SMAR 2019

Performance Assessment of Transversely Stressed Deck Unit Bridges with Damaged Transversely Stressing Bars through Field Measurements

Hanson NGO [1], Matthew HOURIGAN [2], Neal LAKE [1]

[1] Australian Road Research Board, Brisbane, Australia

[2] Queensland Department of Transport and Main Roads, Brisbane, Australia

Contact e-mail: hanson.ngo@arrb.com.au

ABSTRACT: Load testing was conducted on a decommissioned deck unit (DU) bridge span in Queensland, Australia, to investigate the effects of defective transverse stressing bars (TSB) on bridge performance under live loads. The 16 metre simply-supported bridge span tested consisted of multiple adjacent precast prestressed deck units (voided planks) sitting on concrete portal frame piers. The span was constructed by installing the DUs next to each other, filling the gaps between them with grout and tying them laterally with 29 mm diameter prestressed TSBs at every 2.0 metres along the span. A typical 80 mm thick asphalt wearing surface was laid directly on top of the DUs. For this type of bridge, the load transfer mechanism between the DUs has not been fully understood and accurately quantified due to the presence of the upstanding stiff edge beam, the mortar joints between DUs (no shear-keys), and a low level of transverse stressing. It is, therefore challenging to accurately estimate the capacity of the bridge, particularly when some TSB are damaged (e.g. due to corrosion, missing in construction, or removed during a bridge rehabilitation process).

In this investigation, different levels of damage were introduced to the TSB by severing the TSB at various locations throughout the bridge deck. In each damage stage, the response of the bridge span (strain and deflection) was measured while a 62.5 tonne semi-trailer test vehicle travelled back and forth across the bridge at crawling speeds to eliminate dynamic effects.

Key findings of this invesigation include: (i) the mortar joints provide the main lateral load transfer capacity under serviceability loads; (ii) the TSBs contribute to maintain the integrity of the mortar joints; (iii) failure of the system may propagate under service loads.

1 INSTRUCTION

Transversely stressed precast concrete deck unit bridges (TSDUB's) have been in service since the late 1950's and represent a dominant and large portion of the road bridges in Queensland for small and medium spans. Different from the multibeam bridges used widely in other parts of the world which are usually constructed with shear keys, top concrete slab overlay and with or without transverse stressing (West 1973, Badwan and Liang 2007), the TSDUBs have a unique configuration with the presence of the upstanding stiff edge beam, the mortar joints filling the vertical gap (of constant width) between units, no top concrete slab and a low level of transverse stressing. While the structural behaviour of the former has been reasonably well predicted using conventional approaches (Hulsbos 1962, Hambly 1991, Fu, Pan and Ahmed 2011, Obrien et al. 2014), the lateral load transfer mechanism of the latter has not been fully understood and accurately quantified. It has been challenging to accurately estimate the capacity of the bridge, particularly when some TSB are damaged (e.g. due to corrosion, missing in construction, or removed during a bridge rehabilitation process).

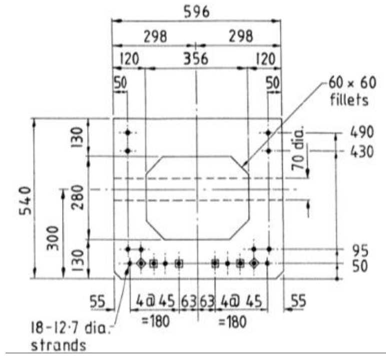
The proposed deconstruction of the Sandgate Road Northbound Bridge (BIS 8558) provides an opportunity to destructively test a real-life TSDUB structure. To probe the effects of TSB damage on the behaviour of the bridge superstructure, a load test program was implemented in March 2017, including controlled load testing and in-service monitoring of one span of this bridge. Damage to the TSBs on the span under investigation was induced incrementally during the test regime.

This report presents the details of the testing program and discusses the results obtained from high-resolution measurements of the bridge response, both prior to and during the stages of incremental TSB damage.

2 BRIDGE DESCRIPTION

Constructed in 1985, the structure consists of ten simply-supported spans, with a span length of between 14 and 18 m. With a span length of 16 m, the test span was constructed using 15 prestressed precast concrete, voided DUs (Figure 1a). These DUs have a rectangular cross-section of 600 mm wide and 540 mm high, which were transversely post-tensioned by 29 mm diameter TSBs located at the mid-depth of the DUs (Figure 1b). Spacing every 2 m along the length of the span, the TSBs were post-tensioned with a force of 350 kN typical for each bar. Between the vertical flat sides of adjacent DUs, a thin layer of mortar (25 mm typical) was poured before tensioning the TSBs. Typically, an 80 mm thick asphalt layer was laid on top of the DUs for use as the deck wearing surface. A carriageway width of 8.5 m carries two lanes of traffic. All spans have a minor skew of 13°. The substructure comprises concrete headstock sitting on cast-in situ concrete piles.

(a) View of the tested bridge span from underneath



(b) Typical cross-section of a deck unit

Figure 1. View of the tested bridge span.

3 TEST PROGRAM

The deck in Span 9 was instrumented with 87 sensors located at the midspan and one quarterspan sections to measure the following:

- strains in the concrete at the top and bottom of the DUs using foil-type strain gauges
- "opening" of the mortar joints using proximity probes located between adjacent DUs

- vertical deflections of each DU using string potentiometers.

A proof load vehicle of a 6 axle semi-trailer configuration (1-2-3) was used for the test program. The axle mass was altered during the testing regime to provide three load levels including 42.5 t, 62.5 t and 82.5 t. These load levels were used to test the bridge in the "undamaged" stages, i.e. before applying damage to the TSBs (D01, D02 and D03, respectively). For the damaged stages, only the 62.5 t truck was used. The test data was recorded at a sampling rate of 100 Hz. The test truck was scheduled to cross the deck with a "walking speed" along two paths including the bridge centreline and a lane centreline (which is 1.0 m offset from the bridge centreline).

Damage was gradually applied to the TSBs on Span 9 by severing the TSBs in seven stages (D1 to D4C) as graphically presented in Figure 2. A 1.0 m diameter rotary blade was used to cut the TSB through the mortar joint from the top of the deck. The damaged stages were applied in the following sequence:

- D1 (red): TSB5 was cut at 2 locations (between DU6 and 7 and DU13 and 14)
- D2 (yellow): TSB4 and TSB6 each was cut at 2 locations (DU6-DU7 and DU13-DU14)
- D3A (green): TSB1-TSB3 each was cut at 2 locations (DU6-DU7 and DU13-DU14)
- D3B (dark green): TSB7 and TSB8 each was cut at 2 locations (DU6-DU7 and DU13-DU14)
- D4A (pink): TSB5 was cut further at all remaining mortar joints (between units)
- D4B (blue): TSB7 was cut further at all remaining mortar joints (between units)
- D4C (purple): TSB4 was cut further at all remaining mortar joints (between units).

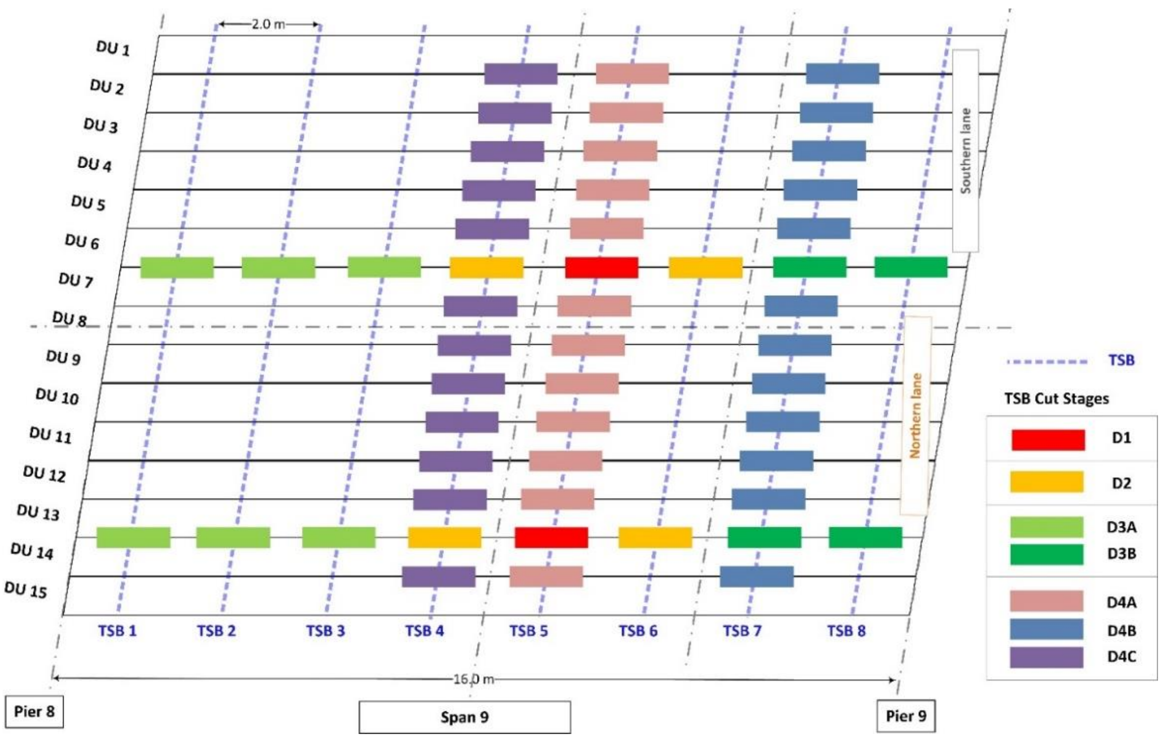


Figure 2. TSB damaged stages.

4 TEST RESULTS

4.1 Distribution of strains

A heat map was used to present the intensity of strains measured. An example is provided in Figure 3 for the damaged stage D3B, where the vertical axis shows the strains in με recorded on 15 strain gauges installed at the soffit of the DUs at the midspan section, while the horizontal axis shows the time elapsed when the test truck crossing the span.

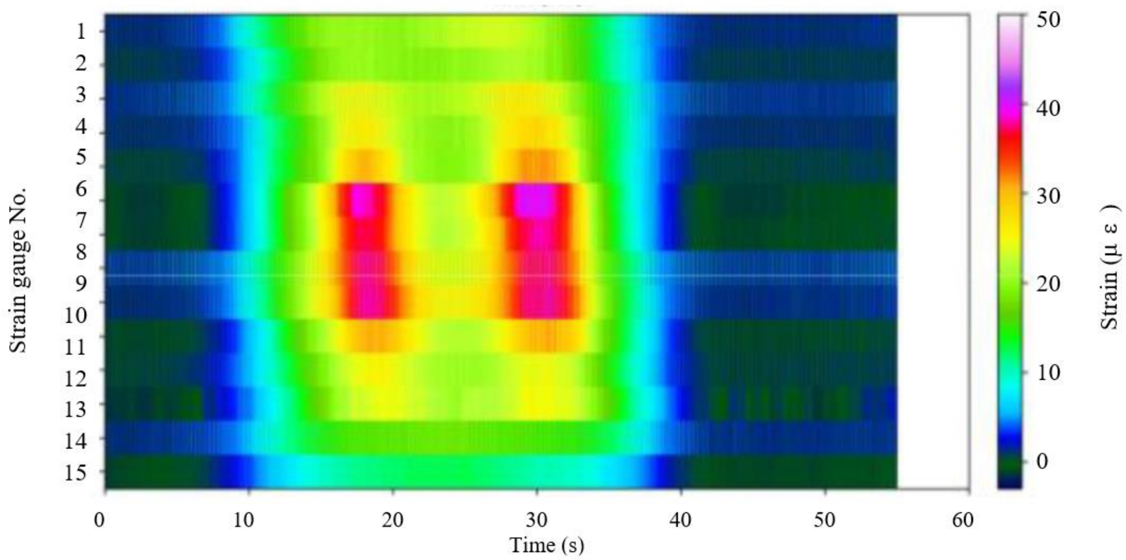


Figure 3. Strain intensity map for the damaged stage 3DB.

Using the strain intensity maps, the changes in the amount of strain taken by each DU between several selected stages including D02, D2, D3B and the last damaged stage D4C are shown in Figure 4. The following observations were made:

- In the undamaged stages (before severing TSBs), the strain under increased truck loading underwent a linear increase across all DUs. The distribution pattern did not change when the load changed from 42.5 t to 62.5 t and to 82.5 t, while the strain in each DU increased by the same fraction.
- On the other hand, as TSB damage was introduced, the strain distribution pattern varied between adjacent units, and the changes became more significant as the TSBs were severed in more locations. At the damaged stage D2, the central DUs, DU7–10, were already taking approximately 25% more load than in the undamaged stage. At the last stages of TSB severing (D4B to D4C), the middle units, DU6–12 appeared to take all the loads.
- The maximum tensile strain (54 με) was reached with the heaviest load in D03, i.e. when the 82.5 t truck crossed the undamaged bridge. In the presence of TSB severing, the maximum tensile strain (εmax) recorded by the most loaded DU was 50 με (DU7) at stage D4C. This value was 32% greater than the strain measured under equivalent load in the undamaged state (D02).

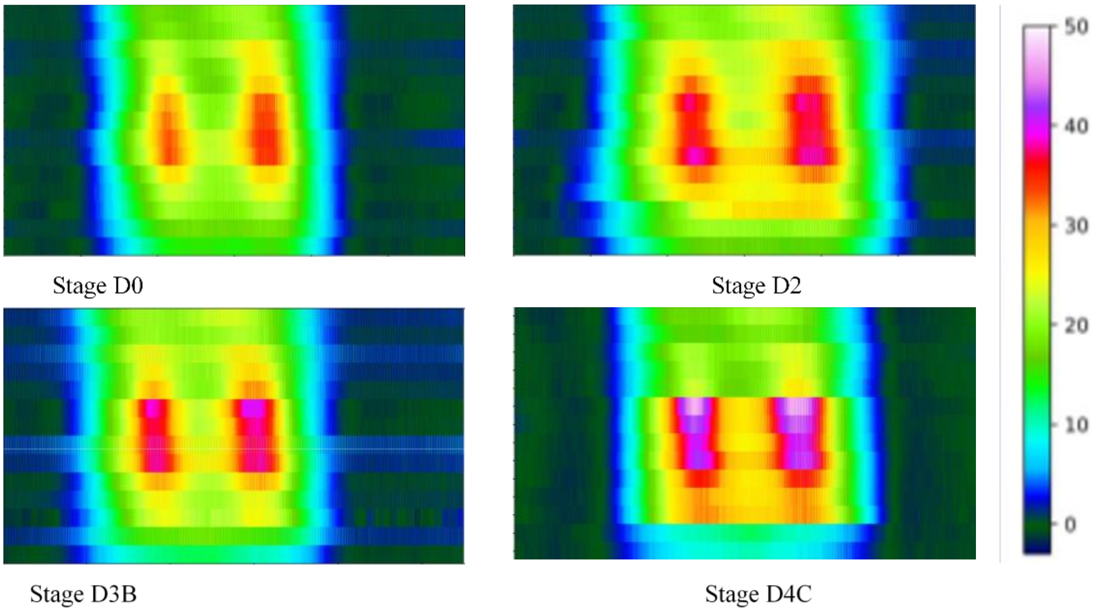


Figure 4. Strain intensity maps for selected damaged stages.

4.2 Deck deflection

The maximum measured deflection was 3.5 mm in stage D4C for DU7. The data from D1 to D4C could be fit either with a bilinear (as seen for load distribution factor (LDF) values in Figure 4) or a linear fit. However, an overall increase was measured with the gradual TSB damage, with a final deflection of 30±8% greater than the correspondent measurement in the undamaged stage. Similar to the maximum strains, the deflection associated with the final damaged stage was close to that measured in D03, i.e. under a load that is 30% greater than what was used in D4C.

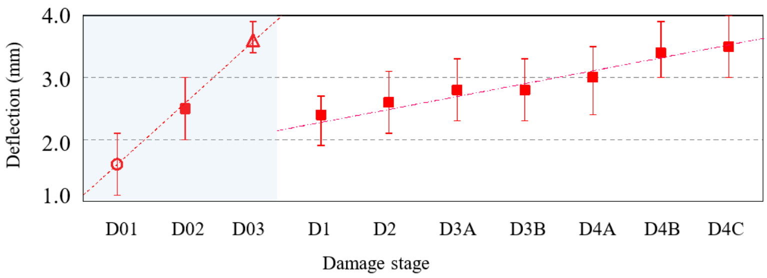


Figure 4. Maximum deck deflection for selected damaged stages.

4.3 Lateral load distribution

Figure 5 shows the distribution of the LDF values derived from the load tests (hollow blue squares). For consistency, all considered tests were carried out with the test truck running along the central path. The truck load associated with each test is indicated on the top horizontal axis. The LDF values are superimposed with the maximum strains measured during each considered test (red stars), under a truck load of 62.5 t. The maximum strains derived for the initial runs of the 42.5 t and 82.5 t loaded truck are indicated by a hollow red circle and a hollow red triangle, respectively. The error bars attached to the strain values indicate the measurement drift before the baselining process. Fits of LDF values for increasing TSB damage are shown by the blue dashed line, for stages without or with minor damage (D0–D3A), and by the black dashed line for stages of significant TSB damage (D3B–D4C). The green-shaded region highlights the testing stages without TSB damage.

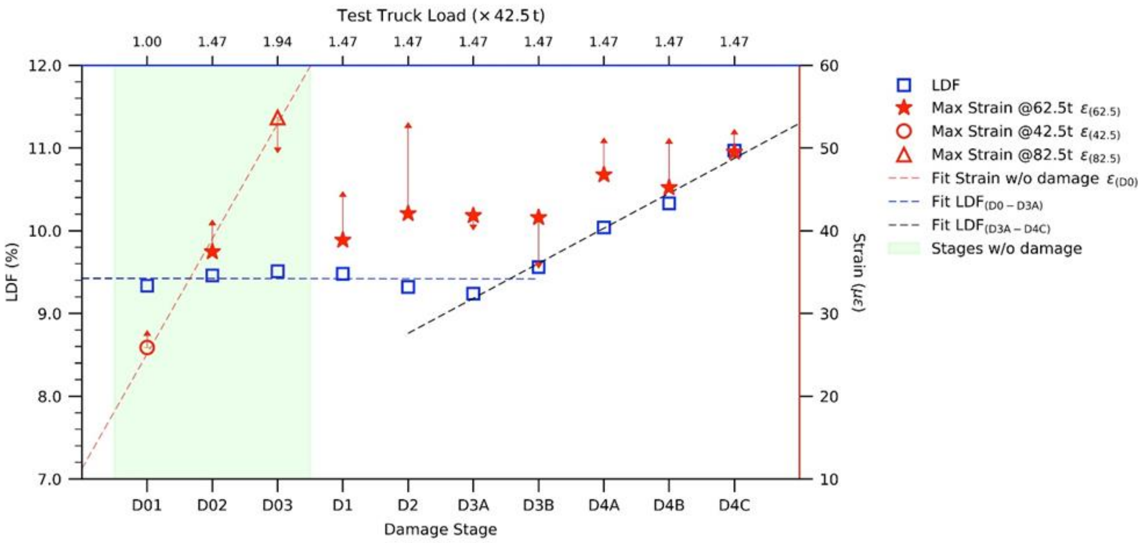


Figure 5. Live load distribution.

It was found that the maximum LDF measured was 11% in the last damaged stage (D4C). The LDF increased by 18% from the undamaged stage to the last stage of TSB severing. The increase in LDF was evident only when the TSB severing was carried out in several longitudinal locations (D3A). The most loaded DUs, after extensive TSB severing (D4C), carried approximately 20% more load than in the undamaged stage.

5 DISCUSSION

It should be noted that the TSB damages were applied during the testing regime, i.e. with a short-term nature. In light of the above findings, the following comments are made

- During the testing regime, the test vehicle travelled back and forth on the bridge in a short period of time. Therefore, the behaviour of the bridge superstructure was investigated with a very low number of load cycles (about 60 runs in 2 days).
- When a TSB was severed, the mortar joint area on top of the TSB was also cut (noting that a 1.0 m dia. rotary blade was used to saw cut the mortar and TSB). The mortar joints away from the cutting areas remained intact, therefore they still contribute to the load transfer mechanism between the DUs.
- In the final testing stage (Stage D4C – see Figure 2), all bars along 2 mortar joints (out of 14 joints) and all joints along 3 TSBs (of out 8 TSBs) were cut. The reduction in the area of mortar along a joint is 34%. In comparison to the whole deck, the reduction in the area of mortar joint is 16%.
- In addition, observations from a destructive load test of a partial TSDUB in laboratory (Ngo and Mir 2017) indicate that the TSBs did not engage in taking load at service load levels (due to its location at the mid-depth of the DUs). They only started taking loads at

very high load levels which are close to the ultimate load. Therefore, at service loads, the main transverse load transfer component was the mortar joint.

- Given the above observations, for Sandgate Rd at the final testing stage (Stage D4C – see Figure 2), there were still substantial areas of mortar joints that remained intact. The stiffness in the transverse direction which relies on the mortar joints was still sufficient for the load transfer between the DUs. Therefore, it supports the observations and measured data from the tests.
- However, it is likely that the integrity of the uncut TSB sections and mortar joints would be lost gradually under the dynamic impact of traffic, should the bridge continue to be open for traffic after the test was completed. Since the TSBs were already cut, there was nothing to hold the units together, and further failure of the mortar joints would likely propagate from the cutting areas under service loads. The DUs would eventually work individually and might fail under service loads.

6 CONCLUSIONS

The effect of the applied TSB damage on the behaviour of a simply-supported TSDUB was investigated via controlled load testing of one span of Sandgate Road Bridge. The load tests were performed during a short period of time on the undamaged superstructure and when damage was incrementally applied to the TSBs on the span under investigation. The controlled load test data were analysed to assess the changes in the behaviour of the bridge superstructure due to various levels of damage applied to the TSBs during the test regime. Key findings from this investigation include:

- The induced damage on the test span led to (i) TSBs were cut, and (ii) the mortar joint areas surrounding the severed TSBs were lost. As observed from the test results, the incrementally induced damages resulted in a reduction in the overall capacity of the structure, as well as an increase in the measured structural responses and a reduction in the lateral load distribution. Apparently, the loss of the transverse prestress and damage of the mortar joints at various locations resulted in the reduced level of structural integrity and the onset of propagation of failure of the lateral load transfer mechanism.
- The changes in the load transfer between the DUs in different TSB damaged stages are proportional to the reduction in the areas of mortar joints rather than on the level of the applied TSB damage. This is due to the fact that the mortar joints between the DUs are the key contributor to the transverse load transfer mechanism between the DUs. The reduction in the mortar joint areas in different damaged stages is insignificant in comparison to the total remaining intact mortar joint areas. As a matter of fact, a substantial portion of the mortar joint areas (86%) still remained intact at the most damaged stage.
- The integrity of the mortar joints plays a critical role in the transverse load transfer mechanism of the bridge superstructure, while the TSBs provide the integrity of the mortar joints under loads. For a deck unit bridge with TSB deficiency, damage to the mortar joints is highly likely due to some overload events. This damage would propagate further under service loads. Eventually, the mortar joints would be lost to a state in which each DU carries loads separately, i.e. a transverse load transfer mechanism is no longer present. The integrity of the overall structure would be lost, and the overall capacity of the structure would be dependant on the capacity of each individual deck unit, that may result in structural failure under service loads.

7 REFERENCES

Badwan, I, and Liang, RY (2007). Transverse post-tensioning design of precast concrete multi-beam deck. *PCI Journal*, 52 (4): 84-92.

Fu, CC, Pan, Z. and Ahmed, MS (2011). Transverse posttensioning design of adjacent precast solid multi-beam bridges. *Journal of Performance of Constructed Facilities*, 25 (3): 223-30.

Hambly, EC (1991). *Bridge deck behaviour*, 2nd edn, CRC Press, Boca Raton, FL, USA.

Hulsbos, CL (1962). Lateral distribution of load in multi-beam bridges. *Highway Research Board Bulletin*, 339, 67-79.

Ngo, H, and Mir, F (2017). Destructive load testing of transversely stressed deck unit bridges. *Austroads bridge conference, 10th, 2017, Melbourne, Victoria*, ARRB Group, Vermont South, Vic, Australia.

OBrien, EJ, Keogh, DL, O'Connor, AJ and Lehane, BM (2014), *Bridge deck analysis*, *2nd Edition*. CRC Press, Boca Raton, FL, USA.

West, R (1973). Recommendations on the use of grillage analysis for slab and pseudo-slab bridge decks. *Cement and Concrete Association*, London, UK.