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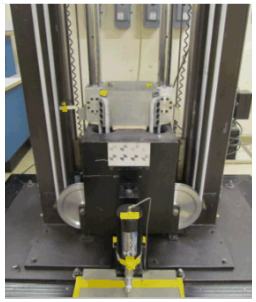

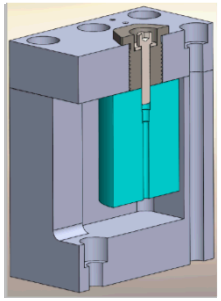

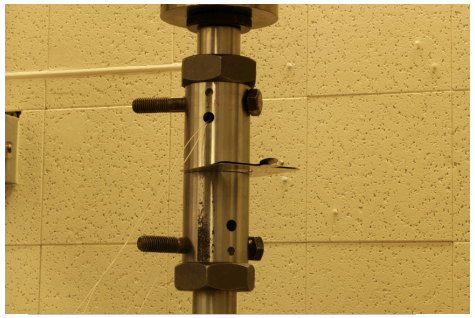

Modeling Threaded Fasteners

A Case Study for Low Fidelity Modeling Techniques

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Evan P. Johnson[2], Thomas Bosiljevac[3]

1: Component Science & Mechanics

2: Advanced Munitions & Mechanical Systems

3: Experimental Environmental Simulation

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Motivation

Sandia National Laboratories

- Large scale, high fidelity analysis is inherent to the types of complex structures that are analyzed at Sandia.

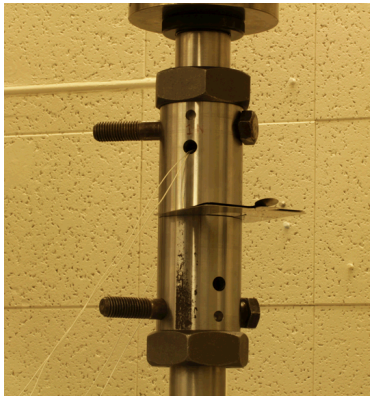
- These complex structures can contain many fasteners, and the fasteners can be:
  - Different sizes
  - Subjected to diverse loadings
  - Loaded at various rates

- It is thus becomes necessary to model fasteners with a lower level of fidelity yet still capture the global behavior of the joint, especially when its performance is critical to the output quantities of interest.

Goal: benchmark performance of low fidelity fastener modeling techniques.

Approach

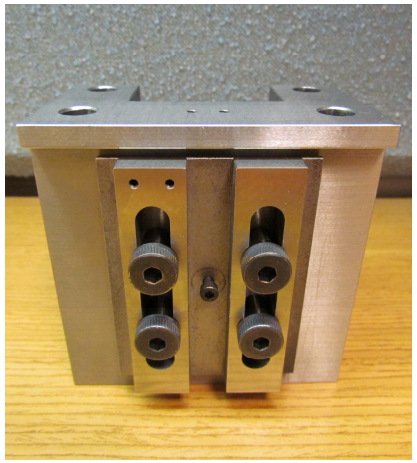
- Perform quasistatic and dynamic testing for pure tensile and shear loadings on NAS1352-06-6P threaded fasteners.
- Calibrate low fidelity modeling approaches to quasistatic test data.
- Extend calibrated models to dynamic analysis and assess performance at elevated strain rates.



Quasistatic Tension Test Setup

Quasistatic Shear Test Setup

Dynamic Tension Test Setup

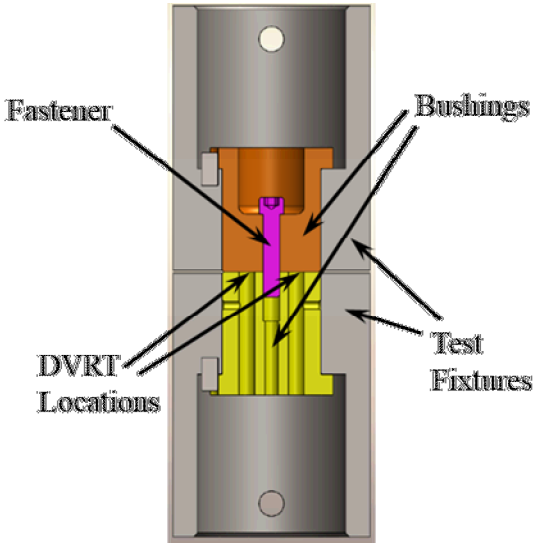


Dynamic Shear Test Setup

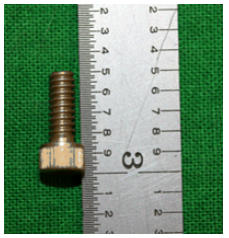
We will focus on the tension tests and analysis

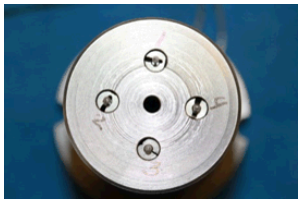
Quasistatic Testing

- Test fixtures made of “hard” tool steel.
- Four DVRTs located in bottom bushing take local displacement measurements of bushing separation
- Tests performed on both preloaded (20 in-lb) and hand-tightened fasteners.



Quasistatic Tension Test Setup

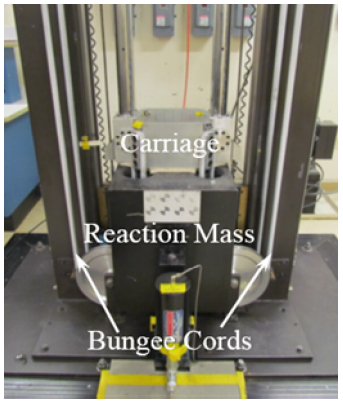

NAS1352-06-6P Fastener


DVRT Locations in Bushing

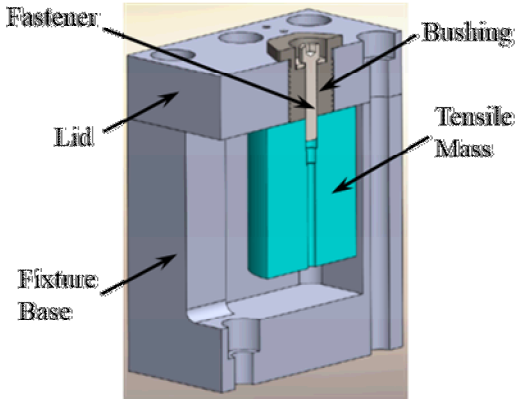
NAS1352-06-6P	SML6-3	SML6-7	SML6-12	SML6-13	SML6-22	SML6-31	SML6-33	Model
Head Diameter, A (in)	0.222	0.223	0.222	0.224	0.224	0.221	0.224	0.226
Head Height, H, (in)	0.1367	0.1365	0.1372	0.1372	0.1371	0.1372	0.1369	0.138
Shank Length, L, (in)	0.3688	0.364	0.3673	-	0.3639	0.3618	0.3686	0.375
Major Diameter, D, (in)	0.134	0.133	0.134	0.134	0.135	0.134	0.135	N/A
Tensile Stress Area, A_s, (in^2)	0.0084	0.0083	0.0084	0.0084	0.0086	0.0084	0.0086	0.0084

Dynamic Testing

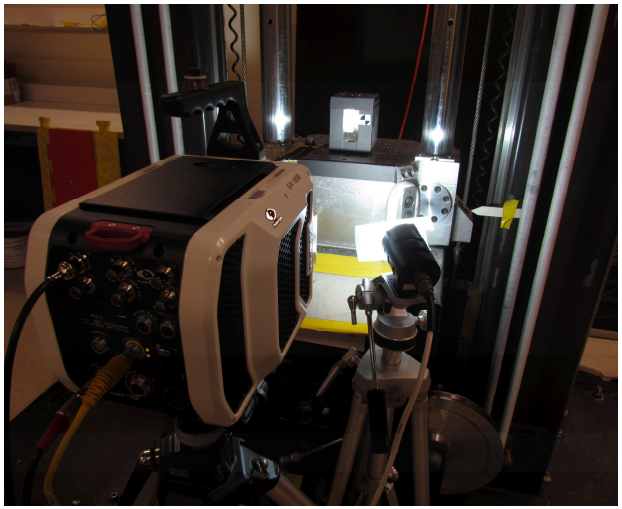
- To create a dynamic loading scenario test fixtures were bolted to the carriage of a bungee accelerated drop table.
- When the drop table carriage impacts the reaction mass the fastener experiences a tensile loading caused by the acceleration of the tensile mass.
- Multiple accelerometers placed on test fixture for validation metrics.
- All tests were performed with the fasteners preloaded to 22 in-lb.



Drop Table



Dynamic Tension Test Fixture



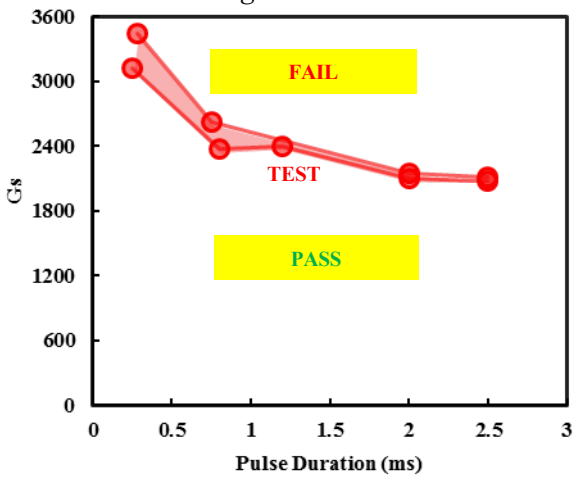
Drop Table Experimental Setup

Dynamic Testing

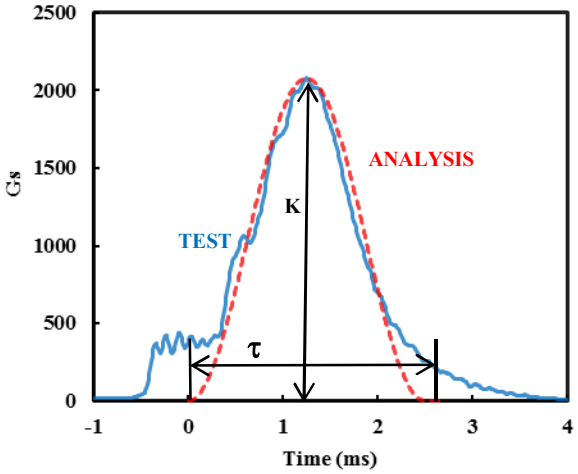
- Main objective: determine failure load of fastener while varying shape of pulse acceleration.
- Five pulse levels were chosen that spanned the entire range of the drop table capability.
- With only four screws to test at each velocity level it was critical to bracket the failure point by achieving both a catastrophic failure and a non-failure within the four tests.
- "Pulses" approximately take the form of a haversine function.

$$Ksin^2\left(\frac{\pi t}{\tau}\right)$$

Bracketing Failure in Test Results



Example Pulse Acceleration



Modeling Approaches

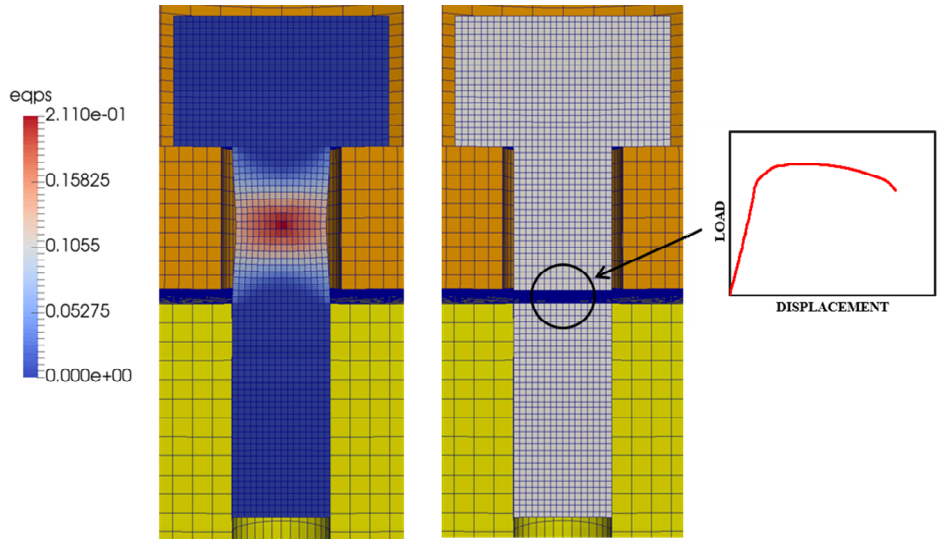
- Studied two low fidelity modeling approaches: Plug and Spot Weld

Plug

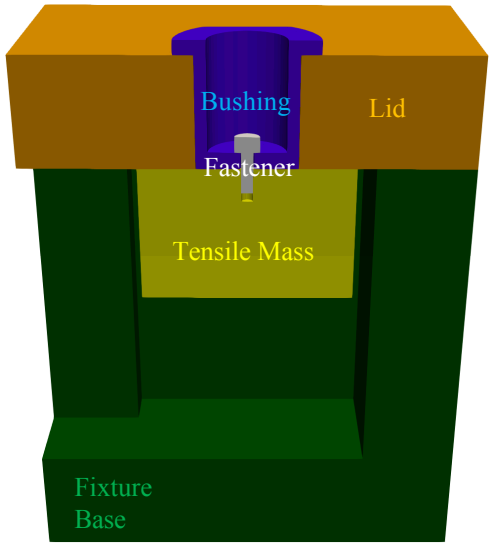
- Hex elements
- Elastic plastic constitutive model
- Piecewise-linear hardening
- EQPS death criterion

Spot Weld

- Hex elements
- Elastic constitutive model
- P-δ defined relationship
- Fails at end of P-δ curve



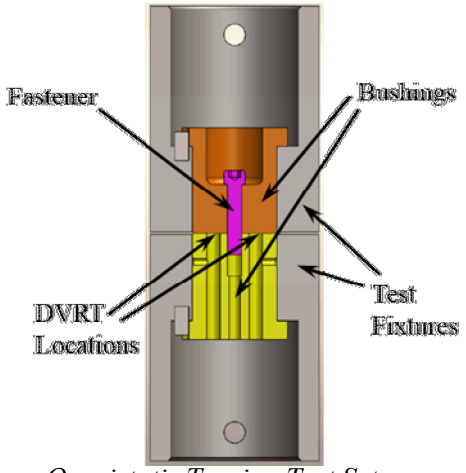
Plug (Left) and Spot Weld (Right) Modeling Approaches



Dynamic Tension Analysis Model

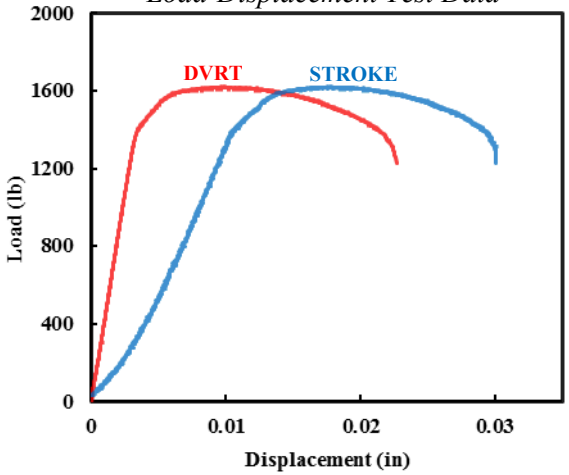
Quasistatic Test Results

- Displacement measurements from stroke and DVRTs were very different.
- Compliance significantly contributes to data acquisition.
- Both modeling methods reasonably reproduce test results.

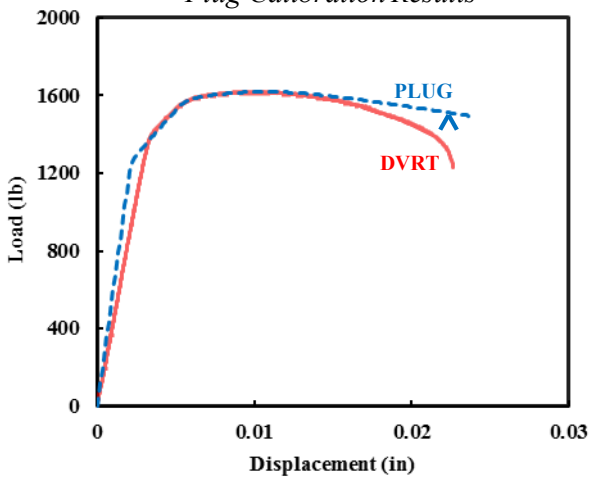


Quasistatic Tension Test Setup

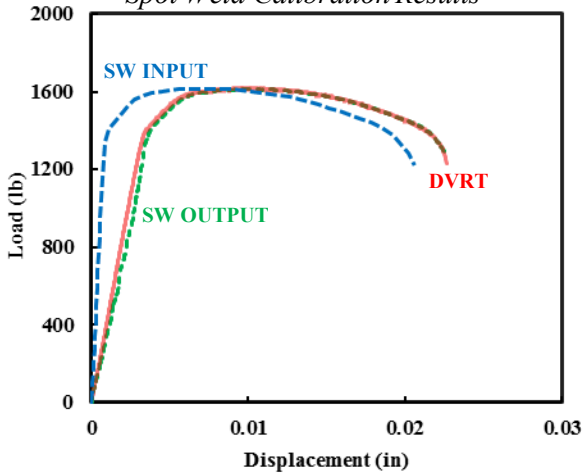
Load-Displacement Test Data



Plug Calibration Results



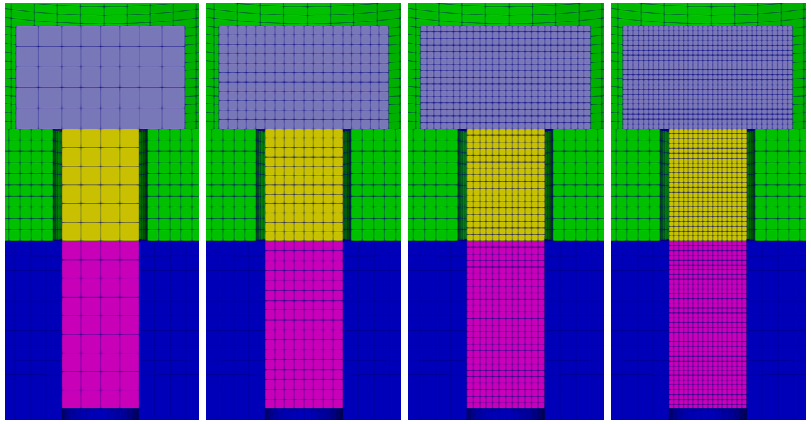
Spot Weld Calibration Results



DVRT data provides a more local and reliable measurement.

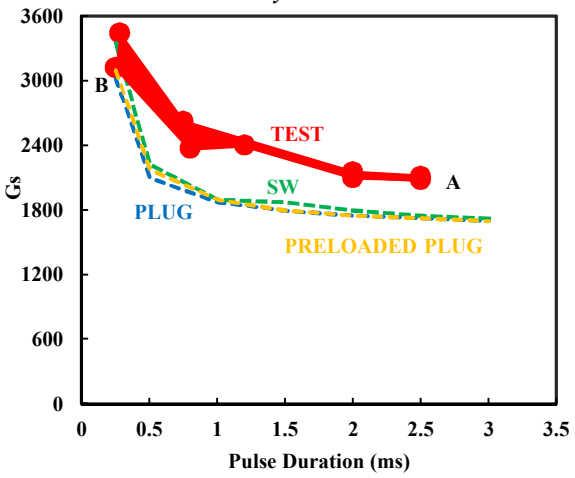
Dynamic Test Results

- Dynamic failure curves were reproduced with each modeling method.
- Failure defined as complete cross-section separation.
- Sensitivity study performed to further assess modeling approaches.

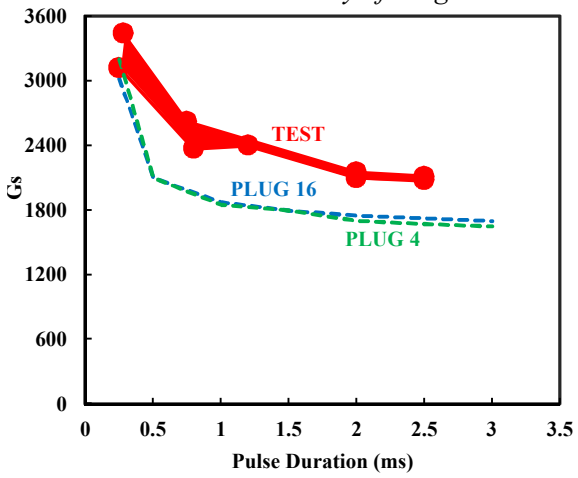


Meshes in Sensitivity Study

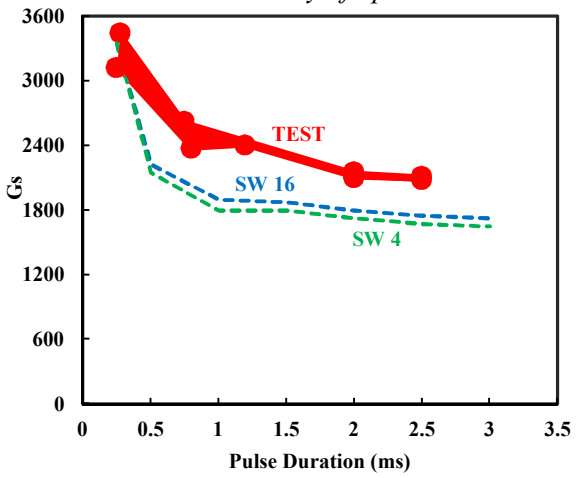
Test and Analysis Failure Curves



Mesh Sensitivity of Plug



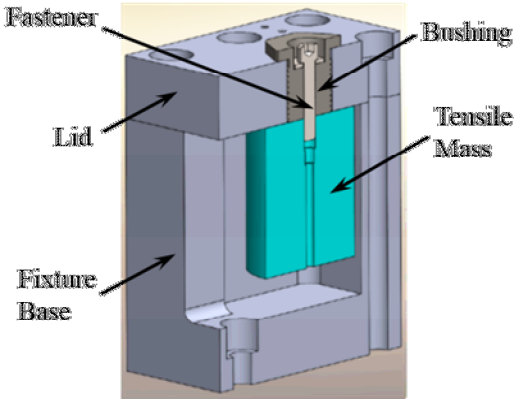
Mesh Sensitivity of Spot Weld



Modeling approaches conservatively predict failure and are insensitive to mesh size.

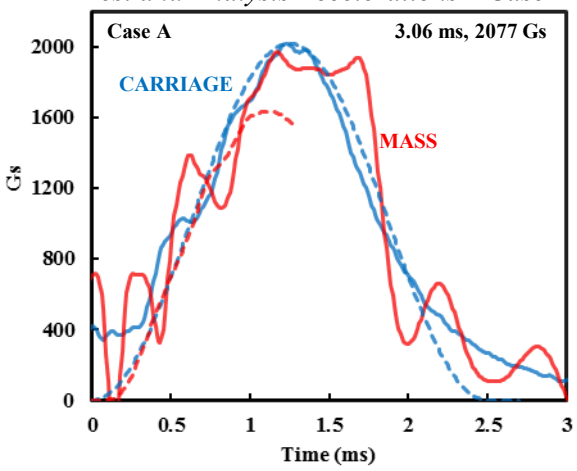
Dynamic Test Results

- Accelerations were compared to evaluate reliability of simulations.
- Accelerations analytically measured and compared to test data from carriage, test fixture, and tensile mass.
- Analysis reasonably reproduces test results.

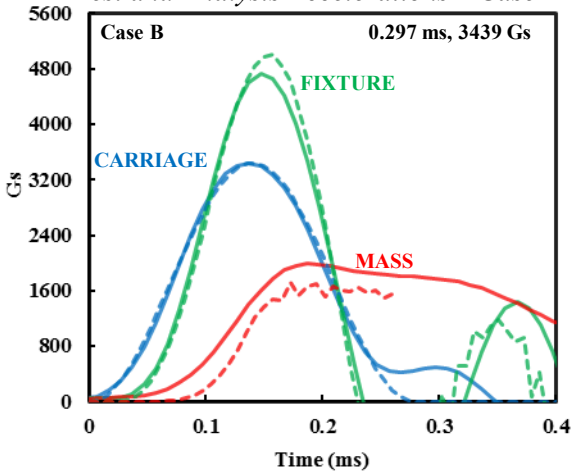


Dynamic Tension Test Fixture

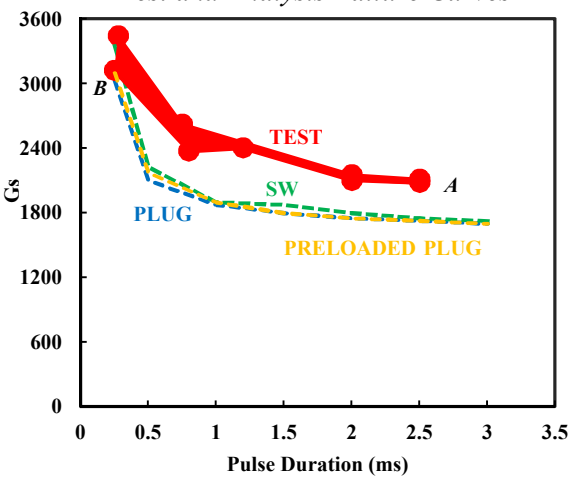
Test and Analysis Accelerations – Case A



Test and Analysis Accelerations – Case B



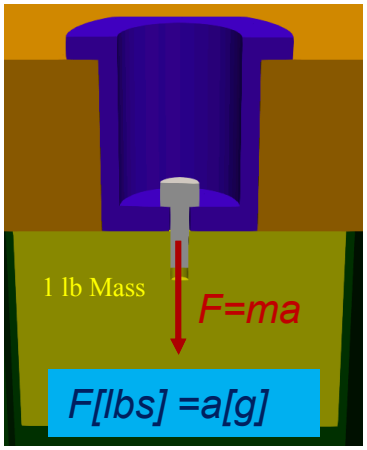
Test and Analysis Failure Curves



Tensile mass accelerations do not vary, but under predicted by analysis.

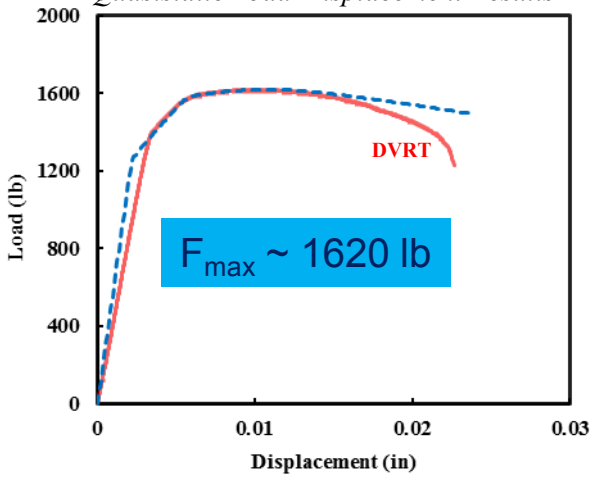
Dynamic Test Results

- FBD shows load on fastener is equal to tensile mass acceleration.
- Test accelerations 20% higher than ultimate load in quasistatic tests.

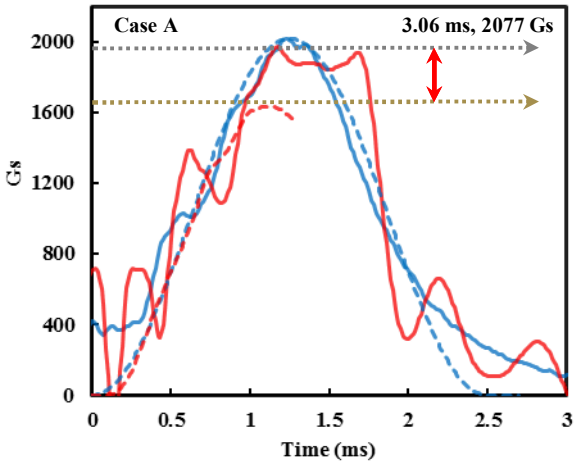


Load on Fastener

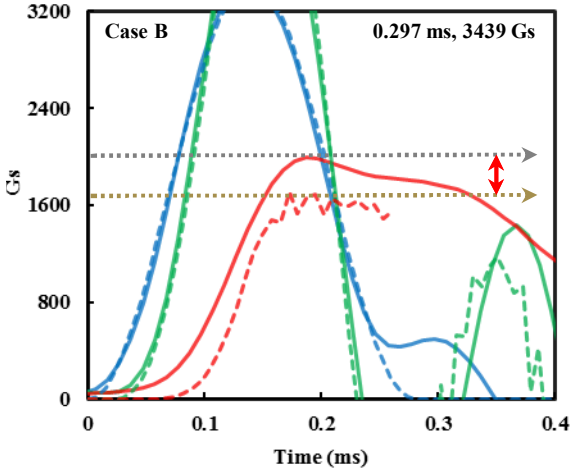
Quasistatic Load-Displacement Results



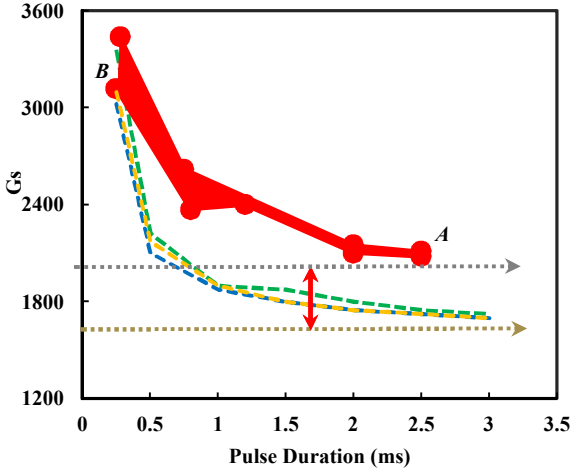
Test and Analysis Accelerations – Case A



Test and Analysis Accelerations – Case B



Test and Analysis Failure Curves



Strain rate effects possibly causing increased load capacity.

Conclusions and Future Work

- Measurement techniques play a significant role in data acquisition and analysis must account for all relevant bodies and compliance.

- The plug and spot weld modeling approaches can be reliably used to model fasteners for monotonic quasistatic tensile loadings.

- When the simple constitutive models associated with these approaches are extended to high strain rate applications, they do not capture the apparent strain rate effects observed during testing.

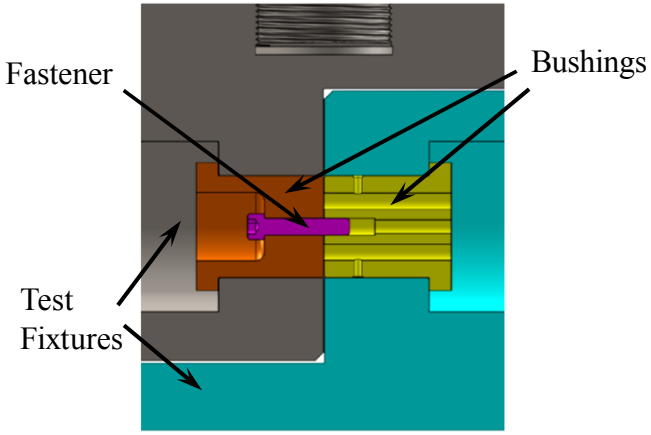
- These initial findings warrant an expanded study that includes testing performed at intermediate strain rates (0.1 – 10 ε/s) and a more complex, strain rate dependent constitutive model (i.e. Johnson-Cook) to further assess the performance of these fasteners and obtain a better, more robust analysis model.

Sandia National Laboratories

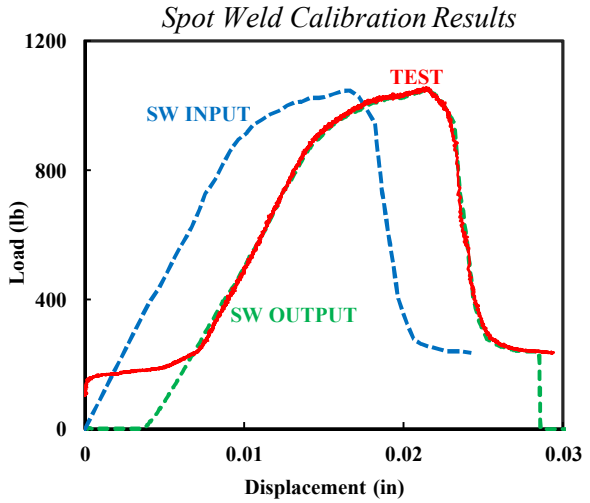
QUESTIONS?

Quasistatic Test Results – Shear

- Displacement measurements from stroke due to lack of confidence in LVDT measurements.
- Spot weld flexibility allows model to accurately capture shear load-displacement behavior.
- Plug approach results are not directly calibrated to shear, and performance is questionable.

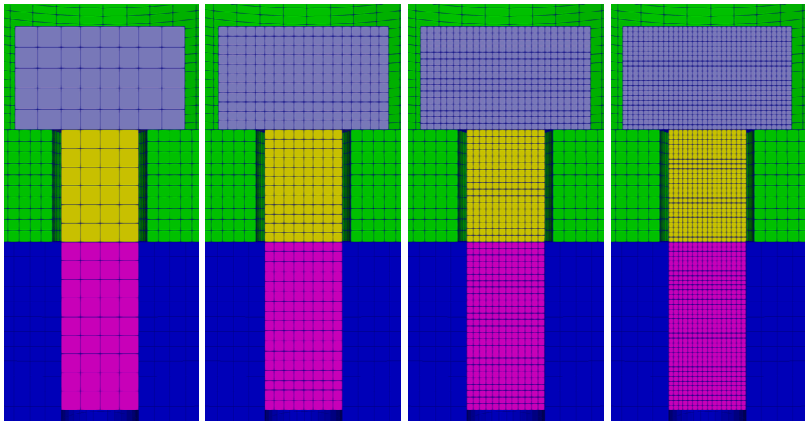


Quasistatic Shear Test Setup

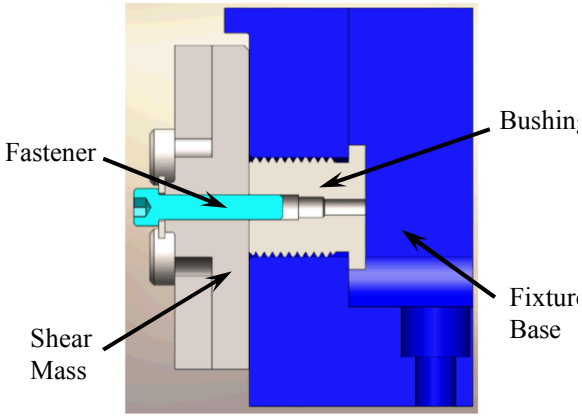


Dynamic Test Results – Shear

- Plug model is very sensitive to mesh discretization.
- Accelerations resemble test data, but analysis mass acceleration is extremely noisy.
- Spot weld may have more favorable results due to insensitivity of mesh.

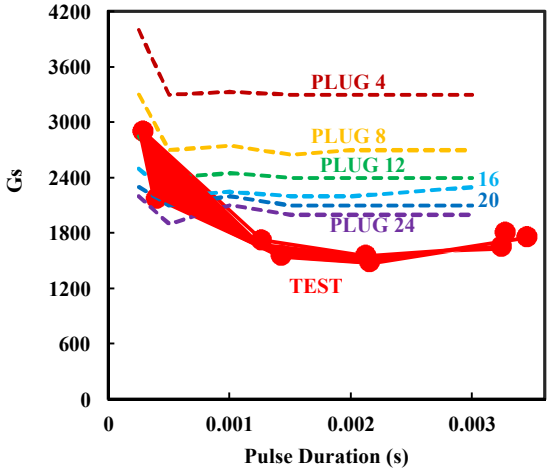


Meshes in Sensitivity Study



Dynamic Tension Test Fixture

Test and Analysis Failure Curves



Test and Analysis Accelerations – Case A