13th October 2013

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SUBSURFACE INVESTIGATION USING GROUND PENETRATING RADAR (GPR) AND ELECTRICAL RESISTIVITY TOMOGRAPHY TO LOCATE THE MACQUARIE PIER, NEWCASTLE.

The University of Newcastle’s Coal River Working Party is a research based organisation interested in the history, geology, landscape, indigenous culture and history, economic and environment of the Hunter region of New South Wales. As part of its ongoing research program, the Coal River Working Party is attempting to locate the Foundation stone of the Macquarie Pier, laid in 1818 by the NSW Governor Lachlan Macquarie on his visit to Newcastle. The Macquarie Pier and breakwater are located in Foreshore Park, Newcastle East, connecting the mainland to Nobby’s island.

This investigation work was commissioned by Mr Gionni Di Gravio on behalf of the Coal River Working Party. The purpose of the investigation is to determine the likely location of the foundation stone using geophysical means including Ground Penetrating Radar (GPR) and Electrical Resistivity Tomography (ERT). The data collection, processing and analysis were undertaken by staff from GBG Australia Pty Ltd in order to identify probable archaeological remains of the pier for possible future investigation work.

As the techniques used in this investigation are geophysical, the results are based on indirect measurements and the interpretation of electrical signals. The findings in this report represent the best professional opinions of the author, based on experience and with consideration of the expected subsurface anomalies at the investigation site.

The following report outlines the investigation and discusses the results.
SURVEY AREA AND TIMING

The Macquarie Pier is located within the Foreshore Park and Nobby's Beach Reserve, approximately 1 km north east of the Newcastle CBD. The areas investigated during this survey are outlined in the Nearmap image below, see Figure 1. The areas, in the main, were clear of obstructions. However, no GPR data could be collected where vehicles were parked, gardens areas, barricaded or fenced areas or in area with frequent traffic movements.

The GPR field work was conducted by a two person crew from GBG, with the field work being undertaken on the 13th August 2013.

Figure 1: Nearmap image of the showing the location of the original pier (re Armstrong's 1830 map) and approximate locations of the investigation areas across Macquarie Pier, Newcastle East. The sites included areas of lawn, roadway and paved parking areas.
BACKGROUND

The Macquarie Pier (or causeway) was initiated to make the harbour safer for shipping as the Stockton oyster bank had become a graveyard for ships. The visionary Commandant of Newcastle, Captain James Wallis sought a solution in the form of a causeway to link the mainland to Nobbys Island.

Work on Macquarie Pier began soon after the Governor’s visit and continued up until about 1823/4. The project was discontinued because Newcastle had ceased to be a penal settlement, and Governor Macquarie was recalled back to England.

After the withdrawal of the main source of convict labour to Port Macquarie in 1823, Newcastle was unable to continue construction of the pier. The Pier by 1830, according to Armstrong’s plan, was ‘partially worn down’ on the ocean side. Shipping was increasingly becoming crucial to the town and so the settlers began a campaign to urge the Government to repair and resume Macquarie Pier’s construction. The pier construction was finally completed during this period from 1833 to 1846.

By 1866 plans were made to rebuild Macquarie Pier, this time using more durable stone quarried from Waratah and brought to the site by rail. The first delivery of quarried stone for the Pier arrived in 1869, and construction was completed by 1873. Further extensions of the Pier to protect shipping from the reef to the Big Ben Rock were completed in 1883 and 1896.

Where exactly the foundation stone was laid is not known, many believe it was lost, but a map by the A.A. Company surveyor John Armstrong, drawn in 1830, indicates the point of commencement of the stonework. This plan is the key to possibly identifying the stone’s present location.

Preliminary investigation by Mr Russel Rigby established the most probable location of the start of Macquarie Pier. Using overlays of the Armstrong plan (and earlier plans) onto modern aerial view of the landscape, he identify the target location to search for the Foundation and inscription stone. The station, from which the lines of the intended pier originate, is at the intersection of Fort Road and Nobbys Drive, approximately 30m south of the “start of stonework on this side” on Armstrong’s plan (see Figure 1, above). This gives a 30m line along which is the likely location of the foundation stone, should it survive. This is somewhere in the vicinity of the footpath adjacent to the grassy amphitheatre near the Fort.

The foreshore area and areas around Nobbys Beach have, in the past, been sites of changing use. The site was originally used by Aboriginal tribes as fishing and camping areas. Europeans later settled in the area. The use of the area around the Foundation stone and pier has changed throughout history resulting in layers of other material being deposited about it. The most significant is the fill used in the 1850’s to reclaim land using sand, debris and potentially coal chitter. During the great depression a shanty town developed around beach at Nobbys. By 1937 there were approximately 81 shack houses. The shanty town was eventually removed to be replaced by military cottages and latter housing for harbour pilots and maritime workers (in the form of wooden cottages). These were eventually moved to more substantial dwellings further up the hill. The site then became a coal storage facility for
the nearby coal fired power plant. Further fill was added post 1900 possible sand dredged from the surrounding harbour. As a result of these changes in use, it is believed that the original foundation stone and pier could be as much as seven meters beneath the current ground surface. As can be seen in Figure 2 below circa 1900, the road above the Pier has been built up by an embankment. The southern end of the pier may have been built onto the original rock cliff.

![Figure 2: Nobbys and Fort Scratchley NSW with Macquarie Pier circa 1900 (Courtesy of Ann Hardy). Approximate location of survey indicated.](image)

**GROUND PENETRATING RADAR THEORY**

GPR is a non-destructive technique that provides high resolution reflection profiles of the subsurface. The technique works by pulsing radio waves, into the subsurface with a transmitting antenna. This energy propagates through the subsurface material as a function of its electrical properties which are in turn a function of its physical and chemical properties. Reflection of energy occurs at boundaries between media which have contrasting electrical properties such as a between soil material and bedrock material. These reflections are detected by the receiving antenna and converted into electrical signals.

A radar gram profile is built up of individual scans collected continuously along a selected line path. Each profile consists of radio imaging which provides subsurface information based on the variations in the Dielectric Constants (the electrical conductivity and resistivity) of materials. The recorded reflections can be analysed in terms of the signal shape, phase, travel time and signal amplitude to provide information about a target’s size, depth and orientation in relation to the material around it.

GPR antennas of high frequency provide high resolution data, but only penetrate to shallow depths, whilst low frequency antennae provide deeper penetration with decreased...
resolution. The depth of penetration achievable with an antenna of a particular frequency is also dependant on the local subsurface conditions. GPR is a method that is generally less successful in soils with high clay content due to the clay’s high absorption factor of radio wave energy. Clean dry sands provide an ideal medium for the propagation of radar waves.

ELECTRICAL RESISTIVITY TOMOGRAPHY (ERT) THEORY

The ERT method detects variations in the electrical resistivity of the subsurface. Factors affecting the bulk electric resistivity of soil or rock include porosity and permeability, and the degree of fluid saturation and fluid flow.

Resistivity measurements are made by inducing an electrical current into the earth through two current electrodes and measuring the resulting potential difference at two potential electrodes. From the current and voltage values, an apparent resistivity value can be calculated. The investigation depth is relative to the spacing between electrodes with greater depths reached by increasing the electrode spacing.

The results from the ERT investigation are presented as interpreted cross-sections showing variations in the measured resistivity of the subsurface with horizontal distance and depth. An example of the ERT setup is given in Figure 3, below.

Figure 3: The ERT setup running in a north-west to south east direction in The Foreshore Park Reserve (Viewed from the East).
DATA COLLECTION METHODOLOGY

The GPR data for this investigation was acquired using a GSSI SIR3000 GPR data collection system with ground coupled 200 MHz and 80 MHz centre-frequency antennas. The 200 MHz antenna was proposed to obtain a deeper penetration than the higher frequency 400 MHz antenna used in 2010. Note that increased penetration comes at the expense of reduced resolution. This means that the feature that can be imaged must be larger and the finer detail will be lost. Similarly, the 80 MHz antenna provides deeper penetration than the 200 MHz antenna. This was used in reserve in case the 200 MHz antenna was not able to obtain the required penetration.

Chainages along the profile line were logged by a calibrated distance measuring device attached to the antenna, with an accuracy of better than ±1 m every 100 m.

GPR data was collected as a series of longitudinal profiles perpendicular to Nobys Road and the expected direction of the pier. Some sections along the profile lines were not scanned due to the presence of gardens, fencing or parked cars.

GPR profile lines were collected by pulling the 200 MHz and 80 MHz antennas over the ground surface at a constant rate. The GPR system was set to record a two-way-travel time of between 95 ns and 140 ns, respectively. Data was recorded with 16-bit resolution, at 512 samples per scan and at a scan rate of 100 scans/m. The 200 MHz was used only in The Foreshore Reserve area as the depth of penetration achieved was insufficient to achieve the depth needed. As a result only the 80 MHz was used across all other areas in an attempt to maximise the depth investigated.

The GPR profiles were collected at line spacing of one or two metres where practicable.

Field notes recording the offset position and the start and end chainages of the GPR profile lines were taken. On-site quality control of the data was achieved in real-time by viewing profiles during acquisition. The profiles were recorded digitally for processing, analysis and interpretation at our Sydney office.
One ERT line was conducted to supplement the GPR data. The line was set out near the location of the expected beginning of the Macquarie pier in The Foreshore Reserve. It was decided that owing to time constrains that GPR was a more efficient technique to identify any possible archaeological remains. Overall the GPR data was of moderate quality, giving data of between 3m and 5 meters depth for the majority of the investigation.

For both techniques a DGPS unit was used to relocate the start and end points of survey lines. A series of points were taken allowing for the survey to be geo-referenced and thus allowing for anomalies to be located and mapped.

**DATA PROCESSING AND ANALYSIS**

**Ground Penetrating Radar**

The collected data was of moderate quality with low signal to noise ratio in the areas surveyed. This was principally due to the local subsurface, fill material. Fill material by its very nature can typically create a large amount of clutter within the reflected signal. This can be partially overcome during processing by applying various filters to the data.

The collected GPR data was processed and analysed using Reflex for Windows Version 7.0.0 developed by Sandmeier Software. The data processing steps were performed as follows:

- Static correction to set the surface reflection interface to zero depth.
• Background removal filter used to eliminate temporally flat noise bands from across the whole record. This makes signals previously obscured by this noise visible.

• Adjust the colour palette for signal amplitudes to improve the contrast of phase changes and signal variation.

• Migration to remove diffraction patterns emanating from small targets. This makes the image cleaner and easier to understand.

Radar signals reflected from a subsurface structure contain a large amount of visual information much relating to the minor variations in the electrical properties of the materials profiled. Consideration was given to the nature and possible cause of the signals recorded by the GPR. The target responses which are consistent with those expected from possible archaeological or building features were identified in the profiles and compared across multiple profiles. Three radargrams collected during this investigation are shown in Figures 5, Figure 6 and Figure 7 below. The three profiles show typical responses to those expected from the interpreted features identified. These lines have been highlighted on the drawings in as cyan lines.

![Possible railway tracks or services](Figure 5: Radargram from data Line 5 (200 Mhz), showing the location of possible railway tracks or services near the foreshore sign (Viewed from the South).)
Figure 6: Radargram from data Line 44 (80 Mhz), showing possible Archaeology near the corner of Nobbys Road and Shortland Esplanade (Viewed from the South).

Figure 7: Radargram from data Line 56, showing possible archaeology near the current start of the pier (Viewed from the South).
**Electrical Resistivity Tomography**

The unprocessed ERT measurements were plotted as pseudo-sections of apparent resistivity with horizontal distance and depth. These give a distorted picture of the subsurface resistivity and were used as a guide for further interpretation.

In order to gain a more accurate resistivity image of the subsurface, inversion modelling of the ERT data was carried out using Res2DInv from Geotomo Software. The software uses the smoothness-constrained least-squares inversion technique to produce 2D resistivity cross-sections. The pseudo-section was inverted through the inversion program with parameters such as damping factors and flatness filters applied. The inversion program was run for a number of iterations until adequate convergence occurred. As well as performing a least-squares inversion, a robust inversion was also run. The robust inversion is designed to locate objects with squared edges such as faults or man-made structures. The results of the ERT survey have been displayed in drawing GBGA1613-05.

**RESULTS AND DISCUSSION**

The 200 MHz antenna was able to image the ground to a depth of only 2m. This antenna will normally penetrate to 5m in sand.

The 80 MHz antenna normally rings making detailed on site observe of the data impossible. Review of the data first requires data processing to remove the ringing. The 80 MHz antenna was also only able to image the ground to a depth of only 2m. This antenna will normally penetrate to 15m in sand. This indicates the material is highly conductive or has a high clay, high lime content, or high moisture content. This can occur as a result of a Perched water table, lime stabilised, high soil salinity or highly conductive material such as coal fines.

The results of the GPR investigation have been plotted in the attached drawings GBGA1613-02 to 1613-04 at a scale of 1:250. GBGA1613-01 is an overview map at a scale of 1:1000 of the entire site showing the location of each area. Interpretations have been overlaid onto the site images provided by the client. The locations of the collected GPR profiles are plotted as green lines. Other features are shown as per the legends and as described below. Owing to the history of the site, the subsurface data profiles contain a large number of responses other than those from the original sea wall, as a result the data quality beyond the near surface was of questionable use. All of the features that have been identified within the data occur in the near surface (<1m). No deeper features were identified due to absorption of signal at increased depth likely caused by road base materials and fill or other construction materials.

There appear to be a possible railway tracks or two parallel services located next to Nobbys road and roughly following the direction of the roadway (see drawing GBGA1613-02). The pair of features is approximately 1.2m apart and could only be traced over approximately 15 m. From the Dial-Before-You-Dig plans a gas main and two water mains are shown within the road reserve. As these Plans are only schematic it is not possible to determine if these features correspond to these services. The location is however located along the alignment...
of the old pier. It should be noted that these only appear on the 200 MHz data set which has better resolution. This indicates they these responses are reasonably small as larger anomalies would have also been evident in the 80 MHz data set.

There were some other linear features located along the edge of Nobbys Road, these have been highlighted in drawings GBGA1613-03 and GBGA1613-04. These show up on the 80 MHz data reasonably well and appear as flat responses. This indicates that the anomaly present possible evidence of deeper construction below the current road.

For the ERT results all interpretations have been marked on the corresponding drawings. The location of the ERT profile is plotted as a blue line on drawing GBGA1613-02. There appears to be a large resistive anomaly located between the path and the road at approximately 2 m depth (refer to drawing GBGA1613-05). This may relate to an older structure such as a road embankment built along the alignment of the old Macquarie Pier. The adjacent material is likely to be fill material add later to fill in the lower lying terrain. While the high elevation makes it is unlikely that this is the old pier itself, the shape seen in the robust inversion appears to be of man-made construction. This is possibly material built on top of the original pier.

**CONCLUSIONS**

The GPR and ERT investigations where performed over the expected location of the Macquarie Pier.

Scaled investigation plan drawings have been overlaid onto geo-referenced aerial images (supplied by the client). The locations of possible subsurface anomalies interpreted from the data collected at these sites have been plotted. In addition to the plan view drawings the results for the ERT surveys have been provided as scaled cross-section drawings showing interpretation of the ERT results.

The data from both geophysical methods have found a number of anomalies that could possibly be indirectly related to the remains of the Macquarie Pier. While the Macquarie Pier cannot be detected directly; some evidence of possible archaeological features within the subsurface has been found that align with the expected location of the pier. By most accounts the top of the pier should be approximately five to seven meters deep. However the features we were able to map appeared only in the top one metre. It is more likely that these features are related to urban construction built on top of the pier. These anomalies could be further investigated by shallow excavation to a depth of one or two metres in order to properly identify the nature of these anomalies and to ascertain whether they relate to past construction or newer construction.

If promising results are found, excavation could be extended to deeper levels at a later date. As this geophysics investigation was limited, depending on the finding of any excavations, additional geophysics could be used. This could include 400 MHz GPR to better map shallow features or additional lines of ERT (or reflection seismic) to delineate the deeper features.
I hope that this report provides you with the information required by your brief. If you require clarification on any points arising from this investigation please contact me.

For and on behalf of

GBG AUSTRALIA PTY LTD

TRENT BOWMAN
Geophysicist

Attachments: DRAWINGS GBGA1613-01 to GBGA1613-05 as Electronic Portable Document Files (PDFs)