SAND2016-0581C

A Numerical Round Robin for the Prediction of the Dynamics of Jointed Structures

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Outline

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Objectives of the study

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Assess the ability for different numerical approaches to model accurately a structure with a mechanical joint

- Create a well-defined benchmark system that facilitates meaningful comparison between the different approaches.
- Develop a metric to compare the numerical approaches with each other, and with experimentally-derived data.
- Determine the best practices for performing a numerical analysis on systems with localized nonlinearities.

Benchmark system

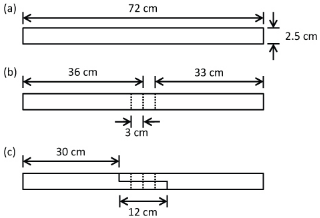

Figure: Brake-Reuss beam geometry

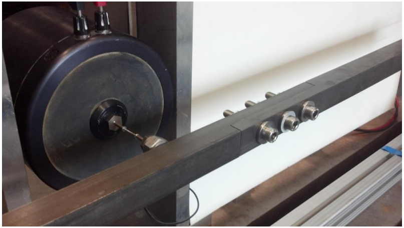

Figure: Brake-Reuss beam

72cm long beam with a lap joint

Non-linear static analysis: modelling

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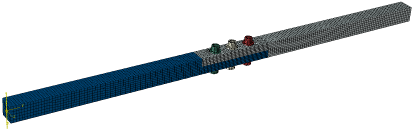

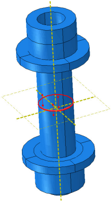

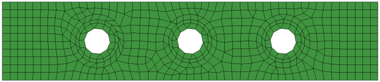

- FE model:
  - 2 beams + 3 monolithic bolt assemblies
  - Fixed-free boundary condition
  - Same isotropic material for all parts
  - Fixed coupling between the washers and the top/bottom surfaces of the beam
  - Each bolt virtually cut into two pieces to apply a 4kN pretension load
- Interface modelling:
  - matching mesh of 592 nodes per face
  - Surface-to-surface approach
  - Pressure-overclosure: ‘hard contact’
  - Contact enforcement: Lagrange multipliers
  - Friction formulation: penalty method, $\mu = 0.6$

Non-linear static analysis: results

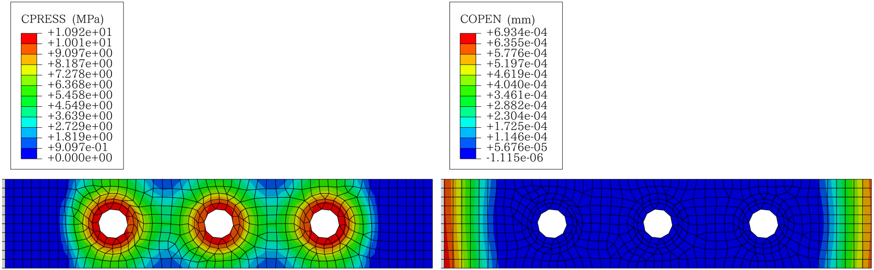

Figure: Contact pressure (left) and contact opening (right)

Static solution used to set the non-linear dynamic simulations

Non-linear dynamic modelling approaches

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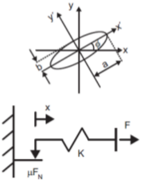
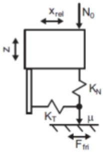
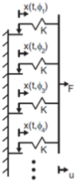
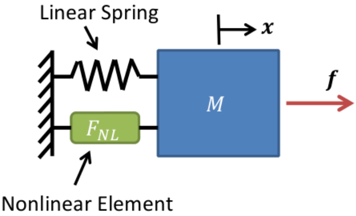
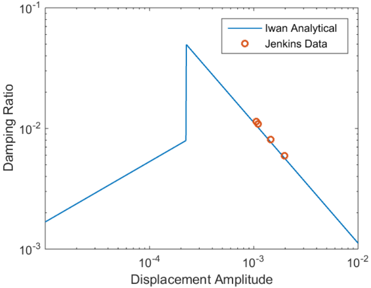
	Stuttgart Approach	Imperial Approach	Sandia Approach
FE Tool	CalculiX	NASTRAN	SIERRA/SD
Model Fidelity	Craig-Bampton ROM	Rubin ROM	Craig-Bampton ROM
Nonlinear Element	2D Jenkins Element 	3D Contact Element 	Iwan Element 
Nonlinear Solver	ROCMAN	FORSE	ROMULIS
Solver Type	Harmonic Balance	Multi-Harmonic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

Comparison on a SDOF system





Equivalent damping ratio:

$$\zeta_r = \frac{D_r}{2\pi M \left|V_r\right|^2}$$

D_r: energy dissipated per cycle
V_r: velocity of the mass at resonance

Match obtained but only in the macro-slip regime of the Iwan element

Brake-Reuss beam NL dynamic analysis

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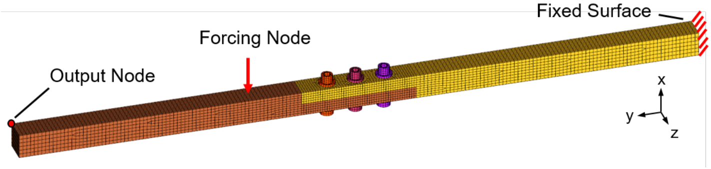

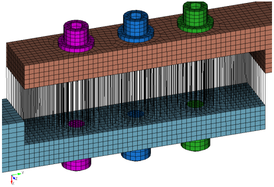

Figure: Tie coincident nodes on the friction interface with Jenkins/3D contact elements

Parameter	Imperial	Stuttgart
Normal Force [N]	From non-linear static analysis	
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 Elements	592	460

Harmonic balance results

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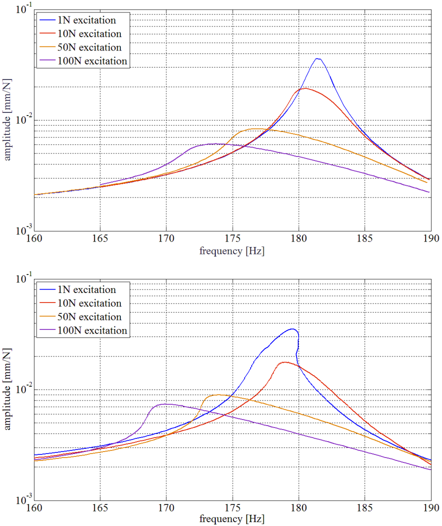
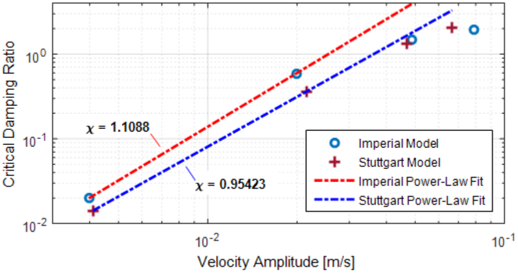


Figure: Stuttgart (top) vs. Imperial non-linear FRFs (bottom)

Iwan element calibration (1/2)



- Power-law fit only valid for low amplitude (micro-slip)
- In previous works, $\chi \approx -0.3$
- Large C_r leads to physically unreasonable value of K_t

$$\zeta_r = C_r \left|V_r\right|^{\chi+1}$$

Iwan element calibration (2/2)

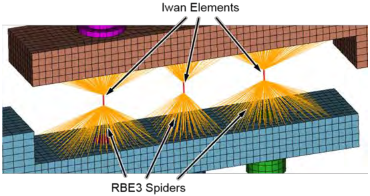


Figure: Iwan joint model

Parameter	Sandia
Slip Force [N]	2400
Tangential Stiffness [N/mm]	1e8
Power-law slope (χ)	-0.15 to -0.9
Power-law intercept (β)	0.05
Number of Nonlinear Elements	6

Figure: Iwan element parameters

Brake-Reuss beam results

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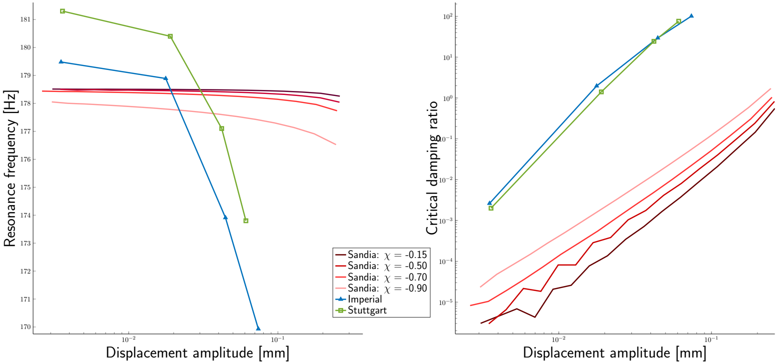

Figure: Brake-Reuss beam: 2nd bending mode behaviour

Conclusions and perspectives

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- Particular care must be taken to model the bolt pretension to obtain accurate initial conditions at the contact interface prior to the non-linear dynamic simulations
- A comparison between transient and harmonic simulations was achieved by using amplitude-dependant variables
- A good agreement was obtained between the two harmonic approaches.
- Qualitative good agreement between the three methods in describing general joint behaviour
- Quantitatively, the Iwan model needs more parameters to reproduce the harmonic balance results

Further work:

- Use of non-linear normal modes as an alternative comparison metric
- Comparison with experimental results

Acknowledgements

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[1]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.