

for

AIAA SciTech Forum,

Jan 8, 2019

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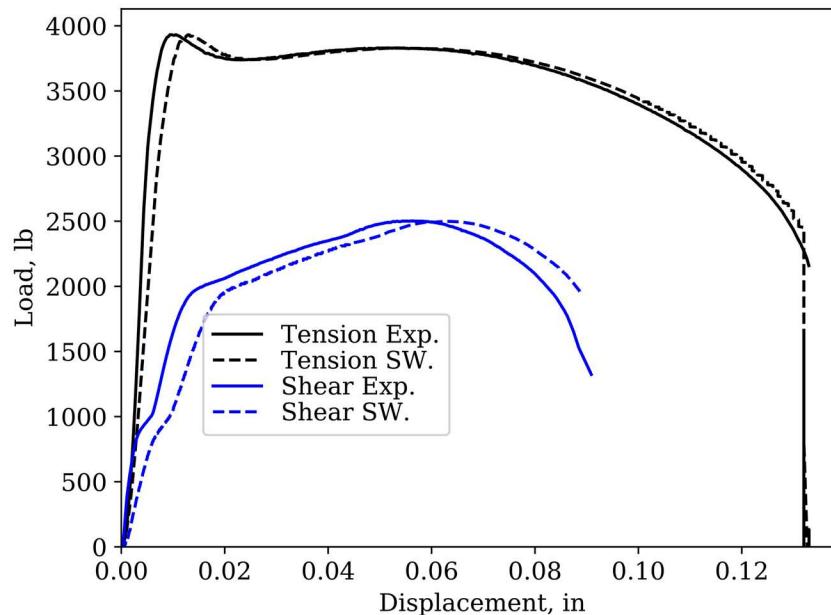
Reduced Order Models

- **Modeling small details like fasteners in large, complex structures is intractable due to the discrepancy of scales.**
- **Fastener failure can have a substantial impact on the failure of a structure.**
- **Fastener failure is complex, and can occur via many different mechanisms.**
- **Reduced order models are necessary for capturing structures' behavior in high detail.**



Current Approach

- Spot welds are used to tie two surfaces together.
- Spot weld properties are assigned from test data.
- Directly maps load displacement data to the two surfaces.
- Interpolates normal and tangential responses for mixed mode conditions.

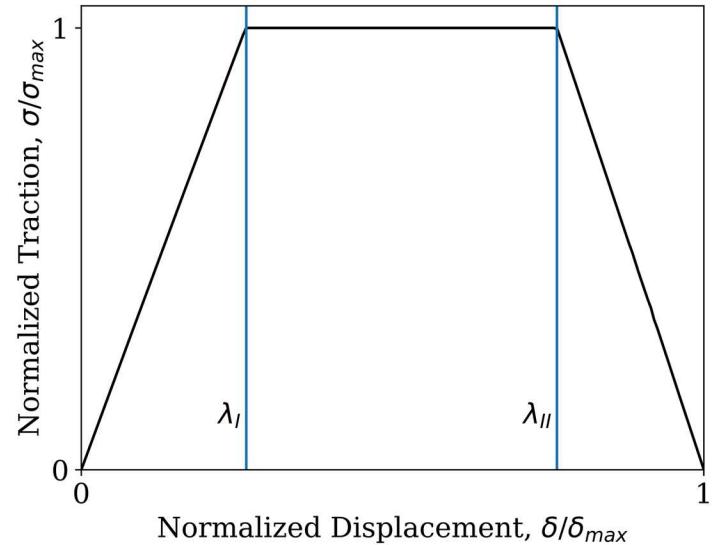




Cohesive Zone Approach

- Cohesive zones offer an alternative method for creating reduced order fastener models.
- Cohesive zones carry moment and can also be used for mixed mode failure.
- The cohesive zone model is a traction (σ) displacement (δ) model with an energy criterion (Γ).

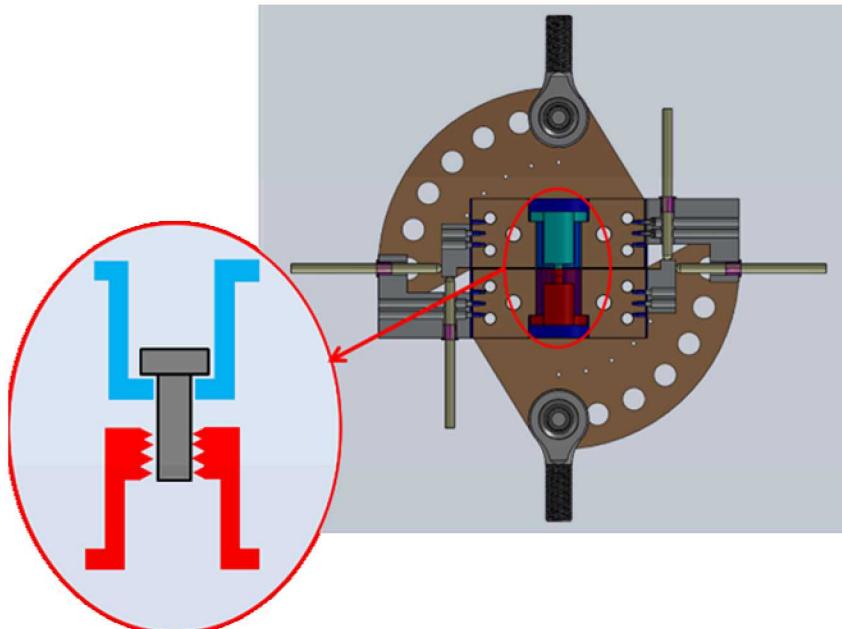
$$\Gamma = \int_0^{\delta_{max}} \sigma \, d\delta$$





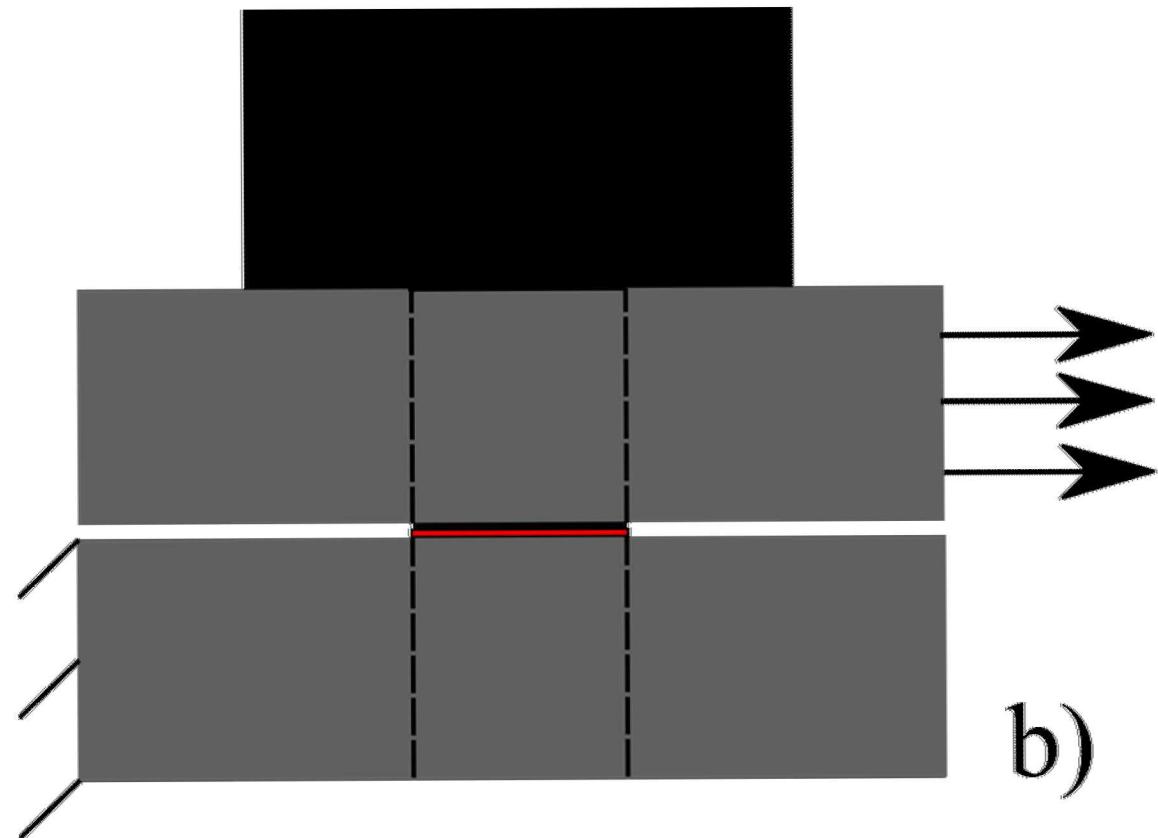
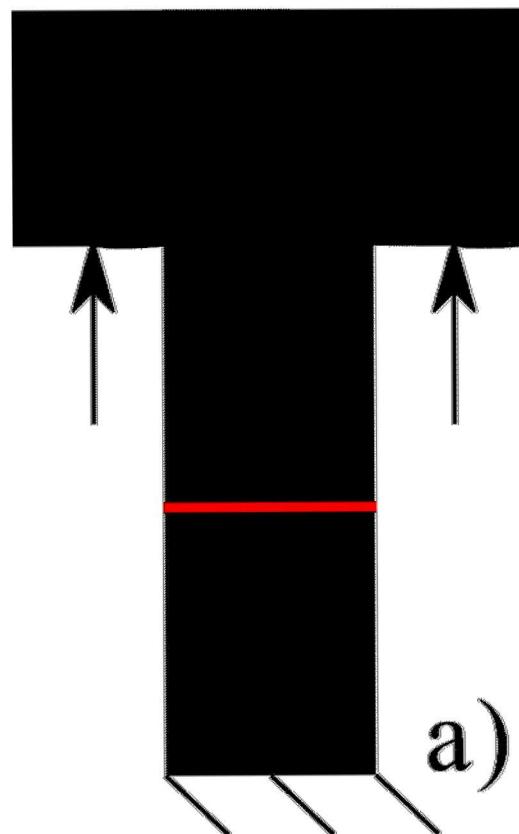
Cohesive Zone Test Scenario

- Test data for fasteners loaded under different conditions was used to validate the cohesive zone approach.
- Test data was also used to create a spot weld model for comparison with the cohesive zone.





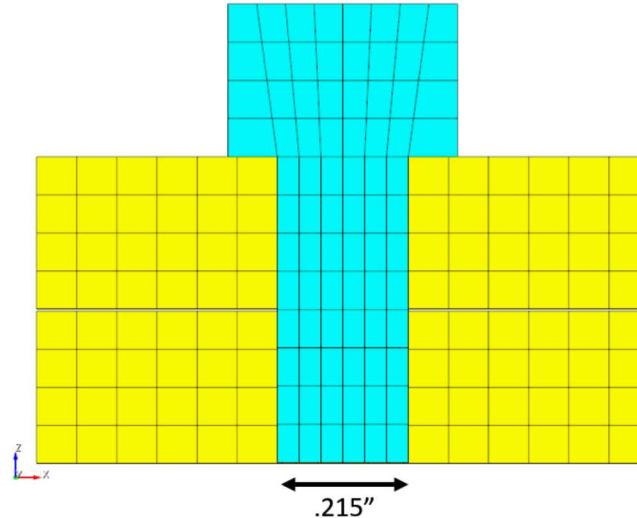
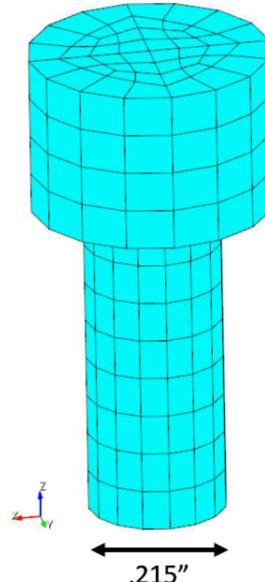
Cohesive Zone Test Scenario Cont.





Simulation Mesh

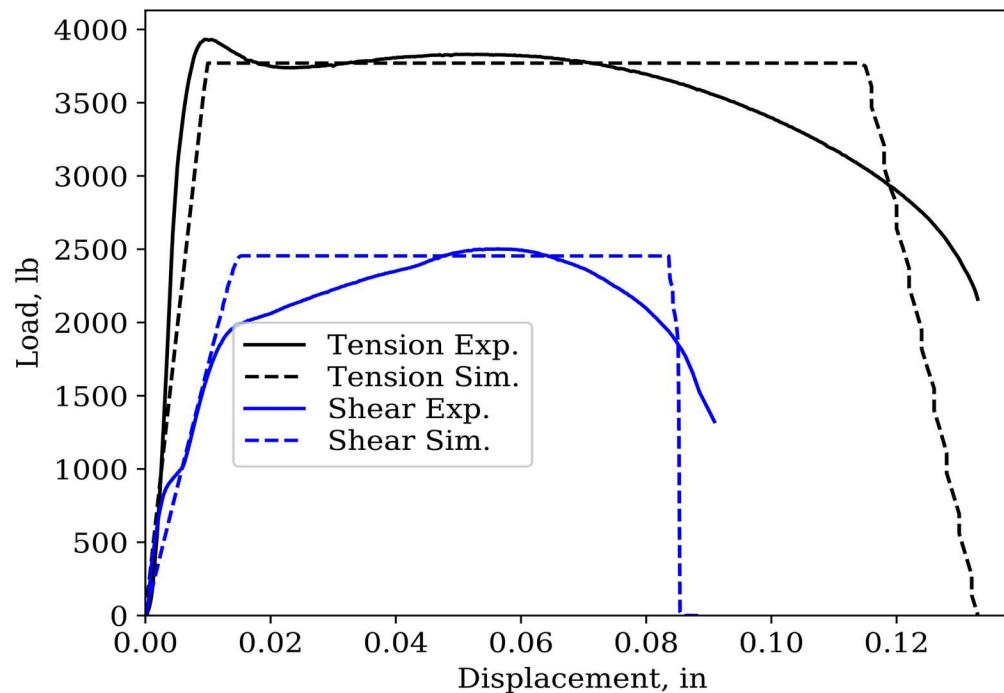
- A simplified plug was used for the study.
- Threads were not modeled.
- Bulk fastener material was modeled as 18-8 stainless steel.





Verification and Validation

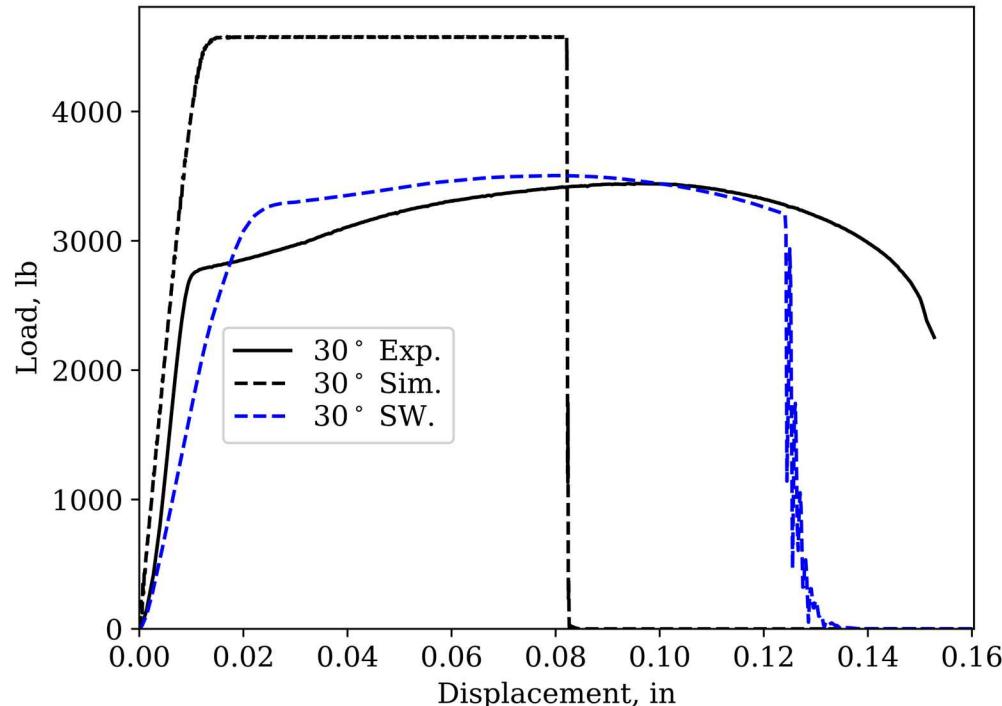
- **Tensile and shear conditions were tested with a mixed mode case at 30 degrees from vertical.**
- **Convergence studies were performed to ensure the model functions with a coarse mesh.**





Verification and Validation Cont.

- The cohesive zone model tested was not intended for mixed mode scenarios.
- Mixed mode models are available and interpolate the zone's response like the spot weld.

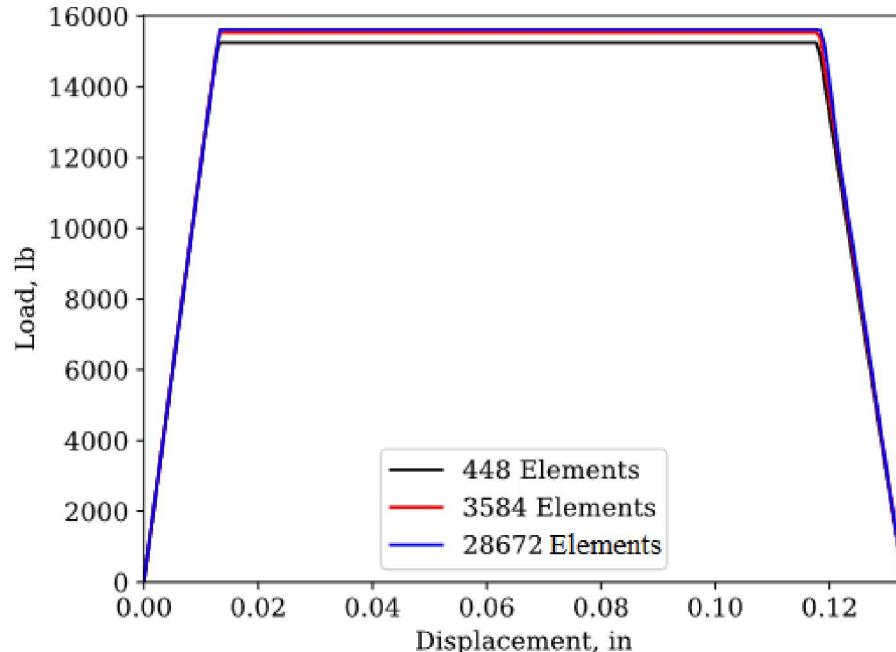




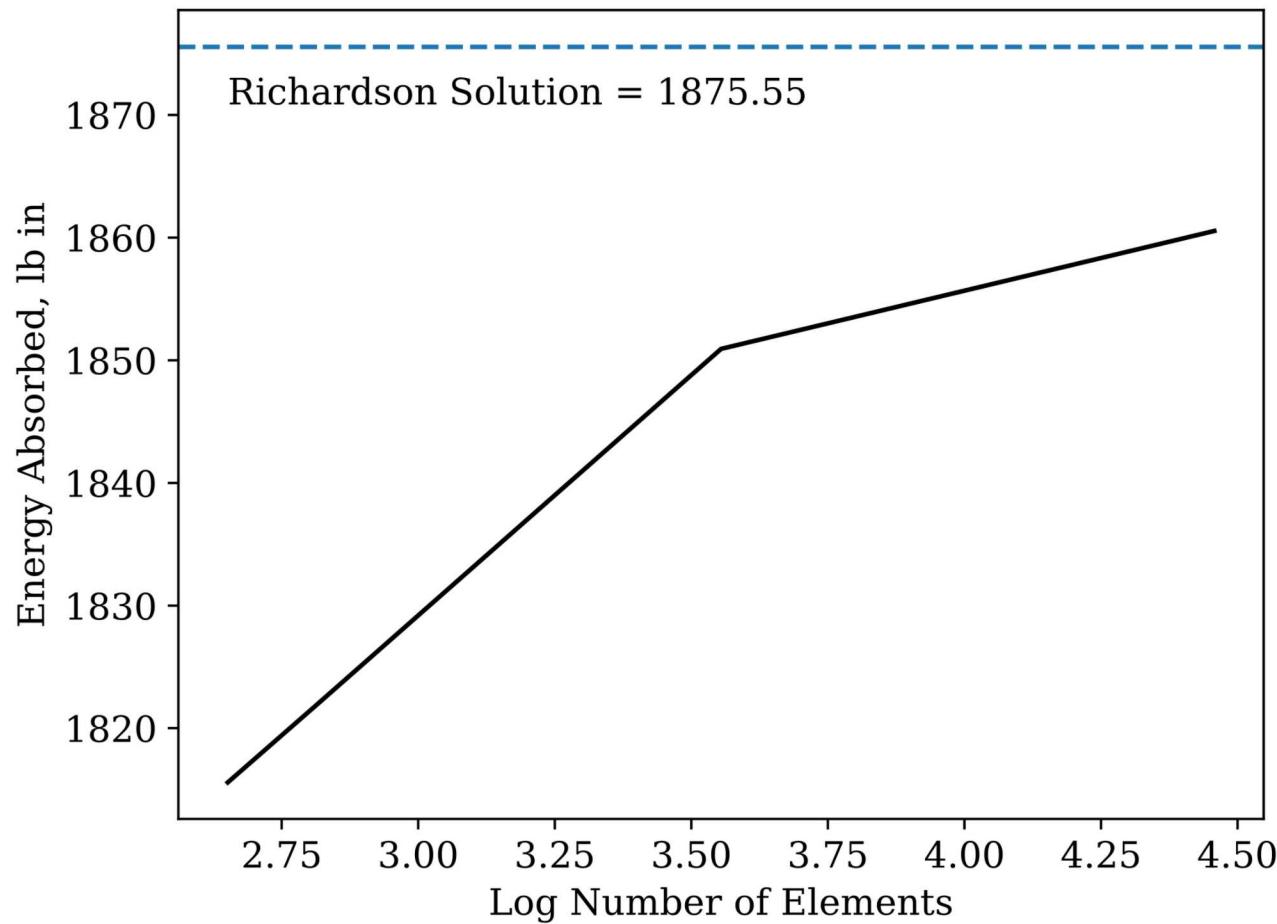
Convergence Study

- All cases show good convergence, as this is a mesh independent technique.
- Small changes in the cohesive elements' areas leads to differences between refinement levels.

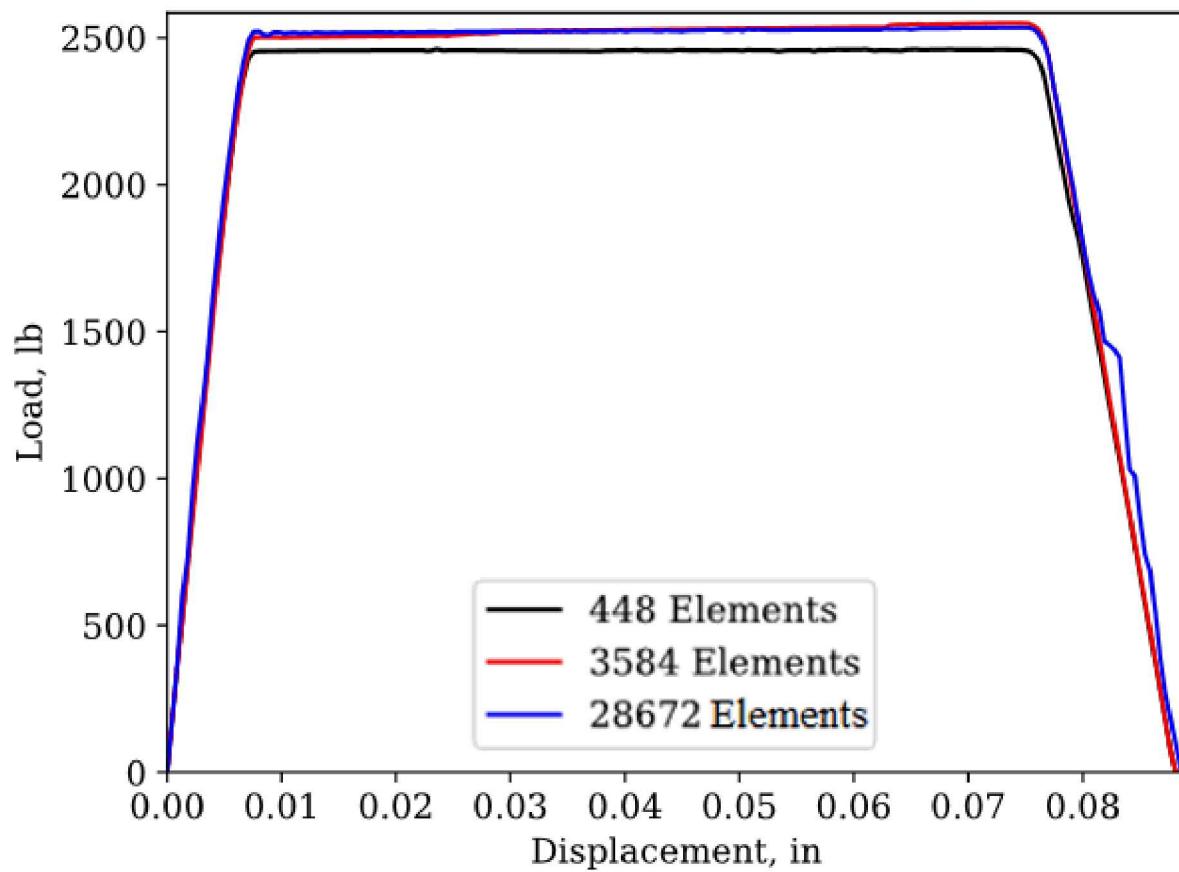
Tensile Convergence Study



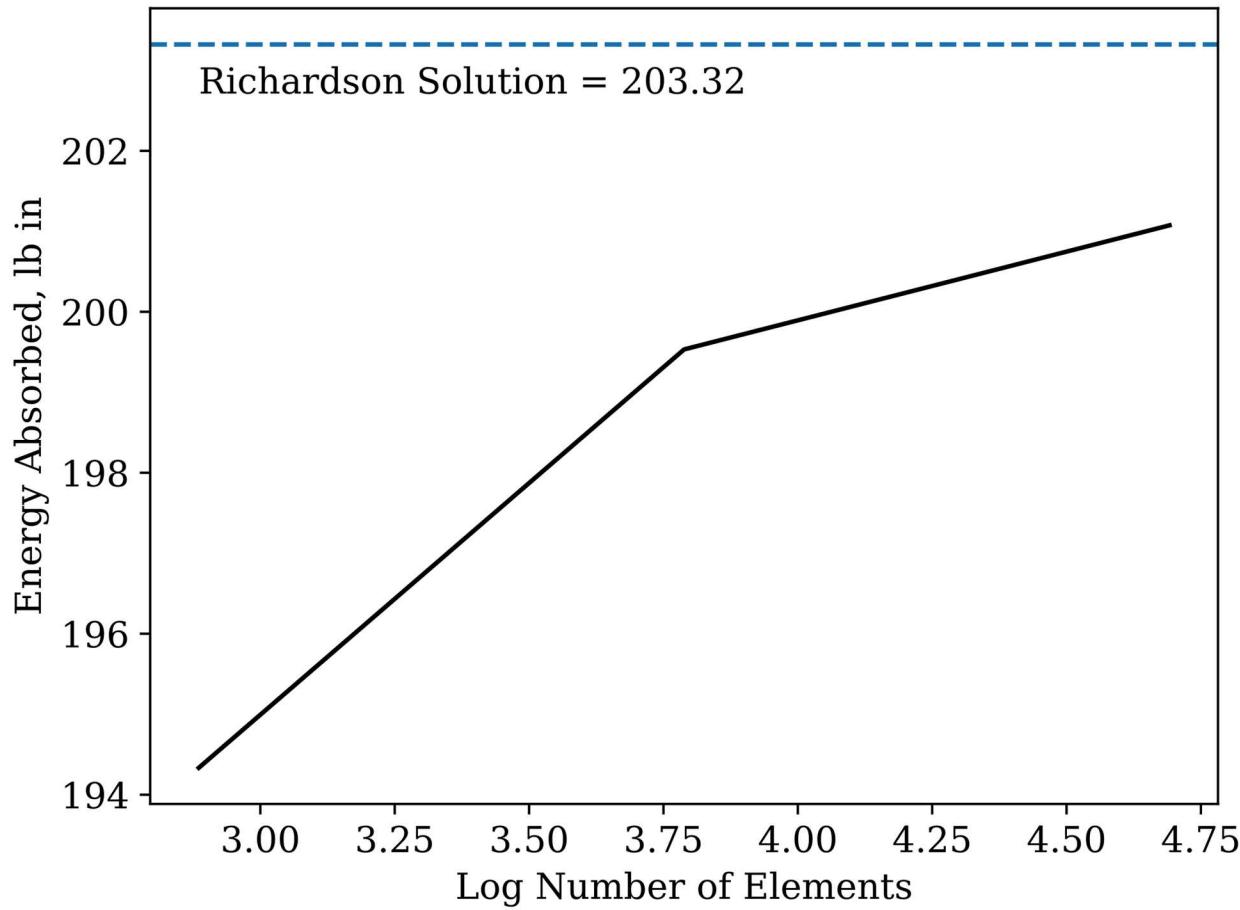
Tensile Toughness Convergence Study



Shear Convergence Study



Shear Toughness Convergence Study





Further Avenues of Exploration

- Cohesive zone models can be extended from single fasteners to rows of fasteners.
- Improving the mixed mode behavior by using a different cohesive zone model.
- Use single cohesive elements to model fasteners.

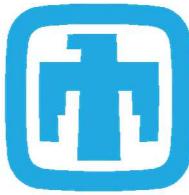


Conclusions

- Cohesive zones provide an easy to calibrate model for fastener behavior.
- Mixed mode models were not tested, but are available in many software packages.
- Spot welds are inherently more accurate, but require significant testing to gather the required load displacement data.



Acknowledgements



Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.



This work was supported by funding from the Undergraduate Research Opportunities Program at the University of Utah awarded to Brett Reeder.