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UNDERSTANDING BASELINE MECHANISMS IN THE RADIAL-AXIAL (RADAX) JOINT

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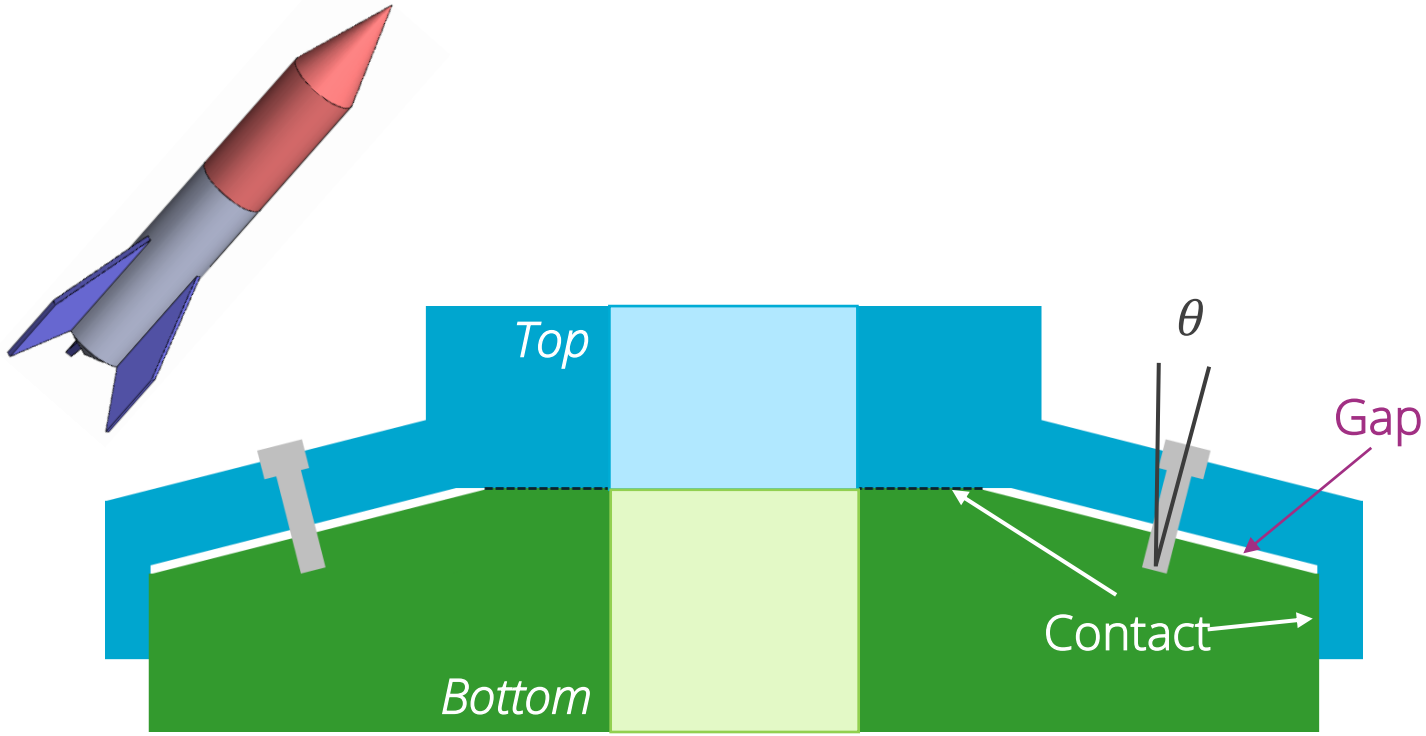
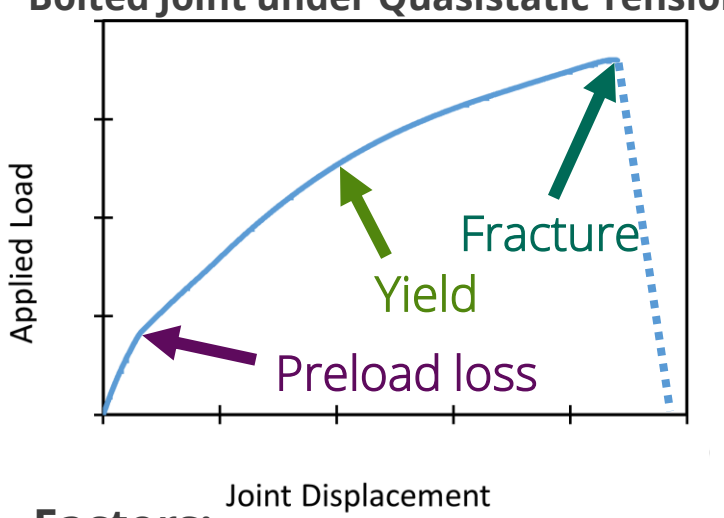
THE RADAX JOINT

Radial Axial (Radax) joints are a bolted joint commonly used in aerospace applications due to their high stiffness and low cyclic hysteresis.[1,2]

However, there is little information quantified information on its mechanical response in structural mechanics (SM) and structural dynamics (SD) scenarios.





Factors:

- Complex loading
- Bolt lot variation
- Process-induced variation

[1] Weydert, John C. (1968), doi:10.2172/5007820
[2] Schindwolf, Eric; Swanson, Bruce; and Millard, William. (1998). *12th AIAA/USU Conf on Small Satellites*

APPROACH: MULTISCALE ASSEMBLIES

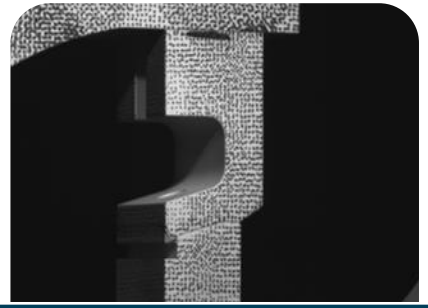
Increasing Mechanical Complexity

Single-Bolt Calibration

- Quasistatic (SM)
- Bolt lot variation
- Tensile loading behavior

- Base mechanical behavior
- Lot uncertainty quantification
- *Experimental*

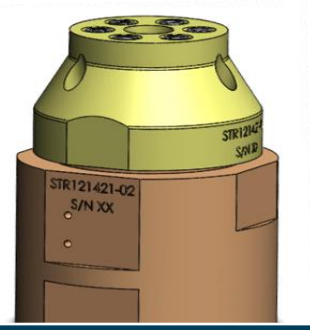
Ongoing



Single-Joint Calibration

- Quasistatic (SM)
- Multiple loading conditions

- Multiaxial loading behavior
- **Model Calibration**



'Mini-Radax' Validation

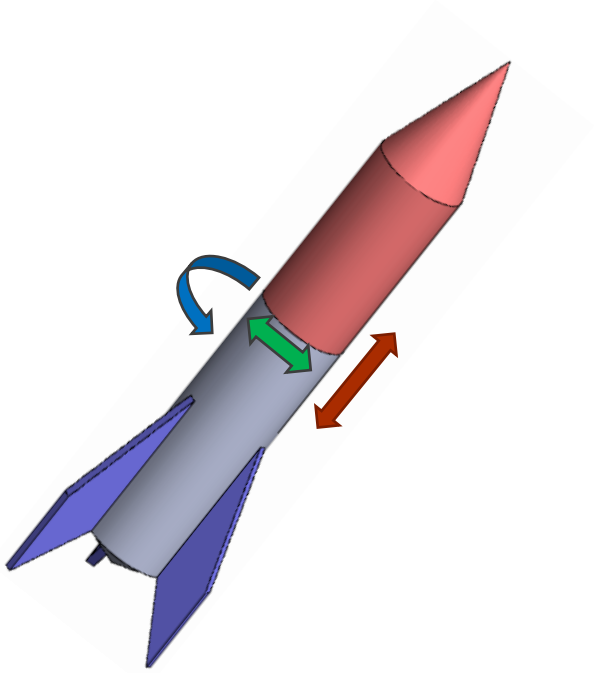
- Quasistatic/Fatigue (SM)
- Vibration (SD)
- **Axial Shock (+Model)**

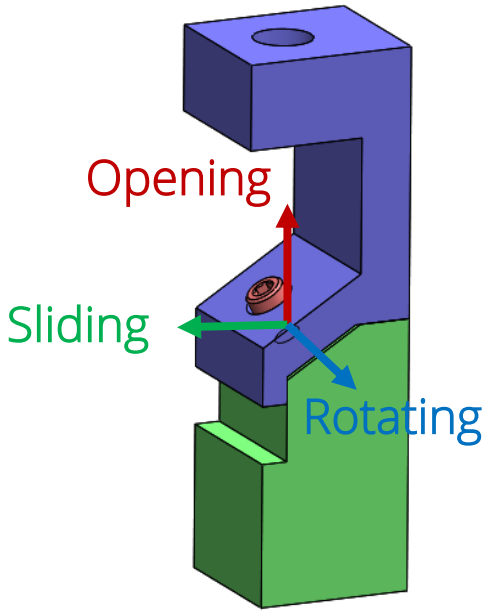
Structural and Dynamic Response of a Laboratory-Scale Radial-Axial (Radax) Joint, Chris Laursen, 10:10 AM

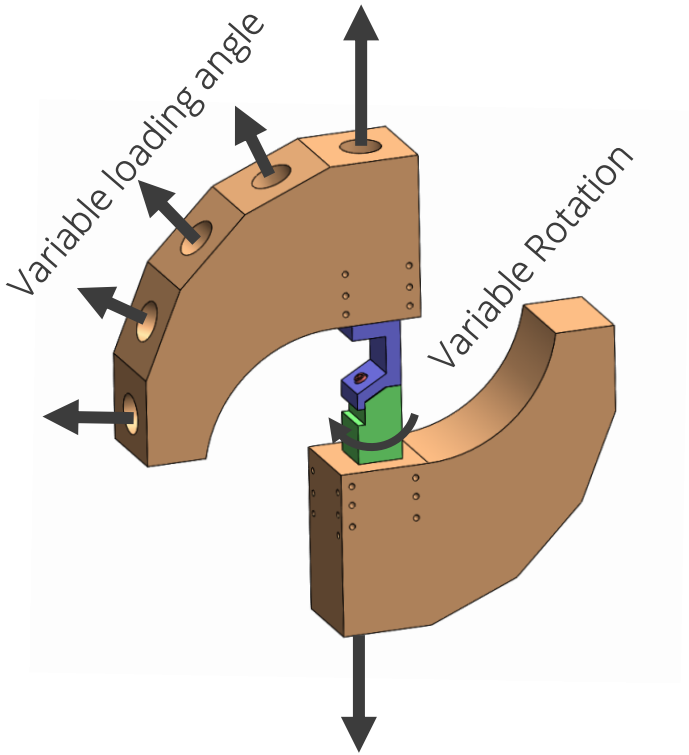
Calibration of Fastener Radax Joint and Statistical Predictions of Joint Performance in Component-Level Drop-Table Testing, Paul Miles, 10:30 AM

SINGLE-JOINT TEST

Multiple loading conditions in one standard setup



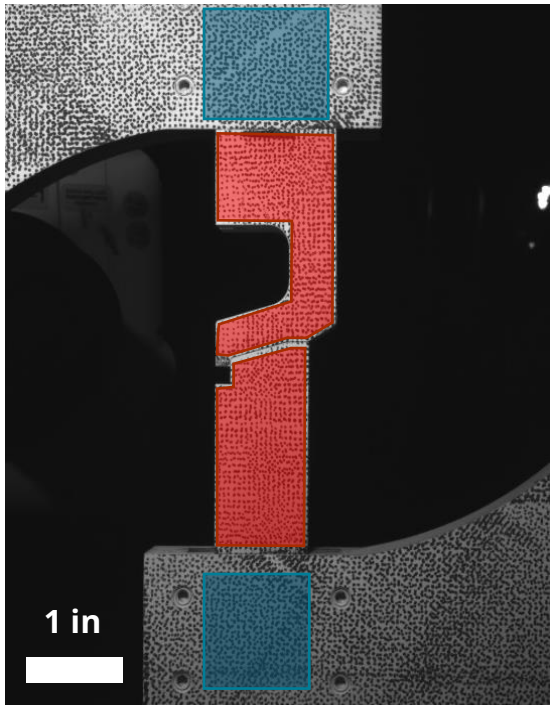




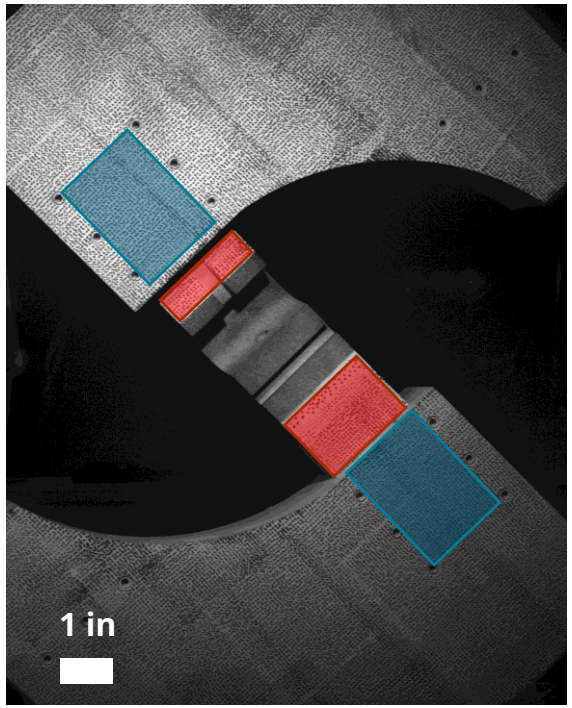
Material	
Bolt	A286 Steel
Joint	Al7075-T6 (Steel Keensert)

DIGITAL IMAGE CORRELATION (DIC) AND DATA ANALYSIS

Opening

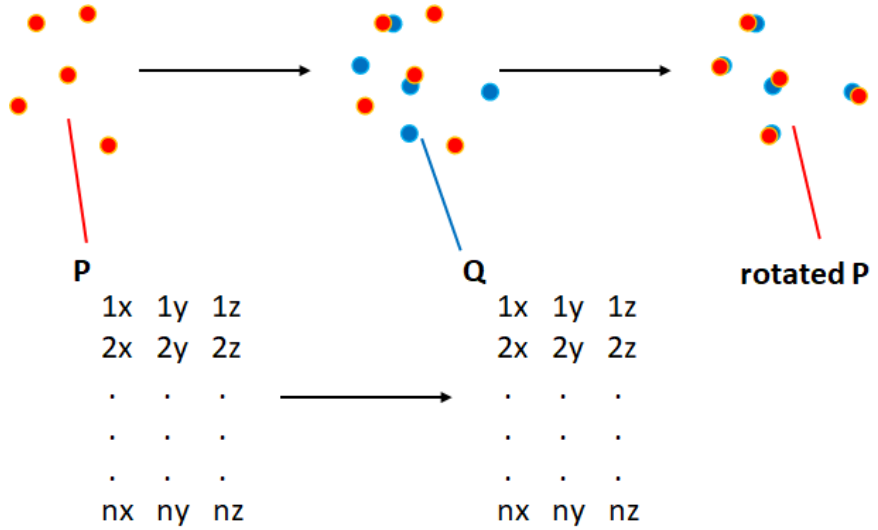


Mixed



Load Direction

Joint Displacement/Rotation
Grip Displacement/Rotation (for B.C.)

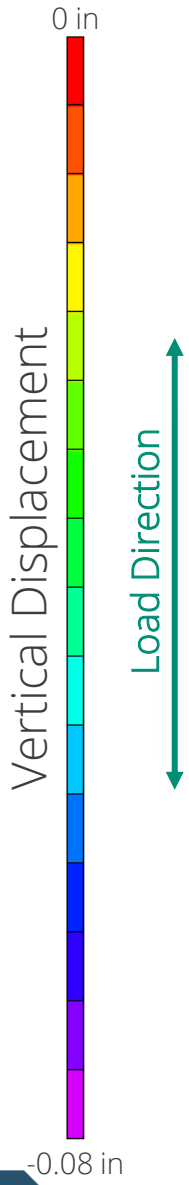


- Kabsch Algorithm [3]
  - Optimal method to track motion of a rigid body, e.g., each joint component
  - Exact solution

[3] - Kabsch (1976), *Acta Crystallographica*

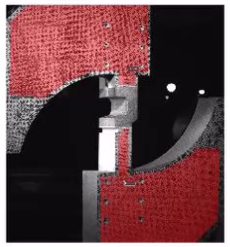
MECHANICAL BEHAVIOR OVERVIEW

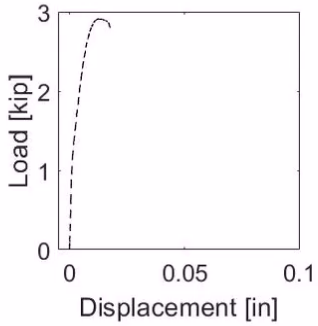
DIRECTIONAL LOADING OVERVIEW

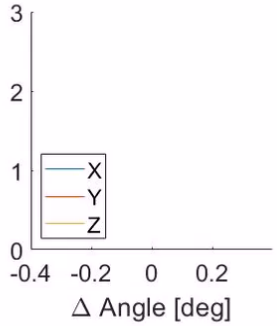


Load Direction

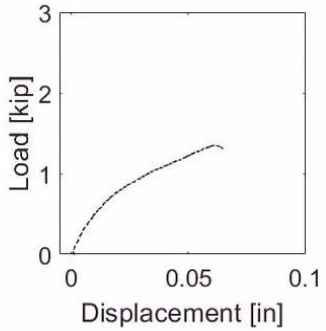
Opening mode

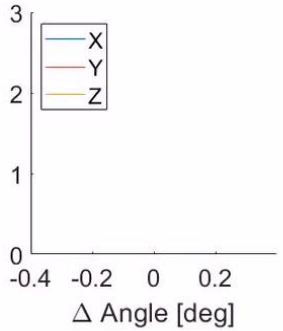




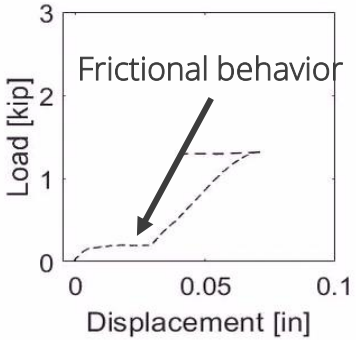


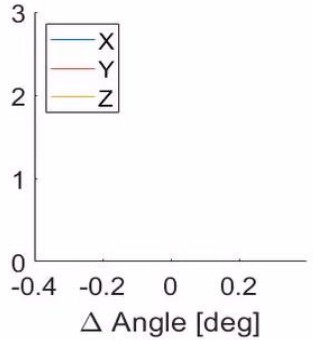
Sliding mode

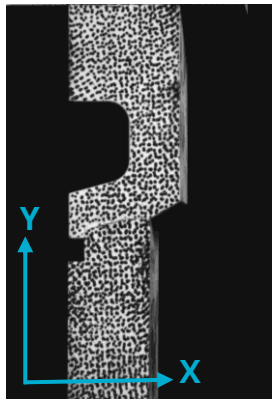


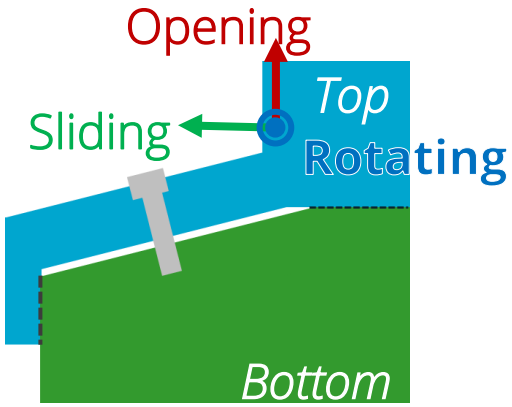


Rotating mode

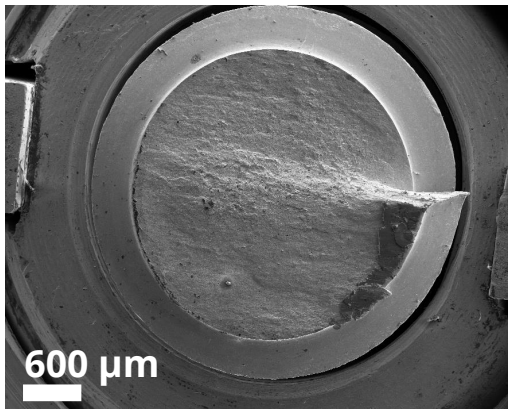








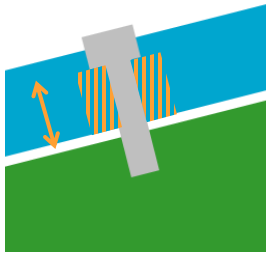
- Little rotation between the two halves of the joints.
- All failures occur in the bolt; little/no flange deformation seen

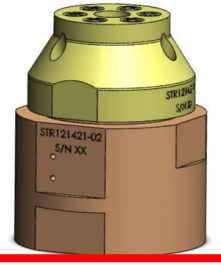


CALIBRATION TESTS

TEST REGIME AND CALIBRATION DATA

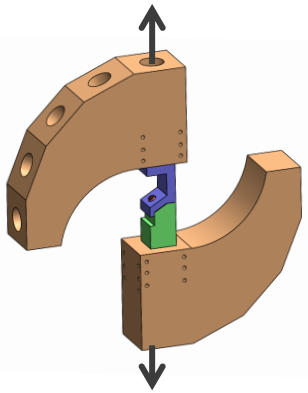
Load Configuration	Flange Thickness	Bolt Size
Opening	Nominal	8-32 (Nominal)
Sliding	"Thin"	¼"-20 (Large)
Rotating	"Thick"	
Mixed (3 modes)		

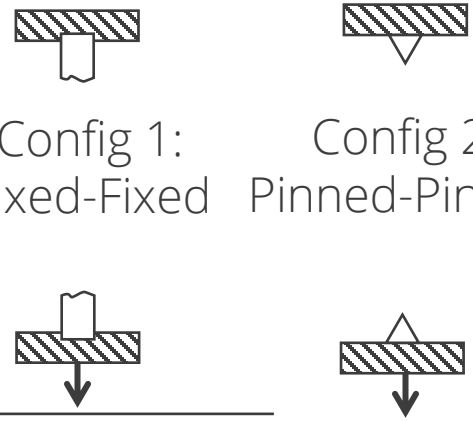




Calibration of Mini-Radax under longitudinal shock loading

- Load Data
- Vertical Displacement between top and bottom of joint



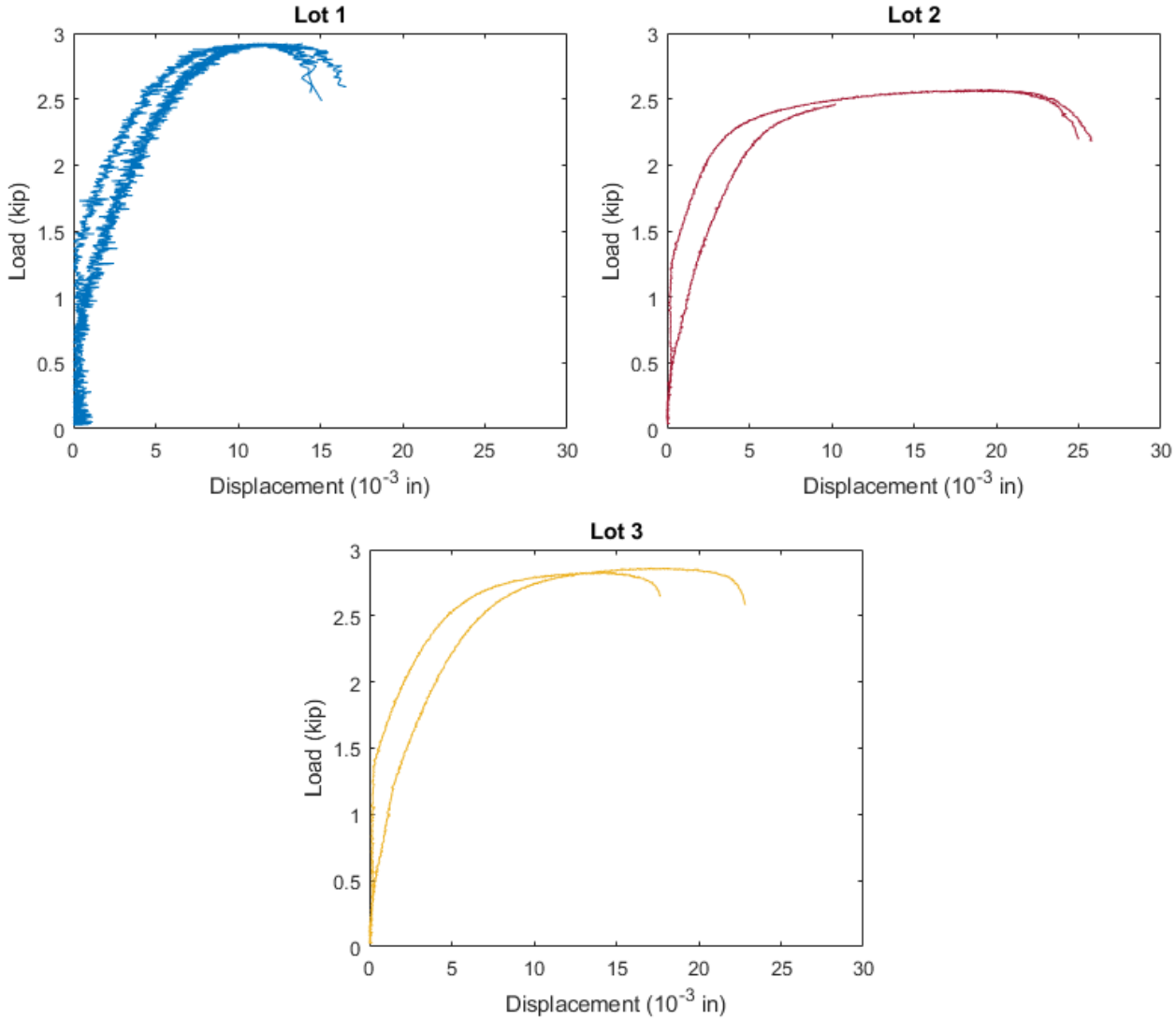


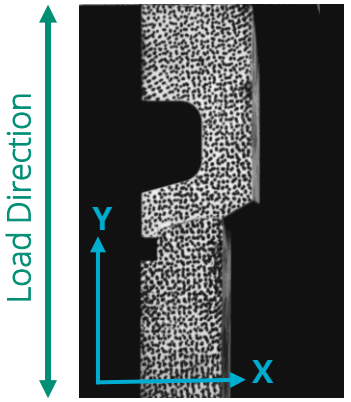
Config 1: Fixed-Fixed

Config 2: Pinned-Pinned

Test Parameters	
Bolt Preload Torque	34 in-lb
Displacement Rate	0.05 mil/s
Bolt Lots	4

OPENING CONFIGURATION: FIXED-FIXED CONDITIONS I

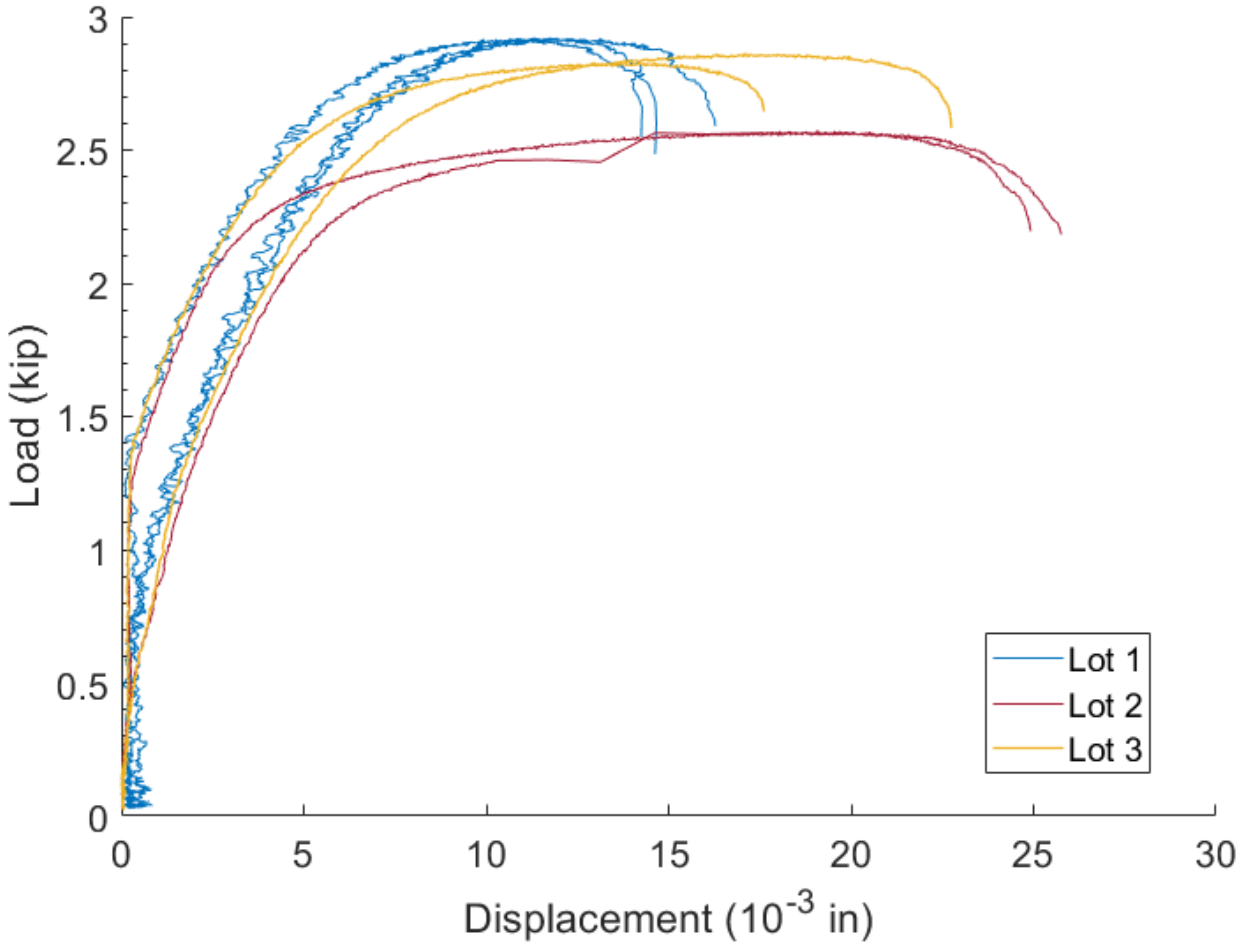




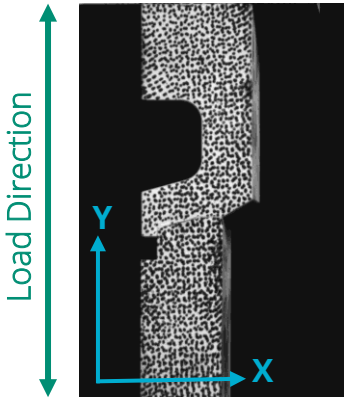
Lot Number	Mean Ultimate Load (kip)	Mean Disp. at Failure (10^{-3} in)
1	2.9	15.7
2	2.6	25.8
3	2.8	20.2

All failures occur in the bolt; little/no flange deformation seen

OPENING CONFIGURATION: FIXED-FIXED CONDITIONS I



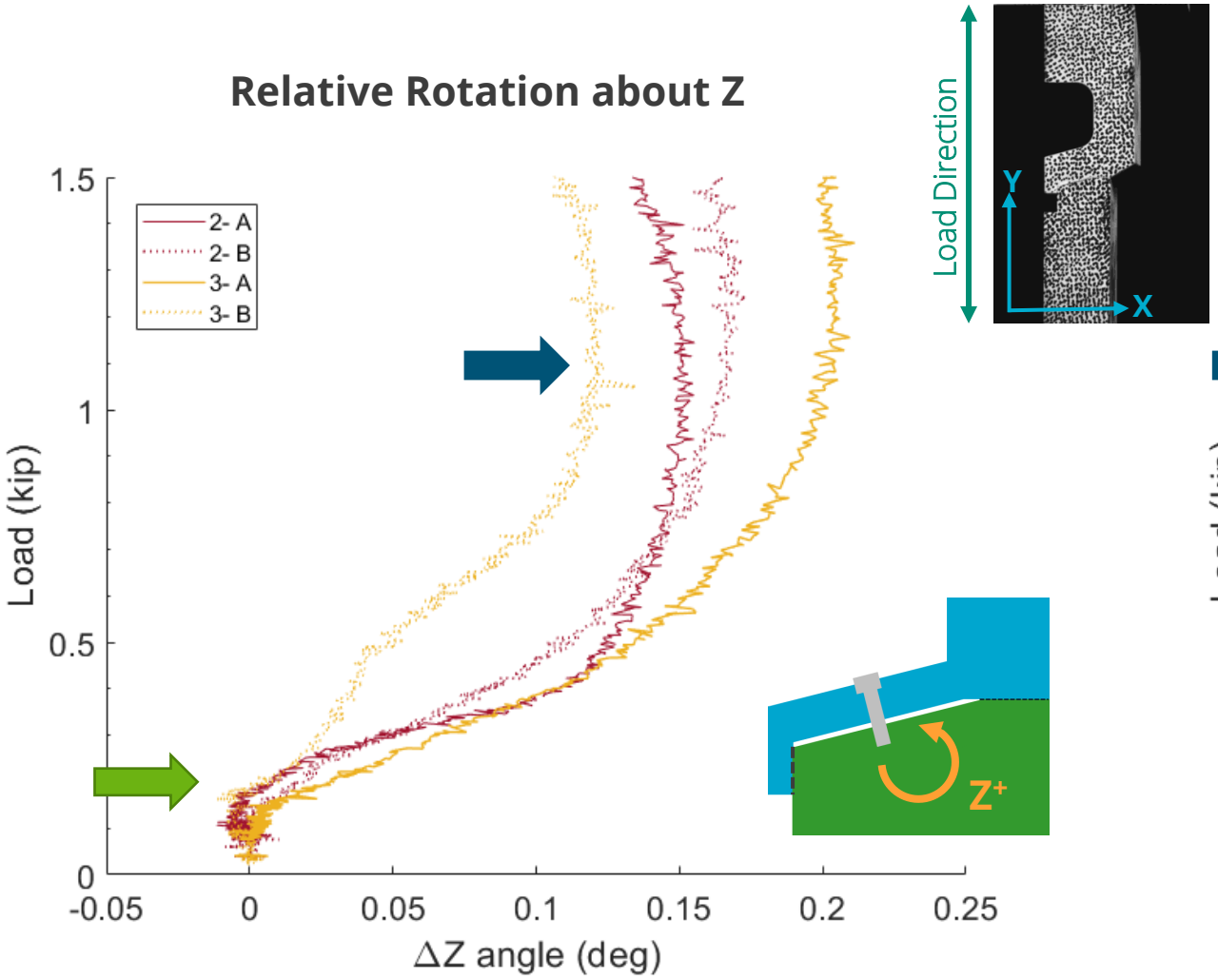
*A moving mean window has been applied to the data to lessen noise for visualization purposes

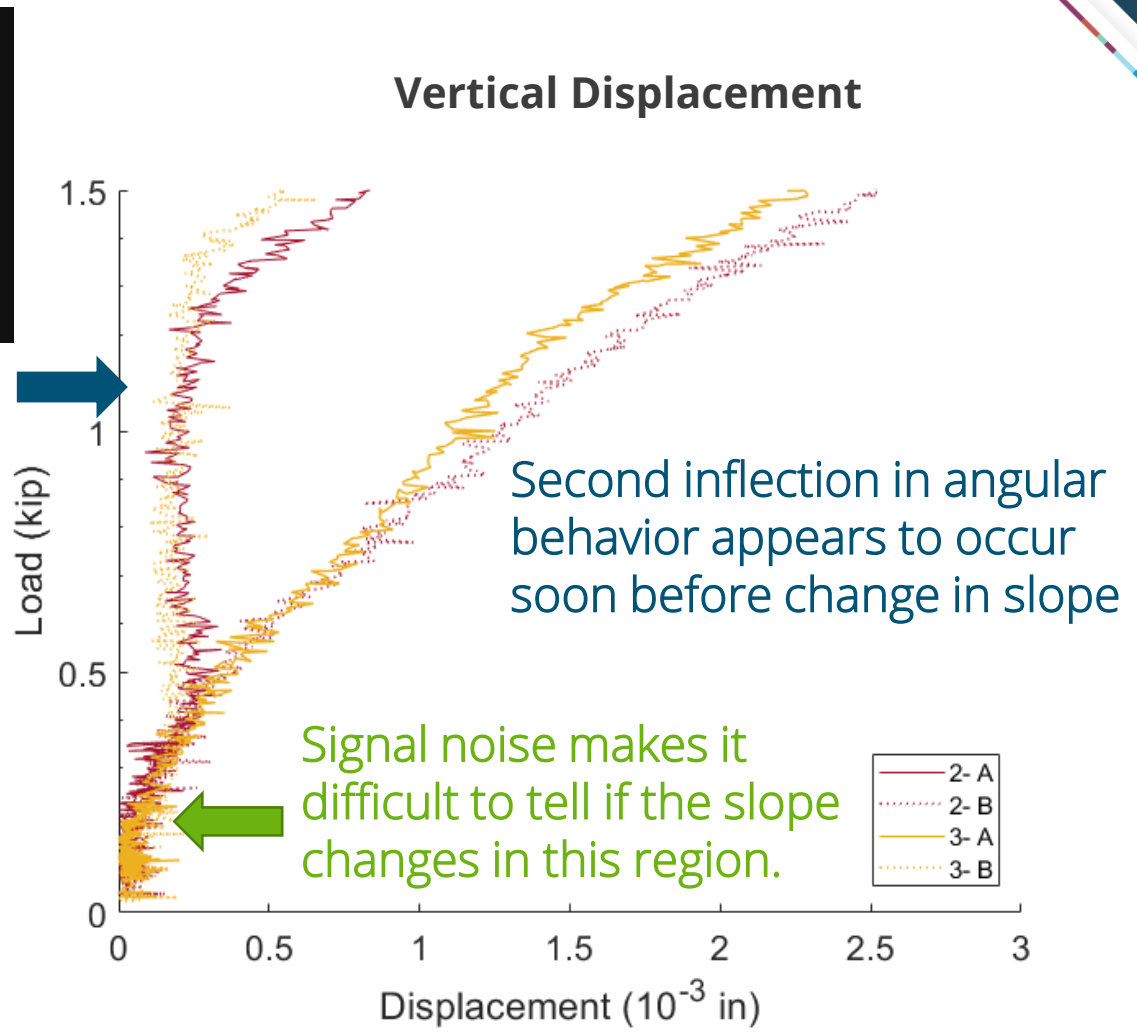


Lot Number	Mean Ultimate Load (kip)	Mean Disp. at Failure (10^{-3} in)
1 (Blue)	2.9	15.7
2 (Red)	2.6	25.8
3 (Yellow)	2.8	20.2

All failures occur in the bolt; little/no flange deformation seen

OPENING CONFIGURATION: FIXED-FIXED CONDITIONS II



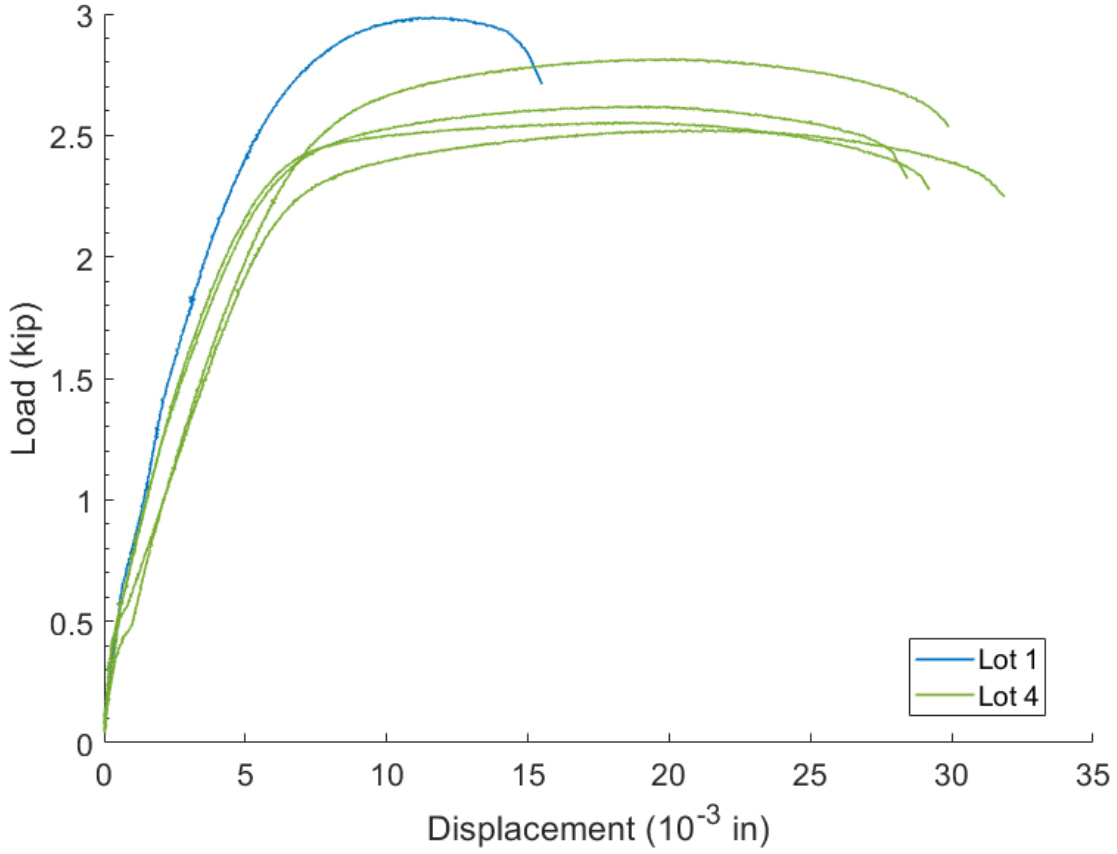


Second inflection in angular behavior appears to occur soon before change in slope

Signal noise makes it difficult to tell if the slope changes in this region.

*Moving mean window removed

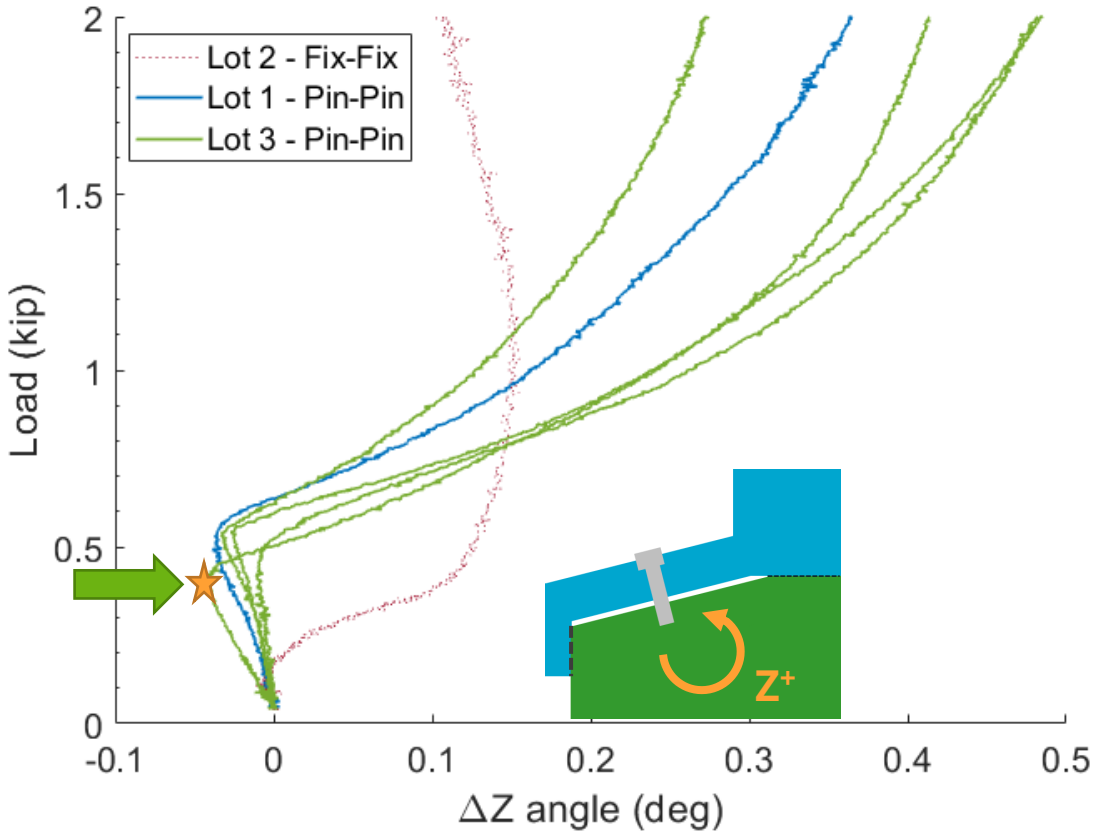
BC CHANGE: PINNED-PINNED CONDITIONS I



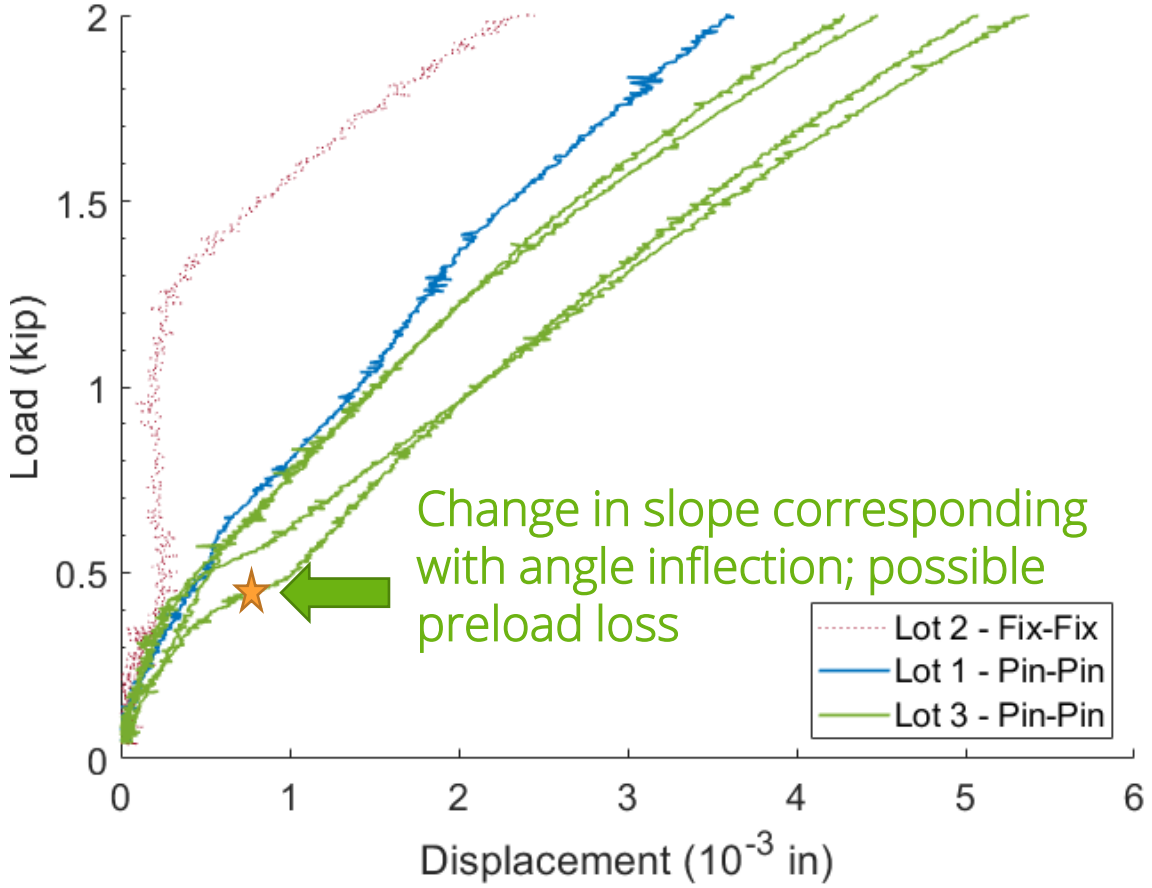
Lot Number	Mean Ultimate Load (kip)	Mean Disp. at Failure (10^{-3} in)
1 – Fix-Fix	*2.91*	*15.7*
1 – Pin-Pin (Blue)	2.97	15.1
4 (Green)	2.63	30.3

BC CHANGE: PINNED-PINNED CONDITIONS II

Relative Rotation about Z



Vertical Displacement



Change in slope corresponding with angle inflection; possible preload loss

CONCLUSIONS

- Baseline mechanical behaviors of RADAX joints determined from single-joint geometry tests.
  - Raw data was passed to computationalists to model the mini-RADAX validation

- Variability in mechanical behavior seen within lots and between lots.
  - In-lot variability possibly stems from process variation, but further repetition is required.

- Changing the boundary condition from fixed-fixed to pinned-pinned affects ‘early’ mechanical behavior of the bolts up to preload, but has less effect on ultimate strength or strain to failure.

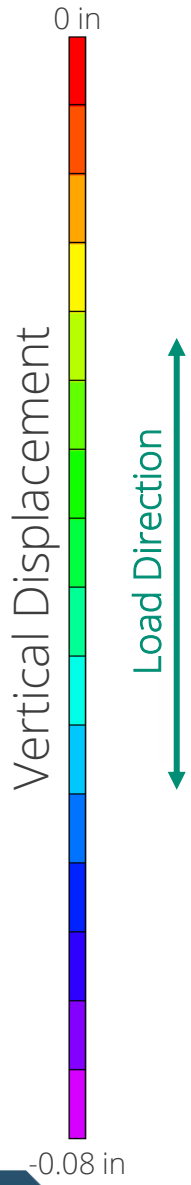
ACKNOWLEDGEMENTS

- Thank you to Darren Pendley and Mark Foster for their aid in testing these assemblies.

- Thank you to John Mersch, Paul Miles, and Debbie Fowler for their feedback and assistance in data analysis, as well as their modeling work.

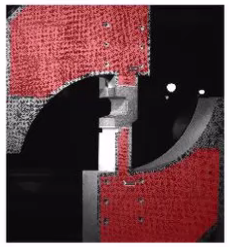
QUESTIONS

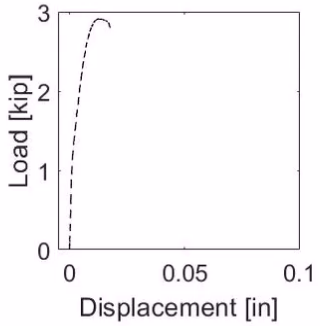
DIRECTIONAL LOADING OVERVIEW

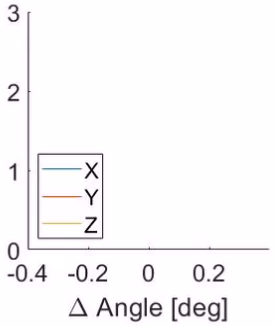


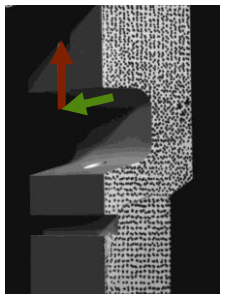
Load Direction

Opening mode









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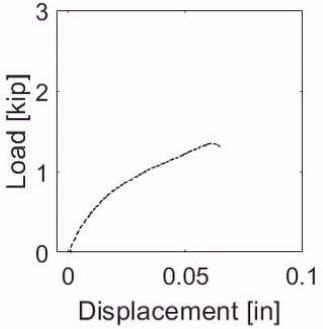
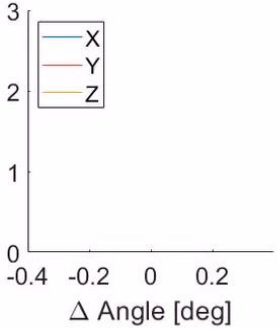
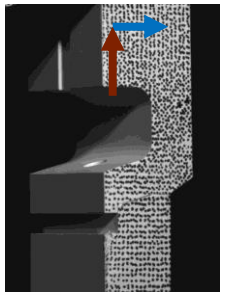
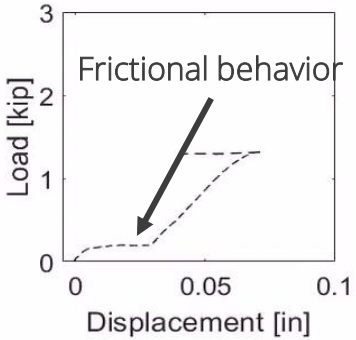
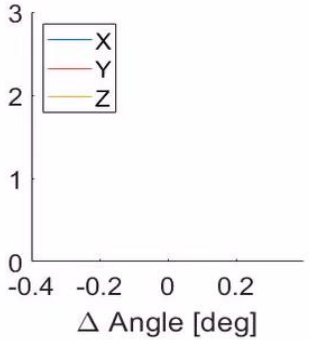


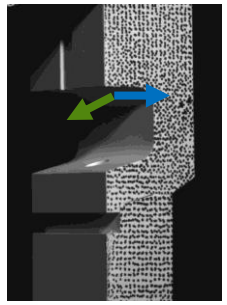




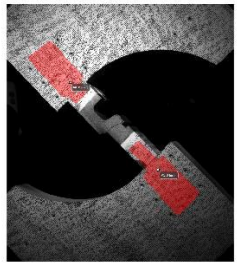
Rotating mode

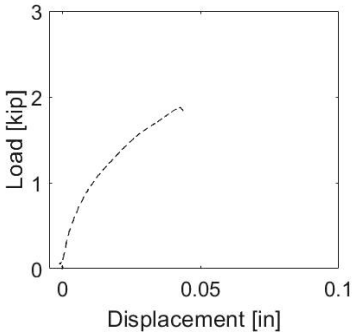




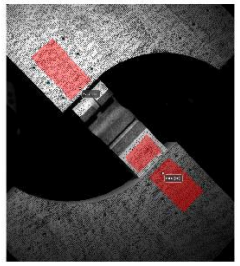


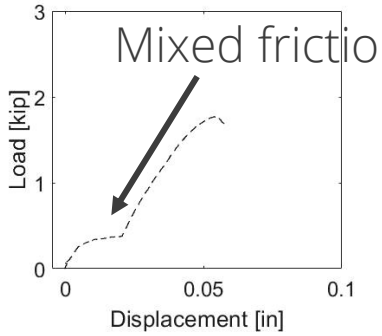
Opening/Sliding



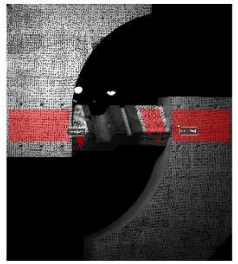


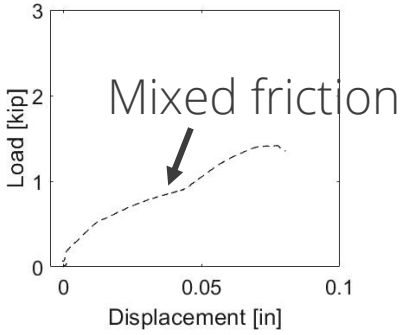
Opening/Rotating





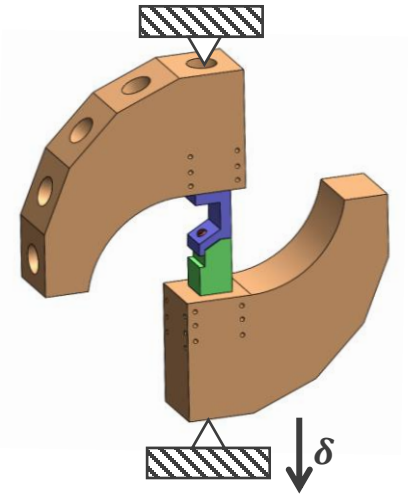
Sliding/Rotating



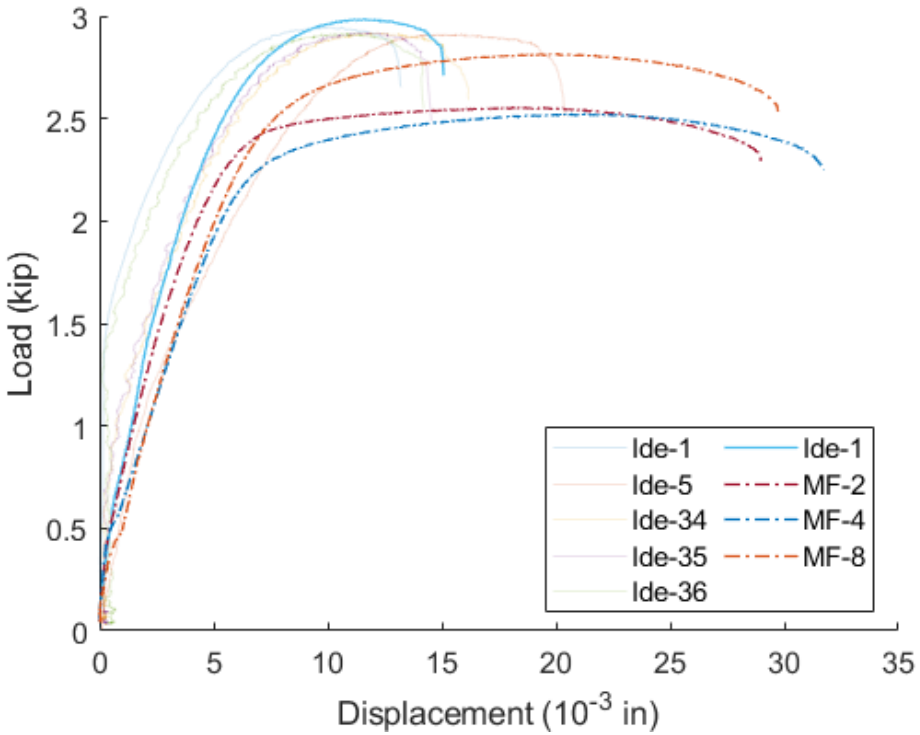


BOLT LOT VARIATION: OPENING CONFIGURATION

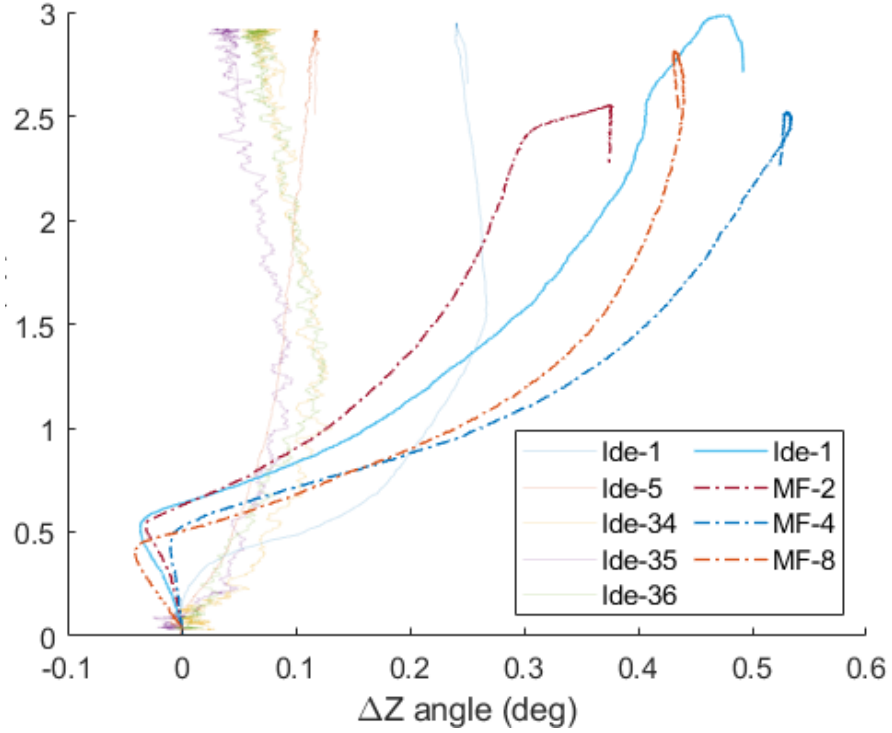
Pinned-Pinned Connection



Vertical Displacement

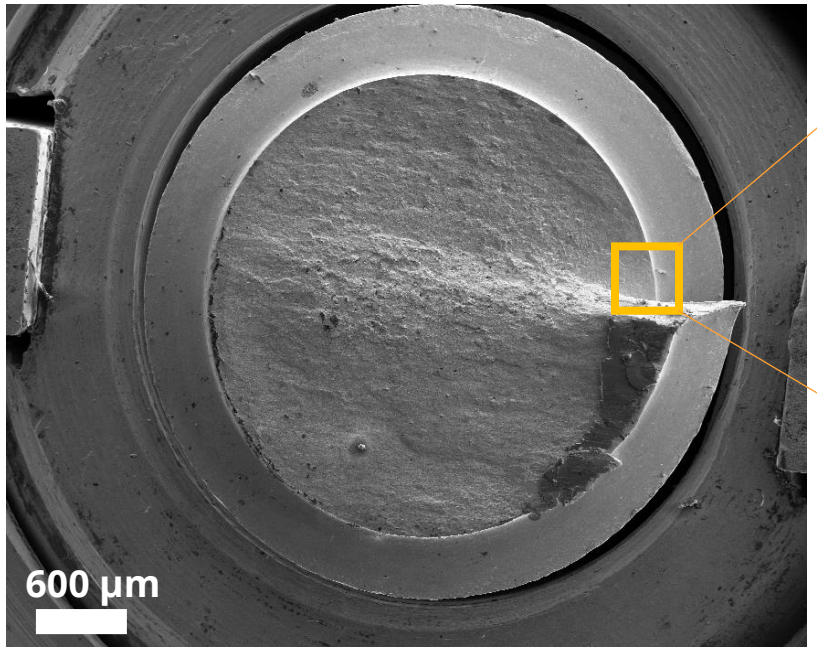


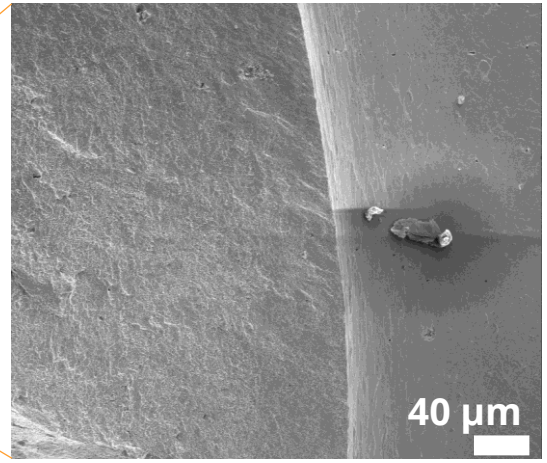
Relative Rotation about Z



- Changing loading conditions has little effect on load/displacement behavior
- Increased rotation may not be reflective of actual conditions.

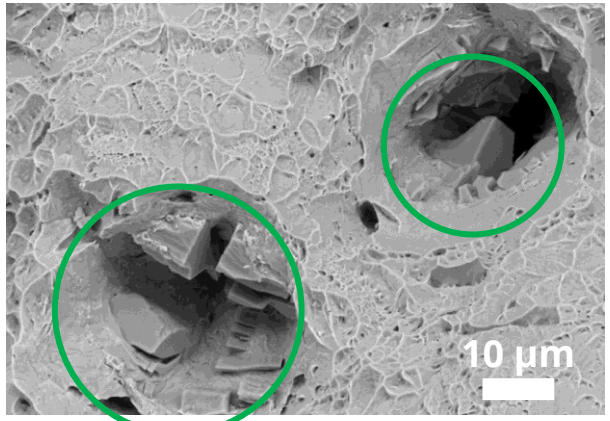
SOURCES OF BOLT LOT VARIATION: FRACTURE SURFACES

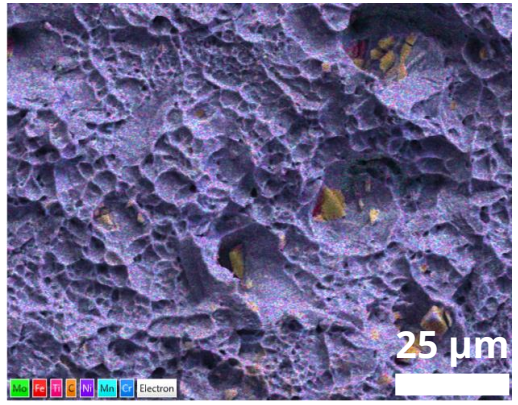


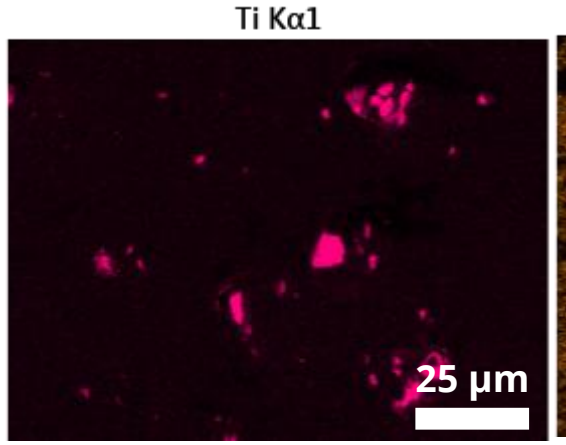


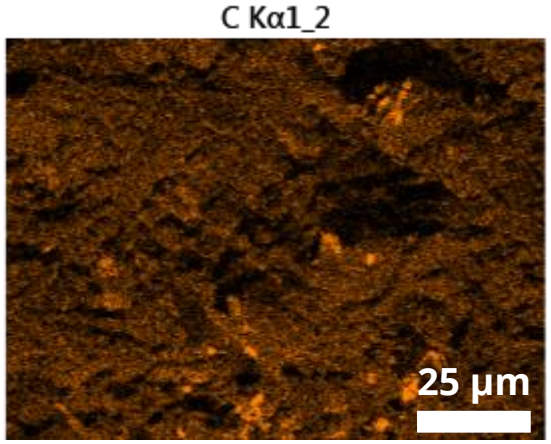
Failure at thread base for all loading conditions.

Few significant differences in fracture surfaces between conditions.



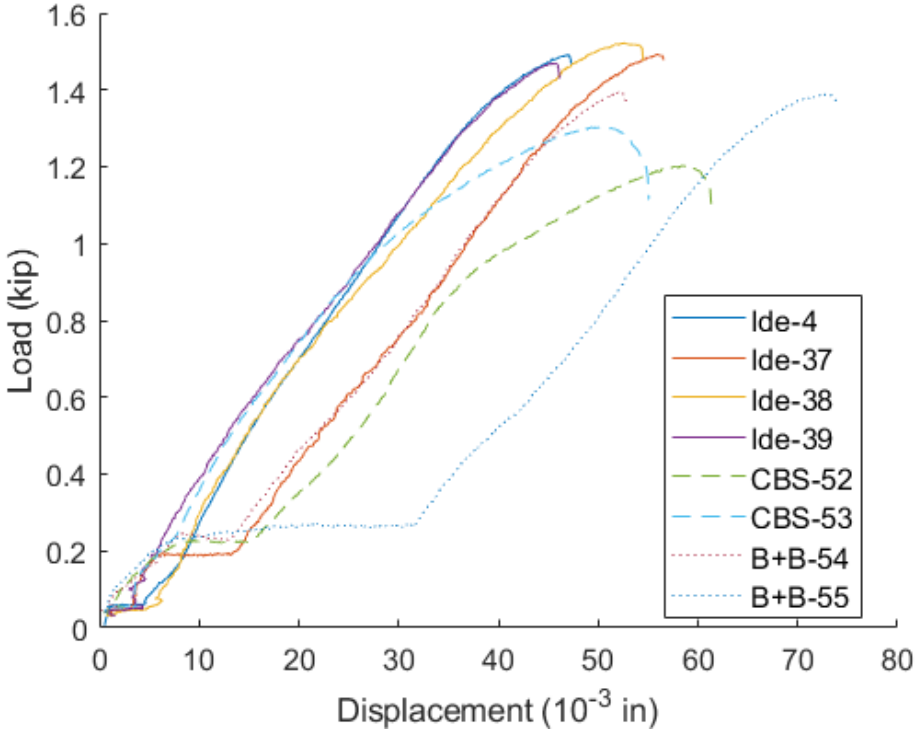


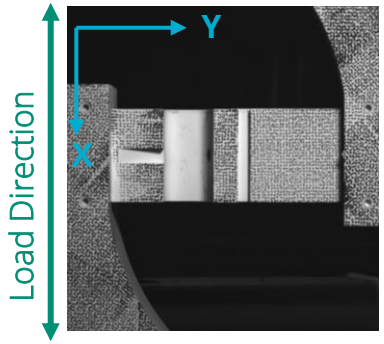




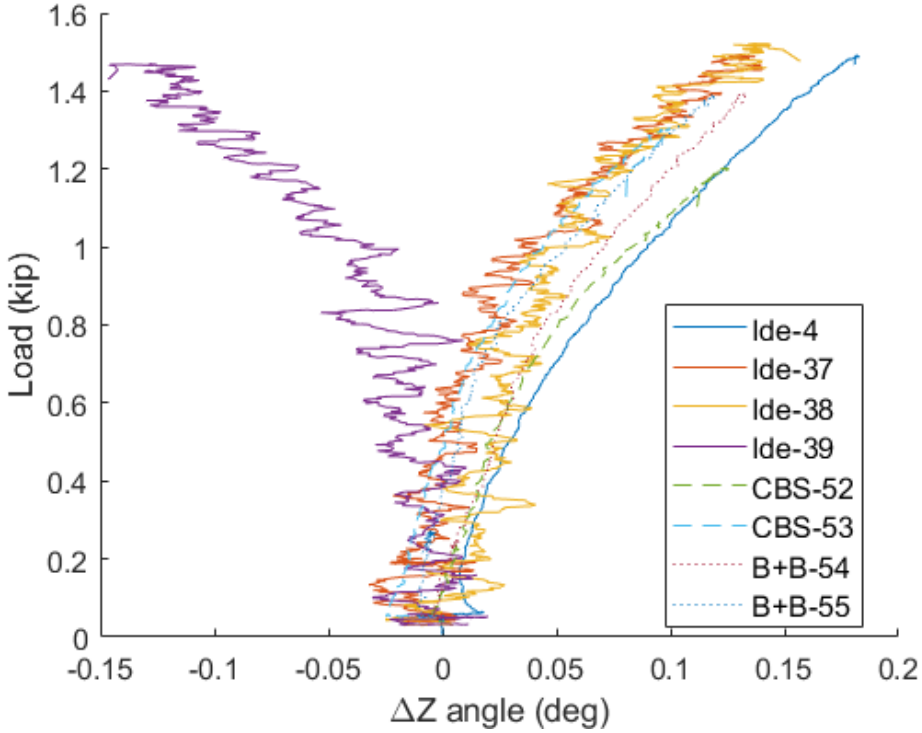
MULTI-FACTOR VARIATION: ROTATING CONFIGURATION

Euclidean Displacement



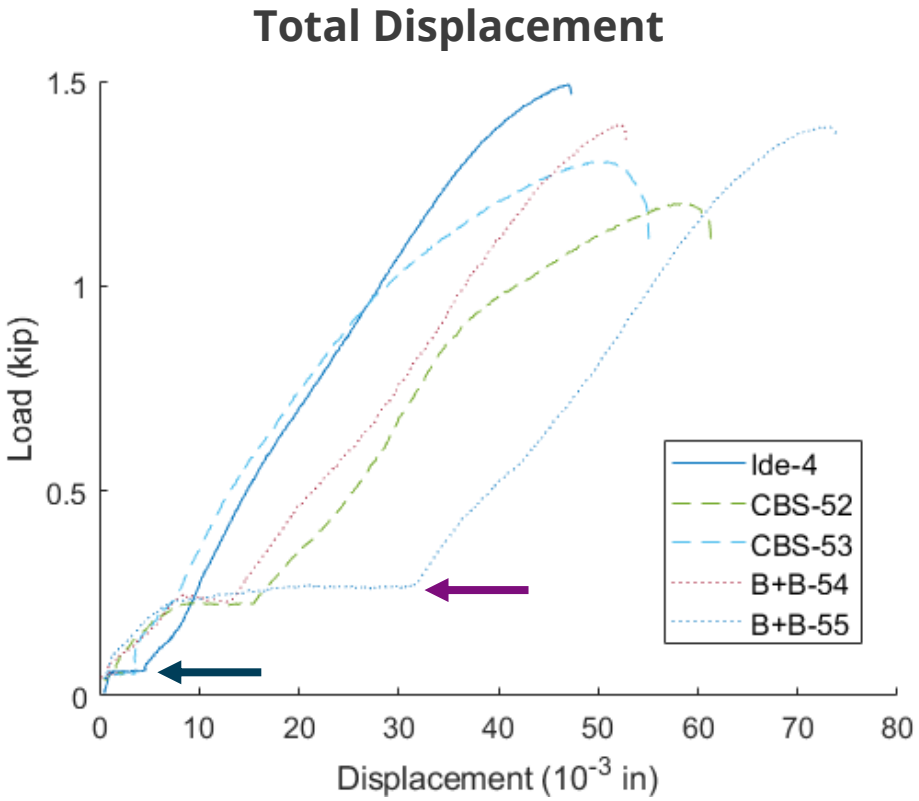


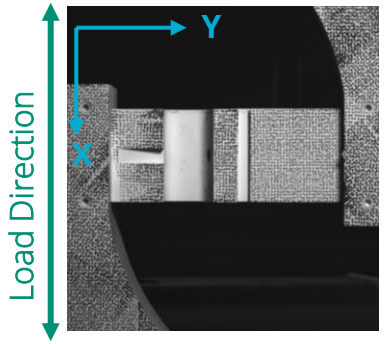
Relative Rotation about Z

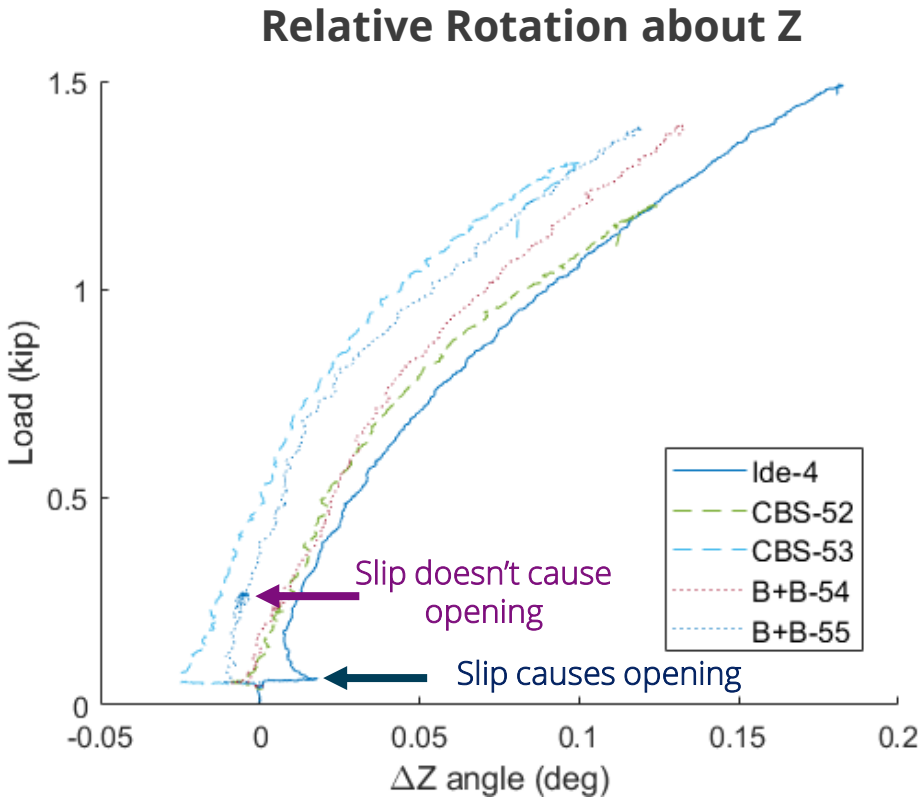


- Bolt lot variation observed in ultimate strength, plastic behavior

MULTI-FACTOR VARIATION: SLIDING CONFIGURATION





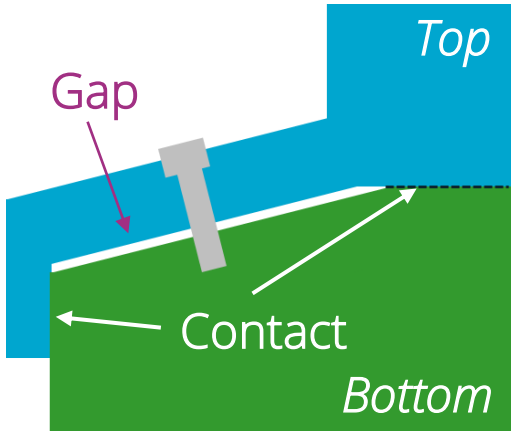


- Bolt lot variation observed in ultimate strength, plastic behavior

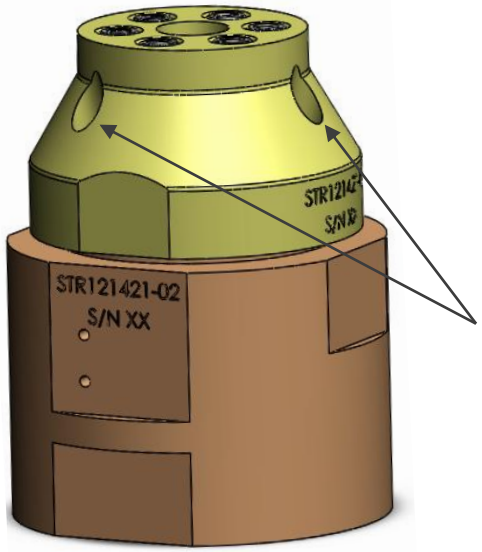
- Stochasticity of frictional behavior likely stems from tribological factors or process variation (i.e., preload variability or relative 'centering' of bolt and flange)

RESPONSE OF A RADAX JOINT IN DYNAMIC LOADING CONDITIONS

Radial Axial (Radax) Joint

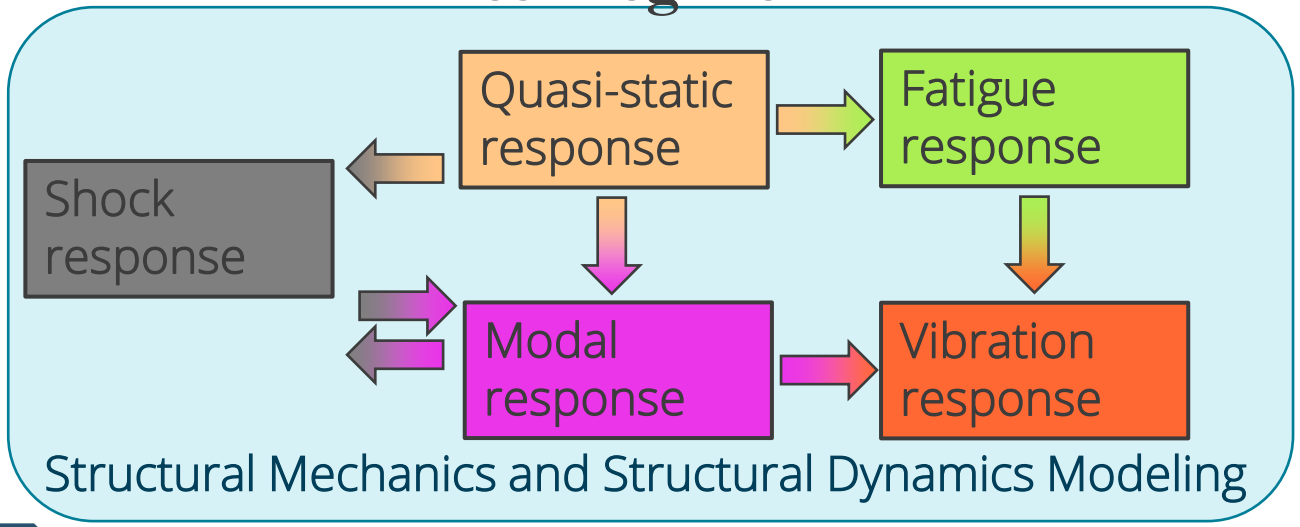


'Mini'-Radax test article



Three evenly-spaced Radax connections

Test Regime



- Over 40 tests that involve DIC
- Need to relate DIC results from one test to another
  - Consistently defined Area(s) of Interest between tests
  - Universal coordinate system
- Generate useful data for calibration of computer models