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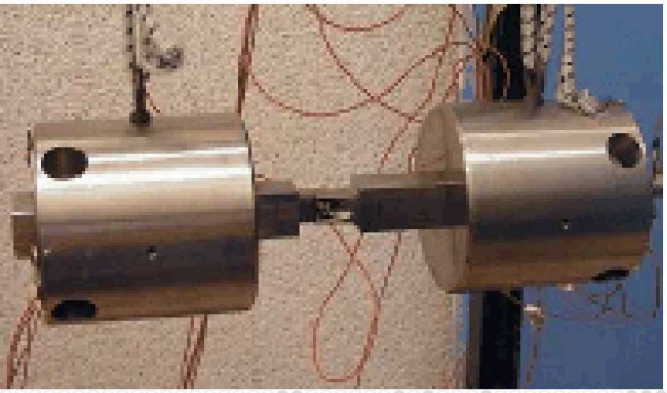
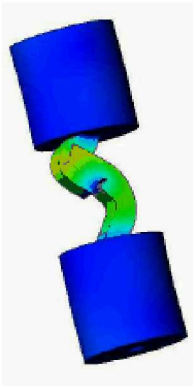
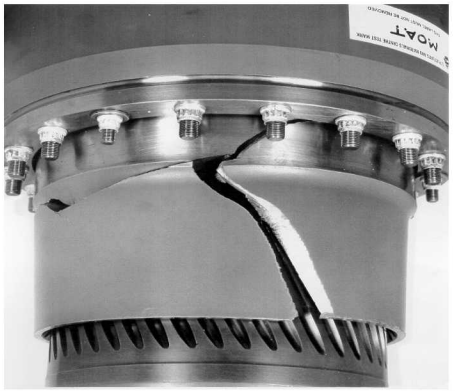


N-O-MAD





Predictive Modeling of Bolted Assemblies with Surface Irregularities

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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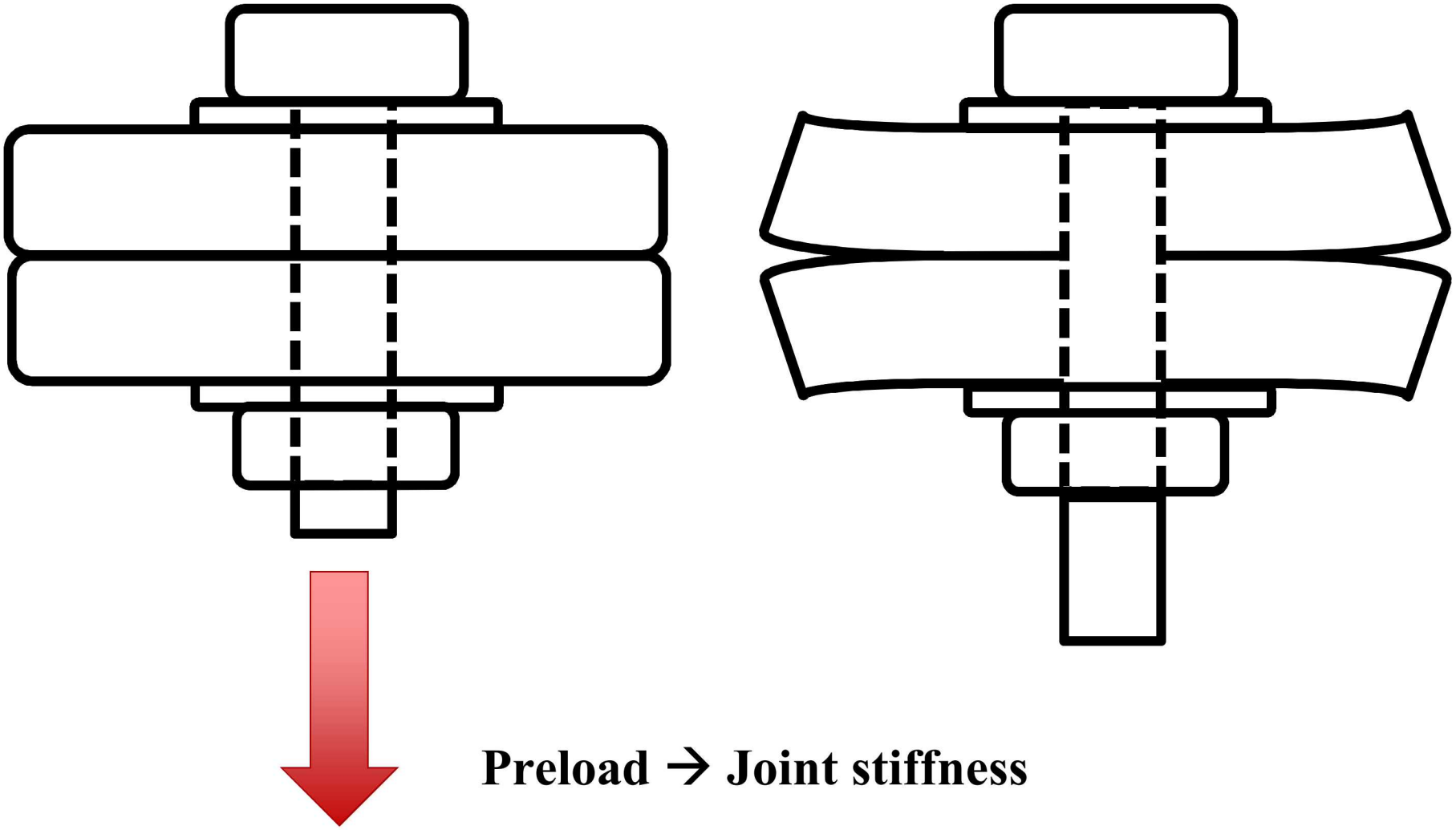
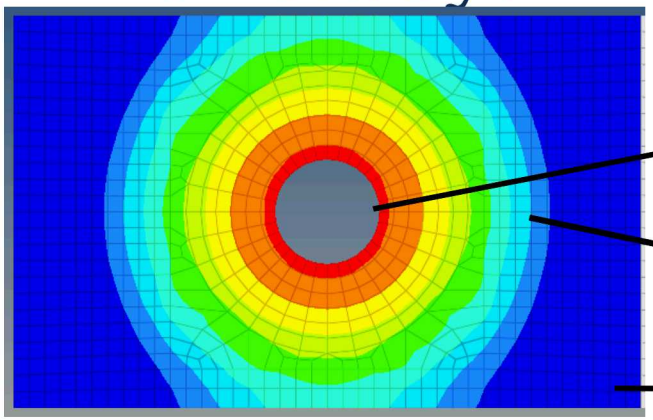
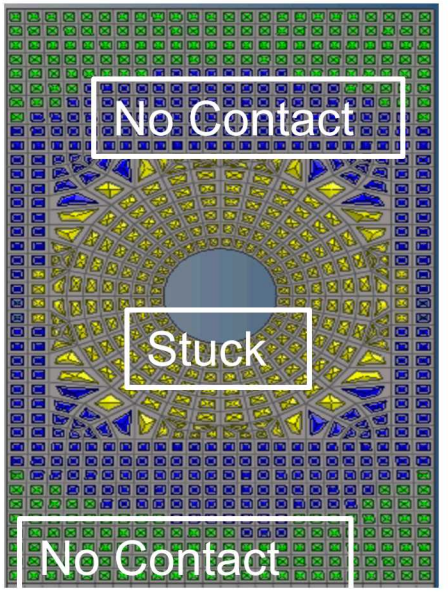
Introduction

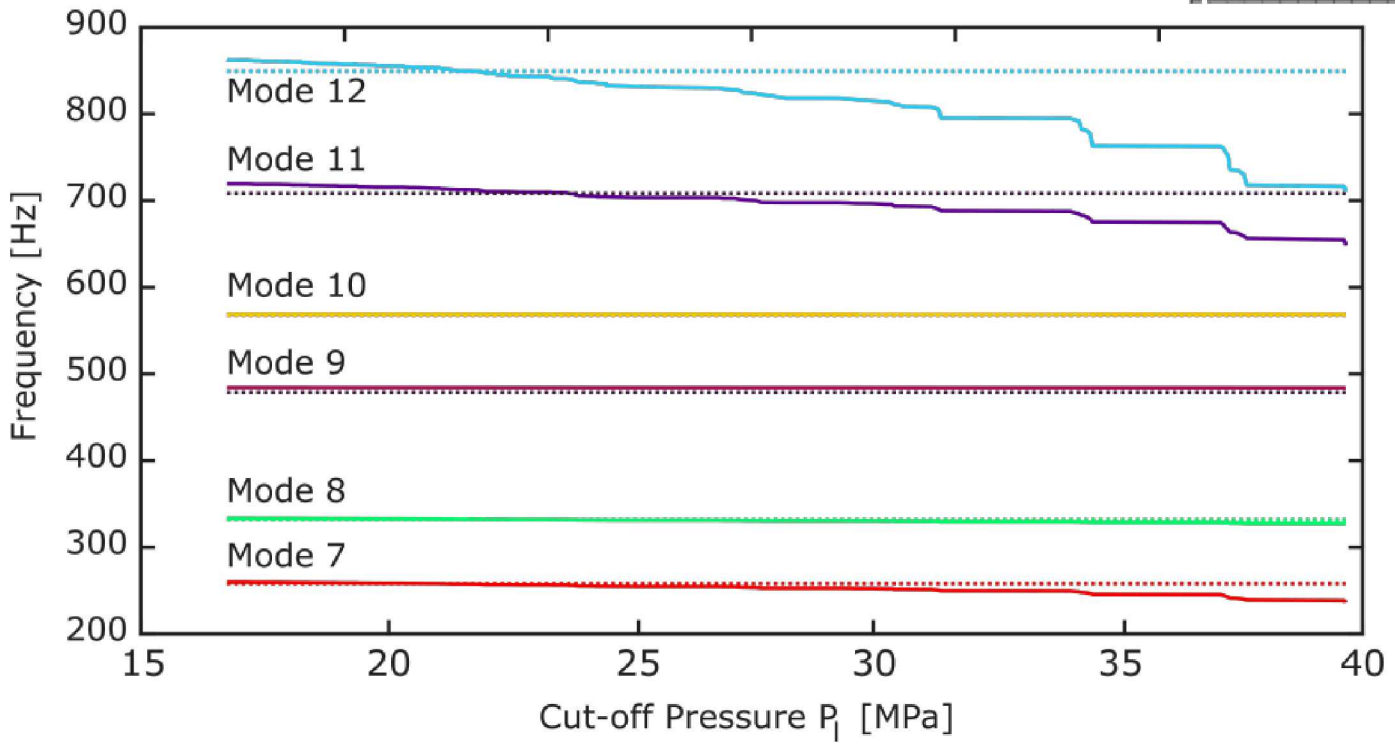


Preload → Joint stiffness

Prior study: NOMAD 2017

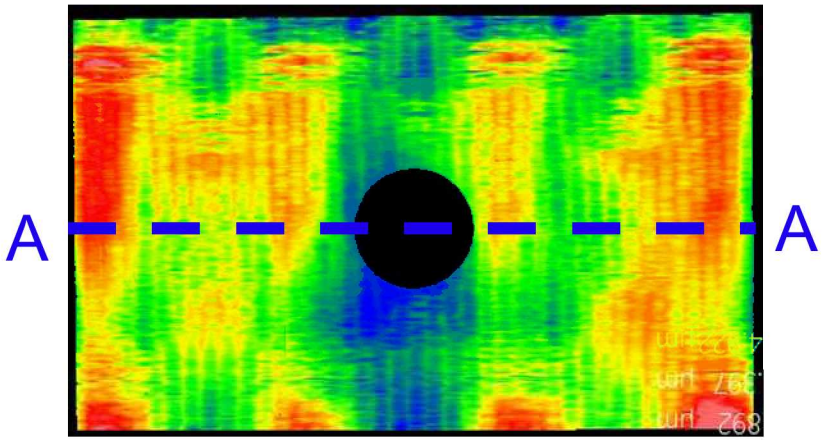


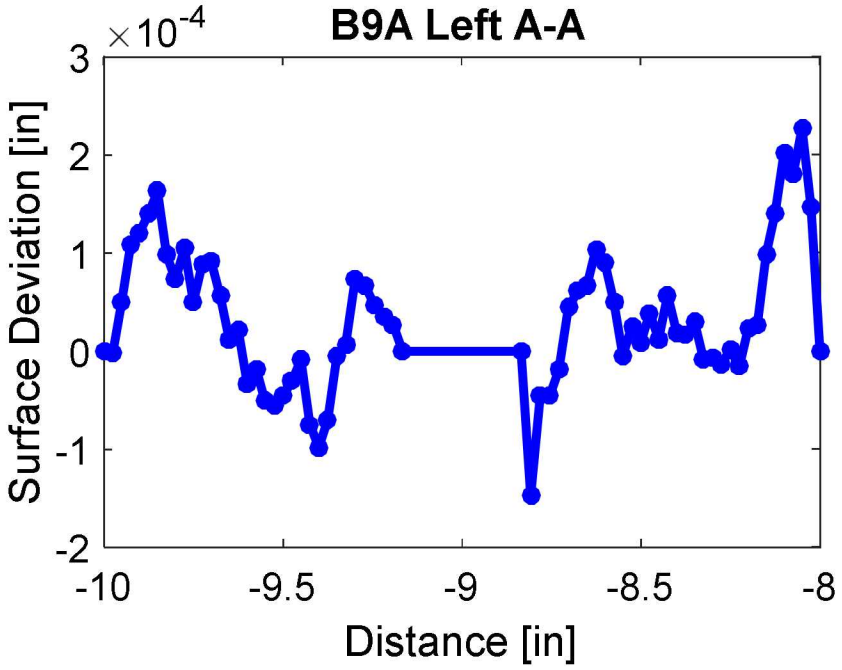




Introduction

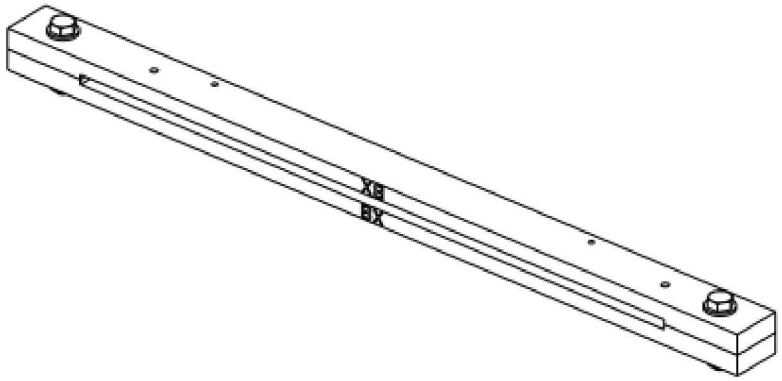
- To what extent do surface irregularities in an interface effect the dynamic properties of a joint?



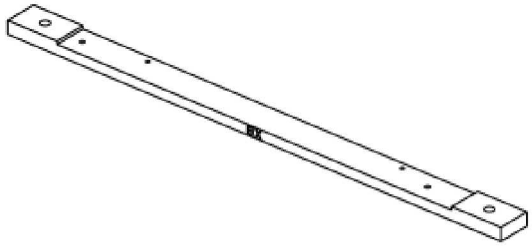


Agenda

1. System Description
2. Single Beam Structure
    1. Experimental Modal Analysis
    2. Model Updating
        1. Density
        2. Young's Modulus
        3. Surface Geometry
3. Assembled Beam Structure
    1. Experimental Modal Analysis
    2. Computational Analysis
    3. Validation
4. Conclusions

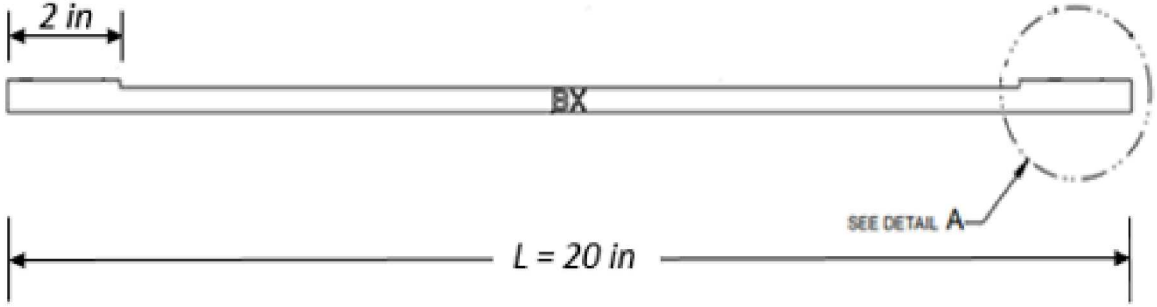


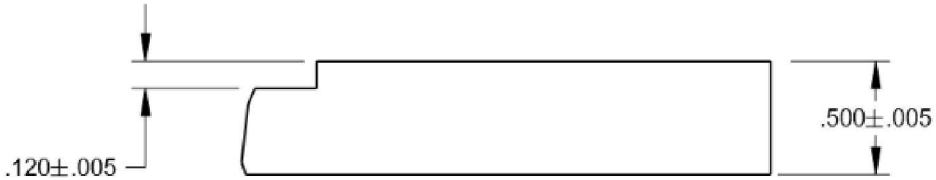
System Description



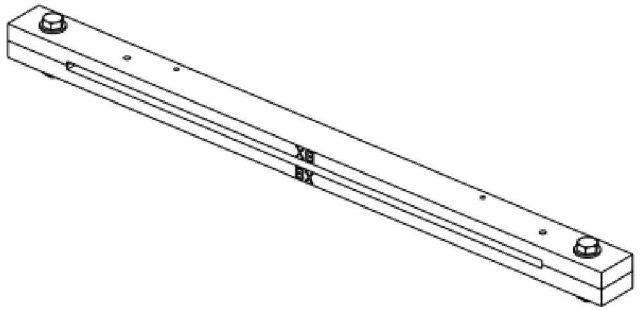
3D ROTATED VIEW
REFERENCE ONLY
SCALE 3/8

Single beam





DETAIL A
SCALE 2/1

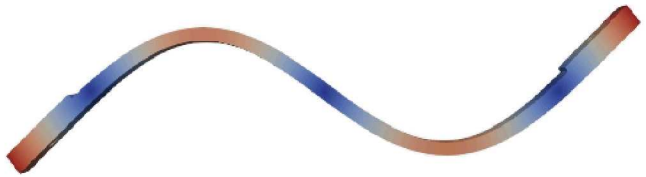


3D ROTATED VIEW
REFERENCE ONLY
SCALE 1/2

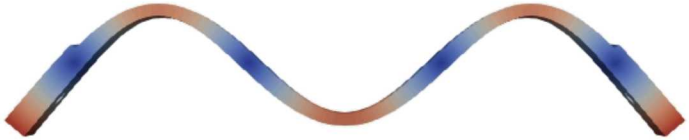
Beam assembly

Single Beam Structure: Experimental Modal Analysis

B9A	B9B	FEA
187.5 Hz	187.1 Hz	189.3 Hz



B9A	B9B	FEA
526.3 Hz	525.1 Hz	523.3 Hz



B9A	B9B	FEA
610.8 Hz	610.3 Hz	603.8 Hz

B9A	B9B	FEA
1042.7 Hz	1042.8 Hz	1037.9 Hz

B9A	B9B	FEA
1545.5 Hz	1541.8 Hz	1530.7 Hz

Single Beam Structure: Model Updating of Density

Serialize components

4340 Alloy Steel Beams

	B9A	B9B
Mass (slug)	7.3E-03	7.3E-03
Density (slug/in^3)	7.3E-04	7.4E-04

Hex Head Screw, .3125-25 UNF-2B

	Bolt 1 (Right)	Bolt 2 (Left)
Mass (slug)	1.0E-04	1.0 E-04
Density (slug/in^3)	6.7E-04	6.7E-04

Washer .344ID, .688OD, .065 THK

	Washer 1 (Right)	Washer 2 (Right)	Washer 3 (Left)	Washer 4 (Left)
Mass (slug)	1.1E-05	1.2E-05	1.1E-05	1.2E-05
Density (slug/in^3)	6.3E-04	6.4E-04	6.3E-04	6.4E-04

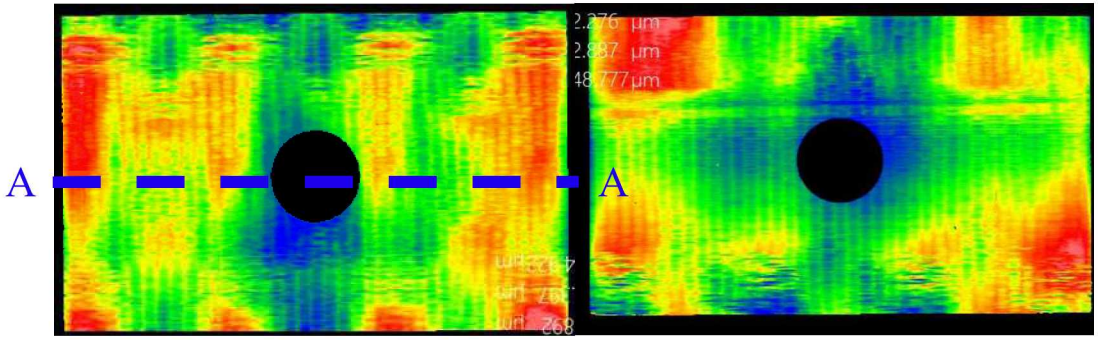
Nut, Hex, .3125-25 UNF-2B

	Nut 1 (Right)	Nut 2 (Left)
Mass (slug)	2.87E-05	2.8E-05
Density (slug/in^3)	9.1E-04	9.0E-04

Single Beam Structure: Model Updating of Young's Modulus

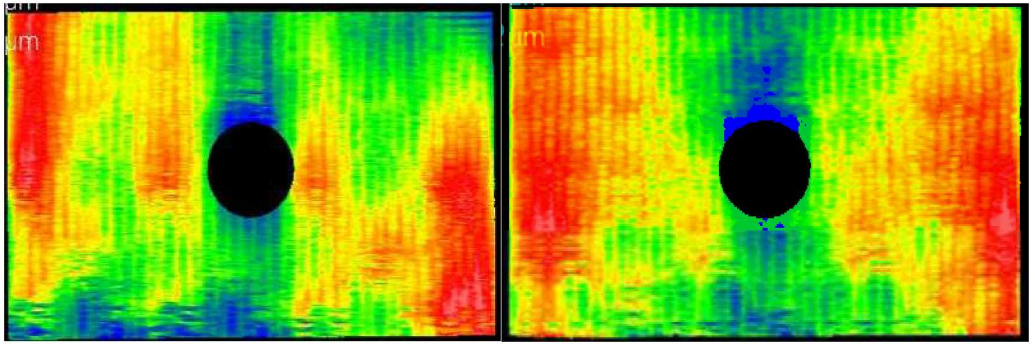
Mode	B9A Natural Frequency [Hz]		B9B Natural Frequency [Hz]	
	Experimental	Young's Modulus Updated FE	Experimental	Young's Modulus Updated FE
1st y-bending	187.5	187.7 (+0.1%)	187.1	187.3 (+0.1%)
2nd y-bending	526.3	527.4 (+0.2%)	525.1	526.4 (+0.2%)
3rd y-bending	610.8	608.1 (-0.4%)	610.2	606.9 (-0.5%)
1st z-bending	1042.7	1046.5 (+0.4%)	1042.9	1044.5 (+0.2%)
1st torsion	1545.6	1541.8 (-0.2%)	1541.8	1538.8 (-0.2%)

Single Beam Structure: Model Updating of Surface Geometry



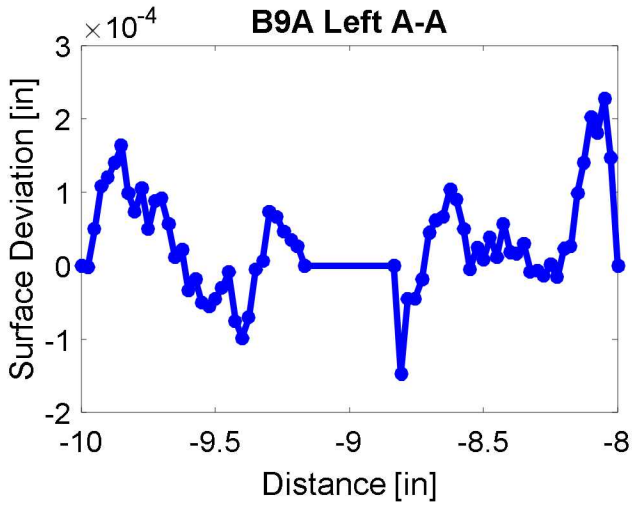
B9A Left

B9A Right

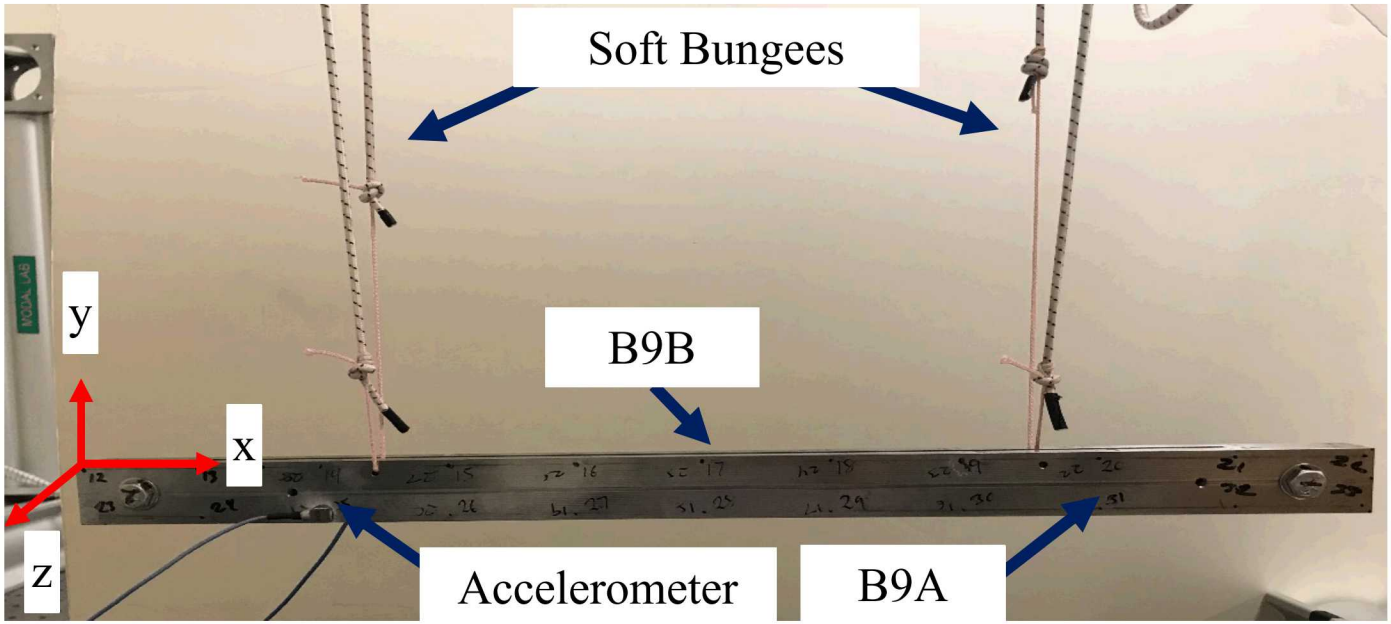


B9B Left

B9B Right



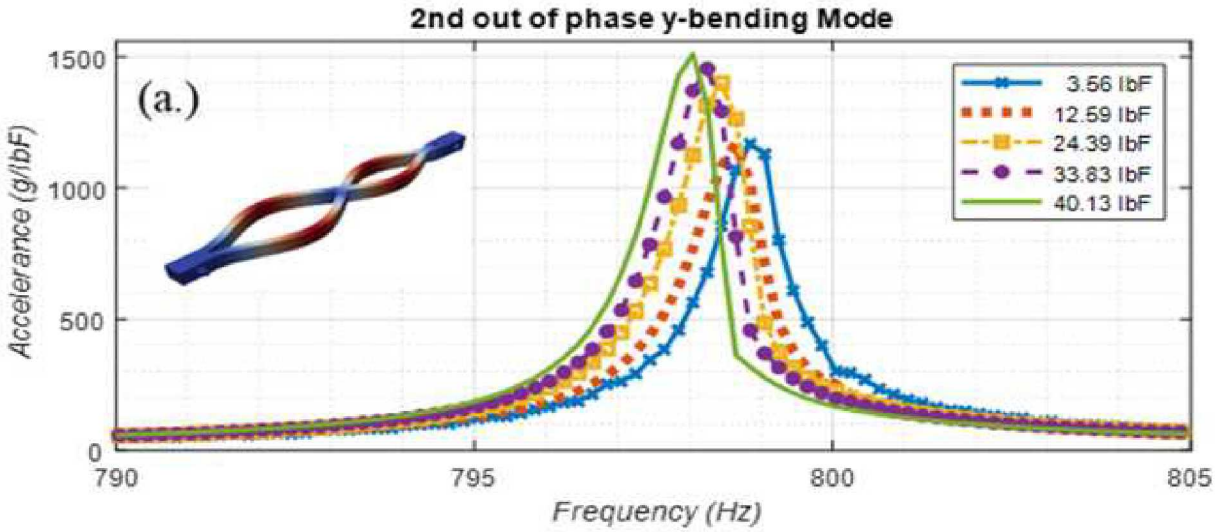
Beam Assembly: Experimental Modal Analysis



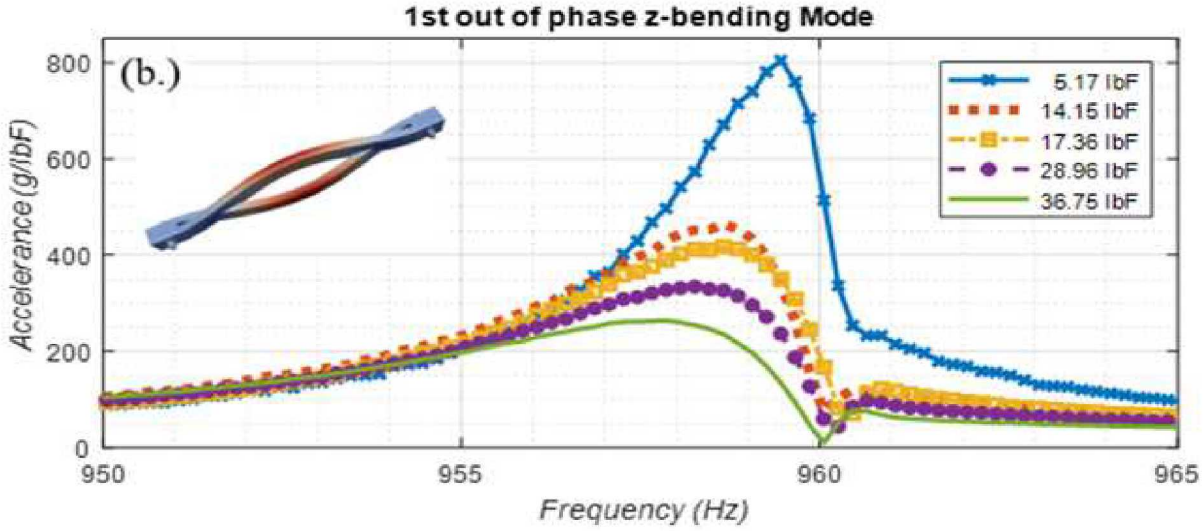
Alignment Tool

Torque Wrench

Beam Assembly: Linearity Study



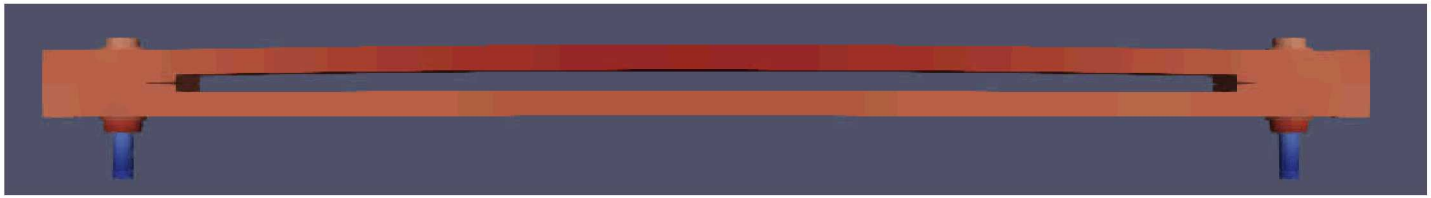
Stiffness decreases

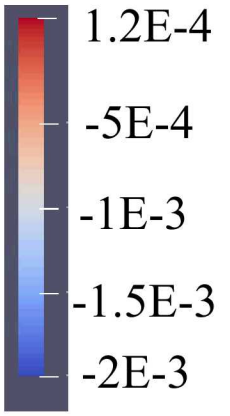


High shearing

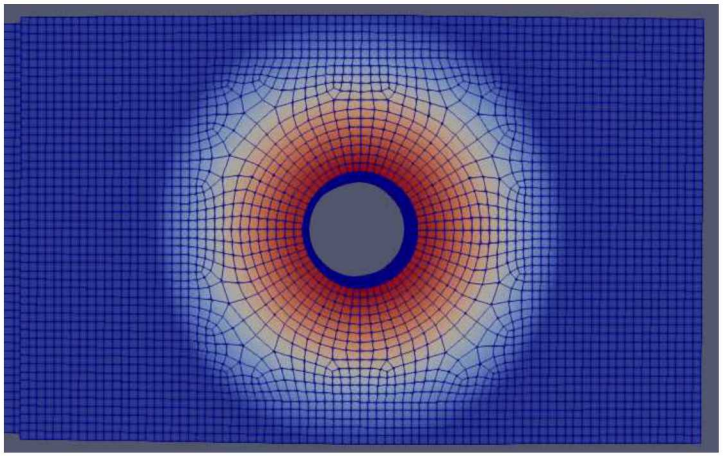
Beam Assembly: Computational Analysis (Nominally Flat)

(a.)

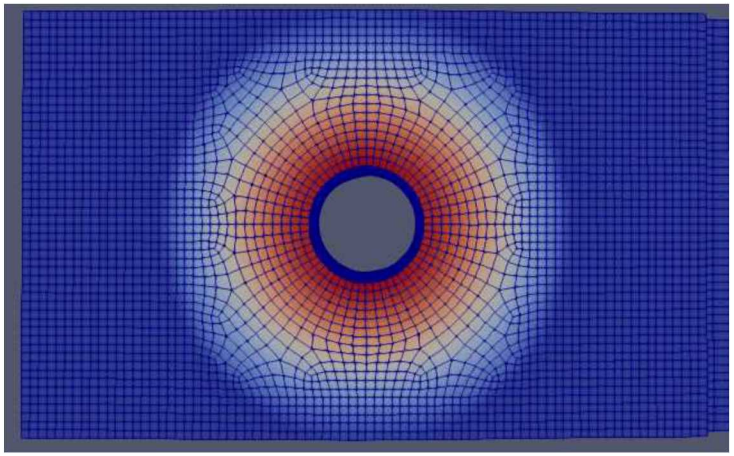


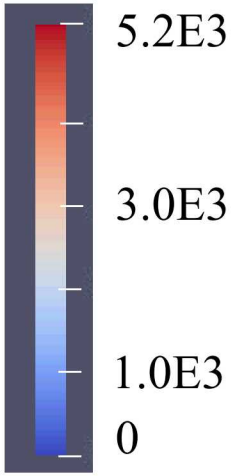


(b.)

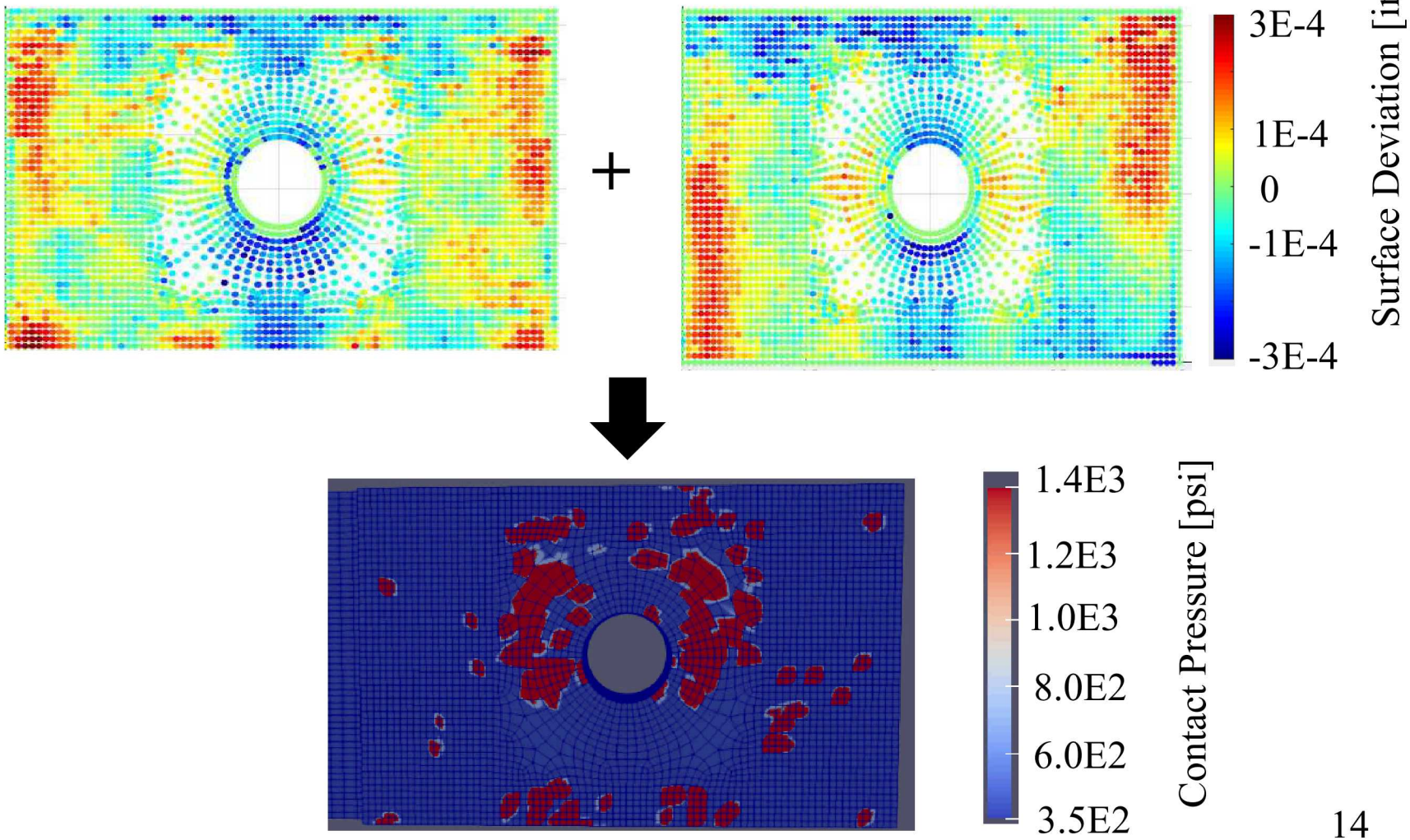


(c.)

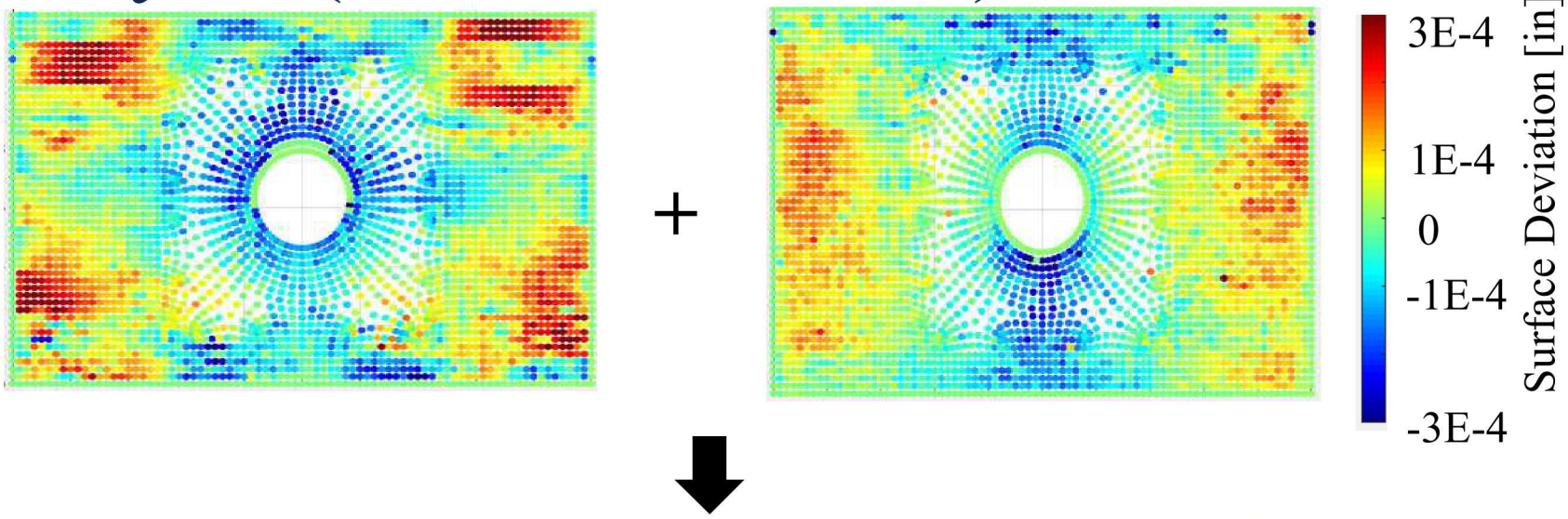




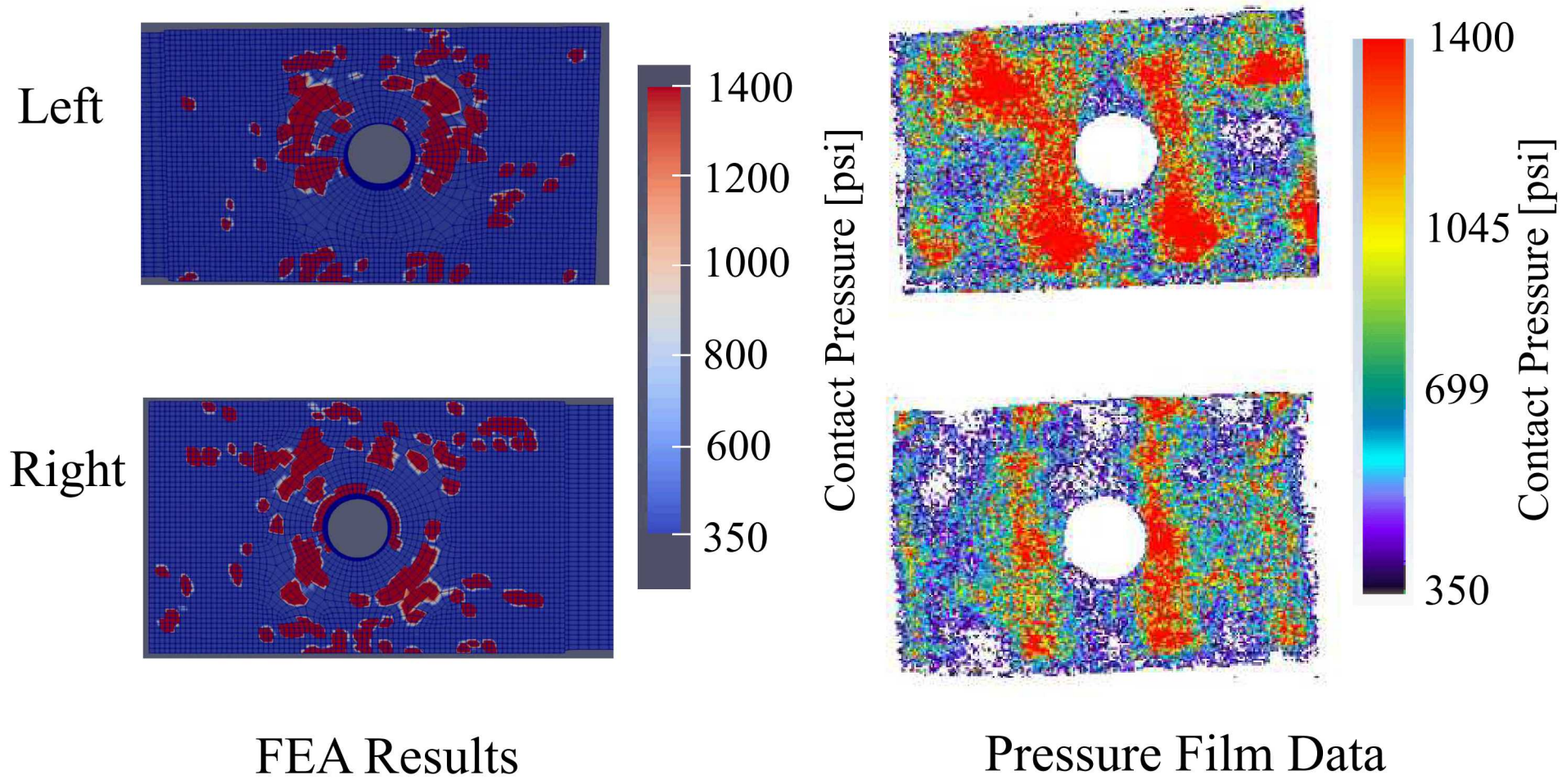
Beam Assembly: Computational Analysis (Perturbed Mesh)



Beam Assembly: Computational Analysis (Perturbed Mesh)



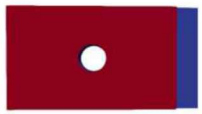
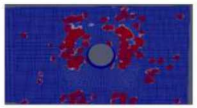
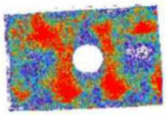
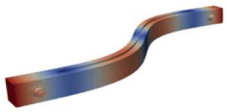
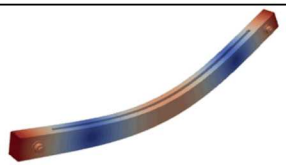
Beam Assembly: Pressure Film Verification



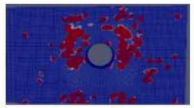
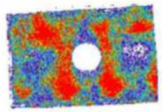
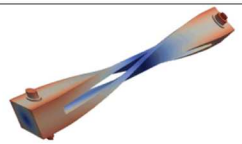
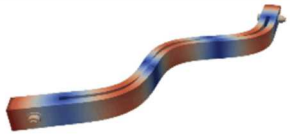
FEA Results

Pressure Film Data

Validation

	Flat surface, fully stuck [Hz]	*Flat surface, preloaded* [Hz]	*Perturbed surface, preloaded* [Hz]	*Experiment* [Hz]
Mode Shape				
	297.0 (+2.2%)	283.0 (-2.6%)	289.2 (-0.4%)	290.4
	359.2 (+1.5%)	354.5 (+0.2%)	355.5 (+0.5%)	353.8
	513.9 (+1.1%)	513.3 (+1.0%)	513.5 (+1.0%)	508.4
	597.0 (-0.3%)	597.0 (-0.3%)	597.1 (-0.3%)	598.6

Validation (Cont.)

	Flat surface, fully stuck [Hz]	*Flat surface, preloaded* [Hz]	*Perturbed surface, preloaded* [Hz]	*Experiment* [Hz]
Mode Shape				
	814.6 (+2.1%)	773.0 (-3.2%)	791.6 (-0.8%)	797.6
	982.9 (+2.8%)	925.9 (-3.2%)	948.7 (-0.7%)	955.6
	1183.7 (-0.2%)	1176.0 (-0.8%)	1178.9 (-0.6%)	1185.6
	1359.4 (+1.1%)	1353.0 (+0.6%)	1353.7 (+0.7%)	1344.4

Conclusions

- High-fidelity modelling of a benchmark jointed structure was conducted
  - Model updating of density, Young's modulus, surface geometry
- Applying tied MPC's to nodes in contact from a preload analysis identifies the pressure distribution of an interface
  - Qualitative agreement with pressure film data
- Significant improvements in natural frequency predictions occur for out-of-phase bending modes
  - Perturbed surface heights contact each other far from the bolt hole
- Future iterations include:
  - Spatially averaging surface heights, testing more topographies

Acknowledgments

- This research was conducted at the 2018 Nonlinear Mechanics and Dynamics (NOMAD) Research Institute supported by Sandia National Laboratories.
- Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525.

Acknowledgments (Cont.)

- The authors would also like to thank Bill Flynn from Siemens Industry Software NV for supplying the data acquisition and testing systems used to collect the experimental measurements presented throughout this work. SAND2018-11908 C