Delaware River Turnpike Bridge Fracture Repair
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Delaware River Turnpike Bridge Fracture Repair

General Information

Year Built: 1956 (61 years old)

Designed By: George S. Richardson, Consulting Engineer, Pittsburgh, Pa.

Carries: Pennsylvania Extension, Eastbound and Westbound Roadways

Over: PA US Route 13, Amtrak Mainline, 3 Local Roads (North Radcliffe, Wood Avenue, Palmer Avenue), Delaware River, River Road

Traffic: Average Daily Traffic (2014) = 41,551
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Fracture Location

40.118295, -74.834551
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Span Length = 269’
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Fracture as found on 1/20/2017
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PA 4-Span Continuous Deck Truss Unit

Legend: Inspection Focus
- "Jumbo" Tension Member (Flange Thickness ≥ 1 ½")
- "Jumbo" Compression Member (Flange Thickness ≥ 1 ½")
Did the bridge fall?
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U19’-U18’

• Post Yield W14x87 in deformed shape (bowed down).
• Intended to be a near ‘zero force’ member.
• Now a contributor to holding the bridge up.

BRIDGE CLOSED
# Delaware River Turnpike Bridge Fracture Repair

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<td>Owner</td>
<td>Pennsylvania Turnpike Commission</td>
<td>Owner</td>
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<tr>
<td>WSP USA</td>
<td>Design Support</td>
<td>Modjeski and Masters</td>
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<td>Testing</td>
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<td>Consultant</td>
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First Steps
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Immediate Action - Repair Plates Drilled for Splice On-Site

Meatball-surgery... skip the factors of safety and get it spliced quickly.

No Phi, direct shear, no forcing of pieces back together.
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Material Sampling for Testing

Taken Night 1.

Delivered to Lehigh University for testing - 1/21/2017.

- Visual Fractographic Inspection
- Stereomicroscopy and Scanning Electron Microscopy
- Light Optical Microscopy
- Chemical Analysis and Mechanical (CVN and Tensile) Testing
Material Sampling for Testing – early results within days

CVN testing results were inconsistent.


Program later expanded

Mis-drilled holes filled with weld metal and ground smooth – INVISIBLE.
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14 Similar Deck Truss Spans of 31 Total Spans
Bridge Length Potentially Affected: \( \frac{2}{3} \) Mile of 1\( \frac{1}{4} \) Miles Total

PA Approach Deck Truss Spans
- 3 Span Continuous Unit: Piers 10 – 13
  Total Length \( \approx 647' \)
- 4 Span Continuous Unit: Piers 13 – 17
  Total Length \( \approx 1078' \)

NJ Approach Deck Truss Spans
- 3 Span Continuous Unit: Piers 24 – 27
  Total Length \( \approx 647' \)
- 4 Span Continuous Unit: Piers 20 – 24
  Total Length \( \approx 1078' \)
Delaware River Turnpike Bridge

Design and procure fall arrest towers
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Foundation Decision

Micropiles chosen over spread footings

- Smaller footprint
- Ability to hopscotch over utilities
- Lesser excavation when shallow foundation pier motion a suspect cause
- Costs comparable
- Needed a decision now, not later
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Rigs 3 (Left) & 2 (Right) Drilling Tower 3 and 4 Micropile Foundations on 1/28/2017

Move, move, move!

Three drill rigs and tender equipment in an area the size of a football field

24/7 operation

Started slow, picked up after first piles

Not rain runoff, that’s drill mud
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Hydraulic Jacks Installed at Towers 1, 2, 3 & 4 on 2/8/2017, Towers 5, 6, 7 & 8 on 2/11/2017
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Putting the Truss back together
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Repair Decision

New member and new splice

Ultimately decided on a two-stage operation to get there:

• Vertically jack the truss back to geometry
• Horizontally post tension the broken chord back to load

HOPE IT BEHAVES AS PREDICTED. TEST THAT IT PERFORMS.
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Design of Strengthening for Vertical Jacking on 2/10/2017

Jack Point
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Strengthening Installed for Future Jacking on 2/21/2017
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All test sensor instruments on PA approach installed – 2/22/2017

The Game Plan
Detailed ‘playbook’.
Step-by-step instructions.
Call-outs for all parties.
All parties agreed on a ‘dry run’ before actual jacking.
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Mock-Up of Vertical Jacking (Dry Run) on 2/22/2017

Dress Rehearsal

Full run with all staff in position and calling out measurements and learning their roles.

Things did not go well, but all the kinks were identified.

Plans were adjusted accordingly.
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Instrumentation for monitoring behavior during jacking installed – 2/22/2017
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Vertical Jacking
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**Vertical Jacking Completed - 2/24/2017**

**Phase I Vertical Jacking Goal:**
Jack from Towers 3 and 5 on the North Truss adjacent to the fracture in four stages (25%, 50%, 75%, 100%). Each stage with 7 to 8 increments of 100 psi before eventually reaching the final goal of 2900 psi.

Towers 1, 2, 4, 6, 7, and 8 to maintain jacking pressure of 100 psi throughout the entire jacking process.

Stage 1: Snugging of Jacks
Stage 2: Removal of Stabilization Splice
Stage 3*: Vertical Jack to 25%
Stage 4*: Vertical Jack to 50%
Stage 5*: Vertical Jack to 75%
Stage 6*: Vertical Jack to 100%

* Each stage had 7 to 8 increments of 100 psi, eventually reaching the final goal of 2900 psi.
What happened

Towers 3/4/5/6 ran heavy on load. Other jacks ran light

Target vertical displacement achieved

Truss models made for ‘fixed’ and ‘pinned’ end configurations – ‘fixed’ was closer to actual

Sensors used to track elastic behavior, displacement measurement governed (tape measure)
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Vertical Jacking Completed - 2/24/2017

Result

Stabilization splice was successfully removed.

Tower 3 and Tower 5 were successfully jacked to an acceptable height increase of 1.44".

This height was determined through Class 1 incremented readings at every 100 psi at every tower during every stage.
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Horizontal Post-Tensioning
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Replacement chord delivered and installed – 2/27/2017

PT brackets installed – 2/28/2017
All instrumentation functioned properly.

For North truss members, models over-predicted the stress by 30%.

For South truss, there was very little stress relief.
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Post-Tensioning - Completed 3/3/2017

The target load of 1500k was achieved in the system. Panel point restoration displacement of approximately 1.375” agreed with lower bound model expectations of 1.3”, but failed to meet the ‘As-Built’ dimension restoration goal of 1.8”. 7% losses during the force transfer
Field Evaluation after PT - 3/3/2017

Secondary members shifted back nearly to the original position

Stringer Bearings - After Fracture, Before Jacking

Stringer Bearings - After Jacking
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**Other repairs**

Channel strengthening of U18’N-U19’N member – 3/6/2017

Bowed member with repairs

Deformation in bowed member
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Load Testing
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Load Test, NJ 4-Span Continuous Deck Truss Unit on 2/8/2017
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PA Load Test Conducted – 3/7/2017

Executed using up to eight overloaded triple-axle dump trucks placed for maximum moment and shear effect directly over top of the repaired north truss adjacent to the point of fracture. This loading was deliberately in excess of what would otherwise be required by current AASHTO Manual for Bridge Evaluation guidance.

The load testing indicated that the truss responded in a linear and elastic fashion with no noted post-yield behavior. The total strain rates carried by the repaired truss were compared to its companion truss on the New Jersey approach side. The total strain rate results correlate well and suggest both trusses behave similarly for flexure and are sharing lateral live load distribution between the south and north trusses.
Strengthening removed – 3/7/2017

Jacks removed and stools reinstalled (not in contact with bridge) – 3/8/2017
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PT brackets removed – 3/9/2017
Radcliffe Street reopened – 3/9/2017
Bridge reopened at 10:30 PM – 3/9/2017

New member and new splice – Final Installation with PT bracket removed
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Non Destructive and Destructive Testing
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Non-Destructive Testing - Ultrasonic Testing

Phase 1 - Sample Areas Near Connections, at:

- 11% of critical 4-Span continuous deck truss unit members
- 8% of critical 3-Span continuous deck truss unit members

‘If we find stuff, we keep going’
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Non-Destructive Testing - Ultrasonic Testing

- Phase 2 - Area near all remaining end connections in deck truss unit members
- Phase 3 - Full length of approx. 40 critical deck truss unit members
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Material Sampling and Testing - Phase 2: Other Members, 4” Dia. Samples
Material Sampling and Testing - Phase 3:

Eastern and Western stubs of fractured chord extracted – 2/26/2017

Fractured chord saved for more testing

Lehigh advancing
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[Diagram showing a timeline with stages of repair including:
- Fractured Truss Discovered
- Stabilization Splice Installed
- Painting Containment Clean-up and Removal
- Micropile Construction
- Stabilization Towers Erected
- Jacks, Saddles and Truss Strengthening Installed
- Vertical Jacking, Stabilization Splice Removed
- Member Removal, New member and P-T Installed
- Horizontally Truss Post-tensioning
- Permanent Splice Installed, P-T Depressurized
- Preparations for Likely Reopening
- Bridge re-opened
- Bridge Reopened
- Tower and Appurtenance Removal, Add'l Bridge Repairs, Site Restoration]
Lessons Learned

1. Dynamic impact effect from fracture is typically expected at 1.5x the force in the member. Analysis suggests 2.0 is more appropriate.

2. Bridges built before modern quality control often have questionable quality. 75 year service life may not be practical.

3. Truss bridges are unpredictably flexible in some spots and rigid in others. The truss sagged, but was still more than 30% stiffer than our stiffest models.

4. Quality procedures. There’s plenty of time to do it right if you don’t have to do it twice.

5. A tape measure made the final call every time. Don’t overcomplicate it.

6. Our intricate plans worked great, but we weren’t afraid to change them on the fly.

7. Stakeholders

8. Every written document is discoverable.

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