# BCA BE Seminar 2022
# Buildings: What Can Go Wrong

# *Lessons Learnt from Bridge Failures*

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# Outline

1. Collapse of the Florida International University (FIU) pedestrian bridge in Miami, U.S. 2018
2. Collapse of a viaduct under construction in Singapore, 2017 *(BE book Chapter 6.6)*
3. Lessons Learnt

# 1.
# Collapse of The FIU Pedestrian Bridge

# The Incident

- 15 March 2018, Miami, Florida, U.S.
- 174 foot long (53m), 950 ton, concrete pedestrian overhead bridge
- 5 workers working on top of the roof, 8 vehicles stopped below,
- 6 victims died, 8 people injured

# Sources of Information

- Investigation report by U.S. Department of Labor, Occupational Safety and Health Administration (**OSHA**) [https://www.osha.gov/sites/default/files/2019-12/2019_r_03.pdf]
- Investigation report by U.S. National Transportation Safety Board (**NTSB**) [https://www.ntsb.gov/investigations/AccidentReports/Reports/HAR1902.pdf]
- Drawings that are publicly available from Florida Department of Transportation (**FDOT**) website [https://cdn2.fdot.gov/fiu/13-Denney-Pate-signed-and-sealed-FIU-bridge-construction-plans.pdf]

**Note**:

- Please refer to the reports in the links listed above for the relevant drawings and photos pertaining to this collapse incident.

# Structural System

- The bridge is not cable-stayed. The steel pipes are not load-bearing elements, but architectural features which can only enhance the dynamic performance of the bridge.
- In elevation, the main bridge structure is in the form of a truss.
- In section, the bridge structure is in the form of an I-section. the Canopy and Deck are acting as the top and bottom flange, and the concrete truss forms the web.
- At the time of the incident, the collapsed span was supported at the two abutment walls.
- The collapse was initiated from North end support

# Structural System

- At the end support, the deck is thickened to form a diaphragm to transfer the load to abutment wall via bearing
- The canopy and deck are pre-stressed along the bridge
- The diagonal struts are also pre-stressed elements using PT bars.
- The two diagonal member 2 & 11 are the last diagonal member joining at the end diaphragm.
- There were 5 workers working on top of the canopy near the north end support. They were carrying out PT works to Diagonal 11.
- Deck slabs are also pre-stressed in transverse direction

# Construction Method

**Accelerated Bridge Construction (ABC)**

- The construction method adopted is Accelerated Bridge Construction (ABC).
- The bridge span was pre-cast at the road side, in stages following a sequence of Deck, Struts, and Canopy, followed by post-tensioning of the cables and PT bars.
- The entire span will then be transferred using the self-propelled modular transporter (SPMT) to its position for erection.

# Deficiencies in Design – 1

**No Redundancy**

- **OSHA Assessment:**
  - **The structure of the main span was determinate, and was non-redundant… if one diagonal failed, the entire bridge would collapse…**
  - **Concrete trusses are rare but they do exist. Steel trusses are preferred because steel is ductile and could cope better with incidental flexural forces…**

# Deficiencies in Design – 2

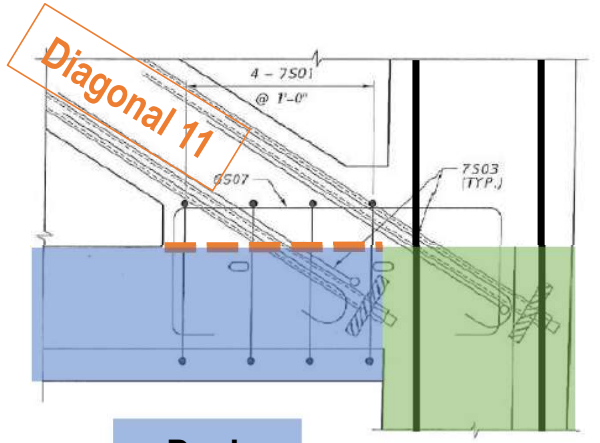
**Inadequate Interface Shear Transfer**

- **OSHA Assessment:**
  - **The interface was not "intentionally roughened"**
  - **Other than the rebar in vertical member 12, rebar crossing CJ did not have adequate embedment.**

| Shear along the interface | Demand (kips) | Capacity (kips) | Ratio |
|---|---|---|---|
| Bef. **Re-tension PT bars** | 1,106 | 906 | 1.22 |
| Aft. **Re-tension PT bars** | 1,579 | 1,086 | 1.45 |

**Cause of the cracks**

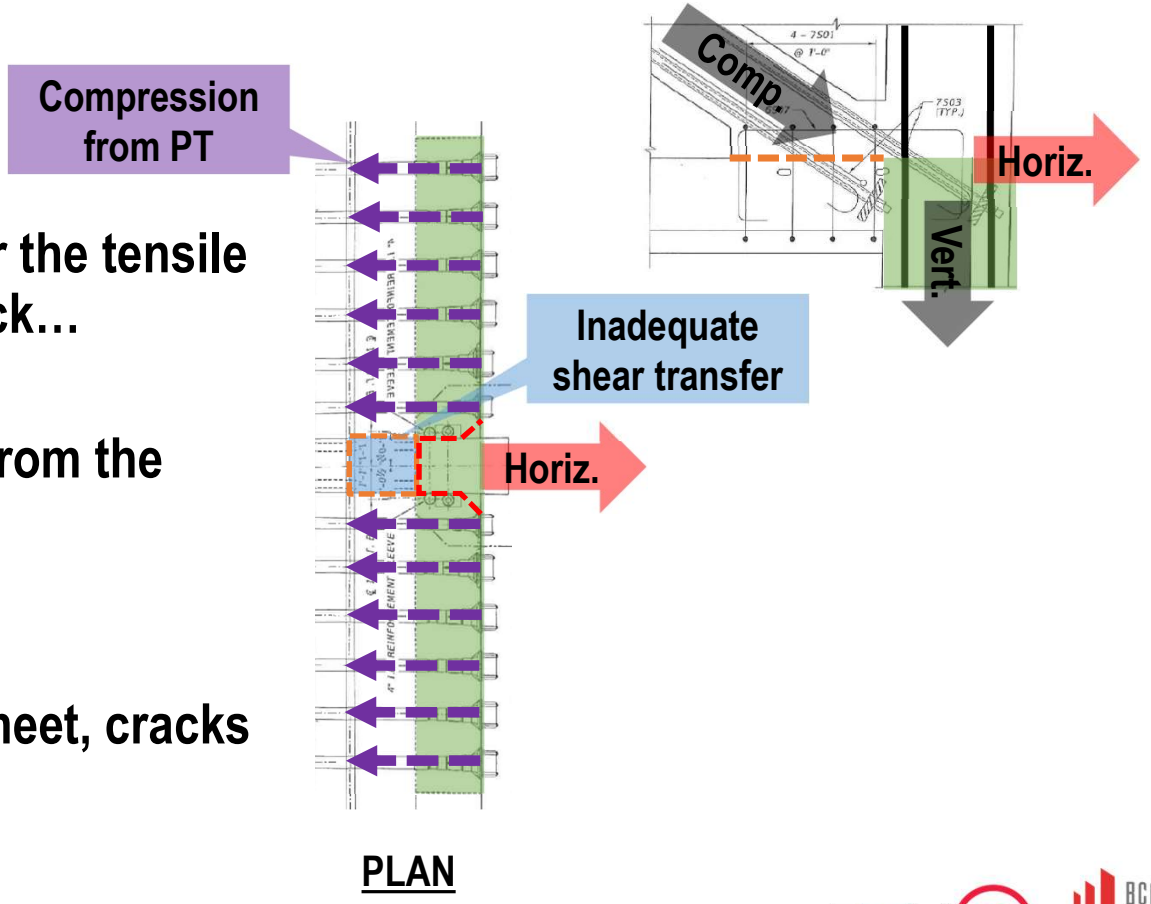
**Triggered the failure when worker re-tension the PT bars**



# Deficiencies in Design – 3

- **OSHA Assessment:**
  - there is no mechanism to transfer the tensile force from the diagonal to the deck…
  - the PT tendons are placed away from the junction…
  - at the 45 degrees line where the compression and tension areas meet, cracks would appear…

**Inadequate Tension Transfer at Joint**




PLAN

# Deficiencies in Design – 3

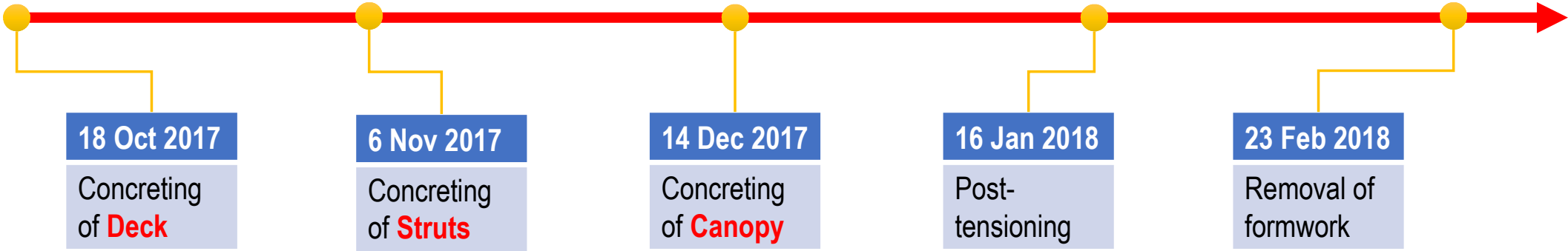
**Inadequate Tension Transfer at Joint**

- **OSHA Assessment:**
  - **Diaphragm II experienced a blow-out of concrete at the junction of diagonal 11 and column 12…**

# Inadequate Peer Review

- According to OSHA Report:
  - The peer review fees and time to conduct the review were rather constrained…
  - Due to the limited resources, the peer reviewer created a scope of work without checking the intermediate stage… (check permanent condition only)
  - The entire review was conducted by one engineer without any assistance from others…

# Failure to Identify and React to Cracks



# Failure to Identify and React to Cracks

**26 Feb 2018**

- Cracks observed at both ends
- Builder reported to Engineer

**7 Mar 2018** 1

- Engineer responded with "**no concern expressed**"

**10 Mar 2018**

Bridge transported by SPMT*

***Self-Propelled Modular Transporter**

# Failure to Identify and React to Cracks

**10 Mar 2018**

- Bridge in position
- Destressing PT bars
- Cracks appear at diaphragm

**12 Mar 2018**

- PT Specialist and Builder informed the Engineer

**13 Mar 2018** 2

- Engineer responded with "**no safety concern**"
- Engineer advised the Builder to **re-tension** PT bars in diagonal 2 & 11

| Shear along the interface | Demand (kips) | Capacity (kips) | Ratio |
|---|---|---|---|
| Bef. **Re-tension PT bars** | 1,106 | 906 | 1.22 |
| Aft. **Re-tension PT bars** | 1,579 | 1,086 | 1.45 |

# Failure to Identify and React to Cracks

**14 Mar 2018**

- Builder sent photos of **enlarged cracks** to Engineer

3

- Engineer analysed the cracks in office

- PT specialist asked the Builder to seal the cracks first
- Builder rejected, and instructed the PT specialist to proceed with the re-tensioning works

# Failure to Identify and React to Cracks

**15 Mar 2018, 7.45am**

- The PE inspected the cracks

**9.00am** 4

- The Engineer had meeting with project team and informed that
- "**No safety concern**. Spalled areas are minor"
- There's inadequacy at node to strut 2 & 11, but **did not recommend shoring**

**Around noon**

- PT specialist started re-tensioning work

**1:47pm**

- Bridge collapsed

# Actions should have been taken

- OSHA Advised:
  - Rescind the instructions to re-tension the PT bars in diagonal 11.
  - Recommend closing the Street, and shore the truss.
  - Determine the cause of the cracks.
  - Perform re-evaluation of its design with an independent peer review.
  - Carry out remedial measures.

# OSHA Concluding Remarks on Project Parties

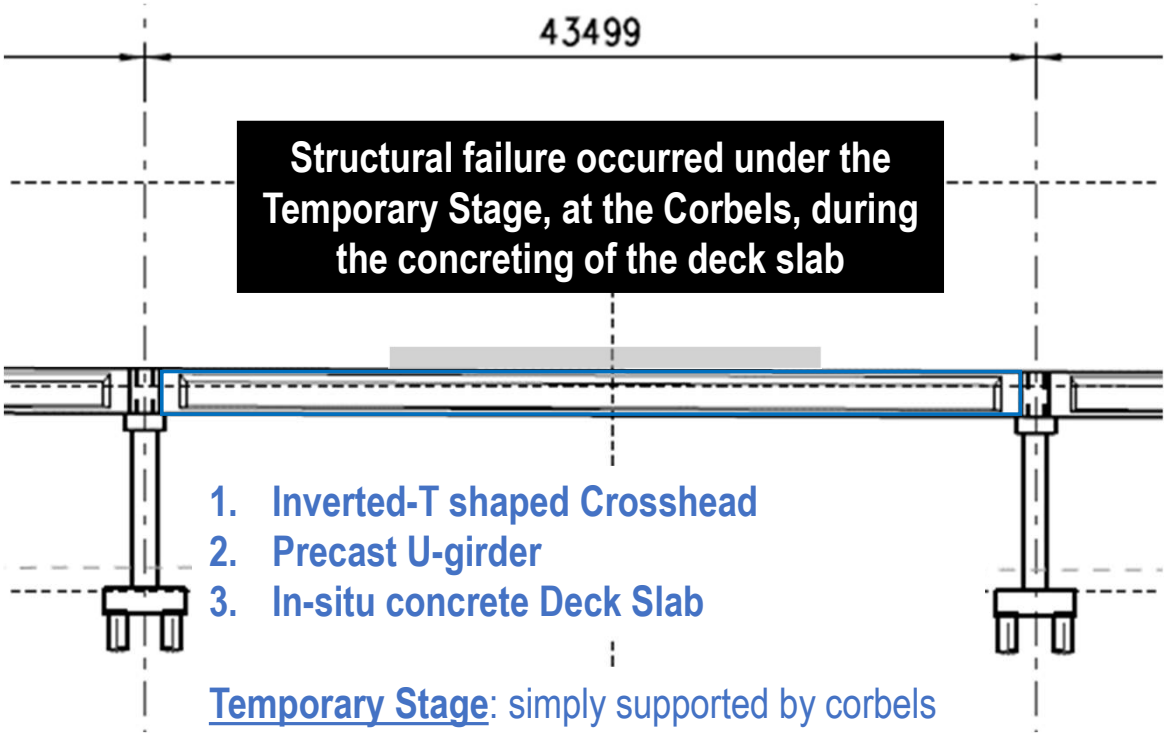
| Role | In SG Context | Key Conclusions |
|---|---|---|
| General contractor (Design-Build) | (Builder) | • failed to exercise its own independent professional judgement to close the traffic on SW 8th Street |
| Structural Engineer of Record (**EOR**) | (QP) | • failed to recognise that the bridge was in danger of collapsing when it inspected it hours before the collapse<br>• structural design deficiencies |
| Independent peer reviewer | (AC) | • did not check the structural integrity of the bridge under different construction stages |
| Construction Engineer and Inspector (**CEI**) | (Supervision Team) | • failed to classify the cracks, which were structural<br>• did not recommend to close the street and shore the bridge |

# 2.
# Collapse of A Viaduct Under Construction

# The Incident

- 14 July 2017, Singapore
- 43.5m span
- During concreting of the deck slab
- 1 worker was killed, 10 others injured

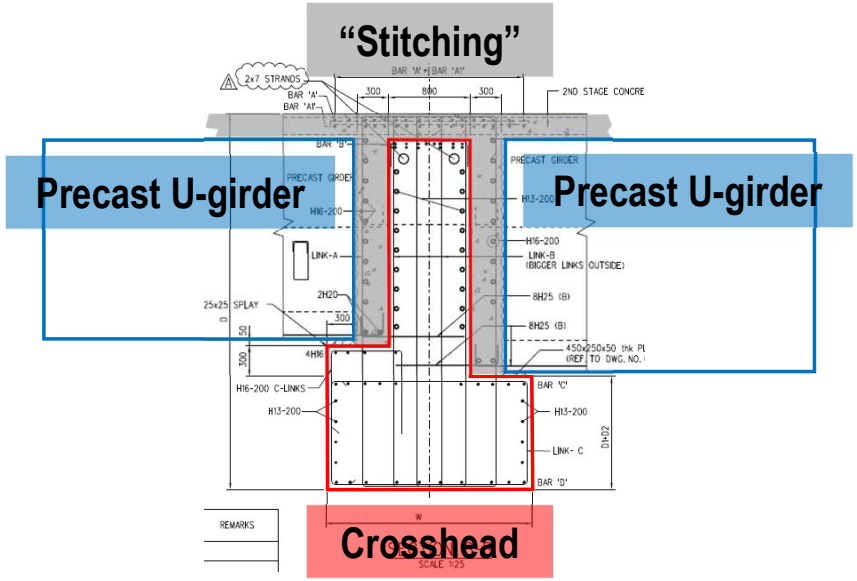
# Structural System

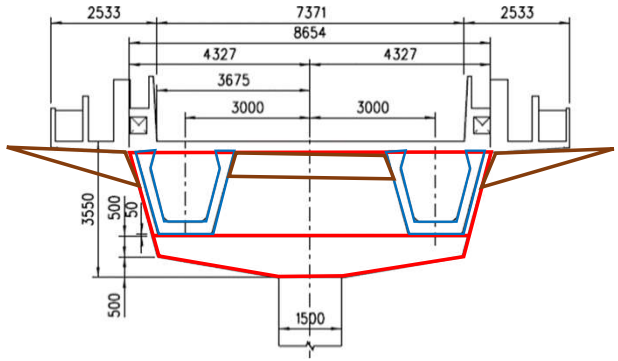



**Structural failure occurred under the Temporary Stage, at the Corbels, during the concreting of the deck slab**

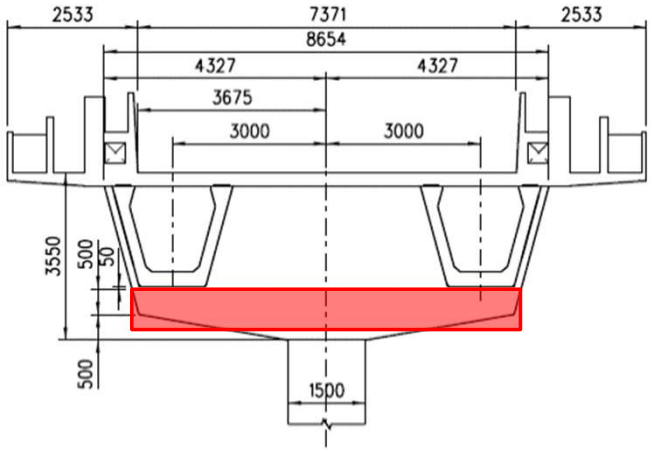
1. **Inverted-T shaped Crosshead**
2. **Precast U-girder**
3. **In-situ concrete Deck Slab**

**Temporary Stage**: simply supported by corbels
**Permanent Stage**: monolithic joint with crosshead



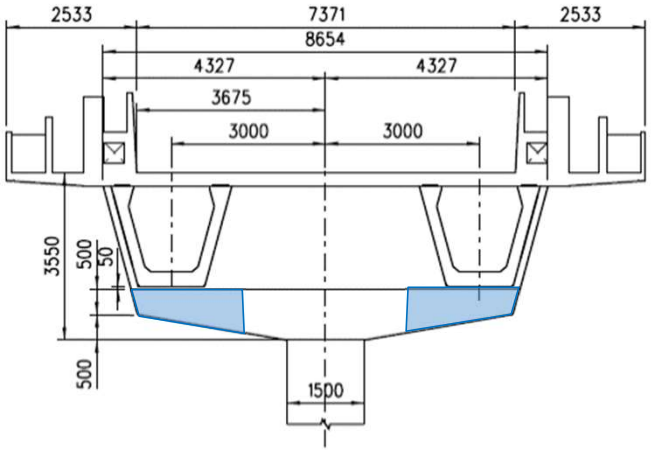



# Deficiencies in Design – Temporary Corbel




**Approach adopted in QP's design**

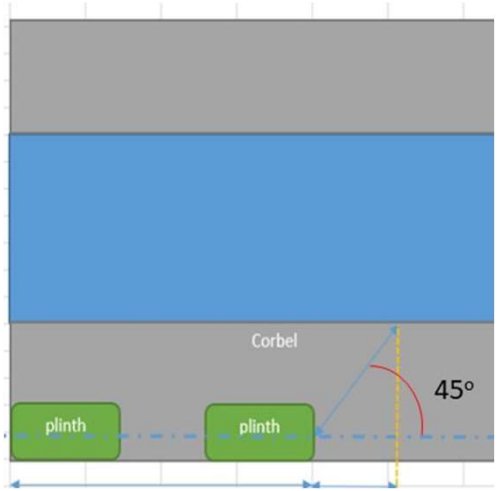
- *Overestimated the width and depth of corbel*




**Approach recommended in textbooks**

- *Reinforced Concrete Design to BS 8110 Simply Explained (A.H. Allen)*
- *Reinforced Concrete: Analysis and Design (S.S. Ray)*

# Deficiencies in Design – Temporary Corbel




**PLAN**

| Stage/Load Type | Check | Load Factor & Material Fcator | As Provided (mm2) | As Required ($mm^2$) | CDR |
|---|---|---|---|---|---|
| Launch (Girder Self Weight Only) | EC Compliance (Factored) | 1.35 (DL), $\gamma_s$=1.15, $\gamma_c$=1.5 | 1810 | 2815 | 0.64 |
| | No Load or Material Factor | - | 1810 | 1773 | 1.02 |
| At Collapse (Self weight+Const'n Live Load) | No Load or Material Factor | - | 1810 | 2783 | 0.65 |

Any signs of distress?

**Assessment Result**

- With the self-weight of the precast U-girder, the corbel was barely adequate if we remove all the load and material factors
- The corbel did not have enough capacity to support additional load from the casting of the deck slab

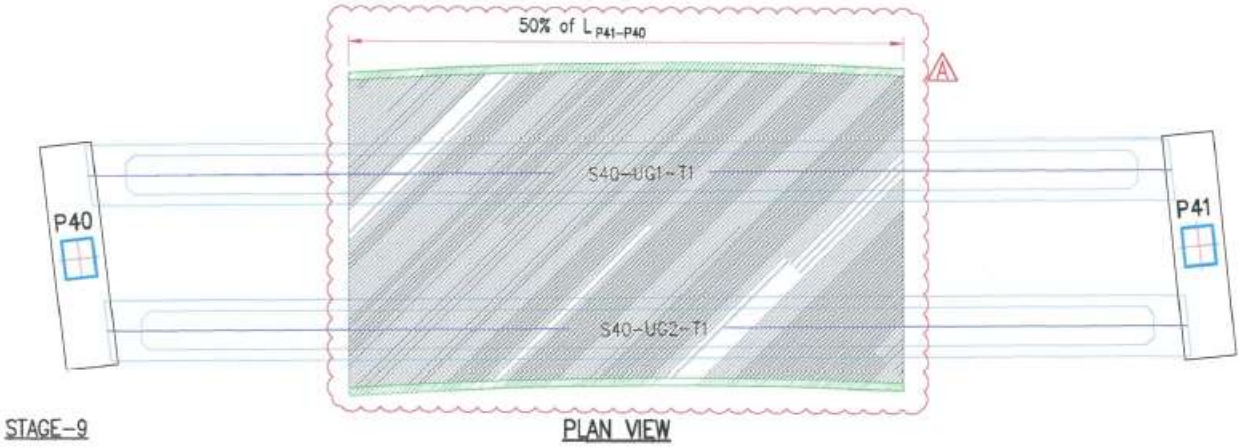
# Cracks Observed

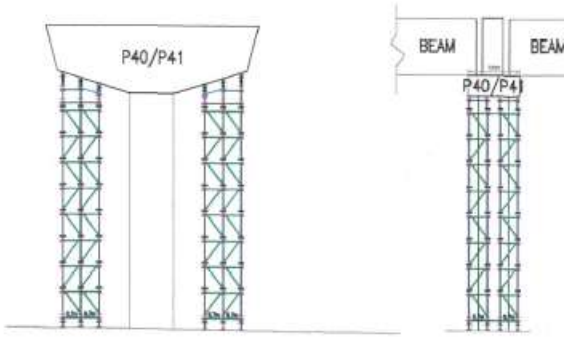
- **Cracks on corbels were observed at adjacent piers before the construction of deck slab at the collapsed span.**


Extracted from LTA's media statement dated 21 July 2017

# Remedial Measures

- **The measures prescribed by the QP could not arrest the design deficiency of the corbels.**




1. **Reducing the area of deck slab from 75% to 50% of span length**

2. **Adding shoring below the crosshead and corbel**

# 3.
# Lessons Learnt

- **Provide redundancy and robustness, esp. for complex structure/construction.**

- **Pay extra attention to load transfer mechanism and provide proper detailing at critical joints. Bespoke design and details are required; and not to use plain standard details.**

- **Take structural cracks seriously, and provide precautionary measures promptly.**

- **Works should not continue until the cause of cracks is determined and the required rectification is completed.**

# Final Remarks

- Bridges are often long-span and post-tensioned structures. Such structure requires specialist experience and knowledge in design, fabrication and construction for safe execution of the project.
- Bridge structures has less redundancy in nature, and could be less robust during the construction stage.
- Everyone should be more vigilant in design, checking, and execution of bridge construction.
- Structural safety should not be compromised under cost and time pressures.

# Thank you

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