A SunCam online continuing education course

Ethics in Design and Oversight:
Florida International University Bridge Collapse

by

Park Doing, Ph.D.

The Florida International University Bridge Collapse - An Issue of Oversight?

A pedestrian bridge commissioned by Florida International University (FIU) collapsed onto SW 8th Street in the Sweetwater section of Miami, Florida at 1:46 PM on March 15, 2018. Six of the eight driving lanes were open to traffic at the time and six people were killed: one bridge construction worker and five vehicle occupants; 6 people were seriously injured: four bridge construction workers and two vehicle occupants; and four people had minor injuries: one bridge construction worker and three vehicle occupants. The first fundamental canon of the National Society for Professional Engineers states that engineers "shall hold paramount the health, safety, and welfare of the public." As the Vice President of the National Transportation Safety Board put it, "we have been building bridges in the United States for over two hundred years, and in other parts of the world for long before that. The science should be well sorted out by now." Is it possible that engineering mistakes were made but that all involved held paramount the health, safety, and welfare of the public throughout? Or, was the fundamental canon of engineering ethics violated? In some accounts and analyses after an engineering failure, accountability is focused on one particular individual or mistake. In other accounts of the same disaster, sometimes accountability is seen to be distributed among many individuals, companies, and agencies. This case study presents evidence to help the course-taker decide who or what is accountable for the FIU Bridge collapse, and thus the proper means of ensuring that similar episodes do not occur in the future.

All direct quotes are from the National Transportation Safety Association Report, "Pedestrian Bridge Collapse over SW 8th Street, Miami, Florida March 15, 2018"

A Problem to be Solved

The path to tragedy with the Florida International University pedestrian bridge began, as many engineering catastrophes do, with a problem to be solved. The main FIU campus is separated from the residential and commercial Sweetwater section of Miami by SW 8th St, also known as Tamiami Trail, or *Calle Ocho*, a busy thoroughfare that is part of the US 41 highway that runs from Miami to St. Petersburg. The location of FIU in this section of the city stems from the original mission of the university to serve working adults who lived in the area. The inaugural class for FIU in 1972 consisted of some 5600 students. From offering only upper level classes through 1978, by the 2000s FIU was an internationally recognized research university with 22 doctoral programs a medical school, law school, school of architecture and school of public health, and over 40,000 students. By 2019, the university had established a D1 NCAA football team, an art museum, and a school of hospitality, among many other markers of a world class international university, and had an operating budget that topped $650M with an enrollment of over 58,000 students from over 160 countries. As a result, the foot traffic of students crossing the busy, fast, SW 8th street to and from the main FIU campus was very high. In recent years, there had been several pedestrian accidents in this thoroughfare. In 2015, FIU hit upon a solution that would solve this safety issue, help with the development of the Sweetwater as a prosperous "collegetown" that could support needed student housing, and serve as a public and prominent display befitting the innovation, leadership, and development of FIU — a uniquely designed and constructed pedestrian bridge.

A Unique Design

The pedestrian bridge was part of a larger project by the university to develop Sweetwater as a viable and functional residential and commercial area where needed private student housing could be built up. The project, partially funded through federal grants administered by FDOT, was dubbed the "FIU University - City Prosperity Project" and became a $120M continuation of the university's historical and aggressive development. As the prominent and visible centerpiece of this effort, the pedestrian bridge was to be endowed with several important characteristics. According to documents soliciting bids for its design, FIU declared that, "This structure should function as more than just a path for circulation; it should be a place to be and a place to be experienced, and the FIU campus and its students must be proud of it…It should be a destination in its own right where community members might linger, gather, and create an urban social space — a linear park." The document specifically noted that, "The selection criteria will be weighed heavily towards an innovative design that represents the intentions of this project, creating a distinctive landmark for the region."

Another factor also drove the design specifications. FIU was a proponent of an increasingly popular Accelerated Bridge Construction (ABC) method whereby bridge sections were pre-fabricated and then assembled in place, greatly reducing road shutdown time. The university had recently opened a center for ABC, which it heavily promoted, and the administration saw the proposed pedestrian bridge as an opportunity to showcase its leadership in this area. Importantly, this construction technique eliminates certain types of bridges, including those supported by cables.

The winning bid, for $14.2 M, was a spectacular synthesis of the design criteria. The design-build combination of FIGG Bridge Engineers (FIGG), the designer, and Magnum Construction Management (MCM), the builder, submitted a proposal with several attention-grabbing features. First and foremost, to give the structure visibility and grandeur, the firms proposed a design that would appear to be cable stayed bridge, with the requisite tall sweeping cables for far reaching display but would in fact be a truss bridge, allowing for the ABC method of construction that the university championed. It would not be a conventional truss bridge though, with the usual support structures on either side of the structure. Rather, the structure would be in the shape of an I beam, with the trusses in one central column down the center. The trusses themselves would also be arranged unconventionally, designed to visibly align with the faux cables emanating from above the bridge. Given that the bridge also had to span a canal parallel to, but narrower than, SW 8th Street, the design had each truss at its own individual angle with respect to the bridge in an asymmetric arrangement. Finally, the bridge would be the first truss bridge built entirely of an aesthetically pleasing Titanium Oxide (TO2) concrete mix. The Engineer of Record, a Florida certified P.E. responsible for signing all documents pertaining to the design and construction plan, was employed by FIGG.

Figure 1 – The winning proposal for the FIU pedestrian bridge.

Figure 2 – Cutaway view of bridge showing single truss, deck, and canopy.

Contributing Factors to Failure

The failure of the bridge was determined by The National Transportation Safety Board (NTSB) to be caused by shear force overwhelming the truss 11/12 node after the main section of the bridge was set in place above SW 8 Street.

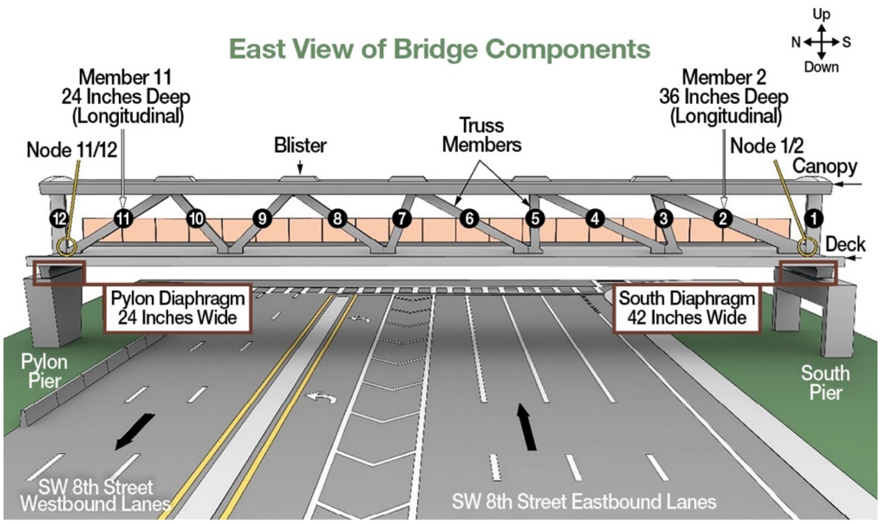

Figure 3 – Depiction of main span of bridge in place over SW 8th Street. Node 11/12, which failed due to horizontal shearing when the main span was in this position, is at the left at the deck level.

Calculation Error and Engineering Judgment Errors in the Design

FIGG used the American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) methodology in the design of the bridge. However, the NTSB determined that FIGG made design errors regarding shear forces, and the resistance to them, of the bridge.

"The AASHTO LRFD states that bridges must be designed to achieve the objectives of safety, constructability, and serviceability...These objectives are met through the theory of reliability based on current statistical knowledge of loads and structural performance. In LRFD design, the anticipated loads on a bridge are conservatively estimated, and the structural system is proportioned to reliably resist those loads. The NTSB concludes that FIGG (1) made significant design errors in the determination of loads, leading to a severe underestimation of the demands placed on critical portions of the pedestrian bridge; and (2) significantly overestimated the capacity of the member 1/2 and 11/12 nodal regions."

The nodal connections between the trusses and the deck and canopy were designed as "cold joints." The trusses and the deck and canopy were poured and cured separately. Steel reinforcement bars (rebar) were housed in the concrete and crossed the interface connection, providing resistance against shear forces. Roughening of the concrete surfaces at the interface can provide some resistance to shear forces also. Vertical compressive forces at the connection provide the rest of the resistance to shear forces. The weight of the bridge and its configuration determine the dead load contribution to vertical compressive forces, and pedestrians and other traffic determine the live load contribution. Finally, post tensioning from rods housed inside the concrete can also provide vertical compressive forces.

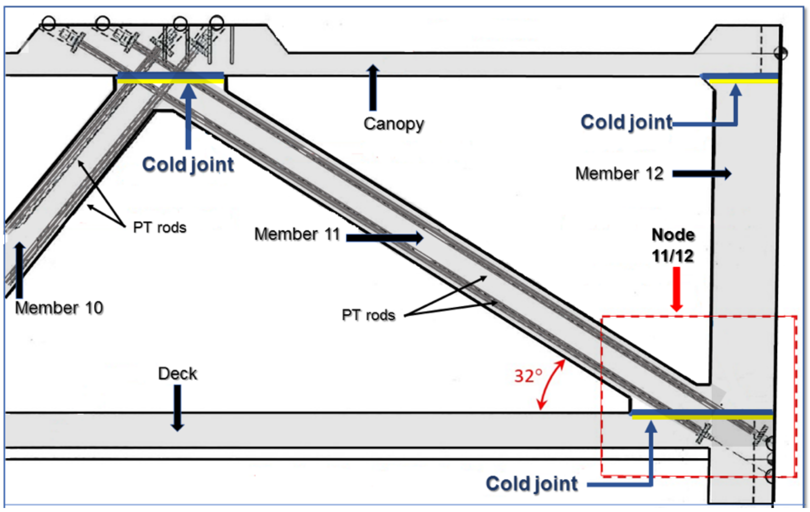

Figure 4 – Diagram of node 11/12 showing the cold joint at the interface and the post tensioning (PT) rods crossing the interface. Reinforcing steel bars (rebar) also crossed the interface.

The first design error involved FIGG's consideration of redundancy. The *AASHTO LRFD Bridge Design Specifications* calls for a redundancy factor to be used in the computation of forces acting in a design. The factor should be 1.05 for non-redundant members, 1 for conventional levels of redundancy, and .95 for exceptional levels of redundancy. FIGG used a redundancy factor of 1 even though, a factor "equal to or greater than 1.05 was required for the pedestrian bridge structure, due to the singular load path provided by the single line truss."

Interestingly, the NTSB noted that even though FIGG should have considered the single line truss non-redundant and used the 1.05 factor, that would actually not have been enough for such a design but pointed out that there was no actual regulatory guidance regarding redundancy in the design of fully concrete bridges. "Although FIGG should have recognized that the diagonal truss members were nonredundant and used a redundancy factor of at least 1.05 in its design, there is no AASHTO or FDOT guidance on redundancy specific to concrete structure design."

The second design error concerned the inclusion of live loads in shear force resistance calculations. The AASHTO LRFD, article 5.8.4.1, states that…the capacity calculation must consider only "permanent net compressive force normal to the shear plane." The FIGG design considered the compressive forces from both permanent (dead) load of the structure as well as the transient live load.

The third design error involved FIGG's use of the AASHTO recommended load factors in its design calculations for interface shear capacity. The AASHTO LRFD states that the load factor on the dead load of structural components can be taken as either 1.25 (to generate a maximum) or 0.90 (to generate a minimum). FIGG used a load factor of 1.25 in its calculation even though the FHWA (spell out?) strongly recommends the 0.90 factor for dead load when determining a minimized interface shear capacity value for purposes of design.

The fourth design error came from FIGGs decision to use computer modeling outcomes that produced an underestimation of the shear demand on the joint, when the designers did have access to computer modeling outcomes that gave accurate assessments. According to the NTSB, this led to an under-accounting of shear demand in node 11/12 by 46%.

"…in several instances throughout the bridge design process, FIGG models produced reasonable estimations for interface shear demand, but these values were not always used in the design of truss members to resist force demands. For reasons the NTSB could not determine, FIGG ignored the appropriate and reasonable interface shear demand values when sizing the main span truss members to resist demand forces. The NTSB concludes that FIGG's analytical modeling for the bridge design resulted in a significant underestimation of demand at critical and highly loaded nodal regions."

Fifth, the fact that the node 11/12 connection would be, as per the ABC construction process, at the end of the "bridge" when the main span was put in place over the road and before the span over the canal had been connected to it reduced the resistance to shear forces in that configuration. The NTSB report faulted FIGG for not taking this construction phase condition explicitly into account.

Sixth, the NTSB found that FIGG did not properly account for discontinuities across the node 11/12 interface, such as drain-pipes housed inside the truss 11 member.

These design errors would lead FIGG to under-design the combination of the size of the concrete trusses and steel rebar housed within them that crossed the connection interfaces and provided resistance to shear forces, which were maximum in the intermediate construction phase when the main span was in place over the road but the back span connecting to it was not yet in place. Given the angle of 32 Degrees between the deck and truss member 11, post tensioning of that member would not increase resistance to the shear force at this interface. In fact, it would rather increase the shear force by a factor of 1.6 over the compressive force.

FIGG asserted that the problem with the joint was that intentional roughening of the concrete at the node 11/12 interface, as was generally recommended by AAHSTO, had not been performed by the contractor during construction. FIGG asserted that this would have had a large effect on shear force resistance at the joint. While FIGG did explicitly specify in its design documents that some nodal interfaces be roughened by the contractor, FIGG did not specify that the node 11/12 interface be roughened, inserting confusion. The NTSB concluded that this was not the cause of the collapse, stating that, "…even if the cold joint surface of nodal region 11/12 had been roughened to a .25 inch amplitude [the AAHSTO recommendation], node 11/12 would not have had sufficient capacity to counteract the demand for load interface shear."

Issues in Independent Review of the Design

According to the NTSB, "errors in design may occur, but systems should be in place to catch those errors when they do occur." How could a bridge with significantly undersigned connections make it through the standard review process?

According to the Florida Department of Transportation (FDOT) *Plans and Preparation Manual (PPM),* the design counted as a 'category 2' bridge and thus required independent peer review.

A category 2 bridge has any of the following:

- New bridge type.
- New materials used to construct bridge components.
- New bridge construction methods.
- Nonstandard or unusual bridge component-to-component configurations and connection details.

The FIU Pedestrian Bridge, in fact, met all of these criteria. The FDOT PPM notes that the design review for such a bridge is intended to be "a comprehensive, thorough independent verification of the original work," and notes that, "an independent peer review is not simply a check of the Engineer of Record (EOR)'s plans and calculations…"

The FIU request for proposals noted that the cost of review would be borne by the design-build firm. FIGG's original proposal included a plan for a different department of FIGG itself to conduct the design review. This plan was rejected by FDOT and FIGG then requested bids from independent design review firms. The winning firm, Louis Berger, had put forth the highest quote but specifically noted that although its bid was the most expensive it would conduct a thorough review, noting that, "a lesser fee may be associated with less effort/value."

After the contract for the bridge was awarded FIGG significantly reduced the fee to Louis Berger, from $110,000 to $61000, and the time for the review, from 10 weeks to 7. This seems to have had an impact on the review process. What was to be a review of thorough scope became a review only of the structure as a whole, not a check on each nodal interface connection or a check of the different construction stages since, according to the Louis Berger engineer tasked with the review, "the budget and time to do this…was not agreed upon with the designer."

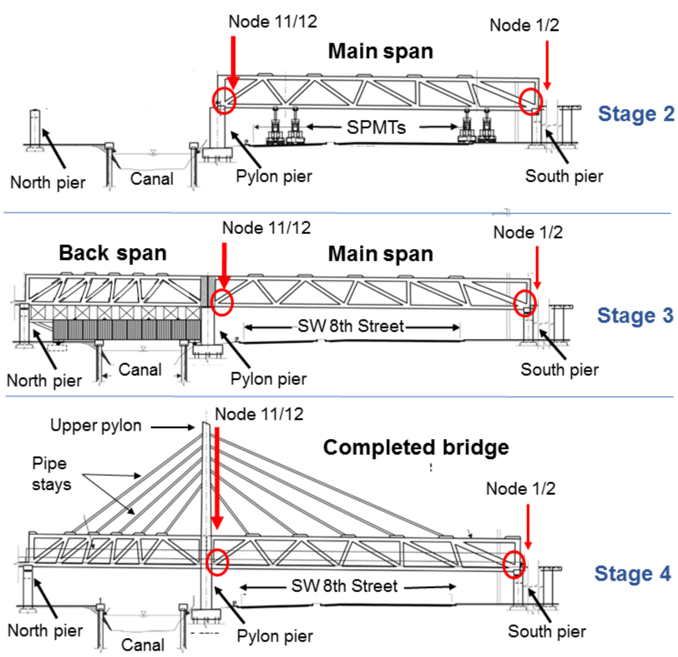

Figure 5 – Stages of bridge construction following the Accelerated Bridge Construction (ABC) method. Only the final stage was reviewed by the independent design firm, Louis Berger.

Adding another insult to the design review process, Louis Berger, it turned out, was not a qualified firm to conduct the review. According to the *Florida Administrative Code* (FAC), a qualified firm for such a review needed to have at least three P.E.s on staff registered with the Florida State Board of Professional Engineers, with each P.E. having five years' experience with complex concrete bridges. Prior to contracting with FIGG for independent review of the FIU Pedestrian Bridge, Louis Berger had not obtained this qualification. A bureaucratic confusion arose from the fact that the firm was listed as a qualified firm on FDOT's website, but FDOT reported later that that was done in error and that a listing on the website should not be taken as the actual qualification credential.

Notably, PPM guidelines do not require either construction sequence analysis or nodal analysis in an independent review, and the fact that Louis Berger was not technically qualified for the review could be seen as a bureaucratic artifact and not a reflection of their true abilities. It is nevertheless a fact that they were not a qualified firm for a type 2 bridge review. The review document was signed by the P.E. at Louis Berger who was in charge of the review.

Response to Concrete Cracking during Construction and Placement of Bridge

The construction of the bridge involved its own set of oversight procedures. FIU contracted with *Bolton, Perez, and Associates Consulting Engineers* to be the engineering and inspection contractor (EIC). The EIC was to oversee the construction and report any "significant discrepancies" from the design plan to FIU and direct the builder, MCM, to correct them. MCM contracted with *Structural Technologies* to perform bridge post tensioning operations and *The Corradino Group* to observe and inspect the post tensioning work. It was during a post tensioning procedure that was not in the original design, but was decided upon by FIGG as a response to cracking of the concrete, that the bridge collapsed.

Cracks occur in structural concrete work for different reasons (loading, temperature, restrained shrinkage) and the *AASHTO LFRD* cites .017 inch cracks as acceptable for outdoor environmental conditions where appearance and corrosion are not an issue and .016 inch cracks as acceptable otherwise. Cracks in the concrete of the FIU Pedestrian Bridge were observed at several points during the construction and placement of the main bridge span and were a significant point of conversation between FIGG, MCM, Bolton Prerez, and Structural Technologies. According to the NTSB, days before the collapse, cracks were observed in the concrete of the 11/12 nodal region that were 40 times the acceptable value. These cracks had grown in size from cracks observed in the same region in earlier stages of construction.

The first cracking occurred in the construction phase as wooden forms that held the concrete in place while it cured were removed. According to the NTSB,

"On February 24, during the removal of the span-supporting formwork, construction personnel working on the structure reported hearing a loud, distinct sound of concrete cracking that came from the structure. Construction activities were briefly halted, and the structure was inspected. A crack was found in the truss member 11 and 12 nodal region near and at the truss member 11 intersection with the deck."

The loud crack sound and the observed cracks were reported to FIGG by Bolton, Perez.

Increases in the cracking at node 11/12 were again observed three weeks later after the main span was set into place. The FIU pedestrian bridge was designed to have all structural elements under compression during its operation. For the bridge to be in the fully compressive state in its final configuration, however, not all of the PT rods needed to be tightened. In particular, the design called for the PT rods in trusses 2 and 11 to remain de-tensioned when the bridge was in place. For the move of the main span into place over the road, however, the truss 2 and 11 PT rods were to be tightened, according to the design plan, to put the main span in a fully compressed state for the move. Once in place, the PT rods in trusses 2 and 11 were then to be released. It was after the release of these PT rods that more cracking was observed at the 11/12 nodal connection. FIGG reasoned that since more cracking had occurred upon release of the truss 11 PT rod, then the proper remedial action would be to retighten the rod and leave it so in the final configuration, even though this was not the way the bridge was designed to operate. This "significant deviation" from the design would normally require written design approval, which would require a review of this new aspect of the design. This did not occur. FIGG insisted throughout the process that the cracks were not a safety issue.

Figure 6 – Cracks at node 11/12 after the main span was set in place over SW 8th Street and the PT rods in member 11 were de-tensioned.

Figure 7 – Cracks at node 11/12 after the main span was set in place over SW 8th Street and the PT rods in member 11 were de-tensioned.

Figure 8 – Close up view of cracks at node 11/12 after the main span was set in place over SW 8th Street and the PT rods in truss member 11 were de-tensioned.

Issues in oversight of the response to cracking

On March 13, FIGG informed Bolton, Perez in an email of its recommendation to retighten the PT rods of truss member 11, noting that, "FIGG thinks will be beneficial for the structure. Again, we have evaluated this further and confirmed that this is not a safety issue" and it made the request to MCM to coordinate the restressing. MCM contacted Structural Technologies with a "rushed request." Structural Technologies responded that their work crews were out of town and asked if the step could be delayed. They were told that it could not be delayed and that, again, it was "not a safety issue." Bolton Perez was not kept in the loop of this coordination and only found out based on a 9 a.m. meeting morning of March 15 that Structural Technologies was already on-site and that the re-tensioning operation would proceed immediately. Bolton, Perez requested a written plan, and was told verbally that the pre-tensioning would be done "incrementally." Representatives from FDOT, MCM, FIGG, and Structural Technologies were present at the meeting. Given that the operation was immanent and since the PT Inspector, the Corradino Group, was not onsite, Bolton Perez sent an employee to observe the pre-tensioning operation. The PT rod would be tightened in 50,000 kilogram-Newton (k-N) increments to 280,000 k-N, it's original tensioned state in the casting yard.

The Instructions from FIGG to MCM belied their full, formal knowledge of the effects of prestressing the member 11 PT rod, noting that if the procedure seemed to be making things worse, then it should be halted. "Based on our evaluation, we anticipate that the crack size will either remain the same or more probably decrease in size. If the crack size increases, the PT bar stressing shall stop and FIGG be notified immediately." A telephone message had been left with FDOT notifying them of the cracks and the determination that there was no safety issue, but that message was not listened to until after the collapse. FDOT was not informed of the re-tensioning procedure. The Engineer of Record for FIGG was aware of the cracks, their history, and the re-tensioning plan, as was FIGG, MCM, Bolton Perez, and Structural Technologies. The Bolton Perez employee at the site observed that the cracks did not increase in size or length before the collapse.

As noted, the angle of truss 11 to the deck was 32 Deg so that tightening the PT rod would actually increase the shear force on the joint by a factor of 1.6 over the compressive force. During the re-tensioning of the truss 11 PT rod, at 1:46 p.m. on March 15 the shear forces overwhelmed the 11/12 nodal connection, blowing concrete debris out horizontally from the end of the span at the deck level, and the bridge span collapsed onto the road.

Figure 9 – Still frame from in vehicle video showing concrete dust and debris blowout at node end of main span north of node 11/12.

Summary Points

The FIU pedestrian bridge was a concrete truss bridge with a single line truss down its center.

The bridge was constructed and put in place in stages, according to the Accelerated Bridge Construction process.

A loud cracking sound was heard and cracks were observed in the 11/12 nodal interface region upon removal of wooden casting forms as the bridge was being constructed in the staging area.

After placement of the main span above SW 8th Street, cracks in the 11/12 nodal interface region were seen to increase in size following the release of post tensioning rods in truss member 11. The release of the post tensioning was according to the design plans.

The decision was made to re-tension truss member 11. This decision was a deviation from the design plans. It was not submitted for a written review as required and requested by the firm contracted to observe the construction process, Bolton Perez. SW 8th Street was not closed for the procedure. The firm contracted to observe post-tensioning procedures, the Corradino Group, was not present.

The angle between truss member 11 and the deck of the bridge was 32 Degrees, thus any post tensioning of that member would increase the interface shear force by a factor of 1.6 over the vertical compressive force.

The 11/12 nodal interface was overwhelmed by shear force during the re-tensioning of truss member 11 and the bridge collapsed onto SW 8th Street.

The Engineer of Record, an employee of FIGG, was aware of the cracks, their history, and the plan to re-tension truss member 11 while the main bridge span was in place over an open SW 8th Street.

The NTSB found that the design firm, FIGG, made several design errors that led to the under-design of the nodal interfaces of the bridge, including not considering the different force configurations at the different stages of the construction process.

An independent review of the separate construction phases was not conducted. Such a review was not required by FDOT.

FIGG noted that a lack of roughening of the concrete at the 11/12 nodal interface could have been the cause of the collapse since such roughening would resist shear force at the interface. The NTSB noted that FIGG did not specify that the surface at the 11/12 nodal interface should be roughened, although it did specify roughening at other interfaces. The NTSB further noted that the under-design of node 11/12 was so significant that it would have failed even if the interface surfaces had been roughened.

An independent review of the specific nodal interfaces was not conducted. Such a review was not required by FDOT.

The firm that conducted the review of the bridge design, Louis Berger, was not qualified by FDOT to review the bridge design.

The review was signed by an engineer employed by Louis Berger.

Recommendations of the NTSB

The NTSB made a variety of recommendations to different firms and agencies based on their report. They directed the Federal Highway Administration (FHA) to

> 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.

They directed FDOT to

> 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.

to

> Revise your *Plans Preparation Manual* to require the engineering firm or company independently peer-reviewing bridge design plans to submit a pre-qualification letter showing that it is qualified in accordance with *Florida Administrative Code*

to

> 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.

to

> require your personnel to monitor and inspect all local agency program bridge projects determined by the department to have uncommon designs.

and to

> Add a discussion about redundancy to the *Structures Manual, Structures Design Guidelines*, emphasizing uncommon bridge designs, as determined by the Florida Department of Transportation.

They directed the AASHTO to

> Work with the FHA 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.

to

> 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."

and to

> 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.

And, they directed FIGG to

> Train your staff on the proper use of…the permanent net compressive force normal to the shear plane…when calculating nominal interface shear resistance.

and to

> Institute a company policy to obtain a pre-qualification letter before finalizing any peer review contract with any engineering firm or company being considered to conduct peer review services.

References

National Transportation Safety Association, "Pedestrian Bridge Collapse over SW 8th Street, Miami, Florida March 15, 2018,"

Scott Judy and Tom Ichniowski, "FIGG's Theory of Collapse Failed to Sway NTSB Team," *Engineering News Record*, Nov. 16, 2019.

Roopindar Tara, "A Bridge Too Faux, Florida's Pedestrian Bridge Would Only Have Looked Safe," *Engineering.com*, March 20, 2018, Accessed July 7, 2019.

Richard Korman and Scott Judy, "Bridge Designer Testifies One Day after OSHA Slams FIGG," *Engineering News Record*, June 19, 2019.

Andres Viglucci and Nicholas Nehemas, "FIU had Grand Plansd for a 'Signature' Bridge. But the Design had a Key Mistake, Experts Say," *Miami Herald*, June 16, 2019.

Mark Hansford, "Future of Bridges – Florida Bridge Collapse Has Some Hard Lessons," *New Civil Engineer*, Dec 16, 2019.

U.S Department of Labor Occupational Safety and Health Administration Directorate of Construction, "Investigation of March 15, 2018 Pedestrian Bridge Collapse at Florida International University, Miami, FL ," July 2019.

"Five Takeaways From The Florida International University Bridge Collapse (A Skilled Trades Perspective)," *thewealthyironworker.com*, November 27, 2019, Accessed July 24, 2020

Nicholas Nehemas, Andres Viglucci, Moniquer O. Madan, "Cracks in FIU Bridge Grew to 'Shocking' Size Days before Collapse, New Photos Show," August 9 2018.