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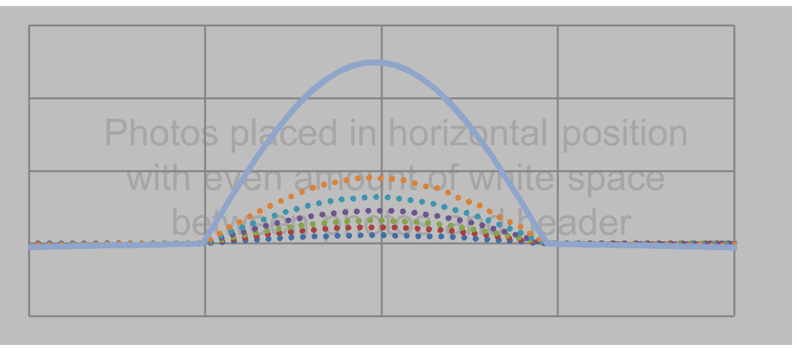

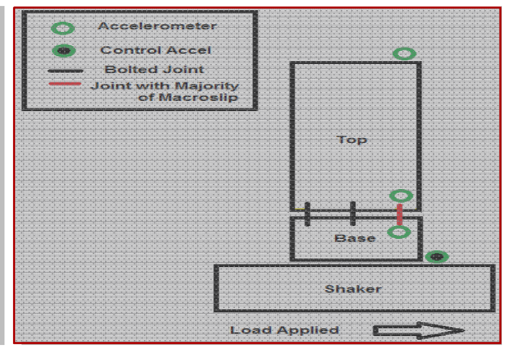

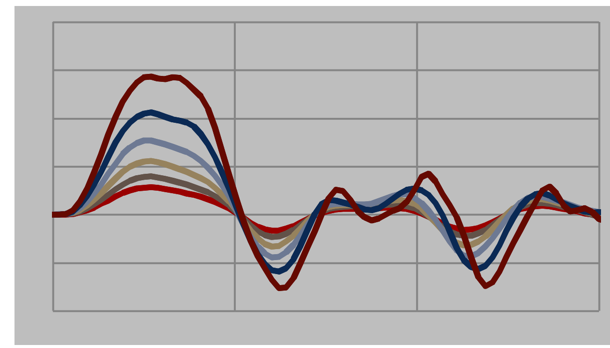

A Method to Capture Macroslip at Bolted Interfaces

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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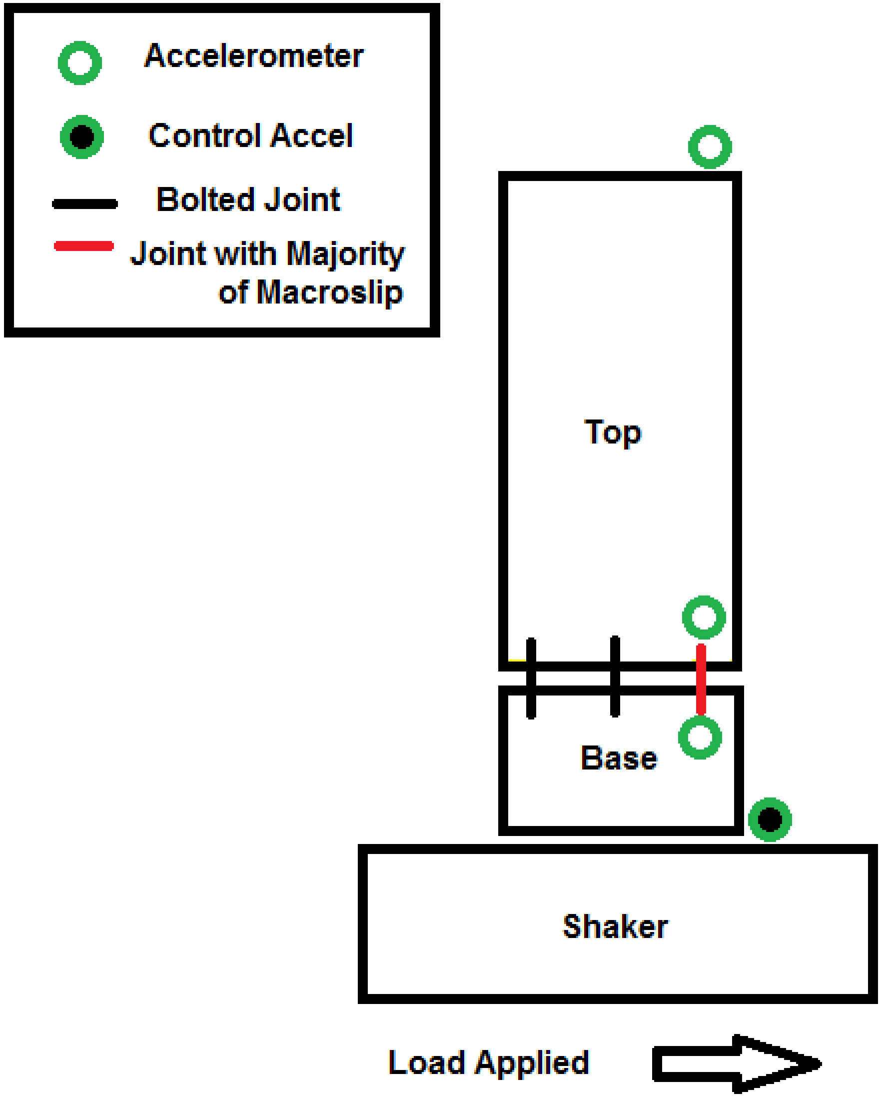
Outline of Presentation

- Problem Definition
- Background Information
- Test Setup
- Test Results
- Analysis Approach
- Analysis Results
- Summary
- Future Work
- Acknowledgements

Problem Definition

- Macroslip - Relative motion at bolted connections can occur for large shock loads as the internal shear force in the bolted connection overcomes the frictional resistive force. This dissipates energy and reduces the response of the components above the bolted connection.
- Need to be able to capture this nonlinear behavior in a structural dynamics model.
- An experiment was performed to induce and capture macroslip in a bolted joint of a simplified aerospace structure. This structure was then modeled in ADAMS with substructure representations of the components, and 3-D contact defined for the jointed connections. Adequacy of modeling method was then assessed.

Test Setup



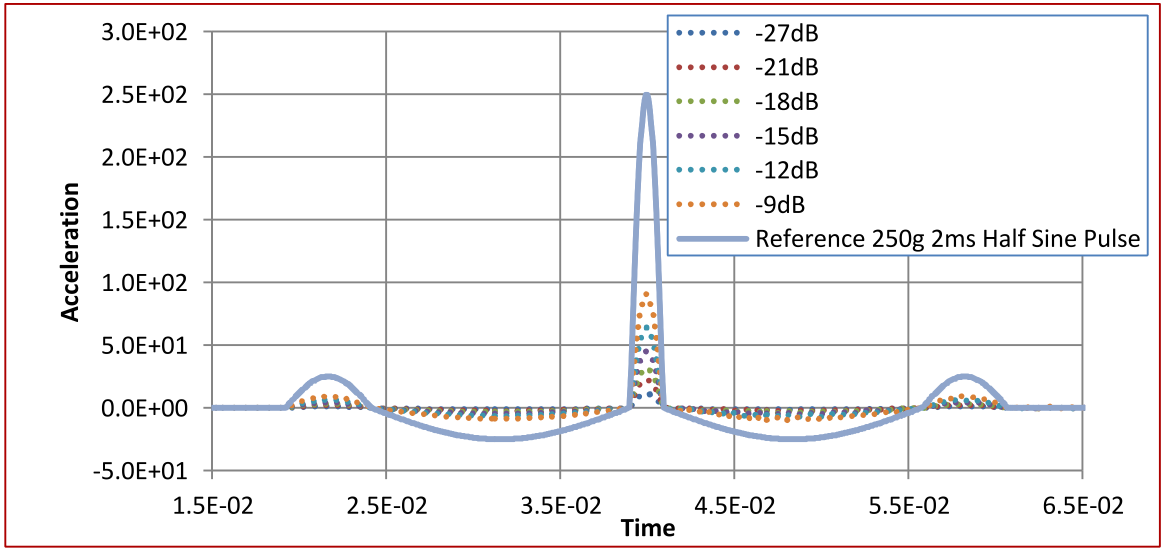
- Experiment set up to induce and capture macroslip in a bolted joint connection of a structure
- Preload was applied and varied to investigate slip as a function of preload
- 2ms duration half sine pulse applied to components via a base acceleration
- Load applied in lateral direction with magnitude of shock and amount of preload varied to investigate the initiation of macroslip

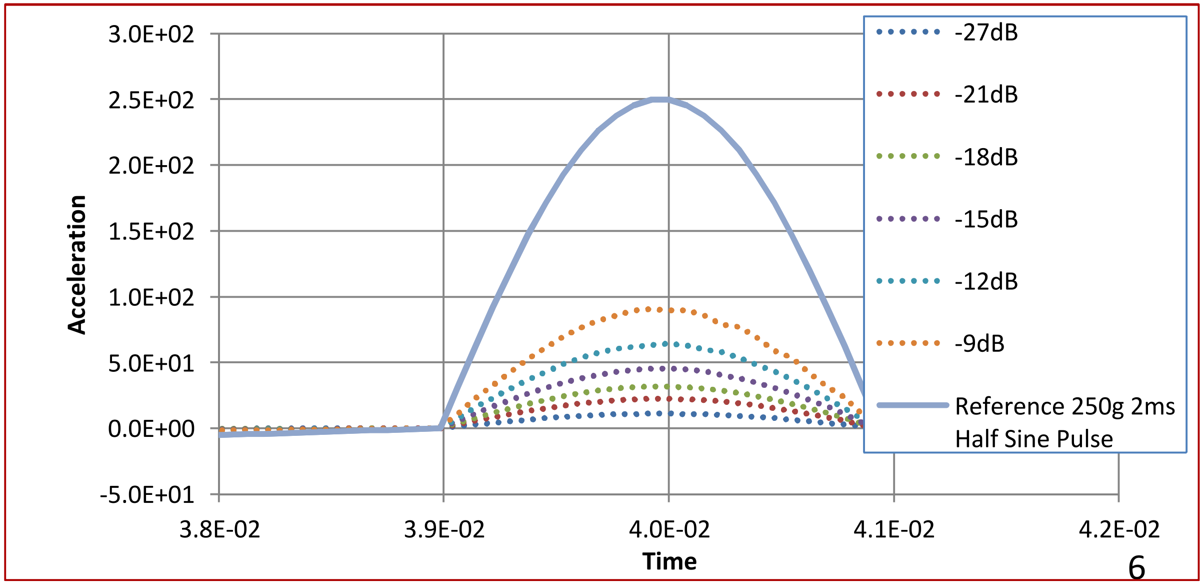
Test Matrix

Test/Torque	Load	Re-Torque?	Test/Torque	Load	Re-Torque?
1.1 / 43 in-lb	-27dB	Yes	9.1 / 70 in-lb	-27dB	Yes
1.2 / 43 in-lb	-21dB	No	9.2 / 70 in-lb	-9dB	No
1.3 / 43 in-lb	-18dB	No	10.1 / 70 in-lb	-27dB	Yes
1.4 / 43 in-lb	-15dB	No	10.2 / 70 in-lb	-6dB	No
1.5 / 43 in-lb	-12dB	No	11.1 / 56 in-lb	-27dB	Yes
1.6 / 43 in-lb	-9dB	No	11.2 / 56 in-lb	-24dB	No
2.1 / 43 in-lb	-27dB	Yes	11.3 / 56 in-lb	-21dB	No
2.2 / 43 in-lb	-24dB	No	11.4 / 56 in-lb	-18dB	No
2.3 / 43 in-lb	-18dB	No	11.5 / 56 in-lb	-15dB	No
2.4 / 43 in-lb	-15dB	No	11.6 / 56 in-lb	-12dB	No
3.1 / 43 in-lb	-27dB	Yes	11.7 / 56 in-lb	-9dB	No
3.2 / 43 in-lb	-15dB	No	12.1 / 56 in-lb	-27dB	Yes
4.1 / 100 in-lb	-27dB	Yes	12.2 / 56 in-lb	-12dB	No
4.2 / 100 in-lb	-24dB	No	13.1 / 56 in-lb	-27dB	Yes
4.3 / 100 in-lb	-21dB	No	13.2 / 56 in-lb	-9dB	No
4.4 / 100 in-lb	-18dB	No	14.1 / 56 in-lb	-27dB	Yes
4.5 / 100 in-lb	-15dB	No	14.2 / 56 in-lb	-6dB	No
4.6 / 100 in-lb	-12dB	No	15.1 / 43 in-lb	-27dB	Yes
4.7 / 100 in-lb	-9dB	No	15.2 / 43 in-lb	-21dB	No
4.8 / 100 in-lb	-6dB	No	15.3 / 43 in-lb	-18dB	No
5.1 / 100 in-lb	-27dB	Yes	15.4 / 43 in-lb	-15dB	No
5.2 / 100 in-lb	-6dB	No	15.5 / 43 in-lb	-12dB	No
6.1 / 100 in-lb	-27dB	Yes	15.6 / 43 in-lb	-9dB	No
6.2 / 100 in-lb	-3dB	No	15.7 / 43 in-lb	-6dB	No
7.1 / 70 in-lb	-27dB	Yes	16.1 / 43 in-lb	-27dB	No
7.2 / 70 in-lb	-24dB	No	16.2 / 43 in-lb	-24dB	No
7.3 / 70 in-lb	-21dB	No	16.3 / 43 in-lb	-21dB	No
7.4 / 70 in-lb	-18dB	No	16.4 / 43 in-lb	-18dB	No
7.5 / 70 in-lb	-15dB	No	16.5 / 43 in-lb	-15dB	No
7.6 / 70 in-lb	-12dB	No	16.6 / 43 in-lb	-12dB	No
8.1 / 70 in-lb	-27dB	Yes	16.7 / 43 in-lb	-9dB	No
8.2 / 70 in-lb	-12dB	No	16.8 / 43 in-lb	-6dB	No

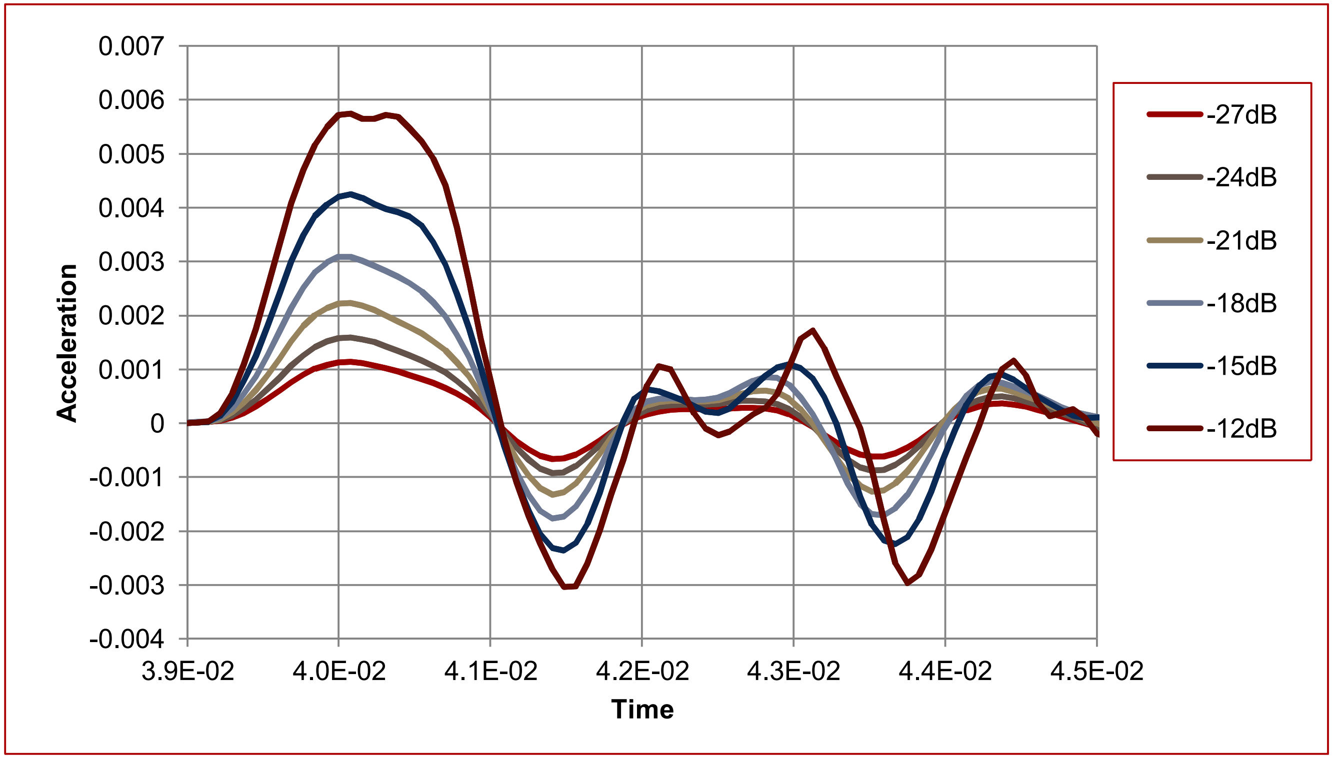
Reference Level is 250 G

Sample Input to Base of Structure

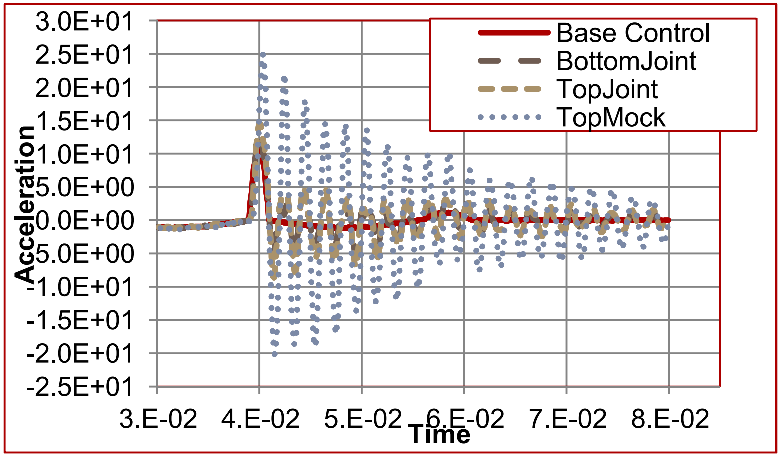


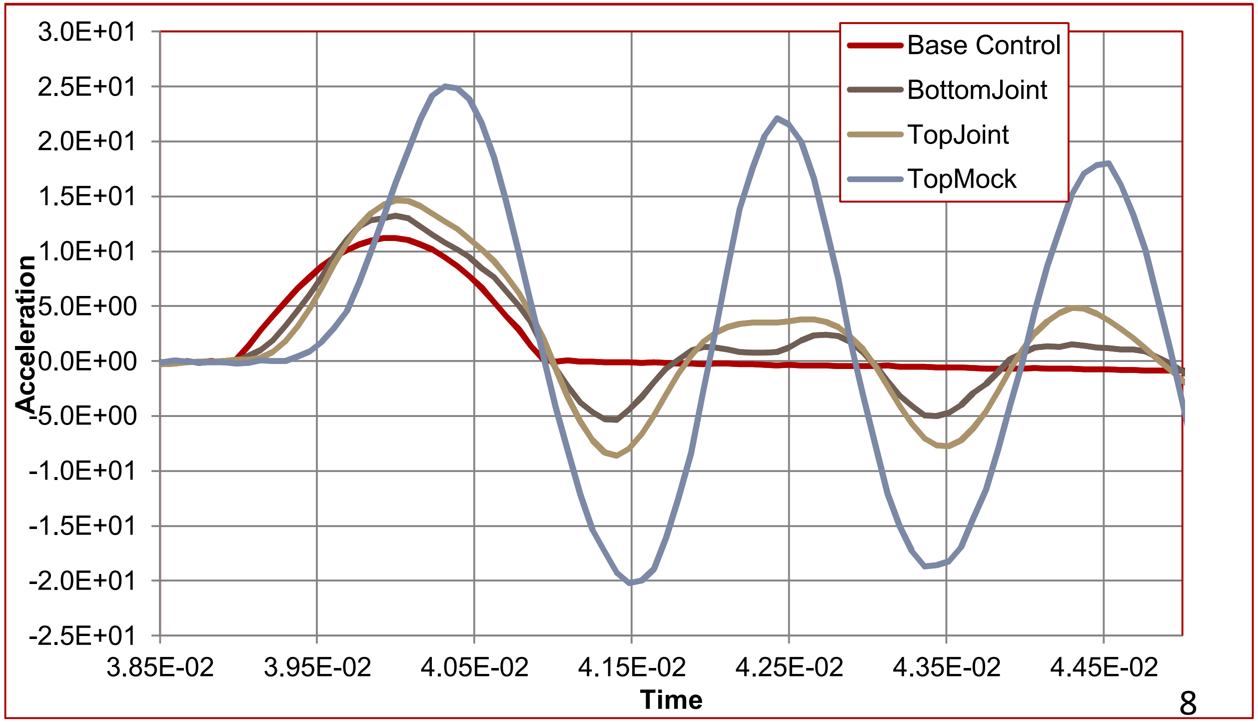


Test Results – 70 in-lb Torque

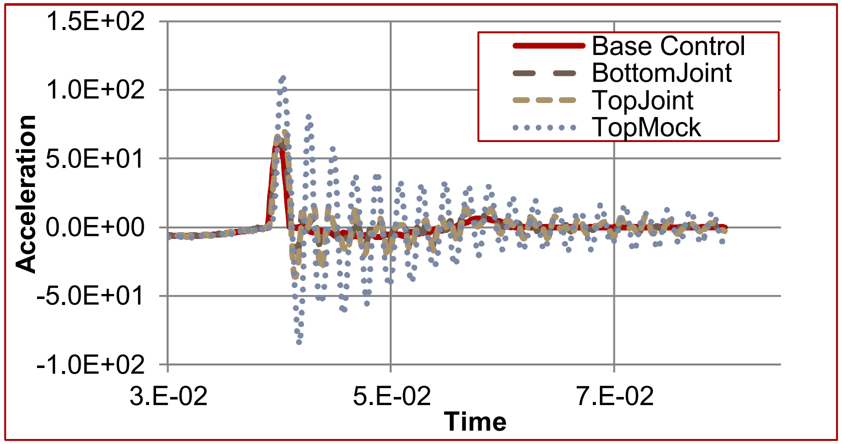


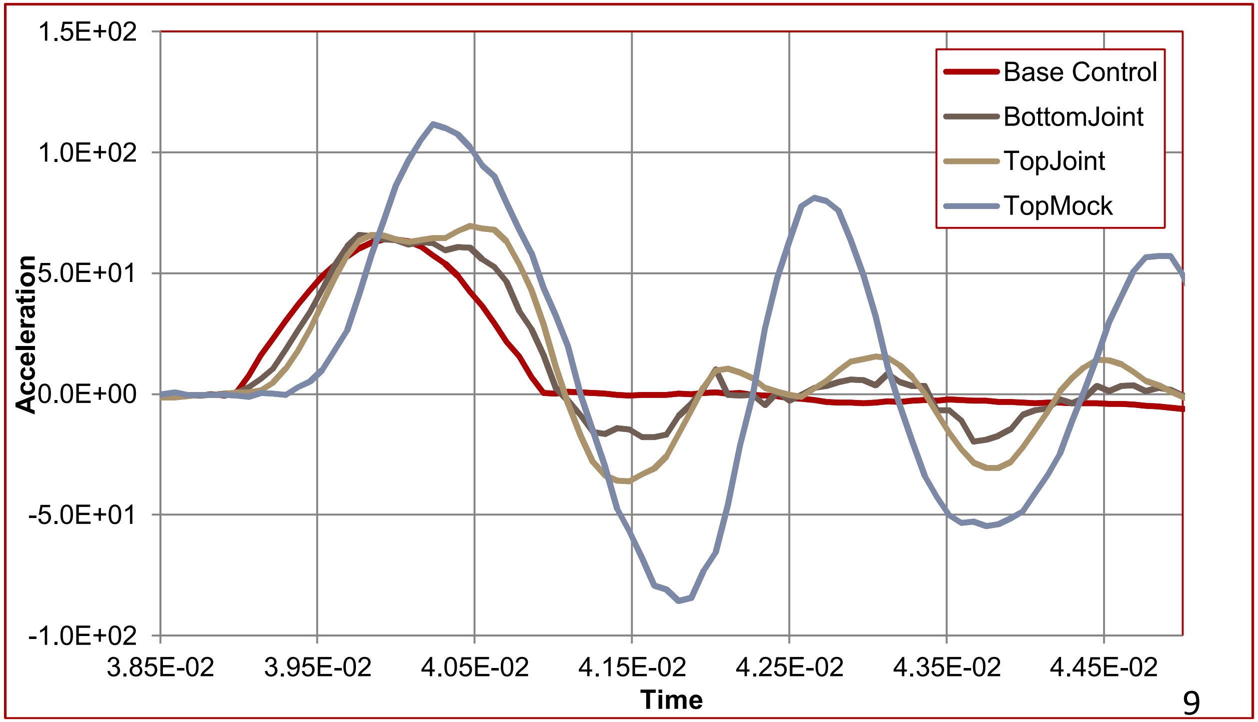
Test Results – 70 in-lb Torque -27dB





Test Results – 70 in-lb Torque -12dB

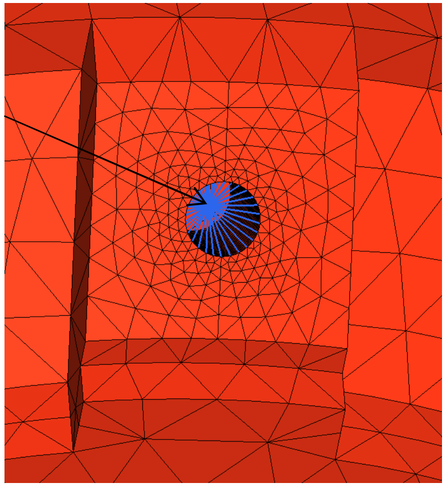




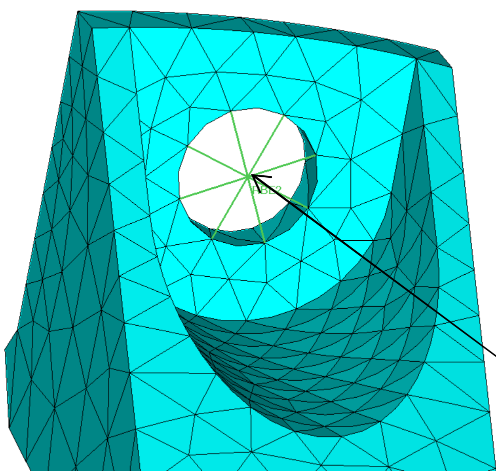
Analysis Approach

- A combination of linear FEMs in the form of substructures incorporated into a nonlinear multi-body dynamics solver.
- Nonlinear portion of model is the complex behavior of the bolted interfaces.
- Contact between preloaded surfaces is included, as well as friction, both static and dynamic
- Top and base were modeled with linear finite element techniques and then reduced to their boundary mass and stiffness representation through substructures (boundaries include the average stiffness at the bolted interfaces)
- Experiments 7-10 were used for comparison of experimental results to modeling results.
- 70 in-lbs of torque (1400 lbs of axial load in the bolts)
- 63 (-12 dB), 89 (-9 dB), and 125 (-6 dB) G peak accelerations

Analysis Approach (Continued)



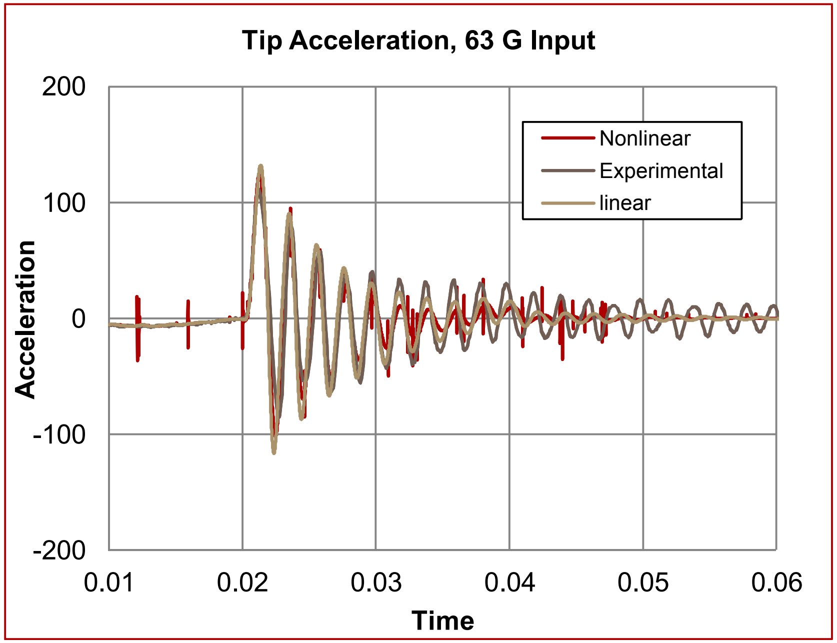
Internal Thread Region

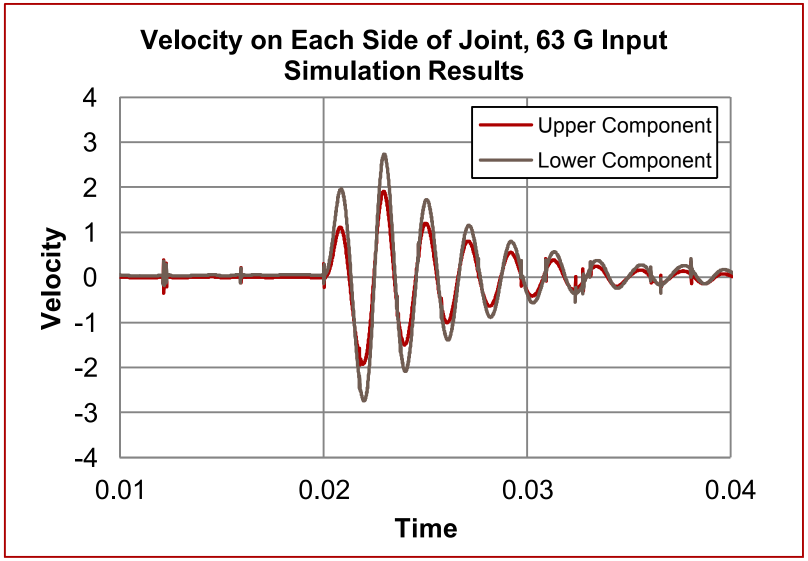


Bolt Head Region

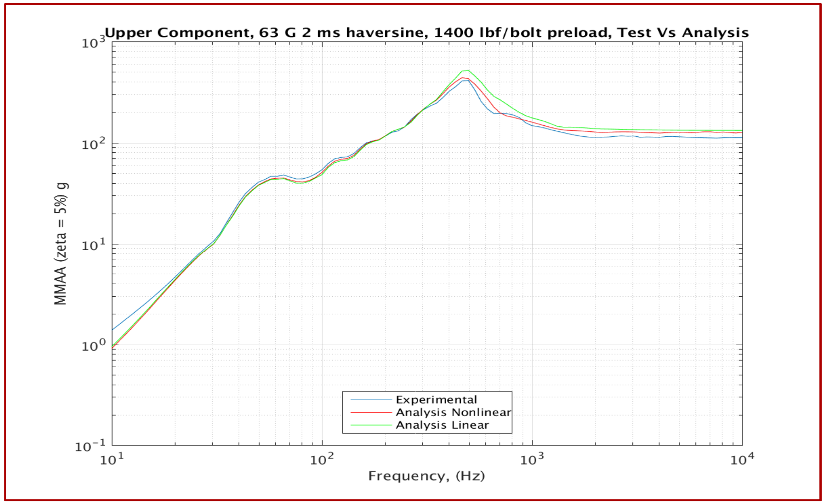
- Substructures imported and boundary nodes connected with spring elements.
- Lateral interaction – Coulomb Friction
- Compressive/Tensile stiffness – Mating parts and preload control
- Shear stiffness - function of preload and friction, bistop element used to account for joint pinning
- Nonlinear solution compared to linear solution using bushing elements

Analysis Results – 63 G Peak Accel

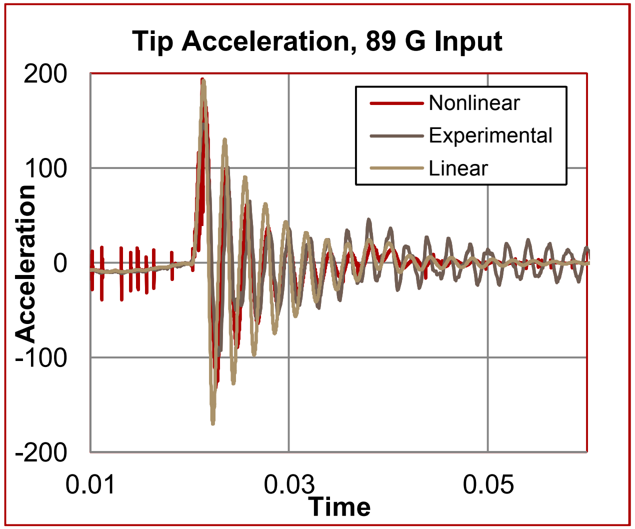


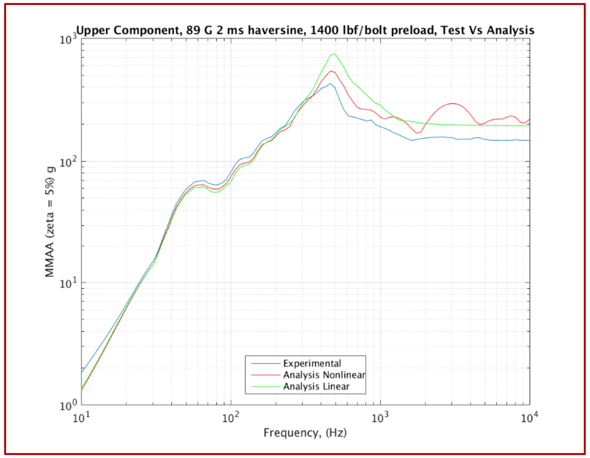


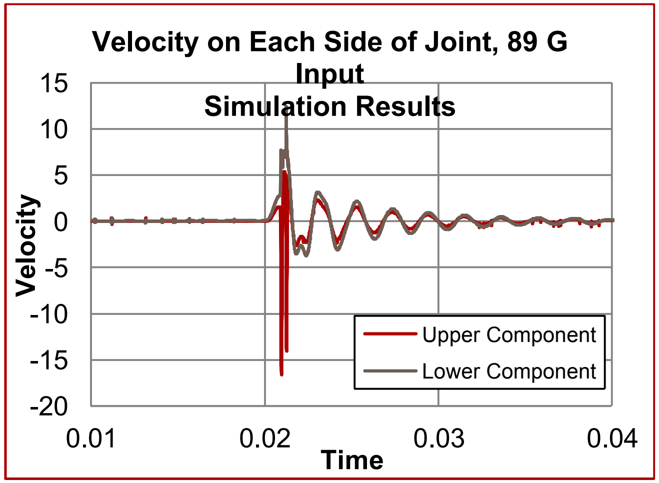
- Examination of velocity shows little or no slipping and near linear response.
- Good agreement between two models and experimental data.



Analysis Results – 89 G Peak Accel







- Slipping has occurred in first half cycle of response.
- Change in period of the response
- SRS shows reduction in acceleration amplitude which is due to energy loss due to macroslip
- High Frequency asymptote is higher for the simulation than for the experiment, as evidenced in the first cycle of the response.

Analysis Results – 125 G Peak Accel

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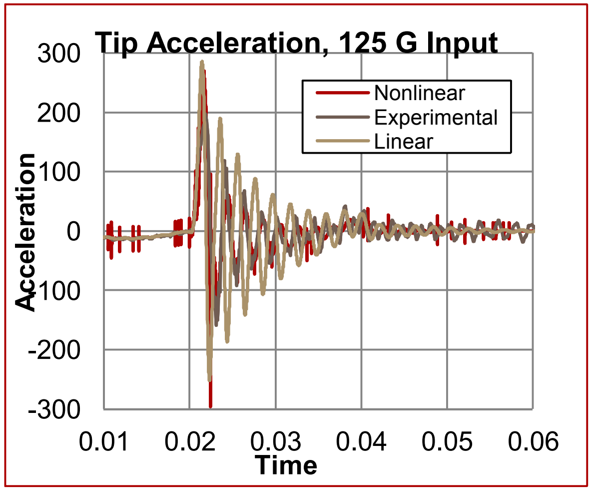

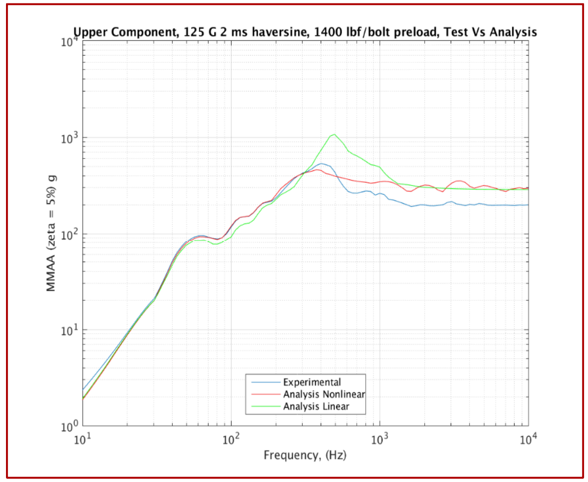

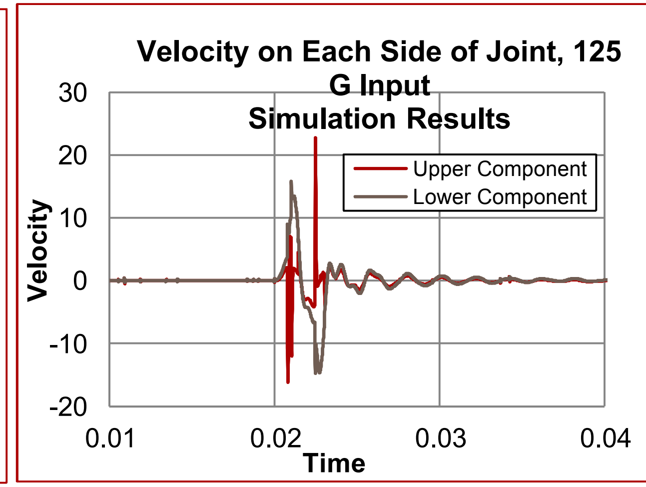

- Slipping has occurred in the first full cycle of the response.
- Change in period as well as amplitude of response observed.
- Nonlinear solution acceleration peaks are higher than the experimental data for first cycle and lower than experimental data for subsequent cycles, but the periods very closely match.
- SRS shows significant reduction in acceleration amplitude due to energy loss due to macroslip.

Summary

- Experiments produced various levels of macroslip at a bolted joint
- A representative experiment was selected and modeled using a combination of linear finite elements within a nonlinear multi-body dynamics solver with conventional numerical integration schemes.
- The modeling techniques were able to improve the ability to capture macroslip in the finite element model representation of the structure, and to prevent massive over-prediction of the response of a structure to a large shock load in which macroslip is induced.
- This approach shows promise for improving analysis capabilities when dealing with mechanical assemblies which experience macroslip at bolted interfaces

Future Work

- Use modeling method to assess how well it does with the rest of the experiment results.
- Apply method to a more complex structure and compare to experimental results.

Acknowledgements

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QUESTIONS?