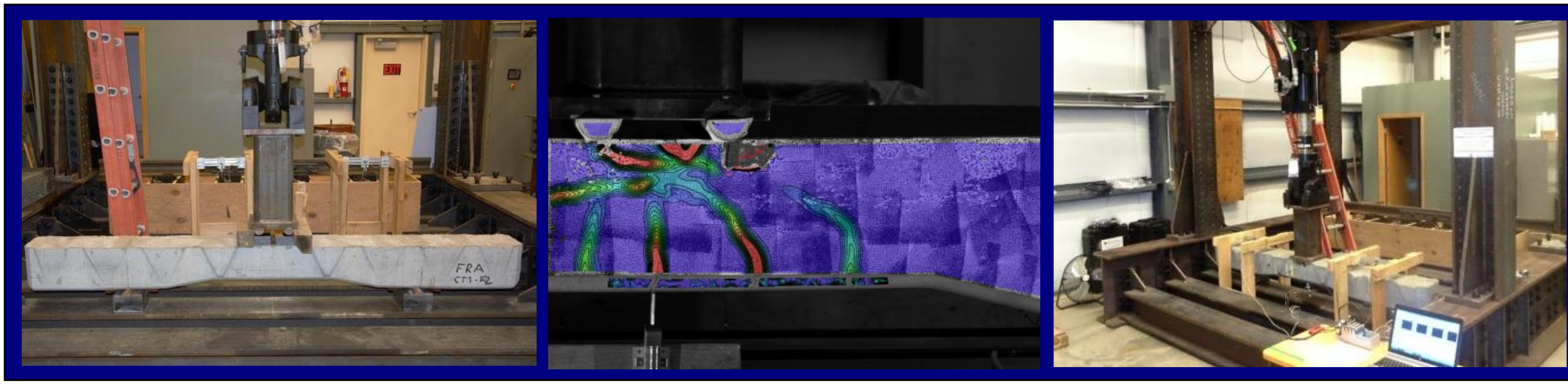
A Load-Deflection Method for Characterization of North American Concrete Crossties



Joint Rail Conference
Track Loading & Crosstie Performance 1
Philadelphia, PA
06 April 2017

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RAILTEC
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

U.S. Department of Transportation
Federal Railroad Administration

Outline

- Motivation & Objectives
- AREMA C- Test
- C- Test Modification Benefits
- Test Protocol
- Failure Modes
- Results & Discussion

Motivation and Objectives

U.S. Department of Transportation
Federal Railroad Administration

Research Motivation

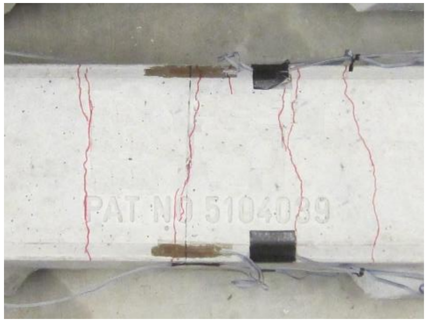
- Need for improved understanding of the performance of deteriorated concrete crossties or concrete crossties with poor support conditions
- Improve safety by preventing derailments in locations where track superstructure components and substructure conditions have not been in the optimal state of good repair

Research Objectives

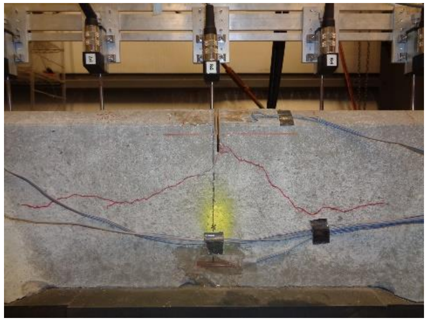
- Determine common failure types and quantify the common track conditions in repeat failure locations
- Quantify the effect worn/degraded track conditions have on critical track component' stress state
- Define concrete crosstie failure

Project Overview – Phases of Laboratory Work

- **Phase 1**: deteriorated crossties and support conditions
  - Gauge widening calculation
  - Quantification of bending moments
    - Various support conditions
    - Center-cracked crossties



- **Phase 2**: extension of Phase 1 with extreme deterioration cases
  - Setting boundaries to the problem
    - Center cracks generated at higher loads
    - Crosstie saw-cutting

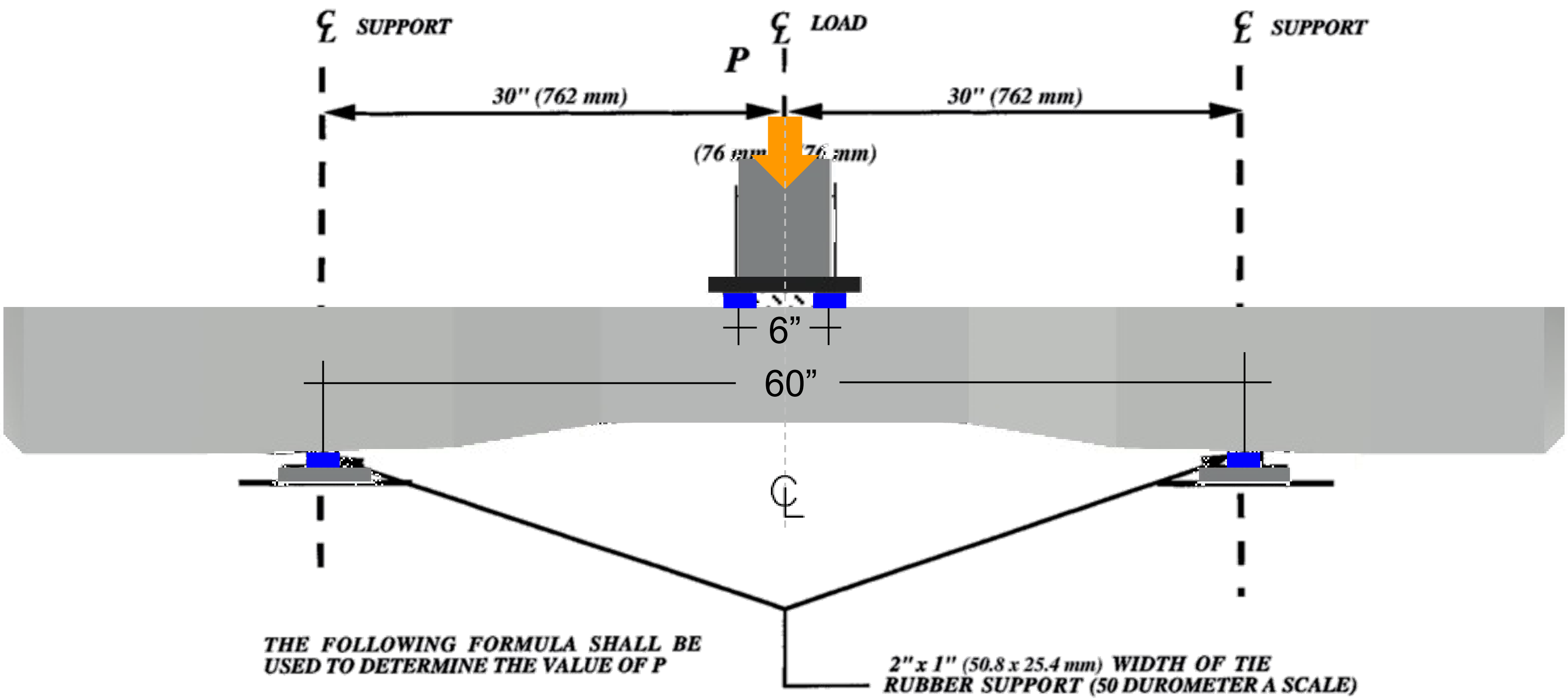


- **Phase 3**: new method of characterizing concrete crossties
  - Load vs. deflection curves for 4-point bending tests
  - Crosstie stiffness, crack generation, ultimate strength
    - Modified AREMA center negative bending moment test

AREMA Center Negative Bending Moment Test

(AREMA Manual for Railway Engineering, Article 4.9.1.6)

- A pass/fail test based on whether or not there are cracks reaching the first level of prestressing steel at the design specification bending moment



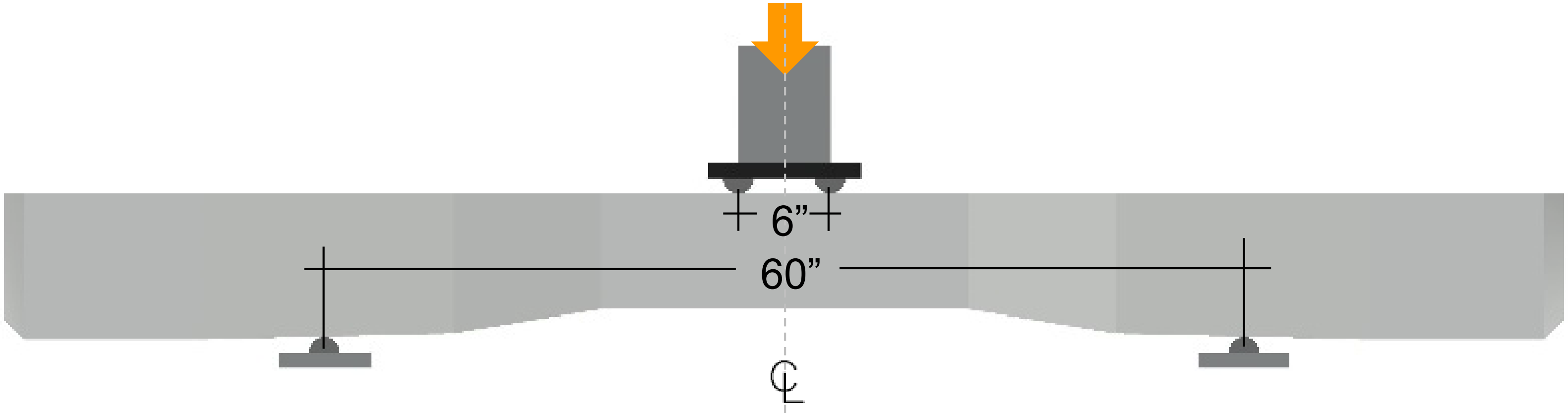
$$P = \frac{2\ M}{27''\ (\text{or } 686\ \text{mm})}$$

A Modified Center Negative Test at UIUC

- **Load Configuration**: four-point bending (*same as AREMA*)
- **Supports**: Steel half-moon bars (*AREMA recommends rubber*)
- **Loading**: Load to failure (*AREMA recommends stopping at specified level*)
- **Instrumentation**: Load cell & Displacement sensor (*AREMA recommends load cell*)

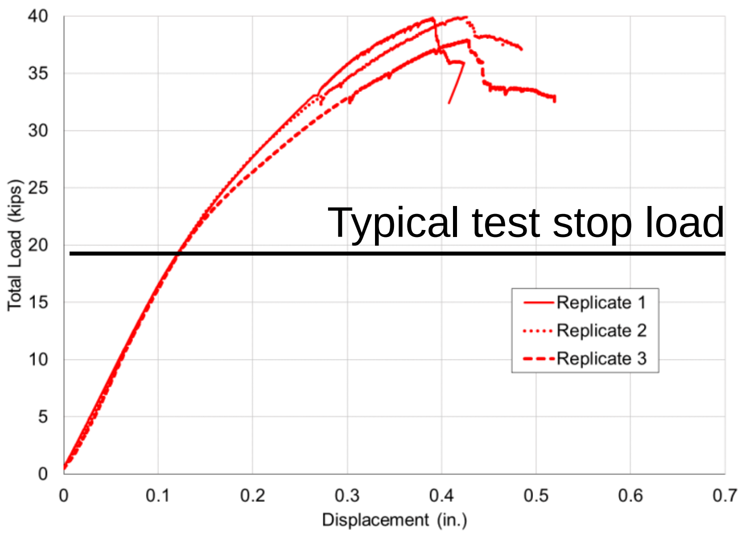
Protocol

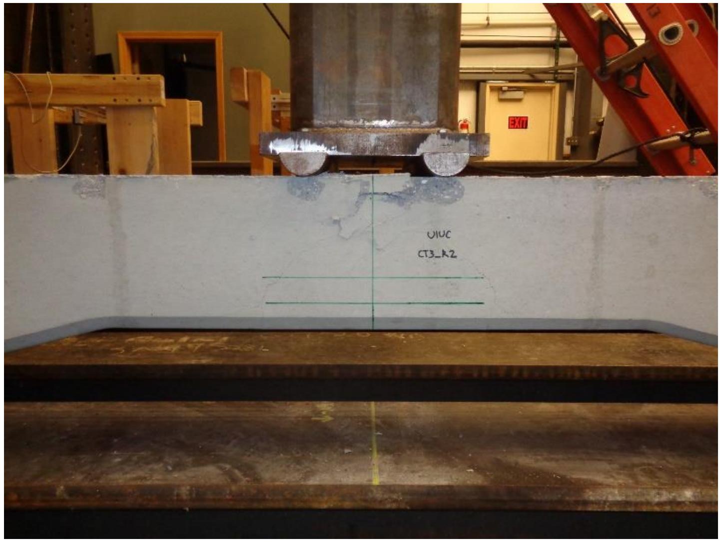
1. Ensure bottom of crosstie provides smooth surface for good contact with steel bars
   – Hydrocal or hard grout may have to be applied
2. Seating load is applied on smooth surface
   – 3 cycles of loading from 0 to 15 kips to ensure uniform contact with supports
3. Execute test
   – Specimen loaded from 0.5 kips to ultimate load at a rate of 5 kips/minute



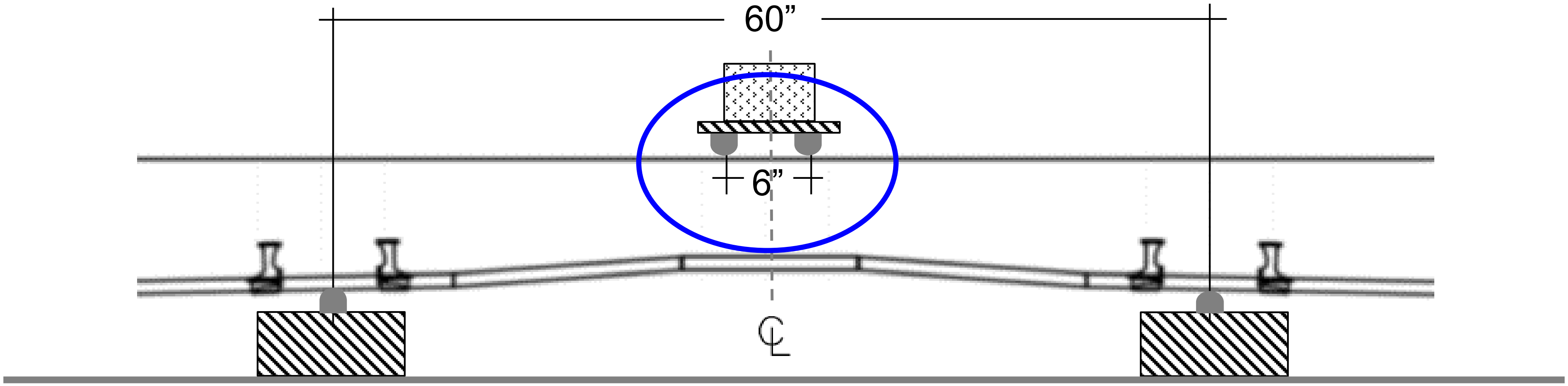
Motivation for Test Modification

- Opportunity for characterization of concrete crosstie bending capacity
  - A pass/ fail test would not provide enough information
  - Quantifiable characteristics from load vs. deflection curve
    - Ultimate capacity (*load cell*)
    - Ultimate displacement (*displacement sensor*)
    - Stiffness assessment (*load cell & displacement sensor*)
- Stiff support conditions to capture displacement of crosstie accurately
  - Half-moon steel bars (or any other preferred way)





6-inch Support Width Selection



PROS:

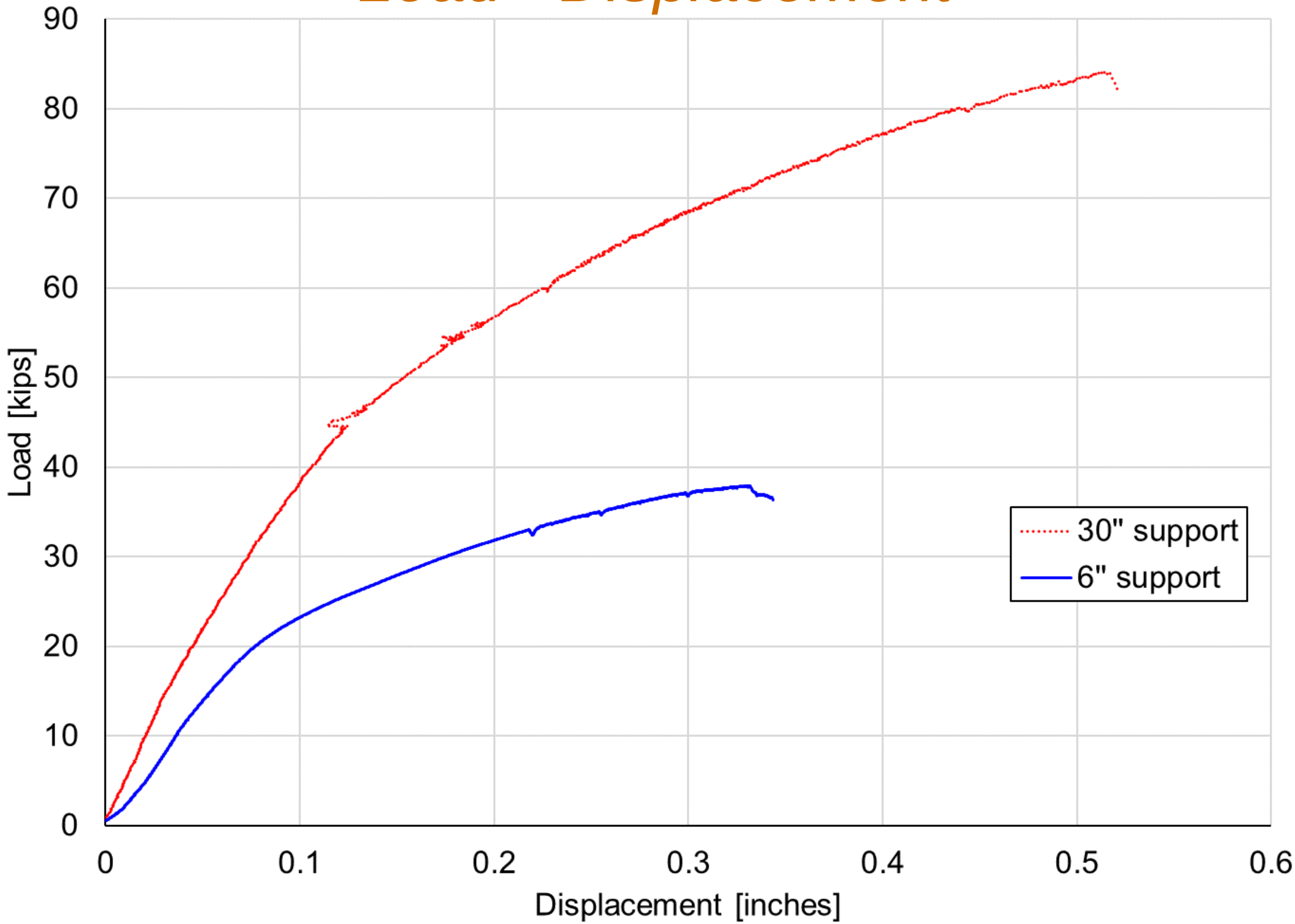
- Maps to AREMA CN-
- Stable setup
- Lower ultimate loads required

CONS:

- Does not map to observed condition in the field
- Proximity of loading bars may lead to failure at lower moment than if further apart

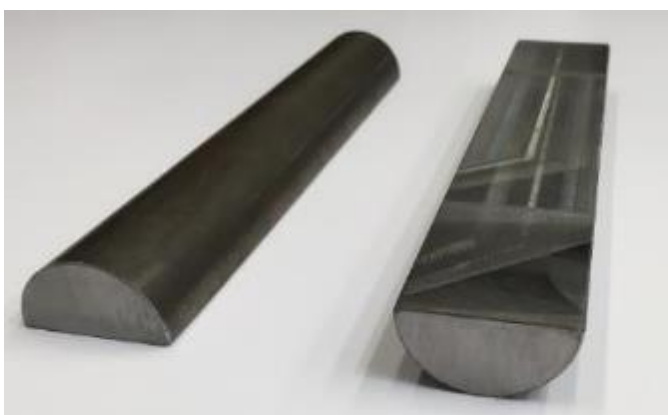
Effects of Using Wider Support Conditions

Load - Displacement



RailTEC's Large Scale Test Frame (LSTF)

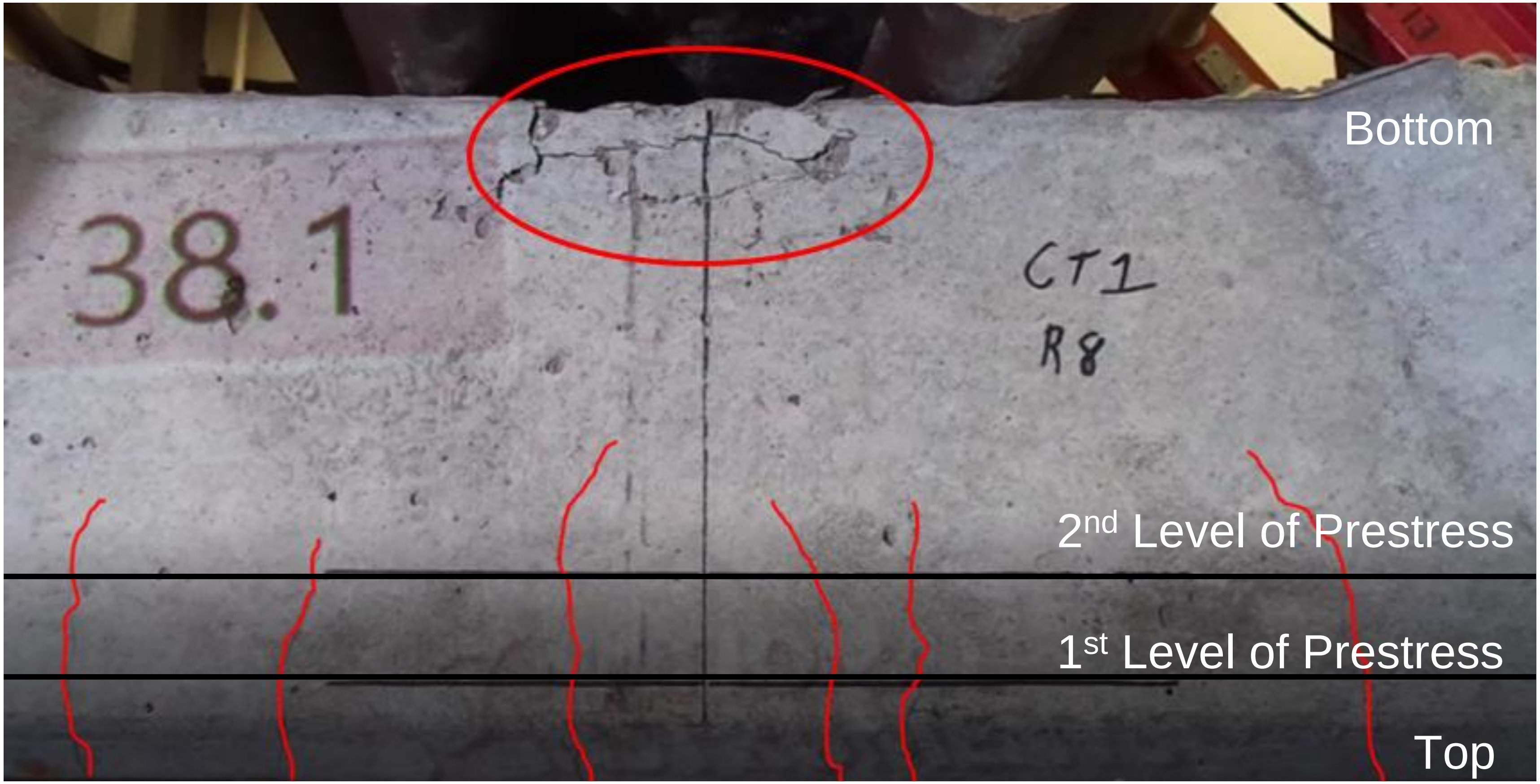
- 110-kip actuator
- Load/displacement control
- Static/dynamic modes
- Adjustable crosstie support
  - Currently equipped with half-moon steel bars as supports

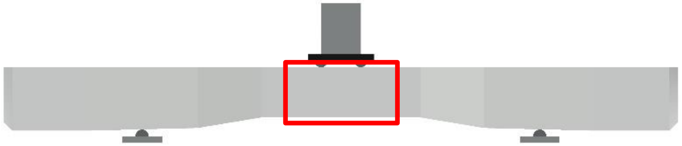


Crosstie Failure Modes

Flexural

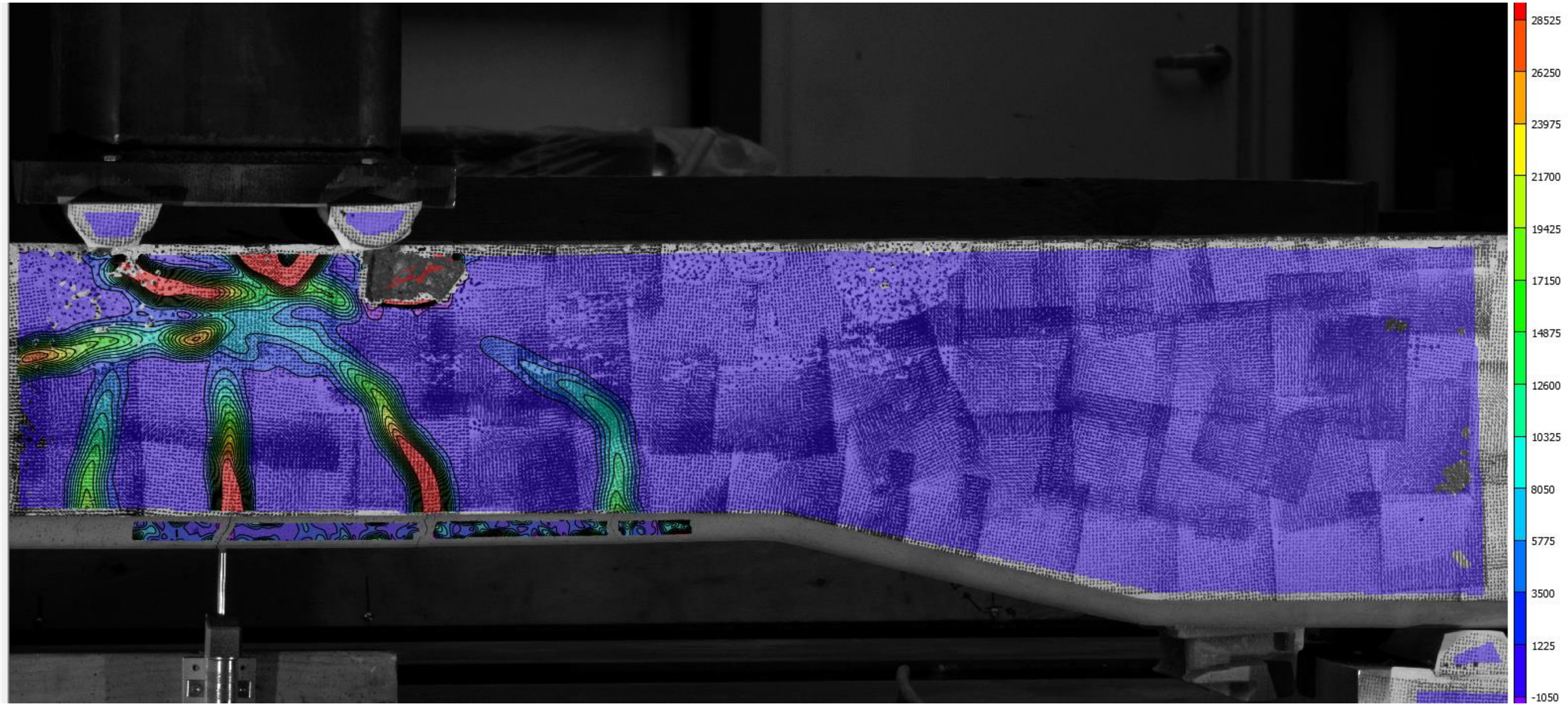
- Crushing failure (bending strength reached)



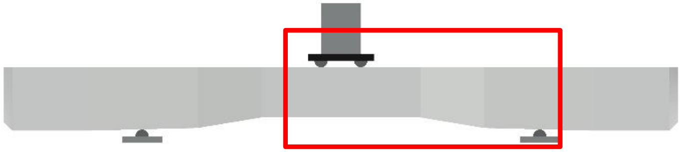


Crosstie Failure Modes (cont.)

Flexural

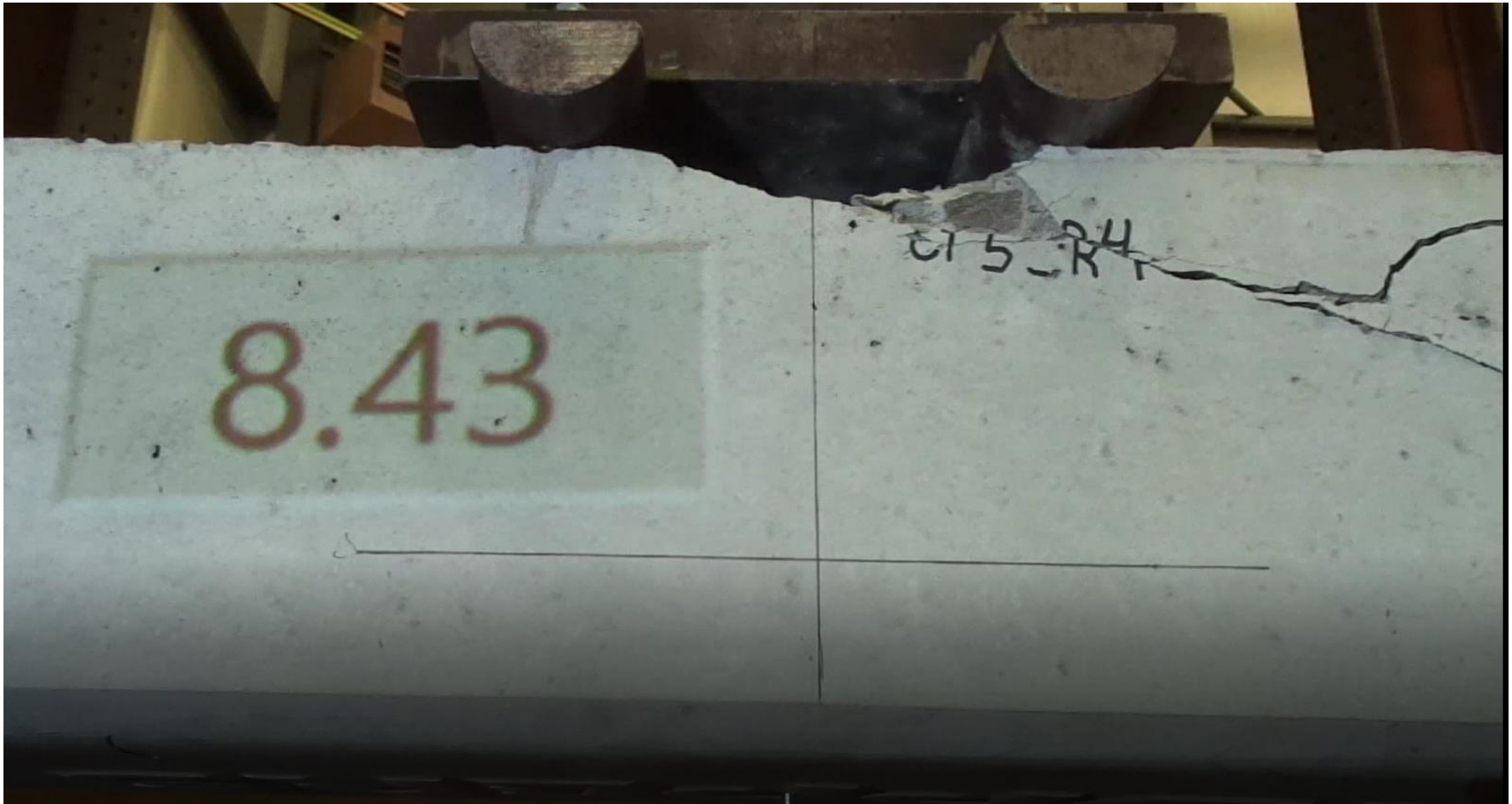


- Compressive failure (bending strength reached)



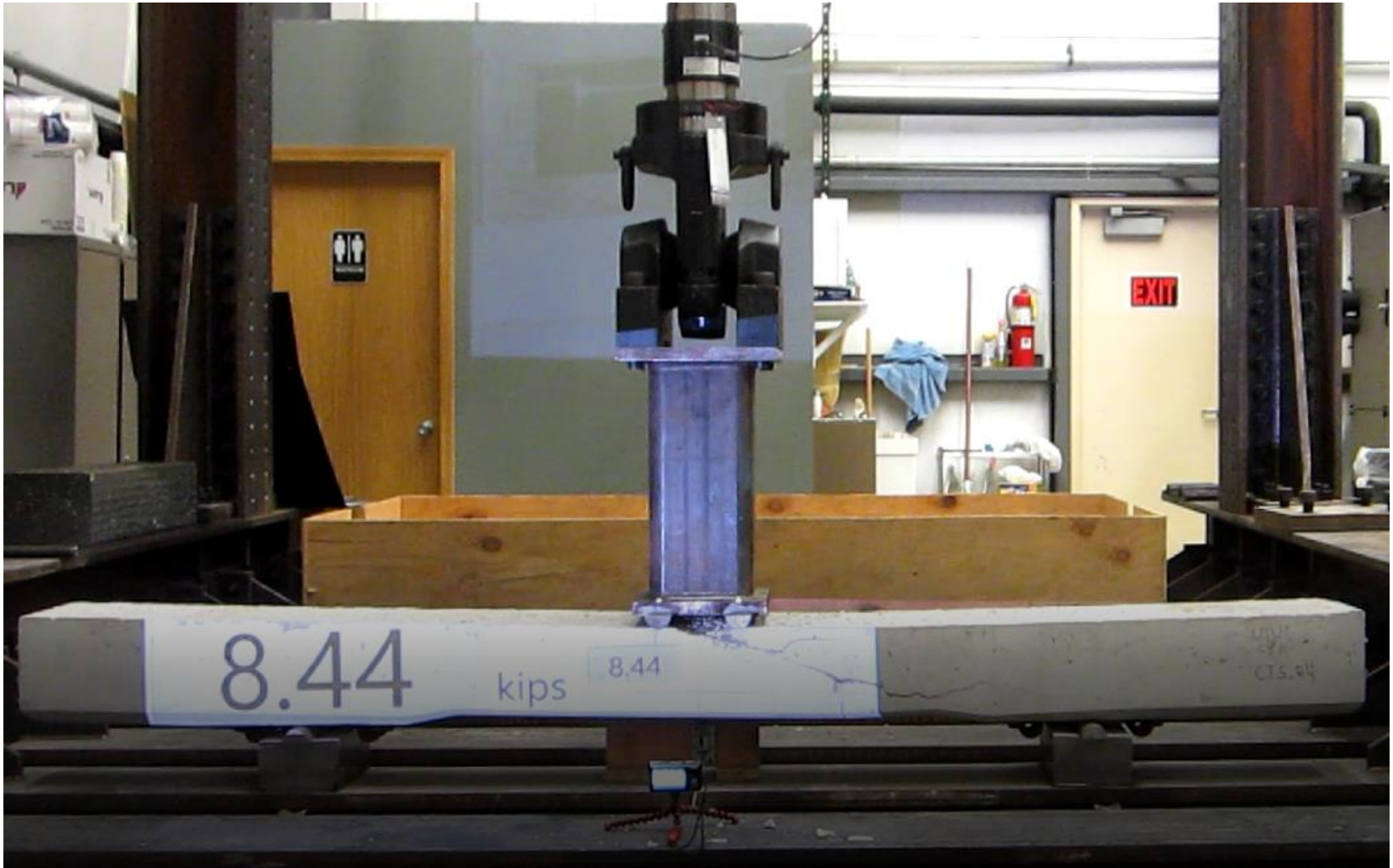
Crosstie Failure Modes
Flexural & Shear

- Combined shear/crushing failure (shear strength reached)

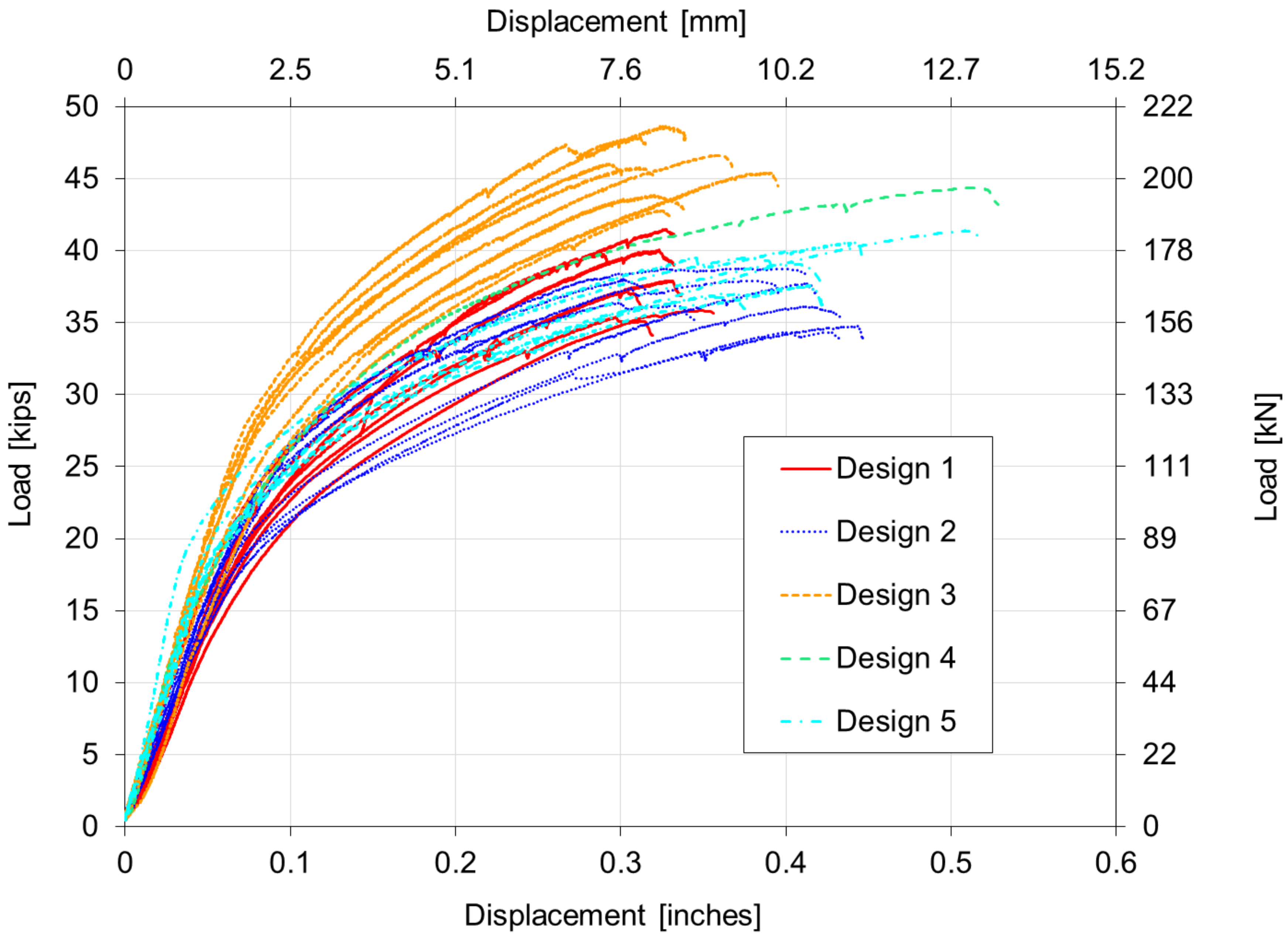


Crosstie Failure Modes (Cont.)
Flexural & Shear

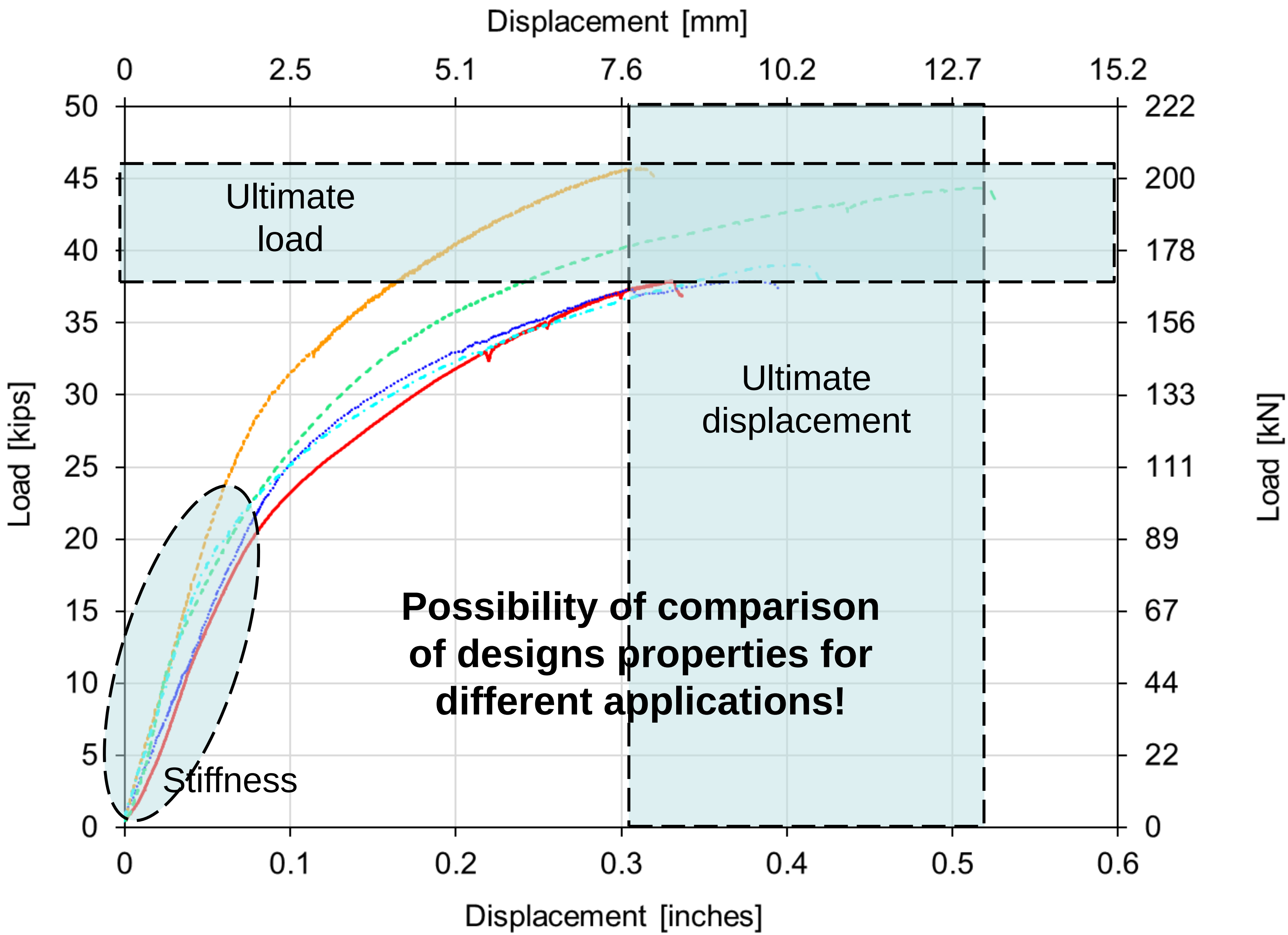
- Shear crack observed from greater distance



Load Displacement Results

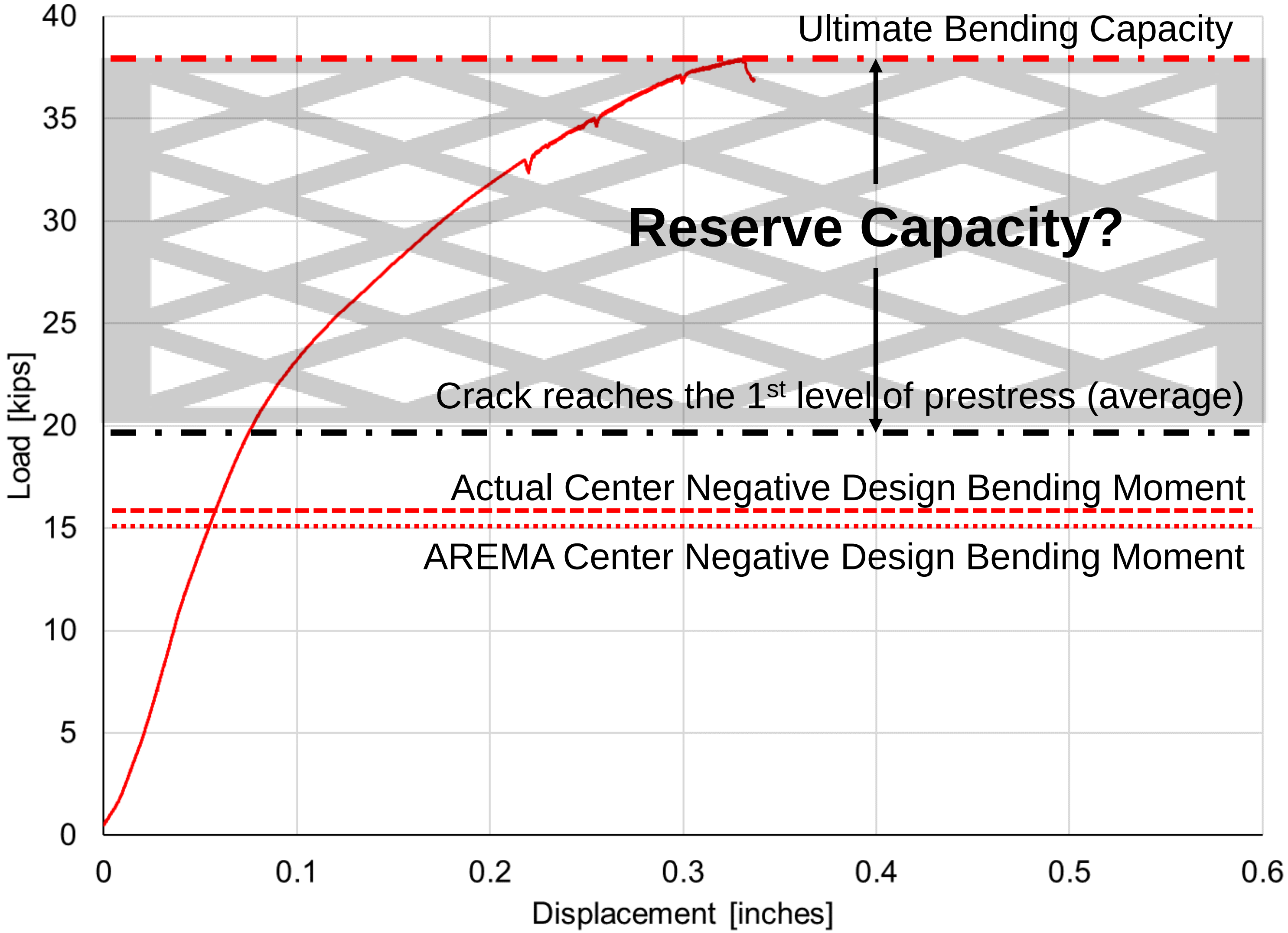


Load Displacement – Typical Replicates



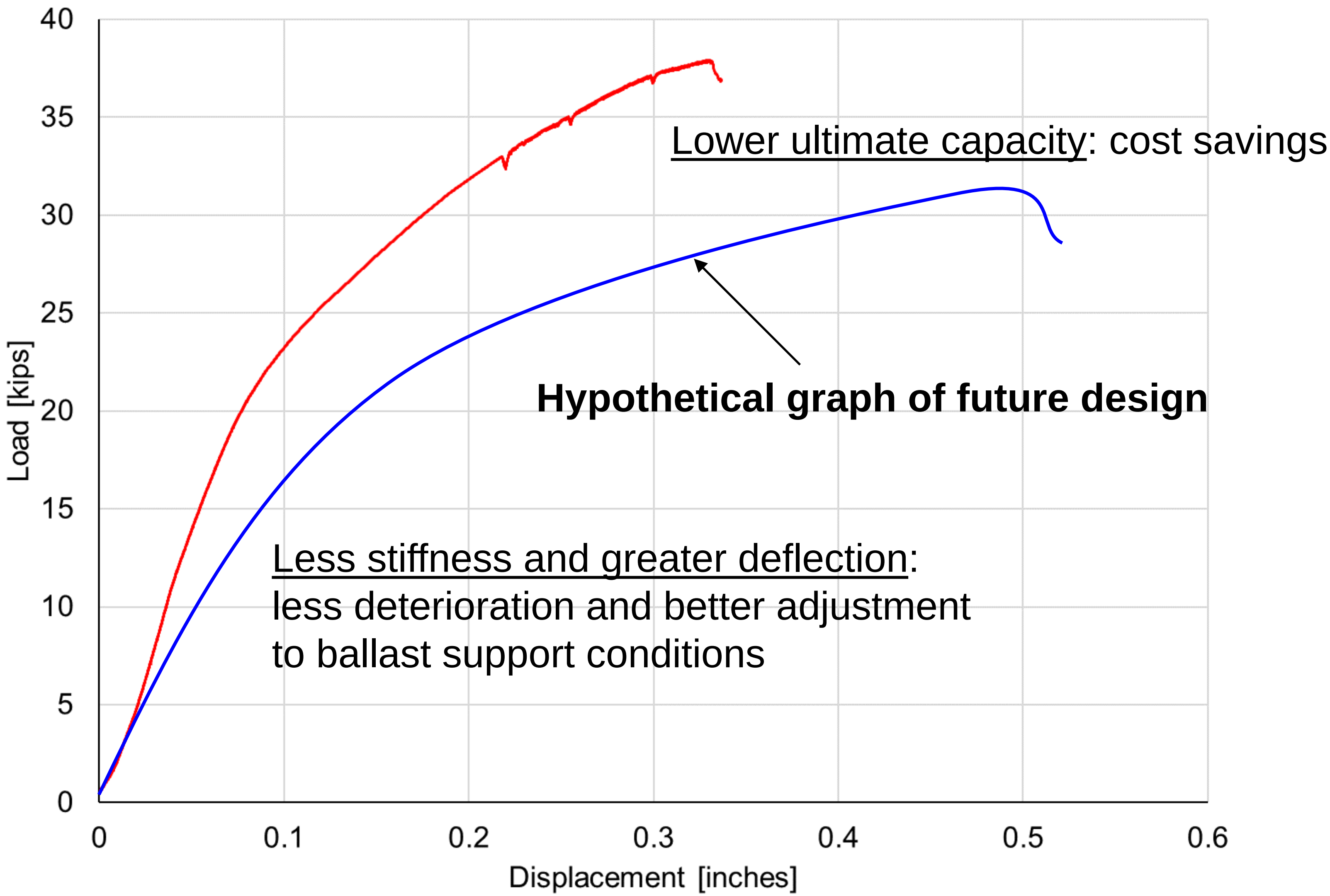
Test Results

Thresholds and Reserve Capacity



Potential Impact

Transitioning from cracking to ultimate capacity design approach



Check of Gage Widening due to Crosstie Bending

$$\Delta g = \frac{2ld - aw}{\sqrt{d^2 + a^2}} + w$$

Δg: Change of gage

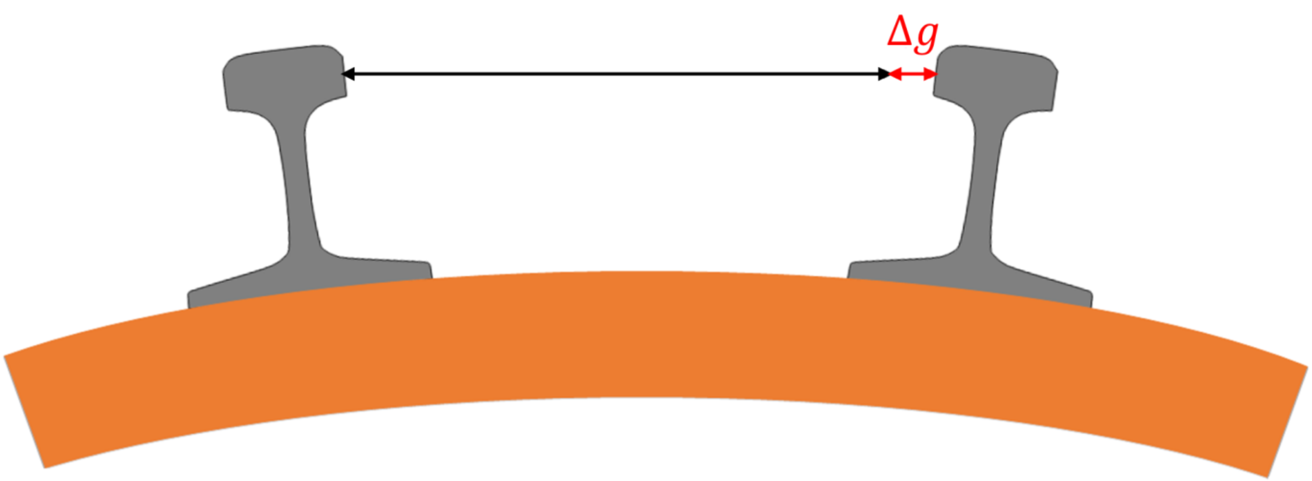
w: Width of rail head

l: Rail height

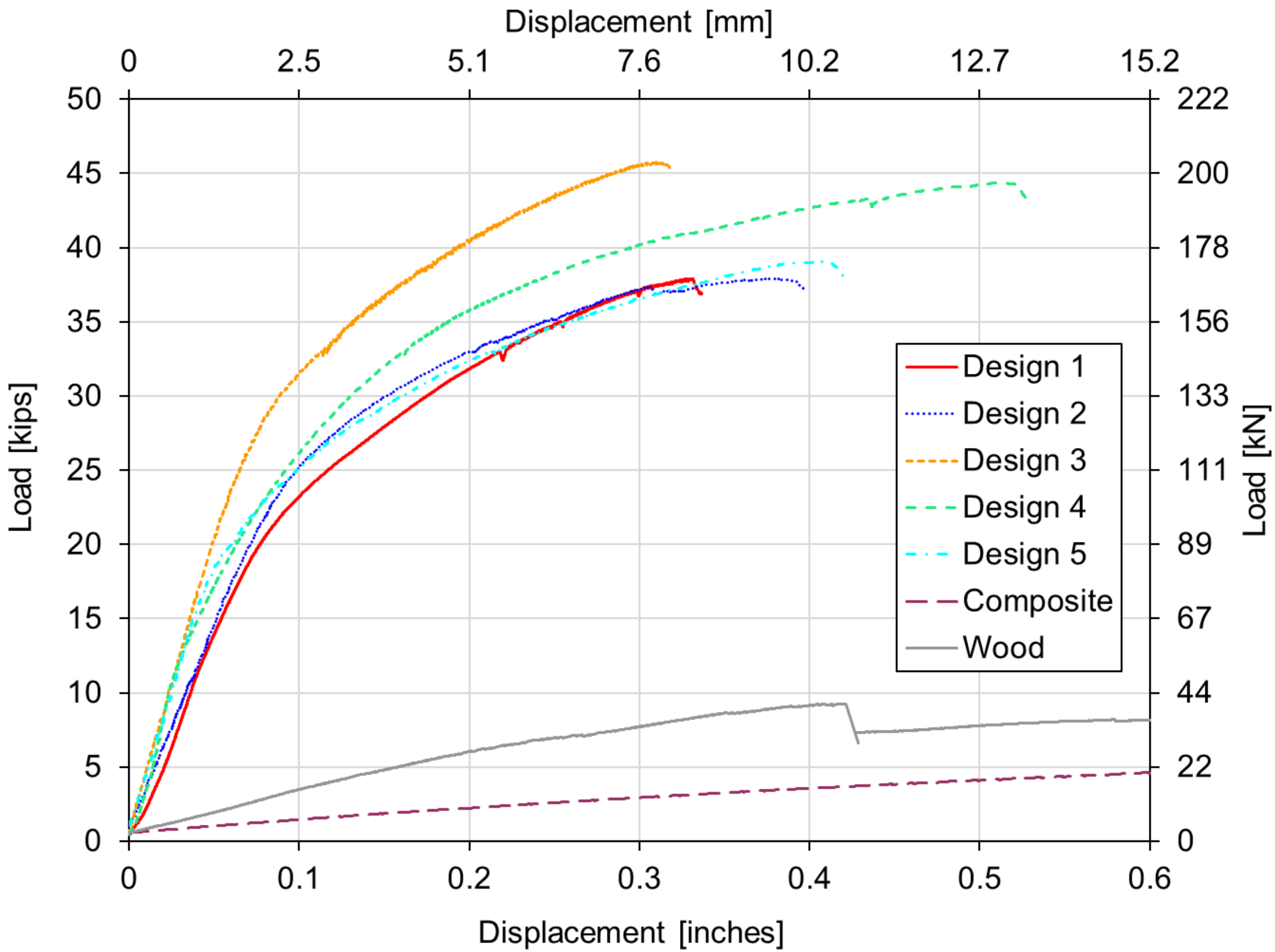
d: Center displacement in center negative bending test

a: Distance from crosstie center to rail seat centerline

- This simplified, conservative equation shows the low impact of higher center displacement on gage widening due to pure crosstie bending
  - 0.27'' of gauge widening for a 0.8'' ultimate displacement (compare with 0.19'' at 0.4'' ultimate displacement)
- **Increasing ultimate deflection should not be a safety concern**



Additional Results – Wood and Composite



*The displacements of wood and composite ties went beyond the displayed range

Conclusions and Discussion

Conclusions

- A center negative test with steel supports and loaded to failure would:
  - Provide quantifiable results
    - Ultimate capacity
    - Ultimate displacement
    - Stiffness assessment
  - Initiate a discussion on designing ties based on ultimate capacity
    - More economical designs
    - Allow for cracking
- Displacements measured, even at ultimate conditions, do not put gage widening at danger

Acknowledgements

U.S. Department of Transportation
Federal Railroad Administration

- **Funding for this research has been provided by**
  - **Federal Railroad Administration (FRA)**
- Industry Partnership and support has been provided by
  - Union Pacific Railroad
  - BNSF Railway
  - National Railway Passenger Corporation (Amtrak)
  - Progress Rail Services, A Caterpillar Company
  - GIC Ingeniería y Construcción
  - Hanson Professional Services, Inc.
  - CXT Concrete Ties, Inc., LB Foster Company
  - TTX Company
- Additional Industry Support provided by
  - Hailing Yu (John A. Volpe National Transportation Center)
  - Rocla Concrete Ties
  - Steve Matteson (Nortrak Voestalpine)

FRA Tie and Fastener BAA Industry Partners:

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GIC
HANSON
LBFoster CXT Concrete Ties
TTX

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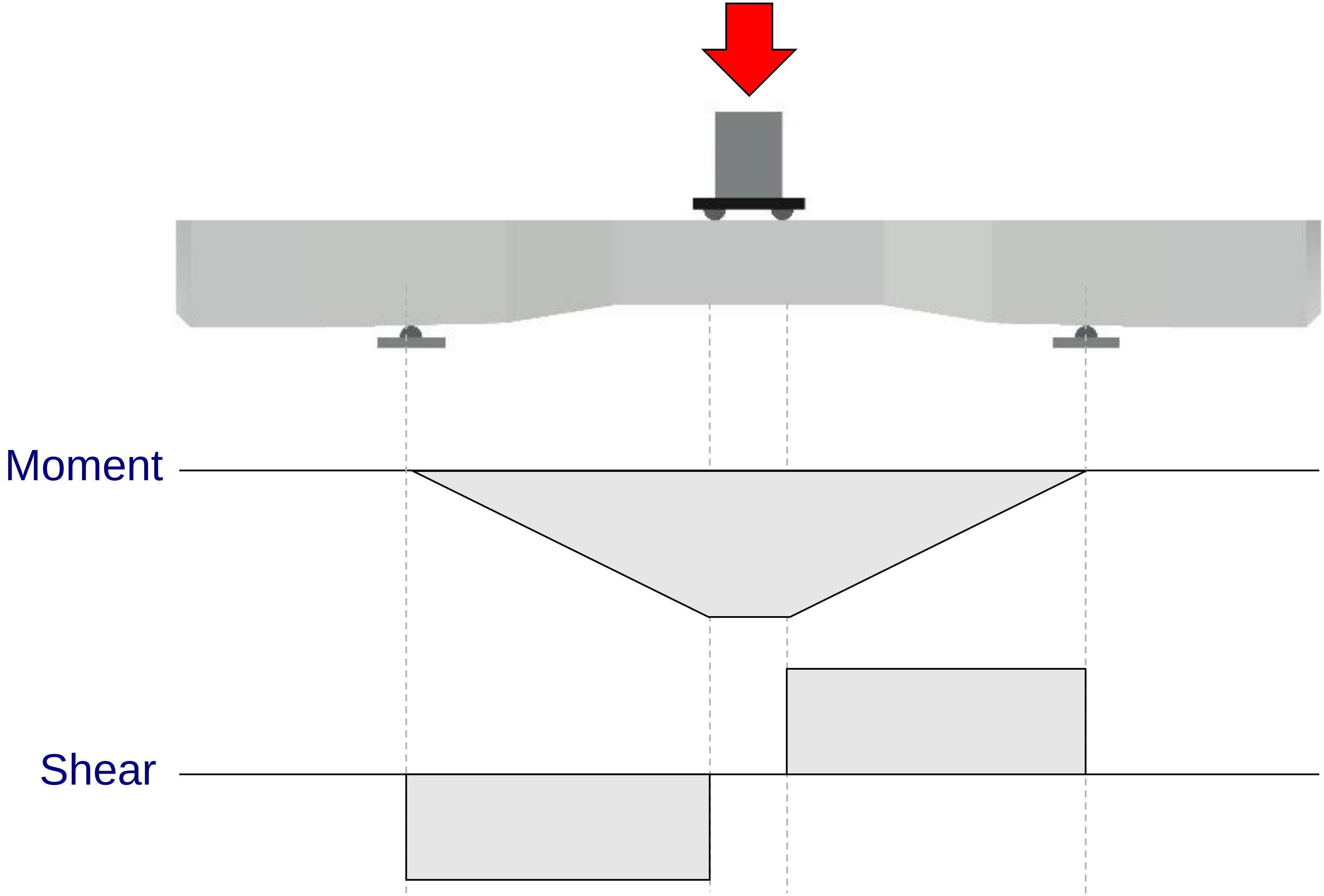
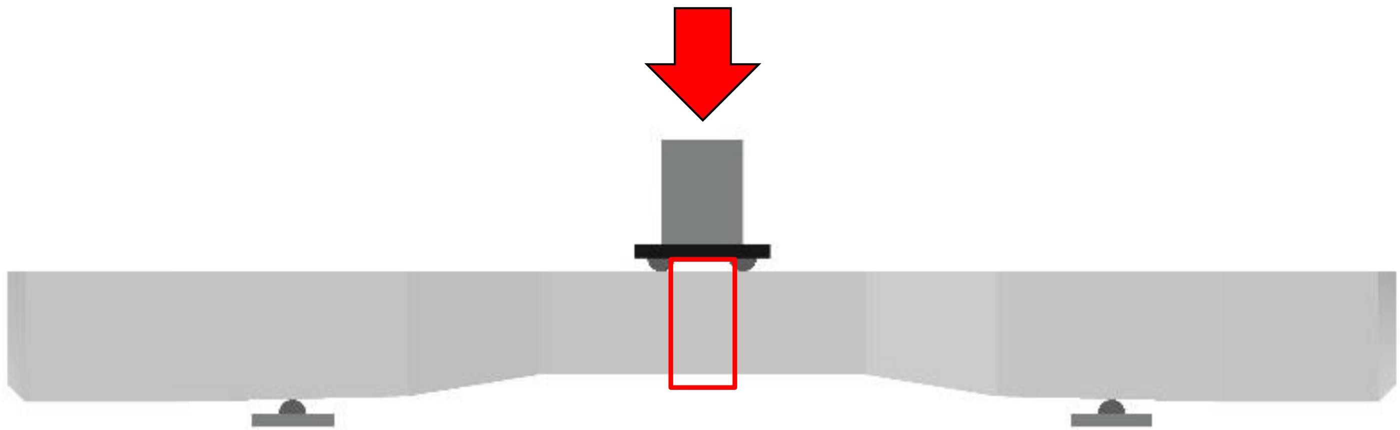
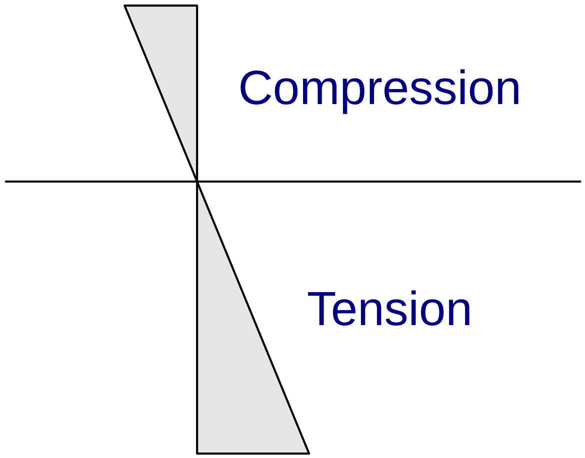
Review of Four-Point Bending Testing

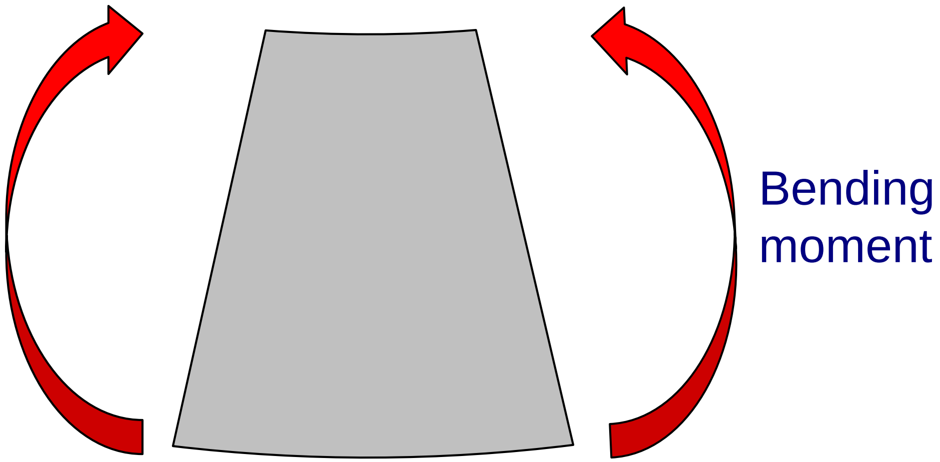


Review of Four-Point Bending Testing (Cont.)



Strain in Cross Section

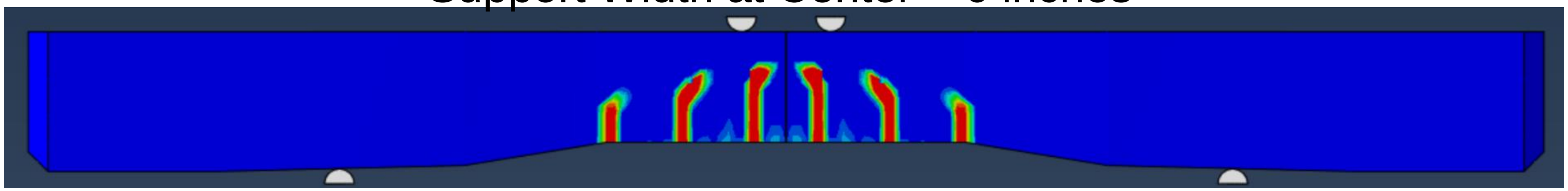




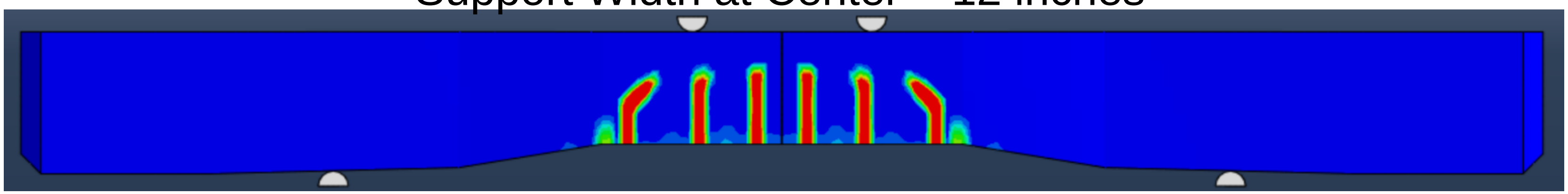
Effects of Varying Support Conditions

Crack Pattern

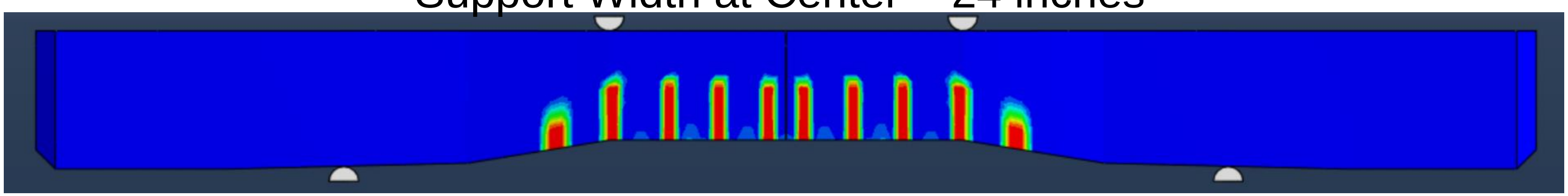
Support Width at Center = 6 inches



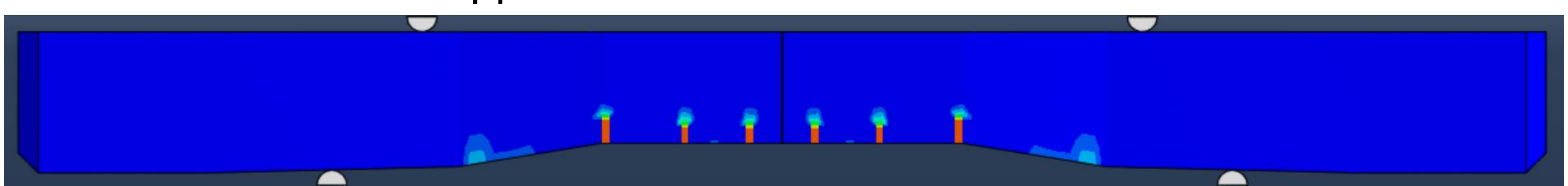
Support Width at Center = 12 inches



Support Width at Center = 24 inches



Support Width at Center = 48 inches



Detailed Test Results

		Sleeper Design				
		1	2	3	4	5
Ultimate load	kip	38.2	36.7	45.9	44.4	38.9
	(kN)	(170.1)	(163.4)	(204.0)	(197.4)	(173.0)
$D_{0.90}$	kip	1.2	1.1	1.1	3.1	1.2
	(kN)	(5.3)	(4.9)	(4.9)	(13.9)	(5.3)
Ultimate Displacement	in	0.320	0.337	0.330	0.512	0.418
	(mm)	(8.1)	(8.6)	(8.4)	(13.0)	(10.6)
$D_{0.90}$	in	0.023	0.031	0.022	0.062	0.023
	(mm)	(0.6)	(0.8)	(0.6)	(1.6)	(0.6)
7.5-kip Displacement	in	0.0266	0.0225	0.0199	0.0188	0.0183
	(mm)	(0.68)	(0.57)	(0.50)	(0.48)	(0.46)
$D_{0.90}$	in	0.0017	0.0024	0.0017	0.005	0.0018
	(mm)	(0.04)	(0.06)	(0.04)	(0.1)	(0.05)
7.5-kip Slope	kip/in	266.5	312.7	360.6	372.1	387.1
	(kN/mm)	(46.7)	(54.8)	(63.2)	(65.2)	(67.8)
$D_{0.90}$	kip/in	25.2	35.6	25.2	71.297	26.9
	(kN/mm)	(4.4)	(6.2)	(4.4)	(12.5)	(4.7)