SAND2015-6184D

# Project 2: Numerical Round Robin for Prediction of the Behavior of Lap Joints

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# Objective

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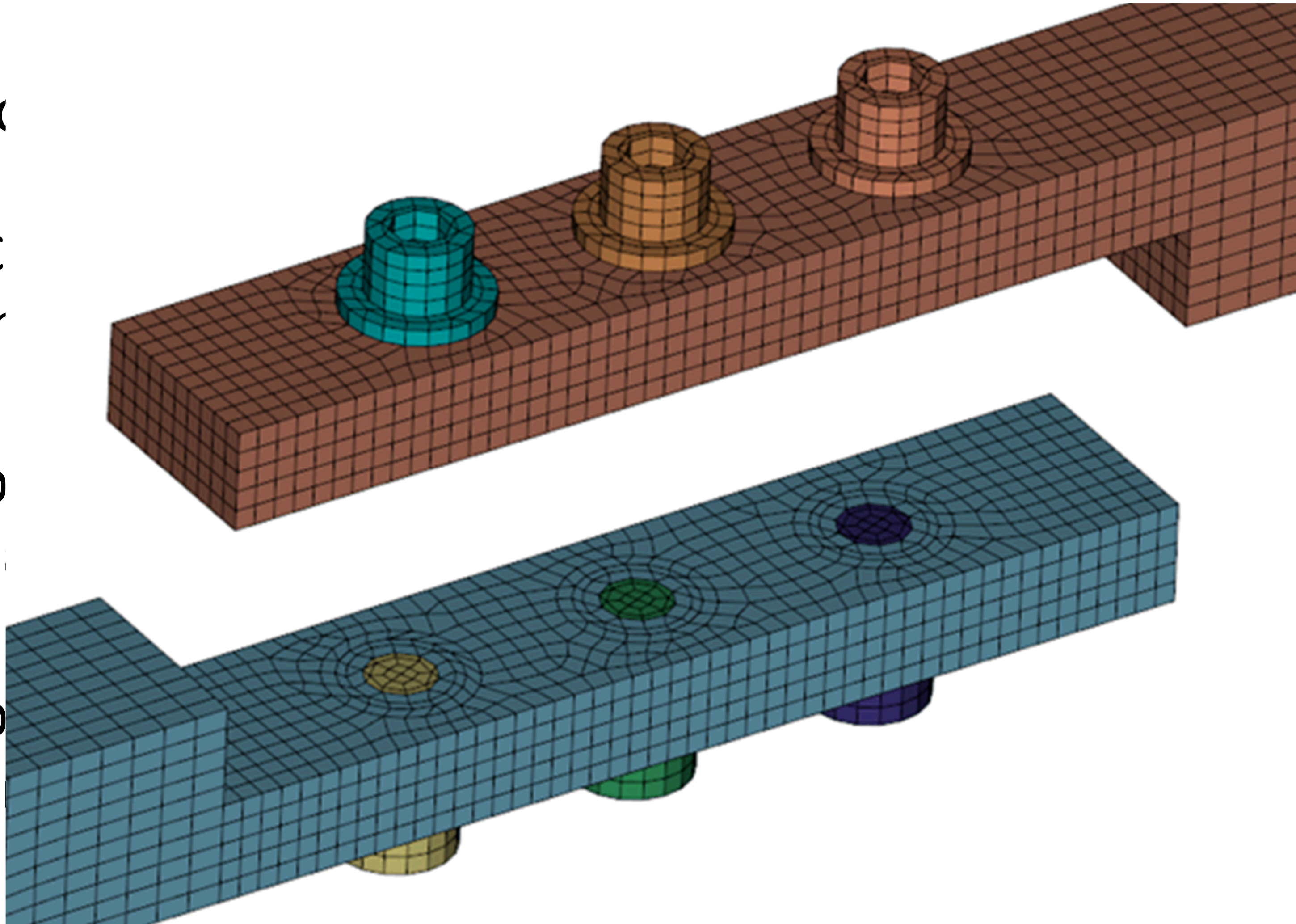
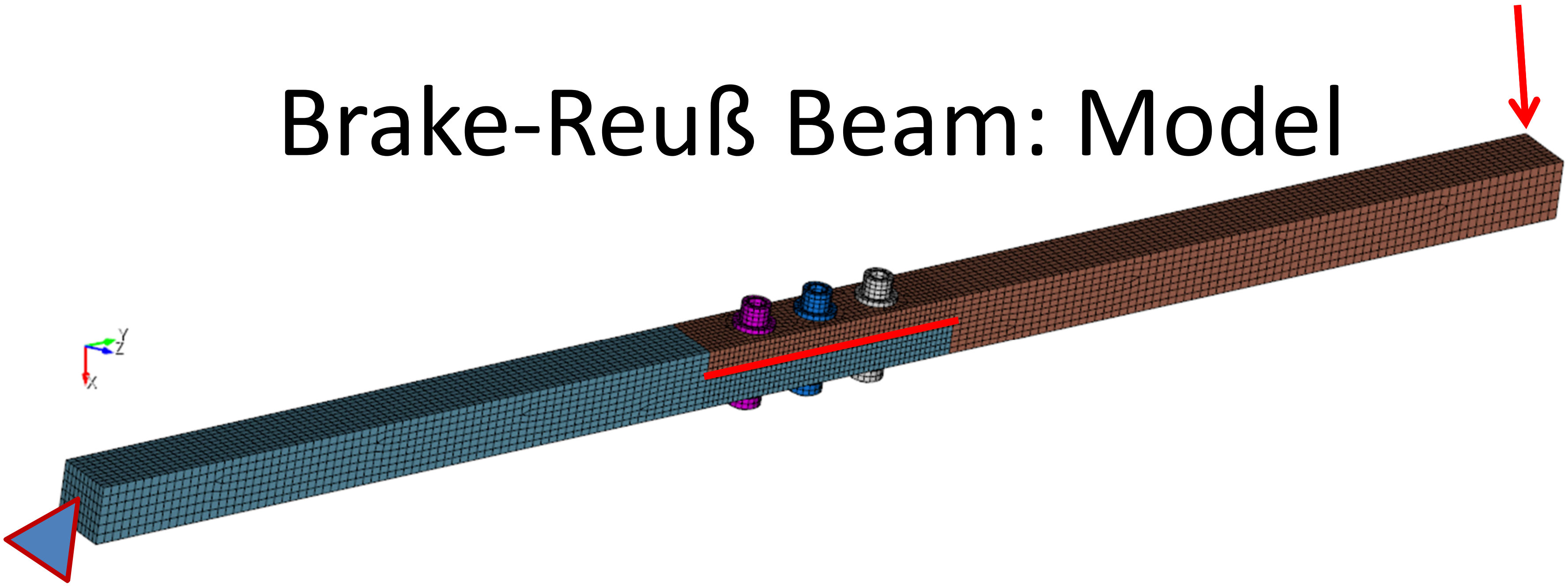
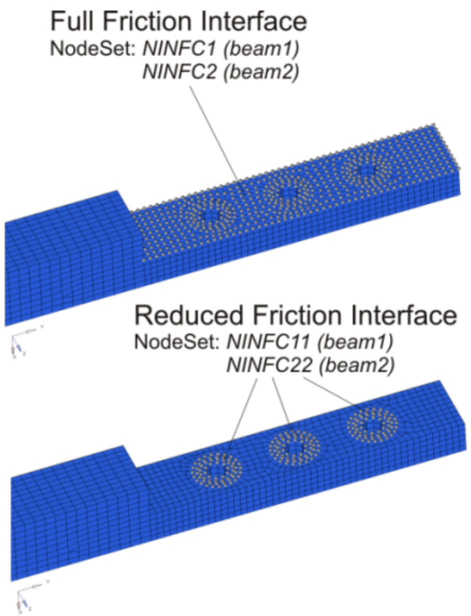


# Brake-Reuß Beam: Model



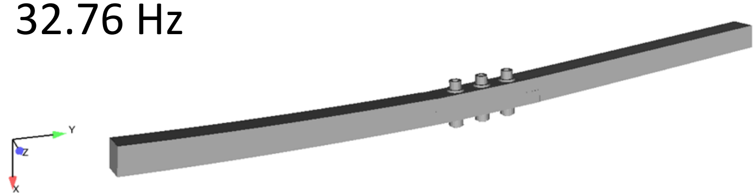



| Finite Element Discretization | |
|---:|---|
| # nodes | 24512 |
| # elements | 19368 |
| Element type | C3D8I / C3D6 |

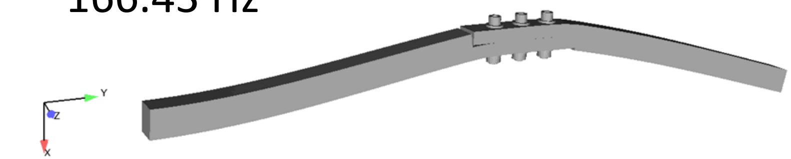
| Material Parameter | Value |
|---:|---|
| Young's Modulus | 182480.0[N/mm^2] |
| Poisson's Ratio | 0.29 [-] |
| Density | 7.9e-9 [t/mm^3] |

# Linear System: Cantilevered Mode Shapes

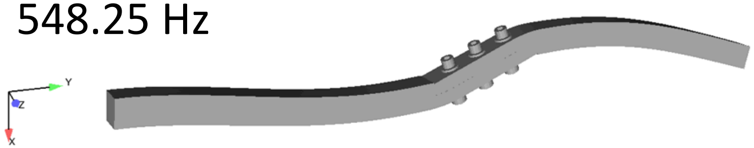
32.76 Hz



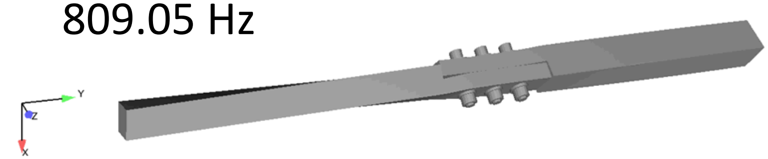
166.43 Hz



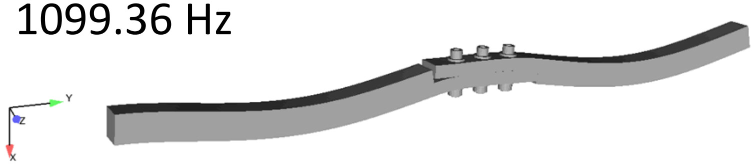
548.25 Hz



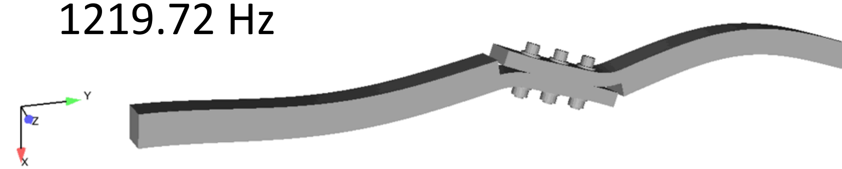
809.05 Hz



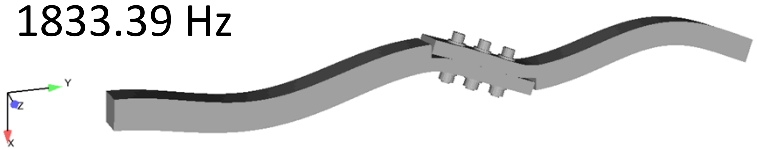
1099.36 Hz



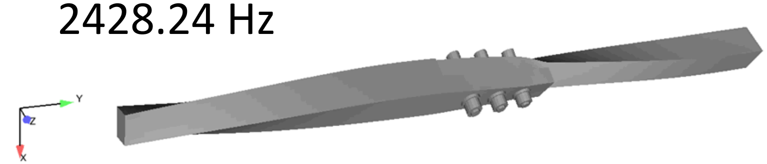
1219.72 Hz



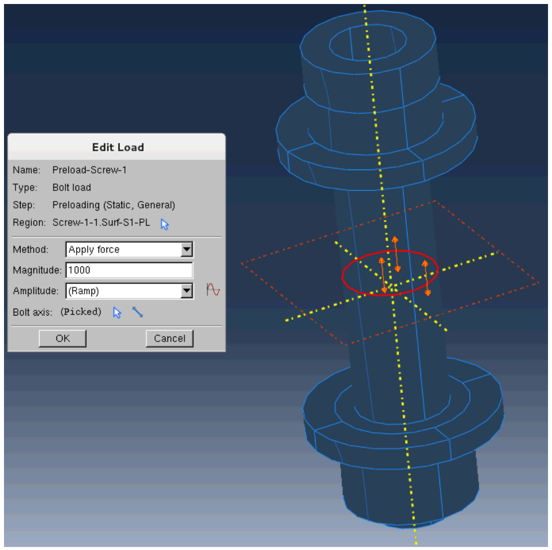
1833.39 Hz



2428.24 Hz



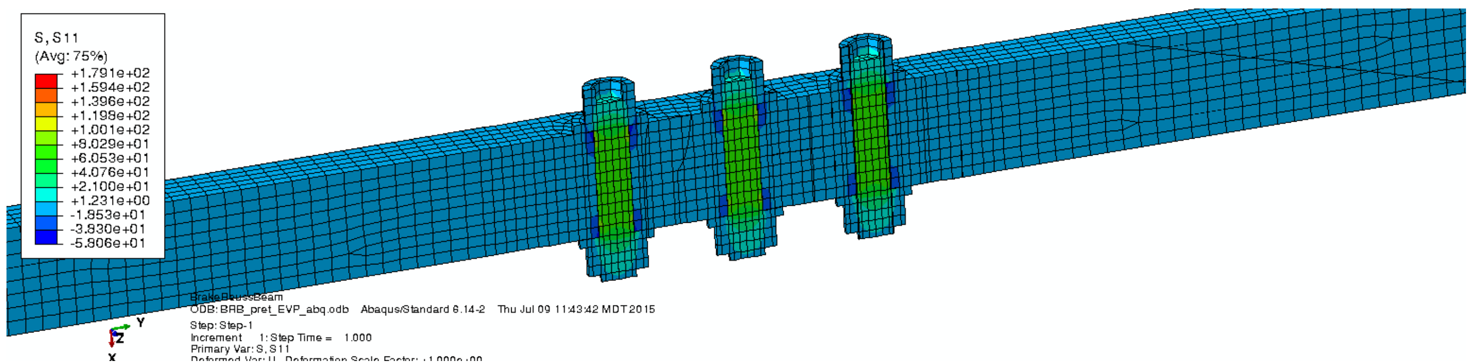
# Nonlinear Static Analysis: Modeling




<u>Contact properties in the friction interface:</u>

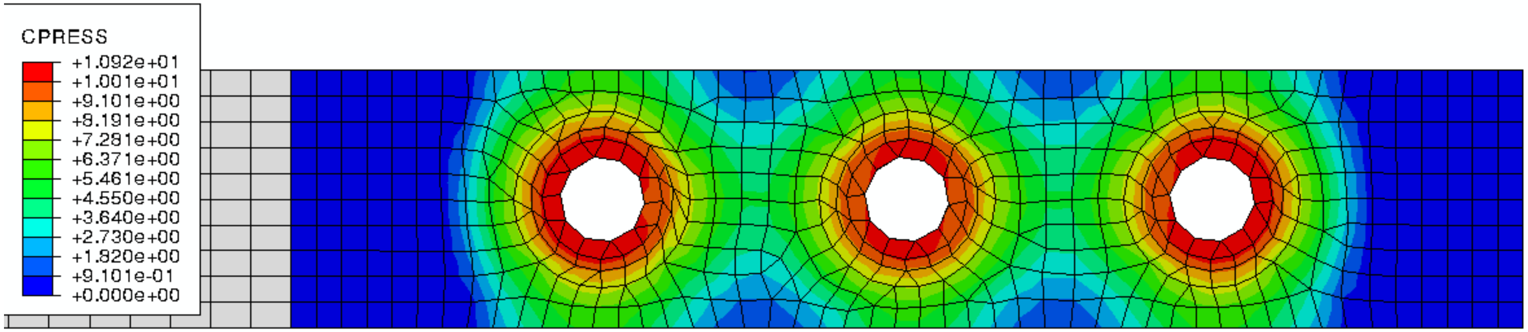
- Surface-to-surface approach
- Pressure-overclosure: hard contact
- Constraint enforcement: Lagrange multipliers
- Friction formulation: penalty method, μ=0.6 [-]
- Applied force per screw: 4kN

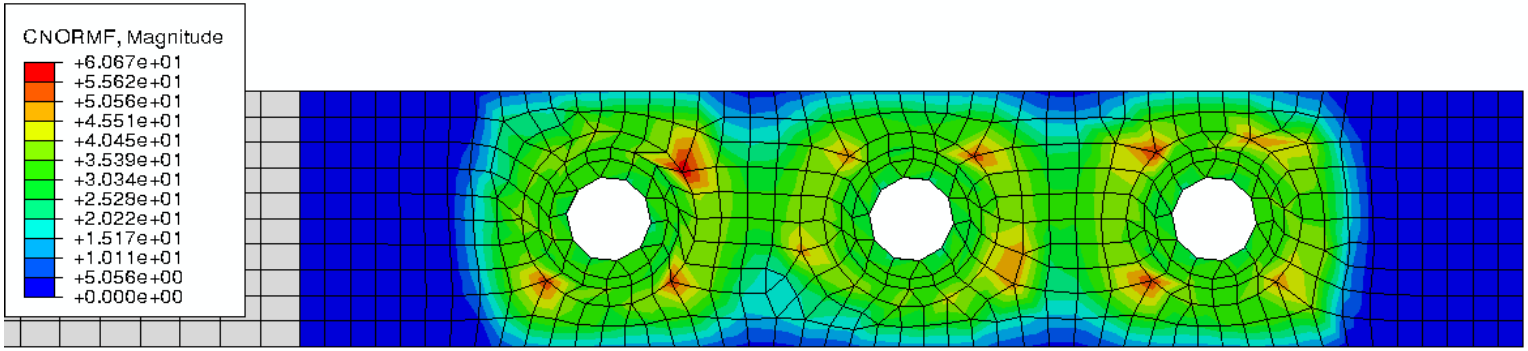
<u>Normal stress distribution in the bolts due to pre-tention</u>



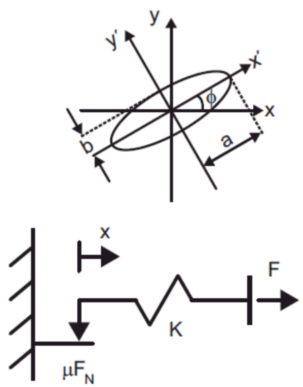
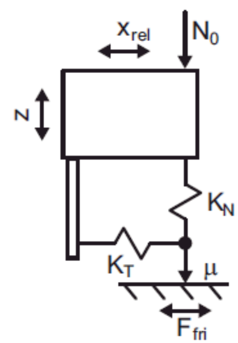
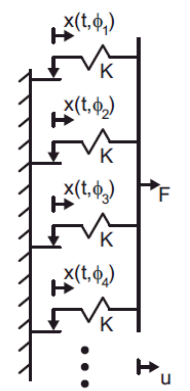
# Nonlinear Static Analysis: Results

- Contact pressure and contact normal force distributions (Abaqus)

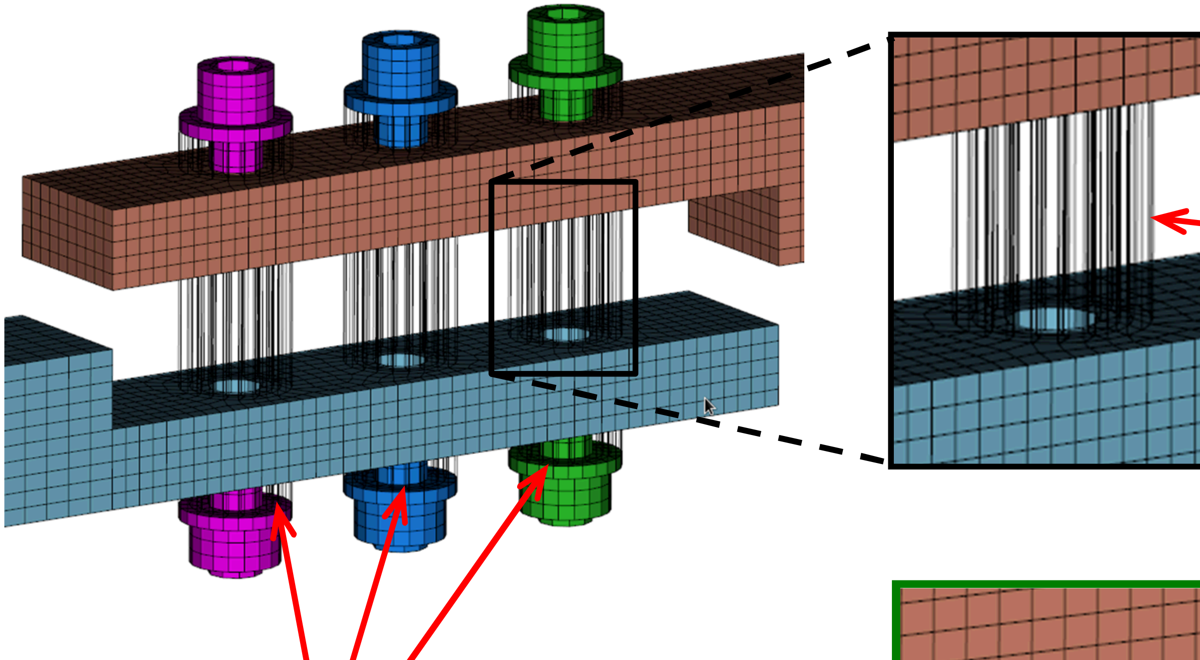


# Considered Approaches for Modeling Joints

| | Stuttgart Approach | Imperial Approach | Sandia Approach |
|---|---|---|---|
| **FE Tool** | CalculiX | NASTRAN | SIERRA/SD |
| **Model Fidelity** | Craig-Bampton ROM | Hybrid ROM | Craig-Bampton ROM |
| **Nonlinear Element** | 2D Jenkins Element  | 3D Contact Element  | Iwan Element  |
| **Nonlinear Solver** | ROCMAN | FORSE | ROMULIS |
| **Solver Type** | Harmonic Balance | Multi-Harmonic Balance | Transient Integration |

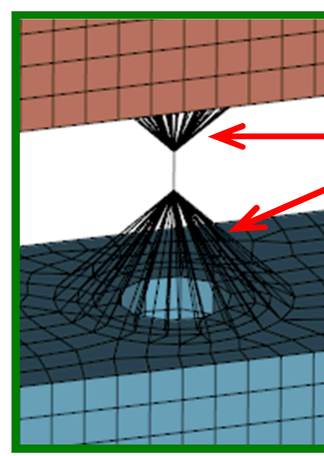
# Contact Interface Modeling



Stuttgart/Imperial Approach

Tie coincident nodes on the friction interface with Jenkins/3D contact elements.

Tie coincident nodes on beam-screw interfaces with MPC's



Sandia Approach

Connect interface nodes to a virtual node with NASTRAN RBE3 element spider.

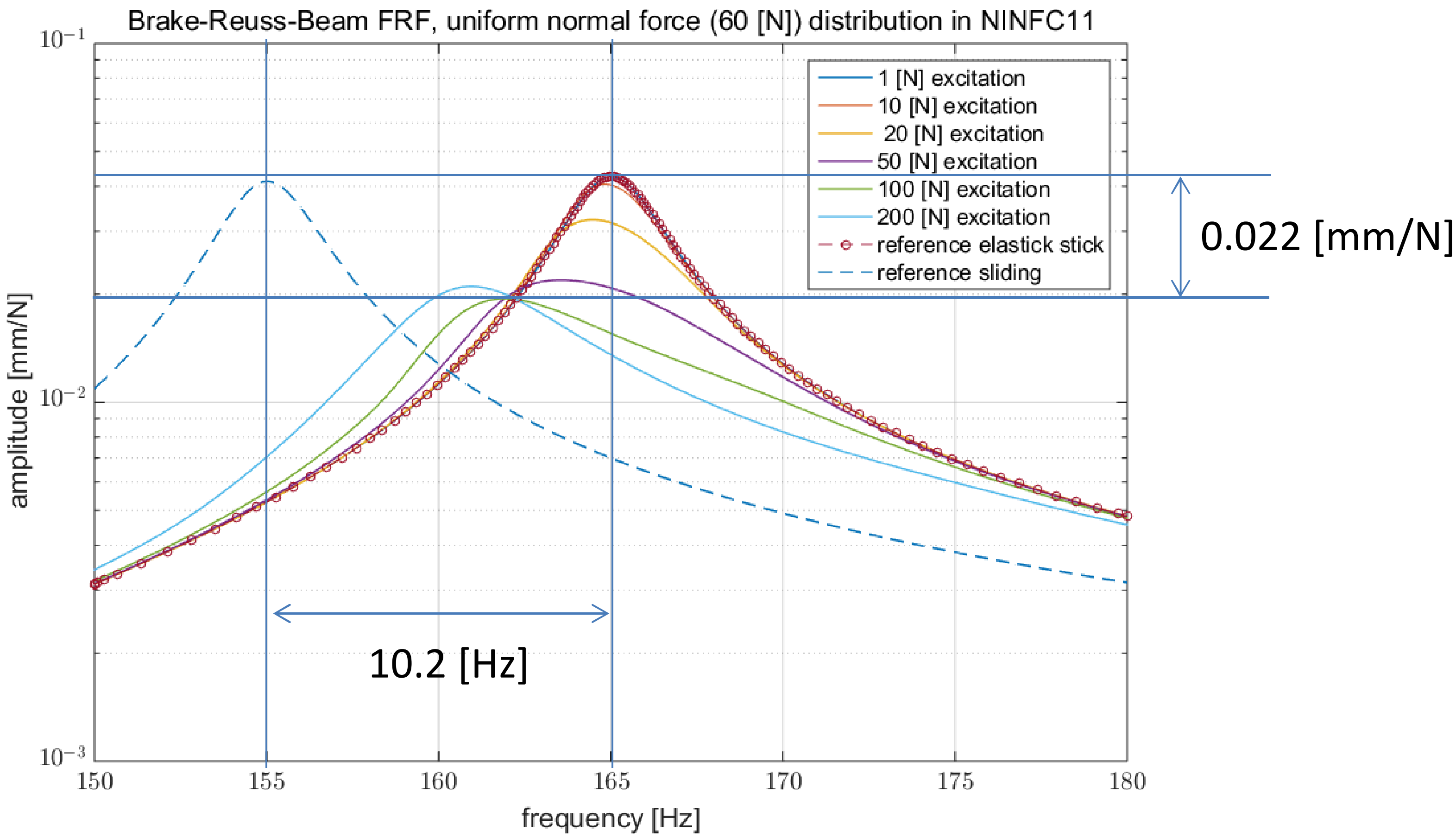
Tie virtual nodes with an Iwan element.

# Nonlinear Element Parameterization

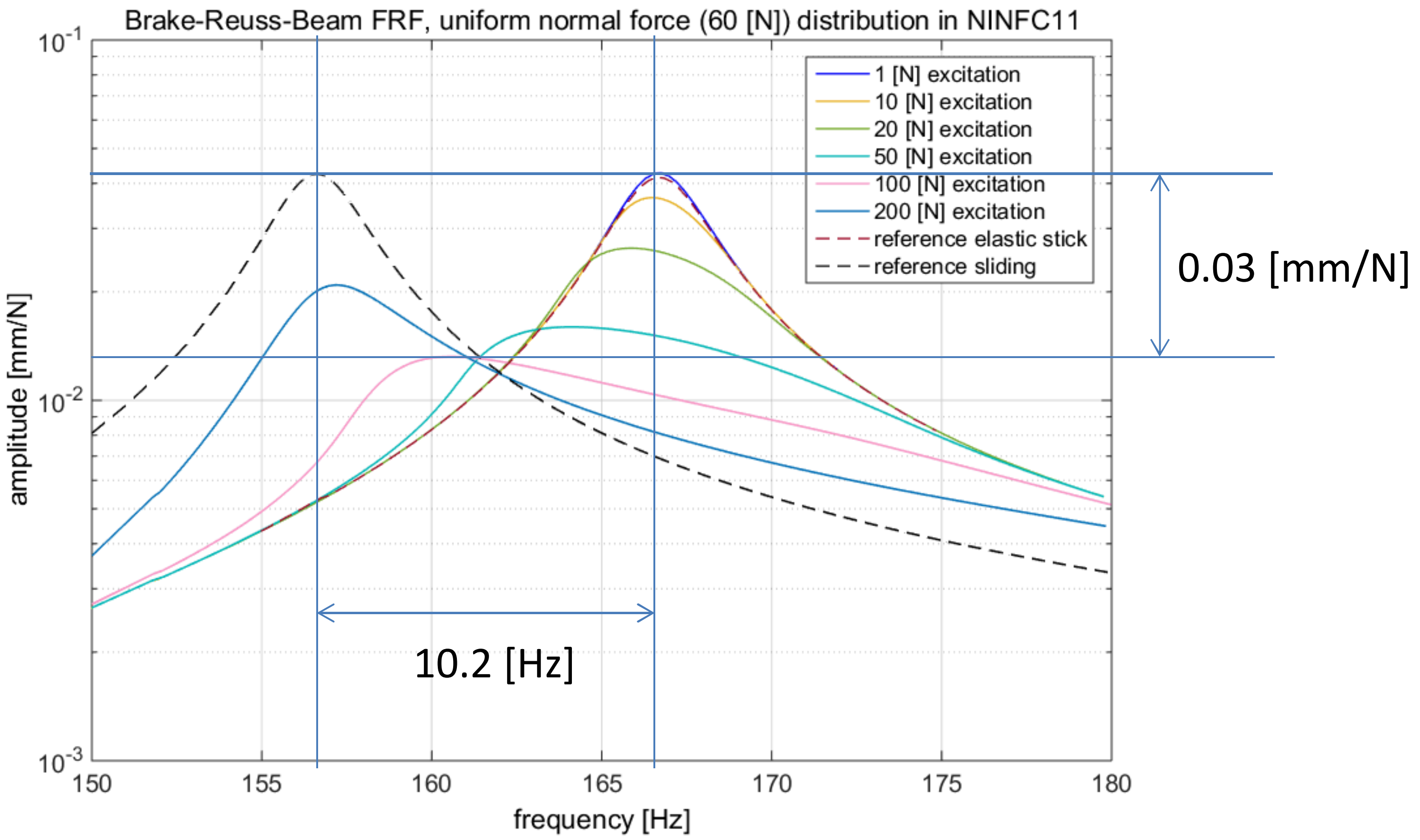
| Parameter | Imperial | Stuttgart |
|---|---|---|
| Normal Force [N] (Uniform Distribution) | 60 | 60 |
| Coulomb Friction Coefficient | 0.6 | 0.6 |
| Tangential Stiffness [N/mm] | 5e4 | 5e4 |
| Normal Contact Stiffness [N/mm] | 1e6 | MPCs |
| Number of Harmonics | 1 | 1 |
| Number of Nonlinear DOFs | 603 | 402 |

| Parameter | Sandia |
|---|---|
| Slip Force [N] | 2400 |
| Tangential Stiffness [N/mm] | 3.35e6 |
| Power Law Slope ($\chi$) | -0.5 |
| Power Law Intercept ($\beta$) | 0.05 |
| Normal Contact Stiffness [N/mm] | 1e10 |
| Number of Nonlinear DOFs | 12 |

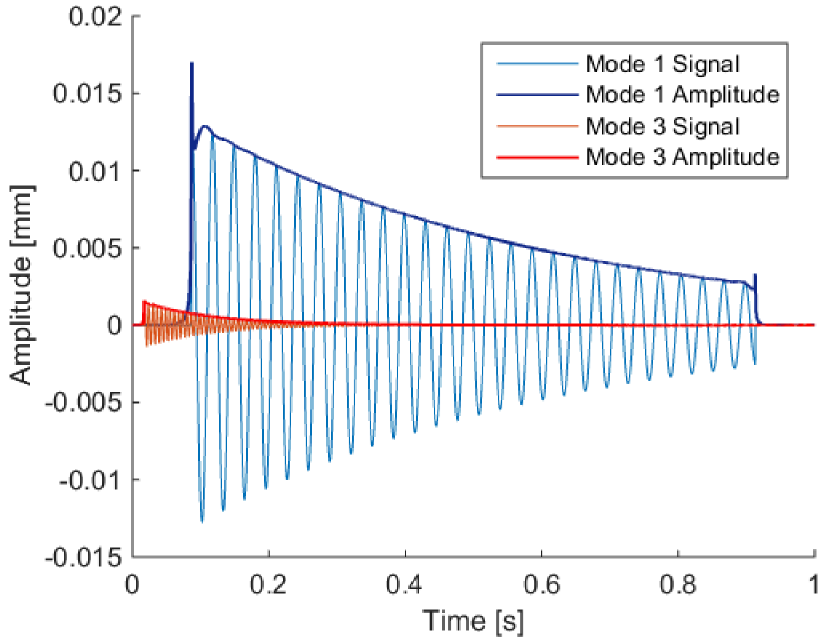
# Preliminary Results: FORSE

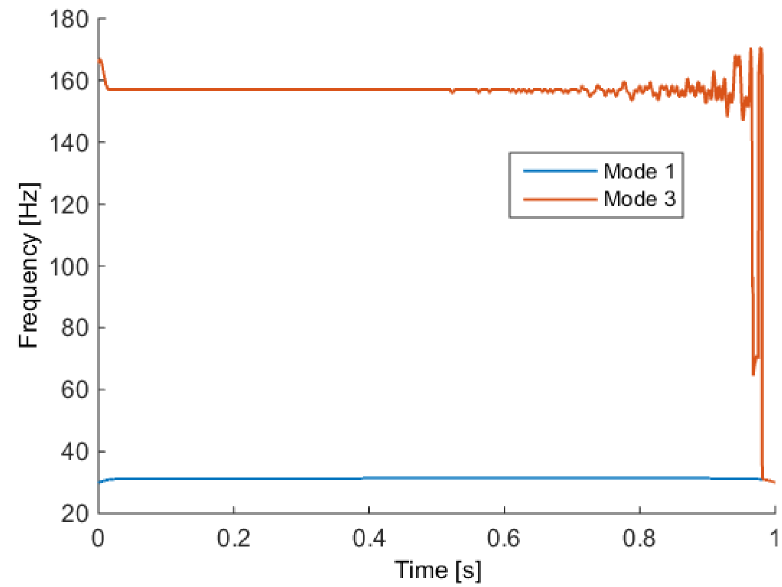


# Preliminary Results : ROCMAN



# Preliminary Results : ROMULIS




Simulate the free response to an impulse that excites the mode of interest.

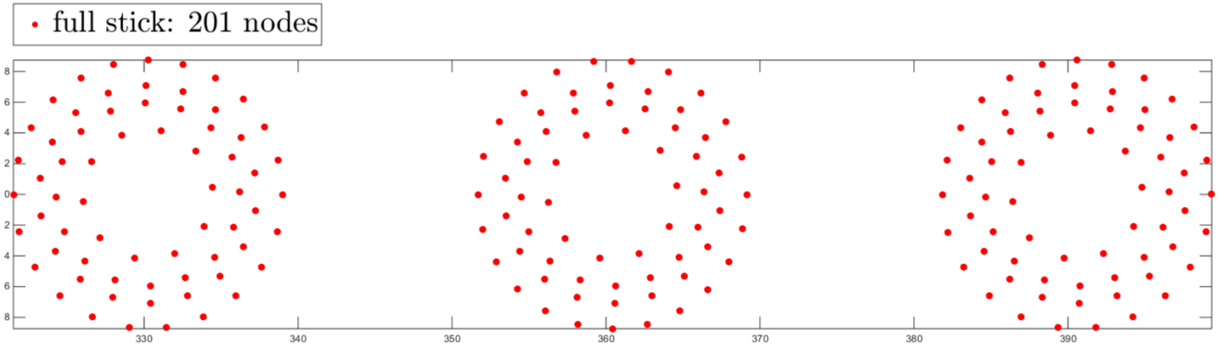
Calculate amplitude-dependent damping and natural frequency from the signal using the methods in [1].

Compare damping and frequency results with those of harmonic results.

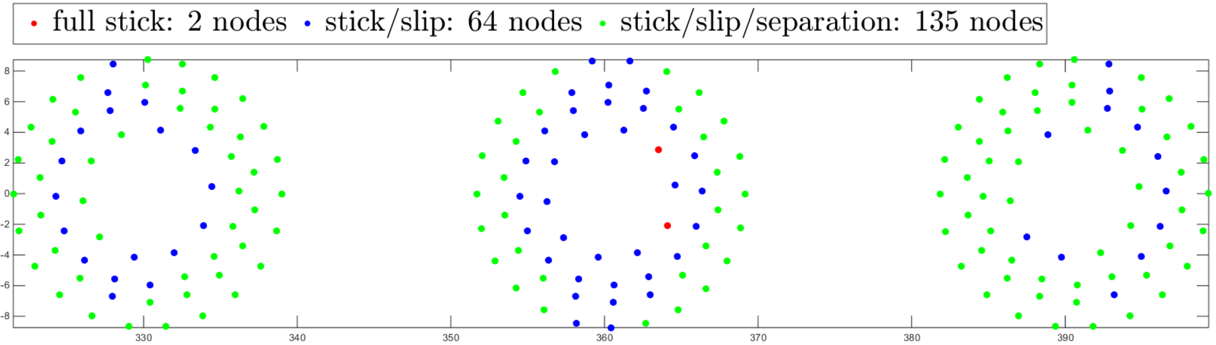
[1] Deaner, B.J., Allen, M.S., Starr, M.J., Segalman, D.J. (2015). “Application of Viscous and Iwan Modal Damping Models to Experimental Measurements from Bolted Structures,” SAND2015-2643J. Sandia National Laboratories.

# Preliminary Results (FORSE): Contact States

1 [N] excitation at resonance (2nd z-Bending):

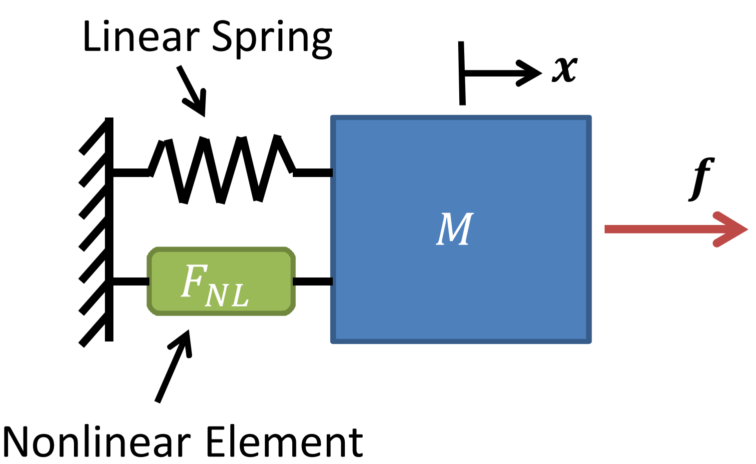



200 [N] excitation at resonance (2nd z-Bending):



# A Method to Tune Nonlinear Element Parameters to Give Similar Dissipation Characteristics

Observe the damping due to the nonlinear element in a 1-DOF system based on the dynamic response to a harmonic excitation at resonance.



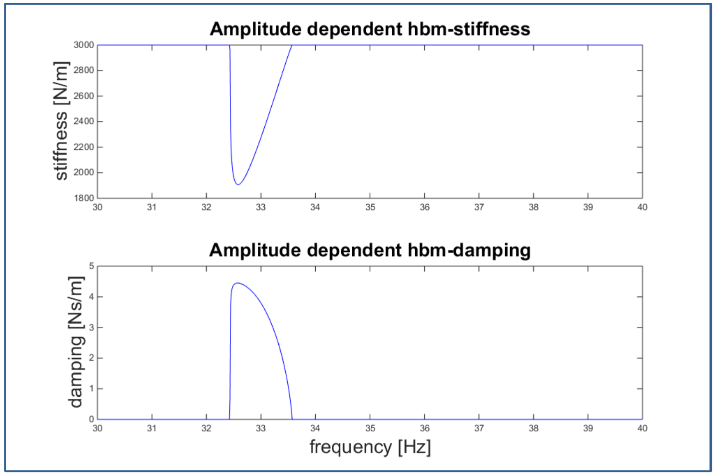

Set Jenkins element parameters as constant and tune the parameters of the other elements to match its damping.

$$M = 1\ [\text{t}]$$
$$K_{linear} = 40000\ [\text{N/mm}]$$
$$F_{slip} = 100\ [\text{N}]$$
$$K_{tangent} = 3000\ [\text{N/mm}]$$

# How Each Approach Calculates Damping

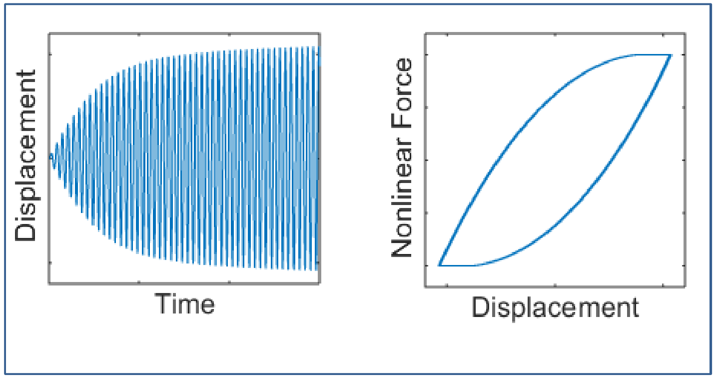
## Stuttgart Approach (Jenkins)

The amplitude dependent nonlinear force contributions at every frequency can be substituted by equivalent linearized stiffness and damping terms. The damping value is extracted at resonance point.



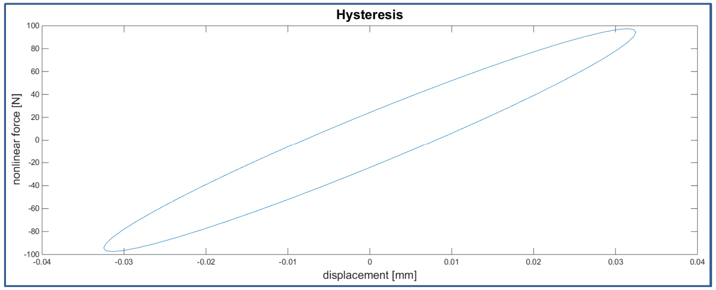

## Sandia Approach (Iwan)

Simulate the transient response to a resonance harmonic excitation until steady-state is achieved. Use the area in the steady-state hysteresis curve to determine damping.

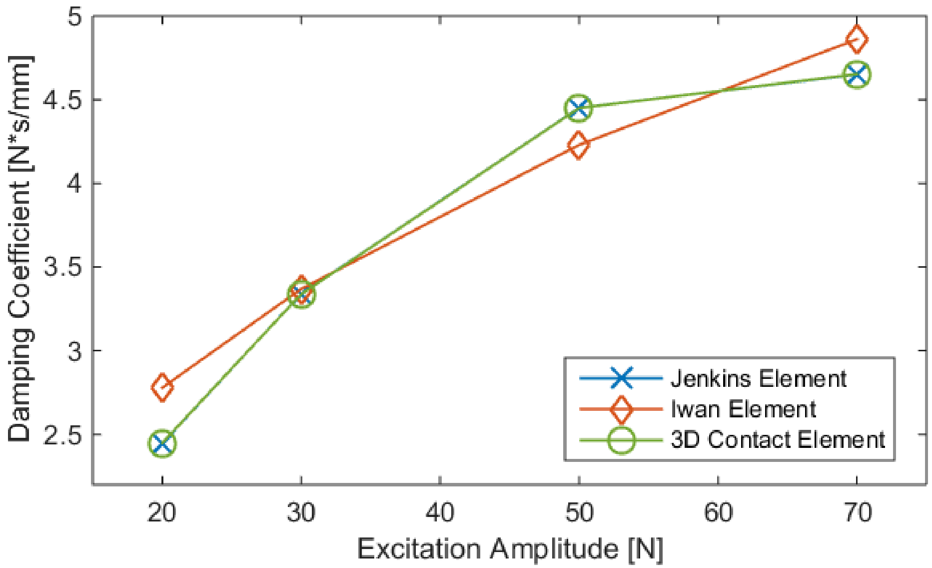



## Imperial Approach (3D Contact)

Generate a hysteresis curve based on the element constitutive model using the time domain DFT of displacement frequency response at resonance. One half the ratio of dissipated energy to kinetic energy is the damping ratio. $\left(\zeta = \frac{E_d}{2 * \max(E_k)}\right)$



# Preliminary Results




Iwan Parameters

Fs = 100 [N]

K_t = 4.5e3 [N/mm^2]

chi = -0.15 [-]

beta = 0.05 [-]

The formulations for an Iwan element and a single friction slider are too phenomenologically different to allow a perfect match.

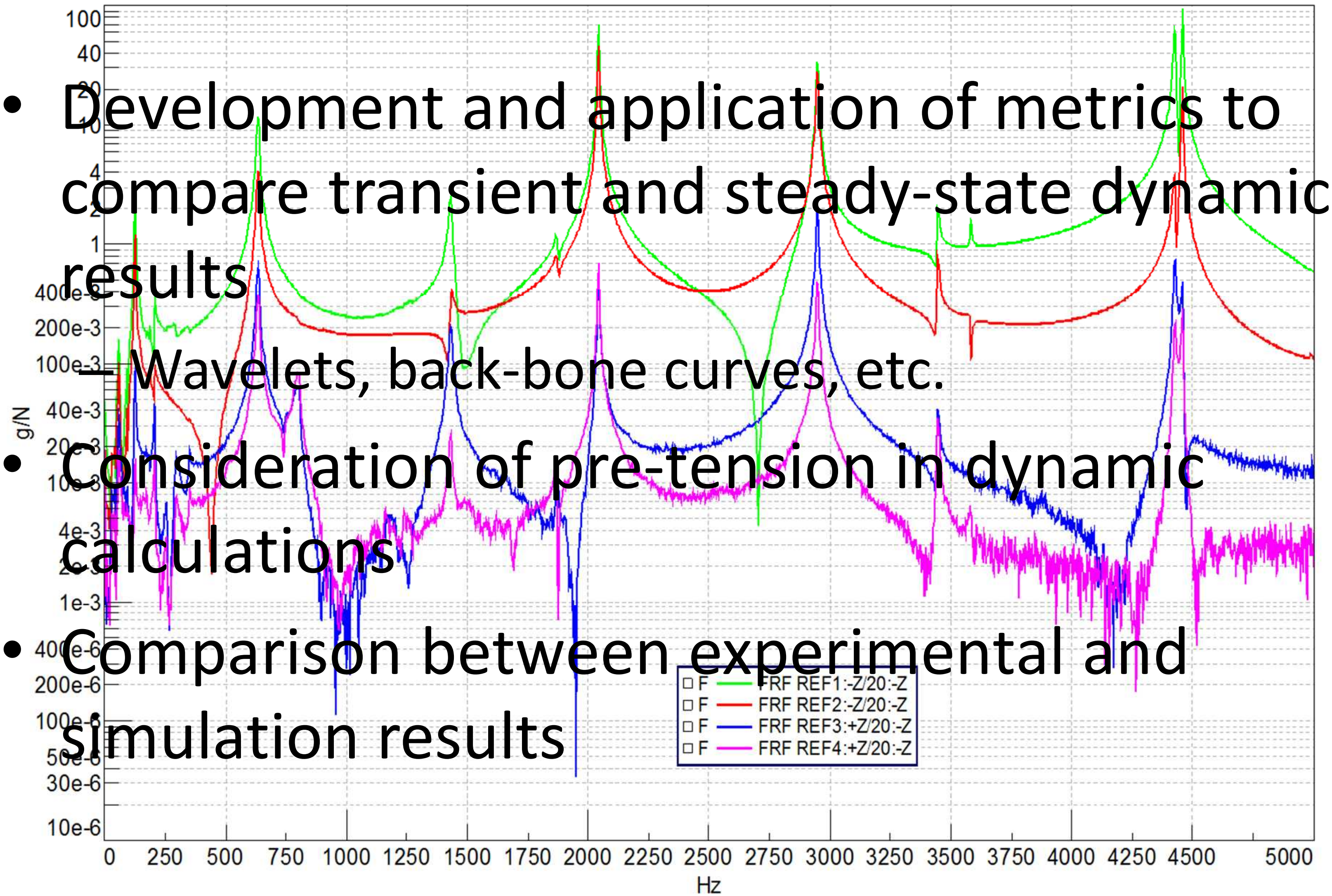
This exercise demonstrates the ability to compare nonlinear elements from both time domain approaches and frequency domain approaches by tracking damping as a function of amplitude.

# Initial Conclusions

- Brake-Reuss-Beam benchmark is suitable as Round-Robin system.
- The elasticity of the interface between the beams must be well represented to capture accurately the stick-slip-separation phenomena.
- Synthesized comparison metrics (e.g. damping vs. amplitude) must be used for the quantification of damping properties.
- Nonlinear FRFs generation is prohibitively expensive for transient methods, and may not be practical as a comparison metric.

# Future Work

- Development and application of metrics to compare transient and steady-state dynamic results
  - Wavelets, back-bone curves, etc.
- Consideration of pre-tension in dynamic calculations
- Comparison between experimental and simulation results



# POSTER LAYOUT