National Transportation Safety Board

Mechanisms of Structural Failure

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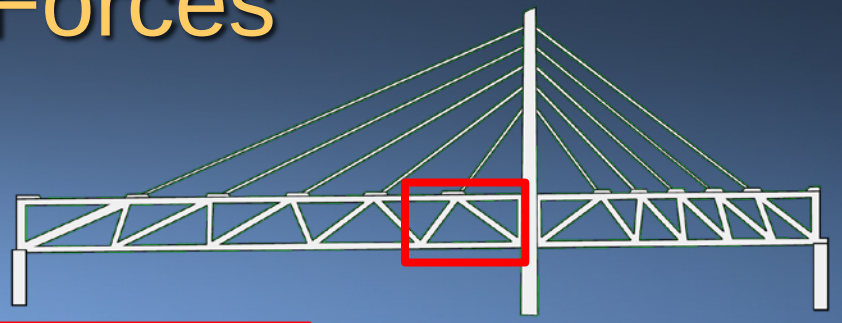
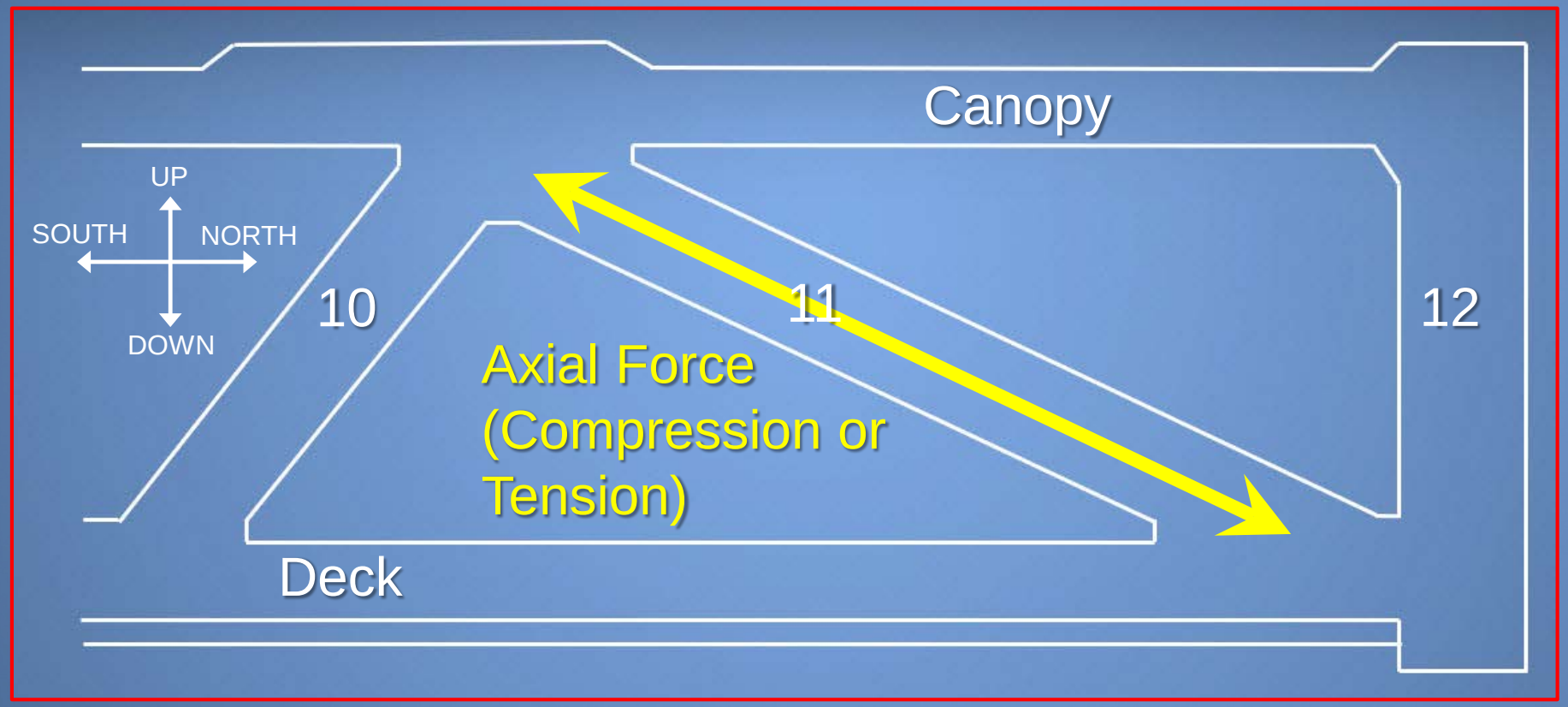
Overview

- Background concepts
- Initial indicators of structural distress
- Load path changes during construction
- Remedial actions to address cracking
- Collapse

Background – Axial and Component Forces





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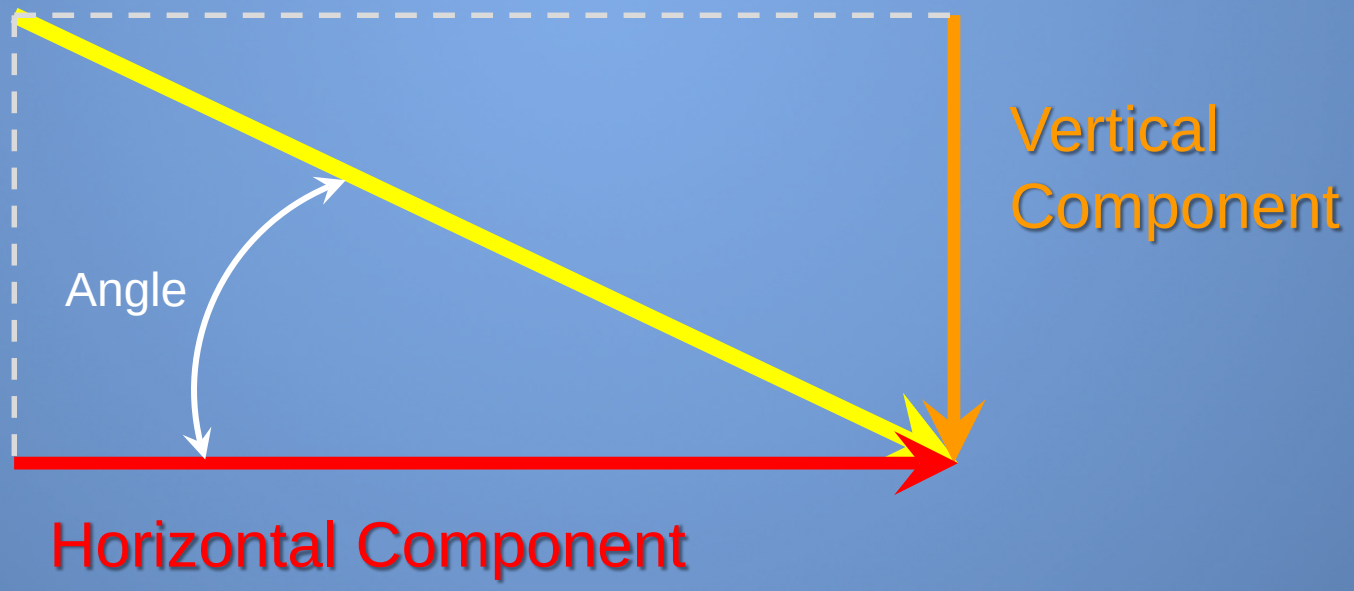
Background – Axial and Component Forces



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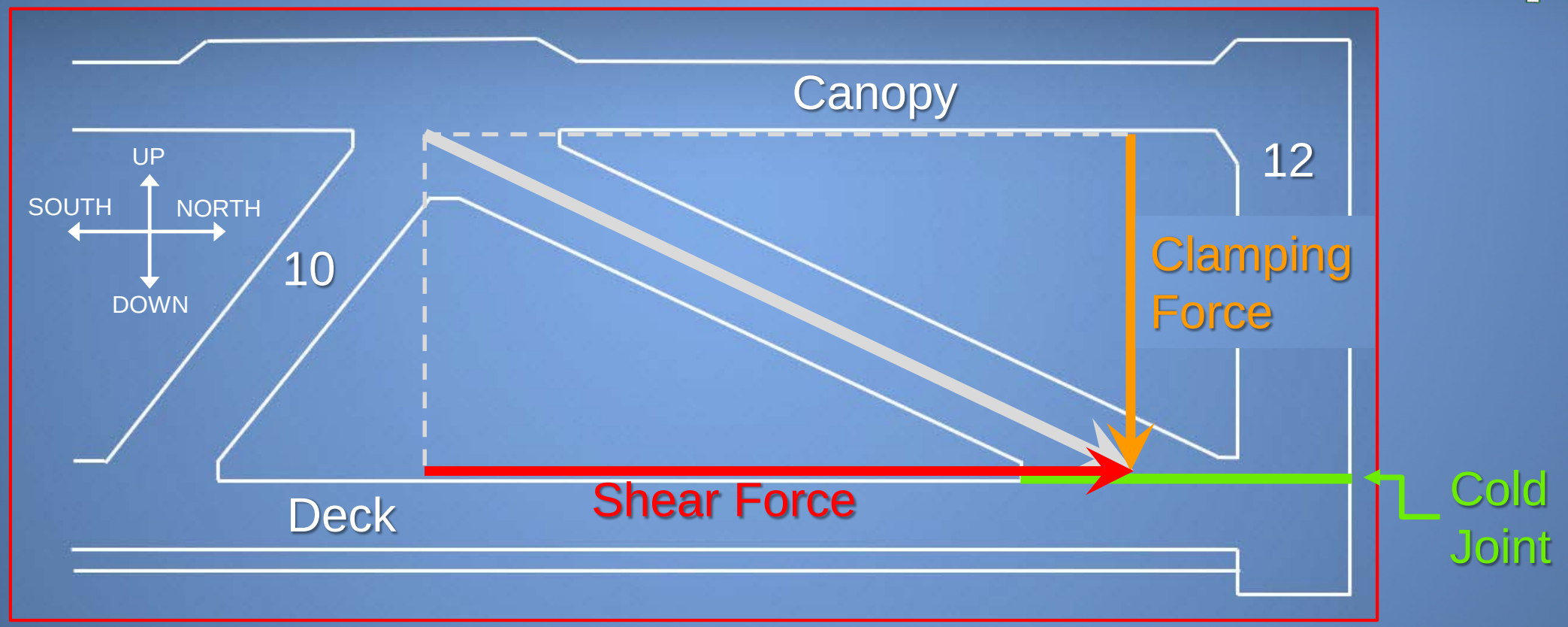

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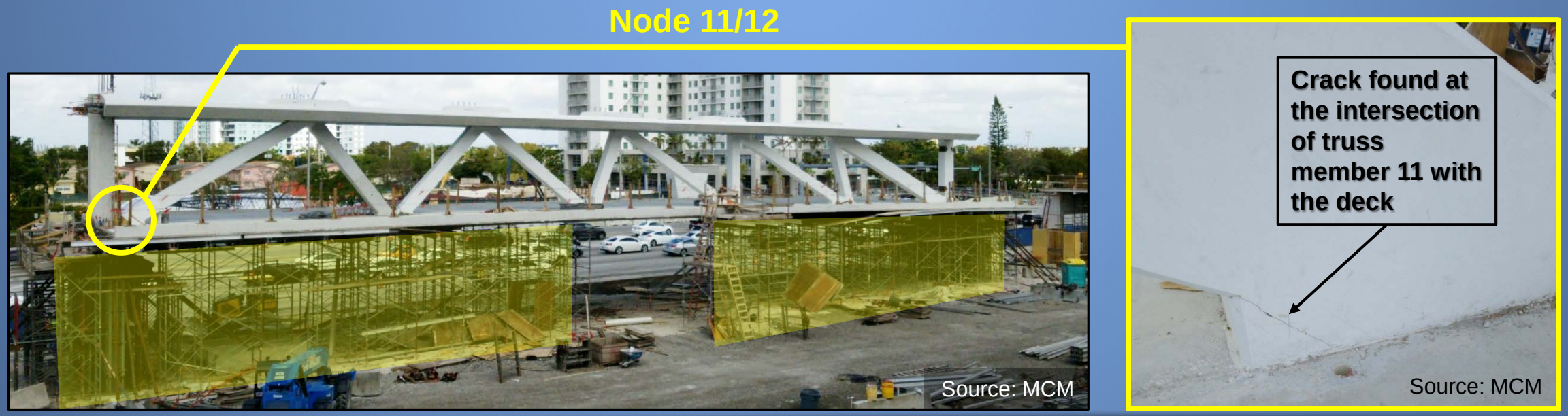
First Signs of Structural Distress

- Falsework removed sequentially
- Distinct concrete cracking noise heard February 24
- Crack found in member 11/12 nodal region



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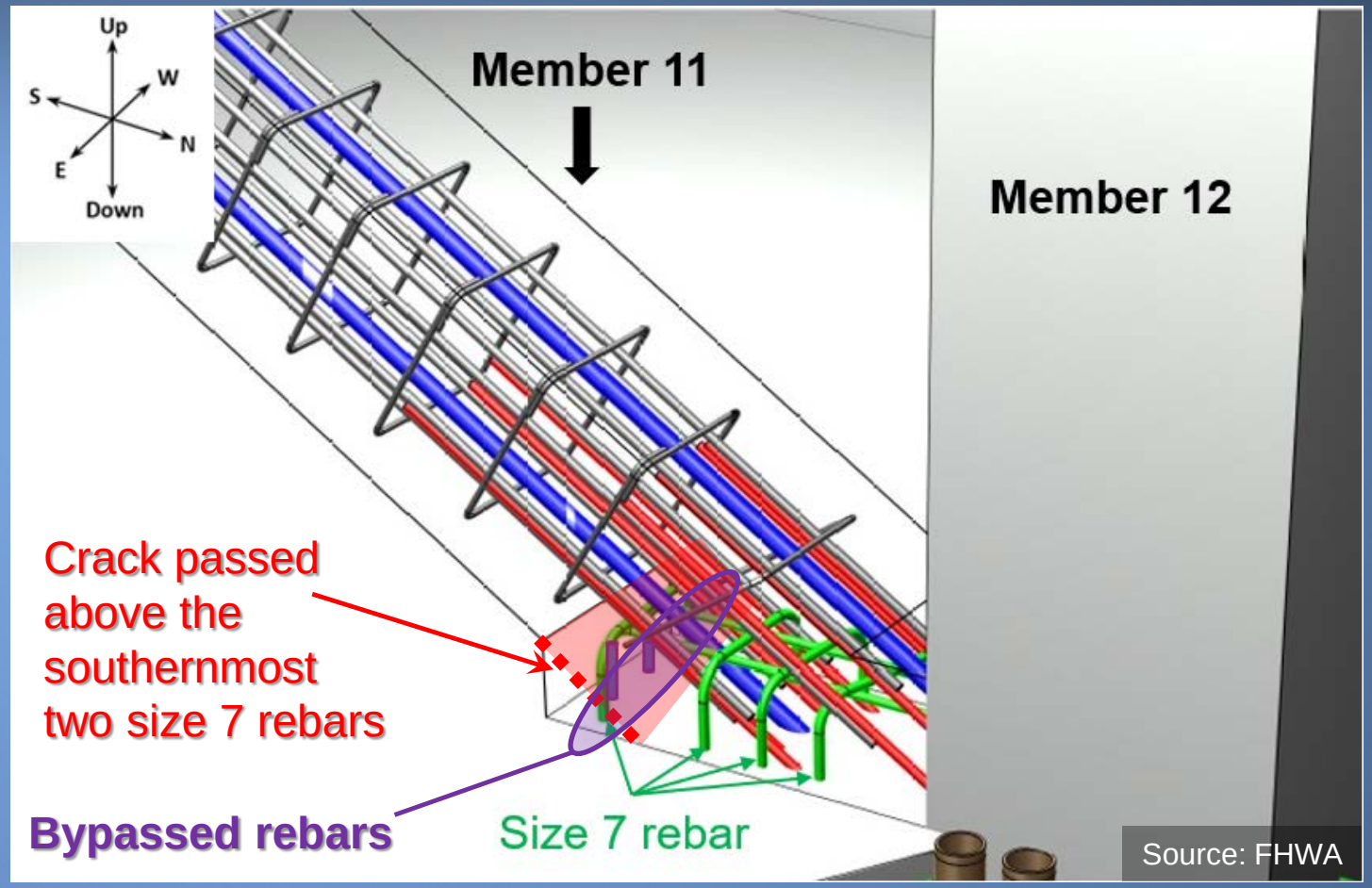
First Signs of Structural Distress

- Portion of crack bypassed 25% of reinforcing steel at base of member 11



Source: FHWA

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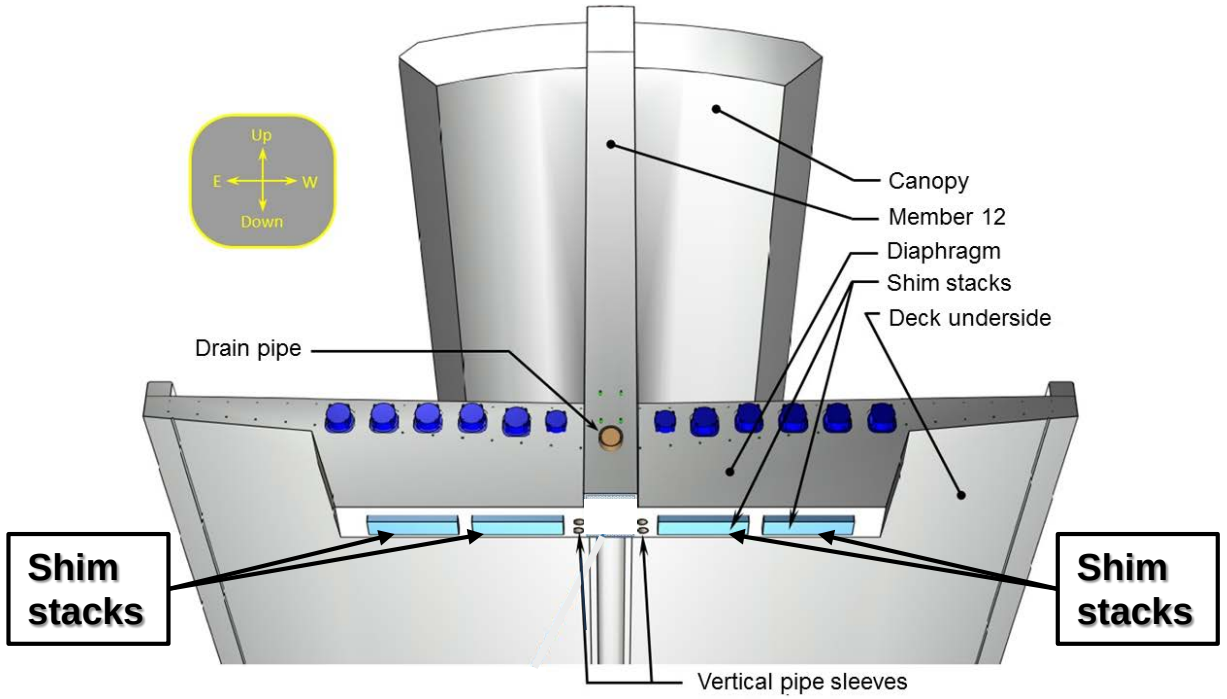
Placement of Main Span on Shim Stacks

- Support configuration changed as bridge moved to permanent piers
- At north end, four shim stacks used
- No shims used directly beneath truss line



Source: FHWA

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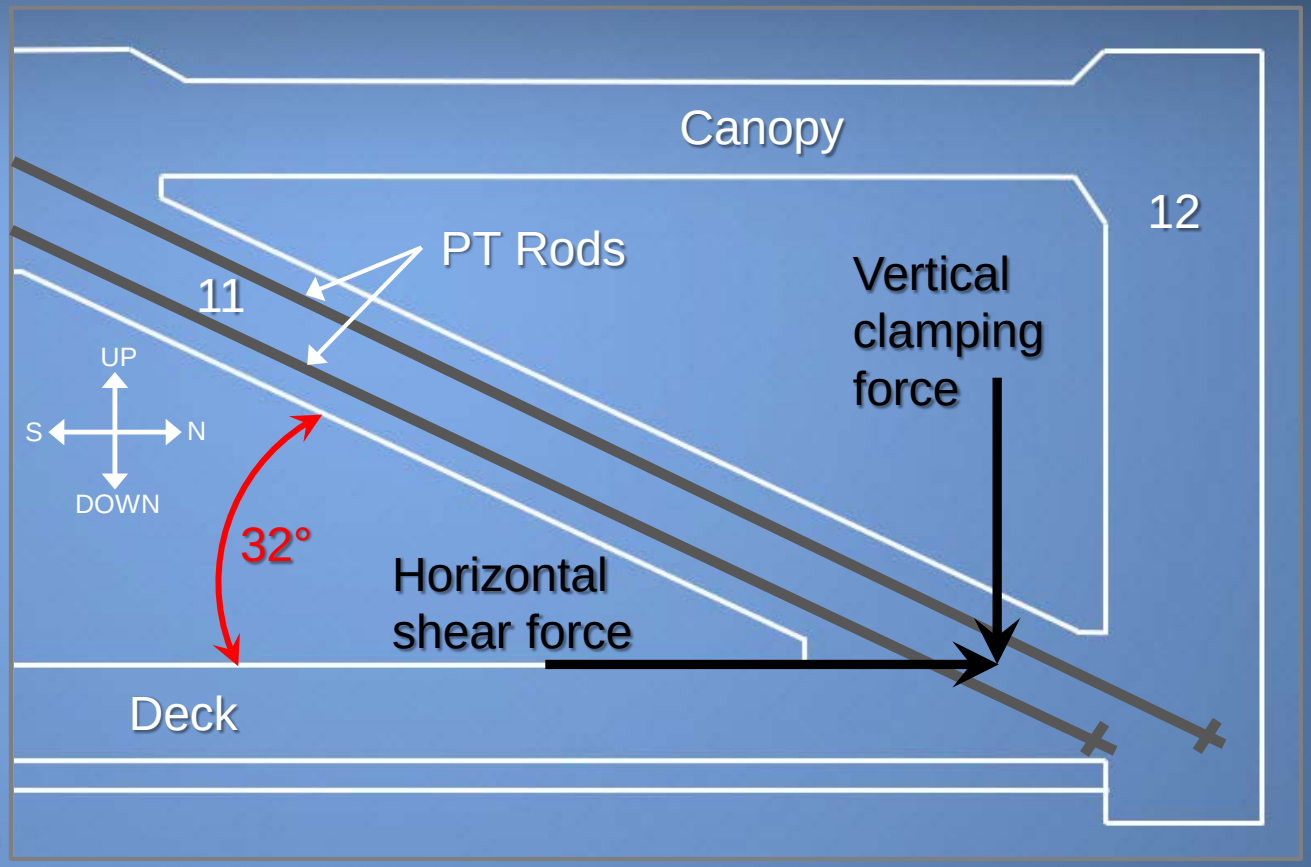
Post-Tensioning Force in Diagonal Member 11

- Post-tensioning purposes
  - Counteracted tensile forces during move
  - Vertical clamping force (beneficial)
  - Horizontal shearing force (detrimental)
- 32-degree angle of member 11 relative to deck
- Magnitude of horizontal force 60% larger than vertical force



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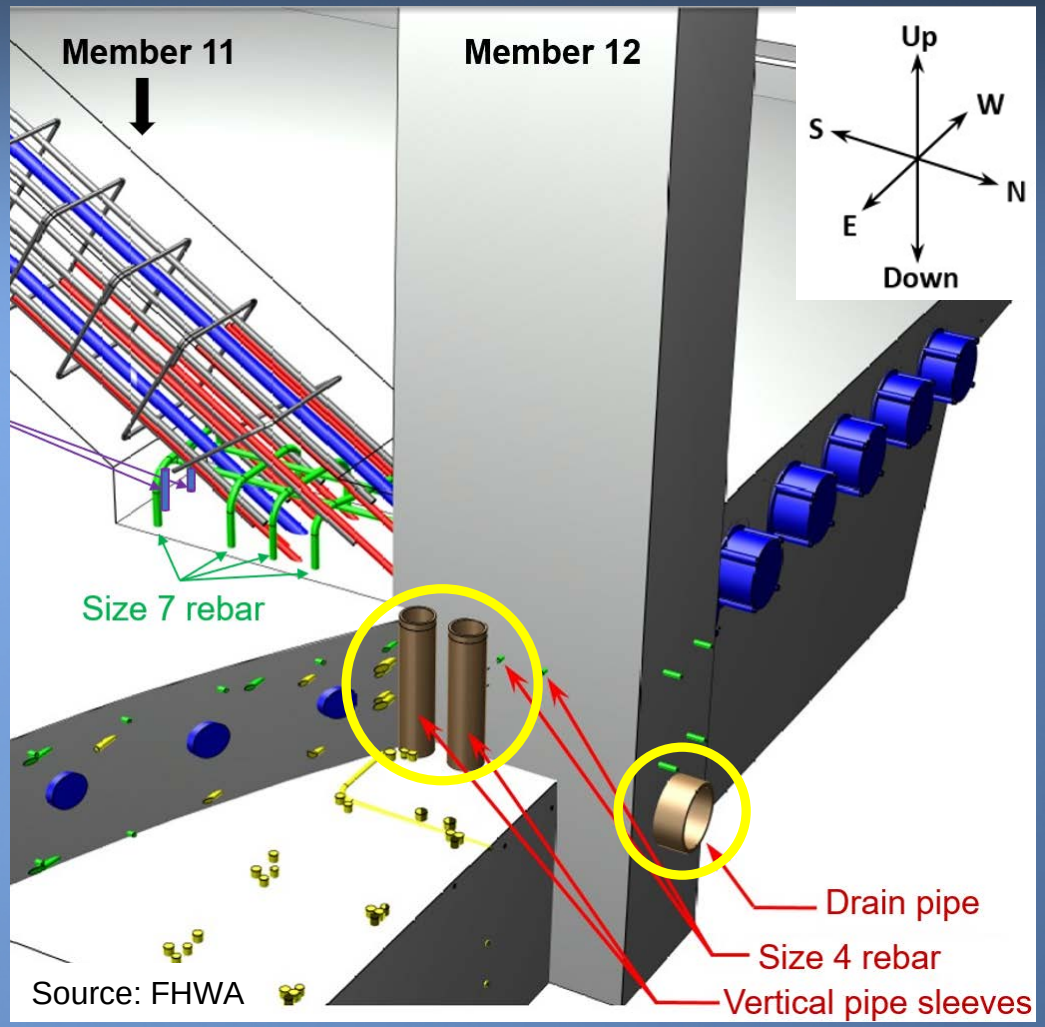
Construction of Node 11/12

- 5 pipes through member 11/12 nodal region
  - Voids in concrete mass
- Surrounding concrete subjected to higher stresses
- Unanticipated redirection of load path
- Placement of steel reinforcement in members 11 and 12 consistent with construction plans



Source: FHWA

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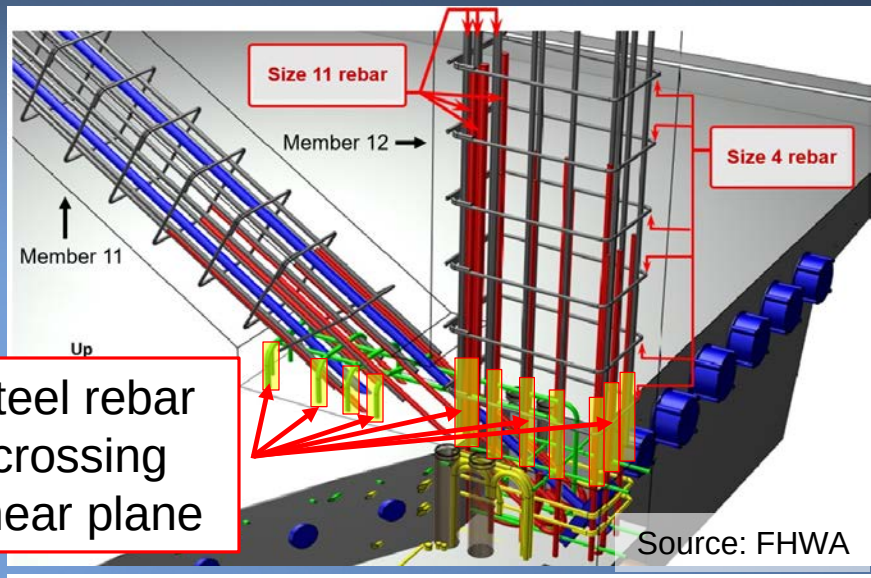
Mechanism Resisting Northward Dislocation

- Two primary mechanisms temporarily resisted northward dislocation
  - Lower portion of member 12
  - Rebar that crossed shear planes under member 11 and beside member 12
- Vertical and confinement reinforcement in member 12
  - Created a column that buttressed load being driven northward



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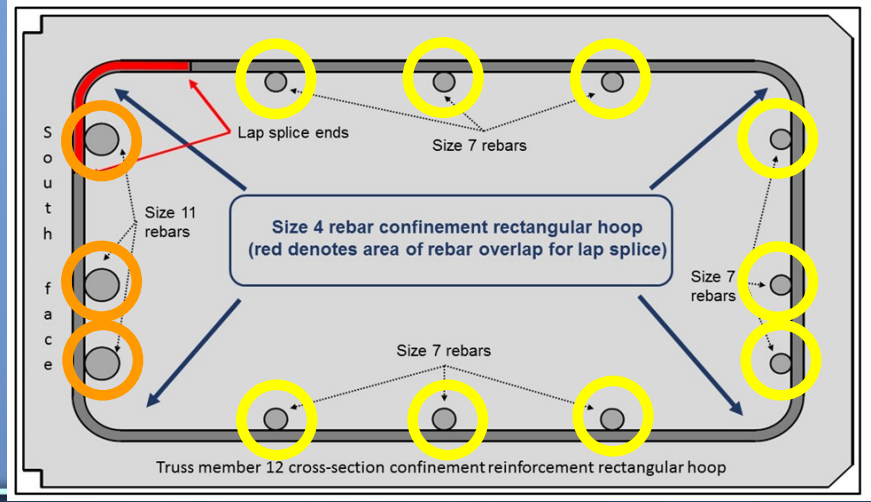

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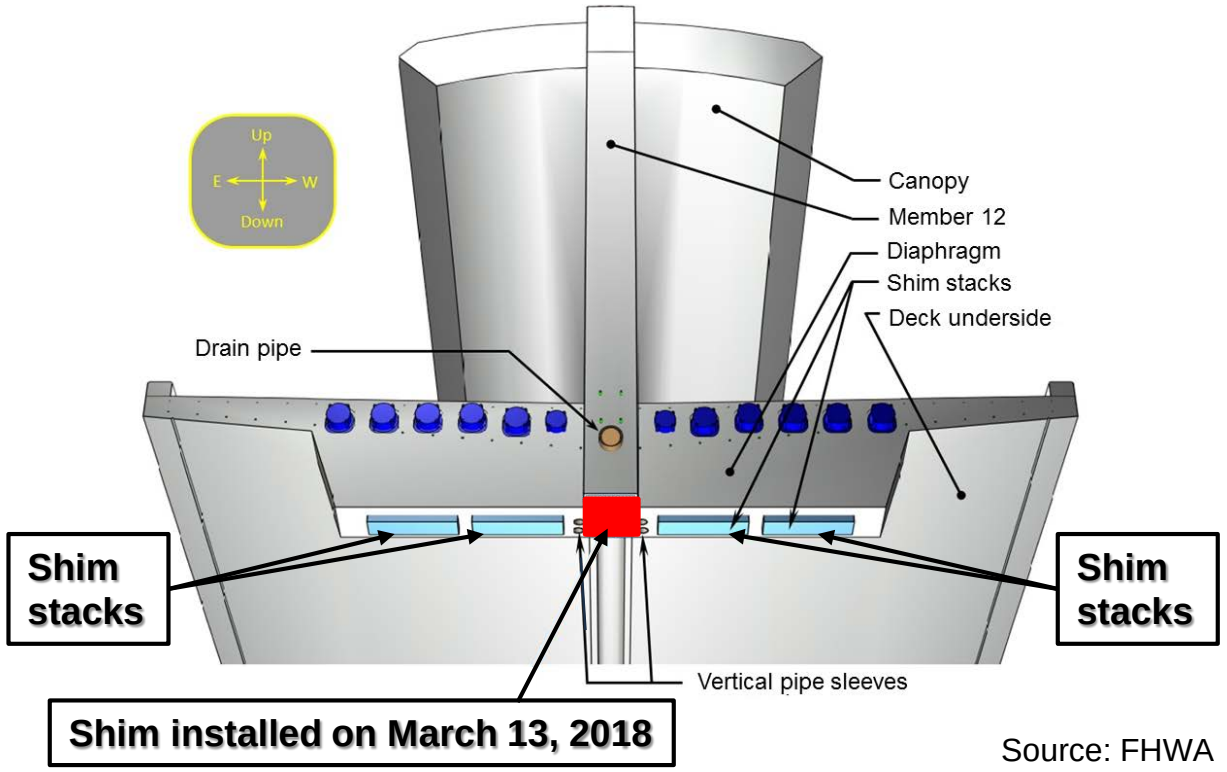
Placement of Main Span on Shim Stacks

- To address cracking, shim was installed on March 13 along bridge centerline
  - Jacking of bridge not required



Source: FHWA

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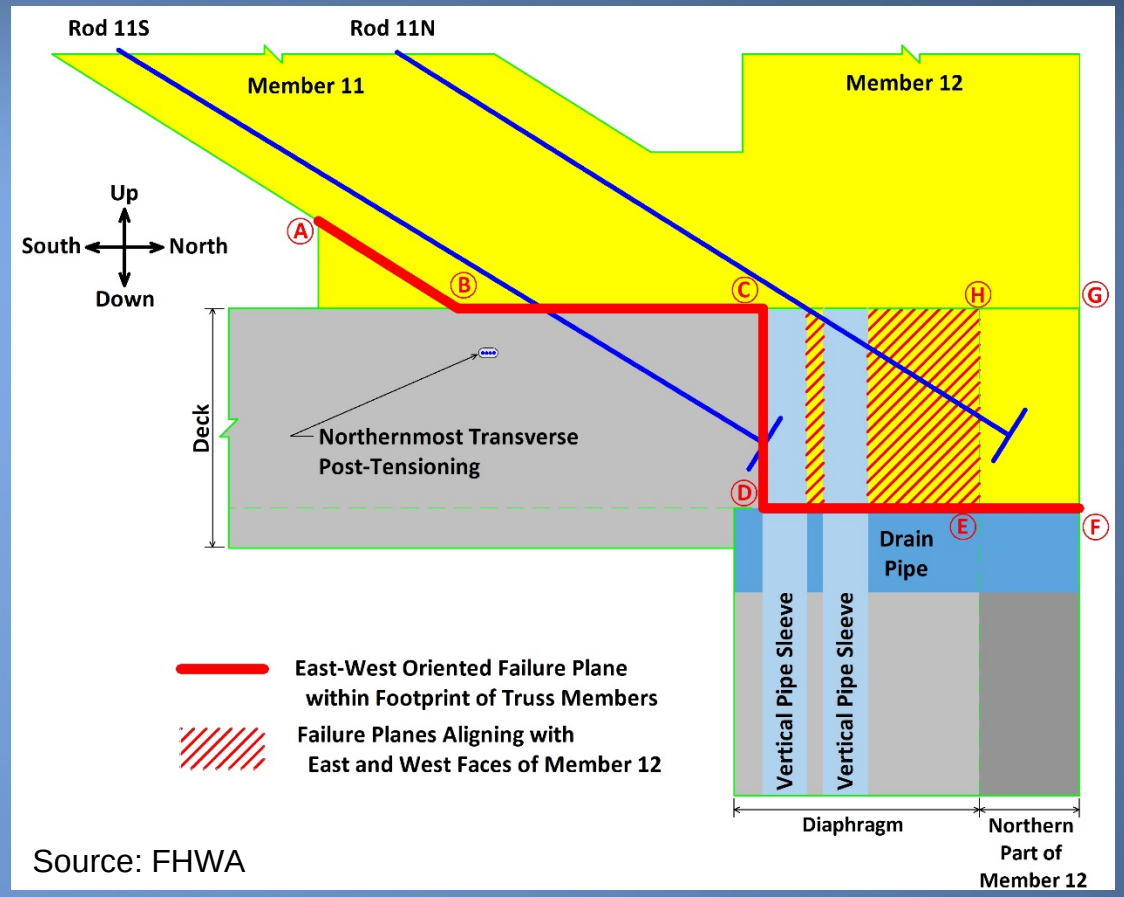
Reapplication of Post-Tensioning in Member 11

- To address distress in structure–
  - FIGG EOR decided to retension member 11 PT rods
  - FIGG EOR intended to return main span to “pre-existing” condition



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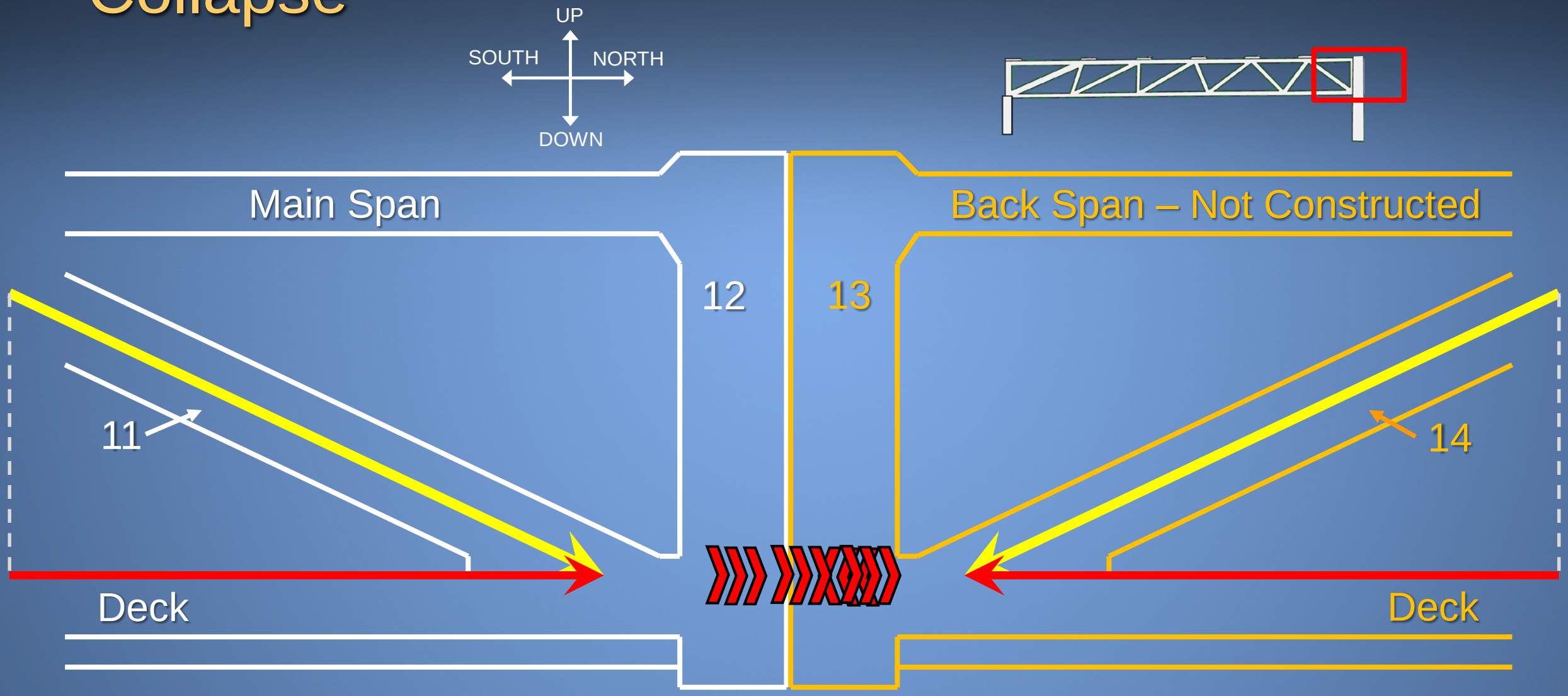
Collapse



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Summary

- FIGG design resulted in less steel reinforcement and diminished resistance to critical interface shear demand
- Member 11/12 nodal region contained pipe sleeves, resulting in void spaces
- Retensioning of member 11 provided additional force across compromised interface shear plane, resulting in collapse of bridge