Investigation into the March 15, 2018 Pedestrian Bridge Collapse in Miami, Florida

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Safety issue areas

- Mechanisms of structural failure
- Evaluation of structural distress
- Bridge design errors
- Independent peer review of complex bridge design
- Redundancy guidelines for pedestrian truss bridges
Introduction and Evidence Testing
Location of FIU Pedestrian Bridge
Bridge Design Concept

Source: FIU, annotated by the NTSB
Pedestrian Bridge Main Span

- Truss members
- Canopy
- Deck
- Pylon diaphragm
- South diaphragm
- Pylon pier
- South pier
- SW 8th Street Westbound Lanes
- SW 8th Street Eastbound Lanes
Collapse and Injuries

March 15, 2018
Animation
Large On-Scene Evidence Collected

- Canopy blister 10/11
- Member 11
- Member 12
- Deck at node 11/12
Evidence from Node 11/12 in Deck
Steel PT Rods and Reinforcement Bars
Evidence Collected
TFHRC Materials Testing Results

• Concrete
  - Tested compression strength
  - Examined internal structure
  - Evaluated tensile behavior

• Steel PT rods and reinforcement bars
  - Tested yield and tensile strength, percent elongation
  - Analyzed chemical composition of PT rods

• All material specimens were within specifications
Mechanisms of Structural Failure
Background – Axial and Component Forces

Axial Force (Compression or Tension)

Canopy

Deck

10

11

12

UP

NORTH

SOUTH

DOWN
Background – Axial and Component Forces

Clamping Force

Shear Force

Canopy

Deck

Cold Joint

SOUTH

NORTH

UP

DOWN

10

12
First Signs of Structural Distress

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

Node 11/12

Crack found at the intersection of truss member 11 with the deck

Source: MCM
First Signs of Structural Distress

- Portion of crack bypassed 25% of reinforcing steel at base of member 11
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
Observed Distress in Member 11/12 Nodal Region

• Cracking consistent with:
  - Interface shear along connection between member 11 and the deck
  - Punching shear surrounding base of member 12
  - Flexural cracking on north face of member 12
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
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
Evaluation of Structural Distress
Cracking in Member 11/12 Nodal Region

- Structure showed notable cracking of reinforced concrete
- Extensive and large cracks in member 11/12 should have been recognized as abnormal
  - Cracks up to 0.016 inch wide – considered acceptable
  - Structural cracks in bridge were up to 0.75 inch wide; > 45 times larger than typically acceptable
- Scale of cracking clear indication that load-resisting mechanisms were failing
FIGG Remedial Plan

• On March 15, 2018, FIGG presented a remedial plan to retension member 11
  - Not shown on FIGG design plans
  - Post-tensioning inspection contractor was not on site

• Retensioning was a change to design plans
  - Main span supported in a different manner
  - Severity of cracks in member 11/12 nodal region had worsened
  - Should have been internally and peer-reviewed by a P.E.
FIGG’s March 15 Presentation

- FIGG EOR stated there was not any concern with safety of the span suspended over the roadway.

Source: FIGG Bridge Engineers - - Slide 11 from presentation on March 15, 2018
FIGG’s March 15 Presentation

- FIGG EOR stated they could not replicate observed distress by analysis & classified observed distress as minor.

Conclusions and Recommendations

- The diagonal type cracks, in excess of FDOT criteria, should be sealed with approved methods and materials (Epoxy injection, etc.)

- The spalled areas have not been replicated by the engineering analyses. However...

- The spalled areas are minor and it is recommended that they be prepared using normal procedures and poured back along with the upcoming “pylon diaphragm” pour (different from and prior to the back span on falsework pours)

Source: FIGG Bridge Engineers - Slide 48 from presentation on March 15, 2018
Responsibilities and Authorities Among Parties

• FIU, FDOT, FIGG, MCM, and Bolton Perez were aware of the cracks and their progression

• Remedial work as FIGG presented at meeting on March 15
  - Placing workers on structure without identifying failure origins

• Bolton Perez could have authorized work to be suspended, acting collectively with FDOT and FIU

• FIU, FDOT, FIGG, MCM, and Bolton Perez had implied authority to stop bridge work
  - Did not act on that authority
Bridge Design Errors
Location of Pedestrian Bridge Failure

Concrete blowout

12 11

SW 8th Street
FIGG’s Demand Models

Source: FIGG, annotated by the NTSB
Exclusive use of results from one model resulted in underestimation of demand at several nodal regions.
Comparison of FIGG & FHWA Modeling Results

Underestimation of demand at critical nodal regions
Simple Calculation to Approximate Horizontal Shear from Dead Load

Bridge Weight ≈ 1,900 kips

≈ 950 kips

\[
F_{11y} = (F_{11}) \sin(32°) \approx 950 \text{ kips}
\]

\[
F_{11x} = (F_{11}) \cos(32°)
\]

(Horizontal Shear)

\[
F_{11} \approx \frac{950 \text{ kips}}{\sin(32°)} \approx 1,793 \text{ kips}
\]

Solve with Basic Statics & Trigonometry

\[
F_{11x} \approx (1,793 \text{ kips}) \cos(32°) \approx 1,520 \text{ kips}
\]

(Horizontal Shear from Dead Load ONLY)

For simplicity assume Member 12 = 0 kips

Vertical Component Must = 950 kips

Construction Joint

950 kips
Demand Errors

- Vertical component is compressive or clamping force
- Horizontal component is shearing force on the interface shear surface
- **CONCLUSION**: Significant underestimation of demand at the 11/12 nodal region.

<table>
<thead>
<tr>
<th>Model</th>
<th>Shear Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIGG’s fixed support model</td>
<td>978 kips</td>
</tr>
<tr>
<td>FHWA check</td>
<td>1,835 kips</td>
</tr>
</tbody>
</table>

1 kip = 1,000 pounds

Source: FHWA, annotated by the NTSB
Release for Construction (RFC) Plan Omission

- RFC plans failed to direct contractor to construct concrete interface surface in a manner that enhances the structural performance of the connection (intentionally roughened to 1/4-in amplitude).

- Standard concrete surface preparation procedures were specified which did not supply the enhanced structural performance assumed in the design.
Capacity Errors

• Permanent compressive loading, $P_c$, and amount of reinforcing steel

• Load factor = 0.90 (conservative estimate)

• Load factor = 1.25 (non-conservative estimate, used in FIGG design)

• **CONCLUSION:** Significant overestimation of capacity at the 11/12 nodal region with insufficient reinforcing across the interface shear surface
Independent Peer Review of Complex Bridge Design
FDOT Requirements for Peer Review

• FDOT requires an independent peer review for all complex structures (FDOT Design Manual)

• FIU pedestrian bridge was identified as a complex structure

• FDOT independent peer review is expected to be a comprehensive, thorough independent verification of the original design work
Louis Berger Peer Review

- Louis Berger performed the independent peer review for the FIU pedestrian bridge
- Louis Berger’s review was inadequate and did not meet FDOT’s requirements
- Independent peer review focused on the general bridge performance in its final (completed) stage
  - Not the different stages of construction and design of critical connections
Redundancy Guidelines for Uncommon Bridges
Bridge Redundancy

- FIU bridge single row of diagonal supports
  - Each member was nonredundant
- Exemplar redundant steel truss bridge
- Concrete truss bridges are rare
  - Research found no other designs
- Truss bridges typically constructed of steel
FIGG’s Interpretation of Redundancy

- Redundancy can be provided
  - Load path redundancy
  - Internal redundancy
- FIGG believed pedestrian bridge was redundant
  - Internal redundancy – longitudinal and transverse tendons, including PT rods
- Lack of load path redundancy
Need for National Guidance

• AASHTO LRFD Bridge Design Specifications
  - Addresses redundancy in design of steel truss structures
  - Limited discussion of redundancy for concrete structures

• No discussion of redundancy in AASHTO LRFD Pedestrian Bridge Specifications
NTSB Final Report and Public Docket

- NTSB Final Report
  https://ntsb.gov/investigations/AccidentReports/Pages/highway.aspx
  - Conclusions, Probable Cause, and Recommendations

- NTSB Public Docket https://dms.ntsb.gov/pubdms/
  - Search for Accident ID HWY18MH009
  - Factual reports, attachments, witness statements, and photographs