FIU UNIVERSITYCITY PROSPERITY PEDESTRIAN BRIDGE PROJECT

WJE

FIU Pedestrian Bridge Collapse: *Testing of Full-Size Replicas of Failed Connection*

Presented by Gary J. Klein, SE, PE

- Executive Vice President and Senior Principal with Wiss, Janney, Elstner Associates, Inc. (WJE)
- 40+ years of bridge investigation and structural research experience, including several shear-related research projects
- Collapse investigations include FIU Pedestrian Bridge (Miami), Koror-Babeldoab Bridge (Palau), and Kansas City Hyatt Walkways.
- ACI Honorary Member: served for more than 25 years on ACI 318 (Building Code) and ACI 445 (Shear and Torsion)
- Elected to the National Academy of Engineering in 2016 for sharing lessons learned from infrastructure failure investigations

Presented July 23, 2020
Minnesota Concrete Council

WJE

FIU Pedestrian Bridge Collapse: *Testing of Full-Size Replicas of Failed Connection*

Introduction

Bridge Description

- Two-span truss; 175 foot main span
- Pylon and stay cables (actually pipes) are architectural features
- Canopy and 32-foot wide deck are posttensioned
- Most diagonals are posttensioned

Introduction

Move of Main Span into Position: March 10, 2018

Introduction

Collapse: March 15, 2018

Introduction

Scope of WJE Investigation

- Evaluation of Failure Pattern
- Structural Analyses
  - Finite Element Analyses
  - Code Evaluation of Failed Deck Connection
- Construction Joint Conditions
- Interface Shear Transfer Testing
- Test-based Evaluation of Deck Connection Failure
- Other Factors

Introduction

NTSB Probable Cause

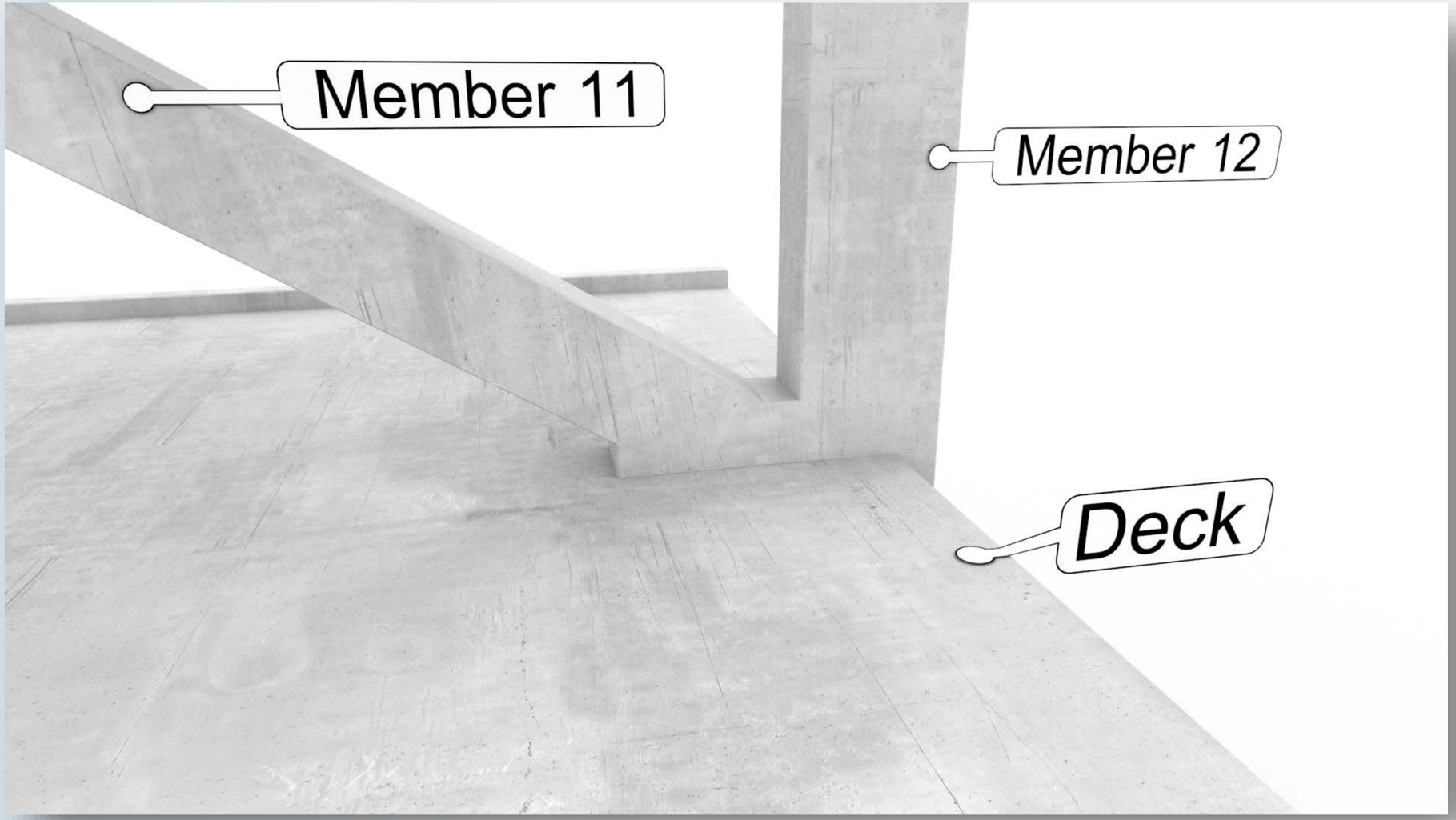
Design mistakes by FIGG as to the load and capacity of the Member 11/12 deck connection

Introduction

WJE Exceptions to NTSB/FHWA Probable Cause

1. Considering the entire construction joint between member 11/12 and the deck, the design as shown on the contract documents meets the AASHTO Code.
2. If the construction joint were roughened as required by the project specifications, which were reconfirmed by email, the collapse would not have occurred.

Background

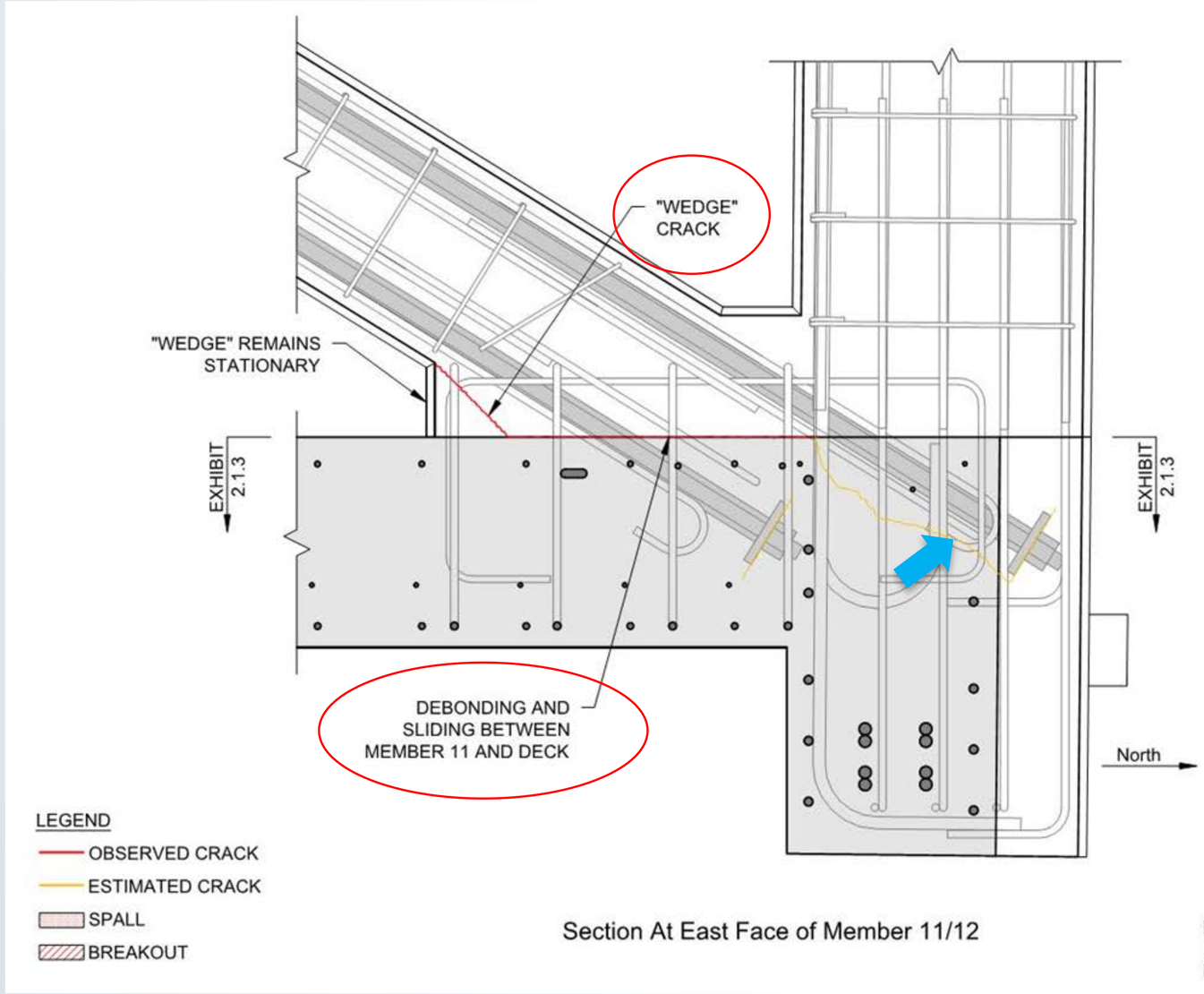


Background

Timeline

October 19, 2017	Deck concrete casting
February 24, 2018	Shoring removal (cracking observed)
March 10, 2018, 12:30 PM	Main span moved into final position
March 10, 2018, 3:07 PM	Very significant widening of cracks observed
March 15, 2018, 11:49 AM	Re-tensioning of member 11
March 15, 2018, 1:45 PM	Main span collapses

After Shoring Removal and Before Move (February 12-March 9, 2018)



Section At East Face of Member 11/12

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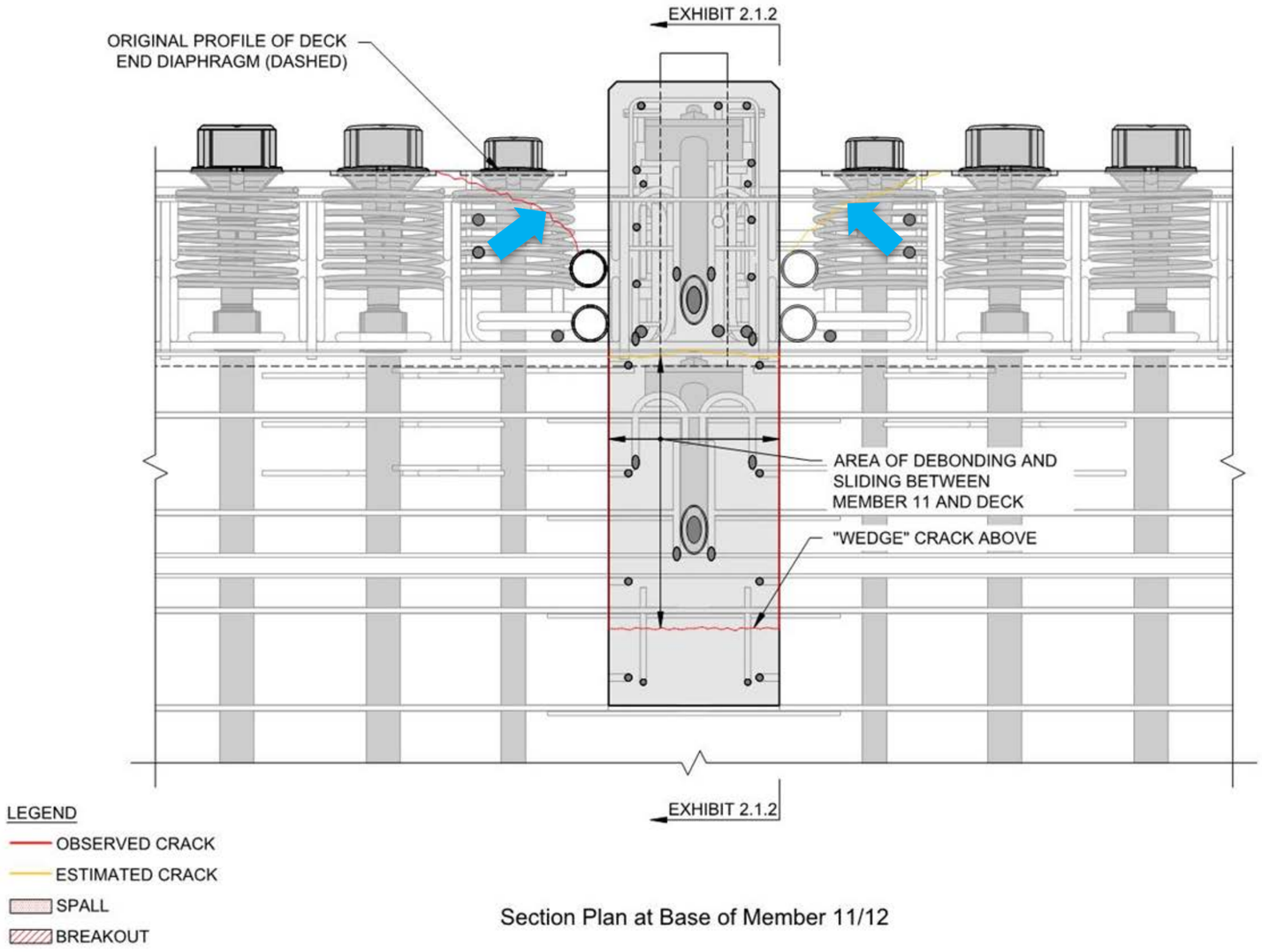
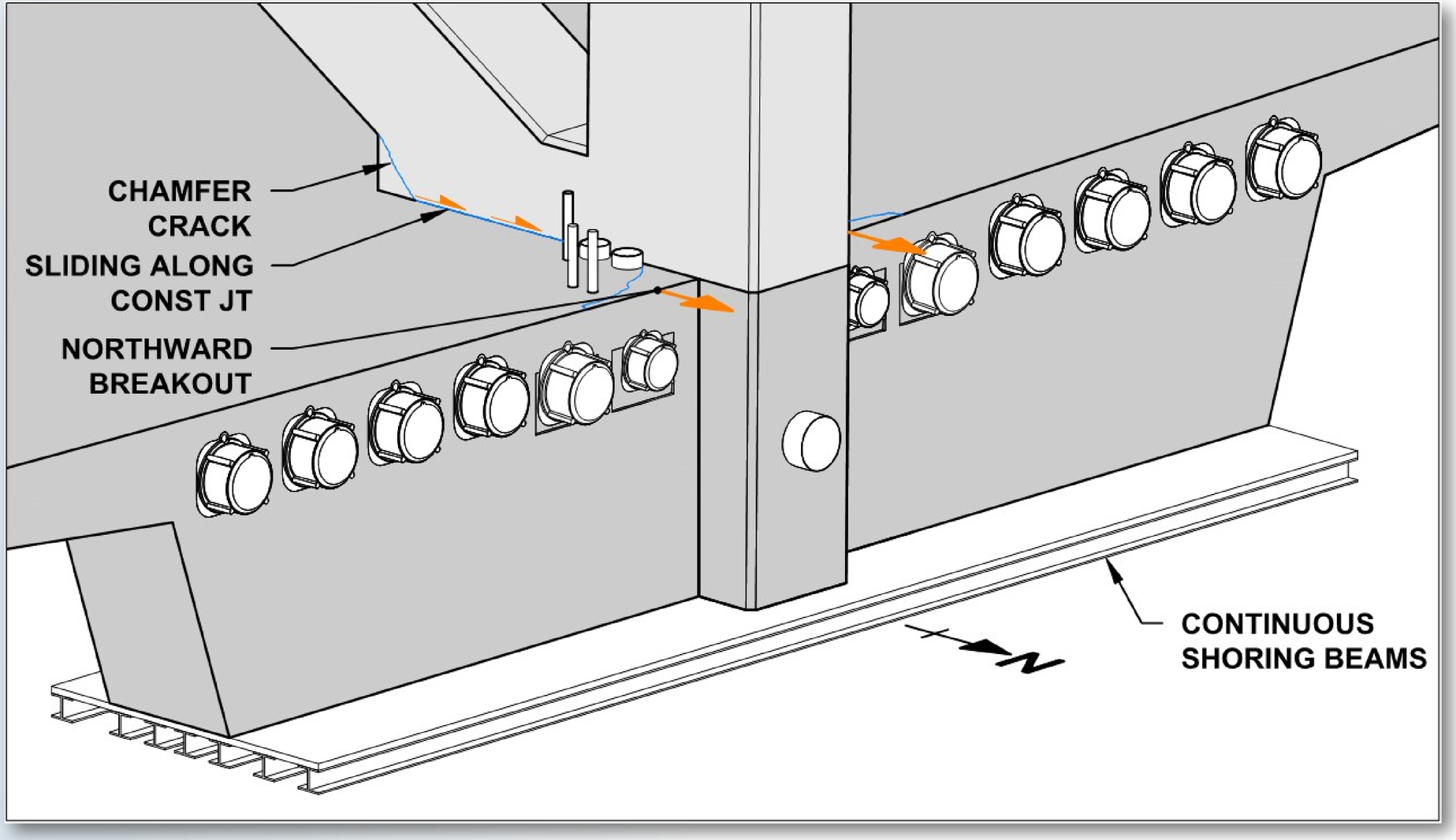
After Shoring Removal and Before Move (February 12-March 9, 2018)

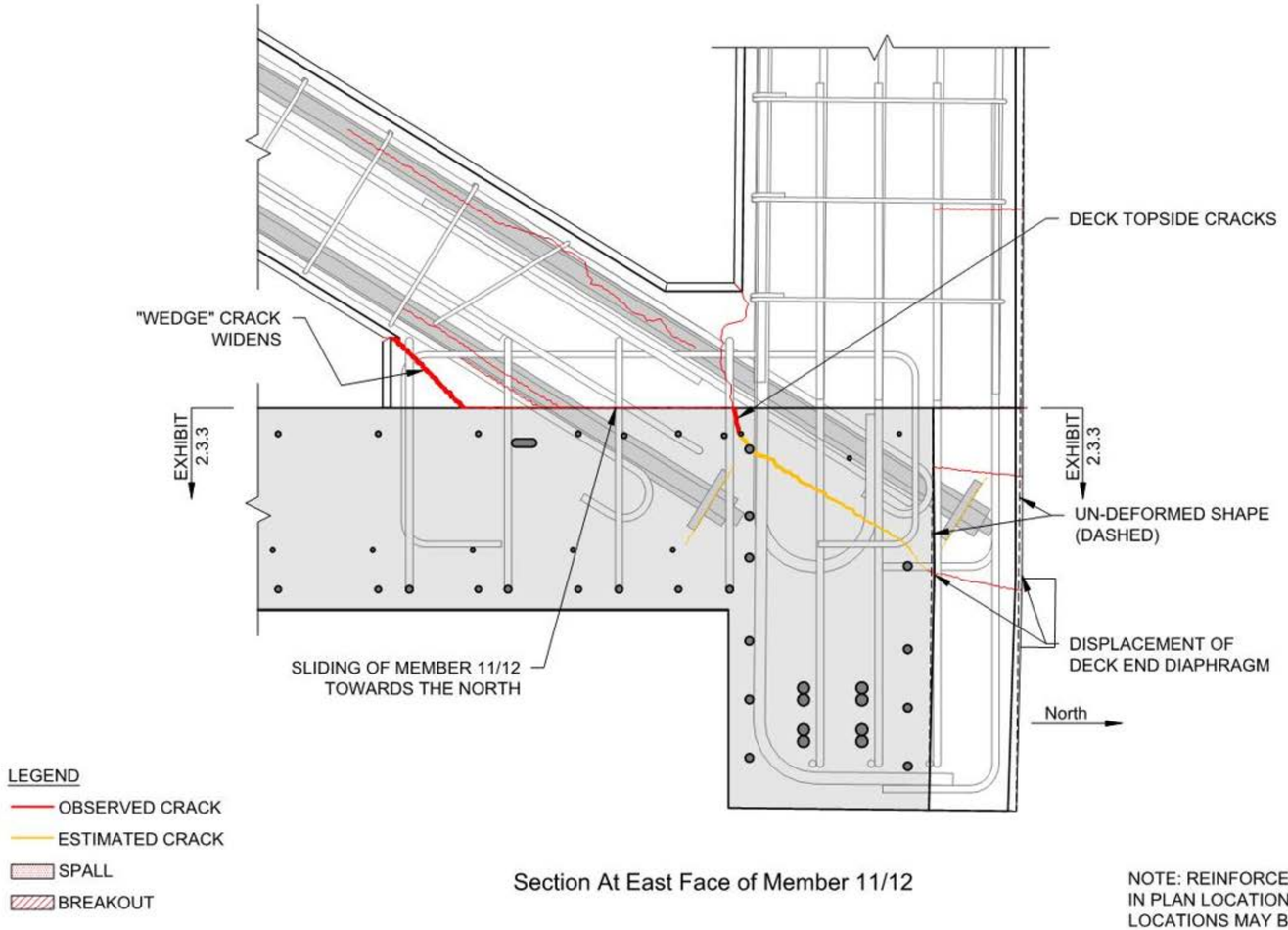


Section Plan at Base of Member 11/12

After Shoring Removal and Before Move (February 12-March 9, 2018)



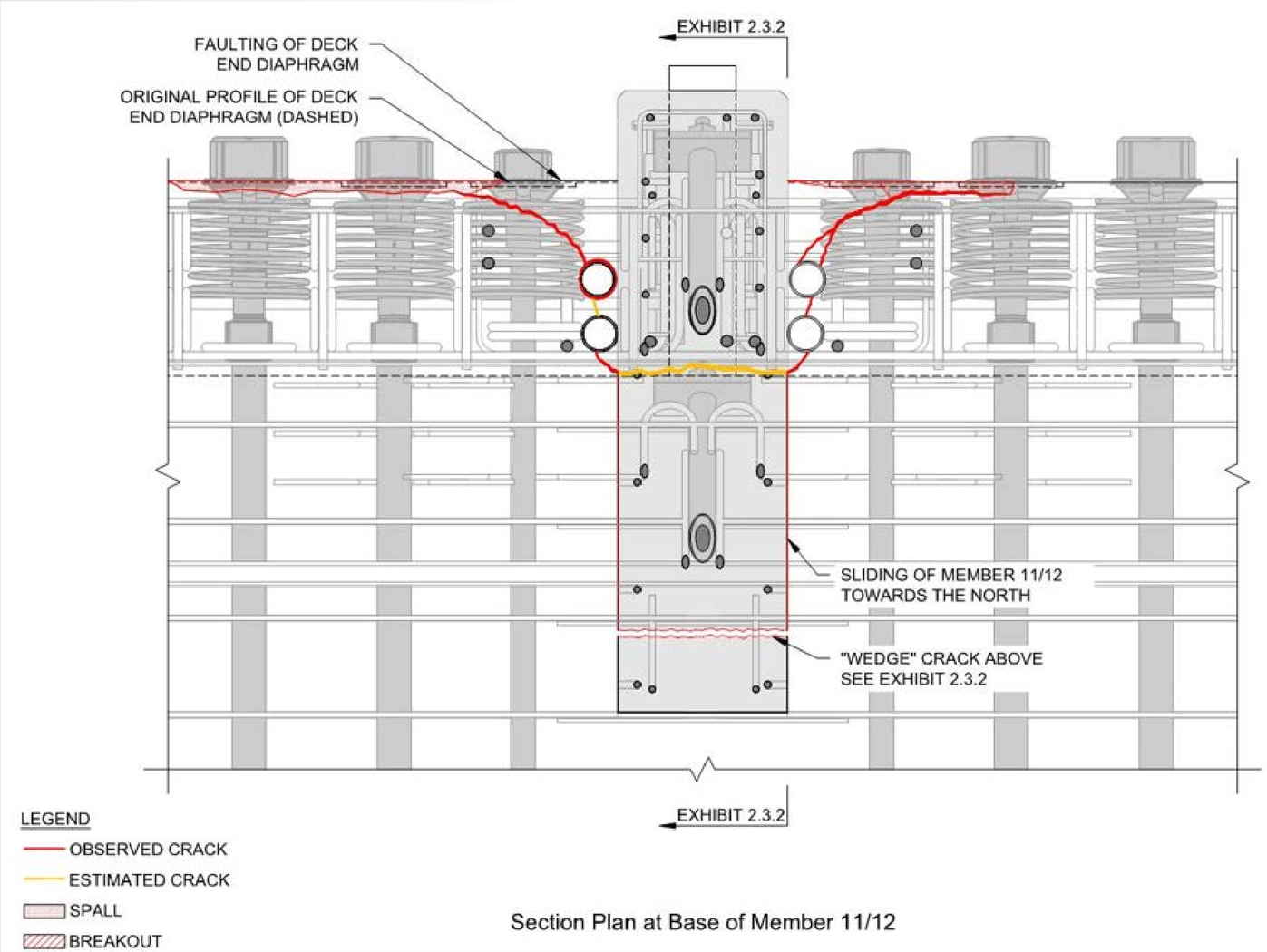
March 12, 2018 at 3 PM



Section At East Face of Member 11/12

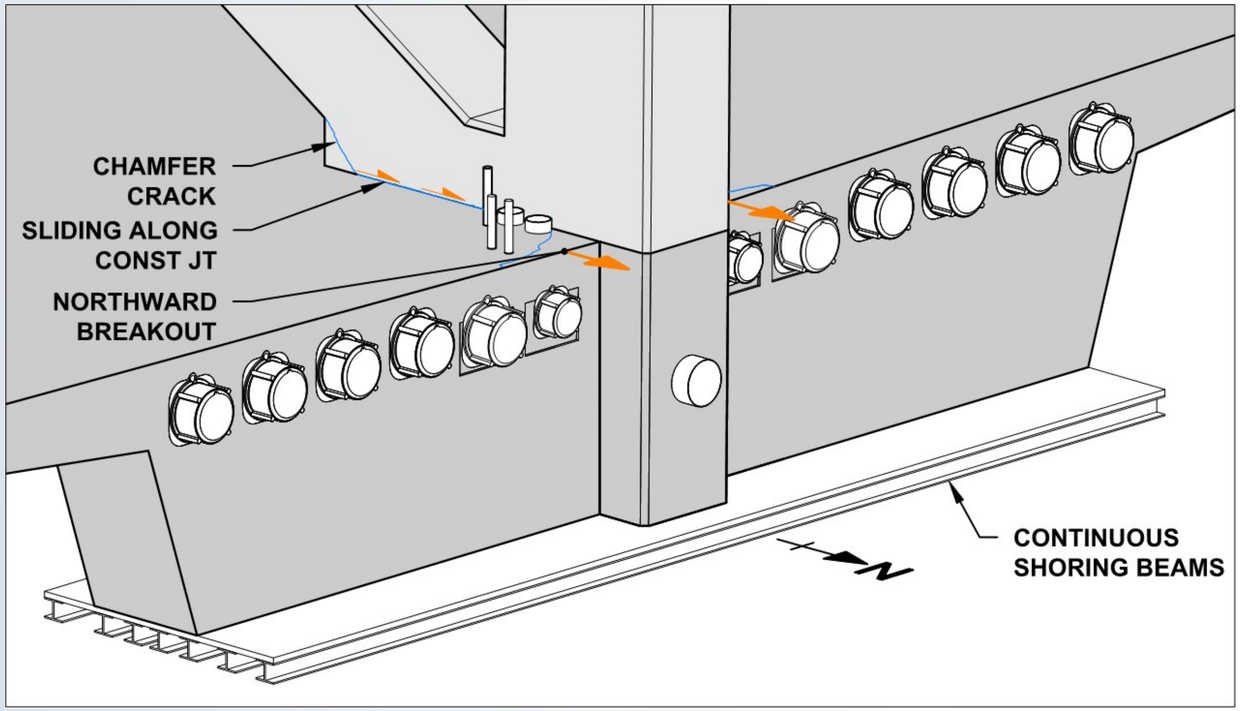
NOTE: REINFORCEMENT IS SHOWN IN PLAN LOCATIONS. AS-BUILT LOCATIONS MAY BE DIFFERENT.

March 12, 2018 at 3 PM

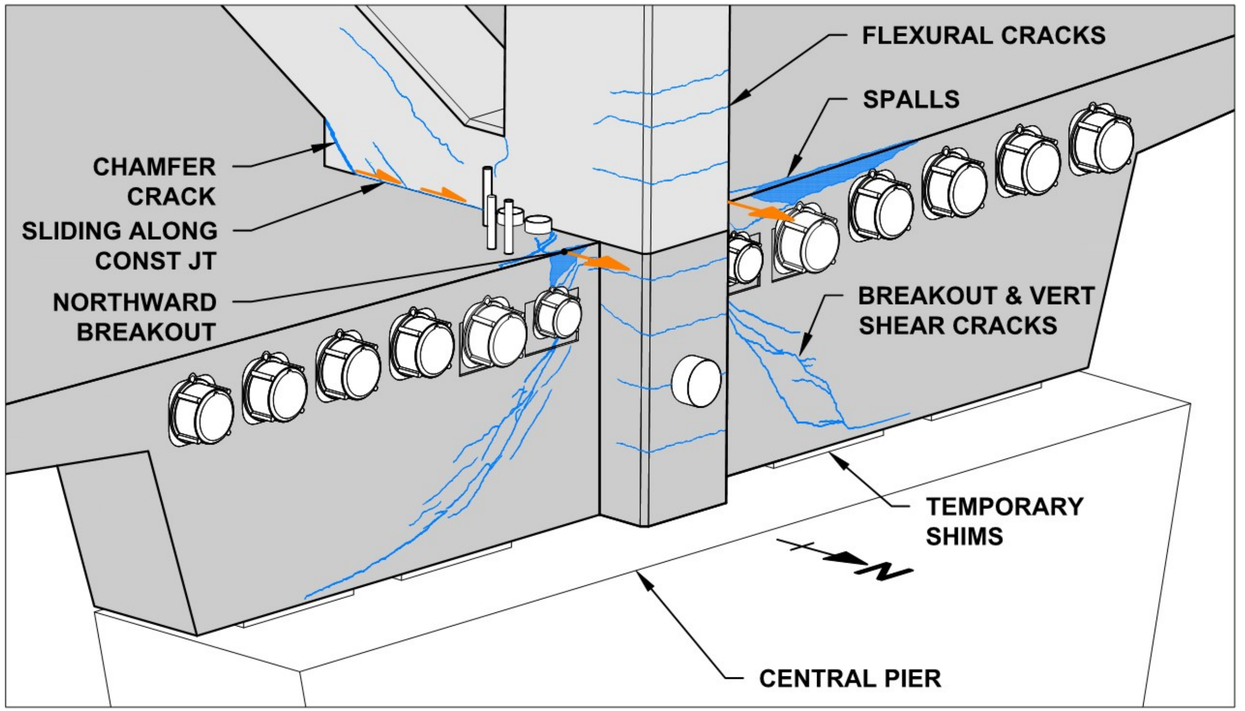


Section Plan at Base of Member 11/12

After Shoring Removal: Feb. 24

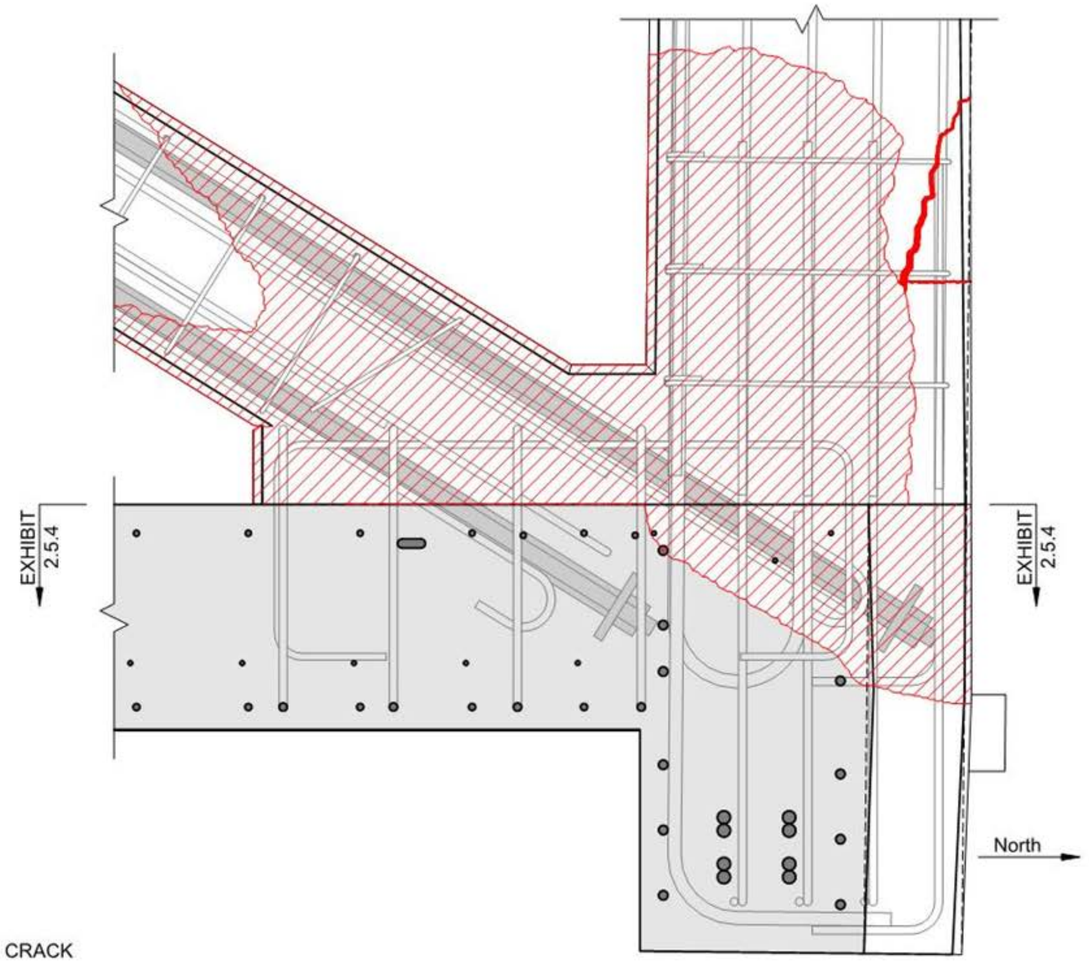


On Final Supports: March 12



After Collapse (March 15, 2018)

After Collapse (March 15, 2018)



Section At East Face of Member 11/12

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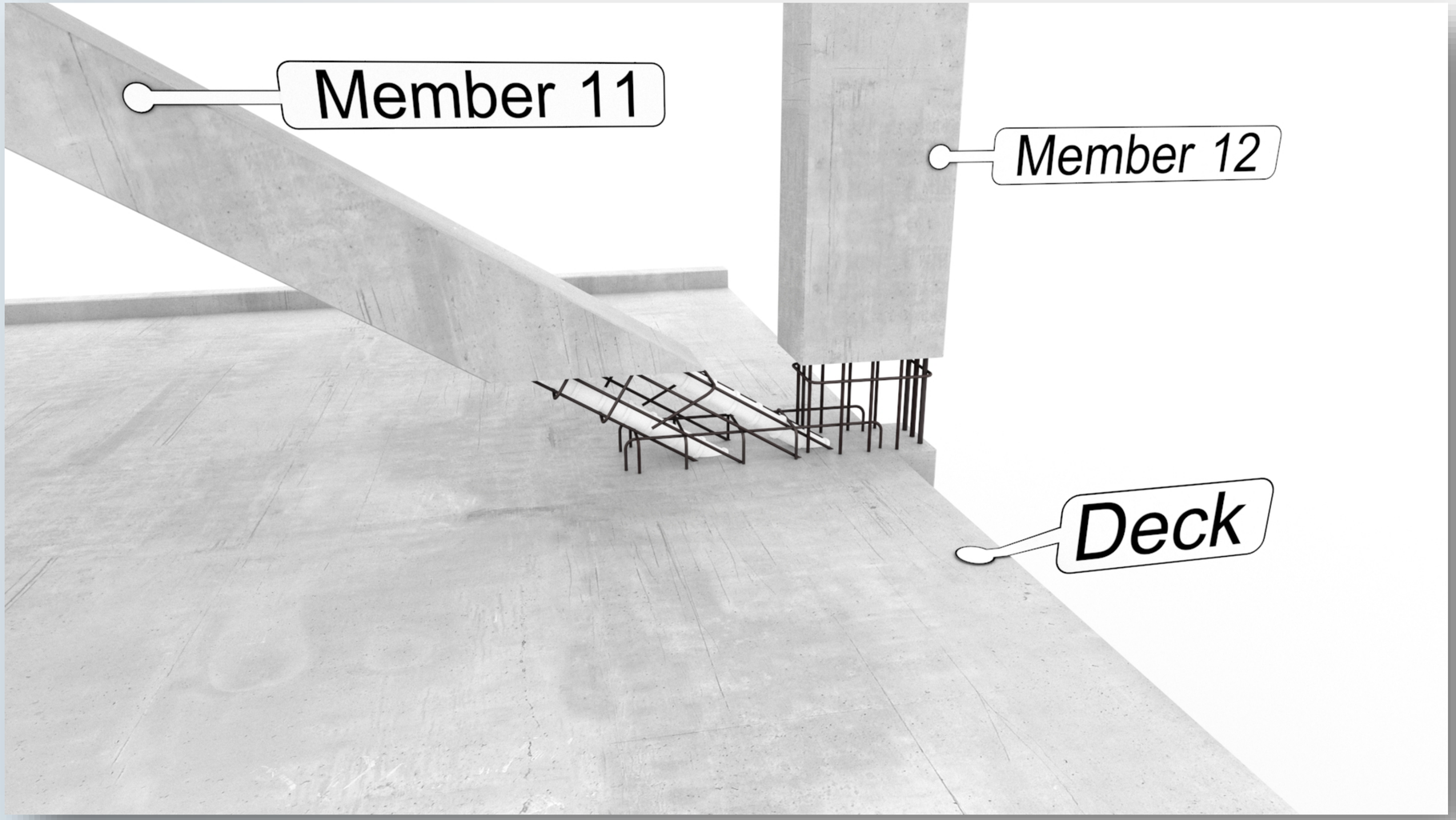
Code Evaluation of Member 11/12 Deck Connection



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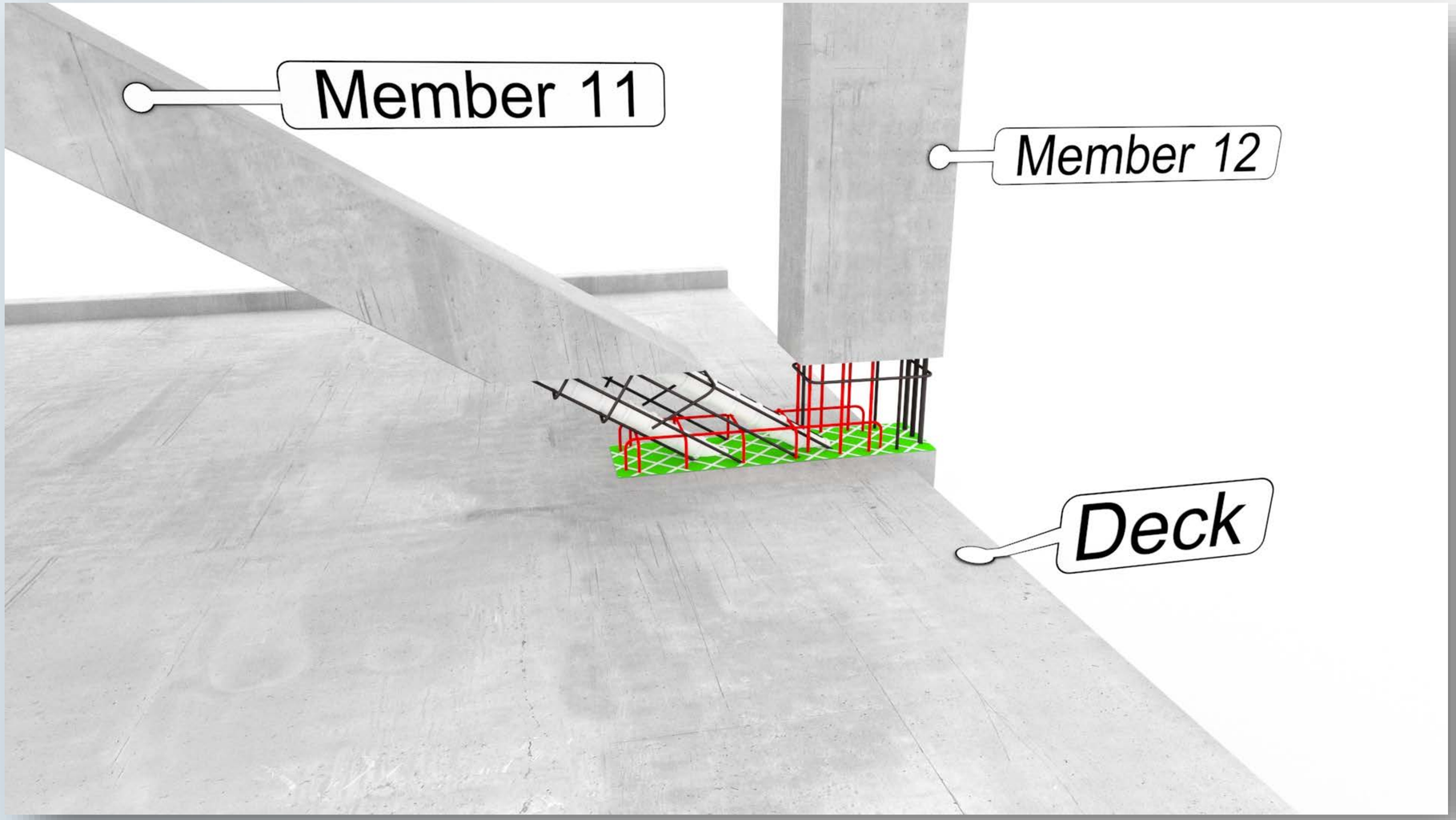
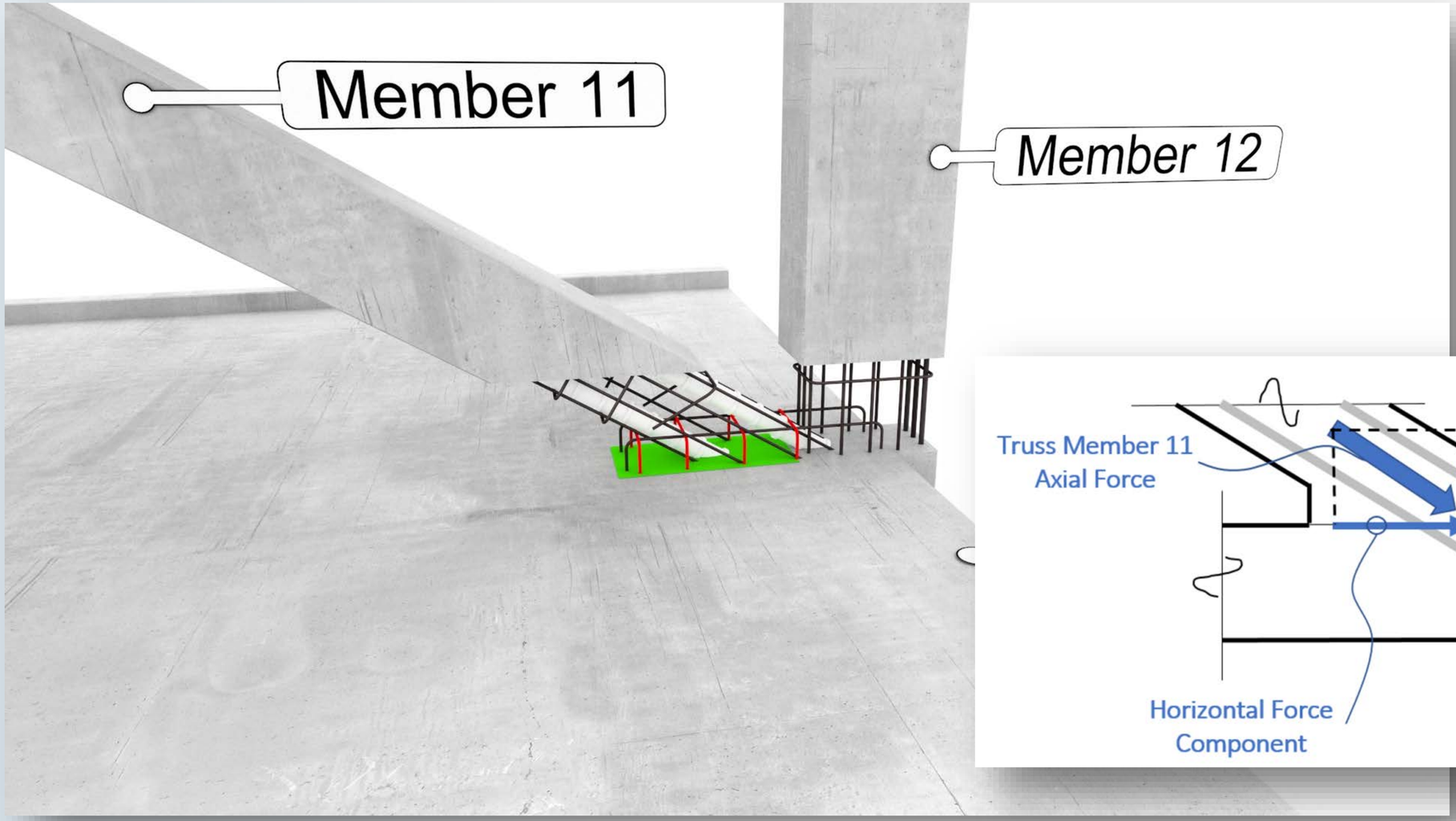


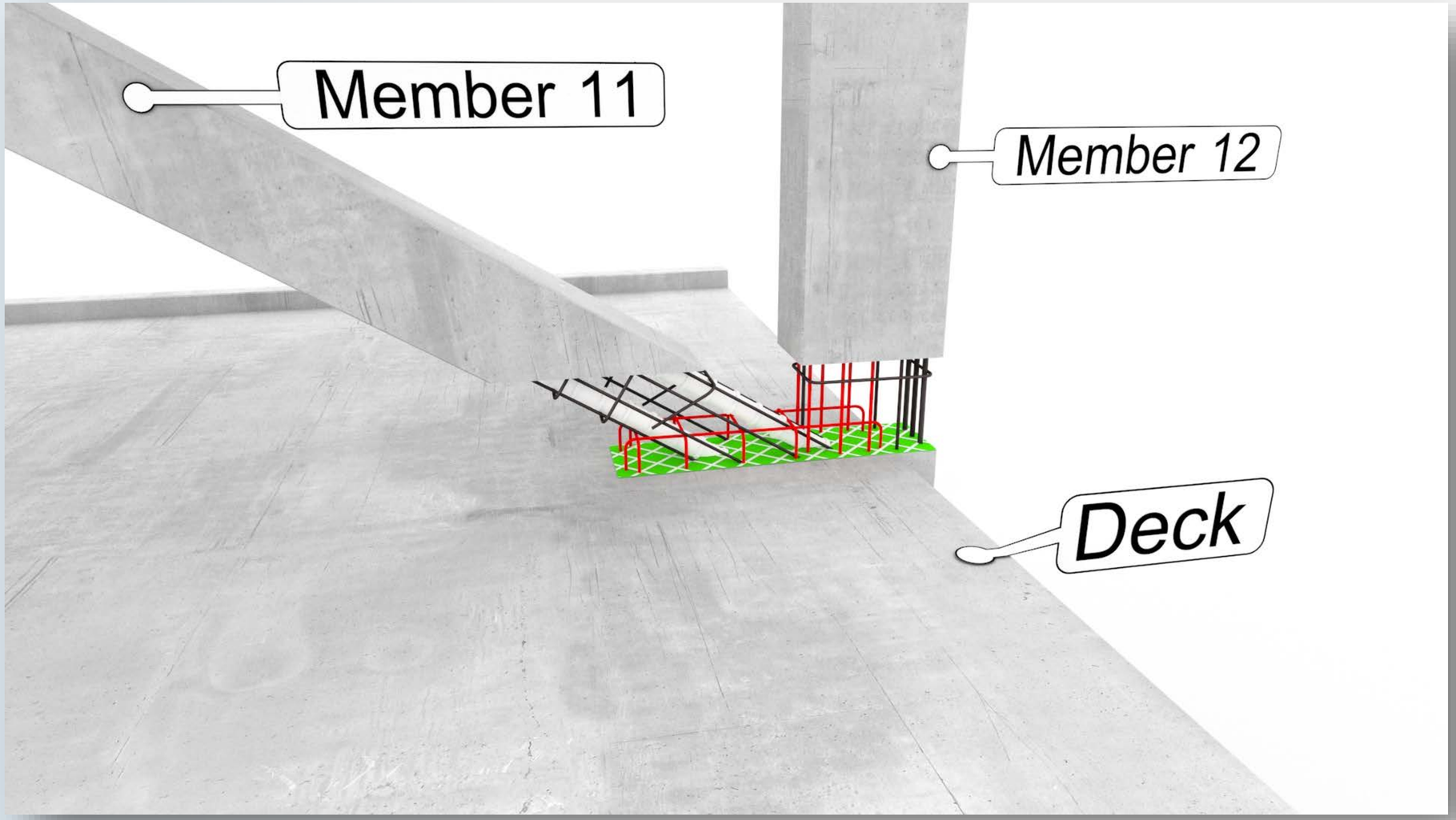
WJE Evaluation

Code Evaluation of Member 11/12 Deck Connection



FHWA Evaluation

Code Evaluation of Member 11/12 Deck Connection



WJE Evaluation

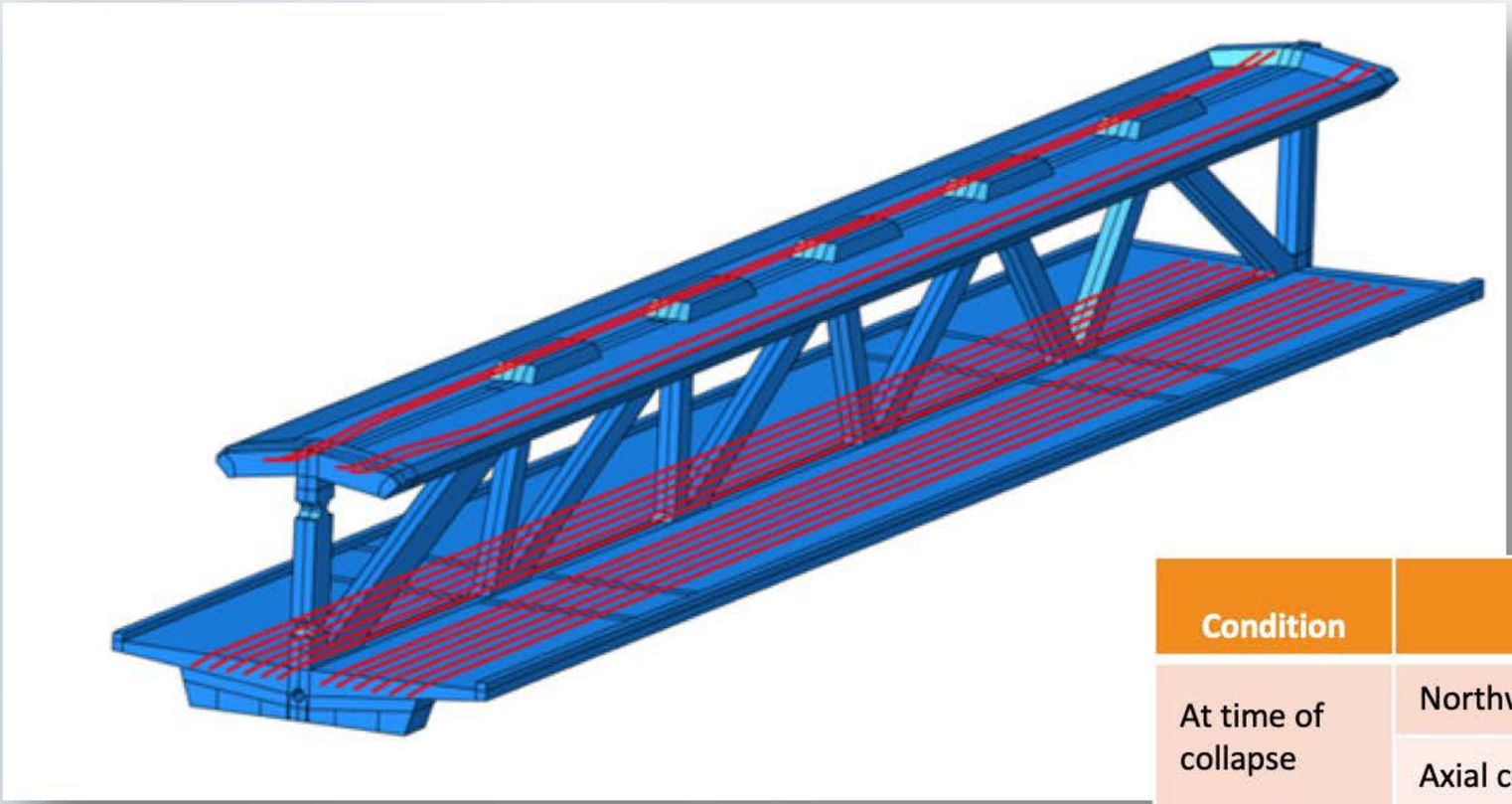
Code Evaluation of Member 11/12 Deck Connection

AASHTO Code:

$$V_{ni} = cA_{cv} + \mu\left(A_{vf} f_y + P_c\right)$$

- ***c*** *is the cohesion factor*
- $\boldsymbol{P_c}$ *is defined as the permanent compressive force*
- *For concrete that is roughened to amplitude of 0.25 inches:*
  - *c = 0.24 ksi;* μ *= 1.0*
  - $v \leq 0.25 f_c' \leq 1.5 ksi$
- *For concrete that is not intentionally roughened (but laitance is removed):*
  - *c = 0.075 ksi;* μ *= 0.6*
  - $v \leq 0.20 f_c' \leq 0.8 ksi$

Code Evaluation of Member 11/12 Deck Connection



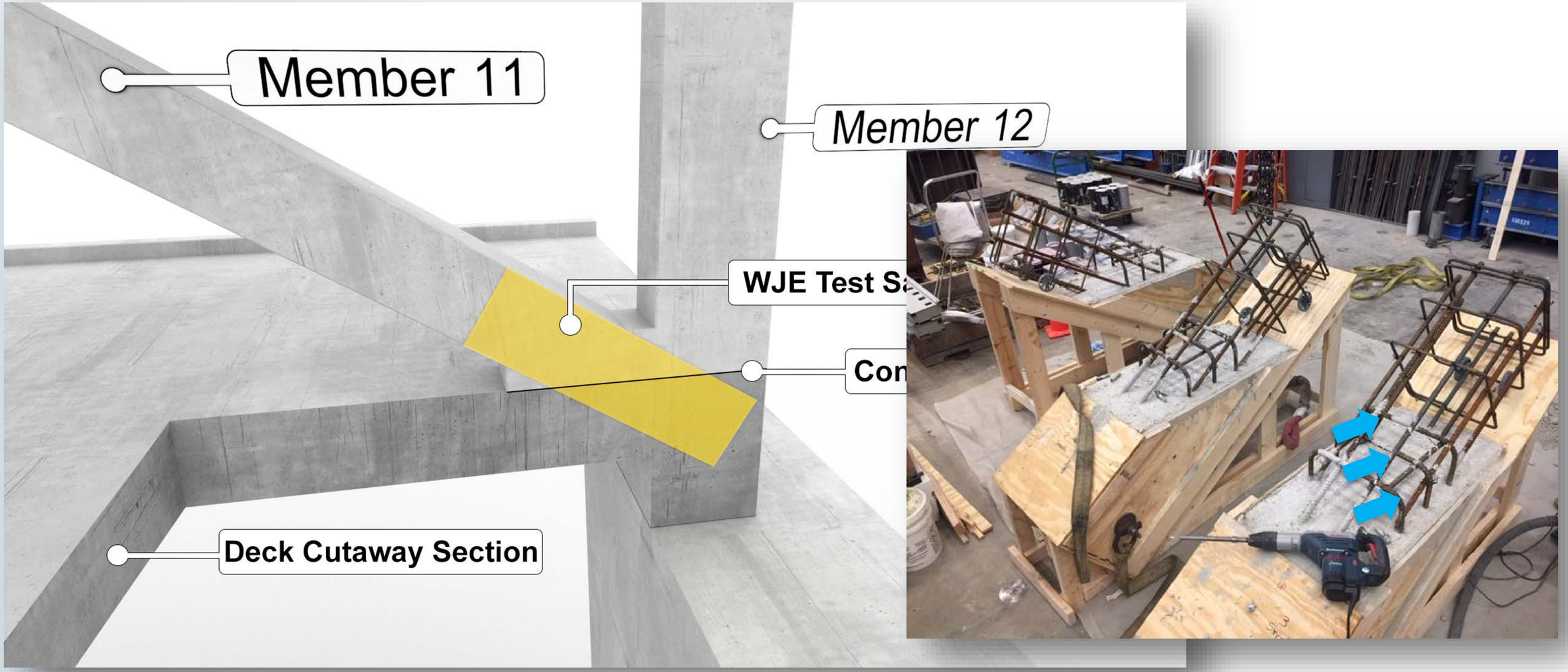
Abaqus Finite Element Model

Condition	Calculated Demand (kips)	WJE	FHWA
At time of collapse	Northward force at M11/12 connection	1677	
	Axial compression in member 11	**1743**	
Factored per AASHTO	Northward force at M11/12 connection	**1979**	1835*
	Axial compression in member 11	2236	
*Does not include construction live load			

Code Evaluation of Member 11/12 Deck Connection

Summary of Shear-Friction Resistance			
Factored Northward Force (kips)	**Surface Condition**	**Factored Resistance**	**Capacity/Demand Ratio (CDR)**
1979	Roughened	2150	1.09
	Not Roughened	1157	0.58

Interface Shear Transfer Testing: Specimens



Interface Shear Transfer Testing: Construction Joint Condition

400-9.3 Preparations of Surfaces: *Before depositing new concrete on or against concrete which has hardened, re-tighten the forms. Roughen the surface of the* ***hardened*** *concrete in a manner that will not leave loosened particles, aggregate, or damaged concrete at the surface. Thoroughly clean the surface of foreign matter and laitance, and saturate it with water.*

Interface Shear Transfer Testing: Construction Joint Condition

June 13, 2017, 7:48 a.m.– BPA to FIGG and MCM

"Please make sure we have FIGG blessing for the construction cold joints treatment…"

June 13, 2017, 7:56 a.m.– FIGG to BPA and MCM

"We have had previous communications with MCM regarding this topic and the FDOT specifications referenced below was to be followed. Let us know if you have any further questions."

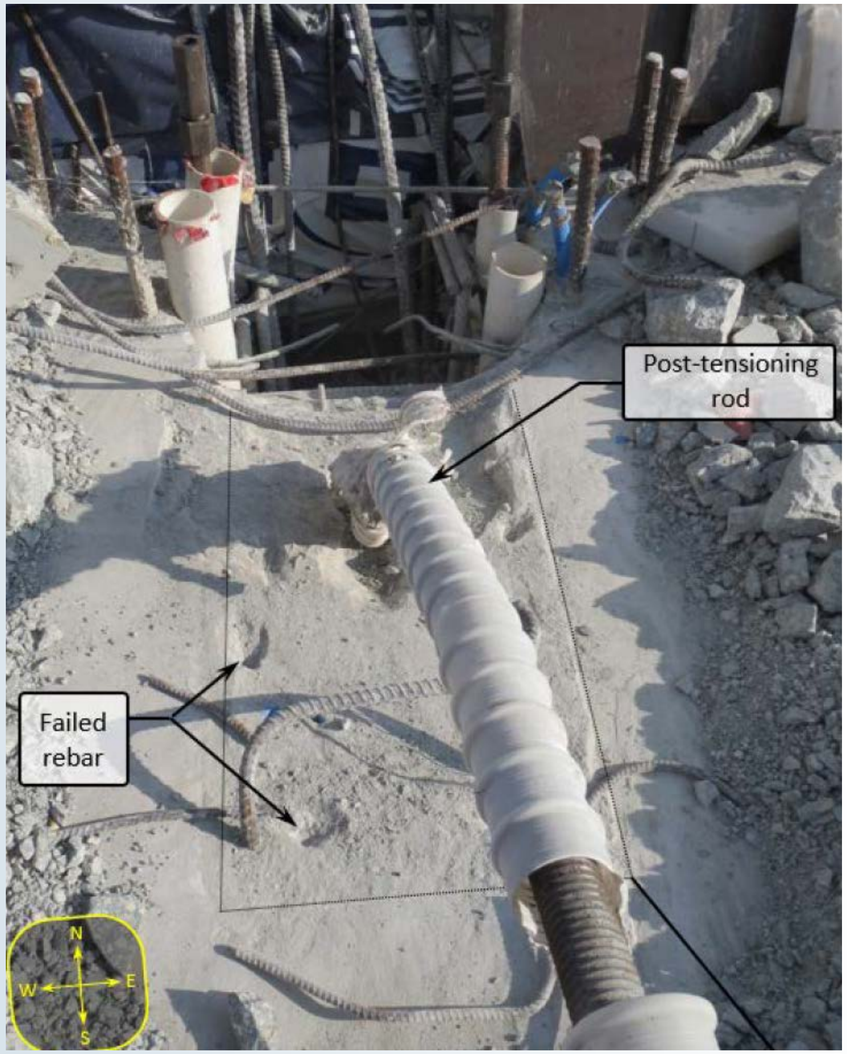
June 13, 2017, 8:04 a.m.– BPA to FIGG

"Thank you."

Interface Shear Transfer Testing: Construction Joint Condition

400-9.3 Preparations of Surfaces: *Before depositing new concrete on or against concrete which has hardened, re-tighten the forms. Roughen the surface of the* ***hardened*** *concrete in a manner that will not leave loosened particles, aggregate, or damaged concrete at the surface. Thoroughly clean the surface of foreign matter and laitance, and saturate it with water.*

Interface Shear Transfer Testing: Construction Joint Condition



FHWA Report on Member 11/12 Joint

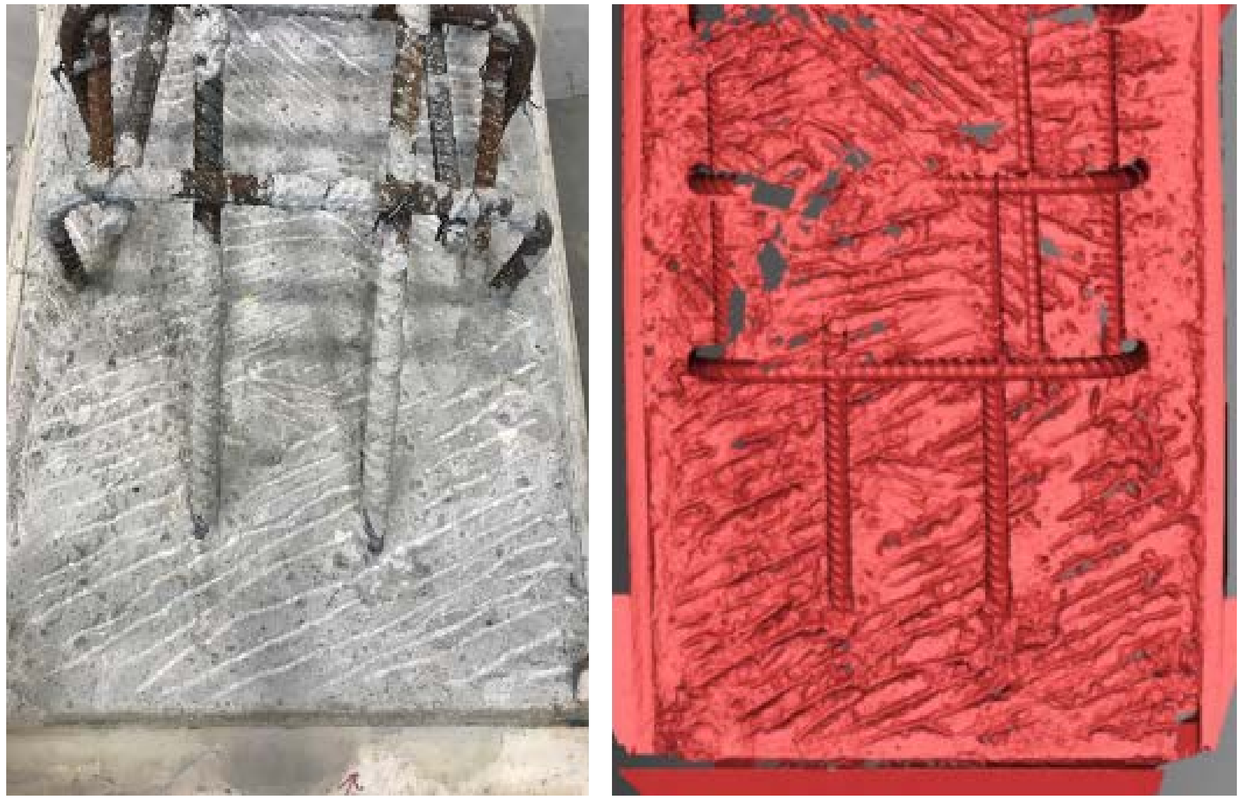
FHWA Conclusion: "The evidence indicates that the failure interface coincides with the original cold joint and that the cold joint was not intentionally roughened."

Interface Shear Transfer Testing: Construction Joint Condition

Photograph and laser scan of WJE Specimen 3 (As-placed)

Interface Shear Transfer Testing: Construction Joint Condition

Surface roughening trials



Photograph and laser scan of WJE Specimen 4 (Roughened)

Interface Shear Transfer Testing: Construction Joint Condition

Laser Scan Data: Standard Deviation (mm)	
Deck Specimen 1 (recovered by NTSB from site)	0.76
WJE Specimen 3 (as-placed)	0.94
WJE Specimen 4 (intentionally roughened)	2.16

Interface Shear Transfer Testing: Pre-Cracking

Stone-splitting wedge sets being used to create a crack across the construction joint of Specimen 6. Most specimens were pre-cracked.

Interface Shear Transfer Testing: Loading and Instrumentation

Linear displacement transducers across interface

University of Illinois Southward-Emery test machine (3 million pounds capacity)

Interface Shear Transfer Testing: Results (pre-cracked specimens)

Specimen	Peak Load (Average)	Member 11 Load at Failure	%
Roughened	2,594 kips	1,743 kips	149%
Non-roughened	1,455 kips	1,743 kips	83%

Interface Shear Transfer Testing: Results

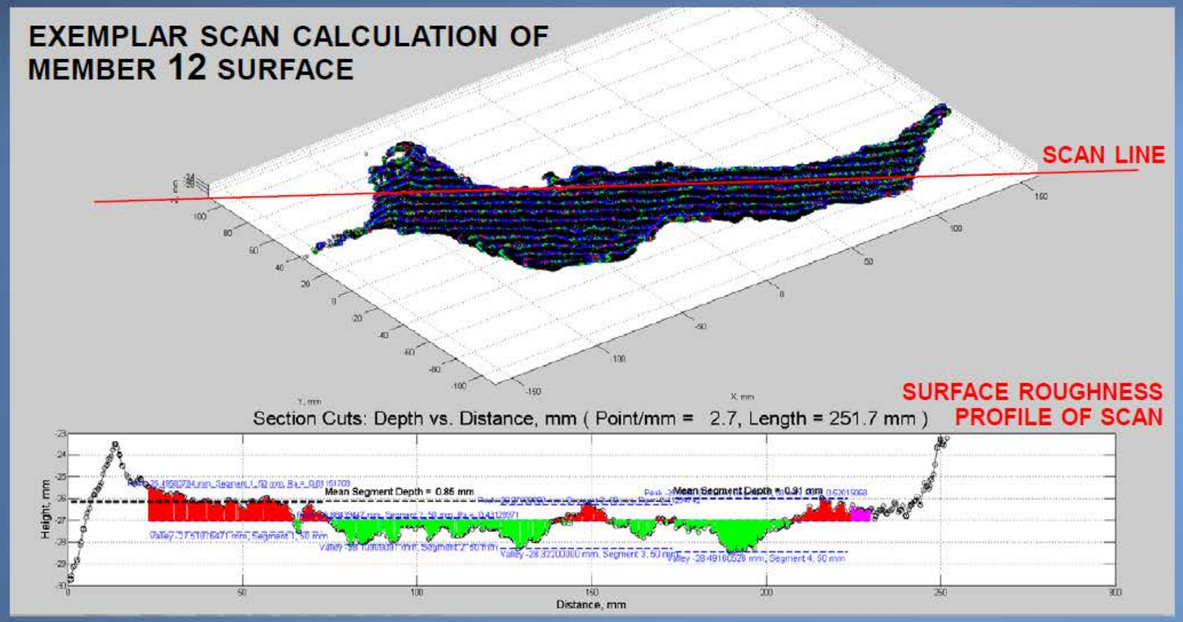
Findings:

- ***Intentional roughening improved the shear capacity of the cracked interface by a factor of 1.78 compared to the as-placed specimens with a cracked interface.***

- ***If the construction joint were roughened as required by the project specifications, which were reconfirmed by email, the collapse would not have occurred.***

Interface Shear Transfer: NTSB Findings

Surface Roughness Direct Measurement



- NTSB developed technique using data analysis of laser scans
- Calculations show cold joint not intentionally roughened

- ***Had cold joint been roughened, bridge could still have failed***

11

NTSB

Interface Shear Transfer: NTSB Findings

- ***Had cold joint been roughened, bridge could still have failed***

- NTSB conclusion

NTSB

Logically, this is not true

- **Joint failed at maximum load**
- **Joint was not roughened**
- **Roughening increases capacity by 78% (both AASHTO and WJE tests)**
- **Therefore roughened capacity would have been 78% more than maximum load = no failure**

Conclusions

WJE Exceptions to NTSB/FHWA Findings

1. Considering the entire construction joint between member 11/12 and the deck, the design as shown on the contract documents meets the AASHTO Code.
2. If the construction joint were roughened as required by the project specifications, which were reconfirmed by email, the collapse would not have occurred.

Thank You! Questions?