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# Dynamic testing of long term performance of tek screws for the Legacy Way Tunnel project, Brisbane

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## Abstract

Legacy Way is Brisbane City Council's 4.6km road tunnel that will connect the Western Freeway at Toowong with the Inner City Bypass (ICB) at Kelvin Grove constructed by Transcity Joint Venture.
The tunnels were driven from west to east requiring below ground box structures to facilitate TBM launch and TBM extraction respectively constructed with the Cut and Cover method. Tek screws are used to fix fireboards to the steel support structure as part of the internal fit-out. This paper describes the dynamic testing required to proof the long term performance under reoccurring wind pressure loading by trucks.

## Introduction

As part of the Legacy Way tunnel project in Brisbane the construction joint venture Transcity comprising Acciona, Ghella and BMD designed and constructed the ventilation system. In the cut and cover structures at either end a steel support structure is used supporting fireproof board to withstand a 2hour hydrocarbon fire. Due to alternating pressure from trucks passing under and along the fireboards, the boards and their supports are dynamically loaded which could eventually result in a fatigue failure. In particular the tek screws used to fix the fireboards to stainless steel purlins were prone to wearing out. This was of particular concern for the overhead boards as a failure of the connections could result in dropping of boards resulting in accidents.

It was decided to carry out testing of the tek screw connection in a real-life model with an as accurate as possible load regime. It was planned to finally test the specimen to its ultimate strength.

## Design of loading

Several international standards have been investigated to verify the most applicable loading.

### Department of Main Roads Queensland (TMR)

The Department of Main Roads provides a technical specification for the design of noise fences (MRTS 15) which requires a 0.65kPa load representing suction imposed by moving vehicles.

### German Guideline for tunnels (ZTV-ING)

The guideline suggests to account for suction/pressure on panels of 0.8kPa for a cross section of 43m$^2$ and smaller.

### AASHTO (American Association)

AASHTO provides guidance for truck-induced gust with the following parameters. V is the truck speed, $C_d$ a drag coefficient and $I_F$ an importance factor. Although the application of a drag coefficient does not apply to a continuous surface, like the tunnel fit-out surface, it was considered a conservative approach for the design. As per AASHTO $C_d$ in this application is considered with 1.7 and $I_F$ is considered with 1.0. The tunnel speed is posted with 80km/h (22.22m/s). Therefore, the resulting pressure is:

$$P_{TG} = 900\, C_d \left(\frac{V}{30\frac{m}{s}}\right)^2 I_F = 839\, Pa \qquad (1)$$

The fireboard panels are typically 1220mm × 2400mm but the number of support beams varies. Based on the joist set-out it was found that the maximum loading occurs for a triple span configuration with a 600mm span between joists:

$$F' = 1.25\, P_{TG} L = 1.25\, \times 839 \times 0.6 = 630kN \qquad (2)$$

The tek screw spacing is 200mm and therefore five (5) screws are used for 1 m length. The tek screw force is therefore:

$$F_{tek} = \frac{630}{5} = 125N \qquad (3)$$

## Fatigue loading and test regime

Initially, a loading regime based on the Building Code of Australia (BCA) requirements for roof cladding was considered. Although the specific test is designed for high loads in cyclone areas, it was found not suitable for the requirements of this particular project. The BCA requires a low-high-low pressure test with only 10361 cycles. This is significantly lower than the expected fatigue loading for the screws.

Based on project specific considerations it was found that the fatigue life of the tek screws required for 41.7Mio cycles. However, a fatigue test of 41.7Mio cycles was considered excessive and a test regime with 10% of these movements, i.e. 4.17Mio cycles, was considered reasonable. For Eurocode certification of dynamically loaded screws and bolts 2.0Mio cycles are considered to simulate infinite dynamic loading.

Further discussions on cycles and test load lead to the agreement to allow for a higher load to address lower fatigue cycles. AS 5100.6 provides the detail category 36 for bolted connections. Figure 13.6.1 of the same code provides a S-N-curve to specify uncorrected fatigue strength reduction.

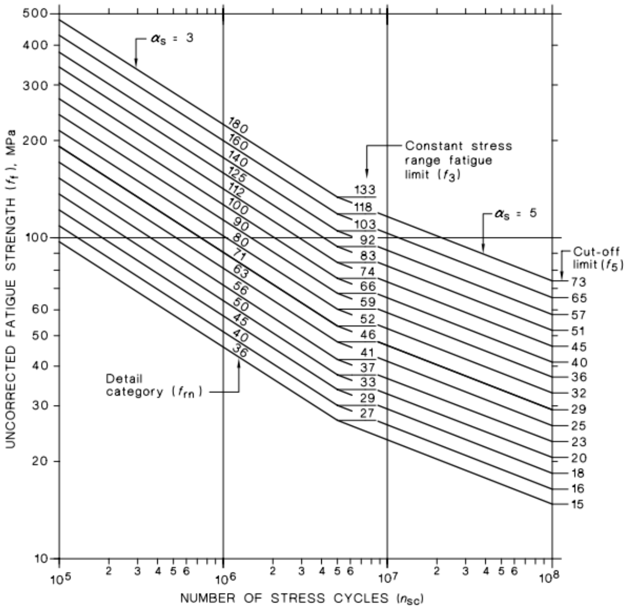

Figure 1.S-N-curve of AS 5100.6

Based on the curve for detail category 36 the uncorrected fatigue strength for 2Mio cycles is 36MPa and for 5Mio cycles 27MPa. Therefore, for 4.17Mio cycles the strength is 29.5MPa. For 100Mio cycles the strength is 15MPa and therefore for 41.7Mio cycles the strength is 22.4MPa. As a result, the strength increase from 41.7Mio cycles to 4.17Mio cycles is 32%. Based on the above calculated tek screws force of 125N the test force would be 165N. It was further agreed to conservatively allow for a 50% load increase and the test load per tek screw was defined to be 250N.

Apart from test load and load regime the tests were based on the BCA requirements and consequently on AS 4040.0, AS 4040.2 and AS 4040.3. Most importantly, a load application speed of 3 Hz was required not to be exceeded. As a result, the test of 4.17 Mio cycles was run for approximately 16 days.

## Description of fireboard support system

The ceiling and wall system comprises structural steel sections with 2.0mm stainless steel purlins (C25020). A detail of the purlin and the system is provided below which shows the ceiling beam (CB) and ceiling joists (CJ).

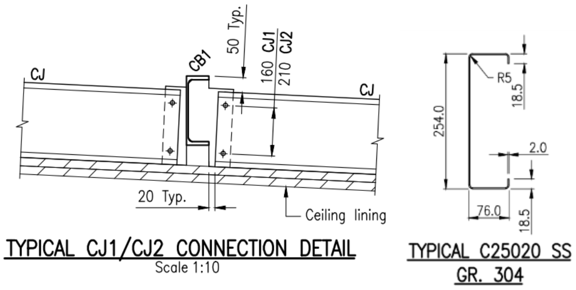

Figure 2.Typical connection detail

The fireboards (promat) are fixed to the purlins with self-drilling and self-tapping bi-metal tek-screws of powers-fasteners. A photo is included below.

Figure 3.Image of self-drilling tek screw

The most important feature of this solution is to fix the fireboards from one side only. This is required as it is not feasible to fix nut and bolt due to the lack of space above the ceiling.

The ceiling boards are typically 1220mm × 2400mm and tek-screws are provided at 600mm centres.

## Test specimen

The test specimen comprised two C25020 ceiling joists, a bridging panel of the size of the purlin flange and a promat board of the dimensions 525mm × 570mm. Three specimens were constructed by the Transcity JV. The first specimen was required for test rig setup and trial and the second for the testing itself. A risk was considered that the tek screws could fail without reaching the design criteria and it was planned to test a setup with spring-washers. This was pre-assembled as a third test specimen.
For the installation of the tek screws it was found to be critical that the torque was limited by a clutch to ensure that the thread does not wear. Checks with a torque meter showed that the torque at installation was approximately 5Nm.
Concept calculations were carried out to define the test rig assembly. Square hollow sections were proposed to load the fireboard. The test load was planned to be resisted by a connection to the top flange. An output of the design model for preliminary calculations is included below.

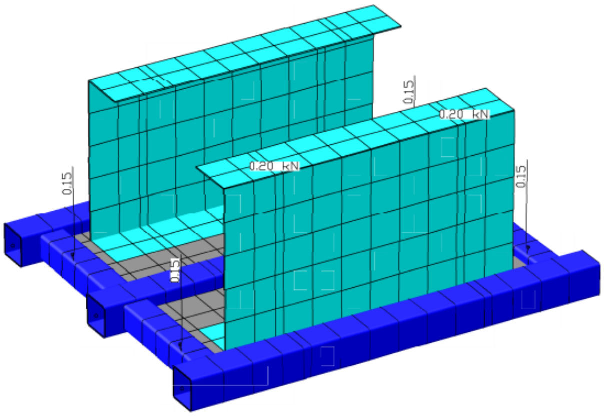

Figure 4.Image of software design model

The testing was carried out at the Cyclone Testing Station in Townsville. The test rig assembly was further discussed and the following arrangement agreed.

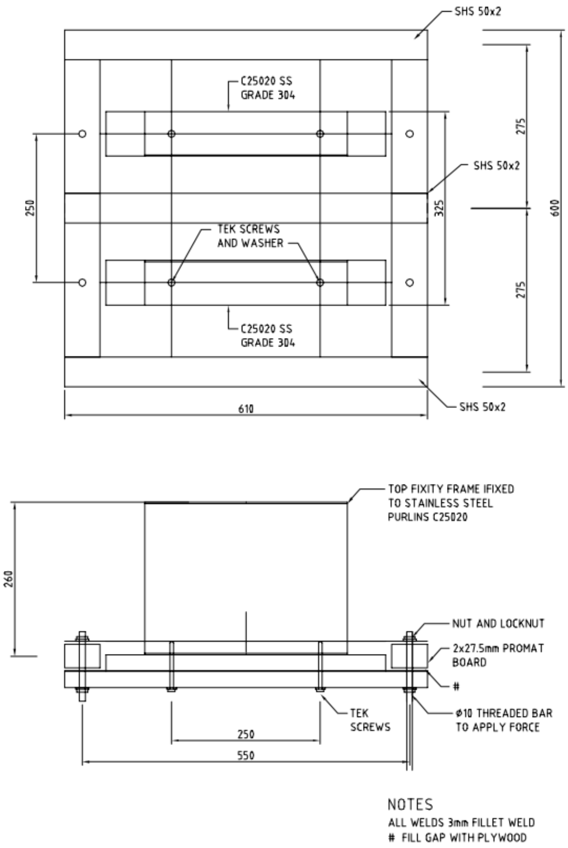

Figure 5.Sketches of test rig assembly

## Fatigue testing

The test specimen was installed in the Cyclone Testing Station's custom pneumatic test facility. The custom pneumatic test rig consisted of a structural steel frame fixed to the strong floor; a pneumatic cylinder attached to the underside of a strong beam with one load cell installed in series to the bottom end of the cylinder rod; and a horizontal steel load frame. The cylinder is driven by a pressure regulated air supply to apply a nominated force to a load frame.

The test assembly comprised four fastener assemblies fixed through two layers of fire board into two steel purlins with two screws per support. Each fastener assembly was marked with a datum line to compare rotational movement during and after the test. The load frame transferred the nominated force to the fire board through three (3) line loads. The line loads were applied to the face of the fire board, using the loading frame driven by a pneumatic cylinder. A load cell measured the applied load on the test assembly.

### Custom Pneumatic Test Facility

The custom pneumatic test facility was designed and manufactured at the Cyclone Testing Station in Townville for the purpose of the fatigue testing. A photo is provided below of the test facility with the test specimen installed.

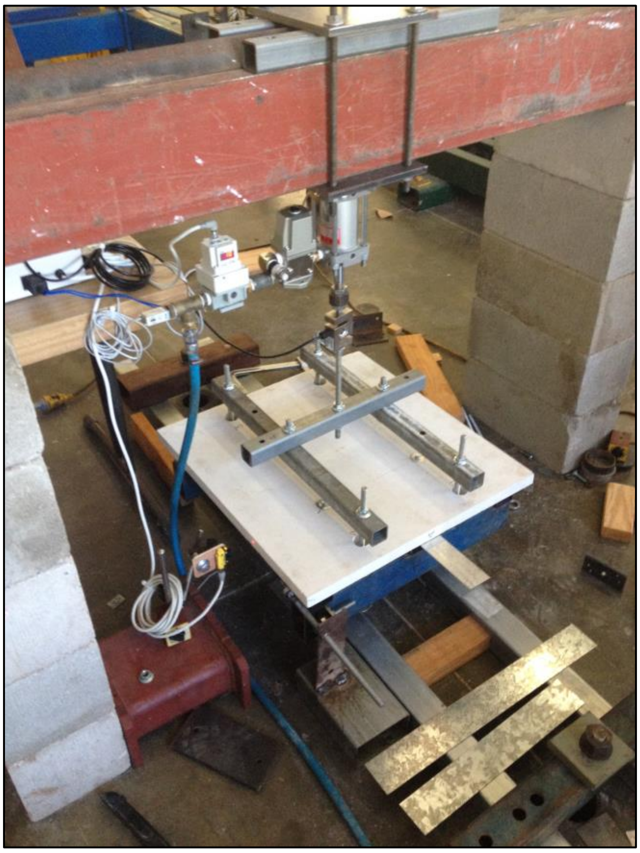

Figure 6.Photo of test rig

The test facility was required to apply the specified load of 1000N and release the load to less than 10% at a frequency of no more than 3Hz. It was important not to release the load completely as this would have resulted in a hammering effect which was not desirable. In addition the test facility was required to control, monitor and log the applied load at all times whilst running autonomously with the ability to safely shut off if the specimen became damaged, providing diagnostics for any stoppages.

In order to achieve all of the requirements, a data acquisition system was integrated into a closed loop control system running from a high power computer operating National Instruments and LabView software. The data acquisition system was used to acquire and log the applied load at all times and the control system had to be custom designed specifically. Some hardware components (including a spring return pneumatic cylinder and valve) had to be custom manufactured in order to meet the operating speed requirement without loss of functionality.

The test rig was setup such that when the cylinder was in an extended position there was a small load applied (greater than 0N but less than 100N). This was achieved by mechanically raising the three line loads. The system then increased the regulated air pressure in appropriate increments causing the cylinder to retract resulting in the three line loads pushing on the test specimen and hence increasing the load. Once the specified load was achieved, the air pressure was logged and the air supply was removed from the cylinder causing it to return to the extended position via the spring installed in the cylinder. The rate at which the cylinder returns to the extended position and hence releases the load applied to the specimen is controlled by a damper. Once a time period had passed the air pressure was then increased to the previously logged value and monitored (and adjusted if required) in order to apply the correct load. This process was continued for the entirety of the test. Watchdogs were implemented within the control system to ensure the load was applied and released at the correct rate.

## Test Rig Performance

The first test specimen was used to commission the custom test rig to ensure all functionality was correct and operational. It was discovered that the two C25020 ceiling joists and square hollow sections that were applying the load had to be accurately levelled using shims in order for the screws to be loaded evenly. The second test specimen was subjected to the entire loading sequence without any unplanned stoppages. A sample of the applied load over a 5 second interval is provided below showing the performance of the test rig applying the specified load to four screws.

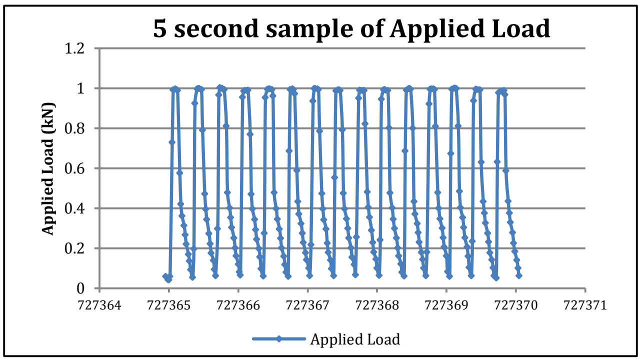

Figure 7.Diagram of applied loads

Throughout the test the screws were monitored for rotation in relation to the datum point marked on each screw and also observed for any gaps appearing underneath the washers.

## Ultimate Load Test

At the conclusion of the fatigue test the same specimen was installed into the Cyclone Testing Station's static test rig to test the screws ultimate strength. The test specimen was subjected to increasing loads in appropriate increments until failure of the test specimen. The screws pulled out of supports at 15.98kN. On inspection one thread on one screw had worn and another screw's cutting tip had snapped off. A photograph of the screws is provided below.

Figure 8. Photo image of tek screws after test

Another ultimate strength test was then conducted on the test specimen used for the setup of the custom test facility. At approximately 9kN the fireboard panel snapped in three places along the entire length of the specimen. A photograph of the test specimen showing the failure is provided below.

Figure 9.Test specimen after testing

## Conclusions

There was no visible rotational movement of the screws during or at the conclusion of the fatigue test. It was also observed that no gaps had developed during the fatigue test. The test specimen with spring washer installed was not tested as this was deemed unnecessary.

Overall, the tests demonstrated that the required fatigue design life for the tek screws were achieved based on the constraints set. The final, ultimate pull out tests gave confidence that the tek screws will last the required fatigue design life. The installation procedure of the tek screws and the corresponding limiting of torque moment was found to be important to not damage the thread of the screws.

## Acknowledgments

We acknowledge Brisbane City Council, Transcity JV and the James Cook University for the opportunity to present this paper.

## References

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AS 5100.6 (2004) Chapter 13.6, Fatigue strength, Figure 13.6.1