PEN Edge

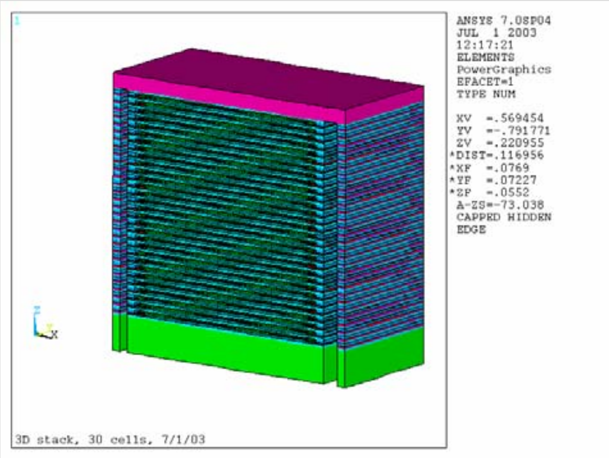


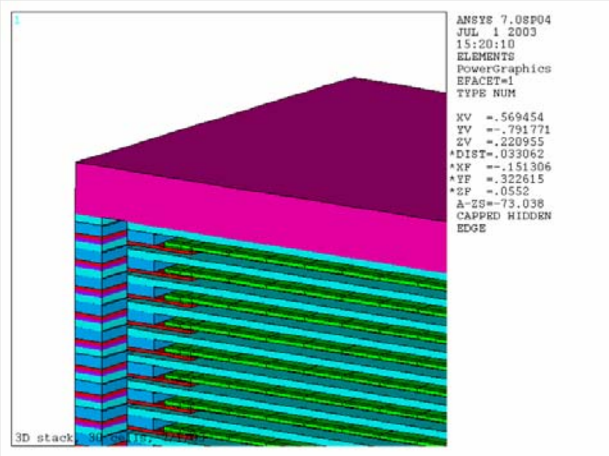
Load Paths for Multiple Planar Cell Stack



Load Paths for Multiple Planar Cell Stack







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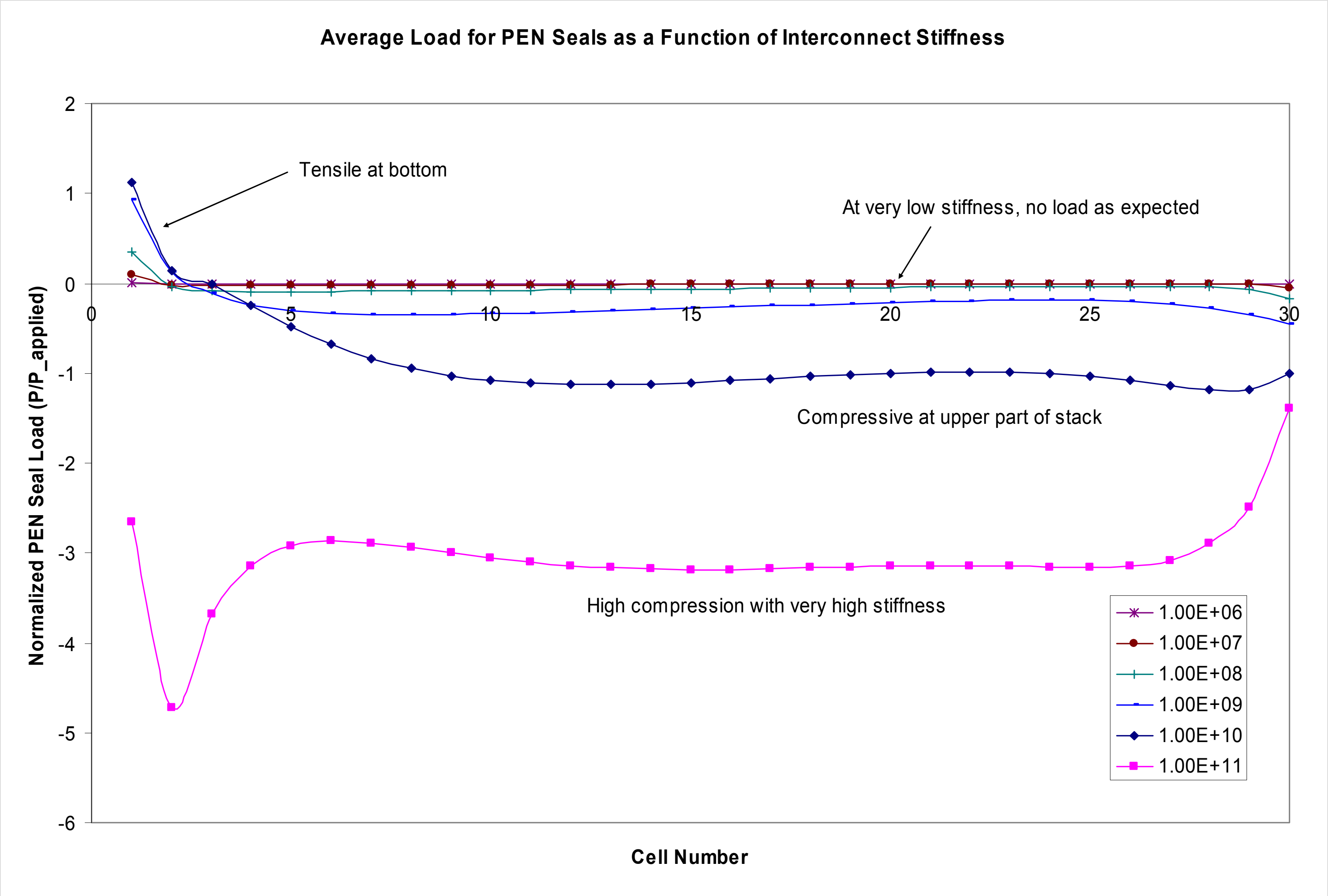
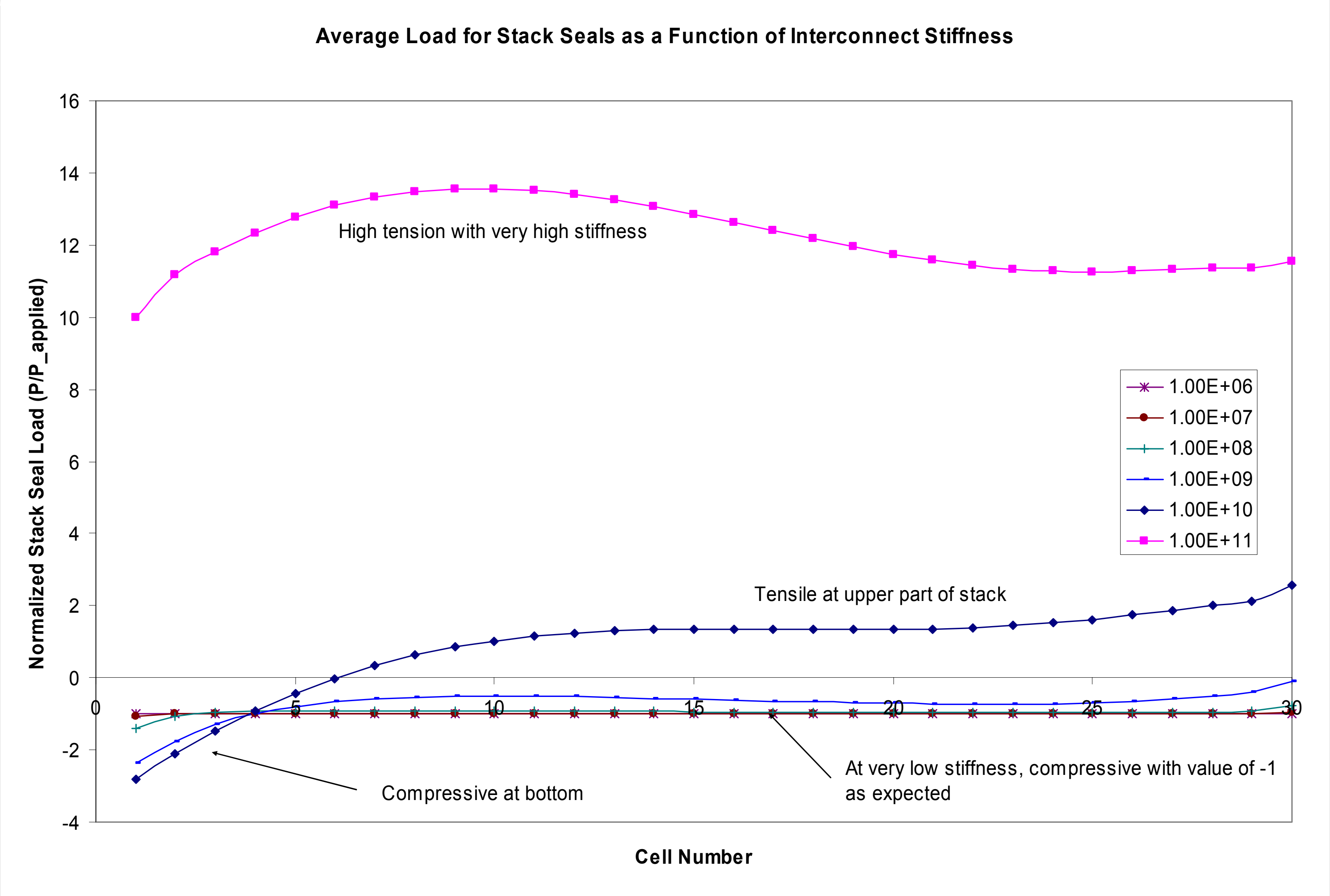
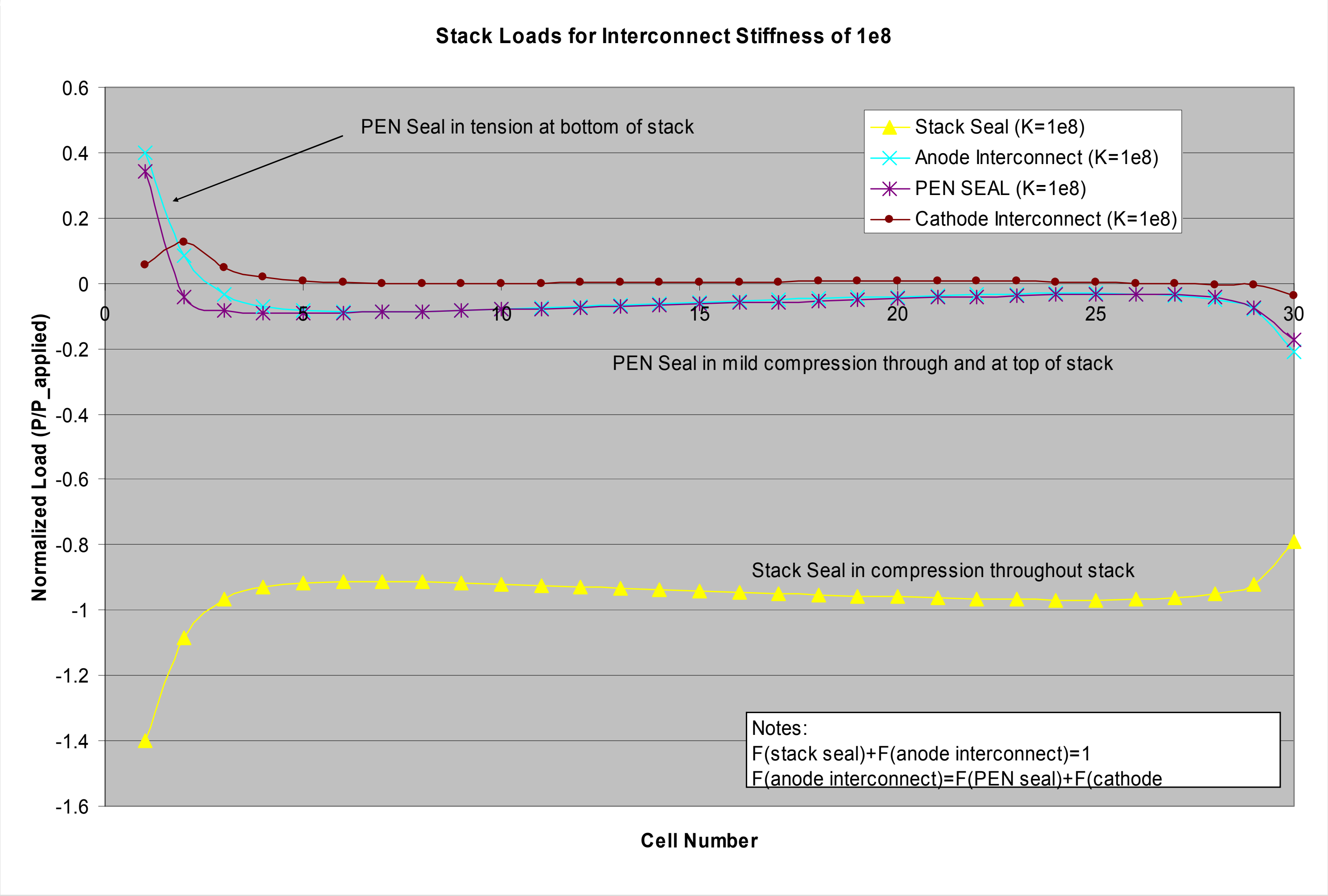


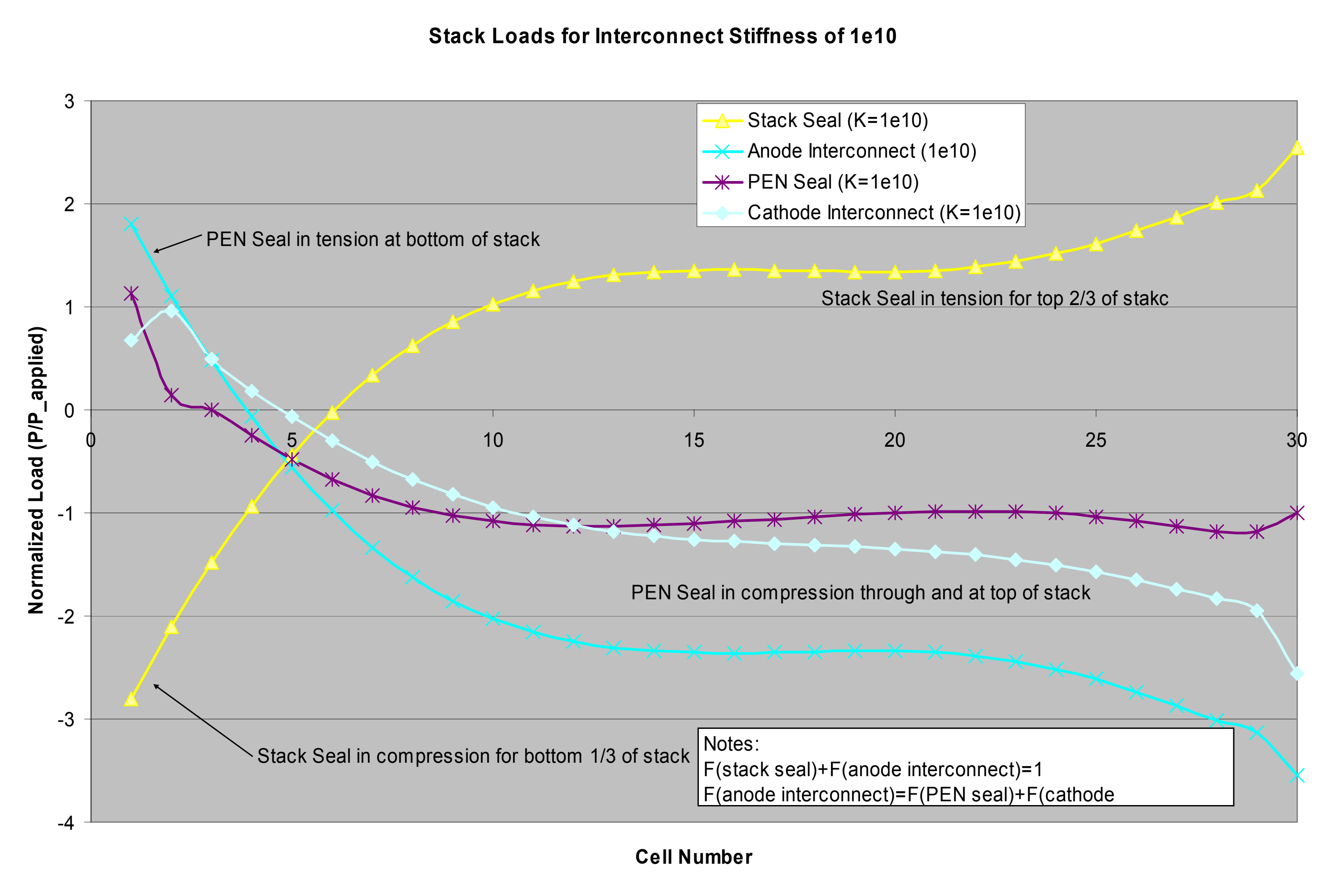
Load Paths for Multiple Planar Cell Stack



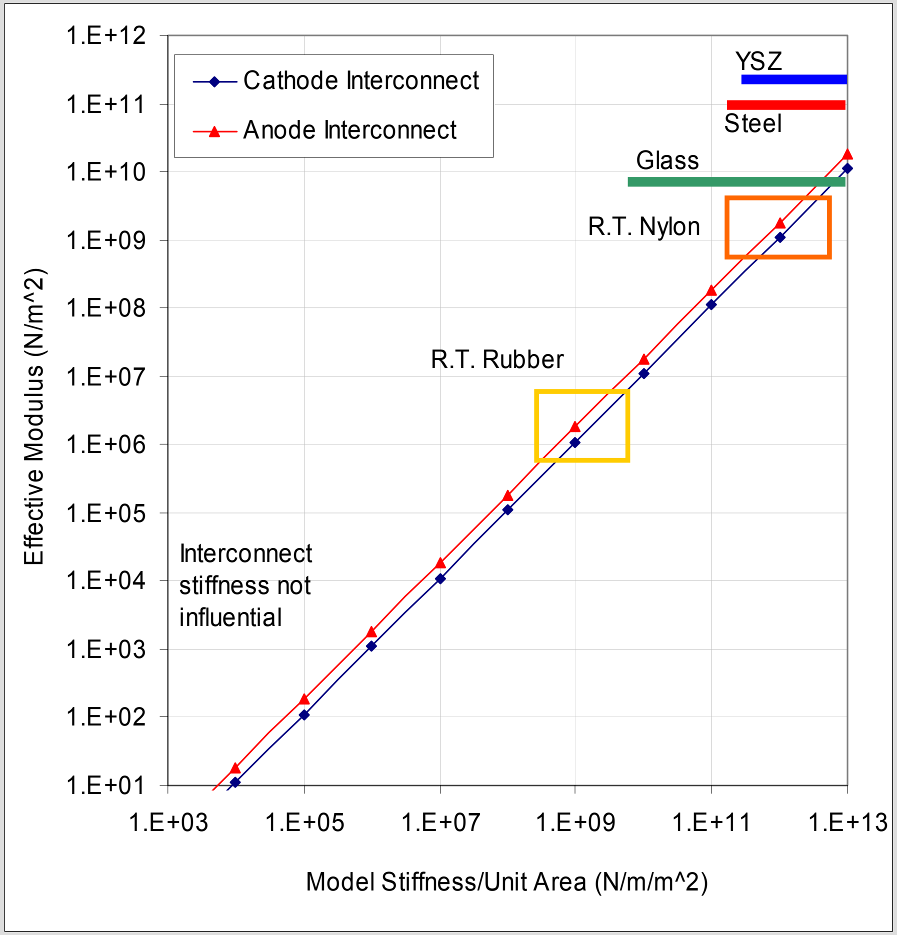
Load Paths for Multiple Planar Cell Stack



Load Paths for Multiple Planar Cell Stack



Load Paths for Multiple Planar Cell Stack



This chart tries to relate the "stiffness" used in the model for the cathode and anode mesh to a modulus. This will help give a feel for what these stiffnesses actually mean.

The stiffness K is actually stiffness per unit area, so K*t where t is the spring length (thickness) would give the effective modulus for the interconnect material if it was a solid layer.