Structural-Safety
SCOSS and CROSS

SCOSS
Standing Committee on Structural Safety

SCOSS Alert | December 2020

LESSONS LEARNED FROM THE 2018 FLORIDA BRIDGE COLLAPSE DURING CONSTRUCTION

Photo 1
Miami Herald via AP

This was a bridge of an unusual design and was being constructed in an unusual manner. The main 53m pre-stressed pre-cast concrete span truss was in position when cracks appeared at a node and over a period of almost three weeks they visibly worsened until collapse occurred.

All parties apparently failed to recognise the bridge was in danger when inspected hours before the collapse. In hindsight, the magnitude of the cracks warranted that the road be immediately closed, and the truss supported to reduce loads, pending evaluation.

The National Transportation Safety Board (NTSB) investigations focused on the design, the peer review checking, the site supervision and the independent checking of the works.

Lessons which must be learned by owners, designers, contractors, checkers and supervisors are given in this Alert.

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1. Introduction

Structural-Safety has two entities; SCOSS, a committee established to maintain a continuing review of building and civil engineering matters affecting the safety of structures, and CROSS, a confidential safety reporting scheme established to capture and share lessons learned which might not otherwise have had formal recognition.

It is a matter of great concern to SCOSS that collapses of concrete bridges during construction still occur. This Alert therefore draws attention to matters which should be considered by all parties involved in the design and construction of infrastructure and the built environment. CROSS has, over the years, received numerous reports of concerns which potentially could have led to structural failures as well as reports on actual failures. Worryingly, time after time, the same themes emerge. These are discussed below, including this example, where all the themes occurred together, leading to a bridge collapse during the construction phase, with tragic loss of lives. It is essential that the lessons learned from this collapse, and the other relevant CROSS reports, are implemented, to enable the changes needed in the industry to prevent such unnecessary tragedies from being repeated.

2. Florida International University bridge collapse: what happened?

The Florida International University (FIU) procured a new footbridge to connect facilities over a main road, and a bespoke reinforced concrete post-tensioned structure was developed (See Figure 1). This comprised two spans, one with a 53m long RC truss main span and a similar, but shorter, second span. The self-supporting pylon and steel tubes are non-structural architectural features.

The first span was cast off site and moved into position by self-propelled modular transporter (SPMT). During lifting, the end diagonals cantilevered from the inboard SPMT supports in tension, so they were post-stressed to bring them back into compression during the temporary condition.

When the main span rested onto the supports, the end diagonals returned to compression in the permanent condition, with the tension rods destressed.

As soon as the bridge had to support its own weight, cracks appeared at the nodes, particularly node 11/12. See Figure 2 and Photographs 2 and 3.

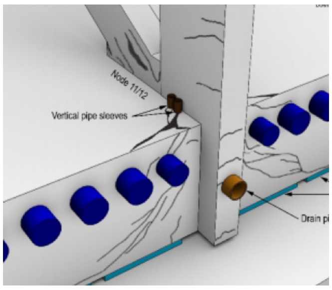

Figure 2
Extent of cracking to the outer diagonal, slab and column (taken from NTSB report Ref 2)

Photo 2
Slab cracking (taken from NTSB Ref 1)

Figure 1
Illustration of bridge structure showing main span

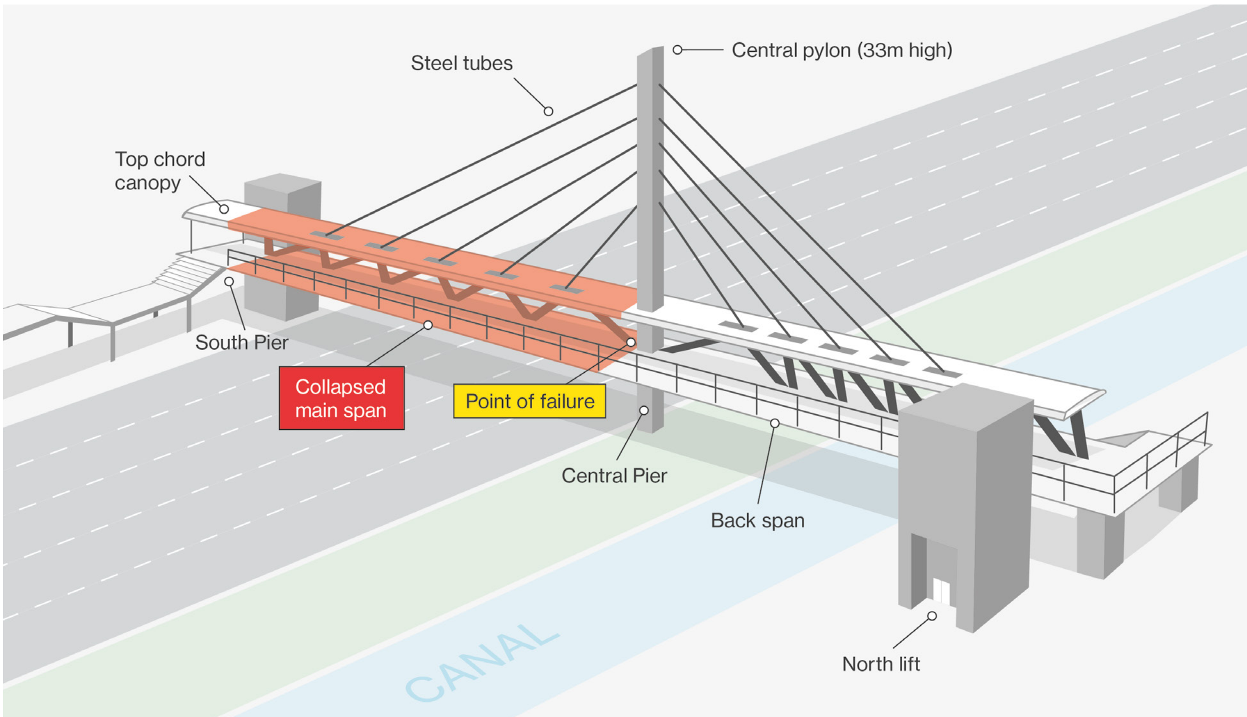

Photo 3
Cracking to diagonal member 11 (taken from NTSB Ref 1)

Over the next nineteen days, the cracks grew until the bridge collapsed. The construction and inspection firms working on the bridge were aware of the cracks, and reported the cracks to the design firm, asking for guidance. In this instance, for this particular Design and Build contract, the Engineer of Record (see note) inspected the cracks. The NTSB report stated that *'...The Engineer of Record repeatedly indicated that the cracks were of no safety concern...'.*

Note: the term Engineer of Record (EOR) is commonly used in North America to define the person responsible for the design phase of a project. The EOR is sometimes appointed as the person technically responsible for seeing that a structure is built according to the design.

On the morning of the collapse, a decision had been made to re-tension the bars in the distressed diagonal under compression thus leading to further compression.

On Thursday 15 March 2018, during the re-tensioning operation, the main span collapsed onto a live road. See Photo 4.

Photo 4
Catastrophic failure of bridge during re-tensioning activities. (taken from NTSB Ref 2)

Only two of the eight traffic lanes were closed at the time of collapse. Eight vehicles, stopped below the bridge at traffic lights, were fully or partially crushed. One bridge worker and five vehicle occupants died. Eight people were injured. The investigations began.

3. Reports

NTSB report – As a result, the National Transportation Safety Board published an **Investigative Update>** (Reference 1), followed by the report **Pedestrian Bridge Collapse Over SW 8th Street, Miami, Florida, March 15, 2018, Accident Report NTSB/HAR-19/02, PB2019-101363>** (Reference 2) making a number of recommendations to the Federal Highways Administration, the Florida Department of Transportation, the American Association of State Highway and Transportation Officials, and the Bridge Designer.

The recommendations strongly resonate with SCOSS as they reflect exactly the type of problems CROSS encounters in the reports on matters submitted to them. These are discussed in further detail in the paragraphs below.

4. Causes and lessons learnt

Structural design – As stated in the NTSB report, the identified probable cause was that the bridge had structural deficiencies. There was, according to NTSB, an underestimation of loads and overestimation of capacity, with incorrect loads and load factors being adopted. These two reported design issues resulted in a node that lacked the capacity to resist the shear force, causing distress in members which could not accommodate the forces.

It was reported by NTSB that inadequate Peer Review checking was carried out; the checker was only contracted to check the finished structure, not the structure during construction. Review of cracks and changes to tensioning procedure were reportedly not subject to Peer Review checking.

It is highly likely that the location of service voids, placed so close to the node which failed, was a contributory factor, as it appears this were not accounted for in the design. It is essential that non-structural service voids are placed only in locations with the written permission of the structural designer, to ensure adequate consideration of structural strength.

Checking the design and design check category – In Florida, a purpose of the Structural Peer Review is to provide independent verification that the structural design is in general conformance with the governing requirements, in this case, the American Association of State Highway and Transportation Officials (AASHTO) LRFD Bridge Design and Florida Department of Transportation specifications, protocols and guidelines.

This is loosely translated in the UK to a 'Design Check'. The need for appropriate levels of design check category for infrastructure development is well established in the UK. Temporary works are covered by recommendations in **BS 5975:2019>** (Code of practice for temporary works procedures and the permissible stress design of falsework). Permanent works are covered by Client assurance requirements, such as the **Design Manual for Roads and Bridges (DMRB)>** for Highways England projects, and Engineering Assurance standard NR/L2/CIV/003 for Network Rail infrastructure.

Typically, complex or unusual designs, or designs which involve significant departures from current standards, or novel methods of analysis or those which require considerable exercise of engineering judgement, will require Category III design checks, meaning:

- The design shall be checked by an organisation independent of the design organisation (that is, by an organisation which is a separate legal entity);
- The design check methodology and analysis shall be independently derived against a common set of design criteria.

SCOSS recommend that the design check category for both permanent works and temporary works are reviewed by a multi-disciplinary team including Principal Designer (PD), Designer, Principal Contractor (PC), and Client as appropriate. This should include the potential to upgrade the design check category of temporary works, which involve permanent works in temporary conditions, to the same category as the permanent works. In the case of the Florida bridge collapse, this would include a fully independent consideration of all temporary conditions by the permanent works and temporary works engineers, so that all parties are satisfied that the agreed sequencing has been independently checked.

Importantly, any changes to the agreed sequencing of installation shall be both designed and checked, prior to execution. In the Florida bridge case, it was reported that no independent check of the decision to reload the diagonal tie bars was undertaken.

<u>Site supervision and independent checking of execution of the works</u> –

In Florida (and elsewhere in the US), the EOR is a professional engineer who is responsible for the preparation, signing, dating, sealing and issuing of any engineering document(s) for any engineering service or creative work.

The EOR could (and should) be granted authority, and be provided with sufficient time, budget and resources to:

- design the facility in accordance with applicable laws, appropriate industry standards and as appropriate for the site conditions;
- provide sufficient oversight during construction of all stages to confirm that the facility has been constructed in conformance with the intent of the design and specifications;
- provide sufficient oversight during the operation of all stages and conduct regular, on site, visual inspections to confirm that the facility is being constructed in accordance with the intent of the design, which may have been modified to suit any changed conditions.

There is no such equivalent position in modern contract procurement in the UK; however, there is a similarity with more traditional forms of procurement, where a Resident Engineer would be appointed to undertake aspects of the above, or a Clerk of Works be appointed to undertake independent overview.

Indeed, in the UK, there are numerous examples, including in reports to CROSS, where a Designer has handed to the Principal Contractor a pack of construction information prior to execution, and that is the last of the Designer's involvement. A collaborative working arrangement, where the Designer has a presence on site to expedite design decisions, and to relay design intent to improve outcomes for all parties, is preferred.

Despite what happened here, SCOSS believe a representative from the Designer's organisation must attend site in similar circumstances; to ensure construction is in accordance with the design, to ensure clear communication of the design intent, to allow expeditious dialogue to facilitate change, and to act as an independent pair of eyes and ears to improve quality and spot the potential for error. Such interventions would enable a level of independence and help to ensure appropriately skilled persons, present on site, may see things that the untrained eye might not.

The measures would have a very small additional cost, yet they would result in significant gains to all parties.

<u>Construction oversight</u> – All parties apparently failed to recognise the bridge was in danger when inspected hours before the collapse. The Construction Engineer and Inspector apparently failed to classify the cracks as structurally significant. In hindsight, the magnitude of the cracks warranted that the road be immediately closed, and the truss supported to reduce loads, pending evaluation.

The evaluation of the cracks, and the decision to re-tension the diagonal member, made by the EOR, constituted a change from the original design, and as such should have been subjected to an independent design check.

The design and build Contractor failed to exercise its own independent professional judgement to close the road.

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SCOSS recommend the following measures for bridges, and other structures:

- Design checks to be undertaken to appropriate design check category, as required by standards and controls.
- When the design or sequencing needs to change from accepted design or sequencing, the instigator of change must always refer back to the Designer. There is a case for improvement in interfaces between CDM (see below) duty-holders, who need to work collaboratively to ensure safe design.

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- Independent supervision of all construction sequencing by an independent pair of eyes and ears might have sent a different message to the site team.
- Supervision to be by appropriately trained professionals, demonstrably competent to understand when things are wrong. It is likely that structural distress might not be picked up as structurally significant with no engineering presence on site.
- There is a case for more education in spotting faults and structural weaknesses amongst site staff, who will know when to call in relevant expertise.

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- There is also a case for more site visits as independent eyes and ears, better adherence to Inspection & Test Plan hold points, improvements to the level of site supervision by the PC's own staff, and up-skilling to recognise faults and discrepancies as they occur. It is the responsibility of the industry to fund this.

CDM regulations – In the UK, under the Construction Design and Management Regulations (CDM) 2015, the Client is responsible for appointing competent Designers and Contractors, and for ensuring they undertake their CDM duties. SCOSS recommend that all CDM duty-holders are defined with leads named on all projects, so duty-holder accountabilities and responsibilities are clear to all.

Duty of care – The NTSB investigation found that, the collapse was the result of a complex series of events and actions by parties at multiple stages of the project. Apparent errors in bridge design, inadequate peer review and poor engineering judgment contributed to the collapse of this bridge. Systems should be in place to catch errors when they do occur.

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General measures – In addition to the above, SCOSS recommend the following general measures:

A. Based on the Florida bridge collapse

- Projects should undertake 'what if' contingency planning. What can go wrong, and how do we prevent it or mitigate it? In the case of the Florida bridge, there were weeks to consider the consequential effects of the developing cracks.
- All increases in crack width, particularly those that occur over a short period of time, must be taken seriously and assessed by an expert.
- Due to the increasingly fragmented nature of the industry, it is often observed that engineering decisions are made by non-engineers, without consulting competent engineers. This results in significant safety risks due to non-engineers not understanding the implications of their decisions. This is a serious and widespread issue, which the industry needs to recognise, and find a way to prevent from happening.
- Design and Build contract procurement methodology needs to ensure that there is an appropriate level of Designer input and supervision on site, to assure quality and safety.
- Projects should check the alignment of the procurement strategy and contracts with the competence of those involved, and the complexity of the work.
- Train engineers to recognise, through learning and experience, the early warnings of failure.
- The industry must do more to ensure competency of individuals and companies is demonstrated.

B. Based on a general review of other similar incidents

- There is often undue pressure on duty holders, which can lead to compromising quality and safety. SCOSS believe that this is unacceptable behaviour, which needs to be rooted out. There is a strong case for improved teaching on behaviours and the impact culture has on safety and quality. The Institution of Structural Engineers and Institution of Civil Engineers resources on engineering ethics are a good starting point for education on behaviours.

https://www.istructe.org/resources/guidance/guidance-on-ethics/

https://www.ice.org.uk/about-ice/governance/royal-charter

- The industry should allow competent professionals to exercise their professional judgement, in a collaborative working environment, and without fear of adverse consequences (punishment).
- SCOSS observe numerous project examples where there has been undue pressure applied by clients (and others) onto designers and contractors to design and execute works to maintain programme and cost without giving reasonable time for persons to undertake their duties fully. This then often results in "cutting corners", which may lead to unintended consequences on quality and safety. The industry should consider putting measures in place to avoid this happening.

Technical Approval and engineering assurance

Some of the recommendations explored in this safety Alert are mirrored in a recent IStructE Viewpoint article **The box girder failures 50 years on - lest we forget>**, published in The Structural Engineer November 2020. In this article, Ian Firth looks back at the box-girder bridge collapses of 1970 and considers the applicability of the lessons learned to structural engineers today. From *'independent checking'*, *'site supervision'* and *'clear allocation of responsibilities'*, to *'generational amnesia'* and *'behaviours'*, these observations and recommendations strongly resonate with SCOSS.

Ian Firth also mentions the 1973 **Merrison Report>** (Committee of Inquiry into the Basis of Design and Method of Erection of Steel Box-Girder Bridges), which was instrumental in developing the Technical Approval process as we know it today.

The Technical Approval (TA) process in England, Scotland, Wales and Northern Ireland was first implemented in 1974, via **BE 1/74>** (The Independent Checking Of Erection Proposals and Temporary Works Details For Major Highway Structures On Trunk Roads and Motorways).

Essential elements of TA were:

- Independent check of Engineer's permanent design.
- Independent check of method of erection and design of temporary works.
- Clear allocation of responsibility between Engineer and Contractor.
- Provision by the Engineer and the Contractor of properly qualified and experienced supervisory staff on site.

Whilst BD1/74 had been updated over the years, the core principles always remained. The current version, published by Highways England in April 2020, is **CG300>** (Technical Approval of Highway Structures).

Since 1974, the Technical Approval process has been leading the way in assuring the safe design and execution of SRN (Strategic Route Network) structures in the UK, which is why it is also used by Local Authorities and other large asset owners.

Network Rail's equivalent 'Technical Approval' process is defined in their standard NR/L2/CIV/003 (Engineering Assurance of Building and Civil Engineering Works).
In Network Rail's case this process is extended to permanent works and temporary works engineering assurance for buildings and civil engineering structures, including (but not limited to) building structures e.g. stations and depots, platforms, bridges, footbridges, drainage, tunnels, under track crossings, retaining structures and earthworks. It includes specific provision for building services and architectural acceptance, embodying the **Network Rail Principles of Good Design>**.

Both processes already embody recommendations which flow from the review of the Florida bridge collapse. Considering all the lessons in this Alert, there would seem to be a case for extending the principles of Technical Approval (or similar) to structures other than those provided by major infrastructure providers.

5. Conclusion

This SCOSS Alert touches on the main learning from the event, whilst the references provide further details. This event occurred from a complex sequence of unfortunate events, but one thing is for certain: the warning signs of distress were clear, and the road traffic under the bridge could have, and should have, been stopped as a precautionary measure. Decisions made on the day of the collapse, contrary to the approved design and unchecked, compounded the issues. This avoidable tragedy needs to be studied carefully and the above recommendations implemented by all organisations involved in the construction industry.

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6. References

References 1 and 2 relate to NTSB reports that have been used in the preparation of this Alert. References 3 to 12 provide further reading about this event and related matters.

1. **Investigative Update: Collapse of Pedestrian Bridge Under Construction, Miami, Florida (HWY18MH009)>**. National Transportation Safety Board.

2. **Pedestrian Bridge Collapse Over SW 8th Street, Miami, Florida, March 15, 2018, Accident Report NTSB/HAR-19/02, PB2019-101363>**. National Transportation Safety Board.

3. **AASHTO>** (American Association of State Highway and Transportation Officials).
   • 2015. AASHTO LRFD Bridge Design Specifications, 7th edition. Washington, DC: AASHTO.
   • 2009. AASHTO LRFD Guide Specifications for the Design of Pedestrian Bridges, 2nd edition. Washington, DC: AASHTO.

4. **ASCE Miami Pedestrian Bridge Collapse; Computational Forensic Analysis>**. ASCE Journal of bridge engineering DOI:10.1061/(ASCE) BE, 1943-5592,0001532.

5. **Load, Capacity Calculation Errors, Inadequate Peer Review Led to Pedestrian Bridge Collapse>**. National Transportation Safety Board News Release.

6. **Pedestrian Bridge Collapse Over SW 8th Street, National Transportation Safety Board Public Meeting of October 22, 2019>**. National Transportation Safety Board.

7. **Pedestrian Bridge Collapse Over SW 8th Street Miami, Florida, March 15, 2018>**. National Transportation Safety Board.

8. **NTSB Board Meeting: Miami, FL Pedestrian Bridge Collapse>**. National Transportation Safety Board video. 3 hours 18 minutes of fascinating discussions.

9. **FIU Pedestrian Bridge Collapse, Florida>**. Presentation by Akram Malik at fibUK event 'Learning from failures'.

10. **Structural-Safety (CROSS/SCOSS)>**. Go to the Quick Search box on the home page of the website and enter the keyword 'bridge' which will bring up over 100 reports on matters of concern about bridges.

11. **Network Rail Safe By Design Guidance>**

12. **A Guide to Improving Value by Reducing Design Error>**. Get It Right Initiative.

Acknowledgement

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