SAND2016-0964C

Stress Waves Propagating through Bolted Joints

Keegan J. Moore

University of Illinois at Urbana-Champaign

Robert C. Flicek

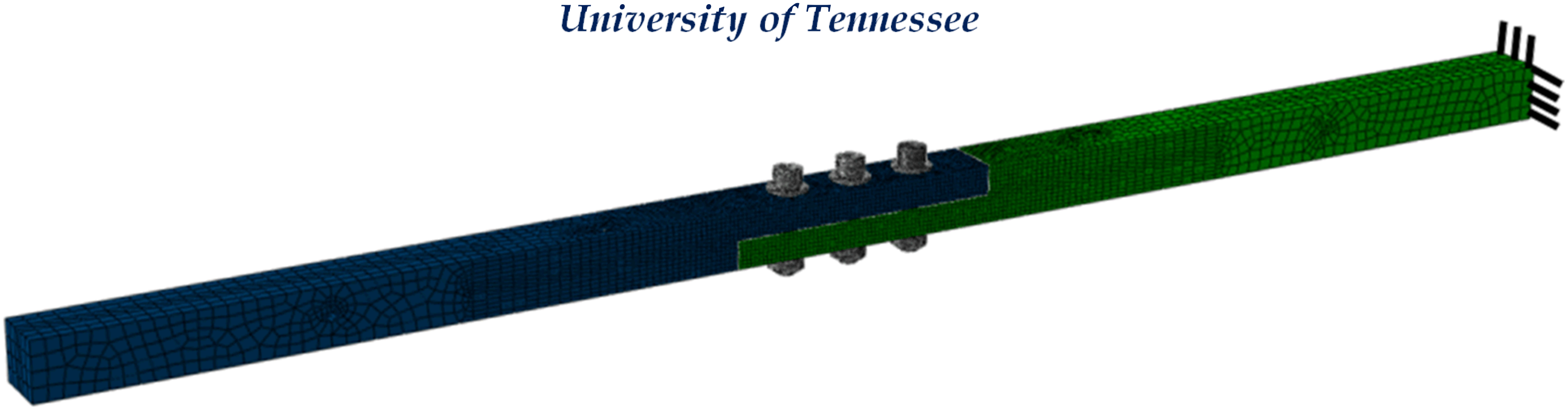
Akima Infrastructure Services, under contract to Sandia National Laboratories

Gustavo M. Castelluccio, Mathew R.W. Brake, Chris I. Hammetter

Sandia National Laboratories

Timothy J. Truster

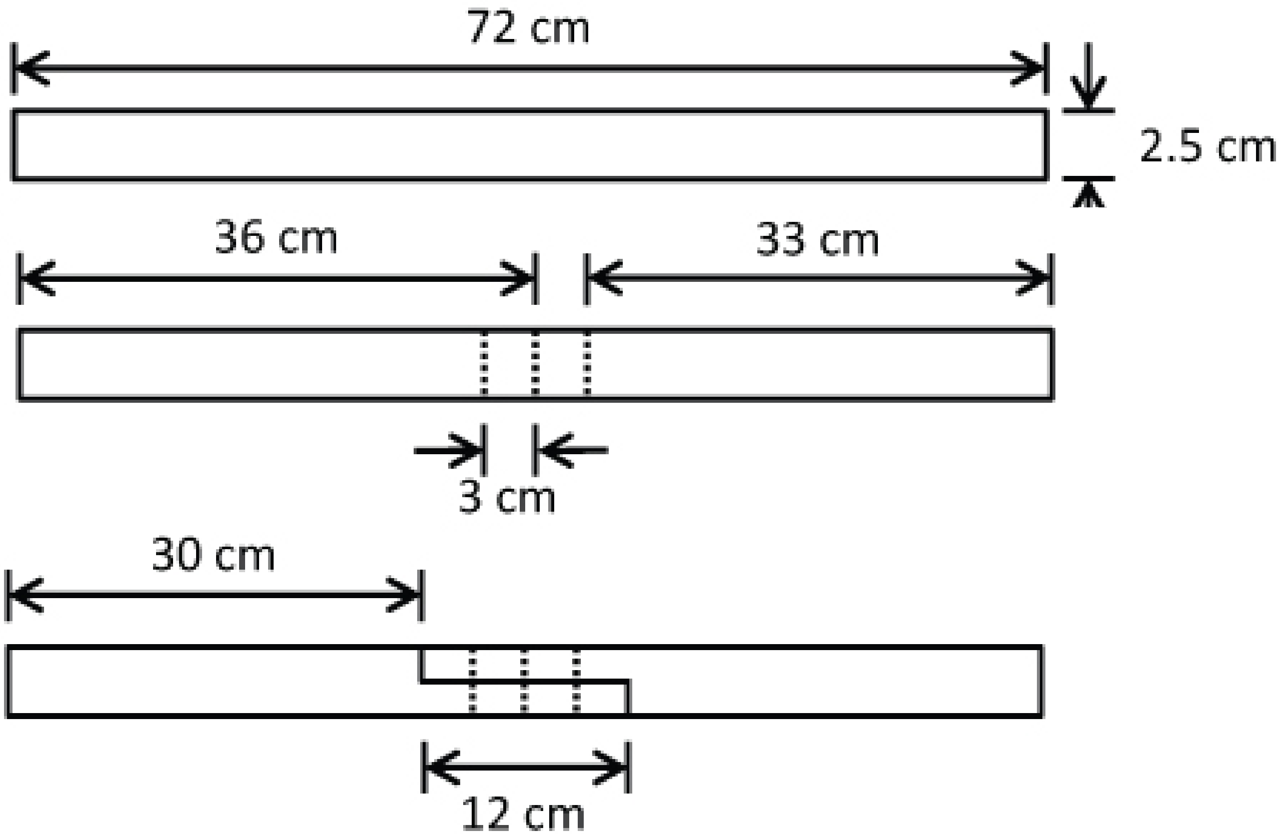
University of Tennessee



Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Introduction

→ Benchmark System: Brake-Reuß Beam



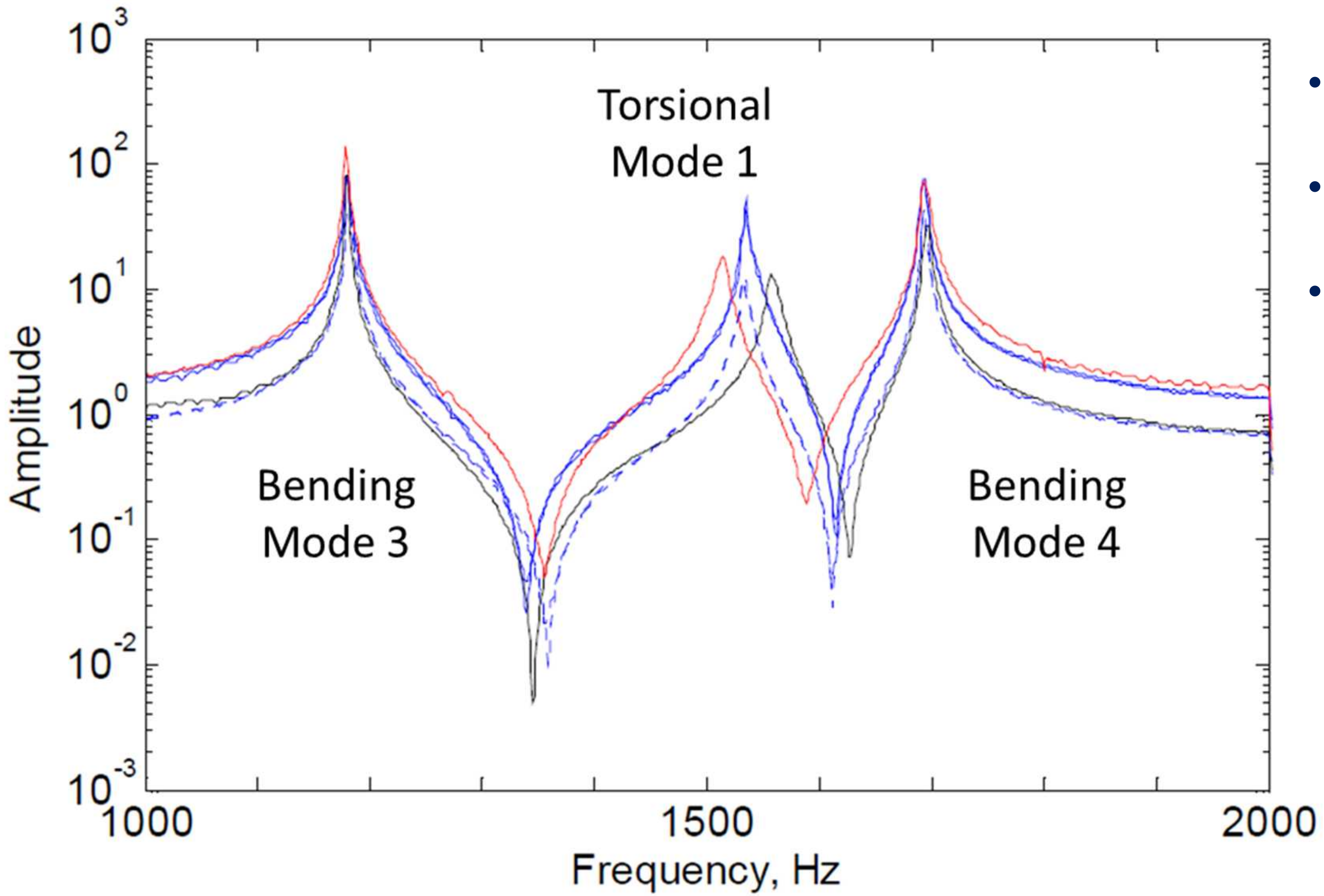
Monolithic beam

Monolithic beam w/ bolts

Two beams joined with a lap joint.

- Brake-Reuß beam: 72 cm long beam with a three bolt lap joint.
- Multiple versions to assess contribution of joint to dynamics.

Introduction
→ Motivation for Current Research

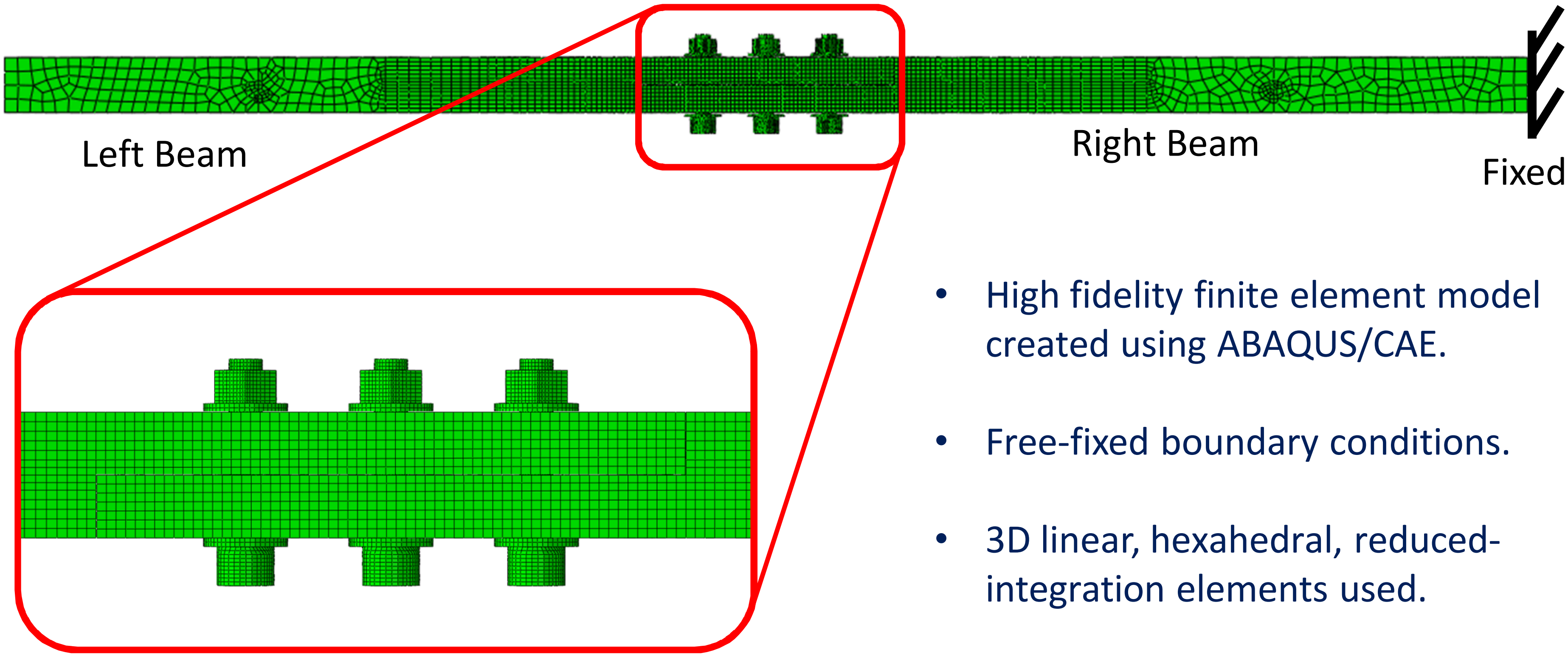


- 5 Nm torque
- Free-free BC
- Off-center shaker excitation

- Torsional modes very sensitive to preloads and tightening order and lack repeatability.

Introduction

→ Modeling Approach

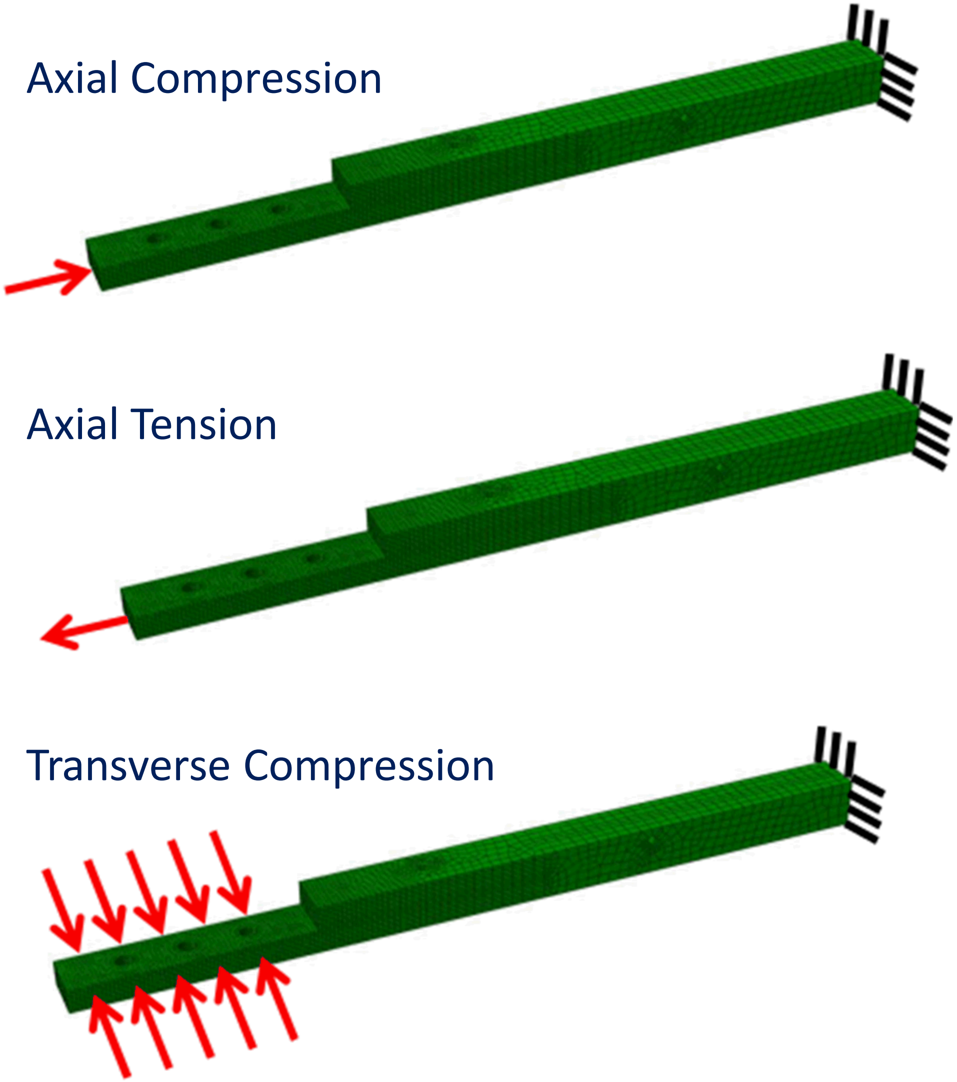


- High fidelity finite element model created using ABAQUS/CAE.
- Free-fixed boundary conditions.
- 3D linear, hexahedral, reduced-integration elements used.

- Nuts, bolts, and washers modeled separately from beams, but connected using node-tie constraints.
- Surface-to-surface contact pair with standard Coulomb dry friction model, $\mu = 0.3$.
- Bolt load of 4 kN applied to each bolt.

Simulation Phase I

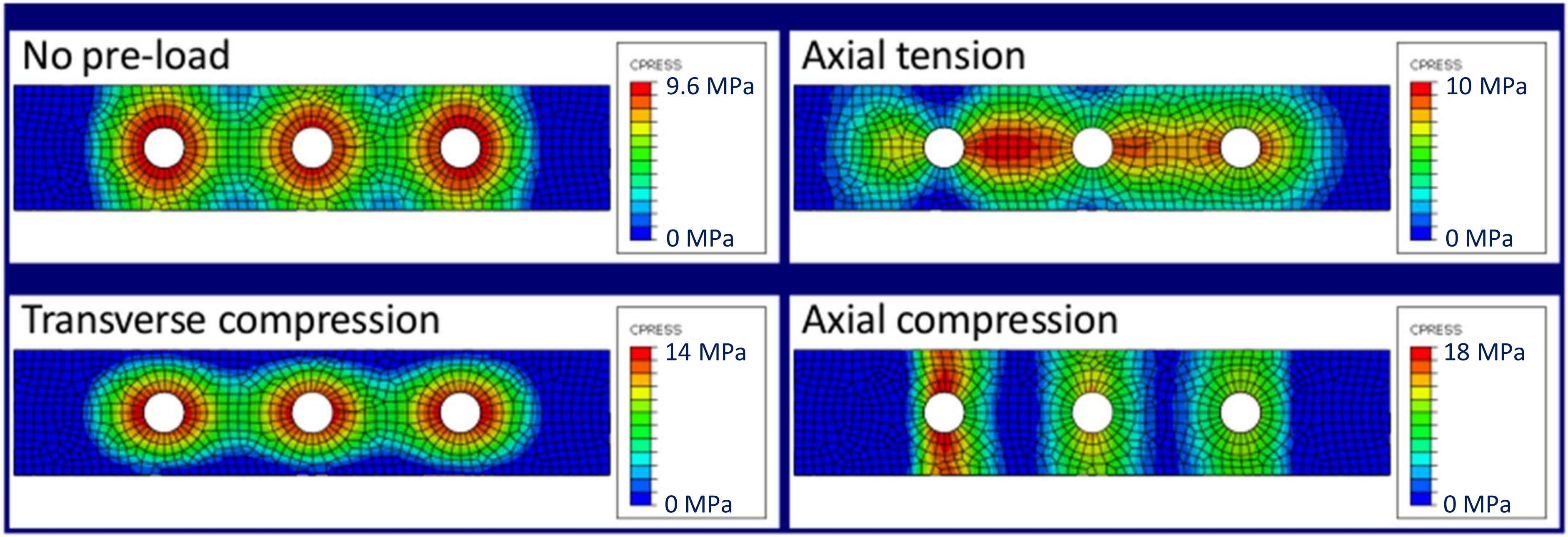
→ Residual Stress Application



- Three types of residual stresses investigated
- Residual stresses installed by
  1. Apply pre-load to right beam
  2. Apply bolt load
  3. Release pre-load
- All pre-loads applied using specified displacements.

Simulation Phase I

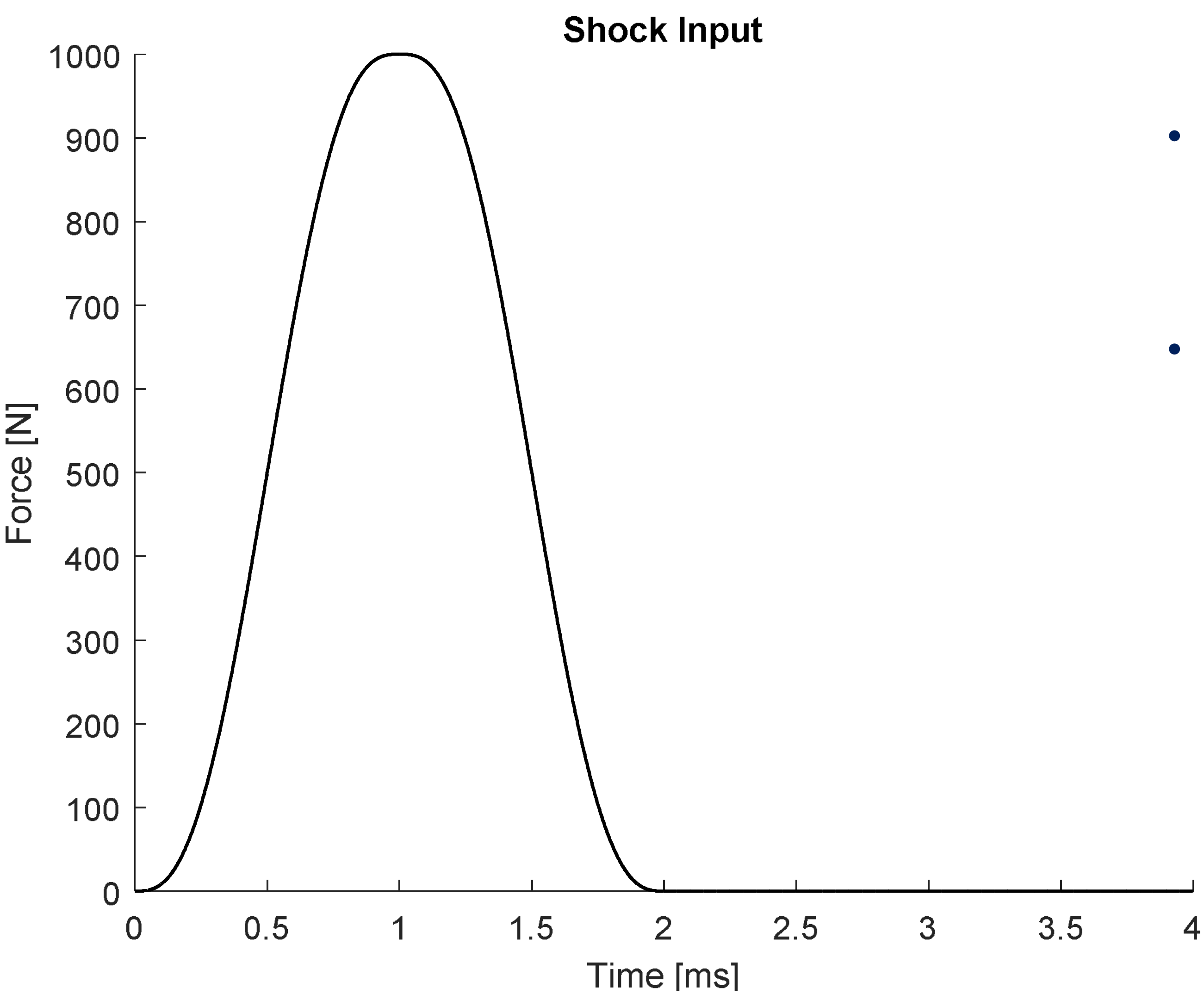
→ Results: Residual Stress Effect on Contact Pressure



- Pre-load significantly modifies the contact's behavior.
- Axial tension and compression have opposite effects.
- Transverse compression has least effect.
- Axial compressions results in separation bands.

Simulation Phase II

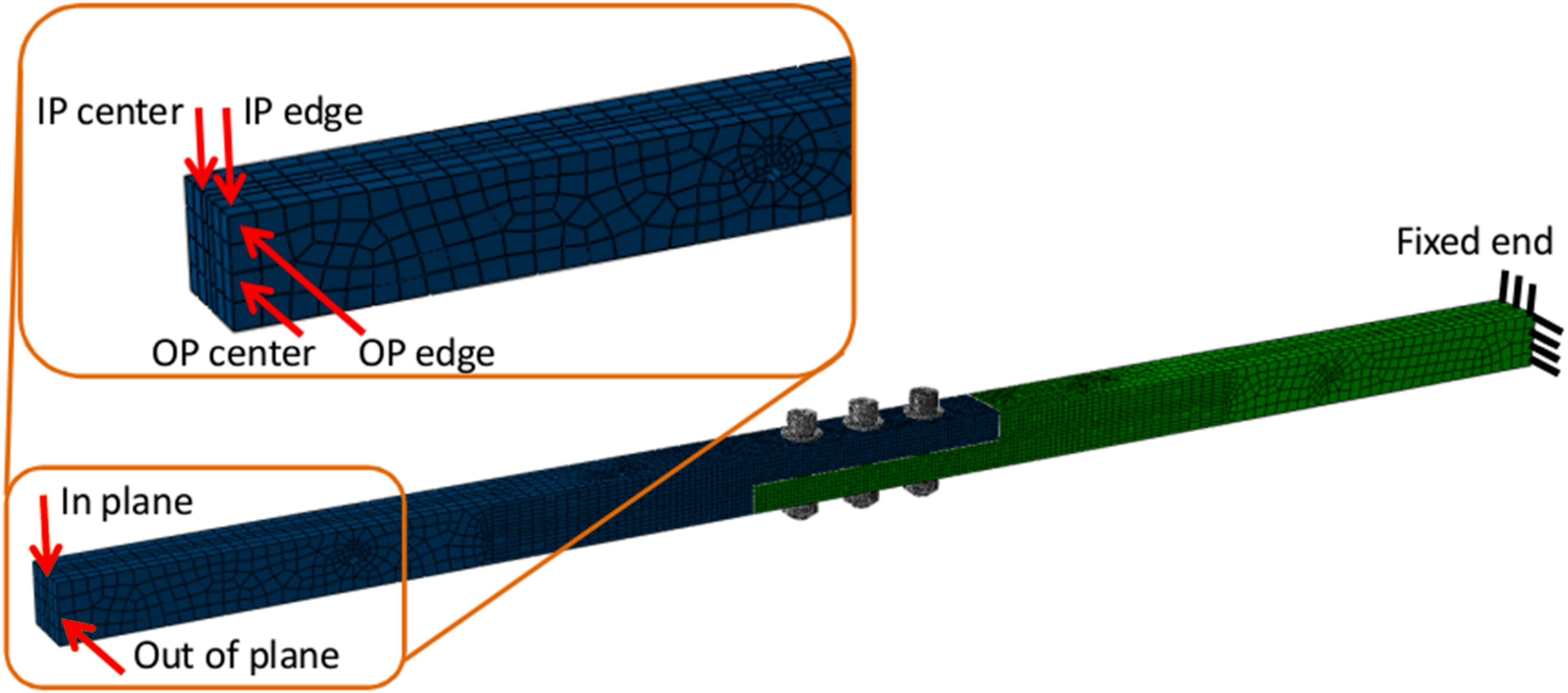
→ Shock Input



- Shock inputs applied using ABAQUS/CAE Smooth Step amplitude command.
- Work done kept constant by varying amplitude and duration of shock.

Simulation Phase II

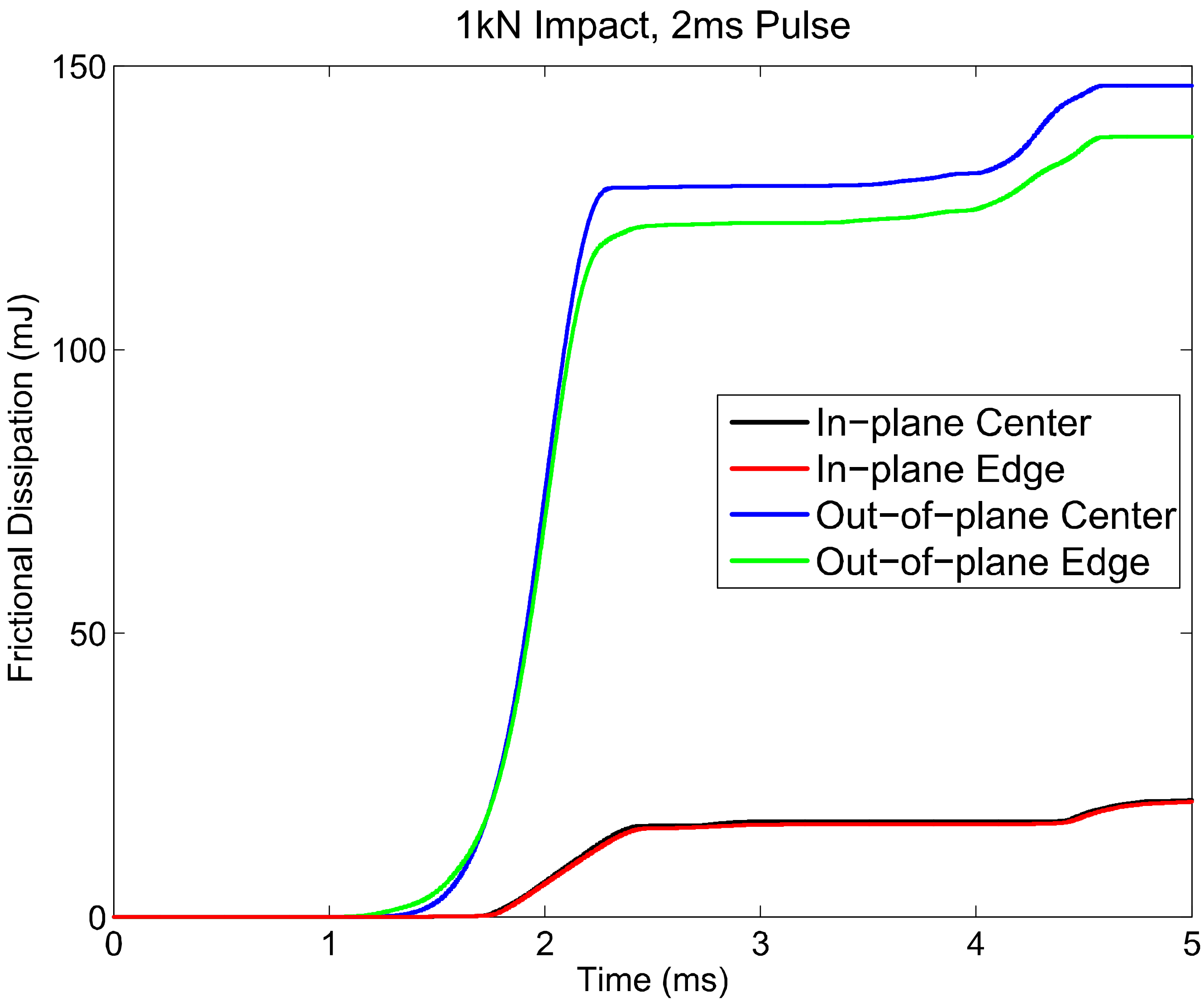
→ Shock Input Locations



- In plane and out of plane loadings considered – beam is stiffest in plane.
- Center and edge shocks considered to compare bending and torsional effects.

Simulation Phase II

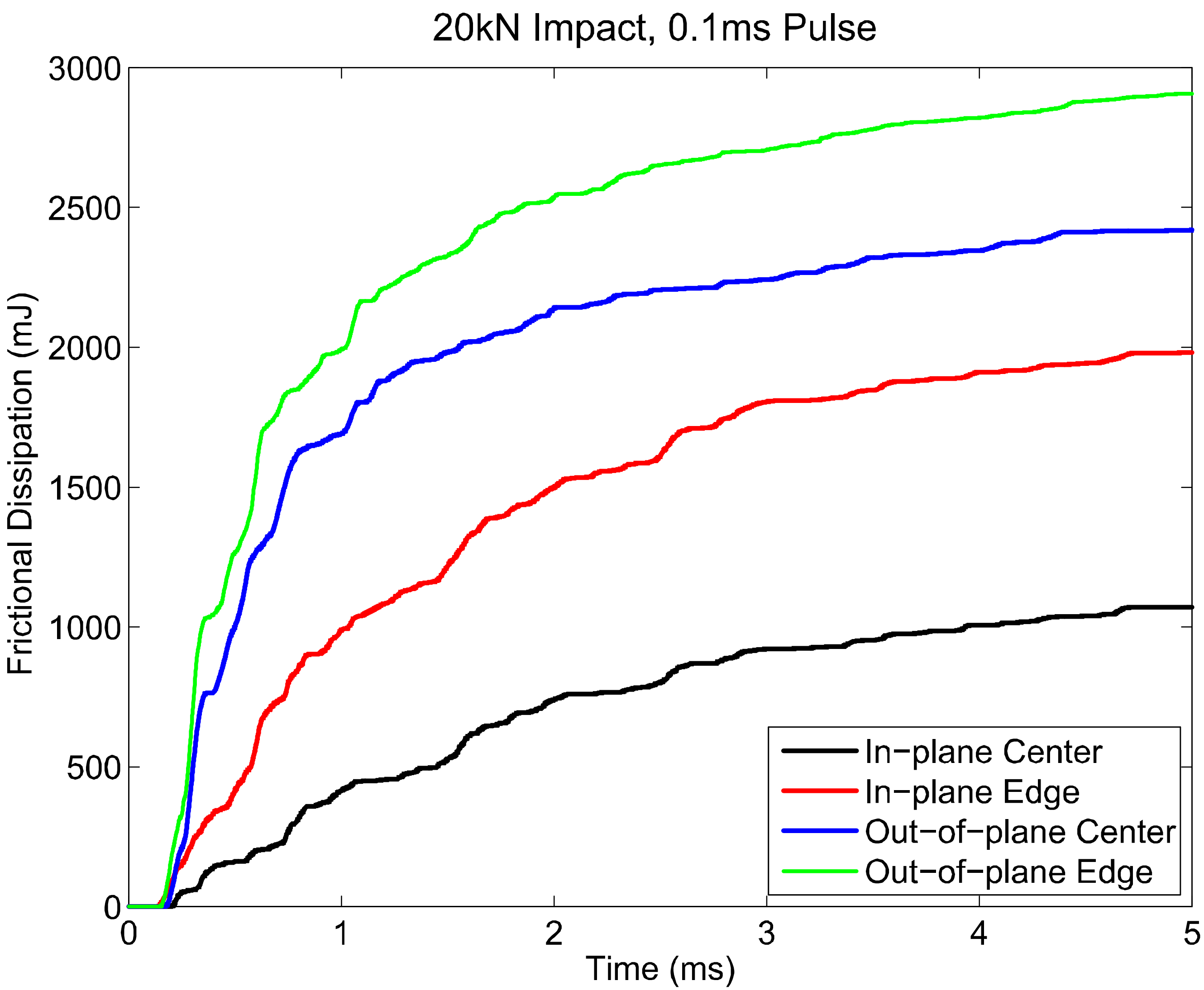
→ Results: Shock Location – Low Amplitude Shock



- Out-of-plane impacts result in higher frictional dissipation.
- Small difference between center and edge impacts.
- Torsional effects minimal

Simulation Phase II

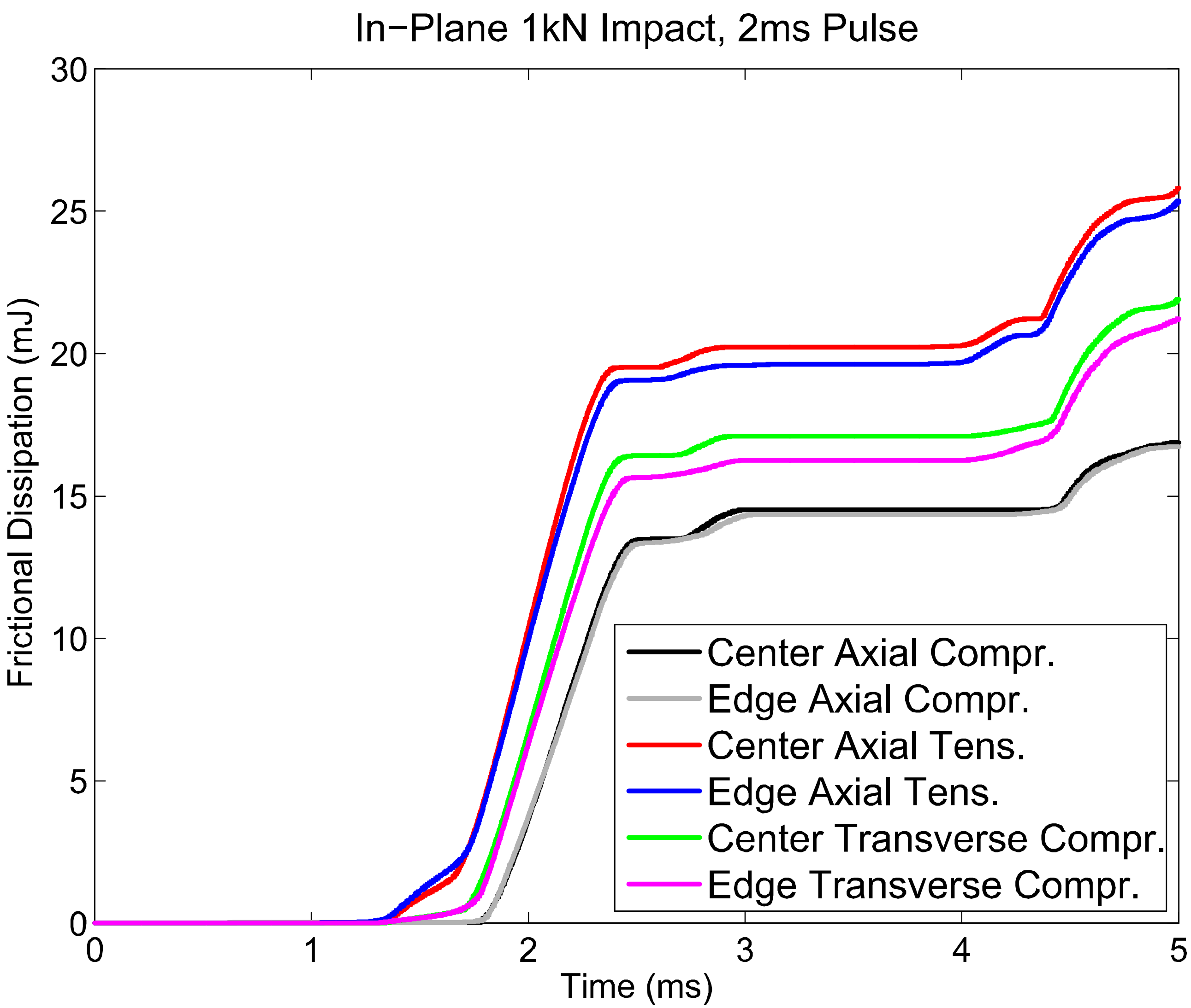
→ Results: Shock Location – High Amplitude Shock



- Out-of-plane impacts result in higher frictional dissipation.
- Large difference between center and edge impacts.
- Torsional effects more prominent.

Simulation Phase II

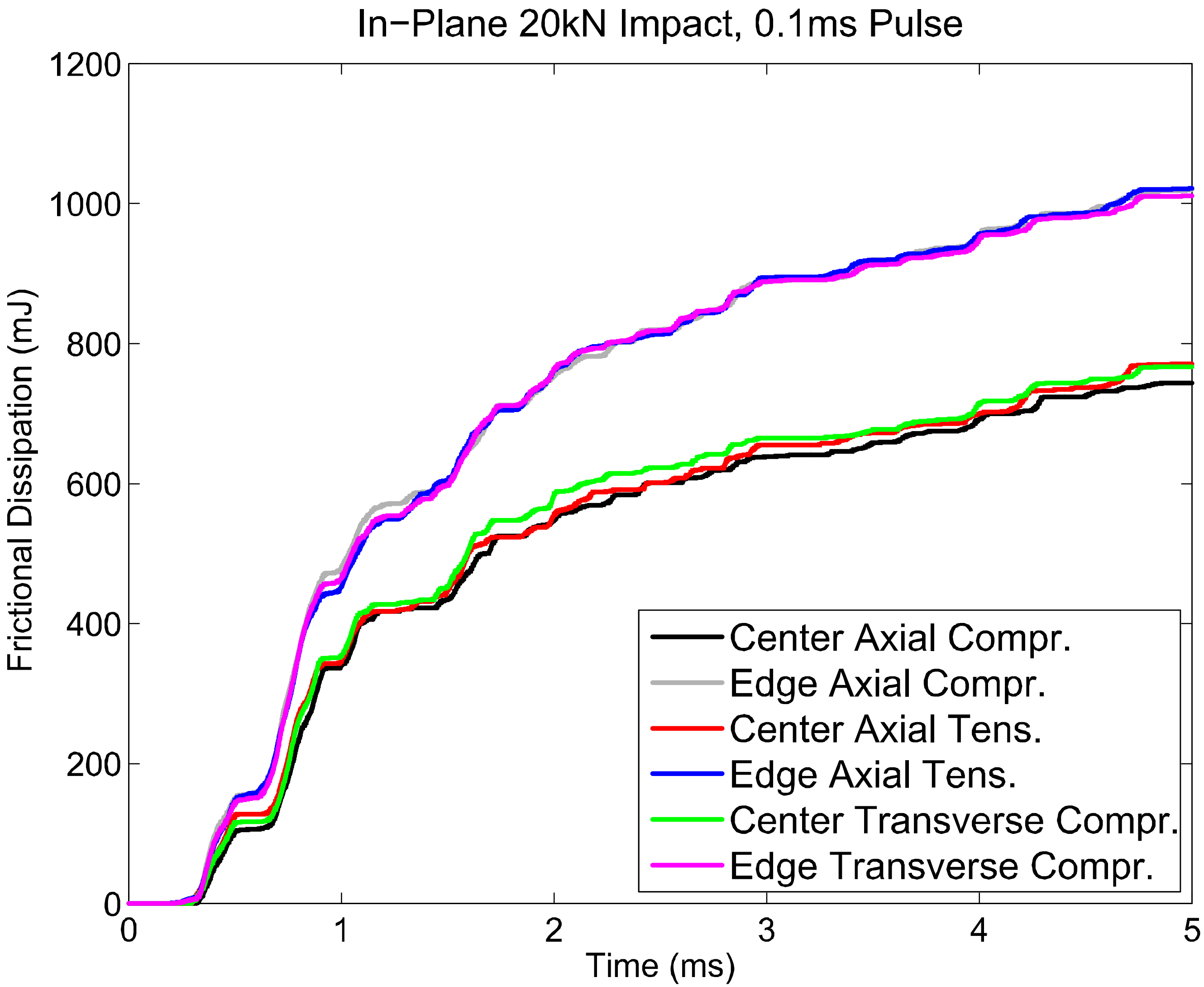
→ Results: Residual Stress – Low Amplitude Shock



- Residual stress has some effect.
- Small difference between center and edge impacts.
- Torsional effects minimal.

Simulation Phase II

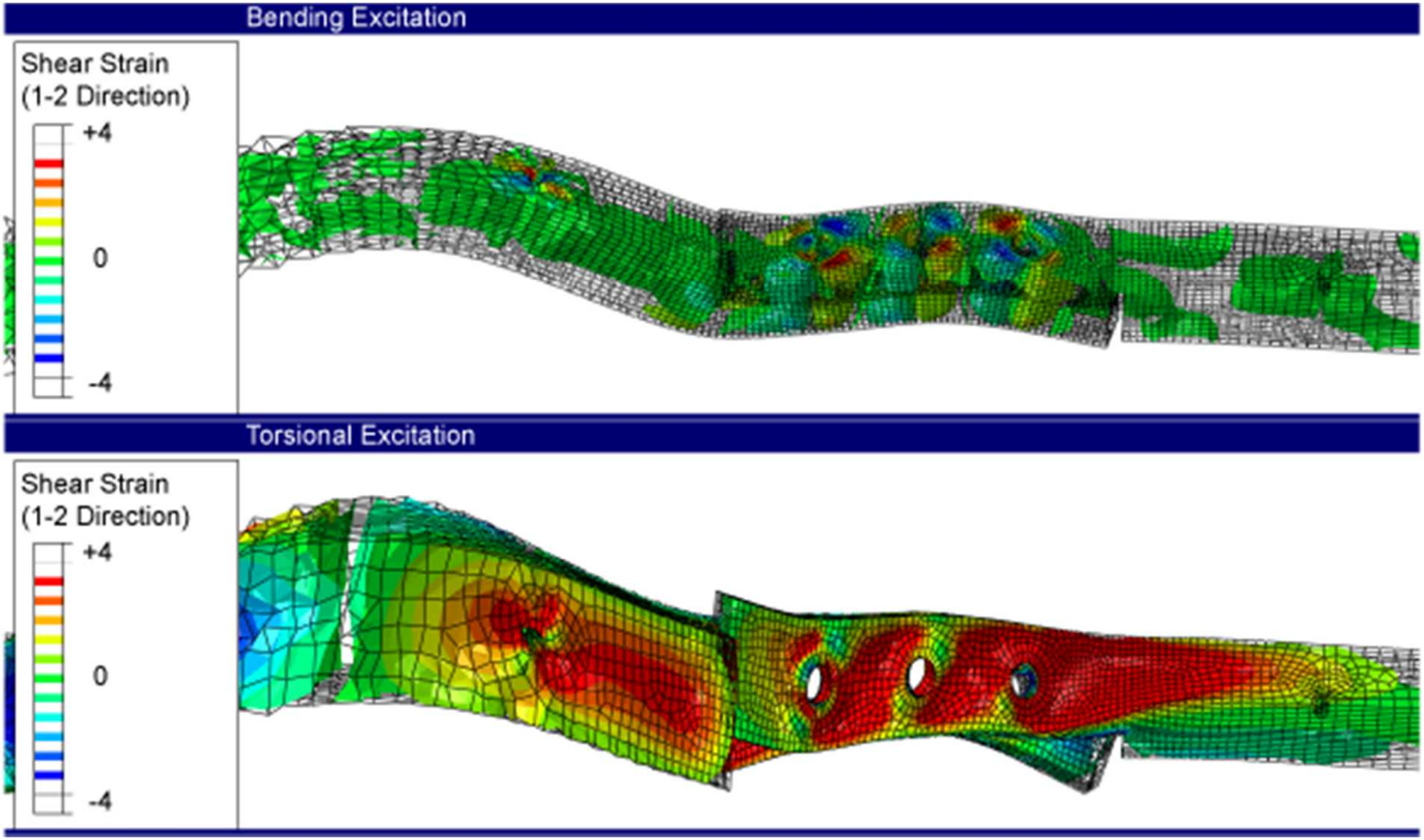
→ Results: Residual Stress – High Amplitude Shock



- Residual stress has minimal effect.
- Large difference between center and edge impacts.
- Torsional effects more prominent

Simulation Phase III

→ Results: Bending vs. Torsional Excitation



- Large shear contributions under torsional excitation.

Summary

- High fidelity finite element model used to simulate dynamic shock response of Brake-Reuß beam.
- Residual stresses have great effect on contact pressure – axial compression results in separation bands.
- Shock loading location varied to study in plane and out of plane bending and torsional effects. Work done kept constant by varying duration and amplitude.
- At low shock amplitudes,
  - Out of plane impacts result in higher dissipation
  - Torsional effects minimal
  - Residual stress effects more prominent
- At high shock amplitudes
  - Out of plane impacts result in higher dissipation
  - Torsional effects more prominent
  - Residual stress effect minimal

References

1. "The Mechanics of Jointed Structures: Research on the Joint Challenges Defined at the International Workshops on the Mechanics of Jointed Structures," Edited by M.R.W. Brake, *Springer*, 2016.
2. M. R. W. Brake, P. Reuss, C. W. Schwingshackl, L. Salles, M. E. Negus, D. E. Peebles, R. L. Mayes, J.-C. Bilbao-Ludena, M. S. Bonney, S. Catalfamo, C. Gastaldi, J. Gross, R. M. Lacayo, B. A. Robertson, S. Smith, C. Swacek, and M. Tiedemann, "The 2014 Sandia Nonlinear Mechanics and Dynamics Summer Research Institute," 2015, *SAND2015-1876*, Sandia National Laboratories, Albuquerque, NM.
3. M. R. Brake, P. Reuss, D. J. Segalman, and L. Gaul, "Variability and Repeatability of Jointed Structures with Frictional Interfaces," *IMAC XXXII A Conference and Exposition on Structural Dynamics*, Orlando, FL, February 2014.