Florida International University Pedestrian Bridge Failure: A study in ethics

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Presenter

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Disclaimer

The facts presented in this presentation are from the report of the National Transportation Safety Board of October 22, 2019. Different analyses and sequences have been introduced into litigation.

Ethics conclusions should be considered as academic exercises.

Ethics conclusions do not reflect on the persons involved since they are based on the NTSB reported facts and those involved have not had the opportunity to defend themselves.

Final ethics determination will be made by the appropriate licensing board.

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Learning Outcomes

Identify the various times in the design/build process that the design flaws could have been identified and corrected, preventing the failure.

Identify the apparent ethical issues arising during the design and building of the FIU pedestrian bridge, leading to its failure.

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Introduction

- FIU intended to build a pedestrian bridge to cross an 8-lane highway and a canal.
- The bridge was constructed using a design/build contract
- The bridge was build using Accelerated Bridge Construction
- The bridge failed on March 15, 2018 about 1:46 PM
- 7 occupied cars, stopped for a traffic light, were crushed
  - 5 occupants died, 2 seriously injured, 3 minor injuries
- Six persons working on the bridge at the time
  - 1 fatally injured, 4 seriously injured, 1 minor injury

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FIU Engineering & Computing

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Concept and criteria for design: T·Y·LIN

"[S]election criteria will be weighed heavily toward an innovative design that represents the intentions of this project, creating a distinctive landmark for the region."

MCM

Report states that ". . . a truss or hybrid of sorts was the best type" of bridge for the site.

MCM was the design-build contractor hired on January 14, 2016 by FIU to perform all work, furnish all materials, equipment, labor, and supplies necessary to construct the pedestrian bridge

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Bolton Perez & Associates

- Provide construction engineering and inspection
- Required to:
  - Observe the MCM work to determine progress and quality
  - Identify and report significant discrepancies to FIU
  - Direct MCM to correct such observed discrepancies.

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FIGG

CREATING BRIDGES AS ART®

- MCM hired FIGG as the "Engineer of Record" to design the bridge
- Provided the final design, construction drawings, and specifications necessary to construct the bridge

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Louis Berger

- Provide "independent" peer design review of FIGG's bridge design
  - Review was to be an extensive check of the entire design
  - Intermediate review were required as the design progressed (90% and 100%)

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- MCM contracted with Structural Technologies to perform the post tensioning of the bridge.
- MCM contracted with Barnhart Crane and Rigging to move the structure from the adjacent casting yard to the final position.
- BPA contracted with the Corradino Group to inspect the post tensioning work.

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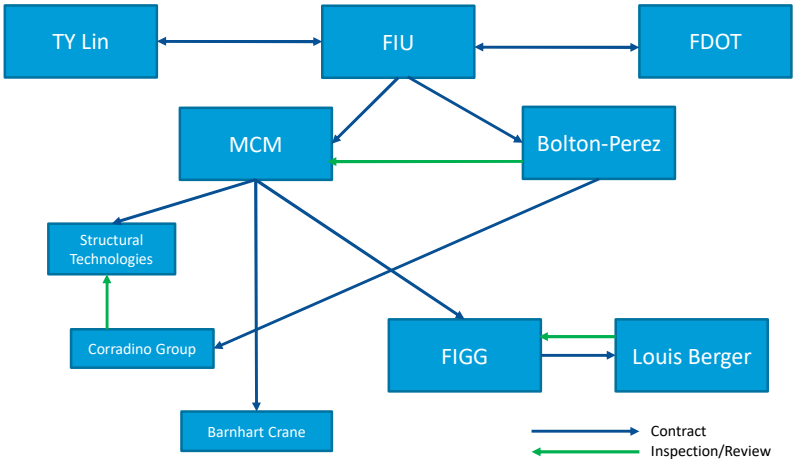
Contractual Relationships



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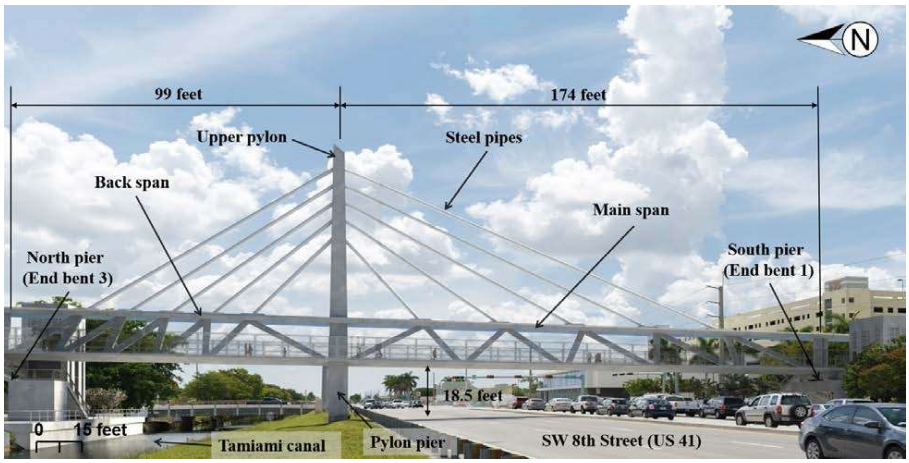
The Bridge Design



Looking East. Source: NTSB Report

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Unique Design Characteristics

- Reinforced concrete for all structural members with added Post-tensioning
- Canopy was top chord of truss
- Deck was the bottom chord of truss
- Deck was cantilevered on each side to form walkways
- Pylon and steel pipes dampened vibrations, but did not contribute to structural support

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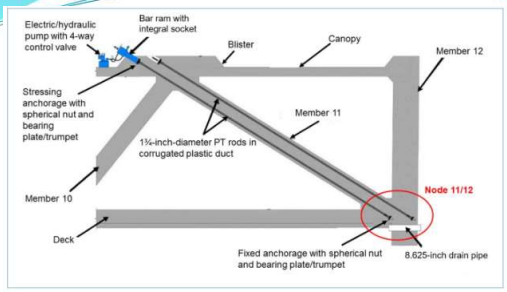

Figure 19. Main span, north end, showing post-tensioning specialized equipment in relation to location of PT rods in member 11. (Source: Structural Technologies, annotated by NTSB)

Design Challenges

- Concrete has little tensile strength, requires tensioning, particularly in truss members subject to tension under load
- Truss design is not symmetrical and diagonal members are at different angles to line up with pipes from the pylon.
- A Single Truss is not load-path redundant

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Design Review

- Since design used design components, details, and construction techniques with <5 years of FL use . . .
- . . . required a peer review by an independent, FDOT-pre-qualified firm having no other involvement with the project.
- Not just a plan check, an independent design verification
- Cost of Peer Review to be incurred by the Design-Build firm
- 10/16: FDOT requested that pylon be moved 11 feet closer to the canal for future bus lane

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Scope of Independent Peer Review

independent confirmation of . . .

- . . . overall compatibility with site geometry and alignment, conflicts with utilities, and compatibility with Traffic Control Plans for each construction phase
- . . . compliance with FDOT, FHWA, and AASHTO requirements and design standards
- . . . completeness and accuracy of plans and special provisions
- . . . constructability assessment limited to fatal flaws in design approach
- . . . structural analysis methodology and assumptions
- . . . (for unique bridge types) verify the design results by using a different program/method

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Peer Reviewer Selection

FIGG requested bids for this service

Three bids were received, Louis Berger was the highest ($110,000), but indicated that the price could be lowered by reducing the scope of the work.

FIGG responded that the original scope had not changed, but the price would be based on the low bid ($61,000) and the time frame was changed from 10 weeks to 7 weeks.

LB accepted both restrictions, and contract was signed September 26, 2016

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A Problem with Qualifications?

- Louis Berger applied for certification in 2013, but the application was rejected due to too few PEs and lacking the required experience in this type of work
- In short, LB was not qualified to do a peer review
- LB also was not pre-qualified by FDOT
- FDOT never bothered to check….

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Scope of Independent Peer Review

- Review, provide comments at 90% design
- Comments and design engineer's responses submitted to FDOT with 90% plans submittal

- Louis Berger did not do this

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Scope of Independent Peer Review

- Review, provide comments at 100% design
- At 100% submittal, the independent peer review engineer shall sign and seal a cover letter certifying the final design and that all comments have been addressed and resolved
- Louis Berger signed and sealed a report which stated: "hereby certifies that an independent peer review of the above-referenced submittal has been conducted in accordance with [FDOT's] Chapter 26 of the Plans Preparation Manual and all other governing regulations."
- FDOT did a quality review of the Louis Berger's Report

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Accelerated Construction Method

- Bridge built in an adjacent yard and then moved into place.
- Temporary supports were used while 3 separate concrete pours were made in order: (1) the deck, (2) truss diagonal & vertical members, (3) the canopy.
- "Cold" joints between truss diagonal members
- After all three pours reached 6,000 psi and prior to removal of the temporary supports, main span deck, canopy, and truss diagonals were post-tensioned

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Temporary Supports (offsite)

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Tensioning for Moving the Bridge

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Cracks Began Before Moving Bridge

- Bolton Perez, inspector, sent reports to MCM, the d-b contractor on February 13 (before removal of temporary supports) and on February 28 (after removal of temporary supports)
- During removal of temporary supports on February 24th, a cracking sound was heard and work stopped briefly.
- "Cracking in truss member 11 and 12 nodal region and truss member 11 intersection with the deck. Similar cracking was found in the nodal region of truss members 1 and 2. Members 2 and 11 were de-tensioned."
- Bridge was moved on March 10th.
- FIGG reviewed the data and responded on March 13th that the cracking was not a safety concern.

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March 13th: Cracks near 11/12 at north end 3 days **after** moving, 5 days before failure

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Cracking at Node 11/12 Addressed by FIGG

	Method	
March 13 9:45 a.m.	Email from FIGG to MCM	"We do not see this as a safety issue"
March 13 4:13 p.m.	VM from FIGG 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"
March 13 5:18 p.m.	Email from FIGG 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"

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Cracking Was Growing

- Meeting on March 15th where design engineer discussed the cracking with FDOT, FIU, Contractor, and CEI team and others
- Minutes by CEI team: "Design engineer assured that there was no concern with safety of the span suspended over the road"
- Minutes by Design Engineer: "Based on the discussions at the meeting, no one expressed concern with safety of the span suspended over the road"

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Diagonal Member 11 (west view):

Tensioned for move,

de-tensioned,

3/15: being re-tensioned at direction of FIGG

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Diagonal Member 11 (east view)

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Total Failure begins, 3/15, 1:46 p.m.

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Failure event complete

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Post-failure Statement by Design Manager

. . . based on the observations from MCM and CEI that the cracks got a little bit worse when they detensioned the PT rods, the direction from the design team was well, let's go back one step backwards, you know, from the design standpoint and go ahead and reinstall those PT rods on the north side only for truss member 11. Not truss member 2; only truss member 11.

Bridge failed during this operation.

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The NTSB Investigation

- Bottom line: the failure that started at the diagonal member 11 nodes was due to under-design of the connection.
- The FIGG Bridge Engineers construction plans inconsistently identified when intentionally roughened surfaces were needed to fulfill the assumptions of the bridge design.
- FIGG Bridge Engineers' analytical modeling for the bridge design resulted in a significant underestimation of demand at critical and highly loaded nodal regions.
- Entire design considered redundant, leading to lower safety factors . . . But when it wasn't

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Additional Conclusions

- FIGG Bridge Engineers (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.
- Based on analytical modeling results, FIGG Bridge Engineers should have considered the loadings from all critical construction stages when designing the pedestrian bridge and determining the governing interface shear demands.

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Additional Conclusions

- In several instances throughout the bridge design process, FIGG Bridge Engineers 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.
- FIGG Bridge Engineers' analytical modeling for the bridge design resulted in a significant underestimation of demand at critical and highly loaded nodal regions.
- The concrete distress initially observed in nodal region 11/12 is consistent with the underestimation of interface shear demand and the overestimation of identified capacity in the bridge design.

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Additional Conclusions

- Because FIGG Bridge Engineers (1) did not use the lower bound load factor for determining the governing net compression, **Pc, in the interface shear; and (2) incorrectly increased and amplified the effects of the clamping force across the interface shear surface, its bridge design calculations resulted in a significant overestimation of capacity.**
- Even if the cold joint surface of nodal region 11/12 had been roughened to a 0.25-inch amplitude, 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.

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The shear issue

- Remember the "cold" joints?
- Shearing force develops due to the angle between the diagonal member and the top/bottom member
- Shearing force resisted by two basic methods: rebar & friction on the interface
- Friction can be improved by "roughing" the concrete; not done here
- Worst case is no-load; usually use load factor of .9; FIGG used 1.25.
- NTSB: 13 additional square inches of rebar was needed at Node 11 to safely resist shearing

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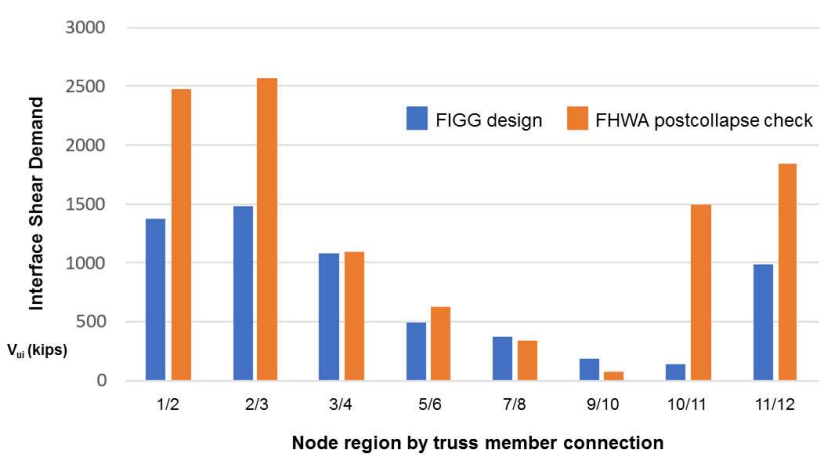
NTSB vs. As-Designed Shear



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Engineer's Response (10/22/19)

- An analysis conducted by Wiss, Janney, Elstner Associates (WJE) proved that if the construction joint at member 11 had been built as required by FDOT Standard Construction Specifications, the construction accident would not have occurred.
- When the FHWA Turner-Fairbank Highway Research Center issued its October 19, 2018 analysis concluding that the concrete cold joints were not intentionally roughened, WJE performed testing of full-scale replicas of the critical connection with both roughened and un-roughened surfaces. WJE's tests revealed, contrary to the findings of the NTSB, that the failure to roughen the concrete beneath bridge member 11 was the fundamental cause of the collapse.

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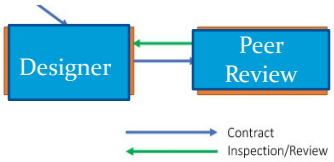
Ethics Issues, EOR

- Peer review contract
  - Conflict?



- Design flaws
  - Failure of in-house review?
- Response to cracking
  - Did they assume data was correct?
- Re-stressing after in-place
  - Didn't reanalyze

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Peer-Review Engineer's Comments to Investigators

My model was for the structure as one structure.

Doing construction sequence staging analysis was not part of our scope.

And again, doing such an analysis requires much more time than what we agreed about.

. . . in the beginning, I suggested to do this kind of analysis, to analyze the connections. I'm talking about the nodes, or the joints to analyze the connections.

However, the budget and time to do this actually was not agreed upon with the designer.

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Independent Peer Reviewer Ethical Issues

Misrepresenting credentials for performing an FDOT review

Contract negotiations

- No change in scope, but OK to cut price?

Inadequate design review

- Didn't meet FDOT requirements
- Rushed?

Unilaterally altered scope?

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Owner/Agent Ethical Issues

Failure to check peer review firm's credentials
Allowing Engineer of Record to negotiate the independent review contract
Not closing the road (public safety)

Construction Inspector Ethical Issues

Allowing project to continue despite cracking
Allowing re-tensioning of member 11 without oversight

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Contractor Ethical issues (Moral? Contractual?)

- Independent Peer review contract
  - Recognize Conflict of interest?
- Not stopping the project over the cracking
  - Too much dependence on design engineer?
- Allowing re-tensioning of member 11 without oversight
  - Rush to fix things?
- Not closing road during re-tensioning of member 11
  - Cracking wasn't an obvious safety issue?

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Legal outcomes

- Lots of lawsuits…
  - Insurance companies paid out $42 million
  - Defendants paid out more in settlement, amounts not released
- FHWA proposed a 10-year suspension from all federal highway projects for FIGG
  - Federal judge denied FIGG appeal
- Florida Licensing Board investigation in progress

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Time to Check Your Notes…

- When/who could have prevented the collapse?
  - Engineer of Record?
  - Independent Peer Reviewer?
  - Owner or DOT representative?
  - Contractor?
  - Construction Inspector?
  - Post-Tensioning specialty sub-contractor?
  - Post-tensioning inspector?
  - Others?

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