A CASE STUDY – GEOTECHNICAL AND GEOPHYSICAL INVESTIGATIONS OF AN OLD STONE HERITAGE BRIDGE AT PARRAMATTA, GREATER WESTERN SYDNEY NSW, AUSTRALIA

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ABSTRACT

This paper presents the methods used and results obtained from a combined geotechnical and geophysical investigation of Lennox Bridge located in Church Street Parramatta, NSW. Lennox Bridge is a Heritage-listed, 19th century, stone arch bridge spanning Parramatta River, constructed in 1839 and widened in 1934-35 under the direction of the Department of Main Roads, which included removal of a western footway and erecting a new reinforced concrete structure. Assessing the foundations and properties of a composite bridge constructed in different centuries presents significant challenges. A Borehole Ground Penetrating Radar (BGPR) technique was employed to assess the depth of the abutment foundations of the older sandstone bridge. A downhole magnetometer was used to determine the founding depth of the later concrete bridge by detecting the presence of rebar inside the concrete structure. Next to the sandstone bridge abutments, a set of boreholes were drilled at a distance of 1m and 4m from the edge of the abutment wall. The purpose of the furthest borehole was to provide a benchmark BGPR profile (without abutment) with which to compare the output from the sounding nearest the wall. The BGPR profiles of the two boreholes are compared to differentiate the presence of stone blocks used for the construction of the abutment and foundations embedded in an alluvial soil profile, down to bedrock. Boreholes were also drilled from the top of the bridge through the abutment to further confirm founding depths below the centre of the abutments.

1 HISTORICAL BACKGROUND OF LENNOX BRIDGE

The first bridge over the Parramatta River at this site, destroyed during floods in 1795, was constructed using timber with a replacement second bridge built between 1802 and 1804 on stone piers using timber railings. Later, single sandstone arch bridge spanning 91 feet (27.73m) was constructed in 1839 and became the third oldest surveying masonry bridge in New South Wales. In the early 1900's the internal structure of the bridge was strengthened to support a new tramway and in 1912 the western side parapet wall was removed to provide a continuous cantilever pedestrian footway of 1.6 m. In 1934-35, the Department of Main Roads extended the footway by reinforced concrete with a sandstone-faced abutment wall. During 1990's the bridge was proclaimed a Heritage structure within New South Wales. In 2012 Parramatta City Council approved the excavation of tunnels through the combined bridge structure on each bank (through the abutments) to create pedestrian access along the riverfront footpaths. Construction of the tunnels began in 2014 and was completed in September 2015.

2 BACKGROUND OF PARRAMATTA LIGHT RAIL

Transport for New South Wales (TfNSW) commissioned the geotechnical and environmental investigation for the design of the Parramatta Light Rail (PLR) project, which is required to meet the growing transportation needs of Western Sydney. The preferred corridor was announced by the NSW government in December 2015 and runs from Westmead to Strathfield via Parramatta Central Business District (CBD). The proposed works include environmental, heritage, geotechnical, geophysical and utility investigations required to inform the next stages of design. Lennox Bridge is situated within the Parramatta CBD area, connecting the suburbs north of the Parramatta River with the Parramatta CBD. The preferred PLR route is intended to cross over Lennox Bridge. Ministry of transport and infrastructure of NSW has announced PLR Stage 2 on October 2017, which connects Greater Parramatta to Sydney Olympic Park.

3 PURPOSE OF THE INVESTIGATION

As a part of the detailed investigations, TfNSW required that a structural and geotechnical investigation of Lennox Bridge be carried out. This technical paper focuses on the geotechnical and geophysical techniques employed as well as a brief overview on the structural investigation undertaken.

4 INVESTIGATION METHODOLOGY

There were three major components involved in the Lennox Bridge investigation, comprising:

Structural component, Geotechnical component and Geophysical component.

4.1 STRUCTURAL COMPONENT

The bridge consists of two major structural elements: an old sandstone bridge (eastern side) and a concrete bridge (western side) thus the approach of the investigation has been accordingly scheduled. The old sandstone bridge consists of a gallery inside and it is visually assessed for internal damages. A truck-mounted, specialised, extension gangway (known as an Under-Bridge Investigation Unit (UBIU)) was employed to inspect the abutment wall and the bridge arch. Figure 1 shows the UBIU on Lennox Bridge and Figure 2 shows the plan view of composite bridge.

4.1.1 Sandstone investigation

The sandstone blocks have undergone various chemical and physical weathering over a period. Following investigations has been undertaken to analyse the current integrity of sandstone blocks facing outside and inside the gallery.

4.1.1.1 Delamination survey

The sandstone bridge was visually inspected to assess the condition of the sandstone blocks and record any evidence of deterioration or defects. In general, the exposed surface of the sandstone abutment was gently tapped by steel mallet to remove the loose layers.

4.1.1.2 Petrographic analysis

The intact lime mortar between the sandstone blocks was cored below the ground level and analysed for minerals present in the mortar and presence of iron oxides.

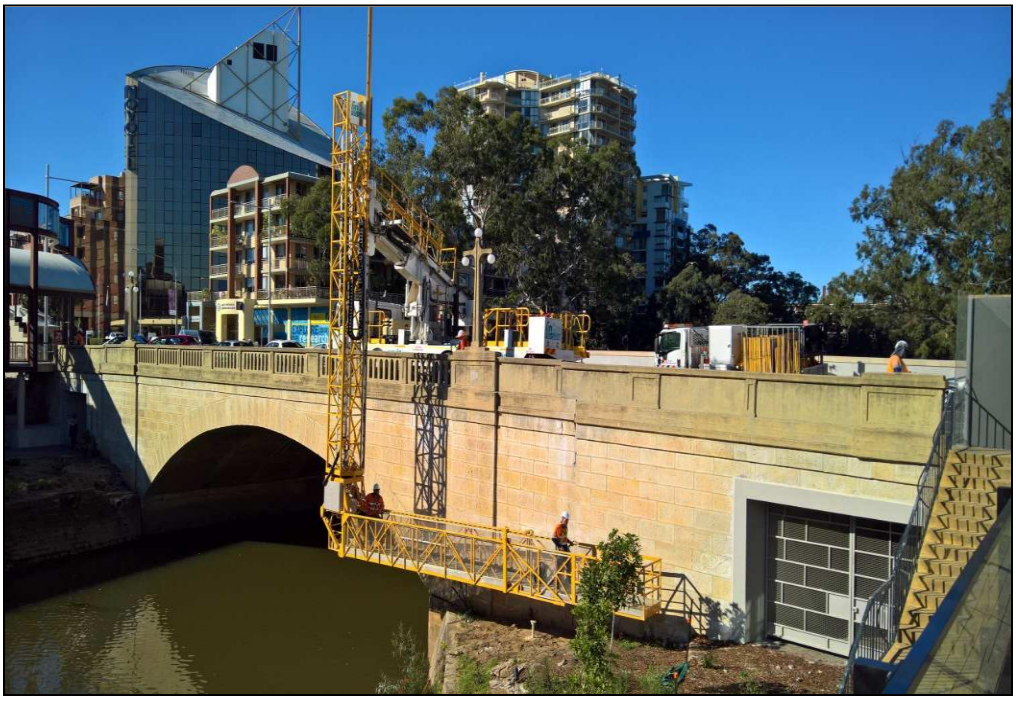

Figure 1: Structural investigation of Lennox Bridge using Under Bridge Inspection Unit (UBIU)

4.1.1.3 Gallery inspection

The sandstone bridge contains several internal galleries on both North and South abutments. Access was gained (by trained personnel) into one of the galleries for visual inspection of the internal sandstone blockwork. Numerous high-resolution photographs were obtained from this inspection.

4.1.2 Concrete investigation

Concrete bridge is covered by sandstone façade on western side of the bridge, however concrete at underside of the bridge is visible and mapped for investigation.

4.1.2.1 Crack mapping

The concrete surface of the balustrade and arch of the bridge was mapped for any cracks and the crack size was recorded.

4.1.2.2 Drumminess survey

The drumminess survey was carried out in the newer concrete bridge section by gently tapping the concrete surface with a small hammer to detect any cover separation from the reinforcement. These areas were mapped to identify the weak spots of the concrete.

4.1.2.3 Reinforcement bar detection

The reinforcement bars of the concrete bridge were detected on the abutment and arch surfaces by scanning with a non-intrusive GPR scanner in specific areas ranging from 1 m by 1 m to 1.8 m by 2.9 m.

4.1.2.4 Concrete coring

Concrete samples were cored from the abutment of the wall to identify the extent of carbonation and chloride ingress.

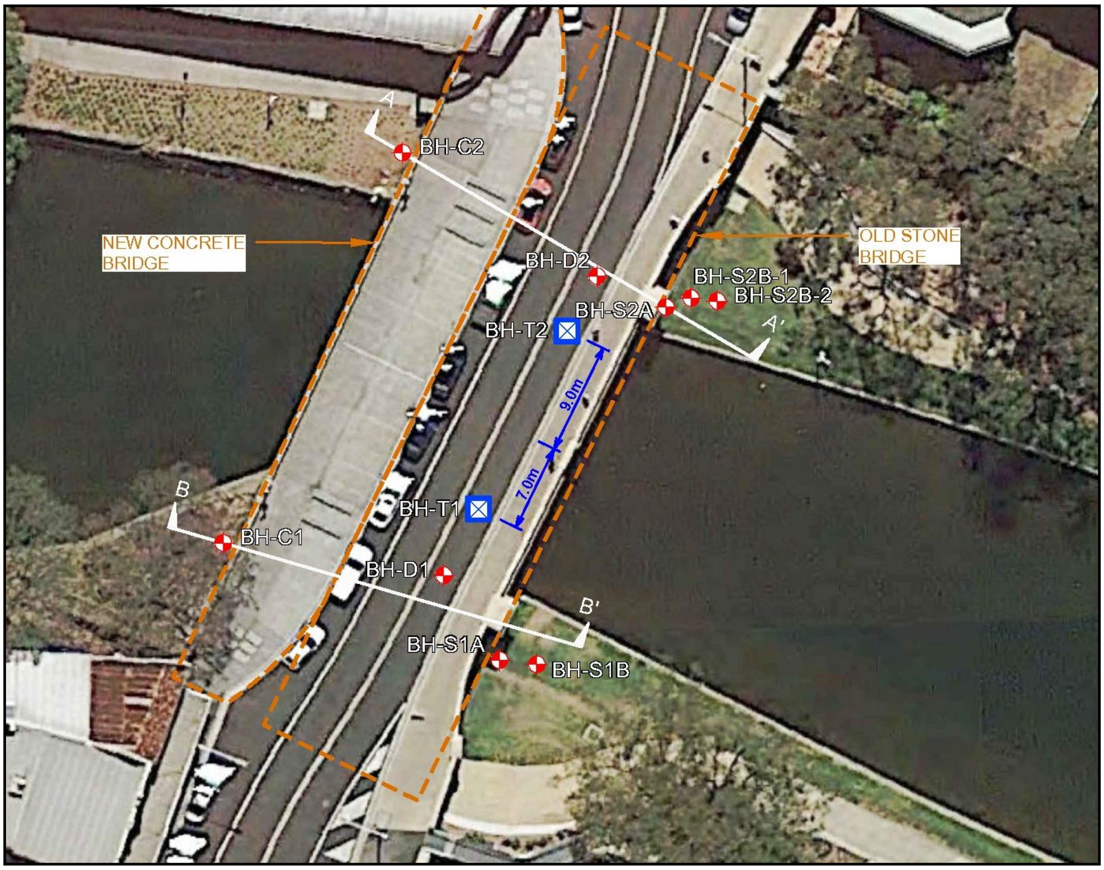

Figure 2: Geotechnical boreholes and trial pits at Lennox Bridge

4.2 GEOTECHNICAL COMPONENT

A total of 8 boreholes were drilled to identify the ground profile and founding depths of the bridge. Down-hole geophysics techniques were used in 6 of these boreholes, located in the riverbank areas next to each of the two abutment structures. A track mounted drilling rig was engaged to complete all boreholes.

Based on previous studies of the area, it was known that the ground profile beneath each river bank consists of a sequence of alluvial deposits over sandstone bedrock. It was anticipated that the bridge foundations (both for the older sandstone bridge and the later concrete bridge) were founded on the bedrock, however this needed to be verified.

4.2.1 Sandstone abutment boreholes

Two sets of boreholes were drilled adjacent to the two bridge abutments on the east side of the older stone bridge. One borehole was drilled approximately 1 m from the edge of the wall, and a second one positioned about 4 m from the edge of the wall. The purpose of first borehole (1 m away) was to carry out down-hole geophysics soundings using BGPR technique, to identify the founding depth of the bridge abutment. The purpose of the second borehole (4 m away) at each side was to provide a benchmark BGPR profile (without abutment) with which to compare the output from the sounding next to the wall. As the radial penetration of the BGPR is only about 2 m to 3 m, the second borehole BGPR sounding was expected to provide the profile through the alluvial sediments only.

The nearest BGPR sounding was expected to detect the abutment wall and foundation construction below ground level all the way down to top of bedrock, thus providing confirmation of minimum founding depth.

4.2.2 Boreholes through the sandstone bridge

Two boreholes were drilled through the abutments of the old sandstone bridge in order to confirm its construction materials and founding depth. Two boreholes were located approximately 14 m apart from the arch of the bridge. The boreholes were drilled into the asphalt of the road, fill materials followed by sandstone blocks and founding bed rock. The roughly rectangular-shaped sandstone blocks are separated by irregularly spaced lime mortar joints with a variable thickness ranging from 30 mm to 150 mm. In one particular zone, the mortar thickness was measured to be 490 mm thick.

4.2.3 Concrete abutment boreholes

On the concrete bridge side, a single borehole was located at each abutment, 1 m from the edge of the wall. Employing a downhole magnetometer probe to detect the presence of steel reinforcement within the concrete foundation, the results were used to infer the base of the bridge foundation.

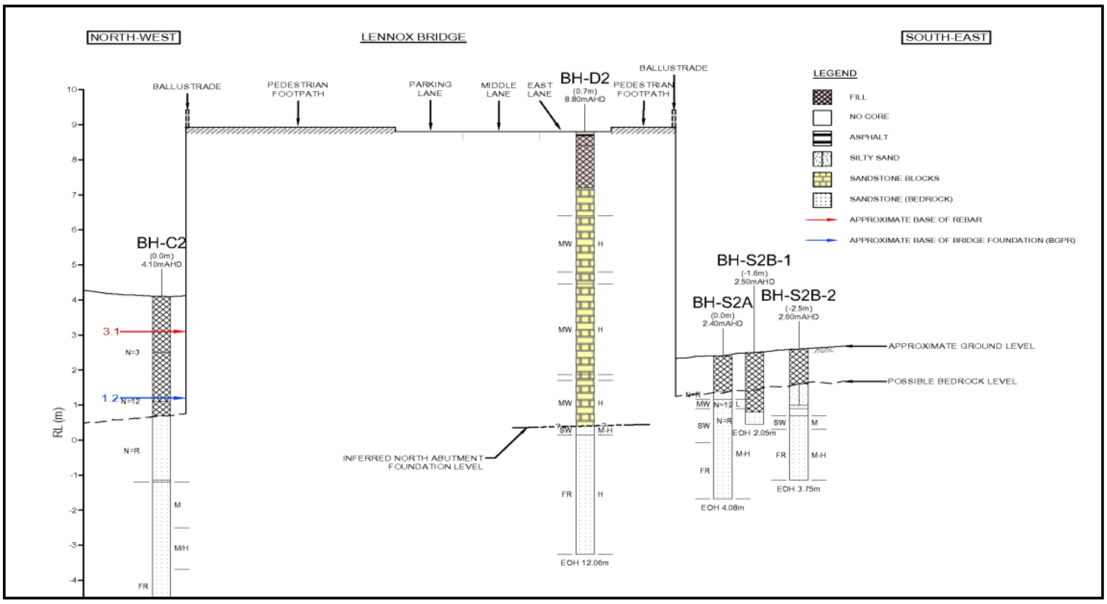

Figure 3: Northern sectional view (A-A') of the boreholes and the bridge.

4.2.4 Trial pits

Two trial pits were excavated on the old stone bridge deck approximately 7 m to 9 m from the middle of the bridge, on opposite ends. The dimensions of trial pits were 0.8 m × 0.6 m × 0.8 m (length × breadth × depth). The aim of the pits was to confirm and sample the fill material between the pavement and the upper surface of the stone arch. Due to Heritage-constraints, the pits were manually excavated using lightweight pneumatic tools. The pits revealed that the fill material is variable containing boulders and gravelly sand above the top of the arch blocks.

4.3 GEOPHYSICAL COMPONENT

The geophysical investigation undertaken at the bridge was carried out at several locations around the bridge. The varying construction methods used on either side of the bridge made it necessary to employ different geophysical survey methods to assist in identifying the foundation depth of the overall bridge structure.

4.3.1 Borehole ground penetrating radar

The BGPR survey was completed in four pre-drilled boreholes on the eastern (old) side of the bridge with the aim of identifying the depth of the bridges' sandstone foundation. Lack of steel reinforcement in the sandstone made other borehole techniques, such as magnetics, inappropriate to assist in identifying the foundation depth.

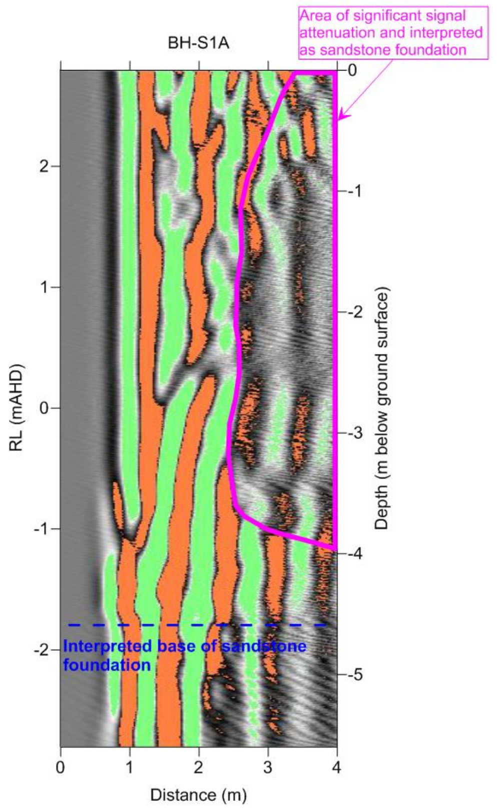

Figure 4: Sample BGPR profile with interpretation

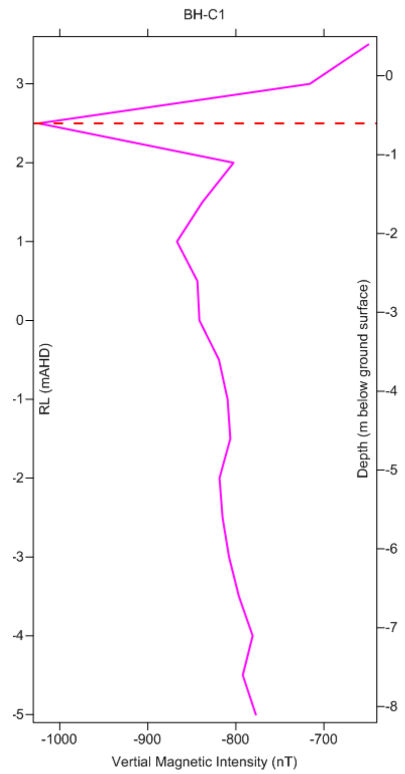

Figure 5: Sample downhole magnetics test result acquired adjacent to the concrete side of the bridge

The BGPR method is similar to surface GPR methods in that it passes radio frequency electromagnetic energy pulses into the ground. However, the equipment is deployed down a vertical borehole and signals are radiated omni-directionally, thus sampling a cylindrical shaped volume of material down the borehole with a radius (i.e. depth of penetration) that is dependent on the dielectric properties of the material. Reflection of BGPR energy occurs at interfaces where contrasting electrical properties exist, such as sub-surface construction layers and natural ground.

The acquired BGPR data were processed, analysed and interpreted using MALÅ Geoscience Radinter software. Where either a large reflector or signal attenuation occurred, this was interpreted as a result of the sandstone foundation of the bridge. Figure 4 shows the results of BGPR data at borehole BH-S1A.

These results of the BGPR corresponded with the base of the sandstone blocks as encountered in the geotechnical boreholes drilled through the bridge. The BGPR survey conducted down the borehole drilled 4 m from the bridge showed no interpretable foundation features and the foundation of the bridge was inferred to be beyond the depth of penetration of the BGPR system.

4.3.2 Downhole magnetometer testing

Downhole magnetometer testing was performed on the western (concrete) side of the bridge to identify the depth to the base of steel reinforcement in the concrete bridge foundation.

Downhole magnetic testing is a passive method based on the measurement of localised perturbations to the Earth's magnetic field measured in nanotesla's (nT). These may be caused by geological features and buried ferrous targets (eg, pipes, cables, drums, iron sheets, steel reinforcement).

Downhole magnetic testing was completed in-situ using pre-drilled, PVC cased boreholes. A Bartington 3-component Mag-03 fluxgate magnetometer was used to measure the magnetic field variations at 0.5m intervals to the maximum depth of the borehole. The magnetic data was acquired with Spectramag-6 software.

The vertical (Z) component of the magnetic field typically provides the clearest indication of the base of the steel reinforcement in the bridge foundation and hence the approximate depth of the foundation. Magnetic high anomalies present in the data usually indicates the approximate base of the steel reinforcement (Jo et. al, 2003).

The magnetic anomaly indicated by the red dotted line was interpreted as base of bridge foundation. Figure 5 shows a sample result of the downhole magnetic testing completed at the bridge site borehole BH-C1.

The downhole magnetic testing was considered successful in determining the base of the reinforcement within the concrete foundation of the western side of the bridge.

4.3.3 Ground penetrating radar (GPR) survey on bridge deck

As part of the overall investigation, a surface-based GPR survey of the bridge deck was completed to identify the top of the stone arch as well as provide preliminary assessment of the fill material beneath the road deck.

GPR data were collected along six (6) profiles parallel to the existing bridge alignment approximately 1.5m apart. The GPR identified variations in the fill material as well as larger boulder size objects within the fill. The GPR survey was also successful in identifying the stone arch of the bridge. The GPR data also showed various linear reflector within the fill material and likely indicate areas of differing fill material and filling 'event' during the bridge construction. Figure 6 shows the annotated GPR profile across the bridge.

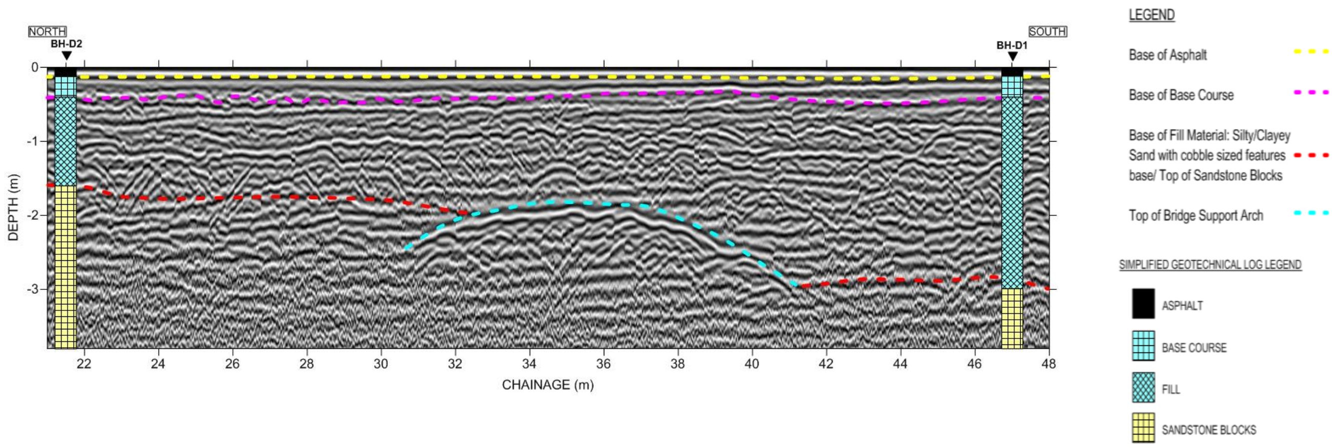

Figure 6: A sample annotated GPR profile acquired across the bridge.

5 DISCUSSIONS

5.1 FOUNDATION DEPTHS

Sandstone bedrock was encountered at variable depths across the two sides of the river. The depth to sandstone bedrock varied between 4.5 m and 5.3 m at the South abutment. In comparison, sandstone bedrock was encountered at much shallower depth at the North abutment, at between 1.0 m and 1.7 m depth on the NE side, and at 3.4 m on the NW side. Generally, the sandstone samples obtained from the bedrock in these boreholes indicate a medium to high intact rock strength based on the laboratory test results.

5.2 COMPARISON OF GEOTECHNICAL AND GEOPHYSICAL INVESTIGATION

The downhole geophysical methodologies provided consistent information on the depth of the old and new bridge foundations as did the GPR results acquired on the bridge deck.

The downhole magnetic testing results successfully identified the base of the concrete reinforcement and were in agreement with available reinforcement 'as built' drawings. Furthermore, the BGPR results were considered successful in identifying the rock soil interface as well as the bridge sandstone foundation, particularly in holes that were drilled close (~1m) from the bridge sandstone foundation.

6 ACKNOWLEDGEMENT

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