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A Seismic Ground Investigation across a Creek for Design of Bridge

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ABSTRACT

A seismic survey across a creek with refraction and multichannel analysis of surface waves (MASW) methods was carried out across Iron Creek south of Sorell, Tasmania. The purpose of conducting the geophysical survey was to obtain a cross section profile of both the creek mud line and depth to the top of basalt, extending from the eastern creek embankment to the western creek embankment. The information on the underlying subsurface profile was used to assist with the design of foundation options for the realignment of Iron Creek Bridge.

The survey consisted of onshore and offshore components: 135 metres on the west bank, 40 metres across the creek and 69 metres on the east bank, therefore it was necessary to use a hydrophone cable as well as land geophones. A sledge hammer was used onshore as a seismic source and a small airgun was used across the creek.

The results were presented as P-wave velocity section from the refraction analysis and S-wave section from the MASW. Two boreholes onshore indicated the depth to basalt with very high strength at 8 metres on west bank and 3 metres on east bank. These depths correspond to P-wave velocity of about 1100m/s and S-wave velocity of about 500m/s. The sections showed that the depth of high strength basalt increases across the creek up to about 10 metres, with the deepest section on the eastern side of the creek. The information obtained from the seismic survey used in conjunction with the borehole information eliminated the necessity of drilling additional boreholes over the creek.

The seismic results could also infer mechanical and engineering parameters including Young's modulus, Poisson's ratio and pseudo-N-value. The results of the seismic survey contributed to the design of the new bridge.

1 INTRODUCTION

Iron Creek is a tidal creek which runs north east of Hobart, Tasmania (Figure 1). A bridge located on the Arthur Highway, a main thoroughfare between Hobart and Port Arthur, crosses the creek. The project consisted of improving the road and bridge alignment and replacing the existing bridge, which had reached its design life. A seismic survey with refraction and multichannel analysis of surface waves (MASW; Park et al, 1999; Suto, 2007) methods was carried out to investigate the ground conditions and confirm the basalt profile across the creek.

For design and construction of roads and bridges, knowledge of underlying ground conditions is essential. Comparing geophysical testing methods, electric and electromagnetic methods may estimate the shape and extent of geological boundaries by testing electric and electromagnetic properties, whilst seismic methods can provide information on the mechanical strength of the ground.

The geophysical field survey conducted across Iron Creek included onshore and offshore operations. The two different kinds of data accumulated presented no problems in compatibility during data processing. The end result presented comparable profiles of P-wave and S-wave velocity structures.

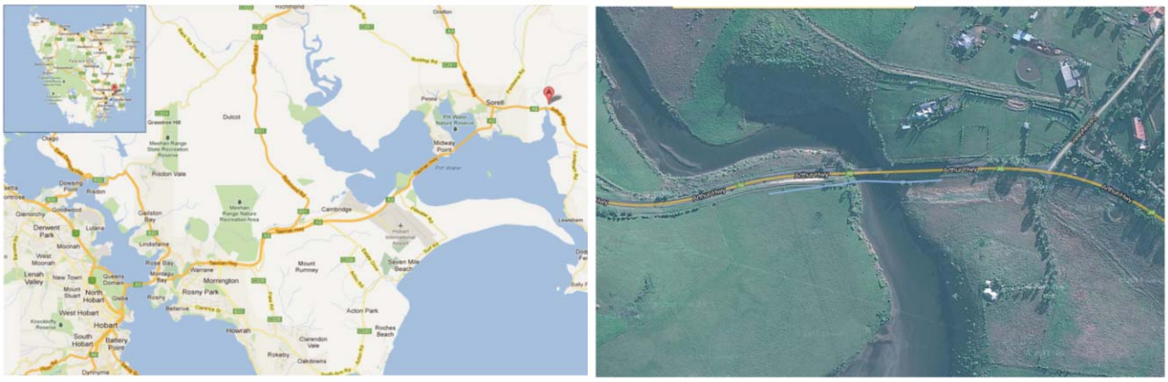

Figure 1. Area and site maps from Google Maps. Approximate survey location line in blue.

2 DATA ACQUISITION AND QUALITY

The survey consisted of onshore and offshore components: 135 metres on the west bank, 40 metres across the creek and 69 metres on the east bank. Conventional spiked geophones were used on land, and a water bottom cable was used across the creek. The refraction and MASW data were collected at the same time with common parameters except for record length and sampling frequency. The data acquisition parameters are summarised in Table 1.

Table 1. Data Acquisition Parameters

Seismic source:	12lb sledgehammer / Airgun
Recording system:	Geometrix StrataView; 24-bit 24-channel recorder
Recording channels:	24 per record
Sampling rate:	0.0625 ms (16000Hz) for refraction 0.5ms (2000Hz) for MASW
Record length:	128ms for refraction 2 seconds for MASW
Geophone / Hydrophone type:	Geospace GS11 7.55 Hz vertical geophones on land / PVDF Piezo Polymer Hydrophones 3-3000Hz
Geophone interval:	3m on land / 2m water bottom cable

The onshore section of the survey site comprised a paddock with light vegetation (Figure 2). For this part of the survey, spiked geophones were used rather than a landstreamer due to the steep slope and thick shrubs near the bank of the creek. A small dinghy was used for the offshore component of the survey (Figure 3) to lay the water bottom cable and to operate the airgun source at shot points on the water.

Figure 2. (Left) Typical field conditions onshore. (Right) Recording system.

Figure 3. (Left) Airgun and water bottom cable. (Right) Offshore deployment.

The road adjacent to the site, Arthur Highway, is a main thoroughfare between Hobart and Port Arthur, and traffic during the survey was constant. This caused some noise to several records of the seismic data.

3. ONSHORE AND OFFSHORE DATA

The data quality of onshore and offshore records is compared. (Figure 4 shows refraction survey data and Figure 5 shows MASW data).

Although there is some noise in the early part of the offshore data, the first breaks of the seismic signals are picked with reasonable confidence.

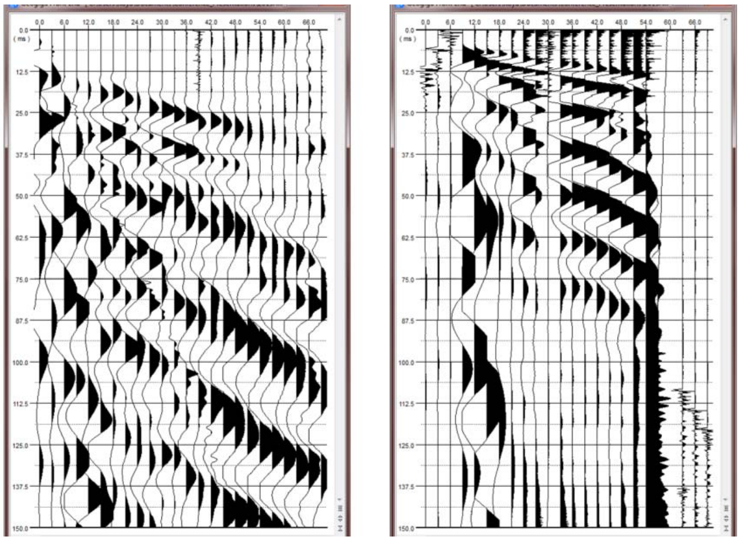

Figure 4. Seismic records for refraction survey. Full time scale is 150ms. (Left) Onshore. (Right) Offshore; Note channels at both ends are out of water and not recording signals.

The contamination from traffic noise on the onshore data was worse in the longer MASW data, as the signal needed to be amplified more for the distant and late part of the data. However, the spectra of this noise are of high-frequency and the surface wave signals are recognised when it is filtered out. In practice, the overtone analysis was performed on the unfiltered data. The noise falls outside of the analysis range of 10 to 50Hz.

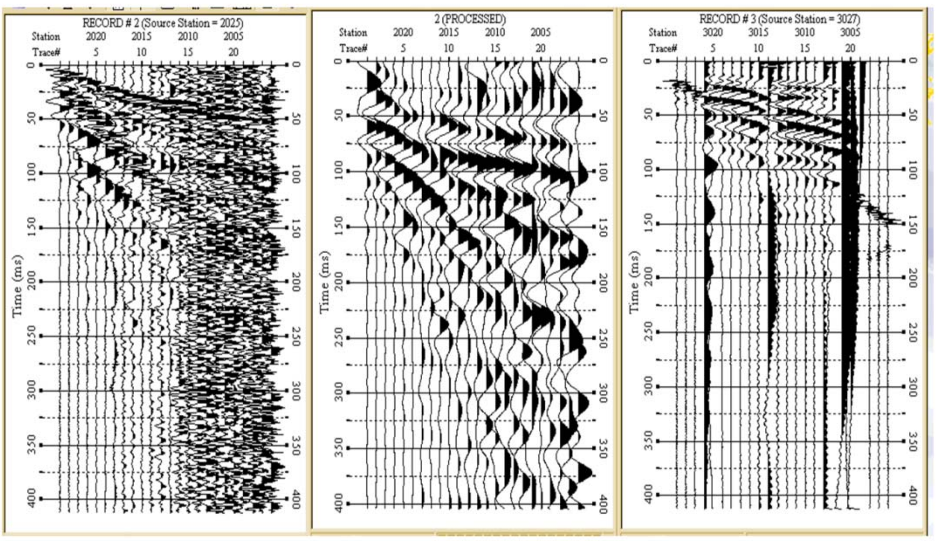

Figure 5. Seismic record for MASW analysis. Top 400ms is displayed. (Left) Original onshore record. (Middle) The same record with a 60Hz high-cut filter applied. (Right) Onshore record.

4. ANALYSIS AND INTERPRETATION

The refraction analysis and tomographic inversion were carried out using the SeisImager® software by Geometrics. SurfSeis® by Kansas Geological Survey was used for the MASW analysis. Figure 6 shows 2D velocity sections along the survey line. The P-wave velocity section was produced through tomographic inversion process of the first break picks while the S-wave velocity section was produced by interpolating the MASW inversion between analysis points every 12 metres. Although there are several different features, these profiles are largely in agreement.

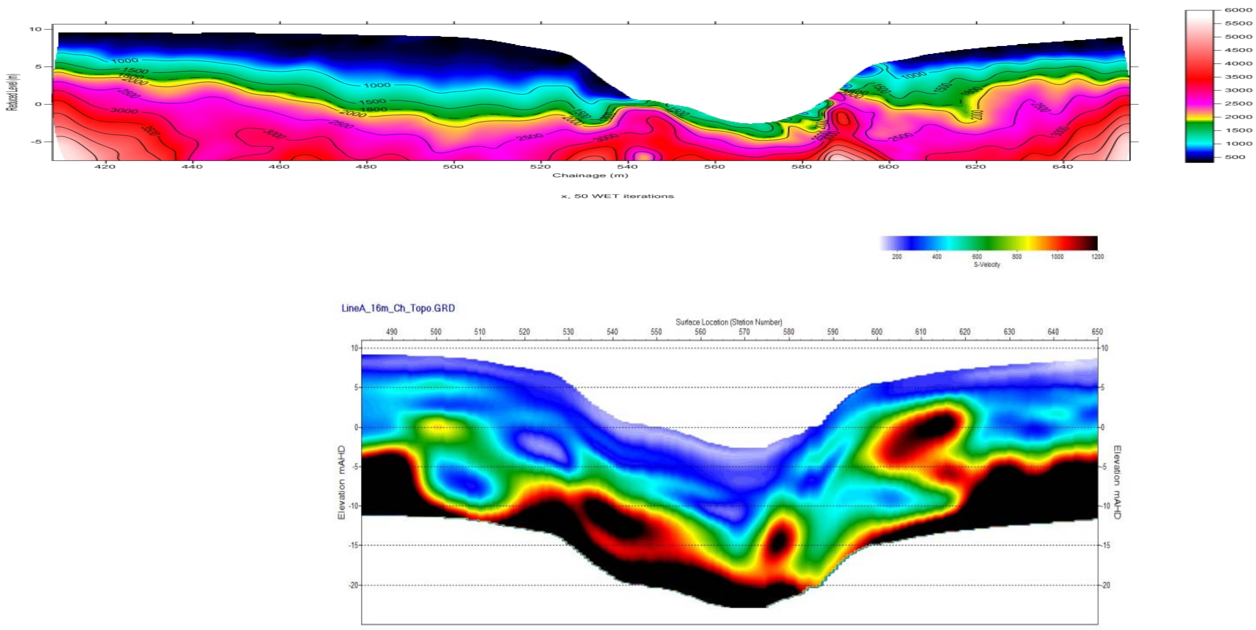

Figure 6. Seismic velocity structure across Iron Creek.
(Top) P-wave velocity structure by refraction; (Bottom) S-wave velocity structure by MASW.

Two boreholes were drilled prior to the geophysical survey along the proposed bridge realignment: one each side of the creek. The borehole logs indicate four geological units, among which the depth of basalt is of most interest. Figure 7 shows correlation between the borehole data and S-wave velocity structure derived from MASW inversion at the nearest analysis point. The S-wave velocity changes reflect the geological boundaries reasonably well, but the absolute values of S-wave velocity do not exactly match the soil/rock type. The description “fresh basalt” corresponds to about 400m/s at BH1 and 600m/s at BH2.

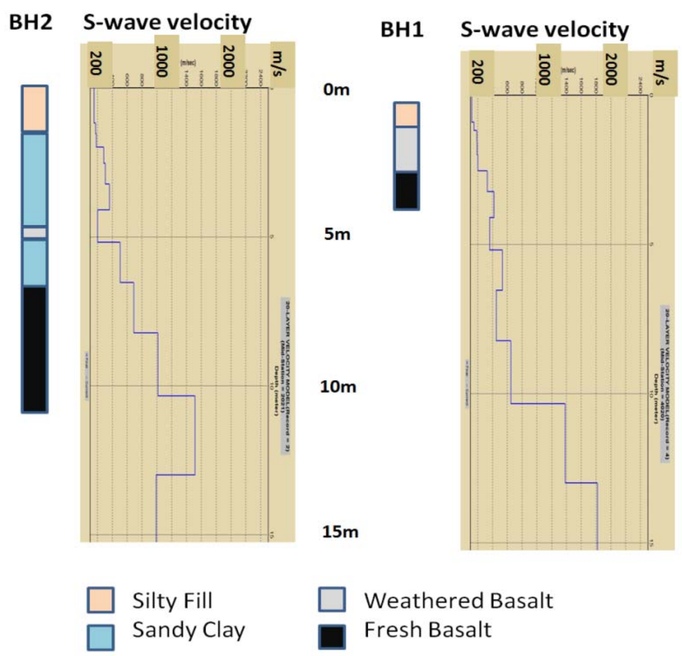

Figure 7. Comparison between lithology at boreholes and S-wave velocity by MASW inversion.

The borehole data is compared to the velocity sections (Figure 8), in which the velocities are blocked to show divisions. The P-wave velocity corresponding to the “fresh basalt” is about 1400 m/s at BH1 and 1600 m/s at BH2. Both S- and P-wave velocities of the “basalt” are faster at BH2 then at BH1. This may be because the qualitative description of rock type of borehole data, “basalt”, has some range in its strength due to degree of weathering, and the seismic velocities may be better representing the strength rather than rock type.

The velocity structures in the offshore part of the survey line are also conformable. It demonstrates the MASW survey can be applied to the offshore survey.

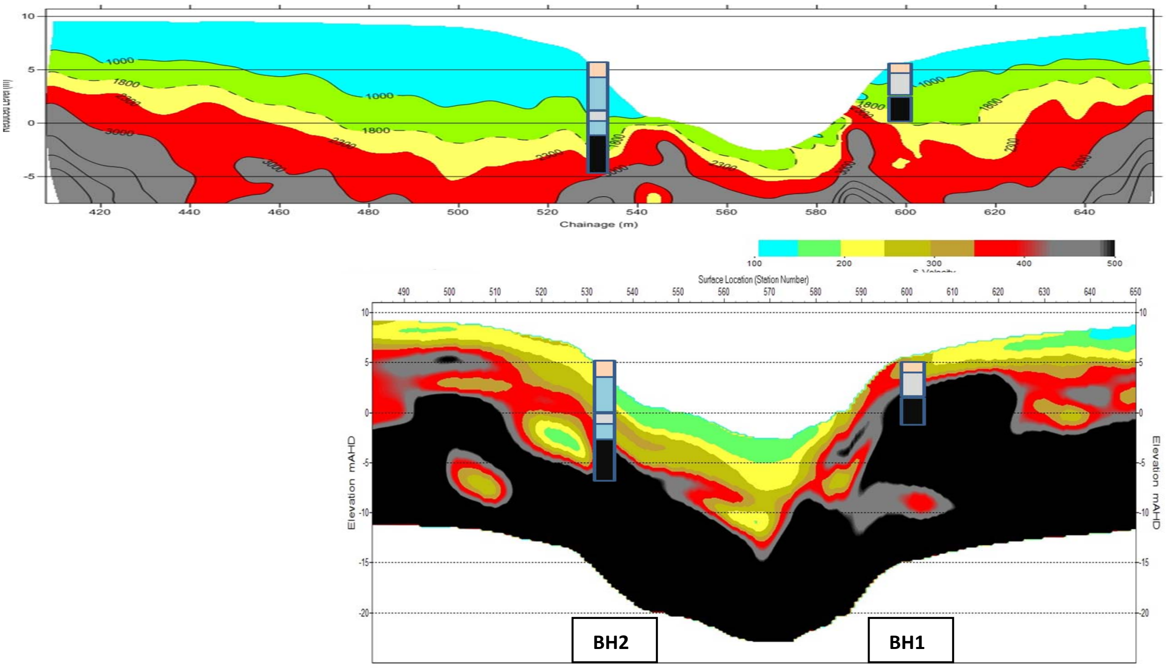

Figure 8. Velocity sections with blocked colour scheme. Borehole lithology the same as Figure 7 is superimposed.
(Top) P-wave velocity structure by refraction; (Bottom) S-wave velocity structure by MASW.

6. ENGINEERING PARAMETERS

6.1. Pseudo-N Values

The SPT N-value is an empirical parameter for soil classification. Despite its ambiguous scientific merit, it is well established in the geotechnical engineering community. Many authorities use this value as a basis of soil classification. Table 2 is an example specified by the government of Queensland.

Table 2. Soil Classification by Department of Main Roads, Queensland

Essentially Cohesive Soils		Essentially Non-Cohesive Soils	
Terms	**SPT N Value**	**Terms**	**SPT N Value**
Very soft	0-2	Very loose	0-4
Soft	2-4	Loose	4-10
Firm	4-8	Medium dense	10-30
Stiff	8-15	Dense	30-50
Very stiff	15-30	Very dense	>50
Hard	Hard>30		

There is a weak correlation between S-wave velocity and SPT N-values and many empirical formulae have been proposed (Suto, 2011). In this project the formula proposed by Suto (2011) is used and called “pseudo-N value”:

$$N = \left(\frac{Vs}{60}\right)^{2.5}. \qquad (1)$$

Figure 9 shows the pseudo-N value sections colour-coded according to the soil classification schemes of Table 2. Although this does not exactly represent the N-values, it gives the engineers some idea of strength of the ground and certainly visualise the values across the site.

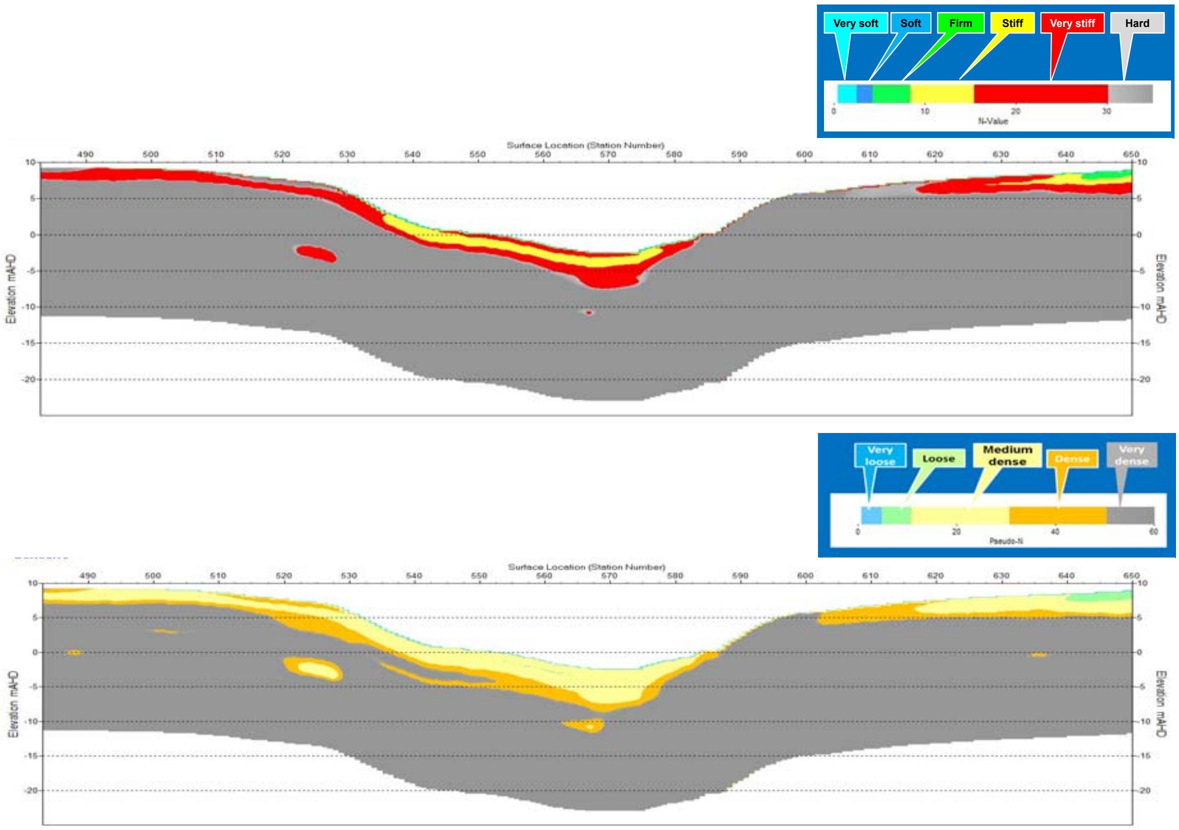

Figure 9. Pseudo-N value sections. (Top) Essentially cohesive case. (Bottom) Essentially non-cohesive case.

6.2 Poisson’s Ratio and Young’s Modulus

From the P-wave and S-wave velocities two physical parameters are estimated: Poisson’s ratio and Young’s modulus. Poisson’s ratio is comprises physical properties derived from P-wave and S-wave velocities. The calculation of Young’s modulus requires density value in addition. Poisson’s ratio (σ) is calculated from the *Vp*/*Vs* ratio as:

$$\sigma = \frac{V_p^2 - 2V_s^2}{2\left(V_p^2 - V_s^2\right)} = \frac{\left(\frac{V_p}{V_s}\right)^2 - 2}{2\left(\left(\frac{V_p}{V_s}\right)^2 - 1\right)} \qquad (2)$$

Assuming density (ρ), Young’s modulus (E) is calculated as:

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

Equation (3) shows Young’s modulus is most sensitive to variation of S-wave velocity.

These parameters are calculated by grid operation and inaccuracy due to interpolation may be expected, however they are considered to show the approximate range and trend of these parameters.

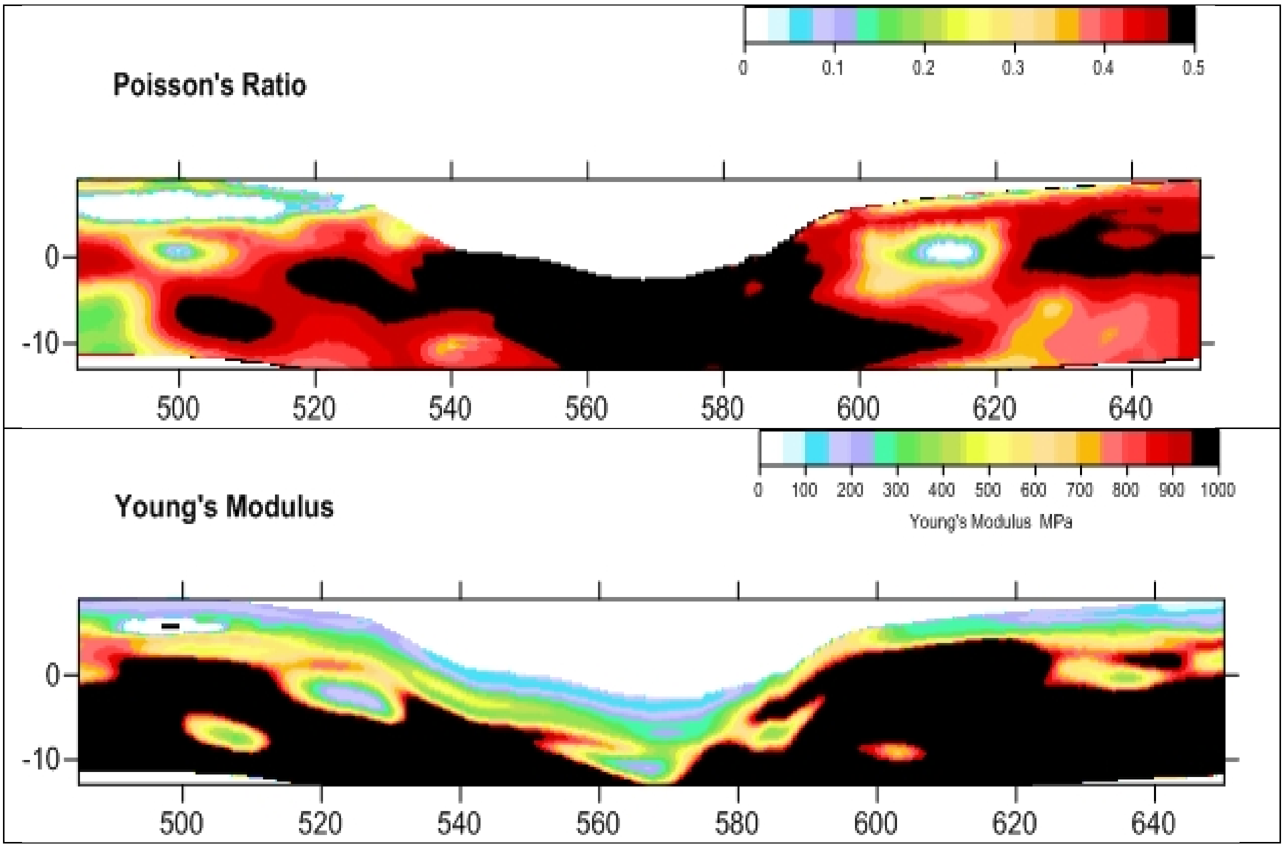

Figure 10. Sections of Poisson's ratio (Top) and Young's modulus (Bottom) inferred from seismic velocity.

7. USE OF SEISMIC SURVEY RESULTS IN THE BRIDGE DESIGN

The results of the seismic survey in conjunction with the geotechnical site investigation report (borehole data) were considered in designing the substructure for the replacement bridge. Since the completion of the investigations, the proposed alignment of the highway and new bridge was shifted; therefore the results of the investigations were used with caution as they were not strictly along the new alignment. Ground conditions exposed were verified by a senior geotechnical engineer during construction phase.

Bridge abutments were designed using borehole data and the basalt profile obtained from the seismic survey. The Port Arthur abutment was designed based on the rock strengths and consideration of the plate nature of the basalt flows, as discussed in the geotechnical investigation report. The Sorell abutment was deemed to be founded on material that comprised floaters within a basaltic clay matrix. The foundation was designed using robust driven steel piles which could displace small to medium (up to 1.0m diameter) floaters in the clay matrix and found on basalt. The designers allowed a contingency of potentially increasing pile numbers and amending the pile cap if the piles did not drive appropriately and if individual piles did not pull up in a consistent nature. No significant issues were encountered during construction.

The pier foundation was designed using information obtained from the seismic survey. The information was compared to the borehole data and the designers were able to obtain limited confidence that in the vicinity of the proposed pier pile cap, there was a sound rock base and that there were boulders in a loose silt matrix above the basalt layer. Bored piles were considered however deemed high risk due to potential shifting boulders and blow in between boulders when the coring piece was withdrawn. The designers concluded there was less potential risk using robust driven piles. The pile cap design was amended to facilitate issues of piles displacing during driving and/or stopping and contingency plans were in place. The piles did not found at exactly the same level, but this was expected based on the information from the seismic survey. Without the information obtained during the seismic survey, there would have been unacceptable risk to progress the pier design without additional geotechnical information.

Figure 11. Construction of the bridge looking towards Sorell (left), and looking towards Port Arthur (right)

8. CONCLUSION

A seismic survey to investigate the ground competence for bridge foundation was carried out across Iron Creek, Tasmania. Compatibility between the onshore and offshore data is demonstrated by comparing the data. The refraction and MASW survey resulted in P-wave and S-wave velocity structures largely comparable, and represent the structure of the strength of the ground.

The data provided valuable information across Iron Creek where borehole cannot be easily drilled. The data were used in designing the second bridge over Iron Creek.

9. ACKNOWLEDGEMENTS

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