Pedestrian Bridge Collapse Over SW 8th Street, Miami, Florida

March 15, 2018

This digest of the National Transportation Safety Board's (NTSB's) Accident Report **NTSB/HAR-19/02** contains a description of the collapse, its probable cause and safety issues, and the safety recommendations in the full report. This digest is not intended to supersede the full report, and in the event of any contradiction or apparent contradiction, the full report is the NTSB's definitive publication on the collapse. The full report and docket can be found at **www.ntsb.gov.**

NTSB | National Transportation Safety Board

Illustrated Digest

The NTSB is the independent federal agency tasked by Congress with investigating highway, marine, rail, pipeline, and civil aviation accidents, determining their probable causes, and making safety recommendations aimed at preventing future accidents.

SPC-20-02

The collapse

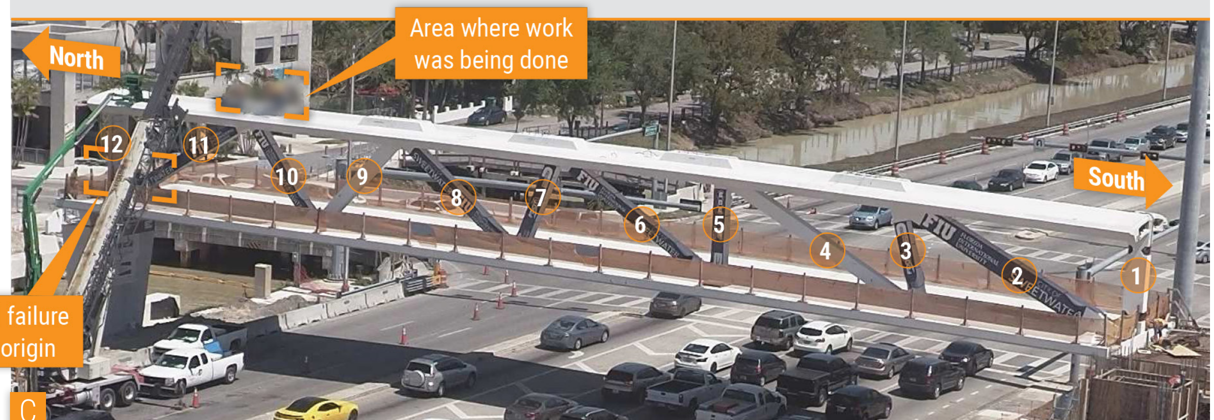
On Thursday, March 15, 2018, about 1:46 p.m., a partially constructed pedestrian bridge in Miami, Florida, experienced a catastrophic structural failure in the nodal connection between truss members 11 and 12 and the bridge deck (*see photo C at right*). The 174-foot-long bridge span fell about 18.5 feet onto SW 8th Street, an eight-lane roadway. Two of the westbound lanes below the north end of the bridge were closed to traffic at the time of the collapse; however, one westbound lane and all five eastbound lanes were open. The collapsing bridge fully or partially crushed eight vehicles, and killed one bridge worker and five vehicle occupants. Five bridge workers and five other people were injured.

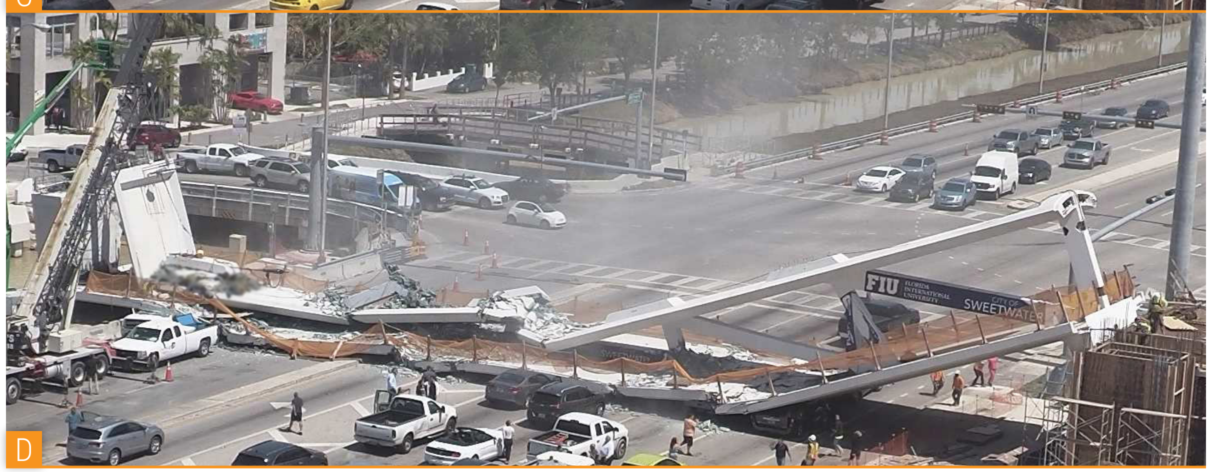
The bridge was part of the Florida International University (FIU) University City Prosperity Project. On the day of the collapse, a construction crew, redacted in photos (C) and (D), at right, was retensioning the post-tensioning (PT) rods within member 11, one of the northernmost of the 12 truss members connecting the bridge canopy and the deck.

The bridge span in this area already had extensive concrete cracking that had progressed significantly in the several days before this work was performed. These cracks were a clear indication that the structure's intended load-resisting mechanisms were failing. The engineer of record (EOR), who worked for FIGG Bridge Engineers (FIGG), stated later that the PT rods in member 11 were being retensioned to return the bridge to a "pre-existing condition."

But there was no way that this severely cracked bridge could be returned to a pre-existing condition through retensioning—the severity of these cracks indicated that the steel reinforcement was already yielding or fracturing and the concrete had lost some structural strength. Although intended to be a remedial action that would return the bridge to a previous state, retensioning the rods located within member 11 increased demand on, and damage to, the member 11/12 nodal region until the distress became critical.

The bridge was built in stages (A) in a casting yard adjacent to SW 8th Street. (*See* The ABCs of ABC, *page 9*). On **March 10**, it was moved on self-propelled modular transporters (SPMTs) onto its support piers (B). On **March 15**, an FIU parking garage camera captured the bridge precollapse (C) and postcollapse (D). (*See* From cracks to collapse, *page 9*).





FIU pedestrian bridge project

The roles of the main participants in the bridge project are described below. (*See also* **Bridge project timeline**, *p. 6*).

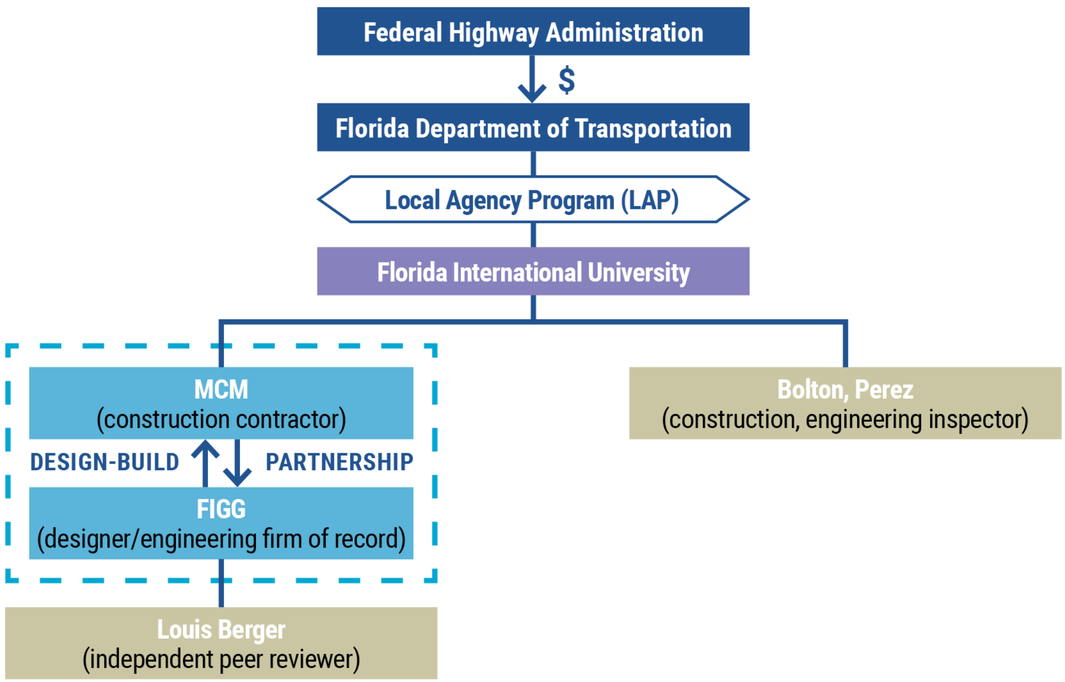
FIU entered into a design-build contract with Munilla Construction Management (**MCM**) to construct the bridge, and a standard professional services agreement with Bolton, Perez and Associates Consulting Engineers (**Bolton, Perez**) to administer, monitor, and inspect the bridge as it was constructed.

MCM, the design builder, entered into a standard form of agreement with **FIGG**, the design consultant, to provide professional design and engineering services that included final design, released-for-construction (RFC) drawings, and specifications associated with the bridge, including that FIGG would serve as the EOR.

FIU coordinated each of these contracts with the Florida Department of Transportation (**FDOT**) and the Federal Highway Administration (**FHWA**) because federal funds were being expended, and FDOT had oversight, on this project. Further, although FDOT had delegated its project oversight to FIU, when issues arose, FDOT was called in to consult. (See NTSB/HAR-19/02, available at www.ntsb.gov.)

FIGG entered into an agreement with the firm **Louis Berger** to perform an independent peer review of the bridge plans, as required by FDOT, which required that the design, including calculations, be independently verified to ensure that the bridge had sufficient capacity to support itself and anticipated loading. Neither Louis Berger U.S., Inc., nor its predecessor—Louis Berger Group, Inc.—was qualified by FDOT for this type of complex concrete bridge design work.

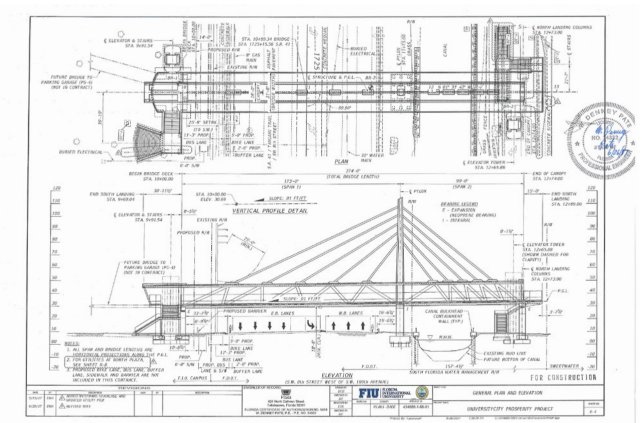
Simplified FIU project organizational chart. Not all entities and subcontractors are shown.



As the lead partner, FIGG was responsible for managing the design team and for acting as the single point of contact with MCM. FIGG was responsible for completing the final structural design and preparing contract documents, including analysis and design of the bridge superstructure, substructure, and foundations related to the final construction contract documents. FIGG was also responsible for making sure the bridge design met required design specifications and state structural design guidelines.

The engineer of record

FIGG was the engineering firm of record, and, as such, employed the EOR. As Florida law states, the EOR is "a Florida professional engineer who is in responsible charge for the preparation, signing, dating, sealing and issuing of any engineering document(s) for any engineering service or creative work." The other parties deferred to the experience and recommendations of the EOR.



A "General Plan and Elevation" drawing from the set of "released for construction" plans showing the proposed structure, bearing the seal and signature of the EOR.

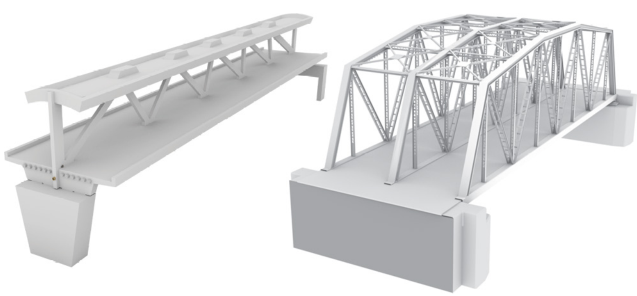
The bridge on the day of the collapse

Nomenclature
The main span included 12 truss members aligned along the structure's centerline. Truss members were numbered (1) through (12) from south to north. A node is a connection between truss members and the deck or canopy.

Unique, complex bridge design

The bridge design included a concrete deck and a concrete canopy connected by a single row of concrete diagonal and vertical truss members, which extended down the center of the bridge. (See ***The bridge as designed***, *page 5*.)

Concrete truss bridges are rare; truss bridges are typically constructed of steel, which can more effectively carry both compressive and tensile forces. NTSB research found no other concrete truss bridge designs similar to the pedestrian bridge.



Above: ***Nonredundant*** FIU pedestrian bridge main span (left) and exemplar ***redundant*** steel truss bridge (right).

A non-load-path-redundant structure has fewer load paths than necessary to maintain stability following the failure of one or more critical components, likely resulting in collapse of the structure. With truss members in a single plane along its centerline, this bridge was not a load-path-redundant structure.

Calculation errors

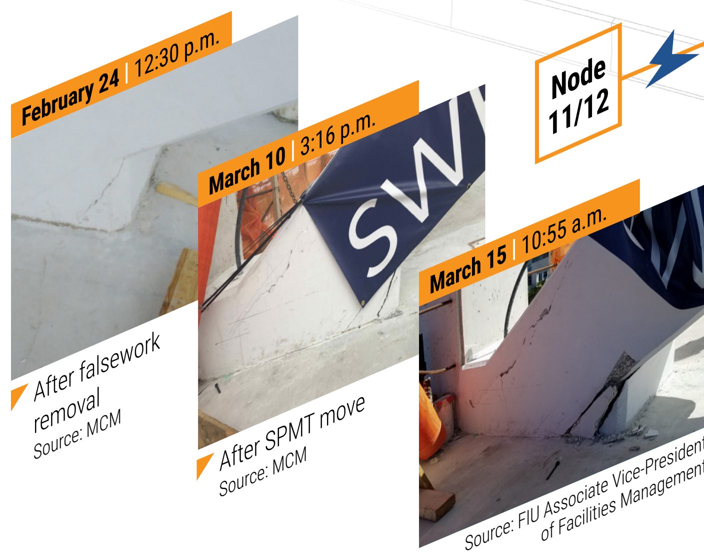
FIGG's bridge design calculations resulted in a significant overestimation of capacity and underestimation of demand—in particular, interface shear demand at critical nodes. (*See* **Internal forces and structural failure**, *pages 6–7*.)

Structural distress

Some cracking is normal in concrete. However, by the day of the collapse, the cracks in the member 11/12 nodal region were more than 45 times wider than is considered generally acceptable for reinforced concrete structures. Representatives of MCM, FIGG, FIU, FDOT, and Bolton Perez could have stopped work or closed SW 8th Street underneath the bridge; none did.

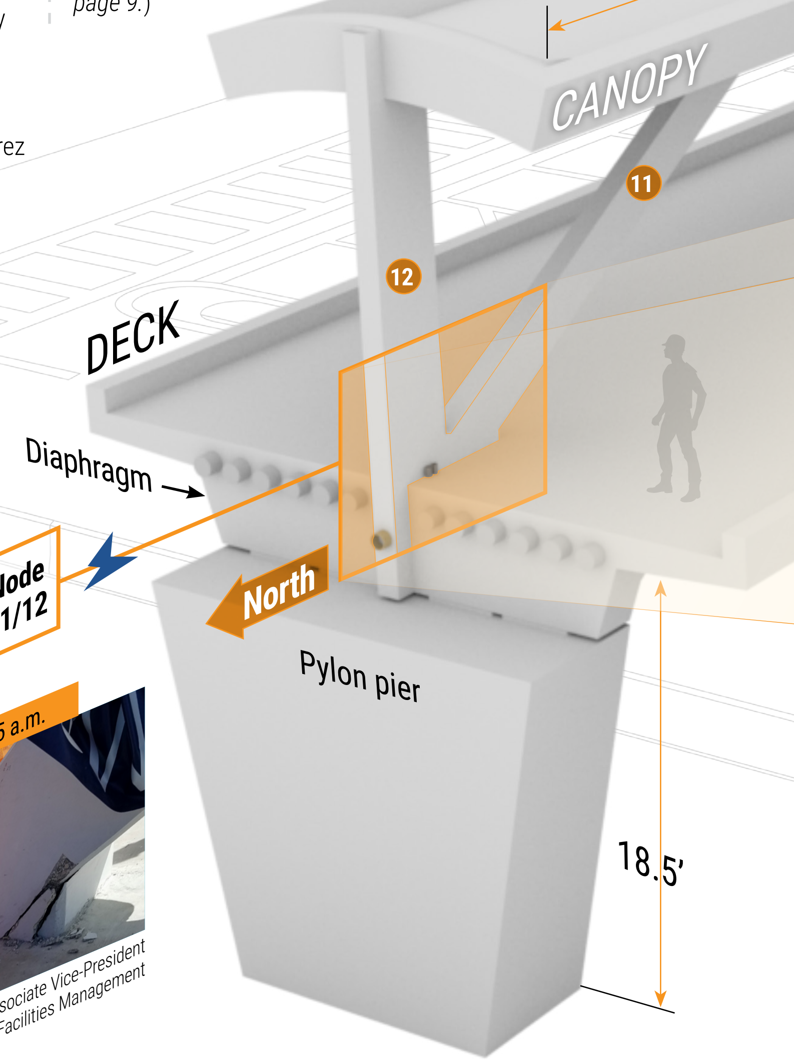
Cracking was first documented weeks before the collapse. (*See* **From cracks to collapse**, *page 9*.) The cracking became markedly worse immediately after the detensioning of member 11 on March 10.

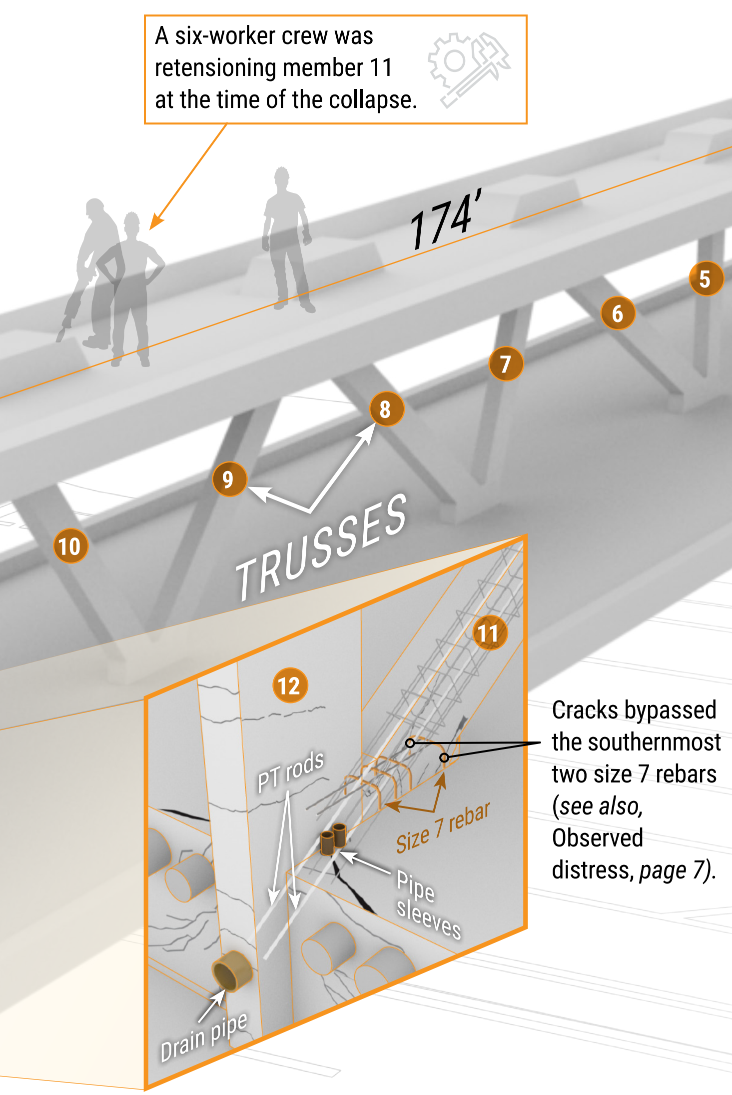
Cracking and spalling continued to worsen over the following days, with node 11/12 further dislocating to the north, until the bridge collapsed on March 15.



Retensioning member 11

On the day of the collapse, without the required independent peer review, FIGG attempted a remedial action: retensioning member 11. The demand that the retensioning placed on the node, in conjunction with the existing forces already on the node, resulted in the failure of the member 11/12 nodal region. (*See* **From cracks to collapse**, *page 9*.)





Cold joint surface of nodal region 11/12

The bridge design plans—with phased concrete placement—resulted in cold joints between concrete pours at the top and bottom of each truss member. A cold joint is a discontinuity where one layer of concrete reaches final set (hardens) before subsequent concrete is placed. According to the American Association of State Highway and Transportation Officials' specifications on load and resistance factor design, the *LRFD Bridge Design Specifications* (*AASHTO LRFD*), cold joints may be roughened to an amplitude of 0.25 inches to qualify for an advantageous design factor. Such roughening was required for this bridge. Intentionally roughening the cold joint would have improved resistance to shearing forces, but even then, node 11/12 would not have had sufficient capacity to counteract the demand load for interface shear—and the bridge would still have been under-designed and could have failed. (*See* Internal forces and structural failure, *pages 6–7*.)

Not enough rebar in node 11/12

Because of FIGG calculation errors, too little steel rebar was embedded in the concrete between the base of member 11 and the deck. In addition, the structural crack that began forming on February 24 (*see inset photo,* February 24, *page 4*) passed above the two southernmost size 7 rebars. So, a portion of the crack, which became a failure point, bypassed 25 percent of the reinforcing steel that was intended to offer interface shear resistance at the base of member 11. (*See* Structural distress begins in the casting yard, *page 6*.)

Voids in node 11/12

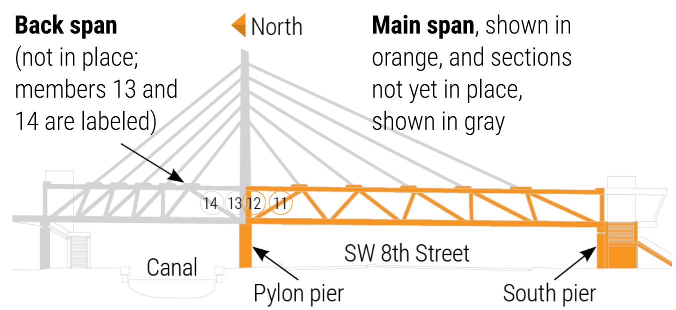
The main span structure included nonstructural elements (hollow pipes) within the concrete. These hollow pipes passed through the member 11/12 nodal region and acted as voids within the concrete mass. The voided areas exhibited a lower stiffness than concrete and were less able to resist applied loads than a monolithic concrete region. The member 11/12 nodal region's nonstructural voids made it less able to resist applied loads, which contributed to the destabilization of this node through overstress and the subsequent collapse of the main span.

The bridge as designed

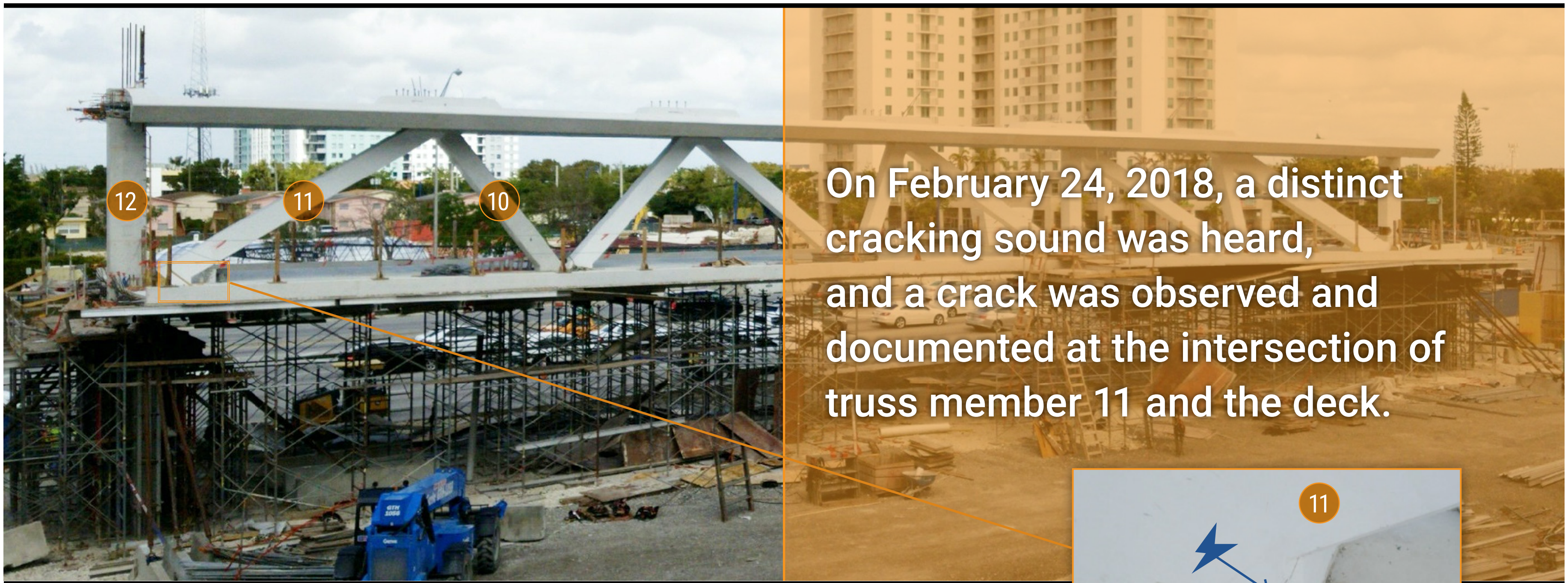
The FIU pedestrian bridge collapsed before construction was finished. Although designed to look like a cable-stayed bridge, it was, in fact, a nonredundant, single-load-path, concrete truss bridge. The section under construction that collapsed extended 174 feet from the the south pier to the pylon pier, with an elevated walking deck 18.5 feet above SW 8th Street. The overall bridge design also included a 99-foot back span that had not yet been constructed. This back span was part of the overall bridge design and was designed to connect to the main structure from the pylon pier at member 12, over the Tamiami Canal, ending at the north pier.

The back span that was never built

Although the design should have allowed member 11 to resist the shear forces on its own, additional resistance could have been provided later in the construction sequence. Once the back span had been built, the horizontal force component from diagonal member 14 would have been pushing south toward vertical members 13 and 12, helping counteract or resist the northward force in truss member 11 at the 11/12 nodal region.



Because the back span had not yet been constructed, however, **the northward shear force caused by the structure's self-weight and the retensioning of member 11 was able to push through the bottom of member 12 and the diaphragm,** causing the bridge to collapse.

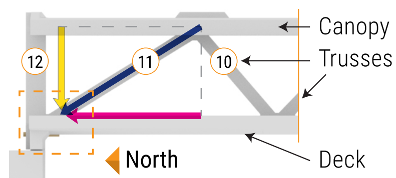


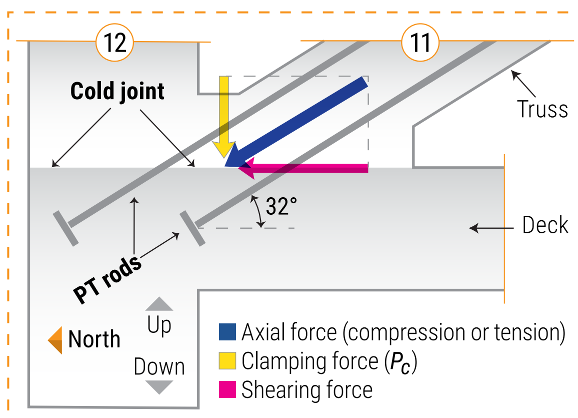
Internal forces and structural failure

Axial and component forces

In this bridge, the vertical, or downward, component force provided a clamping effect across the cold joint between member 11 and the deck. The horizontal, or northward, force provided a shear force at the cold joint, pushing the bottom of member 11 toward the north. Unique to node 11/12:

- PT rods generated vertical clamping force and horizontal shear force
- 32-degree angle produced 60 percent larger horizontal shear than vertical clamping force





Structural distress begins in the casting yard

Because of the errors in FIGG's design calculations, the total amount of reinforcing steel needed was underestimated. Only a 4.8-square-inch, cross-sectional area of reinforcing steel was resisting the northward shear force pushing the bridge deck. An additional 13-square-inch cross-sectional area of reinforcing steel in the interface shear reinforcement area should have been provided.

On February 24, 2018, a distinct cracking sound was heard, and a crack was observed and documented at the intersection of truss number 11 and the deck.

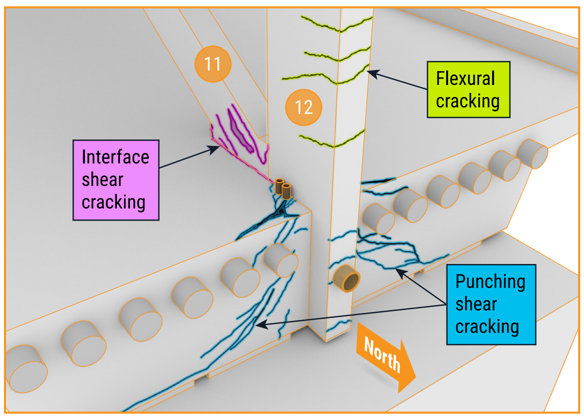
The early cracking at this node under partial loading aligns with the significant overestimation of capacity assumed by FIGG. (*See* **Not enough rebar in node 11/12**, *p. 5*.)

Observed distress

The growing structural cracks were clear signs that the bridge was in distress and failing. (*See* **From cracks to collapse**, *page 9*.) On March 10, the span was moved from the casting yard, on SPMTs, to its support piers. Then post-tensioning in member 11 was removed, and the concrete distress previously observed in the 11/12 nodal region immediately and significantly increased.

The cracking demonstrated three types of structural failure:

- cracking consistent with an inadequate interface shear connection between the bottom of member 11 and the deck
- cracking consistent with punching shear surrounding the base of member 12 due to the nodal region beginning to push northward from the bridge deck
- flexural cracking on the north face of member 12, also due to the nodal region beginning to dislocate from the bridge deck

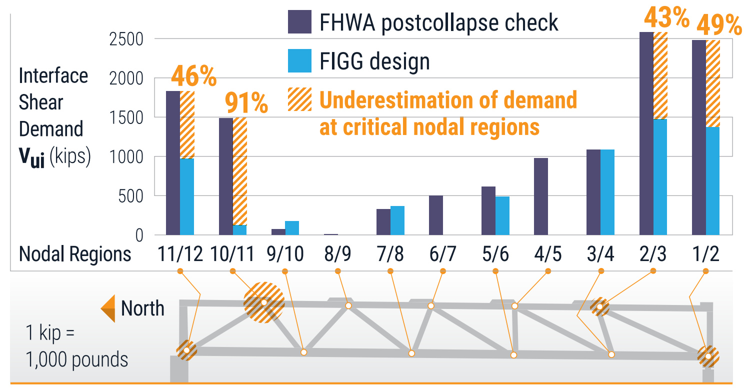


The five hollow pipes within the 11/12 nodal region and diaphragm acted as voids within the concrete mass, subjecting the surrounding concrete to higher stress concentrations and the unanticipated redirection of the load path.

The shear plane under member 11, and the lower portion of member 12—a vertical column from the diaphragm to the canopy—temporarily resisted the northward dislocation of the node. Ultimately, however, the bridge collapsed. The demand placed on the 11/12 nodal region simply exceeded the capacity of the structure.

Bridge design errors: overestimating capacity, underestimating demand

FIGG used four analytical models to determine the demand on the superstructure, each representing the bridge at various stages of completion. Postcollapse, to analyze the FIGG demand values, the FHWA completed four separate structural analyses of the bridge during the specific construction stage when the collapse occurred.

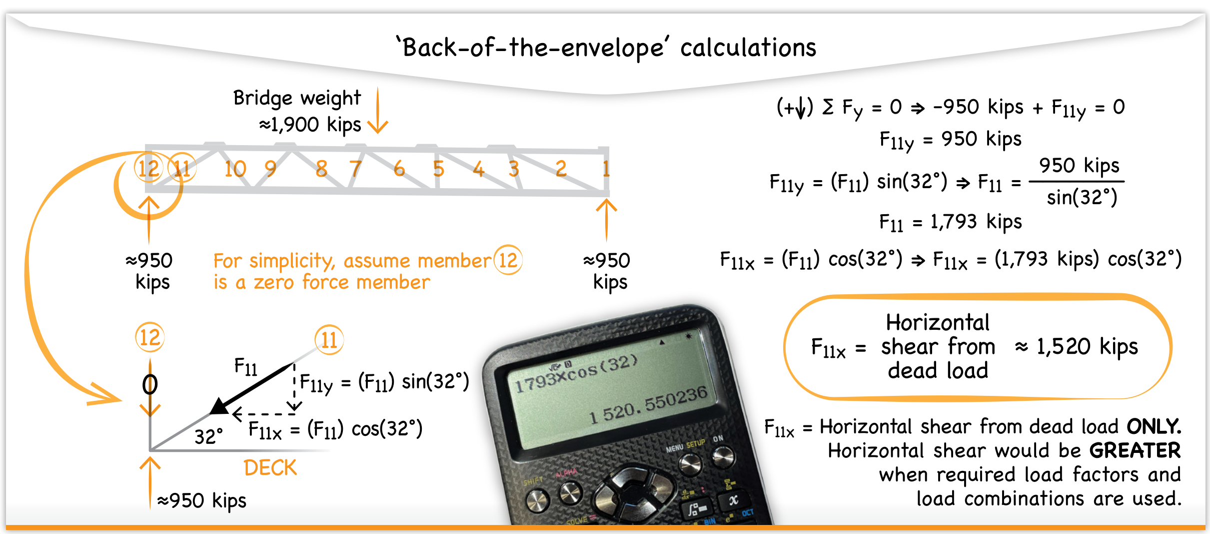


The FHWA's postcollapse analysis determined that the FIGG calculations underestimated the interface shear demand at node 11/12 by 46 percent; the actual demand was nearly twice what FIGG calculated. (The demand at other nodes was also miscalculated; for node 10/11 demand was nearly 10 times what FIGG calculated). See figure at right.

FIGG should have considered the loadings from all critical construction stages when designing the pedestrian bridge and determining the governing interface shear demands. During its design process, FIGG had available model results with nodal region demands that exceeded those acting on the bridge at the time of collapse, but neglected to use them.

FIGG made two substantial errors in its interface shear calculations, resulting in a significant overestimation of capacity. FIGG did not use the lower bound load factor for determining the governing clamping force across the interface shear surface. In addition, non-permanent loads were included in determining clamping force across the interface shear surface, which resulted in the amplification of the effects of those forces.

FIGG also made significant errors in the calculation of demand. The interface shear demand error on the critical node could have been identified (during the design process to double check the results of the computer models) by a simple "back-of-the-envelope" calculation to approximate the horizontal shear demand (as shown below).



A catastrophe years in the making

The collapse of the FIU pedestrian bridge traced back long before the afternoon of the collapse, to FIGG's bridge design errors. (*See* Bridge design errors, *page 7*.)

One such error was that FIGG assigned the bridge a redundancy factor of 1.0, indicating a redundant structure. (See ***Unique, complex bridge design***, page 4.) A factor of at least 1.05 would have been consistent with existing nationally recognized guidance. However, even a redundancy factor of 1.05 would not have prevented the collapse.

There is no AASHTO or FDOT guidance on redundancy specific to concrete structure design. In addition, AASHTO's *LRFD Guide Specifications for the Design of Pedestrian Bridges* (AASHTO 2009) does not discuss redundancy. Our investigation found that redundancy guidelines for pedestrian and concrete truss bridges are needed.

Once the designs and bridge plans were completed, FIGG's errors should have been caught and corrected, but a thorough independent peer review of the complex bridge design[1] never happened. FIGG initially planned to use another of its own design offices for this review. When FIGG was reminded that FDOT required an external reviewer, the company hired Louis Berger, a firm not prequalified for this work type, despite its claim to the contrary.

Louis Berger did not evaluate the nodes of the bridge truss where they connected with the bridge deck and canopy or consider the multiple stages the bridge construction involved.

As soon as the bridge had to support its own weight, cracks appeared at the under-designed nodes, particularly node 11/12. Over the next 19 days, the cracks grew until the bridge collapsed, raising the issue of FIGG's failure to properly evaluate the obvious structural distress and to recognize that the load-resisting mechanisms were failing. FIGG—which employed the EOR—repeatedly reassured other bridge team members that the cracking was not a safety concern. Other team members deferred to FIGG. (*See* 'Not a safety concern', *page 10*.)

The morning of the collapse, despite not knowing the reason for the cracking, FIGG briefed the bridge project team on a plan to retension member 11, reasoning that it was a way to "go one step backwards" (that is, return the bridge to an earlier state). Instead, this retensioning action further overstressed the member 11/12 nodal region and resulted in failure. (*See* Internal forces and structural failure, *pages 6–7;* Stuctural distress, *page 4*.)

In summary, because the design calculations were wrong, the bridge collapsed. Because nobody took action despite clear signs of structural distress, the collapse killed six people and injured ten.

Bridge project timeline

September 5, 2013
DOT notifies FIU of $11.4 million TIGER grant award to build bridge

2014

June 5
Grant agreement executed between FHWA, FIU, and FDOT

June 23
Original LAP agreement executed by FIU and FDOT

2015

November 10
FDOT recommends to the FHWA that the design-build contract be awarded to MCM

November 16
FHWA concurs with the selection of MCM

1 The request for proposals stated that "Prior to submittal to the OWNER (FIU), bridge plans shall have a peer review analysis by an independent engineering firm not involved with the production of the design or plans, prequalified in accordance with Chapter 14-75."

April 28, 2016 through November 8, 2017

Timespan during which design and design calculations were completed

April 28, 2016: MCM enters into a design-builder and design-consultant contract with FIGG; FIGG to serve as EOR

June 30: FDOT reminds FIGG that an independent peer review performed by an independent engineering firm is required

July 6: Louis Berger confirms it is FDOT-prequalified for complex bridge design–concrete (it was not)

August 10: Louis Berger to FIGG: "...a lesser fee may be associated with less effort/value"

August 11–12 (emails): FIGG/Louis Berger: original scope of work unchanged, fee reduced from \$110K to \$61K. Timeframe also reduced, from 10 weeks to 7

September 13: FIGG submits foundation plans to FDOT

September 23: FIU enters into a contract with Bolton, Perez to administer, monitor, and inspect the pedestrian bridge

September 29: FIGG submits substructure plans to FDOT

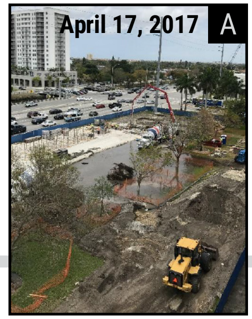
February 10, 2017: FDOT receives FIGG's submission of superstructure plans

The ABCs of ABC

Accelerated bridge construction (ABC) broadly refers to a method of bridge construction that focuses on minimizing the disruption of traffic when building new bridges and uses planning, design, materials, and methods to reduce onsite construction time.

The FIU pedestrian bridge was designed to be cast in sections in a yard adjacent to SW 8th Street **(A and B)**, then moved into place on the concrete piers using SPMTs **(C)**.

A April 17, 2017



B November 6, 2017

C March 9, 2018

January 14
FIU signs design-build contract with MCM

December 12
FIGG requests the closing of SW 8th Street on behalf of MCM, for movement of the precast bridge span

February 5–6
FDOT approves general-use permit including bridge movement plans, as-needed two-lane blanket road closure for westbound traffic

See *From cracks to collapse*, below

J F M A M J J A S O N D
2016
J F M A M J J A S O N D
2017
J F M A M J J A S O N D
2018

From cracks to collapse

2018 February

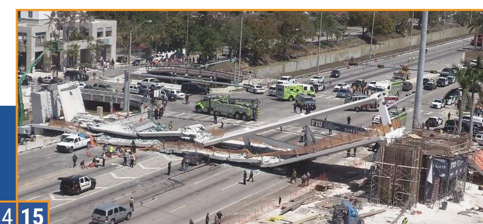
From mid-January to mid-February
Tensioning tendons and rods

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28

February 23–25
Formwork removal; structural cracking first documented

March

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15



Tensioning example: workers on top of canopy stressing PT rods in diagonal supports

February 24
Crack found in member 11/12 nodal region

March 10
Morning: SPMT move of main span
Afternoon: Detensioning of PT rods

Significant cracking progression during detensioning of PT rods

March 15 (times are approximate)
8:00 a.m.: FIGG EOR observes cracking
9:00 a.m.: FIGG meeting with FIU, MCM, FDOT, and Bolton Perez
After 9:00 a.m.: Retensioning of PT rods
1:46 p.m.: **Bridge collapse**

An omission in the construction plans

Finally, the structural performance of interface shear surface between the bridge deck (or walkway) and the lower ends of the truss diagonals was partially dependent on the roughness of the substrate concrete.

The FIGG design calculations were based on an intentionally roughened interface. FIGG was contractually required to deliver final, complete construction plans to MCM. FIGG's construction plans did specifically direct MCM to intentionally roughen some interfaces in other locations in the bridge. **However, FIGG's plans failed to direct MCM to intentionally roughen any of the interface surfaces between the bridge deck and the diagonals.**

Even if the cold joint surface of nodal region 11/12 had been roughened as the bridge design assumed, node 11/12 would not have had sufficient capacity to counteract the demand load for interface shear—and the bridge would still have been under-designed and could have failed.

'Not a safety issue'

Selected communications and photographs related to observed cracks in member 11/12 nodal region.

March 13

9:45 a.m. Email from FIGG design manager to MCM: *"We do not see this as a safety issue"*

4:13 p.m. Voicemail from FIGG EOR to FDOT: *"But from a safety perspective, we don't see that there's any issue there, so we're not concerned about it from that perspective"*

5:18 p.m. Email from FIGG design manager to MCM: *"Again, we have evaluated this further and confirmed that this is not a safety issue"*

March 14

10:50 a.m. Email from MCM to Structural Technologies: *"FIGG has further evaluated and confirmed that the cracks encountered on the diaphragm do not pose a safety issue and/or concern"*

March 15

9:00 a.m. Presentation by FIGG EOR at meeting with FDOT; FIU; MCM; Bolton, Perez (and others): *"And, therefore, there is no safety concern relative to the observed cracks and minor spalls"*

Meeting minutes prepared by Bolton, Perez: *"FIGG assured that there was no concern with safety of the span suspended over the road"*

Meeting minutes prepared by FIGG: *"Based on the discussions at the meeting, no one expressed concern with safety of the span suspended over the road"*

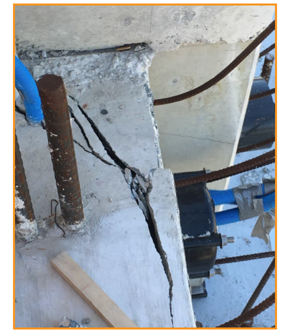
March 13 at 11:17 a.m.

March 13 at 11:18 a.m.

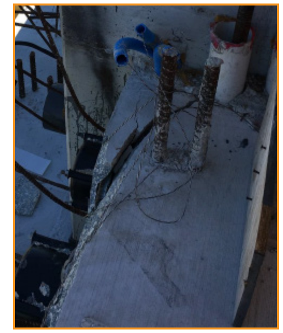
March 13 at 11:25 a.m.

March 13 at 1:02 p.m.

March 14 at 1:42 p.m.



March 14 at 1:50 p.m.



March 14 at 1:51 p.m.

March 15 at 10:55 a.m.

March 15 at 10:55 a.m.

Photo sources:
MCM; Bolton, Perez;
FIU Associate Vice-President of Facilities Management

Probable cause and recommendations

Probable cause

The probable cause of the FIU pedestrian bridge collapse was the load and capacity calculation errors made by FIGG in its design of the main span truss member 11/12 nodal region and connection to the bridge deck. Contributing to the collapse was the inadequate peer review performed by Louis Berger, which failed to detect the calculation errors in the bridge design. Further contributing to the collapse was the failure of the FIGG EOR to identify the significance of the structural cracking observed in this node before the collapse and to obtain an independent peer review of the remedial plan to address the cracking. Contributing to the severity of the collapse outcome was the failure of MCM; FIGG; Bolton, Perez; FIU; and FDOT to cease bridge work when the structure cracking reached unacceptable levels and to take appropriate action to close SW 8th Street as necessary to protect public safety.

Safety issues

The NTSB safety investigation focused on these safety issues (see *A catastrophe years in the making*, page 8):

- mechanisms of structural failure
- evaluation of structural distress
- bridge design errors
- independent peer review of complex bridge design
- redundancy guidelines for pedestrian truss bridges

The recommendations at right address these issues.

Recommendations

As a result of its investigation, the NTSB made the following new safety recommendations.

To the Federal Highway Administration:

- Assist the American Association of State Highway and Transportation Officials with developing a requirement that concrete bridge structures be designed with reasonable estimates for interface shear demand, the cohesion and friction contributions to interface shear capacity, and the clamping force across the interface shear surface. (H-19-24)

To the Florida Department of Transportation:

- Revise your *Plans Preparation Manual* to require that the qualified independent peer review for category 2 bridge structures include checking and verifying the design calculations used for all nodal forces. (H-19-25)
- Revise your *Plans Preparation Manual* to require the engineering firm or company independently peer-reviewing bridge design plans to submit a prequalification letter showing that it is qualified in accordance with *Florida Administrative Code* Rule 14-75 before permitting the firm to sign and seal the 100 percent certification letters indicating that the bridge designs have been peer reviewed. (H-19-26)
- Revise local agency program agreements to specify that when structural cracks are initially detected during bridge construction, the engineer of record, construction engineering inspector, design-build firm, or local agency that owns or is responsible for the bridge construction must immediately close the bridge to construction personnel and close the road underneath; fully support the entire bridge weight using construction techniques that do not require placing workers on or directly under the bridge during installation; and restrict all pedestrian, vehicular, and construction traffic on the bridge until the complete support is in place and inspected. (H-19-27)
- To help facilitate compliance with Florida Department of Transportation standards, require your personnel to monitor and inspect all local agency program bridge projects determined by the department to have uncommon designs. (H-19-28)
- Add a discussion about redundancy to the *Structures Manual, Structures Design Guidelines*, emphasizing uncommon bridge designs, as determined by the Florida Department of Transportation. (H-19-29)

To the American Association of State Highway and Transportation Officials:

- Work with the Federal Highway Administration to develop a requirement that concrete bridge structures be designed with reasonable estimates for interface shear demand, the cohesion and friction contributions to interface shear capacity, and the clamping force across the interface shear surface. (H-19-30)
- Add a discussion about redundancy in the design of concrete structures to section 5 of the *LRFD* [*Load and Resistance Factor Design*] *Bridge Design Specifications*. (H-19-31)
- Add a discussion about redundancy to the *LRFD* [*Load and Resistance Factor Design*] *Guide Specifications for the Design of Pedestrian Bridges*, emphasizing uncommon bridge structures. (H-19-32)

To FIGG Bridge Engineers, Inc.:

- Train your staff on the proper use of P_c (the permanent net compressive force normal to the shear plane) when calculating nominal interface shear resistance. (H-19-33)
- Institute a company policy to obtain a prequalification letter before finalizing any peer review contract with any engineering firm or company being considered to conduct peer review services. (H-19-34)

Glossary of terms

Accelerated bridge construction (ABC): Construction that uses innovative planning, design, materials, and methods in a safe and cost-effective manner to reduce onsite construction time when building new bridges or replacing or rehabilitating existing bridges.

Axial force: The compression or tension force acting in a structural member.

Blister: A concrete block cast on the top or side of a concrete member that typically provides access to a post-tensioning anchorage.

Canopy: Top horizontal member of the FIU pedestrian bridge.

Cantilever*: A structural member that has a free end projecting beyond a support; or a length of span overhanging a support.

Capacity: Ability of a structure to resist applied loads.

Chord*: A generally horizontal member of a truss.

Clamping force: The compressive (vertical) force that contributes to interface shear resistance.

Cold joint: A joint or discontinuity resulting from a delay in concrete placement of sufficient duration that the freshly placed concrete cannot intermingle with the previously placed, already hardened, concrete.

Compression*: A type of stress involving pressing together, which tends to shorten a member; the opposite of tension.

Compression member: Any structural member subjected to a compressive force. In a truss bridge, some structural members (chord or diagonal) are always under compression; some are always under tension; and some, depending on the configuration of the structure and the loading, change from compression to tension and vice versa.

Concrete truss bridge: The FIU bridge was designed as a two-span, single-plane concrete truss containing longitudinal, transverse, and truss member post-tensioning. The truss structure was complemented architecturally with a central pylon and steel pipe stays. Concrete truss bridges are exceedingly rare. Research has revealed no other designs similar to the FIU bridge. Generally, truss bridges are constructed primarily of steel.

Curing*: A process that begins immediately after concrete is placed and finished, and involves maintaining moisture and temperature conditions throughout the concrete for an extended period of time.

Dead load*: Static load due to the weight of a structure itself; also referred to as self-weight.

Deck*: Portion of a bridge that provides direct support for vehicular and pedestrian traffic, supported by a superstructure.

Demand: Design loads imposed on structural members that need to be resisted or supported by the structure.

Design-build: A system of contracting whereby one entity performs both architectural/engineering design and construction under a single contract.[2]

Diagonal*: A sloping structural member of a truss or bracing system. The FIU bridge diagonals connected the bridge canopy and the bridge deck.

Diaphragm*: A transverse member placed within a member or superstructure system to distribute stresses and improve strength and rigidity.

Distress: A physical manifestation of deterioration that is apparent on or within a structure, including cracking, delamination, and spalling of concrete.

Falsework*: A temporary wooden or metal framework built to support the weight of a structure during construction and until it becomes self-supporting.

Interface shear surface: The contact area between two concrete elements that transfers opposing forces across the joint. In the case of a cold joint, the roughness (friction) and associated cohesion across the interface shear surface and the magnitude of the forces compressing the two surfaces provide resistance to interface shear.

Horizontal component: Shearing force on the interface shear surface at the end of an inclined or vertical truss member.

Load*: A force carried by a structure component.

Member*: An individual angle, beam, plate, or built-up piece intended to become an integral part of an assembled frame or structure. Members are the major structural elements of the truss (chords, diagonals, and verticals).

Node (or nodal region): Located at any part of a bridge in which truss members (chords, diagonals, and verticals) are connected. In the FIU bridge, the canopy was the top chord, and the deck was the bottom chord.

Nonredundant structure: A structure with fewer load paths (or main supports) than necessary to maintain stability following the failure of a critical component, likely resulting in its collapse.

Pier*: A substructure unit that supports the spans of a multispan superstructure at an intermediate location between its abutments.

Post-tensioning: A method of prestressing concrete using steel rods or strands that are stretched after the concrete has hardened. This stretching puts the concrete in compression, with the compressive stresses intended to counteract tensile (tension) forces experienced by the concrete.

2 See the Design-Build Institute of America website, accessed September 23, 2019.

Post-tensioning (PT) rod: Prestressing steel rod inside a plastic duct or sleeve, positioned in the formwork before the placement of concrete. PT rods are large-diameter threaded rods secured with large nuts and anchor plates to lock their ends in place so they can be tensioned and/or detensioned as necessary. A PT rod is tensioned after the concrete has gained strength but before service loads are applied to the structure.

PT tendon: Strand of PT wire that is tensioned, then held taut by clamps at each end, and typically cannot be detensioned without cutting the strands. PT tendons were located in the main span bridge deck and canopy.

Rebar: Reinforcing steel bars often used in concrete structures for added strength and stability. Standard rebar classifications rate the bars by diameter as follows:

size 4 = 0.50 inch	size 8 = 1.0 inch
size 5 = 0.625 inch	size 9 = 1.128 inch
size 6 = 0.75 inch	size 10 = 1.27 inch
size 7 = 0.875 inch	size 11 = 1.41 inch

Redundancy: The capability of a bridge structural system to carry loads after damage to, or the failure of, one or more of its members.

Reinforced concrete: Concrete to which steel is embedded such that the two materials act together in resisting forces. The reinforcing steel (rods, bars, tendons, etc.) helps to absorb the stresses in a concrete structure.

Self-propelled modular transporter (SPMT): A platform vehicle with a large array of wheels. SPMTs are used to transport massive objects—such as large bridge sections, oil refining equipment, and motors—that are too big in scale or too heavy for truck transport.

Shear: A force that causes parts of a material to slide past one another in opposite directions.

Shim stack: Multiple layers (or plates) of a material (a shim) stacked to provide support—in this case, to support the main span during permanent placement; a shim plate is a single layer.

Span: Horizontal space between two supports of a structure. A simple span rests on two supports, one at each end, the stresses on which do not affect the adjoining spans. A continuous span consists of a series of consecutive spans (three or more supports) that are rigidly connected (without joints) so that bending moment and shear are transmitted from one span to another.

Specifications*: A detailed description of requirements, materials, and tolerances for construction that are not shown on drawings; also known as "specs."

Substructure: Bridge structure that supports the superstructure and transfers loads from it to the foundation; main components are abutments, piers, footings, and pilings.

Superstructure: Bridge structure that receives and supports traffic or pedestrian loads and, in turn, transfers those loads to the substructure; includes the bridge deck, structural members, parapets, handrails, sidewalk, lighting, and drainage features.

Tendon: A prestressing steel cable, strand, or bar that provides a clamping load to produce compressive stress to balance tensile stress.

Tension*: Stress that tends to pull apart material; the opposite of compression.

Tension truss member: Any member of a truss that is subjected to tensile (tension) forces. In a truss bridge, some structural members are always under compression; some are always under tension; and some, depending on the structural configuration and loading, change from compression to tension and vice versa.

Transverse: Perpendicular to the longitudinal axis; a transverse member helps distribute stresses and improves strength and rigidity.

Truss: A bridge superstructure made up of members whose ends are linked at nodes. The structure is composed of connected elements, typically forming triangular units, where the members act as a single object.

Vertical component: Compressive or clamping force on the interface shear surface at the end of an inclined or vertical truss member that contributes to interface shear resistance.

Vertical truss member: A vertical member connecting the upper and lower chords at nodes.

*Taken from the Federal Highway Administration (FHWA) Bridge Inspector's Reference Manual.

Investigation

NTSB investigators and the NTSB's Chairman launched to the scene upon notification of the collapse on March 15, 2018. The investigation spanned 19 months and concluded with the Board meeting on October 22, 2019, in Washington, DC. More than 120 items totaling more than 6,600 pages of factual and photographic evidence were reviewed and entered into the public docket along with a preliminary report, two investigation updates, several news releases regarding the Board's investigative activities and progress, and the final report with a probable cause, findings, and safety recommendations. Components from the area where the failure occurred were stored securely at a FDOT facility, under the control of the NTSB. Other evidence, including concrete core samples, rebar, and tensioning rods, were shipped to the Turner-Fairbank Highway Research Center (part of the Federal Highway Administration) for testing and evaluation.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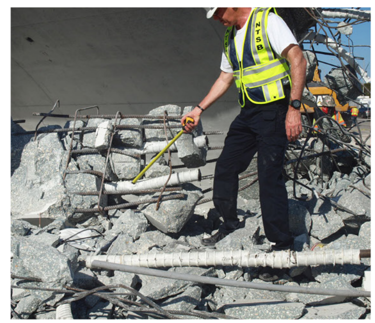


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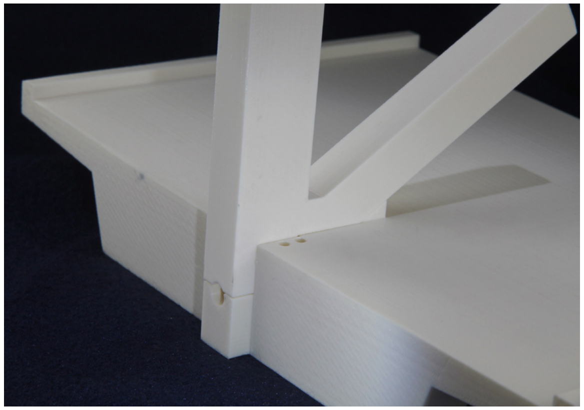
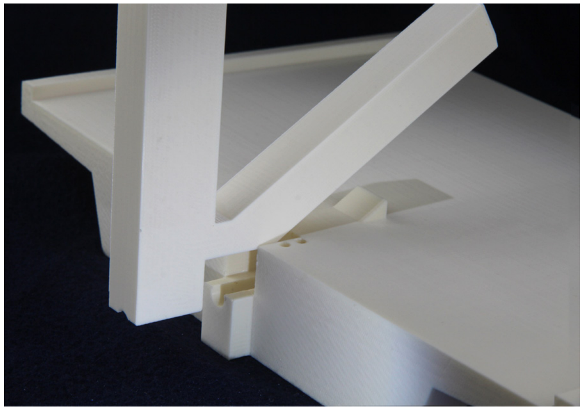
FIGG's Interpretation of Redundancy

Parties to the investigation

Parties to the investigation were the FHWA; FHWA Turner-Fairbank Highway Research Center; US Department of Labor, Occupational Safety and Health Administration (OSHA); US Department of Transportation, Office of the Inspector General; Florida Department of Transportation; Miami-Dade Police Department; Florida Highway Patrol; Florida International University; City of Sweetwater, Florida; Barnhart Crane and Rigging; Bolton, Perez and Associates Consulting Engineers; FIGG Bridge Engineers; MCM; and Structural Technologies.

On June 14, 2019, the NTSB revoked OSHA party status because of a breach of party participation rules. On June 11, contrary to party agreement obligations, OSHA released a report to the public that contained large portions of nonpublic draft NTSB material and also failed to provide investigative photographs to the NTSB as required by its status as a party to the investigation.





The FHWA provided the NTSB with a 3D printed model during the NTSB's investigation. The 3D printed model of node 11/12 illustrates the movement of members 11 and 12 to the north (with respect to the deck) that initiated the collapse of the pedestrian bridge.

The NTSB is an independent federal agency that investigates marine, rail, pipeline, highway, and aviation accidents, determines their probable causes, and makes recommendations to improve safety.

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