Abstract
The Queensland Department of Main Roads is responsible for maintaining the seventy year old Hornibrook Highway bridge. The bridge is currently open to pedestrian/cycle traffic. It is to remain open until an alternative pedestrian/cycle crossing of Bramble Bay is constructed. The 2.7 km long Hornibrook Highway has a timber superstructure that requires extensive remedial work.

The condition of the timber girders was assessed by a combination of visual inspections, ground penetrating radar (GPR), dynamic and static load testing and girder drilling. Termites have been effectively treated using a powdered termiticide.

This paper discusses the methods used to determine the current condition of the timber superstructure, with particular focus on assessing the timber girders.

Introduction
The Hornibrook Highway is a 294 span, 2684 m long bridge predominately consisting of a timber superstructure (decking, girders, corbels) supported by a reinforced concrete substructure. The bridge deck is covered by a thin layer of asphalt.

The bridge which crosses Bramble Bay was built as a toll bridge by the firm M.R.Hornibrook Pty Ltd and was opened on 4 October 1935. The construction of the bridge provided much needed employment during the 'depression' of the 1930's. When it was constructed, the Hornibrook Highway was the longest road viaduct over water in Australia [1]. The forty year toll period ended in 1975 at which time the ownership and maintenance responsibility reverted to Main Roads.

Figure 1. Hornibrook Highway spanning Pine River channel

On 20 December 1979 the adjacent Houghton Highway was officially opened. In 1979 the Hornibrook Highway was closed pending refurbishing. When closed to traffic, a closer investigation of the
Hornibrook Highway was possible. This revealed that deterioration of the bridge was more advanced than previously believed [2]. Since this time the Hornibrook Highway's use has been restricted to pedestrians, cyclists and recreational anglers.

On 20 April 2005, Premier Peter Beattie, Minister for Transport and Main Roads, Paul Lucas and the Member for Redcliffe, Ray Hollis announced the duplication of the existing Houghton Highway road bridge. Main Roads is committed to maintain the old Hornibrook Highway timber bridge until an alternate pedestrian/cycle crossing of Bramble Bay is provided.

**Previous Reports on Structure Condition**

In order to develop a maintenance strategy to meet these commitments, previous investigations and reports by Main Roads were firstly reviewed.

In 2000 the department undertook a large-scale visual inspection of the entire bridge [3]. This identified areas of termite activity, rot in the timber superstructure and some spalling of cover concrete due to corrosion of reinforcing steel in the substructure.

In 1988[4] and 2003[5] investigations of the concrete substructure were undertaken by Dr Alan Carse et al. These included visual inspection, coring and core testing of the concrete substructure. The 2003 report concluded that chloride levels in the piers were well above the corrosion threshold, consistent with the observed level of deterioration. Based on these investigations it is concluded that the concrete substructure could be maintained with sufficient capacity until a duplicate bridge is completed.

The condition of the timber superstructure was a more challenging aspect to assess because no recent drilling information existed; because of the inherent difficulty of assessing internal deterioration of timber members and because of undertaking such investigations on a bridge of this size.

Because of the challenges in undertaking the condition assessment, a combination of visual assessment, ground penetrating radar (GPR) inspection, load testing and targeted test drilling was decided on to assess the timber superstructure. These aspects are discussed below.

**Ground penetrating radar**

Visual inspections are only able to detect external evidence of internal defects. It was known from previous experience that many of the deterioration mechanisms affecting timber girders, such as termite and fungal attack, can lead to the formation of large internal defects but show few external symptoms of distress.

In light of the significant size of the bridge and prohibitive cost to undertake traditional drilling investigations, a ground penetrating radar (GPR) investigation of the timber girders was proposed. The original aim was to undertake a quick GPR survey of each girder to use as a rough guide to differentiate which girders required closer inspection.

### Visual inspection of girders and decks

A detailed visual inspection and classification of the condition of the bridge's girders and deck planks was undertaken from the underside of the bridge in accordance with the department's Bridge Inspection Manual [5].

Girders and deck soffit were visually assessed and rated. The defects noted during the visual inspection of girders included:

- Termite activity
- Rot along the junction of girders and deck planks
- Rot on the inside of outer girders sometimes leaving a shell. The spiking planks and kerb units appear to have initiated the problem
- Rot holes in the sides and tops of girders and significant large internal piping (hollowing) in some girders
- Staining indicating that some girders are holding internal moisture
- Longitudinal splitting along the girders

Some of the girders and deck planks were found to be in a state of partial or total collapse. At these locations, barriers had been erected on the deck to restrict public access.

Some corbels were found to be in similar condition to the bridge girders. Many were badly split, had large pipes and rotten ends or were showing signs of crushing failures. Some had been damaged by termite attack.

Similar defects were found in some of the timber decking. The worst deterioration of the timber deck planks was noted at the outer extremities, probably due to the increased exposure to sunlight and moisture. Poor surface water drainage from the deck in combination with the concrete kerb units is contributing to the problem.

A 30kN dynamic rolling load in combination with visual inspections provided the information that was used in the assessment of deck planks. It was suspected that some of the decking may contain rot at the girder supports. A full assessment of this could not be made because of the scope of the project and physical difficulty in accessing these areas. A trial of a new and novel type of GPR investigation is currently being considered to determine if the condition of the decking can be assessed non-destructively from on top of the deck.
A single horizontal GPR pass was undertaken on all 1752 timber girders, imaging from one side of the girder to the other. A brief calibration was undertaken at the start of each GPR run to confirm the apparent position of the opposite side of the girder in the GPR data.

Normally for this type of survey the GPR results would be calibrated against distance marks along the girder length [7]. However, marking up such a large structure would have taken much longer to complete the survey. So, to expedite the investigation, the GPR antenna was not calibrated for distance but was simply moved along each girder at a steady pace to maintain the approximate proportions of defect extent with respect to girder length.

In shallow easily accessible areas, the data collection was very fast averaging less than one minute per girder, including the time to move between spans. In deep water the survey data had to be collected from a boat, which was slower and more difficult.

The GPR survey of all 292 timber spans was completed in sixteen days onsite. Around 64% of data collection was completed in the first five days, working only 3 to 4 hours per day at low tide. Data collection was monitored in the field in real time, however post processing noticeably improved the resolution of the radargram images.

The raw data was post processed and then arranged as per the actual girder layout in the bridge. This type of layout was particularly useful as it could be easily visualised by the project team. From previous experience with other Main Roads projects using GPR, the areas of suspected deterioration could quickly be identified for further investigation. Figure 3 gives some typical examples of the processed GPR data.

**Figure 2.** Scanning the timber girders of the Hornibrook Highway using GPR

**Figure 3.** Radargram images of timber girders: top - sound girder; middle - girder with some internal defects; bottom - defective girder. (The hyperbolic shaped “bumps” that can be seen in the top and middle girders are the hold down bolts. The strong highly variable signal in the bottom girder masked the presence of these bolts.)

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Analysis of the GPR data indicated a number of girders were in a suspect condition which was in general agreement with the visual inspection. However, there were examples where GPR results indicated the presence of defects that were not reported in the visual inspection and a few cases where the visual inspection reported defects that were not detected by the GPR. The reason for this lack of correlation became clear during later test drilling. This will be detailed later in this paper.

**Load testing**

A load testing rig was purpose designed in-house to load test the timber girders and decking of the Hornibrook Highway (refer Figure 4).

Weighing 10 tonnes, the test rig is fitted with four movable 1.7 tonne concrete ballast blocks and is designed to span each of the girders being tested. Because of the possibility of running over deck planks that were in poor condition, particularly adjacent to the concrete kerbs, the test rig weight was evenly distributed over sixteen 14" wheels. This gave an individual tyre load of approximately 600kg.

The test rig is symmetrical in design, and has steerable turntables and drawbars fitted at each end so it can be towed in either direction. The truck is fitted with a modified towbar to allow towing at three different points. One towing point is on centreline while the other points are at either end of the towbar, which permits offset towing.

The test load is applied using a hydraulic ram and a hydraulic power pack, driven by a portable petrol engine. The power pack is mounted on the tray of the tow vehicle, which enables accurate control of the applied load and rate of loading. The loading system was calibrated with portable scales supplied and operated by Queensland Transport.

There were two types of load tests carried out on the bridge deck and girders (Figure 5). The two tests carried out were:

- **Dynamic rolling load test** — the test involved applying a 30kN rolling load via a polyurethane covered steel wheel to the deck planks, positioned mid-way between girders

- **Static load test** — various vertical static loads were applied to girders in position 3 and 4 with the loading ram in the central position and in the offset position to test girders in positions 2 & 5. Deflections were measured in these positions with a maximum load of 92 kN applied to girders in position 3 and 4 and a maximum load of 55 kN applied to girders in positions 2 and 5. Girders in positions 1 and 6 were not load tested as the kerb and handrails obstructed access of the load testing ram. Visual and GPR inspections confirmed that a large number of girders in location 1 and 6 were in poor condition.

![Figure 5. Testing positions of loading rig with respect to girder positions are shown.](image)

Various methods of measuring deck deflections were trialled. A string line was found to be the most practical method. Each end the string line was hooked to the handle of a 20-litre water container positioned on the adjacent span. The accuracy of this method of measurement was verified by a theodolite located well clear of the test span.

To help remove the effect of any discontinuity/ non linearity in the bridge components, and any localised compression of loaded members (e.g. asphalt surfacing, deck planks, girders, corbels, etc.), an initial reading of 10% of the full load was taken as the measurement benchmark and the load was applied via a 900mm long hardwood plank.
The initial trials found that in general the deflections were much smaller than expected. Some girders that appeared to be of reduced capacity, as indicated by GPR and visual inspections, showed somewhat greater deflections, though these were still lower than expected. It was thought that the smaller than expected measured deflections were due to load redistribution between girders.

Based on these initial results, and due to the large number of girders in the bridge, a decision was made to target only the girders showing notable defects in the GPR and visual inspections for load testing.

Girder drilling
The visual inspection and GPR data indicated deterioration of a number of timber girders. Preliminary drilling confirmed the presence of termites in a number of girders and corbels. Drilling was undertaken to allow direct viewing through the use of a borescope (see Figure 8) and to allow the injection of a powder termiticide into the affected timber girders with the aid of a special termiticide application tool (see Figure 9).

Once the scope of the termite infestation was ascertained, drilling was undertaken to inject termiticide powder into the girders in an attempt to destroy the active termite nests (see Figure 10). The drilling findings also gave a basis on which to validate the accuracy of defect predictions made by the GPR investigation. This was important to resolve a number of inconsistencies noted between the GPR and initial visual investigations.

The drilling investigation was undertaken following the Department’s Bridge Inspection Manual (BIM) [6] as a starting point but then using the GPR data to target other areas outside of the standard drilling regime.

It became apparent early during drilling that the GPR predictions were consistently correct in predicting the majority of internal defects. In the first 60 spans (approximately 180 girders drilled), there was only one occasion where the GPR radargram data showed a defect that could not be found by drilling. Figure 11 shows one of many examples where a GPR predicted a defect that was not detected by visual inspection or drilling following the guidelines in the BIM. When guided by the GPR prediction, a 300mm wide defect was found with test drilling.
There were some instances where GPR did not detect internal defects found during drilling. However, in virtually every instance the defects were in the upper portion of the girder, i.e. outside of the field of view of the GPR antenna. It was recognised that if a second vertical pass had been done with the GPR it would probably have detected these defects as well. In the majority of instances where defects were present in the top of a girder and not detected by GPR, they were often visible on the outside surface and detectable through visual inspections. These observations highlighted the benefits and importance of undertaking both visual and GPR investigations as part of an effective timber girder inspection.

**Termite treatment**

It is believed that the single concrete span at each end of the Hornibrook Highway was a design feature of the period to discourage termite invasion from the mainland. It is now understood that at certain times of the breeding cycle subterranean termites may fly significant distances to lay eggs and establish new colonies. It appears that this is the source of the termite infestation in the Hornibrook Highway.

The visual inspections identified evidence of a termite presence (e.g. nests, mud galleries, etc.). Girder drilling along with GPR testing confirmed this. Based on this evidence, the elimination of termites was considered an essential step in the maintenance strategy for this structure.

To address the termite issue, a trial of a powdered termiticide was proposed. A powdered form was considered advantageous compared to a liquid form as it could be applied through a drill hole while limiting the risk of spills or leaking into the marine environment through cracks or splits in the girders. After an initial field trial proved very successful in destroying termite colonies, the remainder of the bridge was treated.

**Conclusion**

The aim of this study was to assess the current condition of the superstructure of the Hornibrook Highway with a view to maintaining the bridge until an alternate crossing for pedestrians and cyclists was available.

A combination of GPR and visual inspection was used, and was demonstrated to be highly effective and reliable, in detecting and pinpointing defects in timber girders. Defect predictions made by these methods were consistently verified by test drilling. Based on experiences from this project, it is considered essential that visual inspections of timber girders be supplemented with GPR wherever possible as it has significant benefits in targeting test drilling and reducing the amount of drilling required.

Many of the spans are exhibiting lower than expected deflections under an applied point load. It is suspected that this is due to load distribution between girders of a span. Despite evidence of girder deterioration, visual evidence of some decking deterioration, load testing and low measured deck deflections, the superstructure capacity is adequately carrying and distributing a test load.

The dynamic rolling load test has shown that the decking currently has sufficient load capacity. A future condition investigation of the deck planks by a new GPR unit is planned. The aim is to broadly map deck plank defects from the running surface of the deck.

The use of a powdered termiticide has been effective in controlling termites. The elimination of termites is seen as one of the steps in slowing the rate of deterioration.

As there is no similar detailed historical data available to compare with, the rate of deterioration of the superstructure is unknown. It is currently proposed that ongoing assessment of the Hornibrook Highway will be undertaken.
References
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