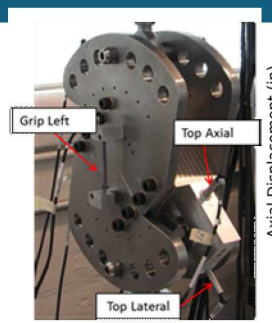
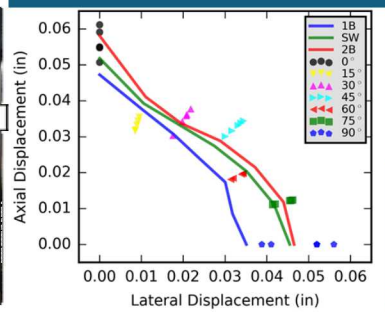
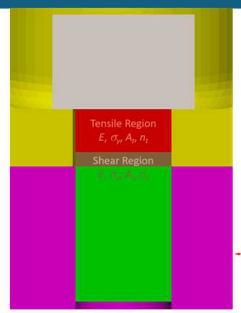
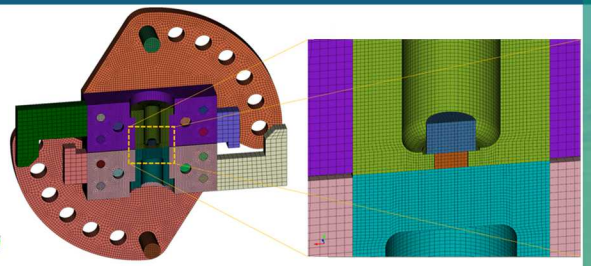
SAND2019-13552C

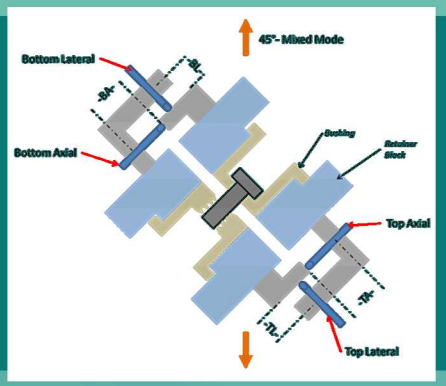
Calibration Strategies and Modeling Approaches for Predicting Load-Displacement Behavior and Failure for Multiaxial Loadings in Threaded Fasteners











PRESENTED BY

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Sandia National Laboratories

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Motivation

An essential part of Sandia's mission is predicting the performance of complex systems and structures subjected to abnormal environments through analysis.

Fasteners are an integral connector in many of these system and structures, but many of our fastener modeling approaches had not been quantified or validated.

This is a complicated problem…

Numerous fasteners exist in these systems and can be:

- Different sizes
- Loaded at various rates
- Subjected to diverse loadings

Difficulties:

- It is infeasible to test all fasteners to obtain expected behavior
- Modeling fidelity requirements of system level models are restrictive.

Goal: Assess the best low-fidelity faster approaches in their ability to accurat load-displacement behavior and t

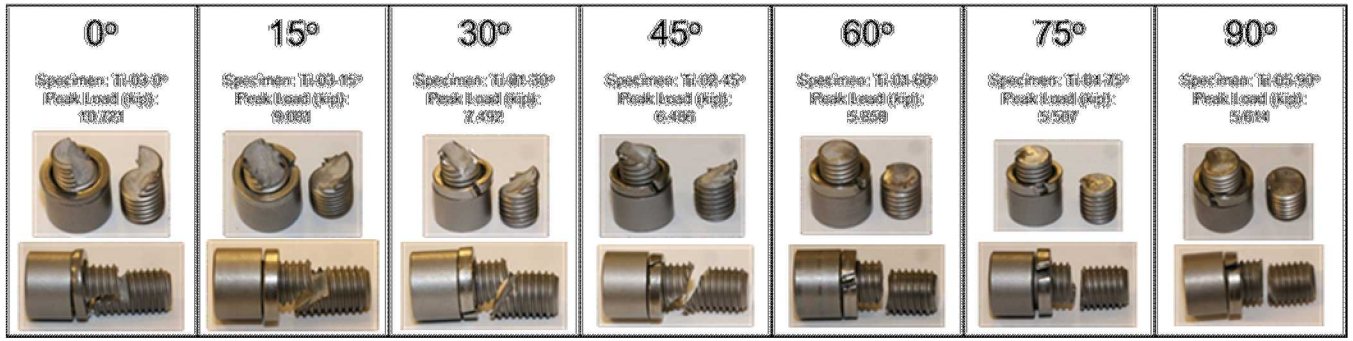
QoIs

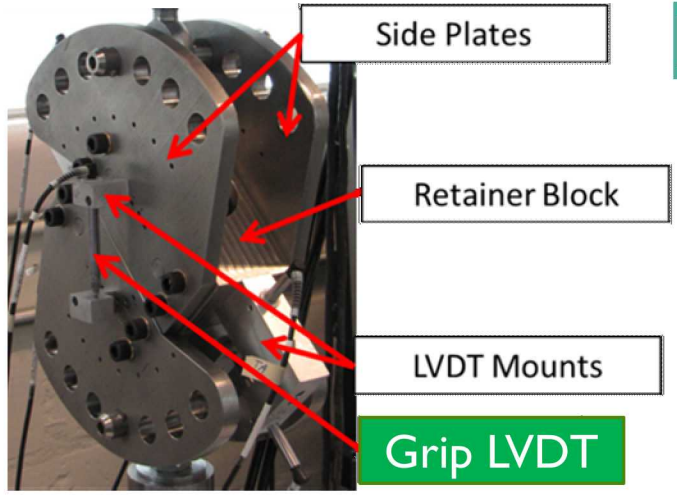
Peak Load
Failure Displacement
Energy Absorption
Compliance

Our Study: Predicting Multiaxial P-δ Behavior

A series of quasistatic tests were performed on ¼-28 x ½ MP35N fasteners.

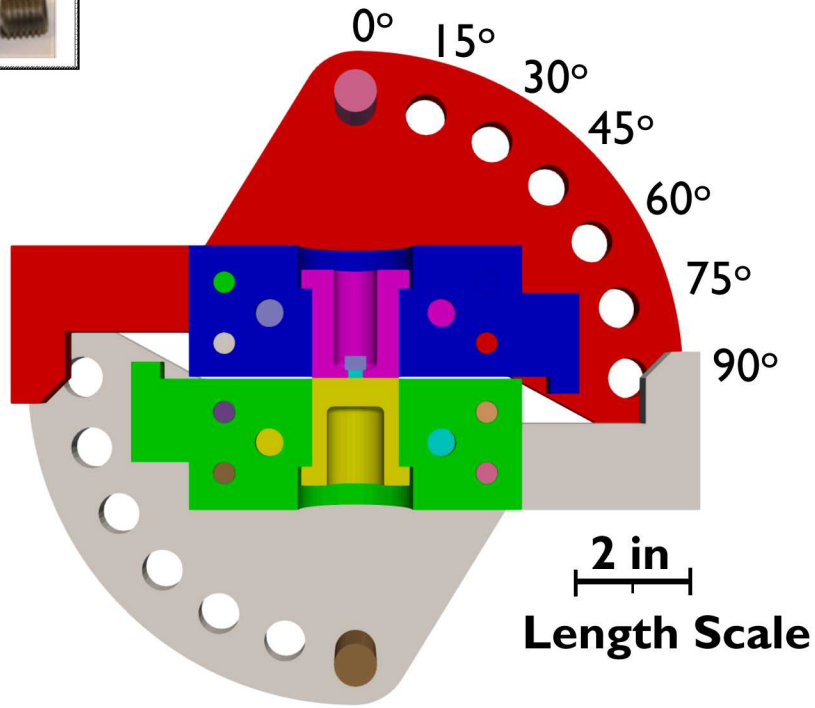
Test fixture enables fasteners to be pulled from Tension (0°) – Shear (90°) in 15° increments.





Main source of δ measurement!

Calibrate & Validate



This is a rich data set!

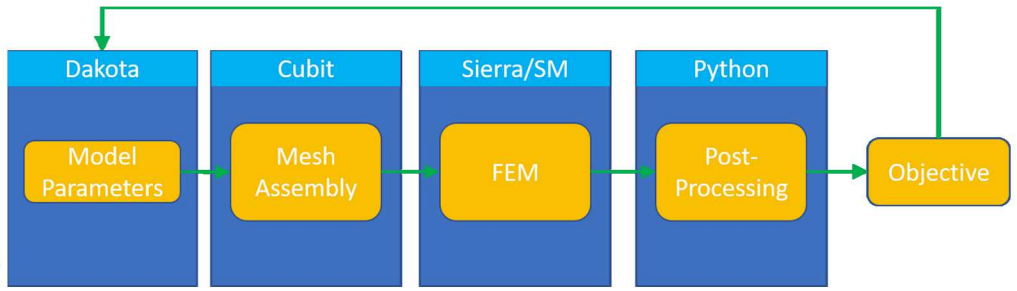
- Typically, we only have tension.
- At a minimum, we have a lot of data to validate our model.
- What if we take it one step further?
- **Let's use all of the data to calibrate!**

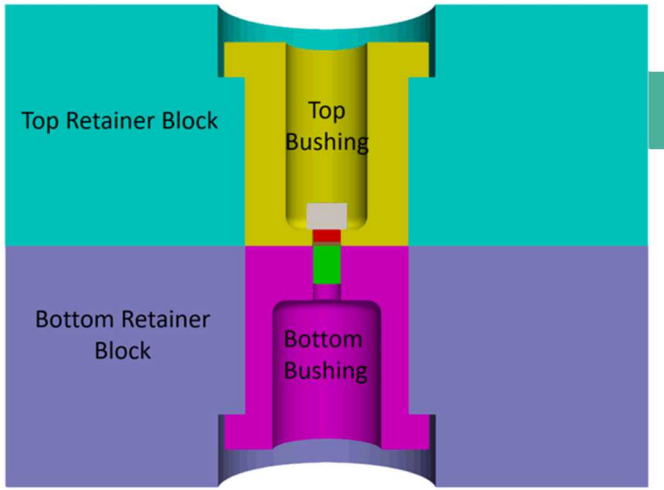
Compare our advanced calibration approach with more common methods. How much better do we do?

Approach

Calibration Approach: How will we calibrate to multiple datasets?

- Generate material properties, run all angles, compare to test data (one test from each angle)
- Use smaller analysis model for calibration





$$H=\sigma_y+A(\varepsilon_e^p)^n$$

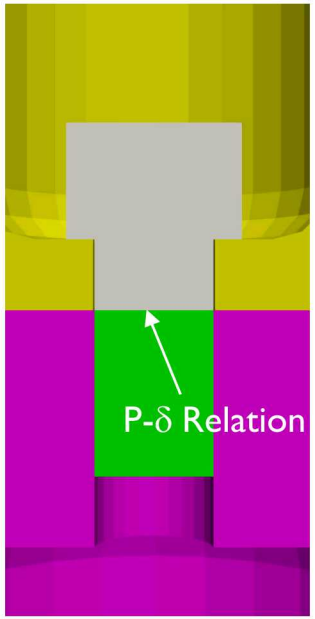
Constitutive Model: Which constitutive model is conducive to this type of calibration?

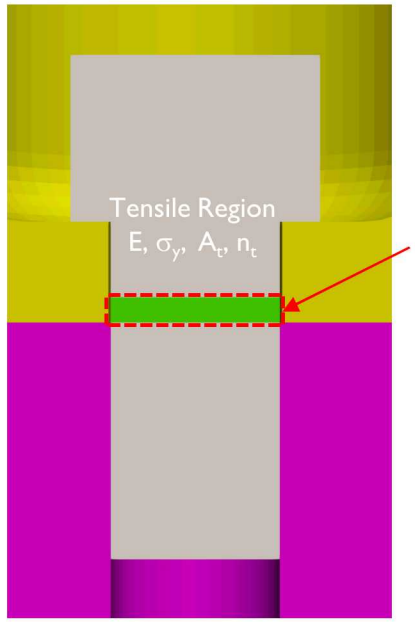
- Power Law Hardening

Low-Fidelity Fastener Models:

- Plug
- Spot weld
- **Two-Block Plug**

Compare typical plug and spot weld approaches with two-block plug calibrated to all angles.



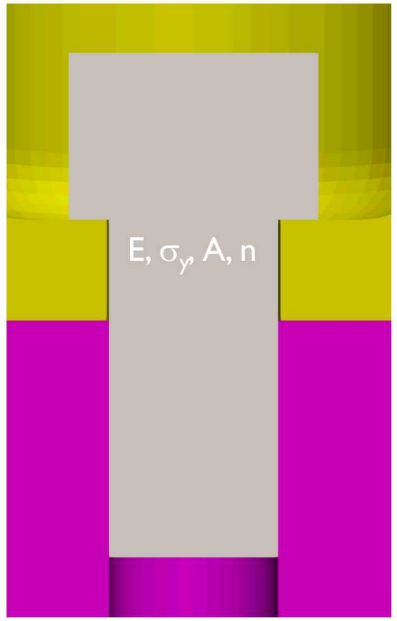


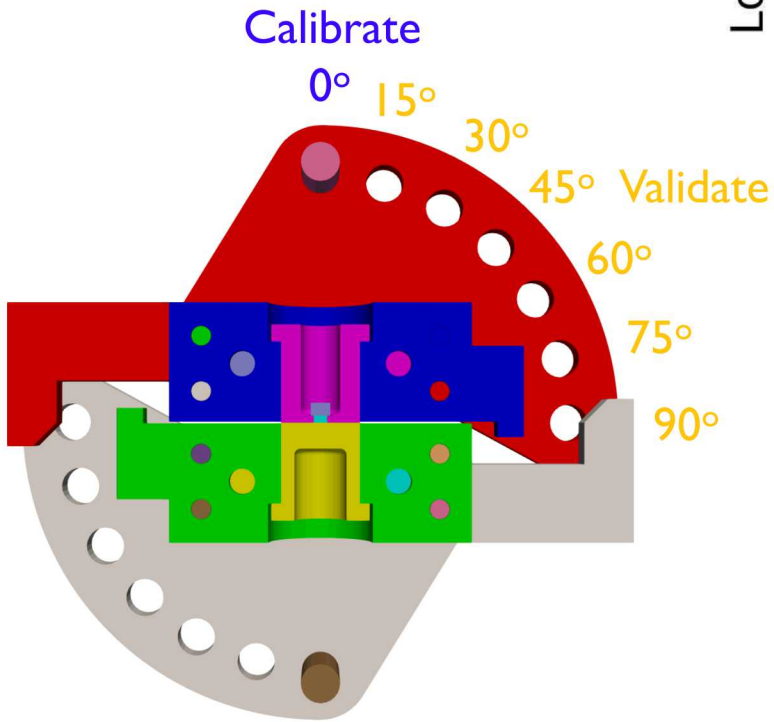
Results – One Block Plug

Calibration: Used optimization workflow to calibrated power law hardening model (σ_y, A, n) to 0° results.

- Equivalent plastic strain failure criterion calibrated after to best approximate 0° failure.
- Model captures 0° data well, but gets increasingly worse as the angle get larger.
- shear dominated loadings (60°-90°) perform the worst.

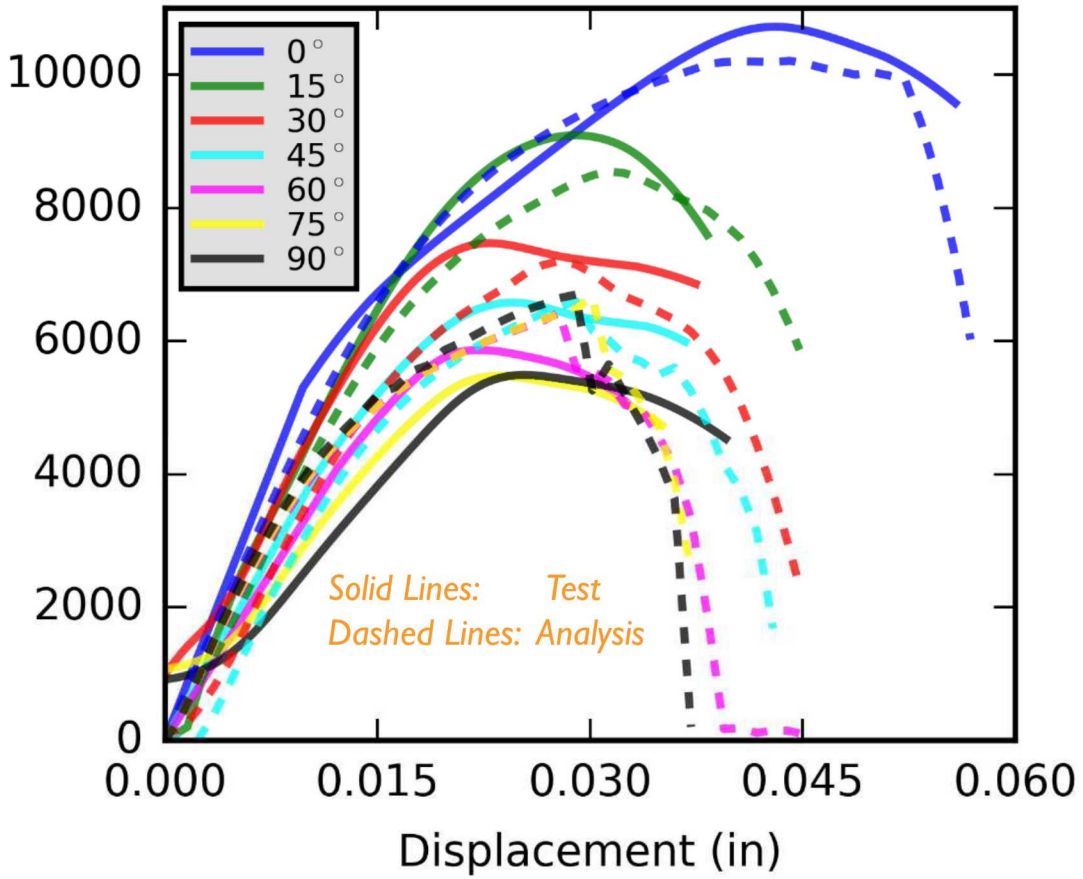
One-Block Plug





QoIs

Peak Load
Failure Displacement
Energy Absorption
Compliance



Captures tension, but performs worse as angle gets larger

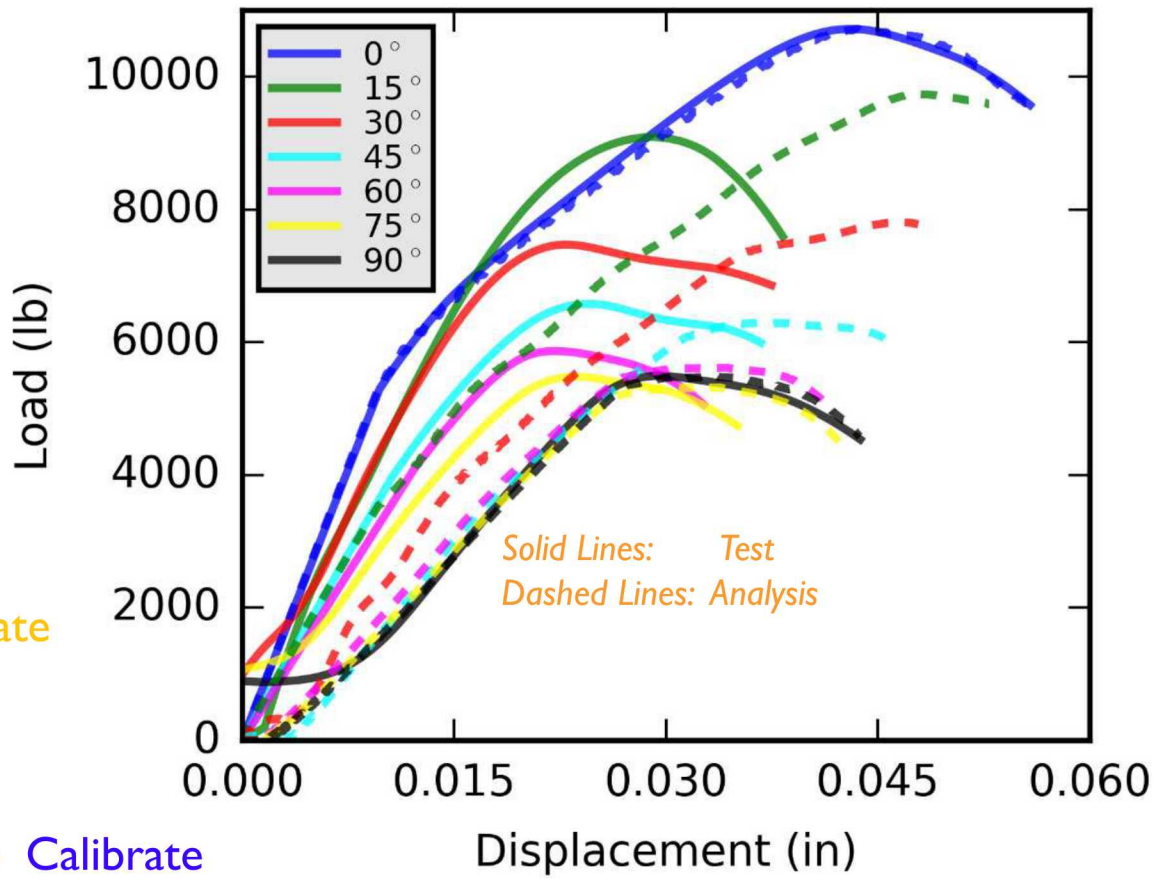
Results – Spot Weld

Calibration: 0° and 90°. Use test data to begin and adjust accordingly.

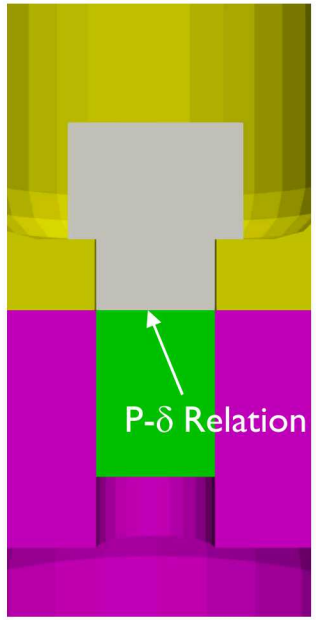
- Had to shift 90° due to compliance of simulation
- Model captures 0° and 90° data very well, but compliance and displacement off at intermediate angles.
- Good news: can modify failure envelope to increase agreement

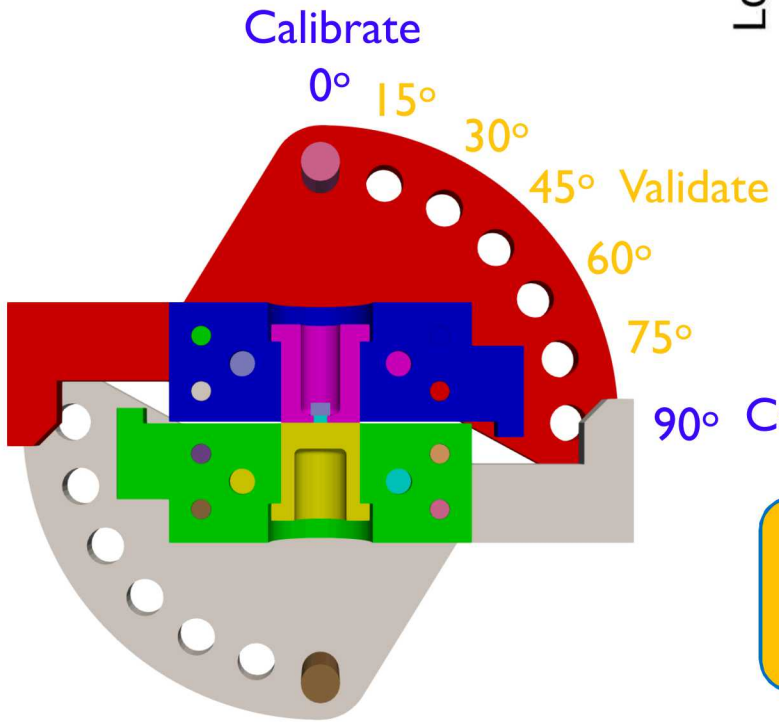
QoIs

Peak Load
Failure Displacement
Energy Absorption
Compliance



Spot Weld





Captures tension and shear, but doesn't perform as well at intermediate angles

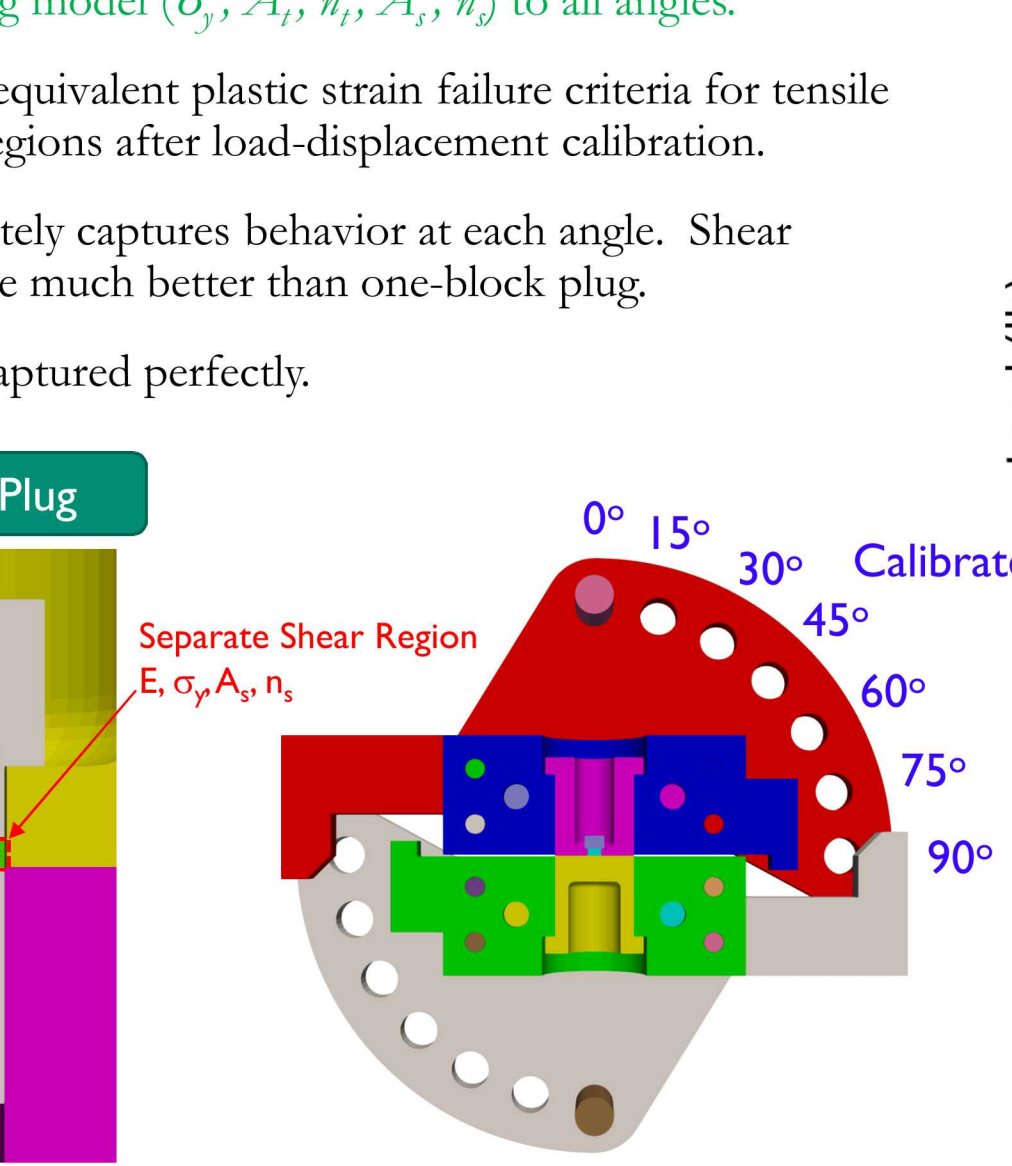
Results – Two-Block Plug

Calibration: Used optimization workflow to calibrated power law hardening model (σ_y, A_t, n_t, A_s, n_s) to all angles.

- Calibrated equivalent plastic strain failure criteria for tensile and shear regions after load-displacement calibration.
- Approximately captures behavior at each angle. Shear performance much better than one-block plug.
- No angle captured perfectly.

QoIs

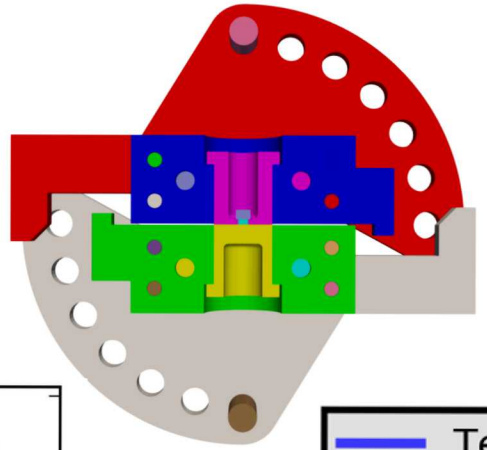
Peak Load
Failure Displacement
Energy Absorption
Compliance



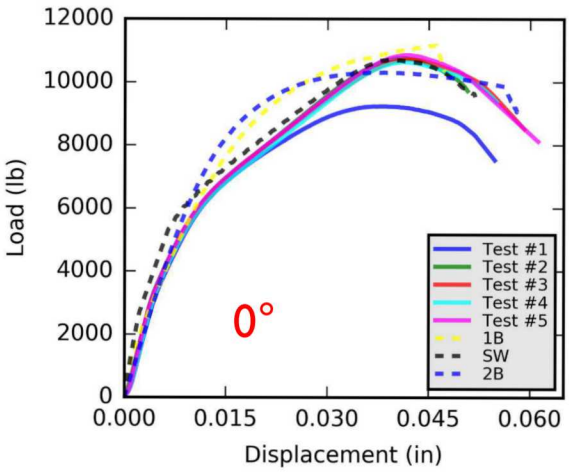
Two-Block Plug

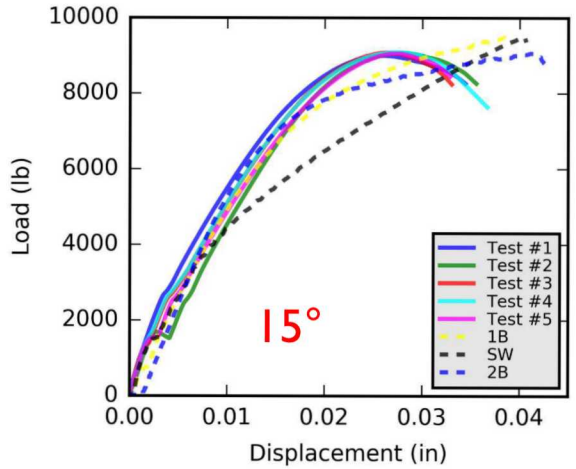
Best approach to capture global behavior at all angles.

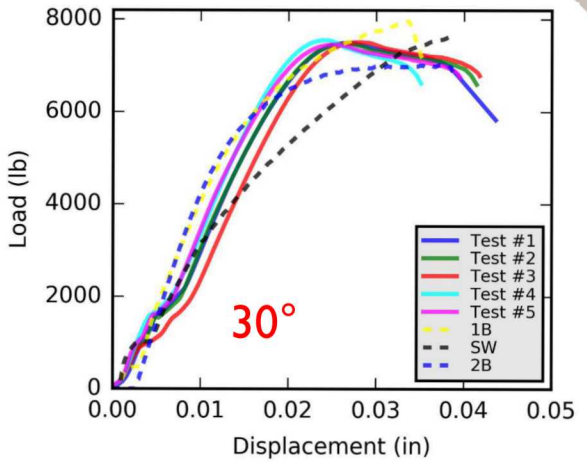
Validation – High-Fidelity Model

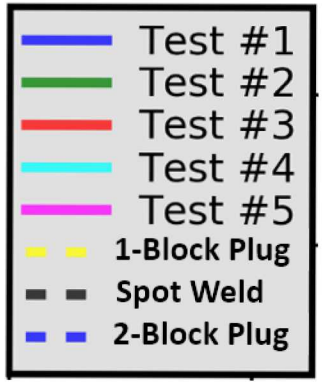


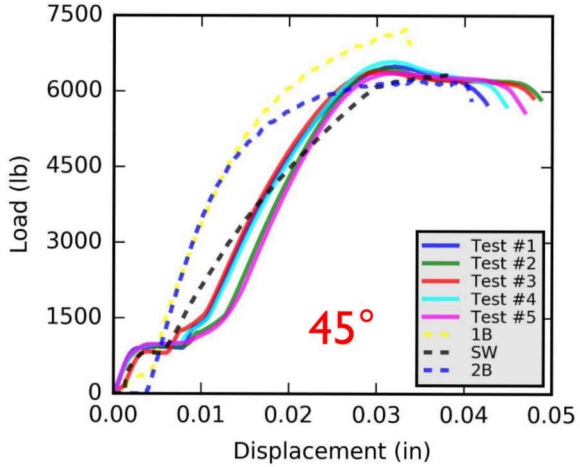
Use calibrated models in high-fidelity analysis model and compare to raw data.

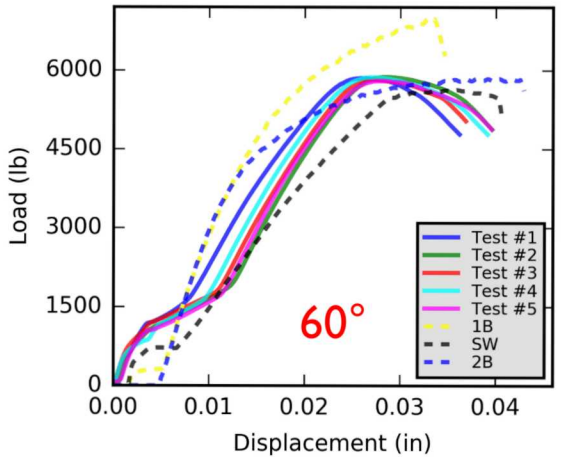


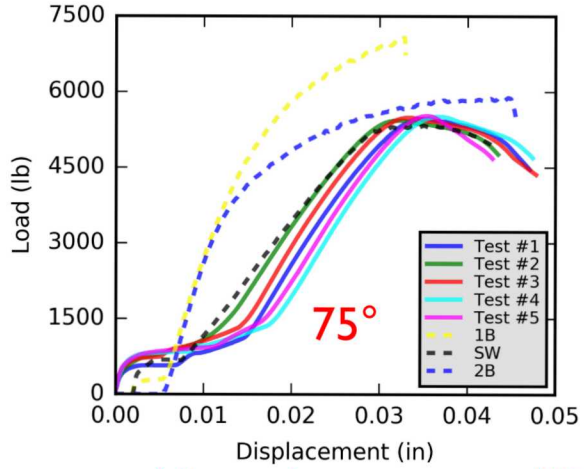


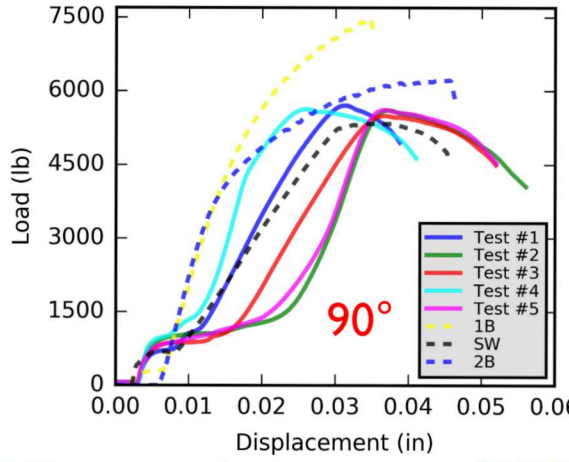








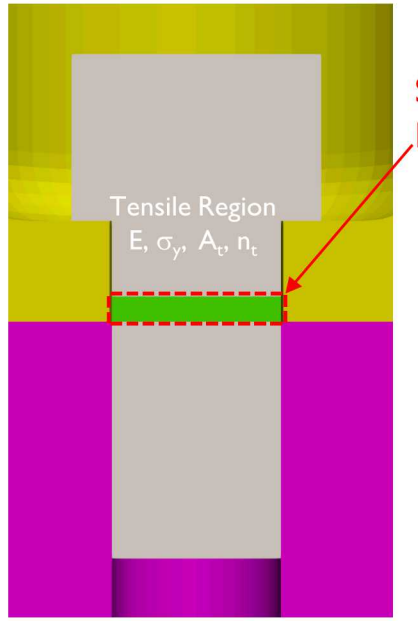




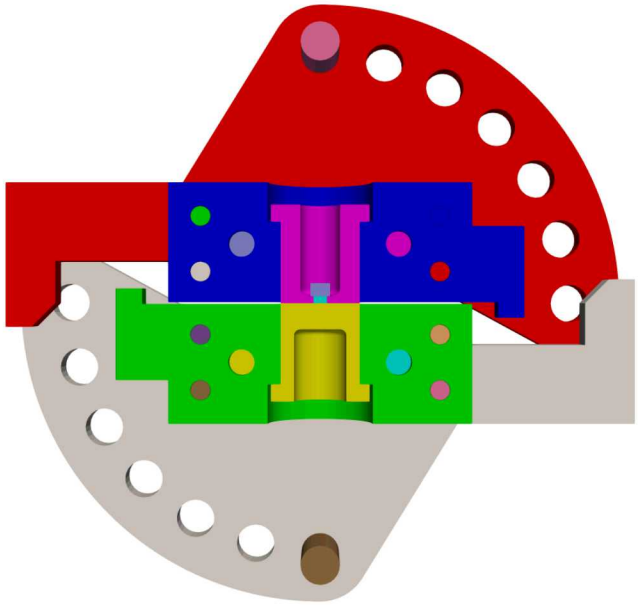
Note spot weld results use a modified failure envelope.

Conclusions

- The optimization workflow successfully calibrated our model to the test data
- Two-Block approach facilitates capturing tensile and shear behavior
- Spot Weld with adjusted failure criterion also performs very well



Thank you!



Future Work

Can we calibrate to a subset of the data and obtain just as good of a model?

Are there models that will perform even better?

Will a different optimization strategy provide a better solution?

Acknowledgements:
Testing: Theresa Cordova, Sharlotte Kramer, Cayetano Mendoza, and Matthew Ingraham
High-Fidelity Model: Doug VanGoethem, Steve Gomez