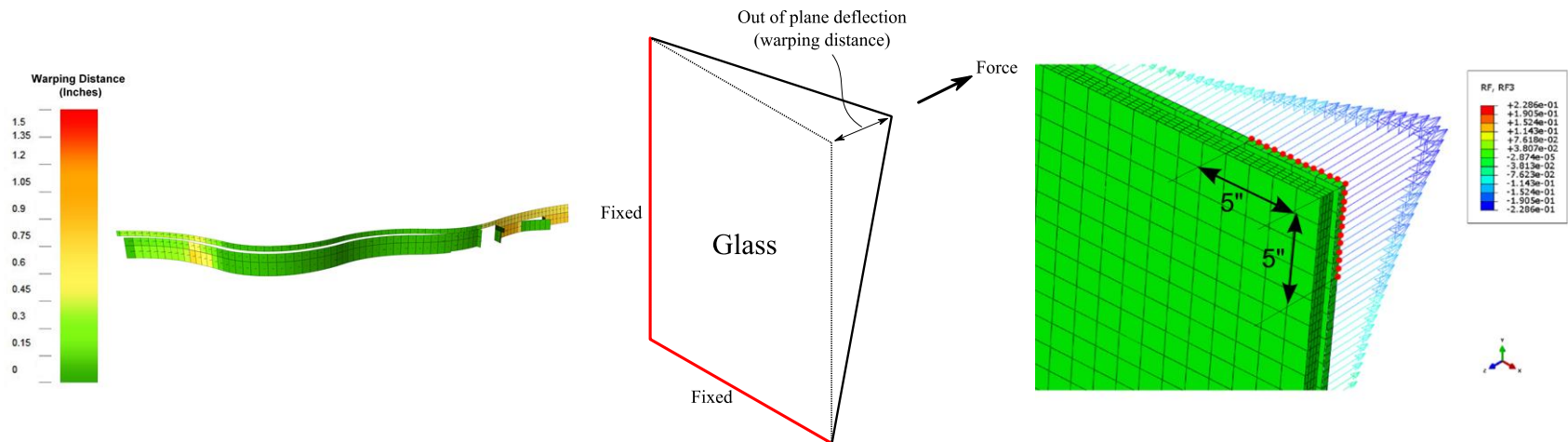


FEA of Structural Silicone of Warped Insulated Glass Units



Kedar A. Malusare

Stutzki Engineering

May, 2017

Stutzki Engineering – What we Do ?



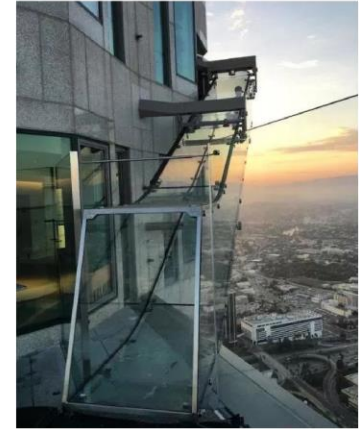
John Hancock Tower,
Chicago



Tilt (94th Floor)



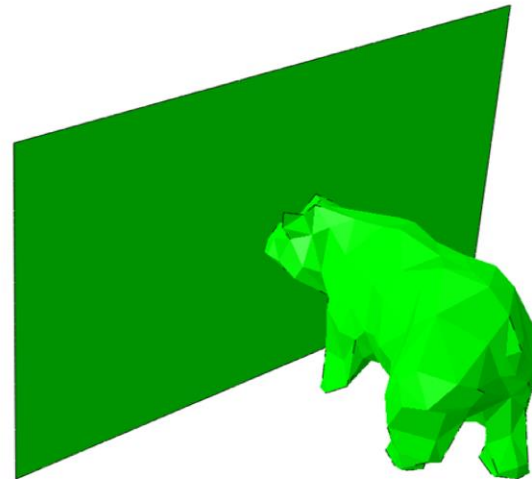
US Bank Building,
Los Angeles



Glass Slide (70th Floor)



Brooklyn Academy of Music,
New York.



Wildwood Zoo, Marshfield,
WI.

Future of skyscrapers



Pittsburg Skyline



Chicago Skyline



Turning Torso,
Malmö, Sweden

Revolution Tower,
Panama City

Kuwait Trade Center,
Kuwait

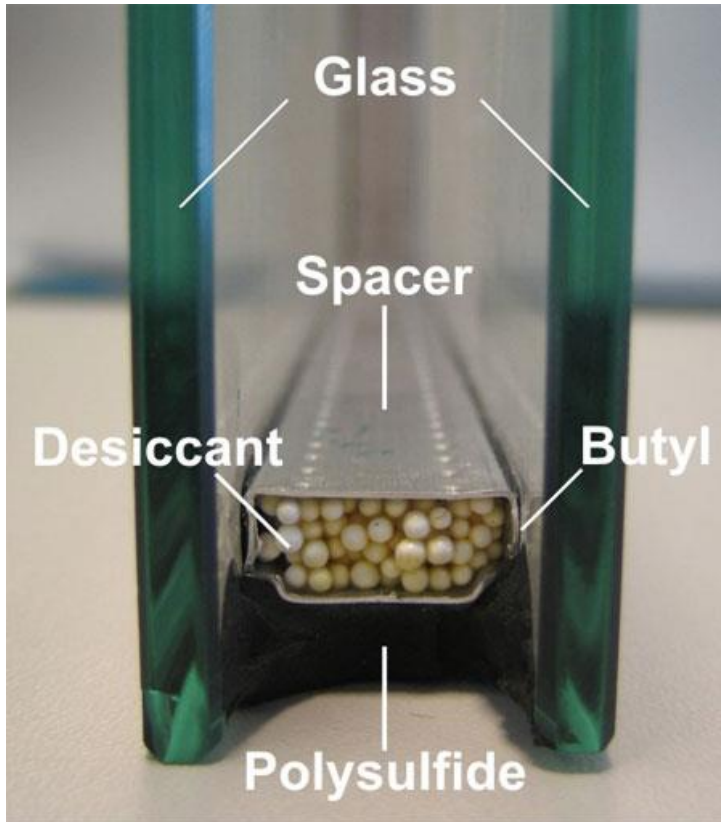
Absolute World Towers,
Mississauga, Canada



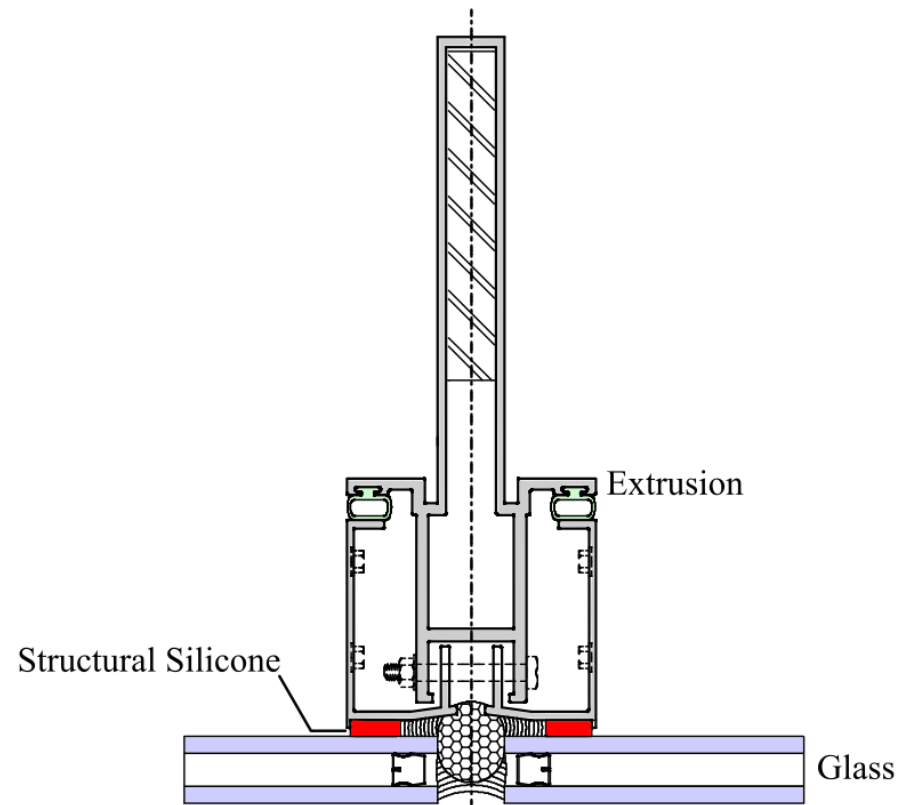
Evolution Tower,
Moscow

Insulated Glass Units

What is an insulated glass unit ?



Section on an IGU



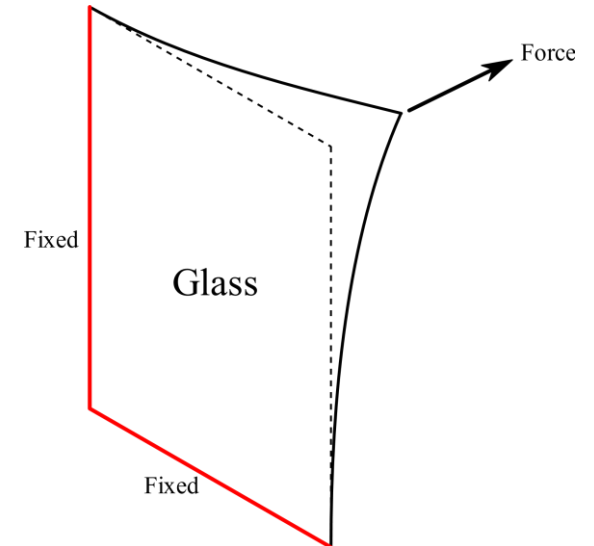
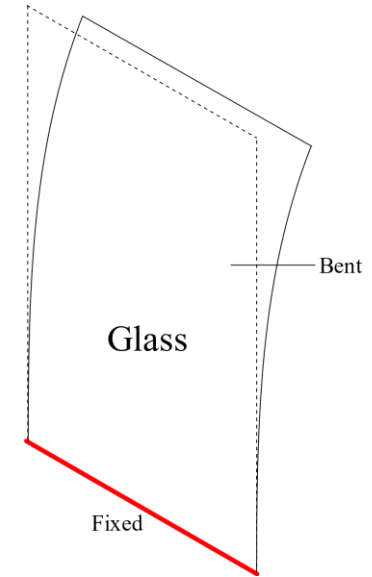
Connection Detail of an IGU

Cold Bent Glass

What is cold bent glass ?

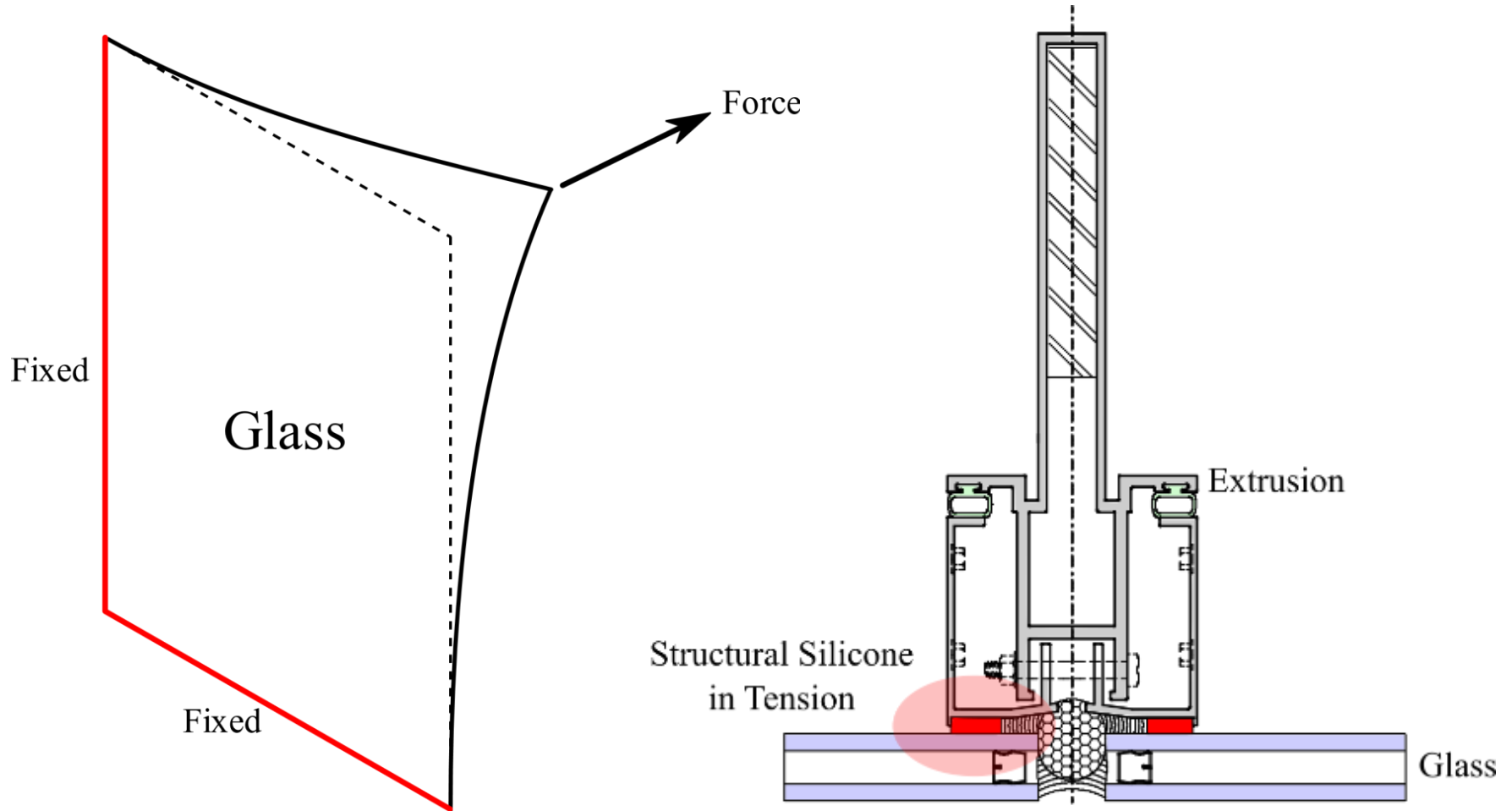


Evolution Tower



Consequences of Cold Bending of Glass

Cold bending of glass puts the structural silicone in a state of stress



Purpose of Talk

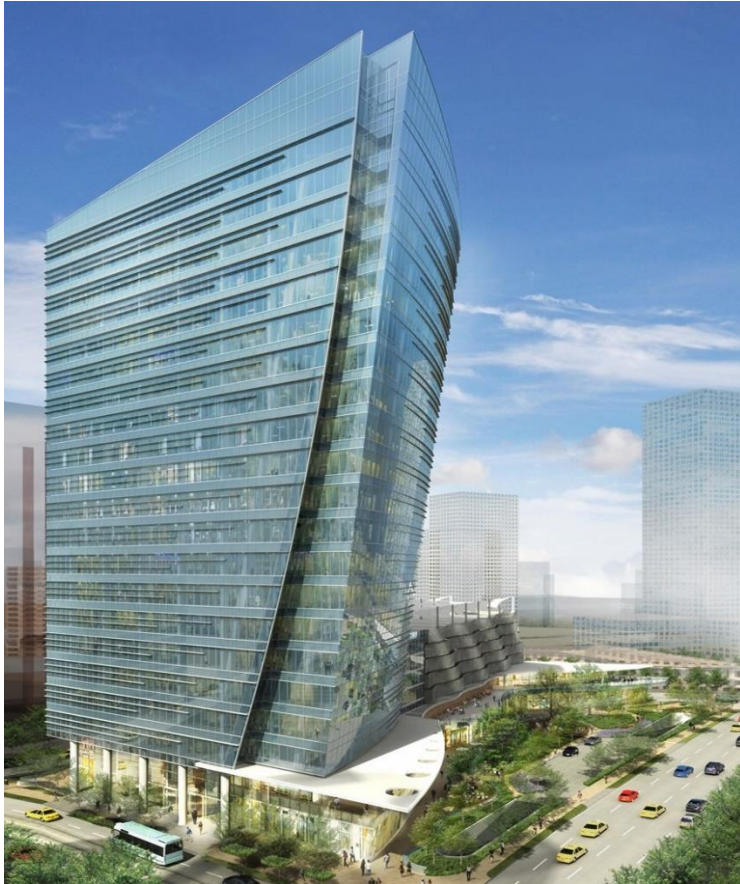
- Organic shaped skyscrapers is the future – *Incentive for cold bending*
- What is an Insulated Glass Unit
- What is meant by cold bending of glass
- What is Structural Silicone (Glass)
- What happens to the structural silicone in cold bending

Can the structural silicone hold the cold bent glass in shape ?

If the average stress is < 1.00 psi !

McKinney and Olive

Project in Dallas, TX

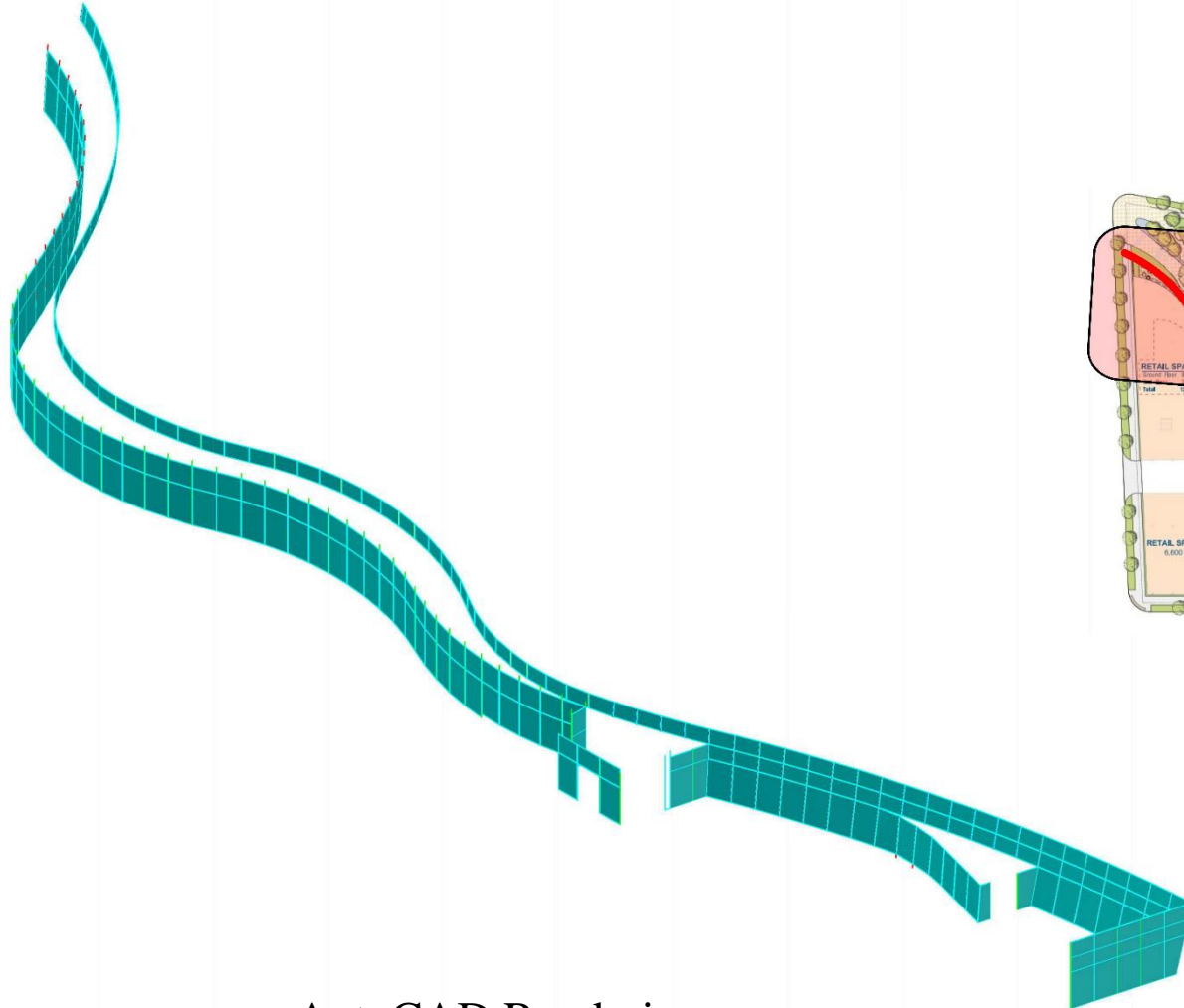


Building



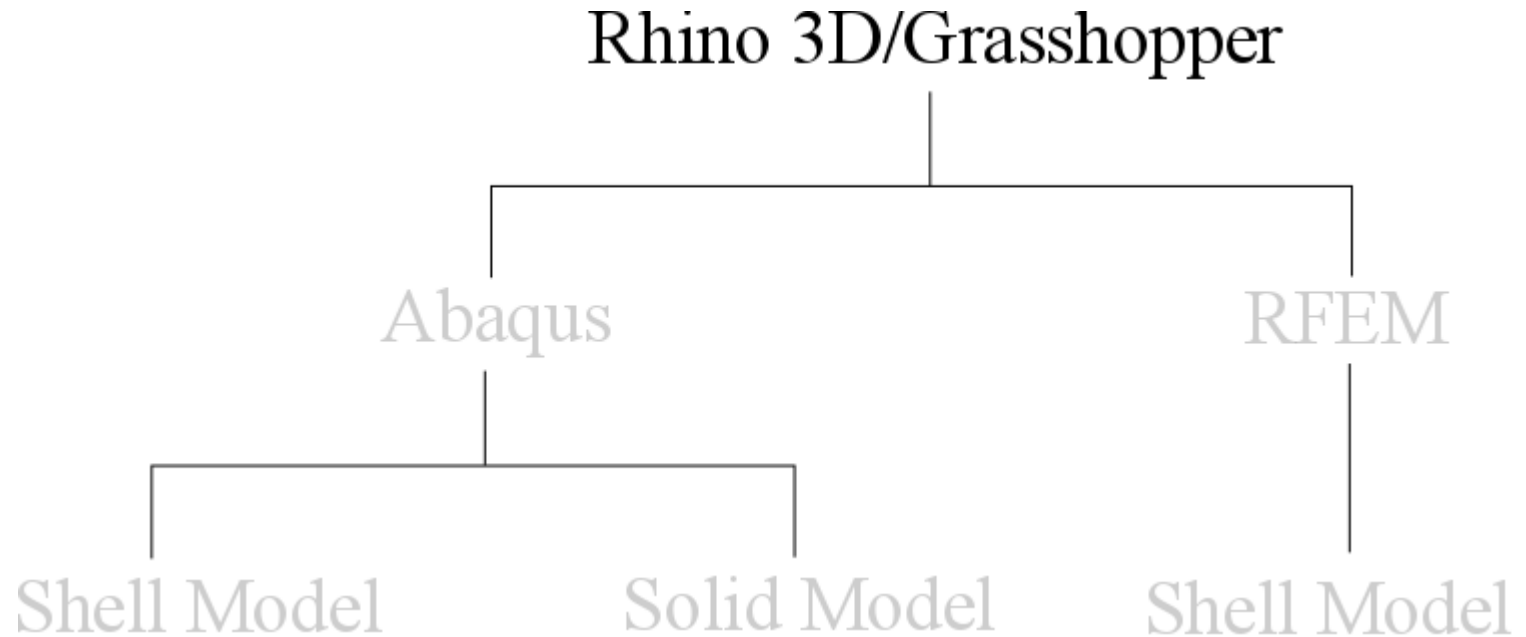
Glass Wall

Serpentine Glass Wall

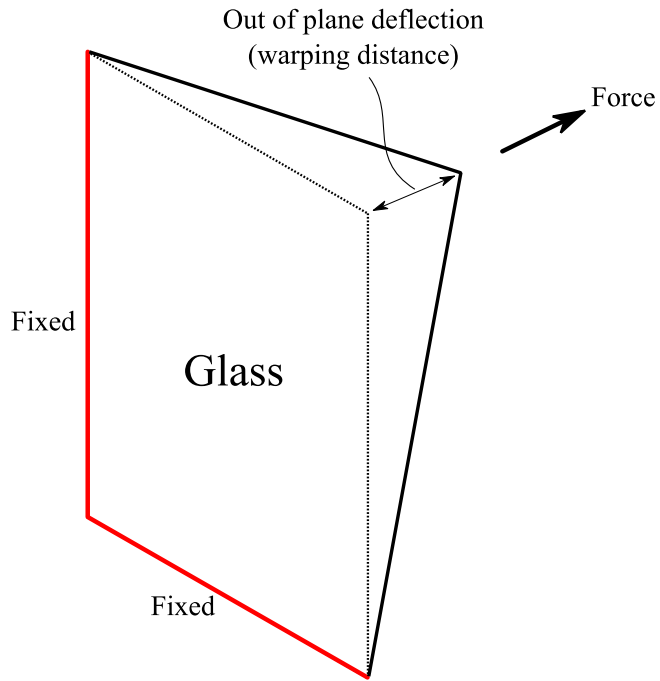


AutoCAD Rendering

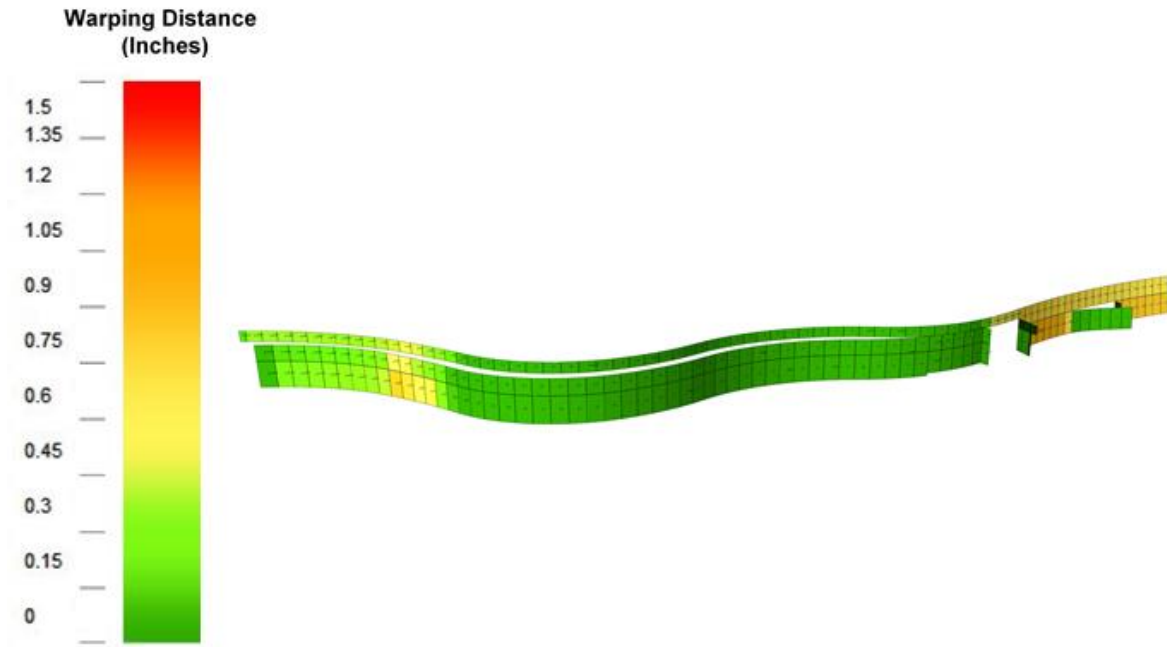
Rhino Modeling



Warping Distance in Rhino 3D/Grasshopper

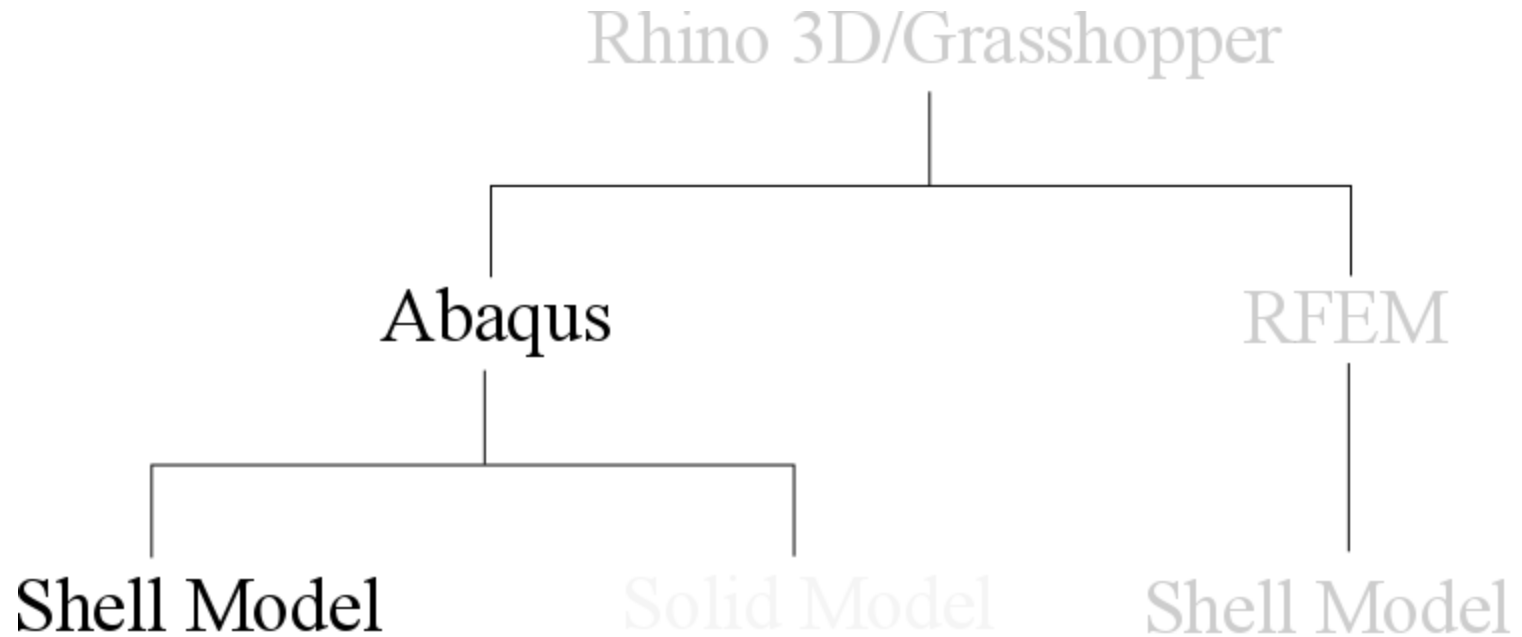


Concept

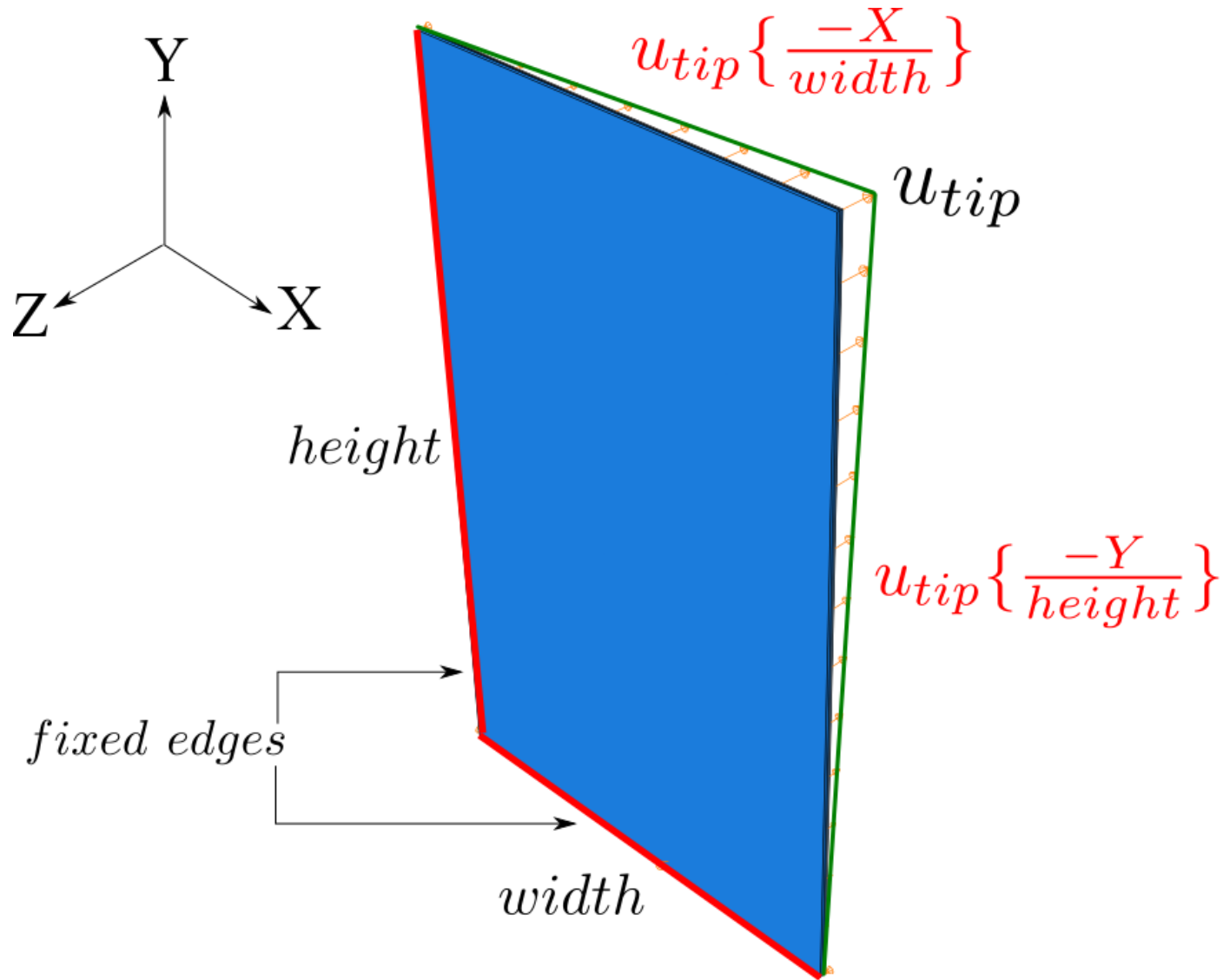


Results

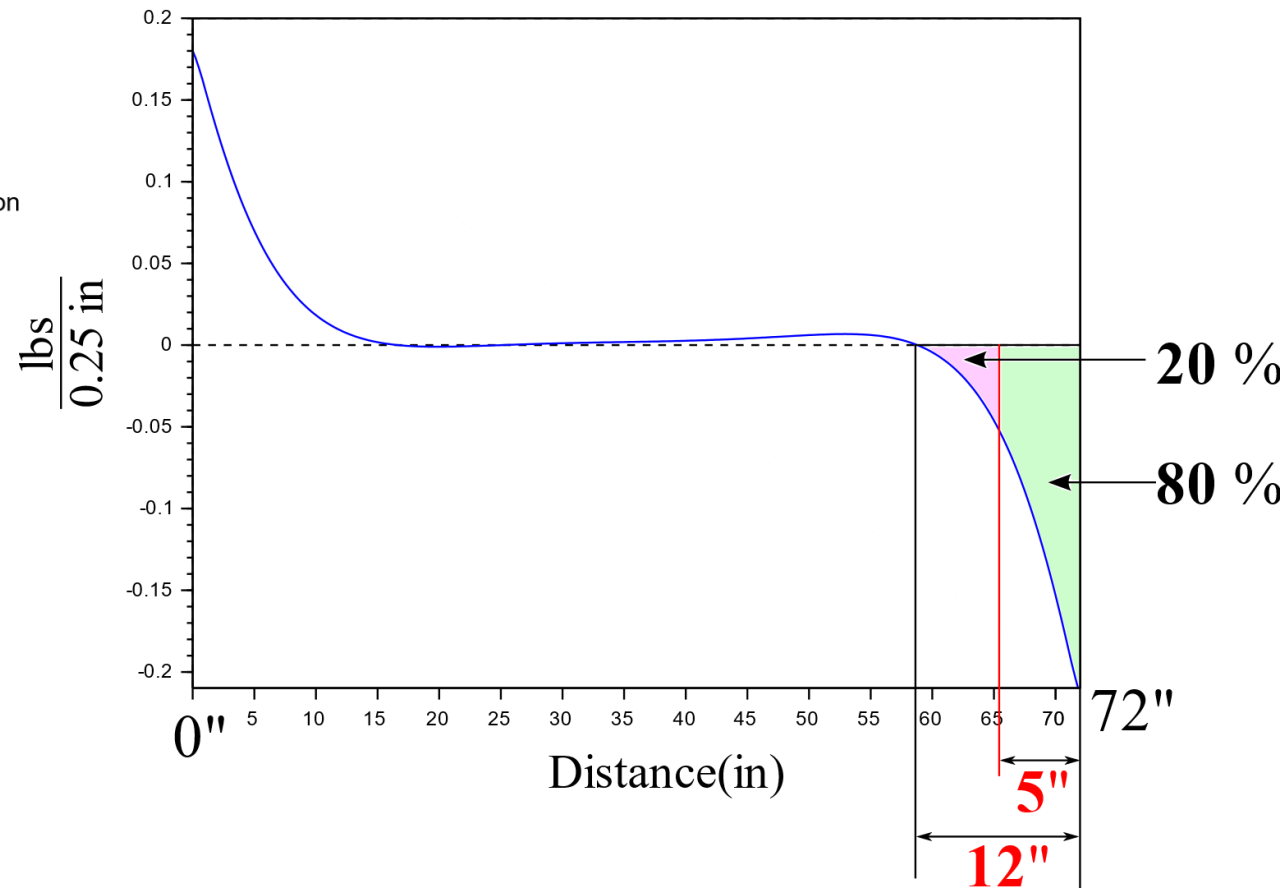
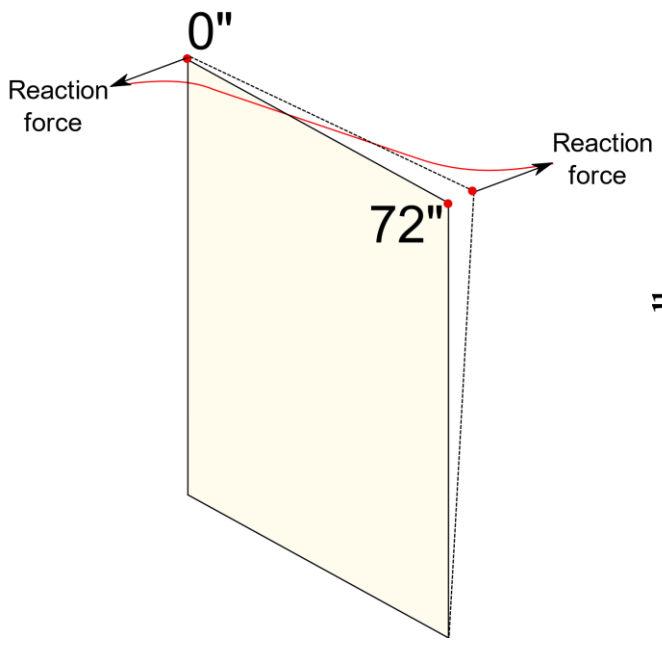
Abaqus Modeling - Shells



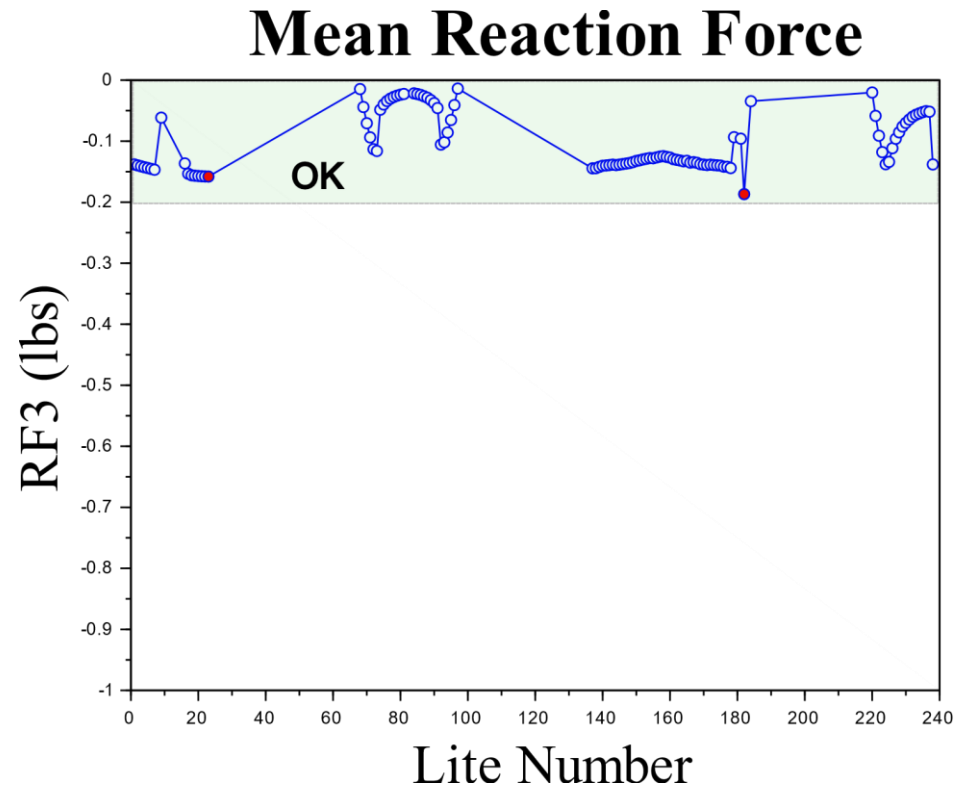
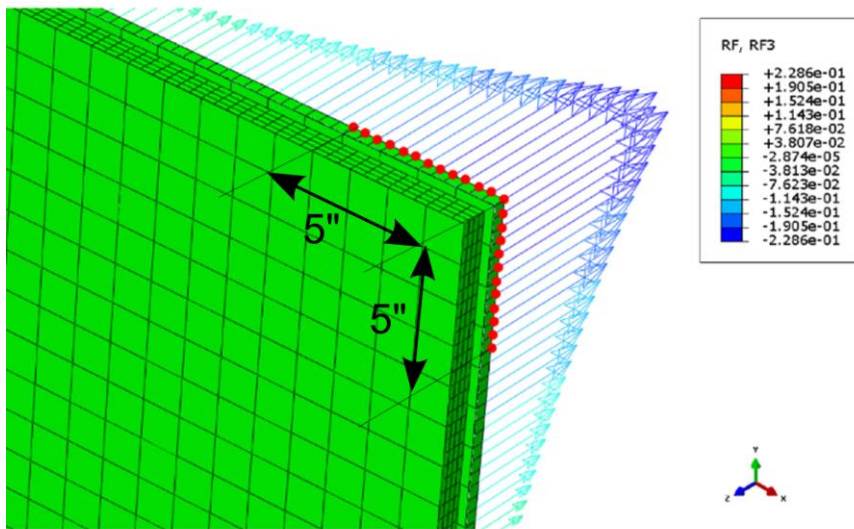
Abaqus Model



Variation of the reaction force on warped edge



Mean Reaction Force



Hand Calculations - Abaqus

$$\sigma = \frac{P}{A} = \frac{RF}{Area} = \frac{RF_{mean}}{\text{spacing between nodes} \times \text{width of silicone}}$$

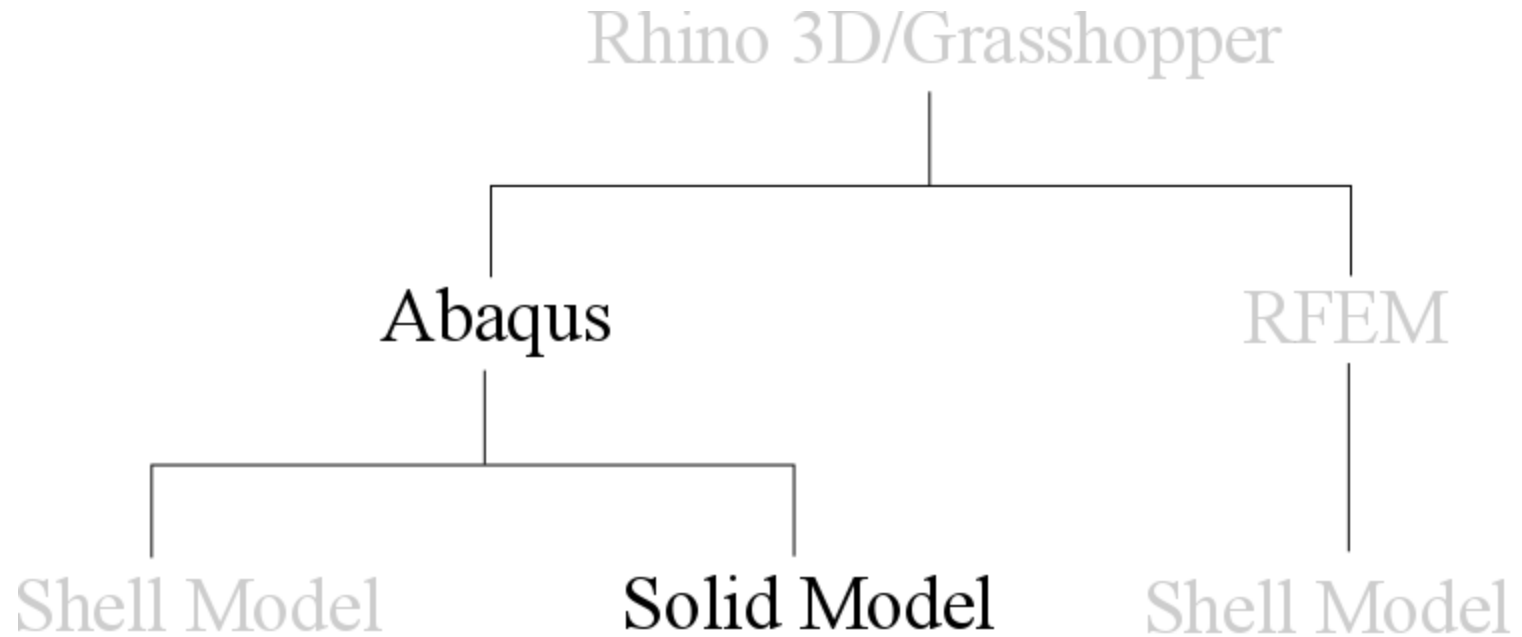
Spacing between nodes = 0.25"

Width of silicone = 1"

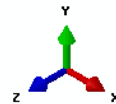
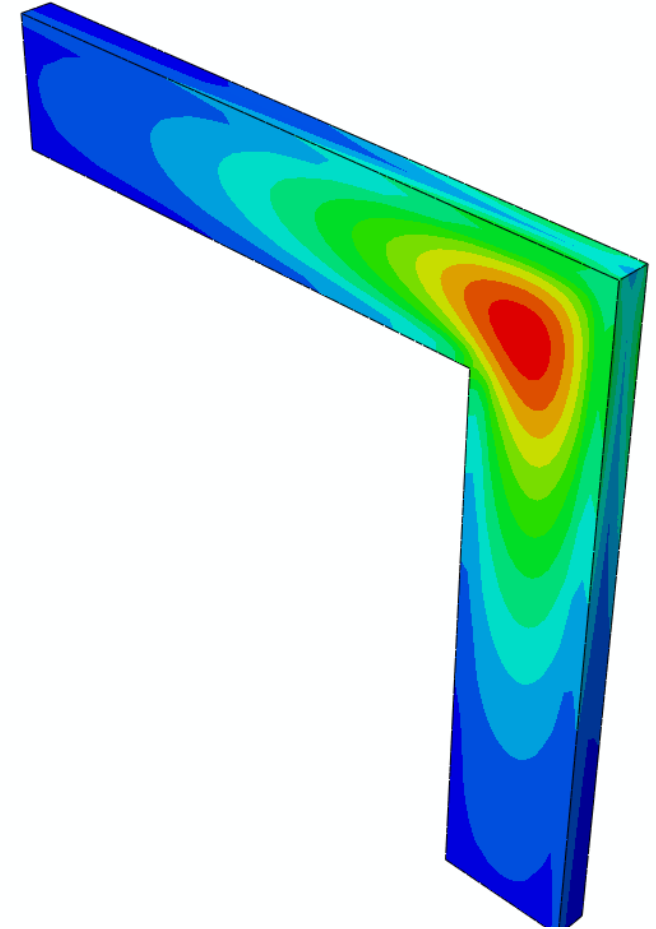
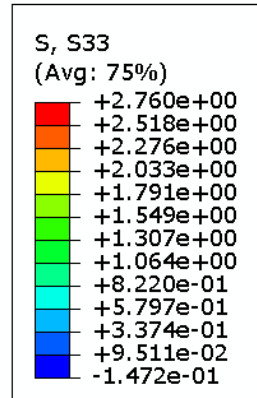
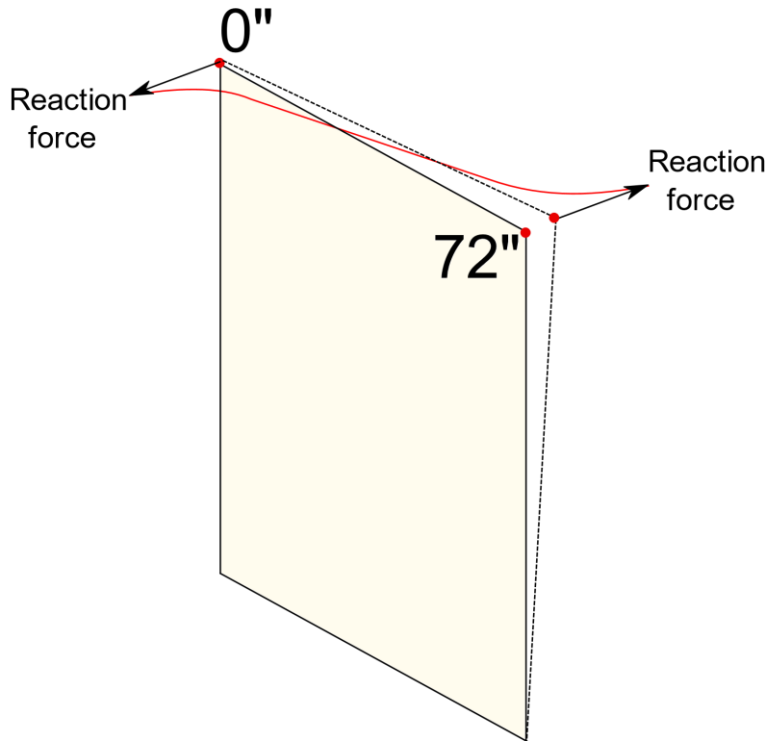
The mean reaction forces and the corresponding average stress for worst case lites is

Lite #	Mean Reaction force (lbs)	Stress (psi)	Allowable Stress (psi)
23	0.142	0.57	1.0
182	0.169	0.68	1.0

Abaqus Modeling - Solid



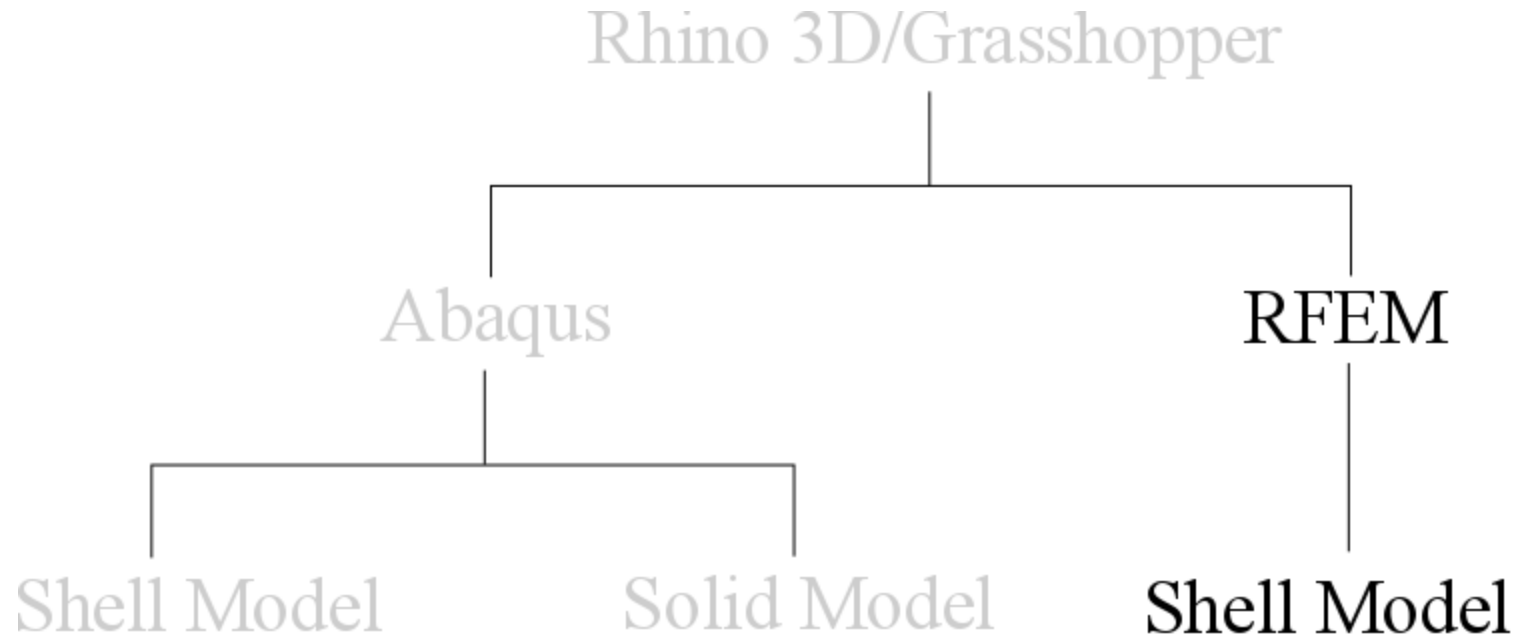
Solid Model



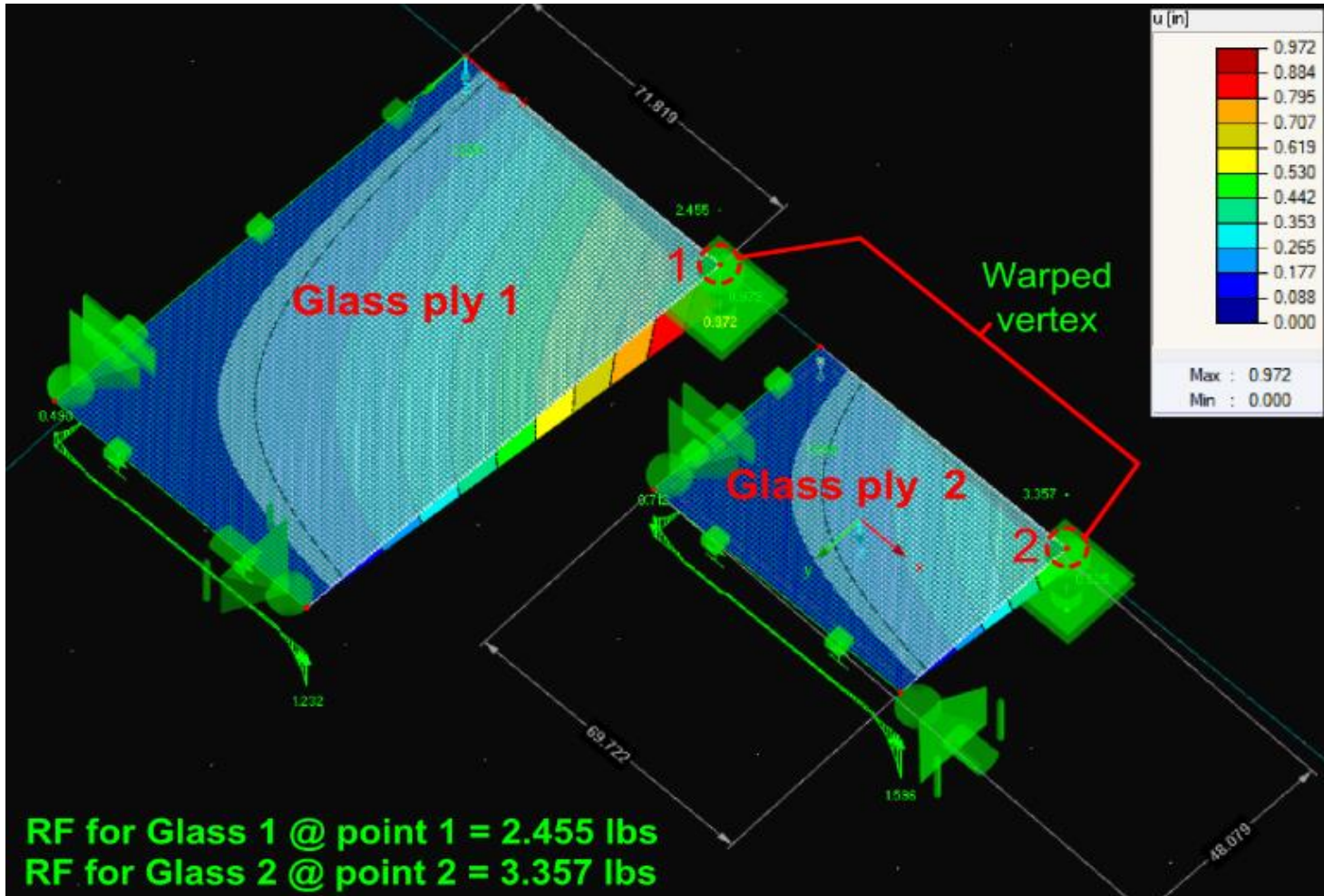
Lite #	Stress (psi)	Allowable Stress (psi)
23	0.61	1.0
182	0.76	1.0

$$\langle \sigma \rangle = \frac{1}{V} \int_V \sigma_{ij} dV$$

Modeling in RFEM

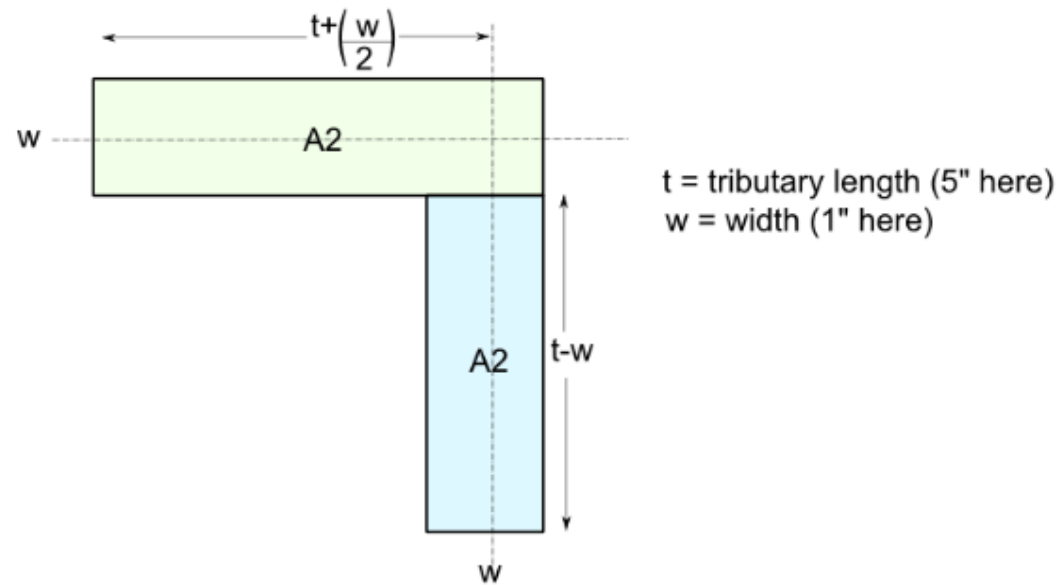


Modeling in RFEM



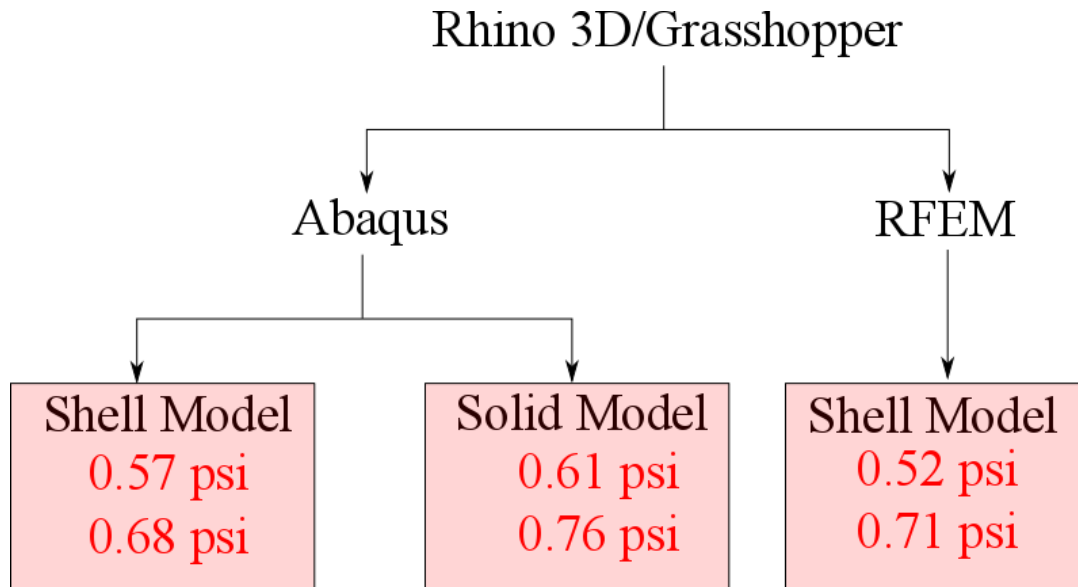
Hand Calculations - RFEM

$$\sigma = \frac{P}{A} = \frac{RF}{Area} = \frac{Total_RF}{A_1 + A_2}$$



Lite #	RF one ply (lbs)	Total RF (lbs)	Stress (psi)	Allowable Stress (psi)
23	2.455	4.910	0.52	1.0
182	3.357	6.714	0.71	1.0

Comparison of Results



Lite Num	Stress (psi)			Allowable Stress (psi)
	Abaqus (shell)	RFEM	Abaqus (solid)	
23	0.57	0.52	0.61	1.0
182	0.68	0.71	0.76	1.0

The structural sealant is safe !

Conclusion

- Cold bending of glass
- Behavior of structural silicone in cold bending
- Use Abaqus (shell and solid) to compute average stress
- Use RFEM to compute average stress

Thank You.