Repair of Corroded Steel Beam/Girder Ends with Ultra High Strength Concrete

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Problem Statement

- Extensive corrosion of bridge girders occur beneath deck expansion joints due to leaking joints.
- Corrosion damage is the cause of approximately 15% of bridges receiving a structurally deficient rating.
- The United States spends *$8.3 billion* annually to repair and replace corrosion damaged highway bridges.
- Corrosion at girder ends may significantly reduce the bearing capacity.

Existing Repair Methods

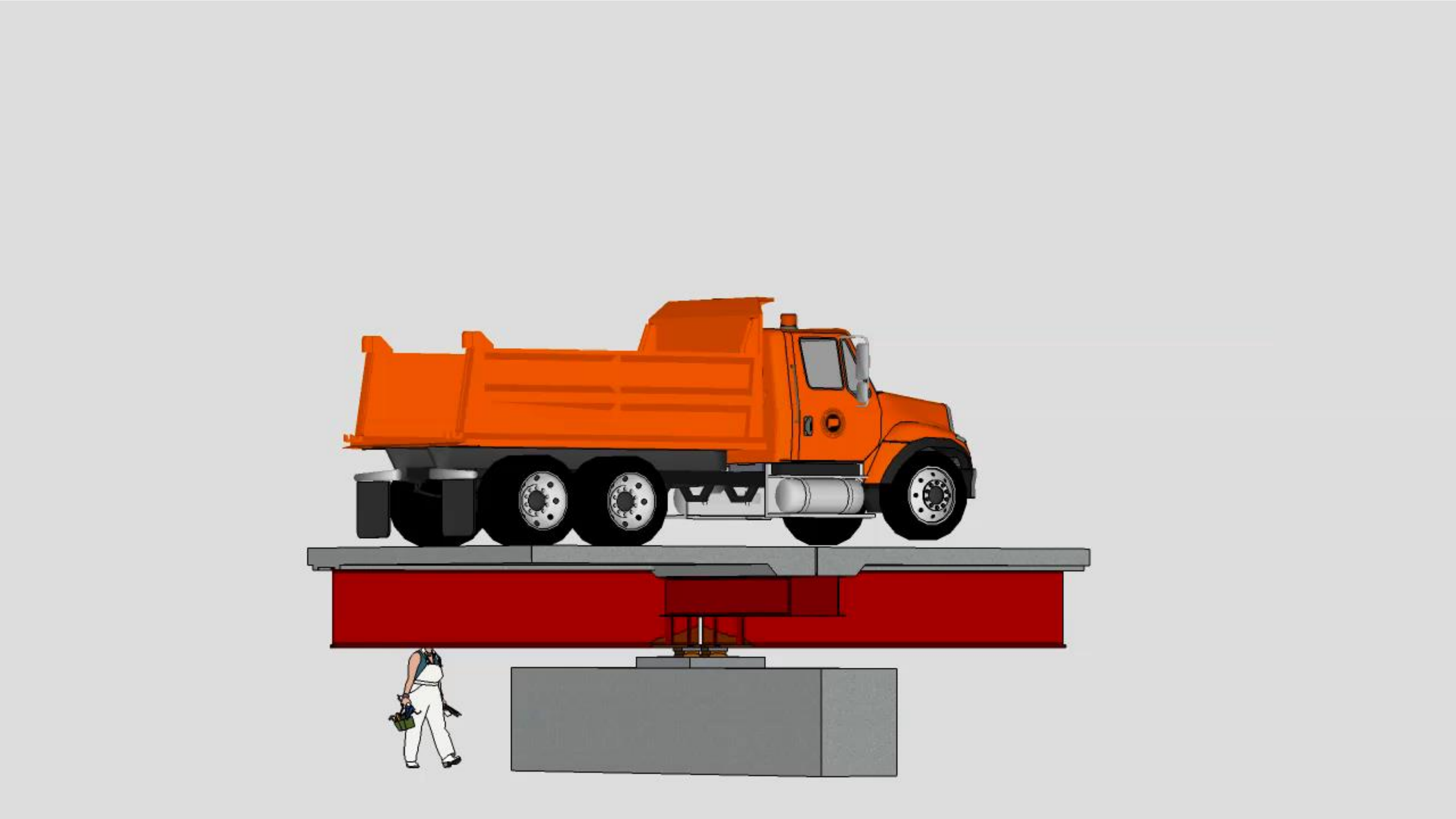
Standard procedures to repair corroded steel girder ends:

1) jacking the structure to relieve the loads
2) cutting out the corroded section of steel
3) welding a new steel section into place
4) lowering the span and removing the jacks

- This process is expensive and time consuming
- It my require lane closure and lead paint removal
- Continued corrosion remains an issue

Novel Repair Method

A low cost, low impact, easy to implement method is being studied at UCONN



Research Components

Phase I (Budget ~$110k –Final Report completed in June 2015)

I. Proof of the Repair Concept
- 1/2 –Scale Experiment on Rolled Girders (Intact, Damaged, Corroded)

II. Preliminary Finite Element Simulations

(In 2016, the project was selected as one of the sixteen High Value Research Projects by AASHTO's Standing Research Committee)

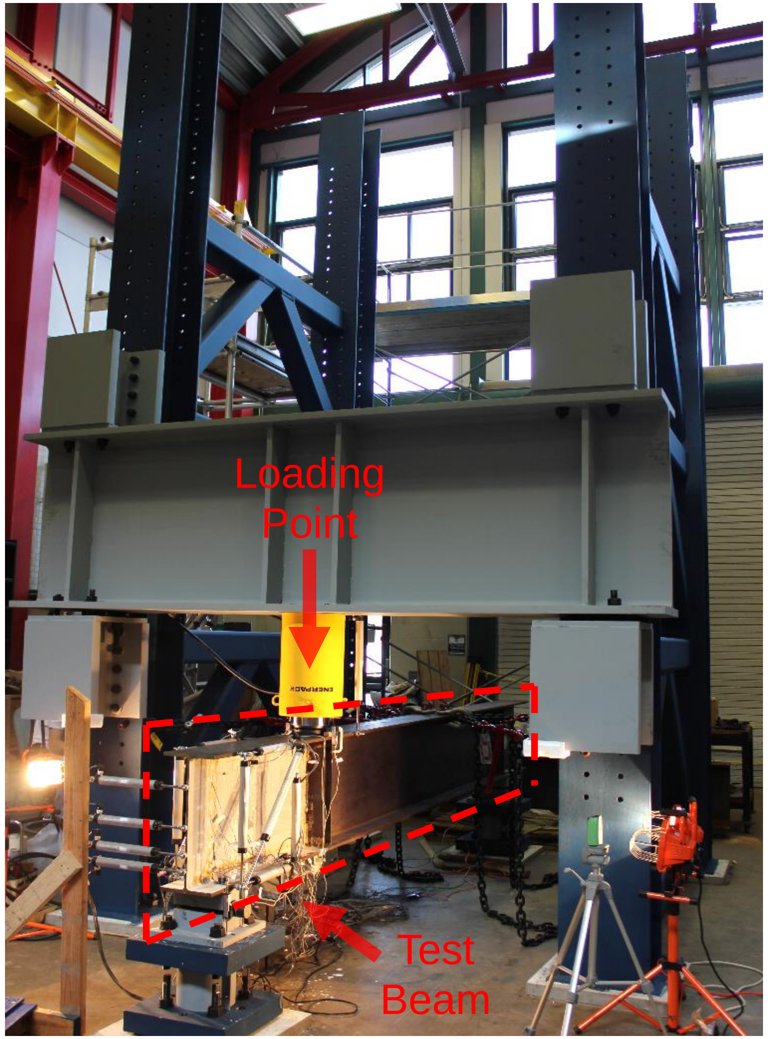
Phase II (Budget ~$670k – ongoing, will be concluded in 2018)

I. Study of Shear Stud Capacity in UHPC
- Push-Off Tests
- Finite Element Modeling

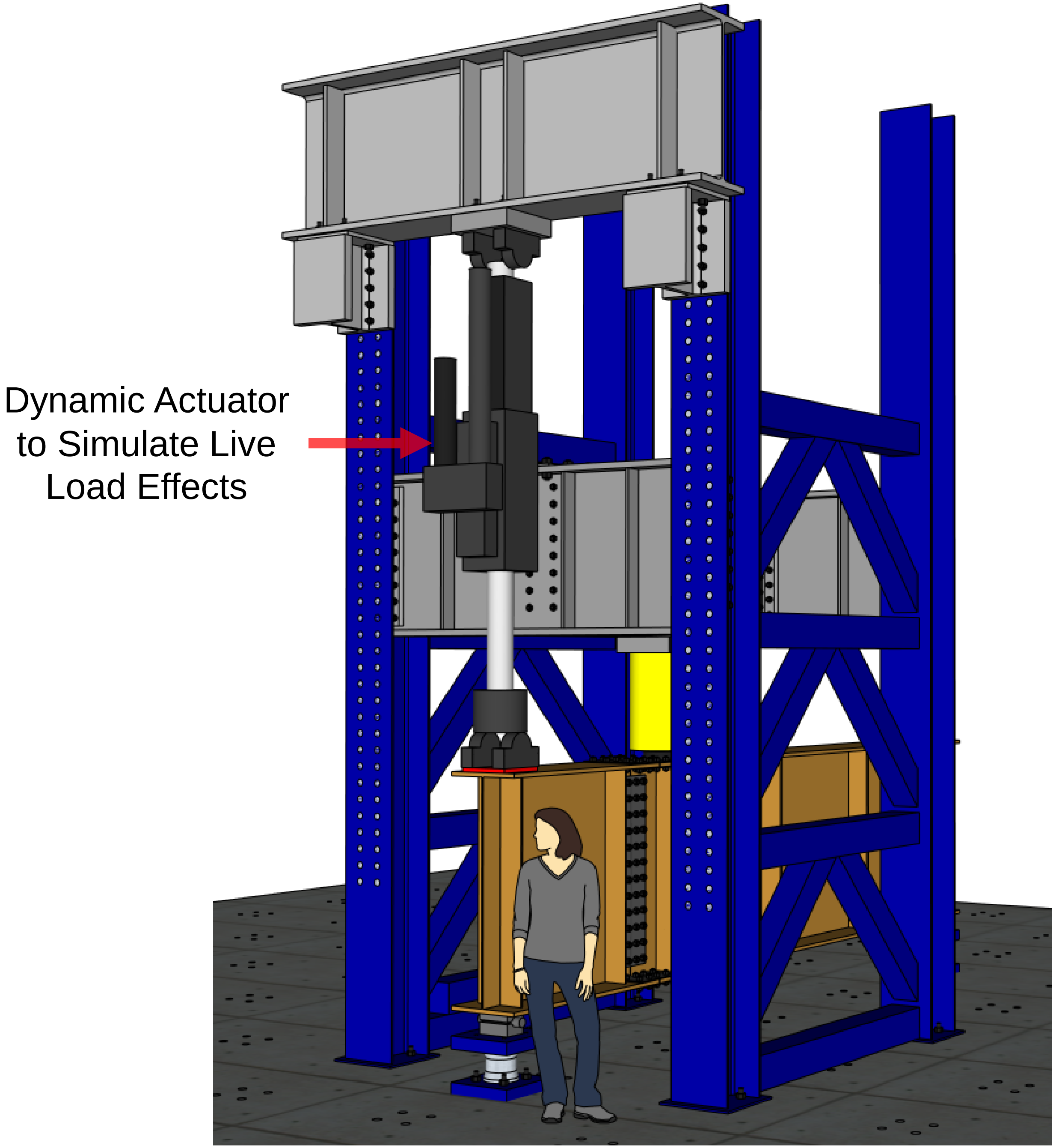
II. Full-Scale Plate Girder Testing
- Repair will be Performed Under Simulated Live-Load Effect
- Two or Three Repair Geometries

III. Development of Design Guides for the Repair Method
- Finite Element Modeling of Full Span Bridge Girders
- Repair Design for Pilot Project

Large Experiment



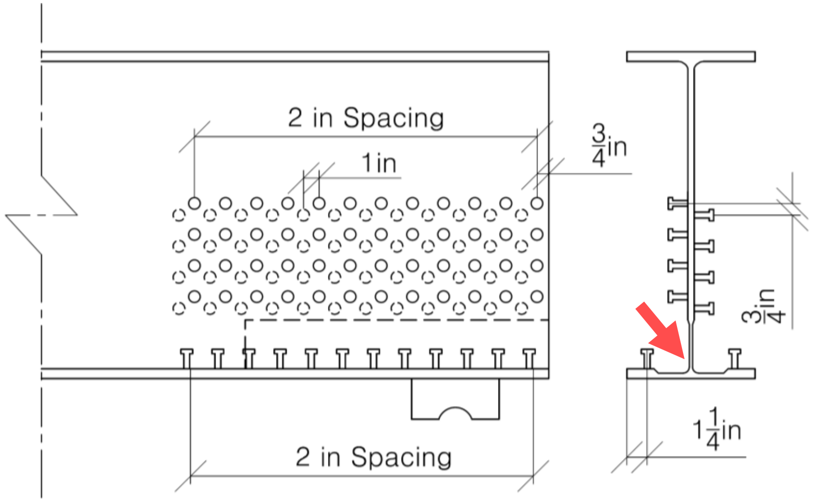
Experimental Setup of Phase I (550 kip)



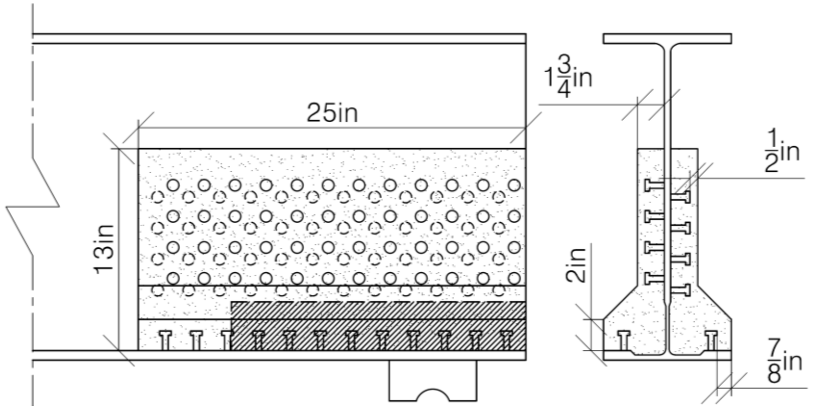
Experimental Setup of Phase II (1000 kip)

Test Specimen (Phase I)

- Three 1/2 –scale experiment were performed on 21-in deep rolled beams
  - ***Intact:*** to measure undamaged capacity.
  - ***Damaged:*** Reduced section was administered using milling machine (~70% reduction) to simulate corrosion.
  - ***Repaired:*** the same section reduction as damaged, but with studs welded on the web and flange to incase the reduced section in UHPC.



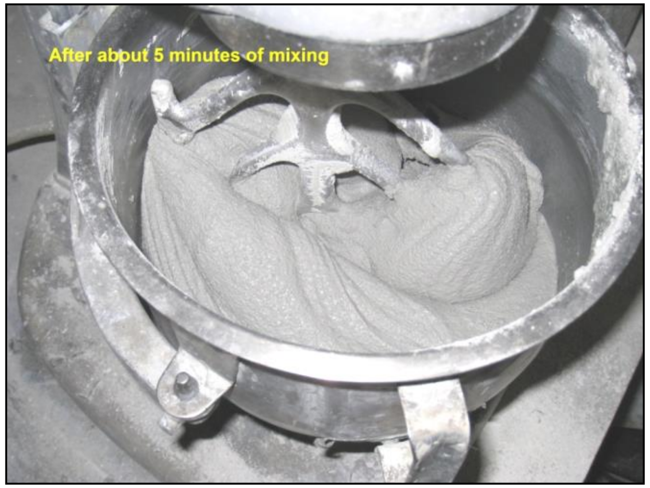
Layout of Studs

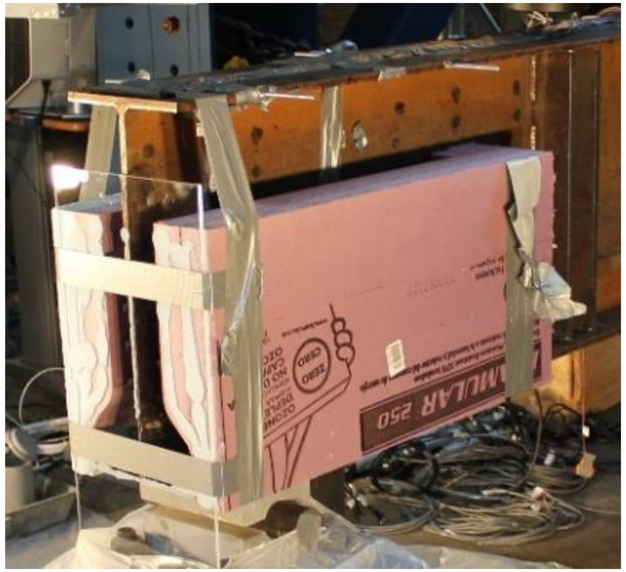


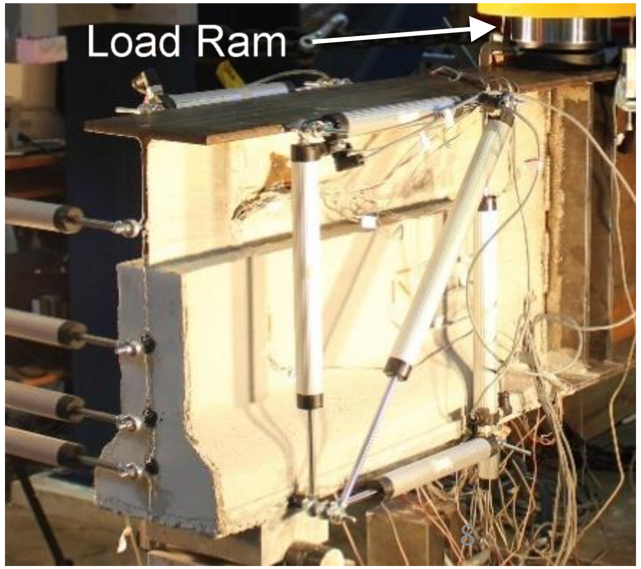
UHPC Panels

Ultra High Performance Concrete and Casting

- Proprietary mix design by Lafarge
- Gain 12ksi in 12hrs (JS1212)
- Significant, flowability and workability
- May be pumped or cast from the top



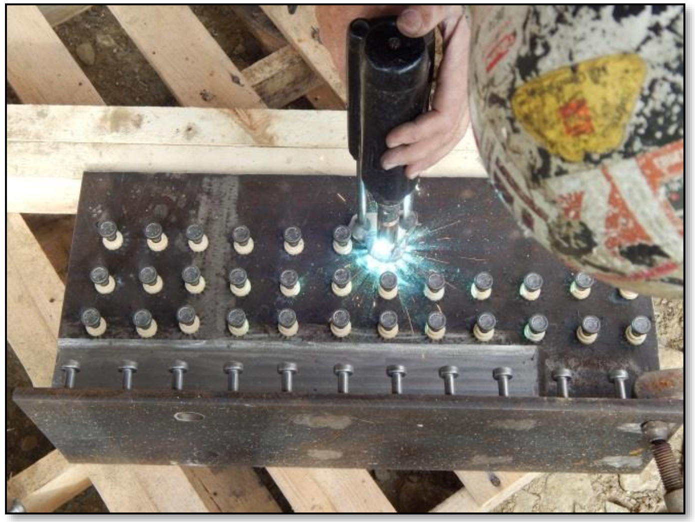




Welding of Shear Studs on the Beam

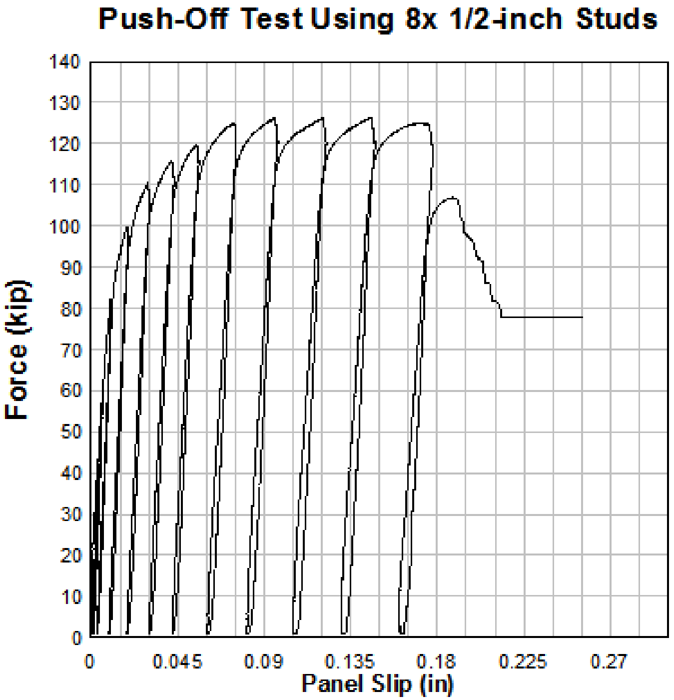
- Stud welding can be performed using a stud gun
- Studs can be welded in tight spaces, like between stiffeners
- Minimal surface preparation
- They provide a new load path!

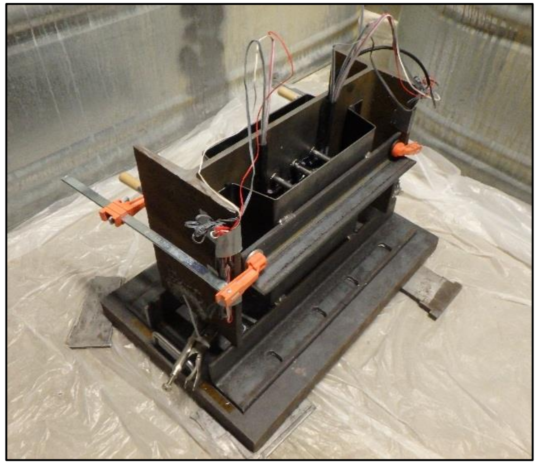
Web Shear → Studs → UHPC Panels → Bridge Bearing



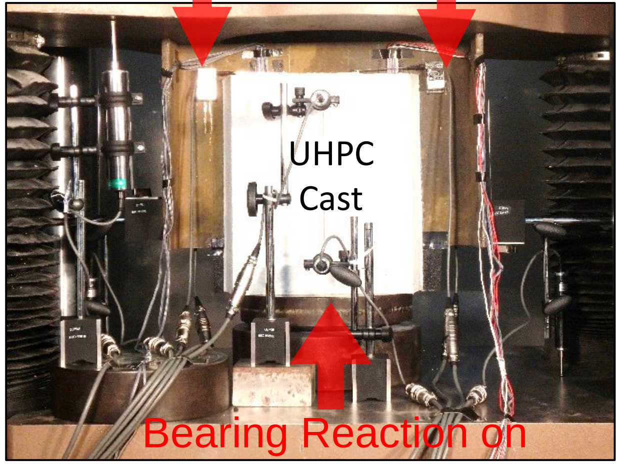
Push-Off Experiments

- Experiments performed to study:
  - the stud's shear strength in UHPC
  - Effects of welding on old steel (A7 Steel)
  - Layout, minimum spacing, length
- Observations
  - Capacities are larger than regular concrete
  - Studs shank shear-off after the weld collar
  - Failure is ductile





Loading Points on Steel

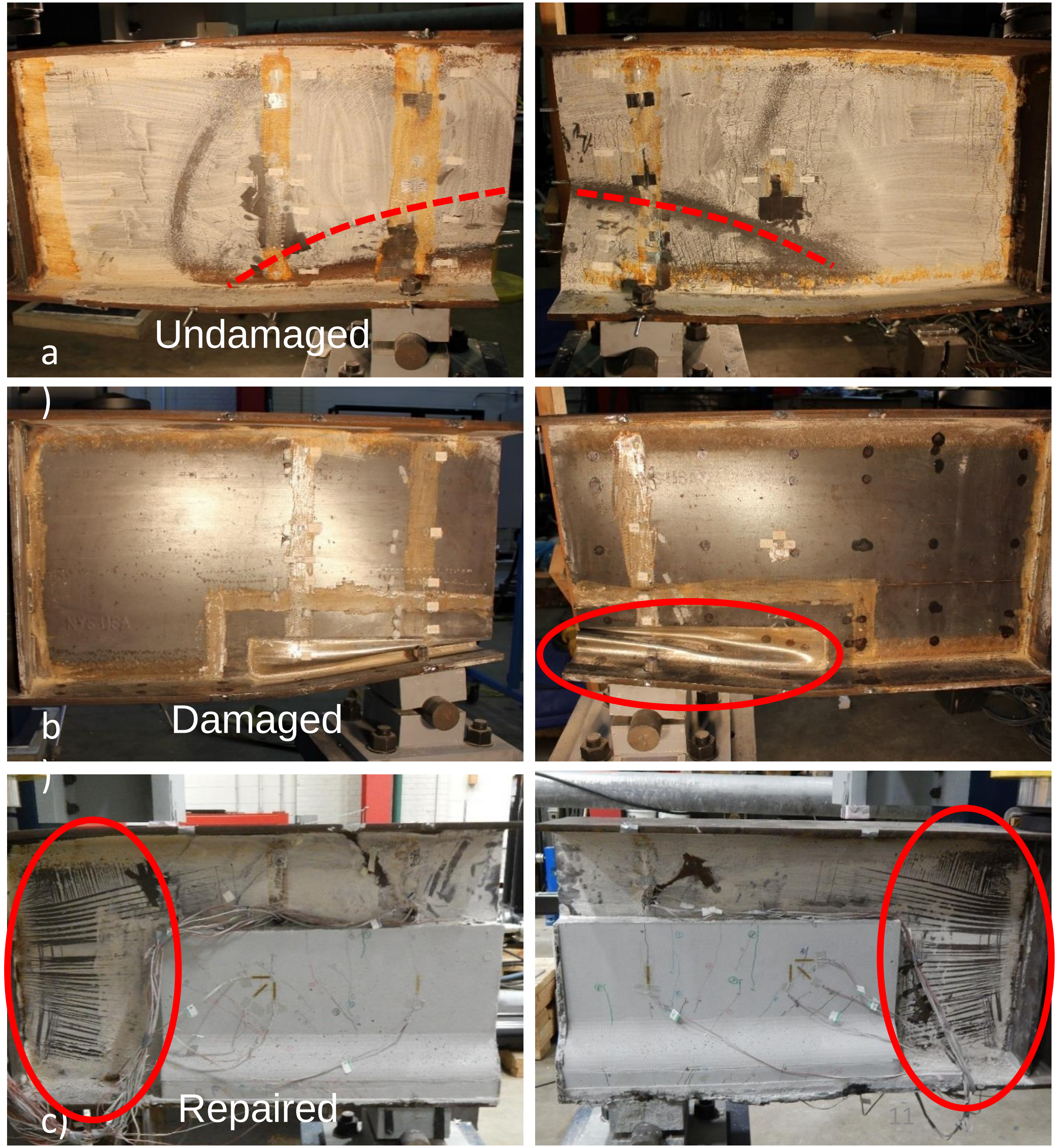


Bearing Reaction on UHPC Panels

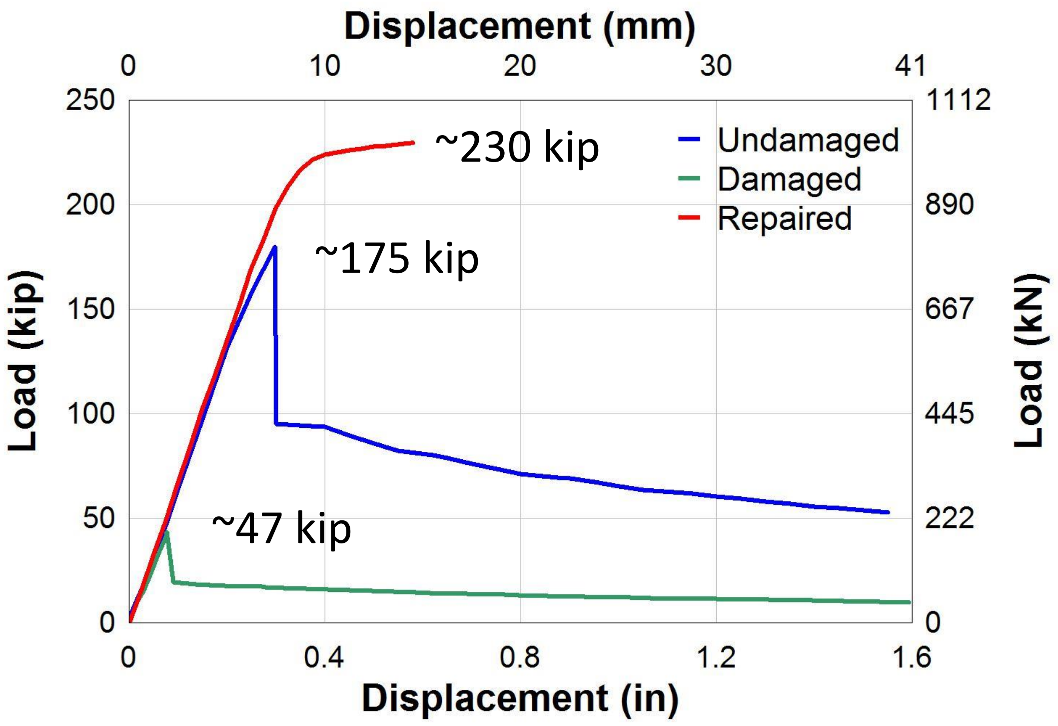
Stud Capacity, 1/2" Diameter (kip)	
AASHTO LRFD 6.10	12.8
Eurocode 4	10.2
Hegger et al. (2006)	15.0
Luo et al. (2015)	14.7
UConn Experimental	**15.8**

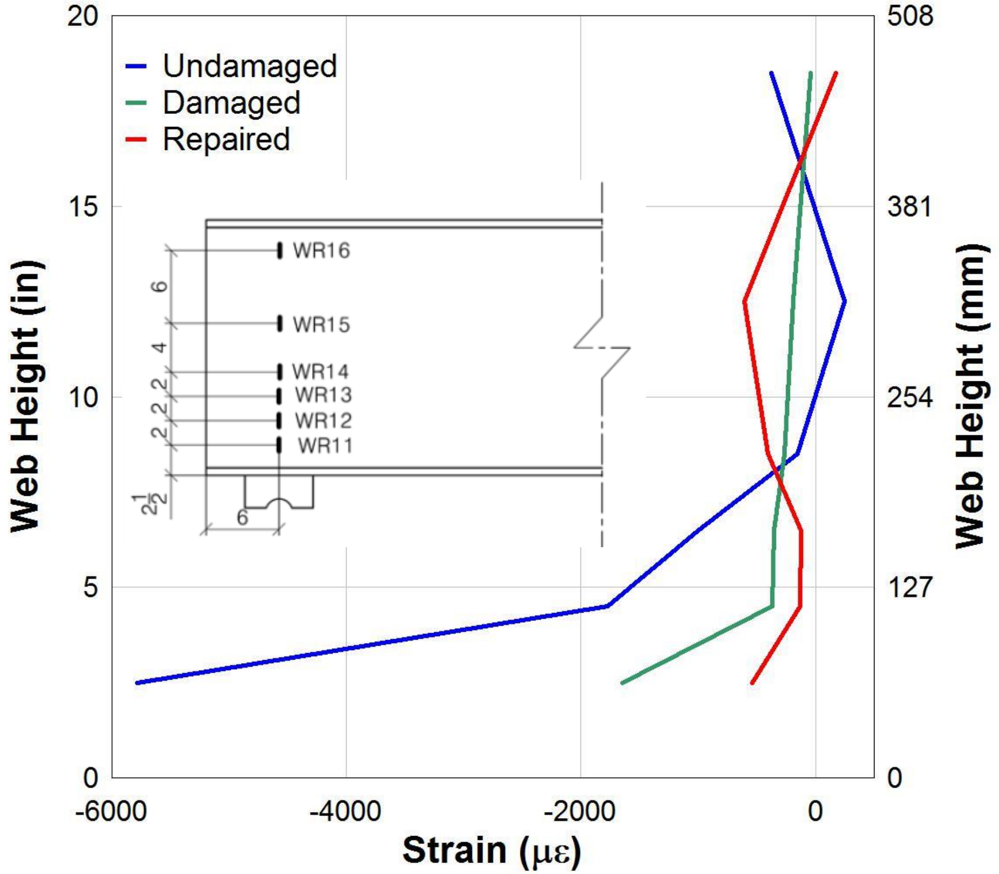
Failure Modes of Rolled Girder

- The undamaged girder failed due to global web buckling
- The damaged girder failed with local buckling of the reduced web section
- The repaired girder did not fail. Flexural yielding controlled the capacity.



Experimental Results

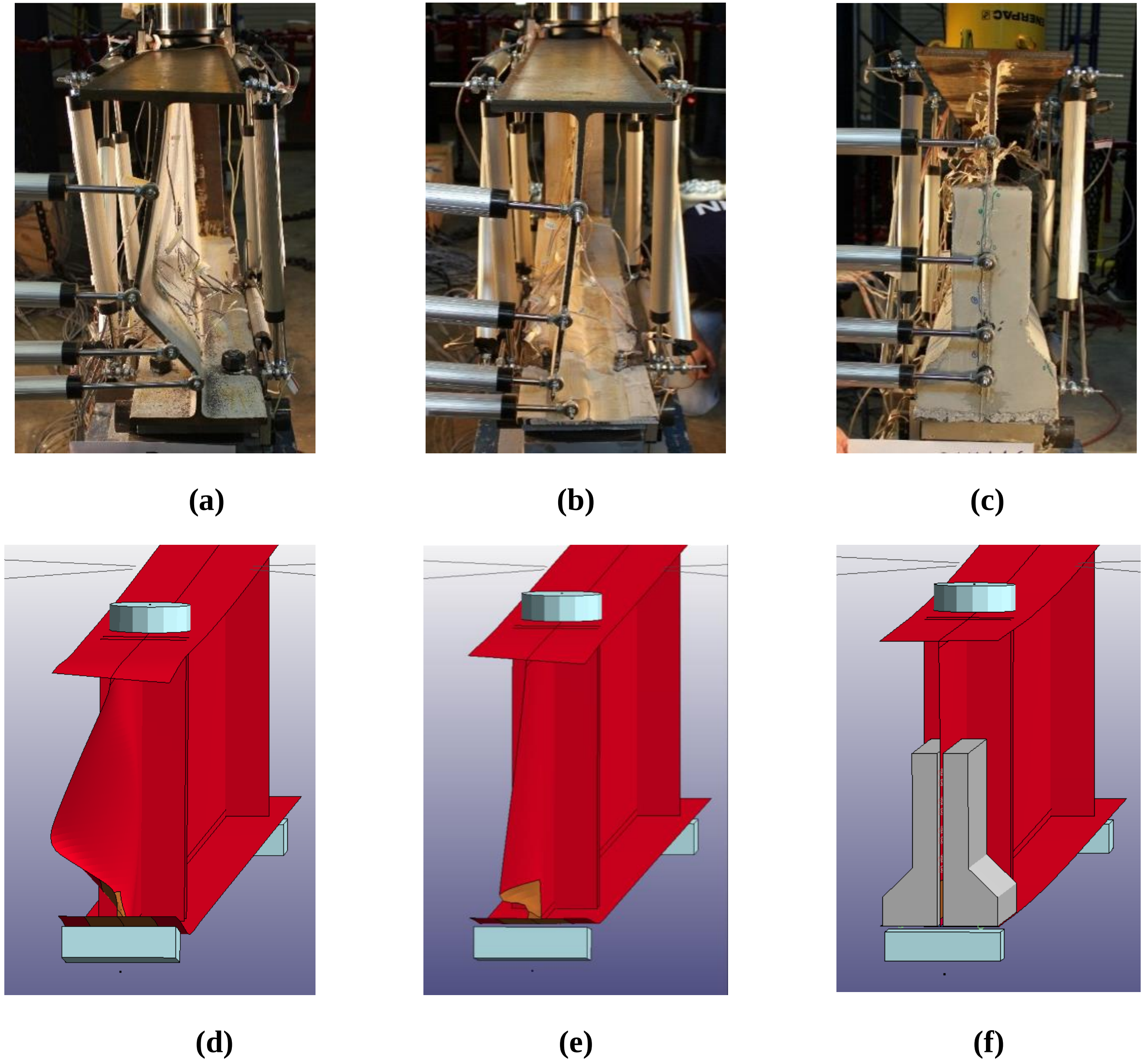




- 70% loss in cross-section →75% reduction of capacity
- The repaired girder capacity was **25% higher** than undamaged

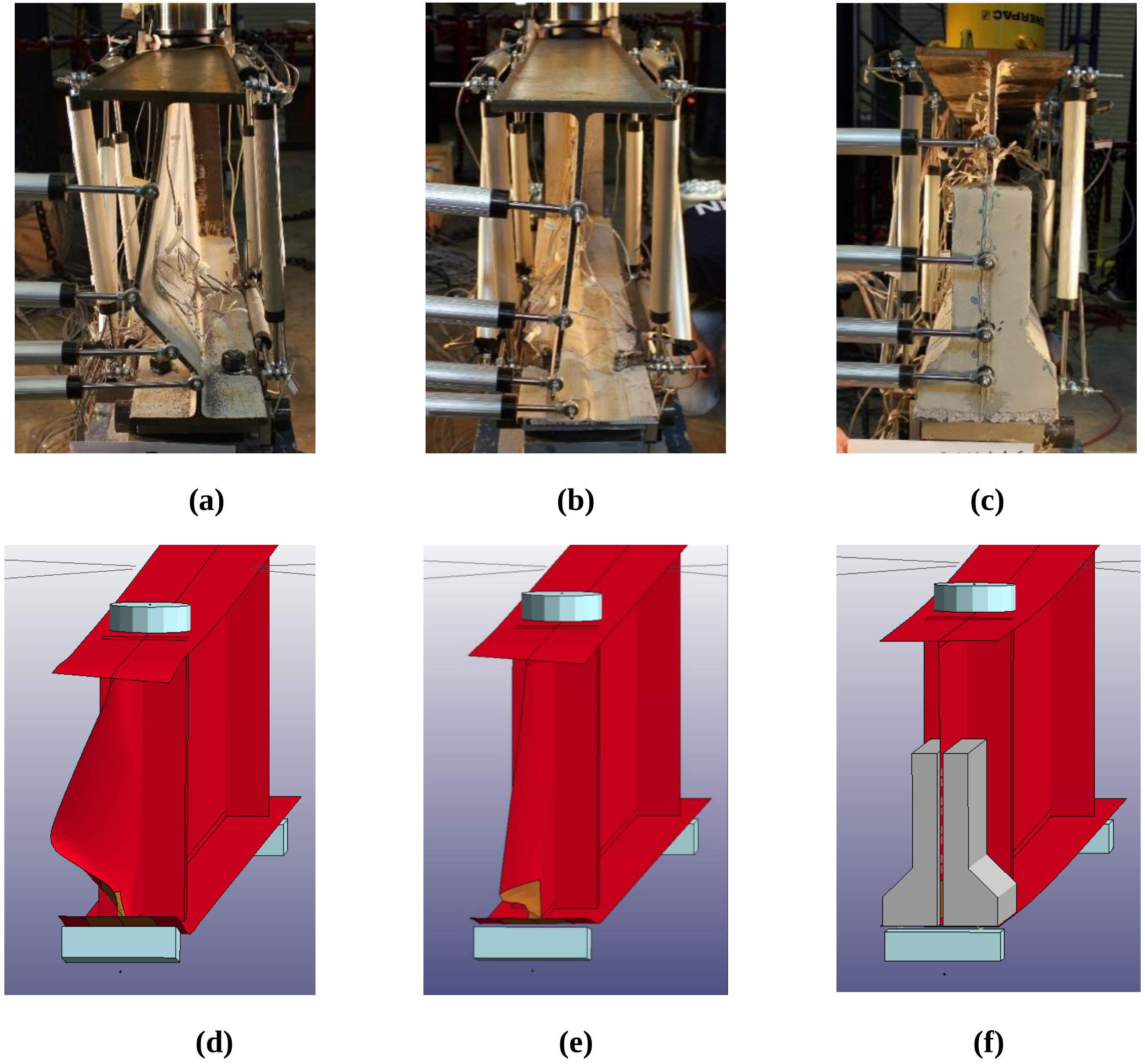
Finite-Element Simulations

- LS-Dyna was used for FE simulations
- Good agreement found between the experimental and analytical results
  - Modes of failure
  - Load-displacement relationships
- The modeling methodology will be used to study different geometries
- It enables development of standard details or customized designs



Deformed Shapes of (a) Experimental Undamaged, (b) Experimental Damaged, (c) Experimental Repaired, (d) FE Undamaged, (e) FE Damaged, and (f) FE Repaired Girders.

Finite-Element Simulations



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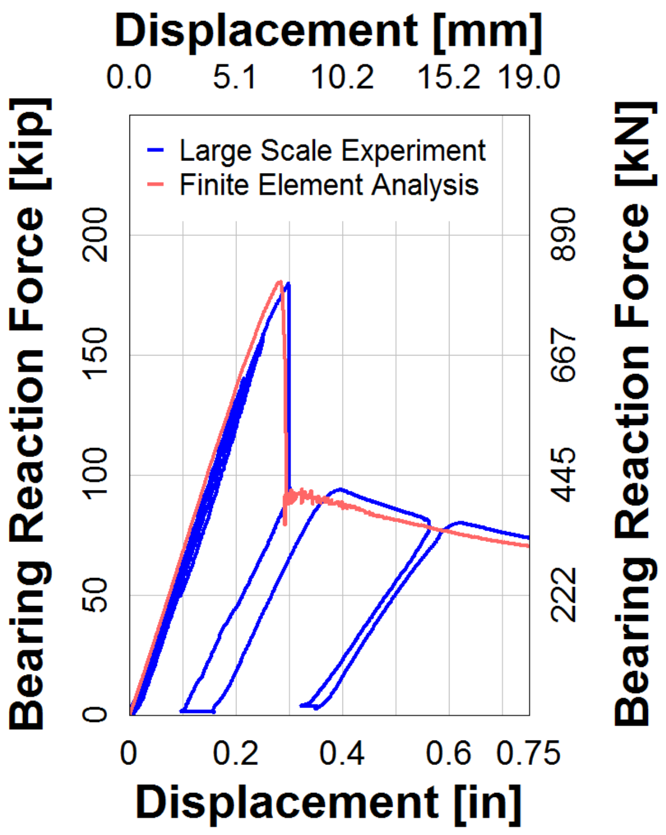
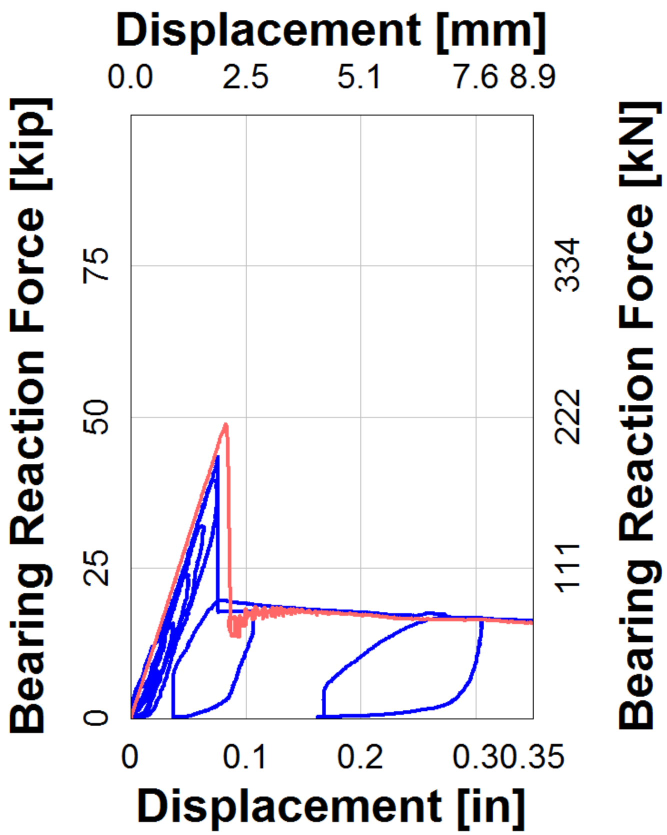
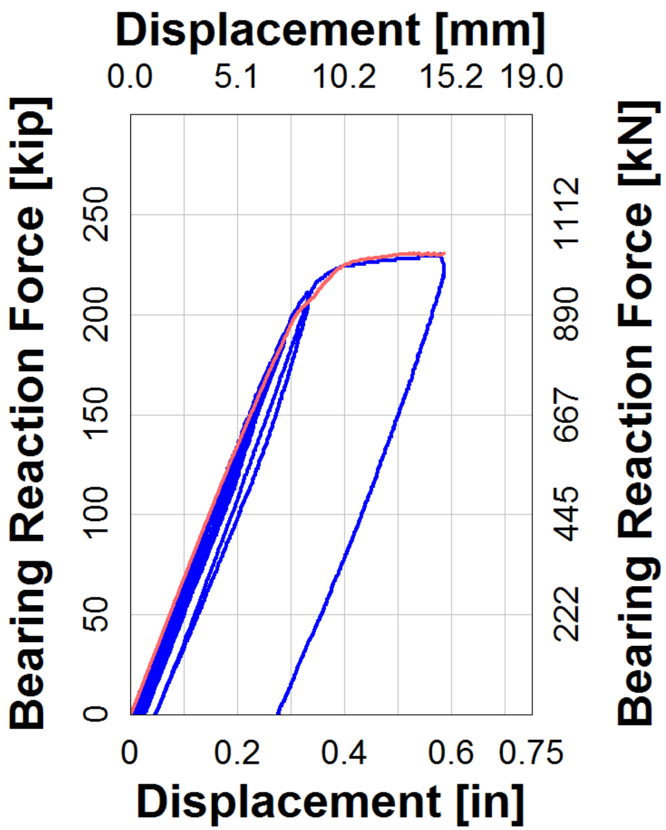
Finite-Element Simulations



Undamaged Beams



Damaged Beams



Repaired Beam

Example Design Calculations

Calculation for the number of studs using: 1) Capacity Design, 2) Fatigue, 3) Force Demands

Number of Studs Needed Based on the As-Built Strength of Beams With Bearing Stiffeners

	Geometric Properties				Design Demand			1/2 Inch Diameter Stud Capacity			5/8 Inch Diameter Stud Capacity				
Shape	Web Thickness (in)	Web Depth (in)	Total Depth of Beam (in)	Flange Thickness (in)	Design Based on Bearing Capacity (kips)	Design Based on Shear Capacity (kips)	Design based on Controlling Capacity (kips)	Strength Based on Bearing of Stud on Web (kips)	Stud Capacity (kips)	Controlling Stud Capacity (kips)	Strength Based on Bearing of Stud on Web (kips)	Stud Capacity (kips)	Controlling Stud Capacity (kips)	Number of 1/2" Studs Needed	Number of 5/8" Studs Needed
36WF135	0.600	34.02	35.60	0.790	500	426	426	41.76	15.80	13.43	52.20	23.00	19.55	**32**	**22**
36WF160	0.653	33.96	36.00	1.020	532	463	463	45.45	15.80	13.43	56.81	23.00	19.55	**34**	**24**
36WF182	0.726	33.96	36.32	0.725	579	515	515	50.53	15.80	13.43	63.16	23.00	19.55	**38**	**26**

Number of Studs Needed Based on the As-Built Strength of Beams Without Bearing Stiffeners

	Geometric Properties				Design Demand			1/2 Inch Diameter Stud Capacity			5/8 Inch Diameter Stud Capacity				
Shape	Web Thickness (in)	Web Depth (in)	Total Depth of Beam (in)	Flange Thickness (in)	Design Based on Bearing Capacity (kips)	Design Based on Shear Capacity (kips)	Design based on Controlling Capacity (kips)	Strength Based on Bearing of Stud on Web (kips)	Stud Capacity (kips)	Controlling Stud Capacity (kips)	Strength Based on Bearing of Stud on Web (kips)	Stud Capacity (kips)	Controlling Stud Capacity (kips)	Number of 1/2" Studs Needed	Number of 5/8" Studs Needed
36WF135	0.600	34.02	35.60	0.790	225	426	225	41.76	15.80	13.43	52.20	23.00	19.55	**17**	**12**
33WF130	0.580	31.34	33.31	0.855	209	380	209	40.37	15.80	13.43	50.46	23.00	19.55	**16**	**11**

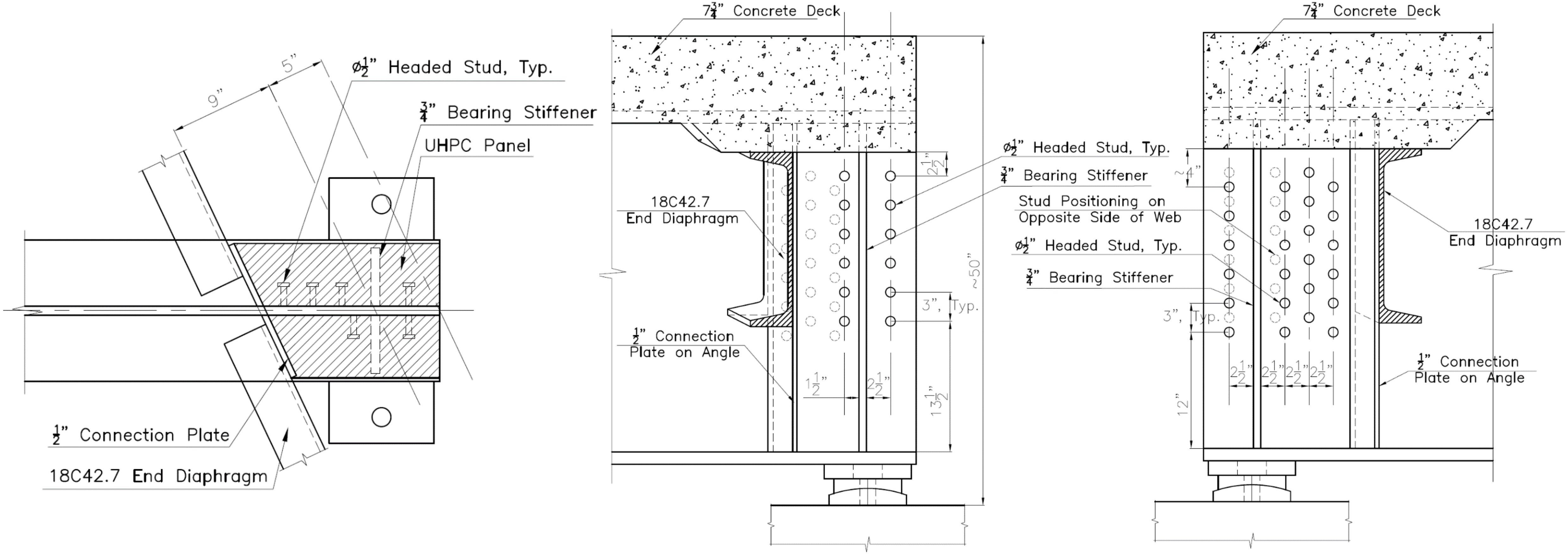
Number of Studs Needed Based on Fatigue Calculations

Fatigue Calculation Used	Shear Force at Girder End (kips)	Number of 1/2" Studs Needed	Number of 5/8" Studs Needed
Wheel Load	21	**15**	**10**
Fatigue Truck	41	**30**	**19**

Number of Studs Needed Based on HL-93 and Strength 1

	Shear	Number of 1/2" Studs Needed	Number of 5/8" Studs Needed
HL-93*1.75	116	**9**	**6**
Strength 1	301	**22**	**15**

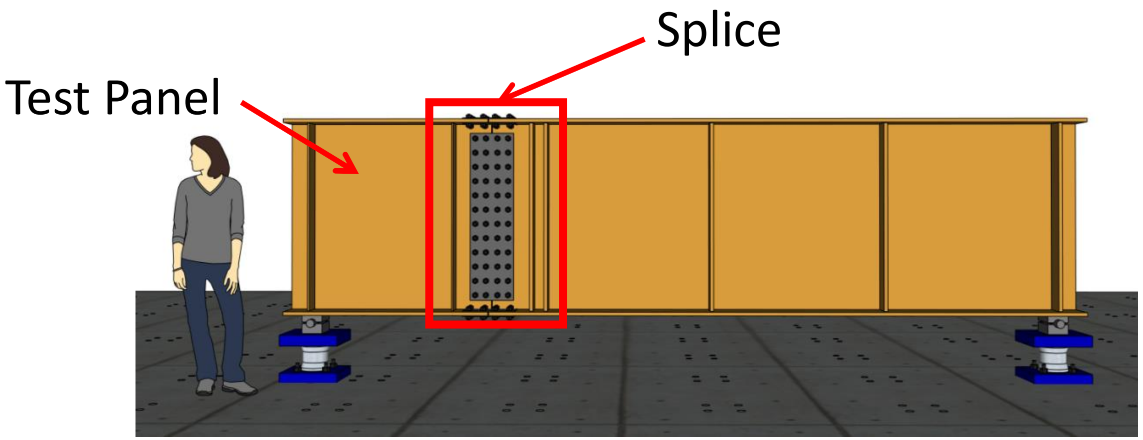
Sample Repair Detail

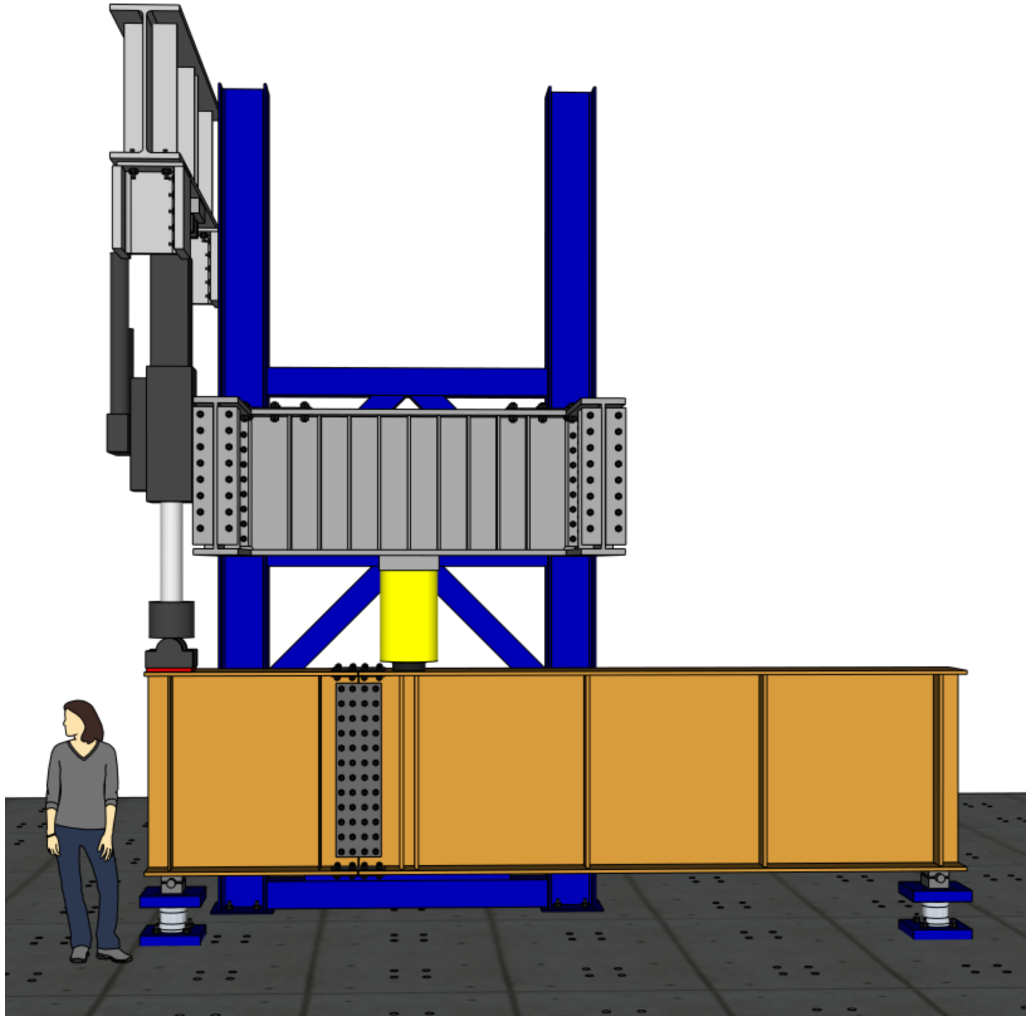


The research team is working with the Connecticut DOT to identify a bridge for the implementation of the repair.

Phase II Plate-Girder Experiments

- Designed after realistic plate girder bridges
- The test panel can be replaced between experiments for efficiency





Thank you for your time!