Case study of ground improvement at an industrial estate containing uncontrolled fill

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ABSTRACT

A proposed 1.5 hectare industrial estate in Tweed Heads, New South Wales was covered with 1.5 to 2 metres of uncontrolled fill. The site had been undeveloped for many years due to the problematic ground conditions. In order to render the site suitable for development the challenge was to engineer the site such that an allowable bearing capacity of 100 kPa was achieved.

Ground improvement using impact rolling was adopted. After initial impact rolling, non-intrusive, surface wave seismic methods were used to assess the nature of the subsoil. Reliance on traditional intrusive methods alone and on a method specification was considered too risky given the variable nature of the fill material at the site that included building demolition debris and significant quantities of organic material.

A seismic survey was used, using the Multi-channel Analysis of Surface Waves (MASW) method, that allowed near surface anomalies (such as zones of organic matter) to be identified and allowed correlations of seismic velocity with Young's modulus. The seismic test results generally provided good correlation with the traditional geotechnical investigation methods that were also undertaken and enabled deficient areas to be identified and reworked or excavated and replaced.

The ground improvement proved successful in achieving the required 100 kPa bearing capacity.

1 INTRODUCTION

The 1.5 hectare area at Tweed Heads, New South Wales, had been left undeveloped for many years; however, it was now considered a prime piece of real estate, despite the geotechnical challenges it posed mainly due to the presence of typically 1.5 to 2 metres of fill. The fill consisted of gravelly clay with some sand and building demolition debris with significant amounts of organic material, over natural soils consisting of fine to medium grained sand. Groundwater was encountered across the site typically 1.5 metres below ground level (near the natural ground surface).

Proposed development consisted of single storey precast/tilt-up panel warehouse type structures and the local Council required that an allowable bearing capacity of 100 kPa be achieved at the site as a condition for granting development approval. A number of previous geotechnical reports and investigations were undertaken at the site, and offered wide ranging recommendations on an allowable bearing capacity.

The remediation and testing works that have been recently carried out to render this site suitable for development are described.

2 GROUND IMPROVEMENT & SITE INVESTIGATION METHODOLOGY

In order to improve the ground conditions at the site, medium level dynamic compaction using a square impact roller was adopted. This option was favoured over excavation and replacement of the existing fill for economic reasons. Rolling dynamic compaction has been used for various applications around Australia for over two decades and an example of a similar application was reported by Avalle & McKenzie (2005).

In order to quantify the improvement following impact rolling and to ensure that the 100 kPa allowable bearing capacity had been achieved across the site, a seismic surface wave survey was conducted analysing seismic velocity to provide a generalised assessment of subsurface conditions at the site and to identify near surface anomalies where lower velocities occurred.

Reliance solely on traditional geotechnical investigation methods was considered too risky given the variable nature of the fill material. Boreholes and test pits had been previously undertaken at the site during previous investigations, leading to wide ranging reports and recommendations of site conditions. A method specification (i.e. 'x' passes of the impact roller) was also considered inappropriate given the need to quantify bearing capacity across the whole site. All impact rolling, seismic testing and traditional testing was carried out in the presence of an experienced geotechnical engineer, so that an equivalent Level 1 supervision by AS 3798 was undertaken.

3 MULTI-CHANNEL ANALYSIS OF SURFACE WAVES (MASW) SEISMIC SURVEY

Based on previous work in similar situations (Terra Australis Geophysica 2006) the Multi-channel Analysis of Surface Waves (MASW) seismic survey method was chosen to be appropriate for the site. The MASW method, developed by the Kansas Geological Survey, was selected in order to assist in the identification of anomalies (such as voids) from analysis of seismic velocities, as well as providing information on the effectiveness of compaction in a timely and cost-effective manner. This method analyses the response of the ground to seismic stimulation as shown diagrammatically in Figure 1 and provides an S-wave velocity distribution profile unlike conventional refraction surveys, which present P-wave velocity information. A more detailed explanation of the MASW method is given by Park et al (1999) and Park et al (2005) and is beyond the scope of this paper.

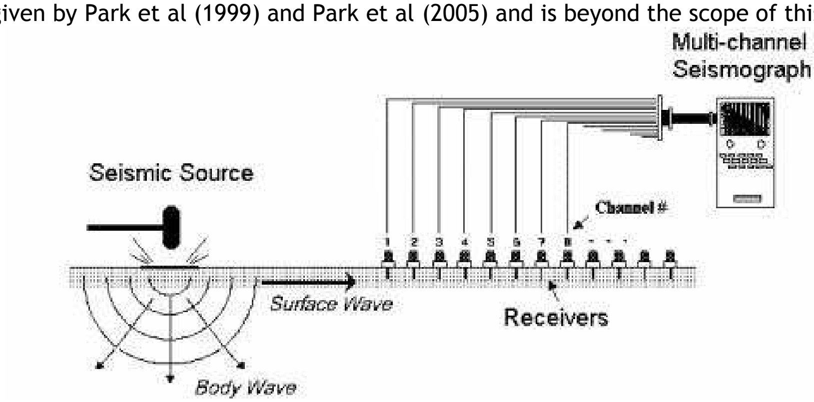

Figure 1: MASW survey method (Kansas Geological Survey 2006)

The seismic source used at this site was a 50 kg steel weight dropped approximately one metre onto a steel plate. On impact, data recording in a 24-channel data acquisition system is initiated with seismic travel times of surface waves recorded on geophones of 4.5 Hz natural resonant frequency each spaced one metre apart in a linear array. The seismic source and the first two geophones used on one seismic profile at the site are shown in Figure 2.

Figure 2: MASW site survey

The MASW testing was conducted along a series of 11 north-south profiles across the site (each approximately 100 m long and spaced 12 m apart). A total of 122 analysis points were used, which was considered sufficient to meet the requirements of this project. However, if required, denser coverage could be made using additional analysis without further data acquisition.

Using the MASW method, one-dimensional surface wave velocity profiles were obtained along a survey line at each geophone location with commercially available SurfSeis software. Two examples of surface wave velocity versus depth profiles obtained at the site after analysis are shown in Figures 3 and 4. Figure 3 indicates well compacted fill overlying competent natural soil, indicating competent ground, which was verified by field density testing (~98% standard compaction) within a test pit that was excavated coincidental with the survey location. Figure 4 shows a 0.3 m layer that was identified in the seismic survey as having poor compaction despite underlying nearly 1 m of compacted fill. Low field density test results (91-94% standard compaction) within test pits and subsequent excavation of the fill in this area found large tree trunks and loose organic matter at the depths corresponding to the low seismic velocities indicated on the section.

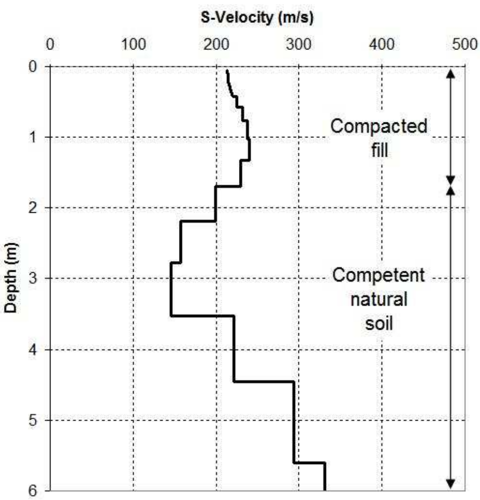

Figure 3: Compacted fill

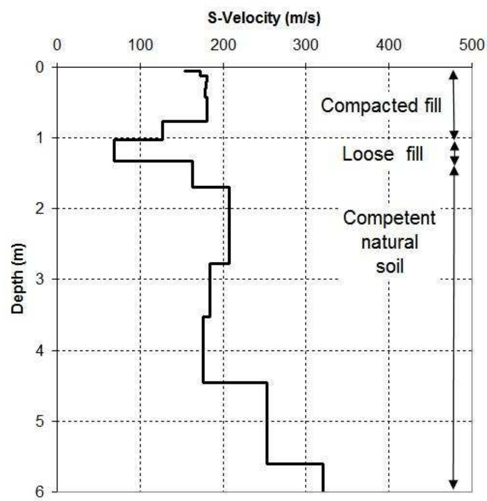

Figure 4: Poorly compacted layer of fill

Two-dimensional sections along the seismic lines can also be developed by interpolating and gridding between each analysis (geophone) point. The sections can be used to highlight weak or uncompacted zones of underground soil. A typical two-dimensional cross section generated from the site is given in Figure 5.

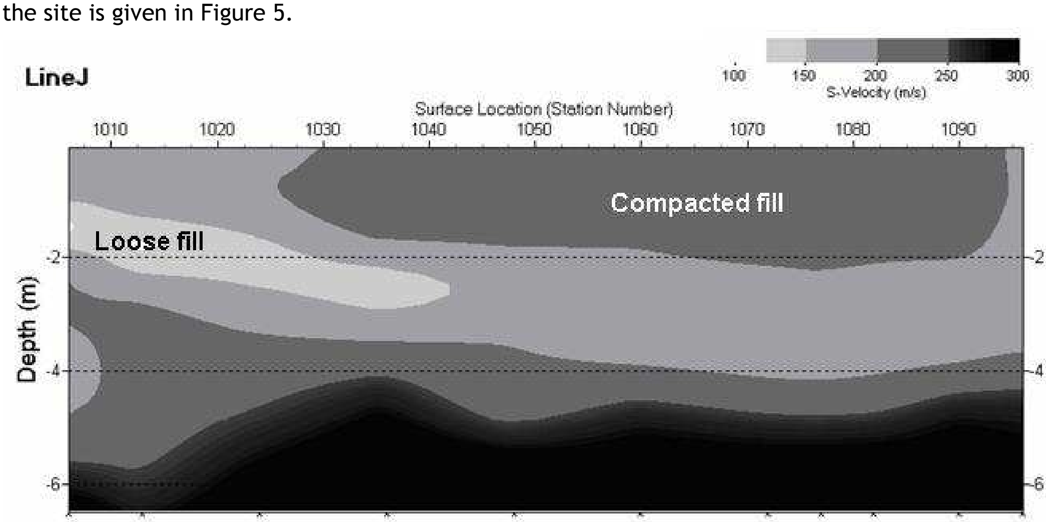

Figure 5: Two-dimensional cross section generated from MASW seismic survey

By determining S-wave velocity across the site, the Young's modulus can be determined from Equation (4). The value of Young's modulus would be equivalent to the tangent modulus or small strain modulus, so that a very small allowable settlement using this Young's modulus for a loading pressure of 100 kPa was adopted as the criteria for obtaining the appropriate bearing capacity.

$$E = 2G(1+\upsilon) \qquad \text{(e.g. Bowles, 1996)} \qquad (1)$$

$$\upsilon = \frac{V_p^2 - 2V_s^2}{2\left(V_p^2 - V_s^2\right)} \qquad \text{(Sheriff, 1991)} \qquad (2)$$

$$G = \rho V_s^2 \qquad \text{(e.g. Sheriff, 1991)} \qquad (3)$$

Combining equations (1), (2) and (3) gives:

$$E = \rho V_s^2 \frac{3\left(\frac{V_p}{V_s}\right)^2 - 4}{\left(\frac{V_p}{V_s}\right)^2 - 1} \qquad \text{(Sheriff, 1991)} \qquad (4)$$

Where,

$E =$ Young's modulus

$V_p =$ P-wave velocity (determined from Poisson's ratio)

$V_s =$ S-wave velocity

$\upsilon =$ Poisson's ratio (estimated using typical values based on the logging of test pits at the site)

$G =$ Shear modulus

$\rho =$ Density (determined from field density tests undertaken at the site)

In equation (4), it can be observed that Young's modulus has a linear relationship with density, a fairly neutral relationship with Poisson's ratio (expressed in terms of the *Vp/Vs* ratio), but is very sensitive to *Vs*, because it is proportional to S-wave velocity squared. *Vp* can be determined using refraction survey, except when there is a velocity reversal. A sensitivity analysis that was undertaken found that variations in density, Poisson's ratio and the *Vp/Vs* ratio parameters (based on measured values and typical ranges for the given site soil conditions) had a relatively small effect, compared with the variation in *Vs*, which was by far the greatest contributor to Young's modulus. Hence the variation in *Vs* across the site gave a good indication of the variation of *E*.

4 COMPARISON OF MASW SEISMIC TESTING WITH TRADITIONAL SITE INVESTIGATION METHODS

Correlations were made with traditional (intrusive) geotechnical investigation methods consisting of 182 dynamic cone penetrometer (DCP) tests, logging of 33 test pits, and conducting 33 field density tests. All tests results are included in URS (2006).

Each test pit was dug such that a field density test could be undertaken at, or below the expected founding depth of footings supporting the proposed development. Field density testing, pocket penetrometer testing and logging of the exposed soils in each of the test pit locations was undertaken. Test pit locations were spread across the site (with some locations coincidental with the seismic survey gridlines to enable direct comparison and correlation of results).

Whilst the DCP test results generally supported the field density and seismic survey test results, less emphasis was placed on DCP results as parts of site were not ideally suited to DCP testing, with a number of tests terminated at shallow depths on large gravel sized material. A large number of DCP tests were carried out to compensate for shallow test results, and to check poorly compacted areas indicated by the seismic survey.

A summary of MASW seismic survey results for a depth corresponding to 1 m below ground level, together with DCP and field density tests is shown in Figure 6. Apart from one area where there was an anomaly that required intrusive investigation (later proven to be building rubble bridging fill within the top 0.4 m), the MASW survey results generally gave good correlation with the other testing methods adopted (DCP, test pits and field density tests). Low-velocity layers (*Vs*<200 m/s) that were identified from the MASW survey corresponded well to low field density tests (<97% standard compaction) and poor DCP results (less than 5 blows per 100 mm). The low-velocity (less compacted) layers were predominantly encountered around the perimeter of site, where access for the impact roller was more difficult, as the fenced site made it hard for the impact roller to impart sufficient energy to the soil due to the roller encountering access related issues and traversing these areas at slower speeds.

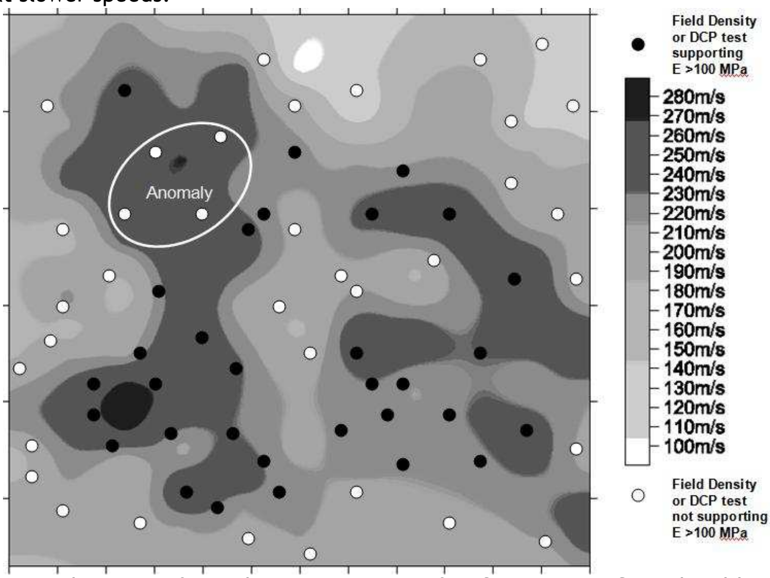

Figure 6: Plan view of site showing summary of MASW survey, DCP and Field Density tests

5 DETAILS OF REMEDIAL WORKS FOLLOWING SEISMIC SURVEY

Further impact rolling on areas identified in the seismic survey with *Vs*<200 m/s was undertaken. The improvement in density that had been achieved was quantified with further test pits and field density and DCP testing. Most parts of site that were previously identified as having low-velocity (*Vs*<200 m/s) corresponding to insufficiently compacted layers, responded well to further impact rolling as indicated by successful density testing giving a compaction >98% standard.

The areas of fill that did not respond to further compaction were excavated and these areas revealed organic-rich fill, often containing large timber pieces, old tree trunks and large tree roots. The areas of organic-rich fill were removed and replaced with imported fill, which was compacted in layers using the impact roller.

A final series of test pits, field density tests and DCP testing was undertaken whilst the impact roller was still working on site, which enabled on-the-spot feedback to be given; therefore identifying areas where any further passes of the impact roller were required. All ground improvement and site investigation works were carried out successfully over the period March to May 2006, with the seismic survey completed within three days.

6 PROJECT COMPLETION AND LESSONS LEARNED

Experiences gained from the project included the following:

- The presence of a full-time Geotechnical Engineer undertaking Level 1 supervision was of benefit to the project, as the supervising Engineer was able to identify areas of site that required greater attention, hence enabling efficient use of time and equipment.
- The impact roller proved a very effective method of proof rolling the site, as soft spots could often be readily identified by the supervising engineer and operator.

- As seismic methods are reliant upon measuring ground vibrations from the source using a series of geophones, each test (taking only a few seconds) in this project was undertaken during periods of low external vibrations (such as from passing traffic, construction equipment on the opposite side of site, aircraft, strong winds). Occasional external vibrations were noticed during the recording of data; however, as seismic data was displayed and monitored immediately after recording, any re-tests deemed necessary could be performed immediately. Such re-tests were only necessary for approximately 5% of records.
- Whilst others such as Avalle & McKenzie (2005) have used geophysical methods (continuous surface wave methods) on impact rolling projects, it is understood that this is one of the first applications of the MASW seismic survey method in Australia to quantify ground improvement.

7 CONCLUSIONS

Ground improvement using the impact roller has proven successful in achieving the required bearing capacity, allowing shallow footings to be designed and constructed at a site that was geotechnically challenging due to a history of uncontrolled filling. The seismic survey using the MASW method generally gave good correlation with dynamic cone penetration tests, test pits, and field density tests, with V_s<200 m/s corresponding to regions of lower than acceptable density. This enabled areas of insufficient compaction to be identified and reworked or excavated and replaced.

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