Refraction Microtremor method for delineation of layers and lenses, and assessing liquefaction potential within an alluvial setting – Morobe Province, Papua New Guinea

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SUMMARY

Refraction Microtremor (ReMi) is a relatively new method in the geophysics industry. ReMi provides high resolution seismic shear wave velocity models up to 200m depth and as such has the potential of being an efficient method for assessing the soil liquefaction potential in seismically active regions.

This paper presents a geophysical investigation carried out as part of a geotechnical feasibility study for a proposed Tailings Storage Facility (TSF) in the Morobe Province of Papua New Guinea. The primary objective of the investigation was to use geophysical methods to obtain subsurface parameters to assess the liquefaction potential within an interbedded and lensed clay/gravel alluvial setting. ReMi together with down hole and cross hole seismic methods were used to generate shear wave velocity information of multiple layers with depth, and in particular to define seismic velocity inversions.

ReMi data was acquired using two array setups specifically targeting the top 100m of subsurface material and the top 50m of subsurface material at increased layer resolution. The data was inverted to produce shear wave velocity soundings which were correlated with the cross-hole and down-hole seismic methods, and with bore hole Standard Penetration Tests (SPT). The soundings were compiled to generate high resolutions shear wave velocity sections, analysis of which proved pertinent in defining the interconnectivity of the lensed clay/gravel and shear wave velocity variations for the calculation of liquefaction potential thresholds.

Key words: ambient seismic, refraction micro-tremor, ReMi, Papua New Guinea, soil liquefaction.

INTRODUCTION

Soil liquefaction within seismically active regions of Papua New Guinea, presents a variety of problems. Soil liquefaction can be detrimental to potential tailings storage facilities, due to the underlying saturated soils, and their ability to lose strength and stiffness due to seismic activity and changes in stress condition. In order to assess the liquefaction potential at a proposed Tailings Storage Facility (TSF) site, Wafi Jolpu JV consulting through GBG Australia undertook a geophysical survey within a remote area of the Morobe province, known as Finchif. This area was a known flood plain at the base of the Timini range with dense jungle, rivers and channels.

The project objectives were to identify changes in deltaic sequences, ranging from; very weak permeable and highly porous layers of coarse grained alluvium (sand, gravel and cobbles), to consolidated interconnecting clay lenses/layers of fine grained alluvium (silt and clay). These deltaic sequences overlie weak and weathered siltstone formations, which in turn overlie bedrock. The geophysical investigation was designed to target depth to bedrock and to generate shear wave velocity models for assessing the liquefaction potential of the site. In addition to the shear wave velocities, definition was sought of the interconnectivity of fine grained alluvial lenses.

Refraction Micro tremor (ReMi) was determined as the most suitable surface geophysical method that would address the investigation objectives to the required target depth and spatial coverage. ReMi utilises passive seismic sources (either from natural sources or human activity) through the dispersive properties of Rayleigh Waves. With the method ambient, low frequency ground vibrations are recorded by a string of vertical-component geophones over a long time period. The resulting dispersion curves are inverted to obtain S-wave velocity (Vs) soundings for the centre of the seismic receiver array. In addition to ReMi, downhole geophysical methods including Cross Hole Seismic and Vertical Seismic Profiling datasets were acquired in order to measure direct P- and S-wave velocities.

The principal results of the investigation yielded S-Wave velocity values ranging from 150m/s in shallow lenses, to 650m/s at deep bedrock levels. The ambient noise including that from nearby earthworks and drilling activity was found to be an excellent seismic energy source with resulting dispersion curves with high signal to noise ratio. The generated S-wave models were provided to the client for use in the overall geotechnical study combining Cyclic Stress Ratio (CSR), Cyclic Resistance Ratio (CCR) and soil stiffness calibrated with SPT corrected values.

ReMi ACQUISITION METHOD

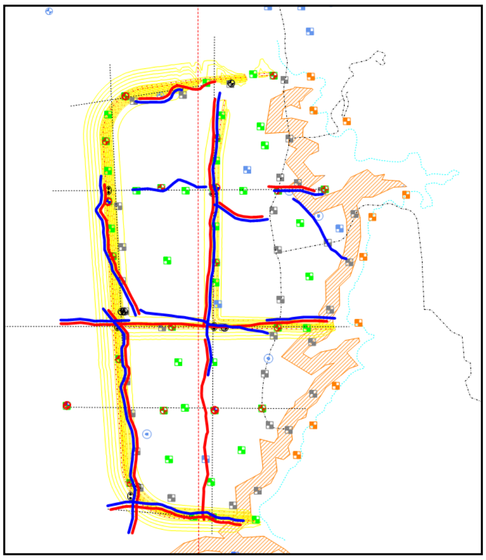

Figure 1: Survey area and lines of ReMi over the proposed TSF. Red lines indicate Deep ReMi, Blue lines indicate Shallow ReMi data collection.

The ReMi dataset was acquired over a total of 28km of traverses including 14km of "deep" ReMi targeting the top 100m of subsurface material and 14km of "shallow" ReMi targeting the top 50m of subsurface material. The ReMi dataset was acquired as a series of traverses along critical profiles of the proposed TSF including along the dam walls to be constructed in multiple phases (Figure 1).

ReMi data was acquired using a 24 channel linear seismic array with 10m spaced 4.5Hz geophones and 5m spaced 10Hz geophones for the deep and shallow ReMi set ups respectively. Vs soundings (seismic velocity with depth) were acquired at the midpoint of each seismic array, after which the entire array was moved up the traverse by 20m and repeated. By combining individual soundings in post processing, 2D S-wave velocity profiles were generated.

Prior to production various recording parameters were trialled including record length, sample interval and number of stacks. The optimum parameters in regards to data quality and production rate for the soundings included recording fifteen 20 second records which were later stacked to produce a summed record of ambient seismic energy. A sample interval of 2 milliseconds was chosen based on previous ReMi investigations of similar nature carried out by GBG Australia and supported by available literature (Rucker, 2003) (Basavanagowda, Govindarahu, & Ramesh Babu, 2012). Higher sample intervals were not required due to the frequency range targeted by the ReMi method. The acquisition parameters are shown in Table 1.

Table 1 - Summary of ReMi acquisition parameters:

Setup	System	Geophone interval (m)	Geophone centre frequency (Hz)	Spread length (m)	Record length (s)	Number of records (stacks)	Sample interval (µs)	Array type
Deep ReMi	24 Channel	10	4.5	230	20	15	2000	Linear
Shallow ReMi	24 Channel	5	10	115	20	15	2000	Linear

DATA PROCESSING AND ANALYSIS

The acquired ReMi data was saved in .DAT format. A total of 15 individual data files relating to a single sounding location were combined in SurfSeis (V4, KGS, 2013) for the generation of dispersion curves (Figure 2).

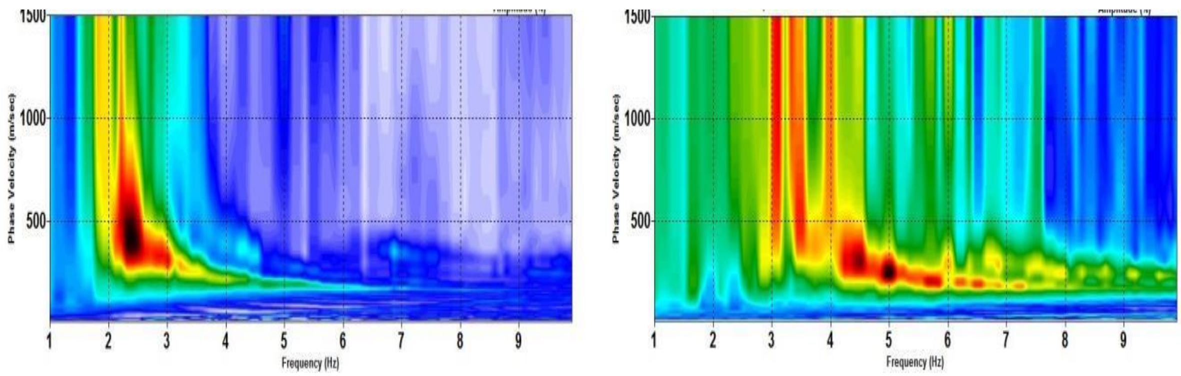

Figure 2: Generated dispersion curves for the deep ReMi setup (left) and shallow ReMi set up (right)

Data analysis involved manually picking the fundamental Rayleigh wave mode of the dispersion curves (phase velocity against frequency) and inverting to a Vs sounding assuming a 20 layer model. The soundings corresponding to the deep and shallow setups were combined in order to generate a single sounding with near surface high resolution and to the target investigation depth. These were correlated with the results of the cross-hole and VSP, as well as Standard Penetration Tests (SPT) carried out within a number of boreholes by the client (Figure 3).

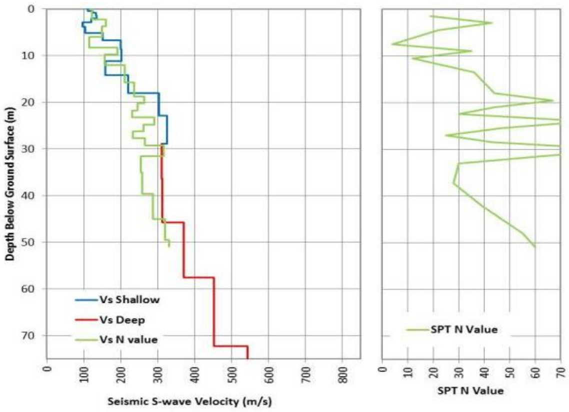

Figure 3: Vs sounding for deep ReMi (red), shallow ReMi (blue) and converted SPT values (green).

The generated Vs soundings along each traverse were then corrected to topography and combined to produce 2D seismic S-wave velocity profiles (Figure 4). Analysis of the 2D sections allowed for detailed interrogation of the dataset including the identification of clay lenses within the near surface and the interconnectivity of such lenses (Figure 5).

After identifying areas of low S-wave velocity within the near surface interpreted as lensing and analysing the connectivity, further analysis was carried out including modelling the bedrock topography shown as the transition to high velocity with an anticipated substantial weathering zone, and back correlation to SPT values in order to generate apparent SPT sections (Figure 6).

The results of the investigation were provided to the client in digital format for input into the geotechnical model to assist in assessing the liquefaction potential and hence feasibility of the site for the proposed TSF.

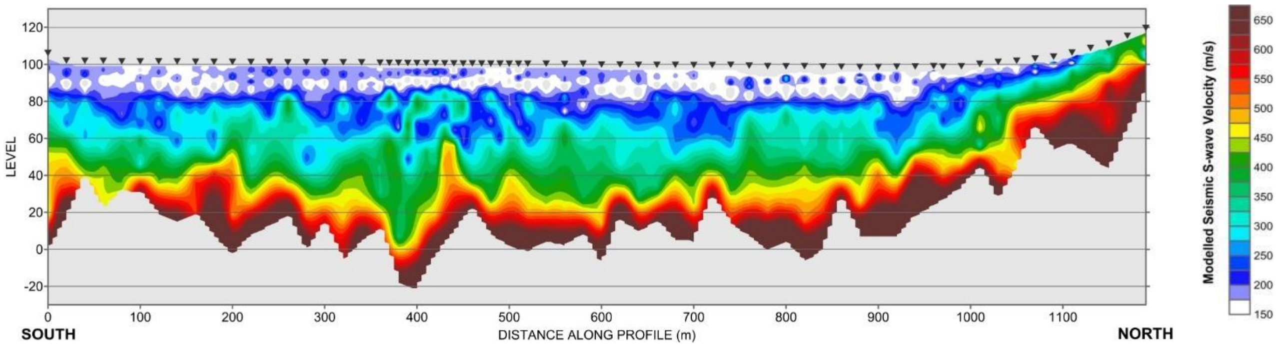

Figure 4: Generated S-wave velocity section, showing the Vs model with level and distance. Depth is to ~100m and distance along the profile is 1200m. Vs values are shown as per the colour scale

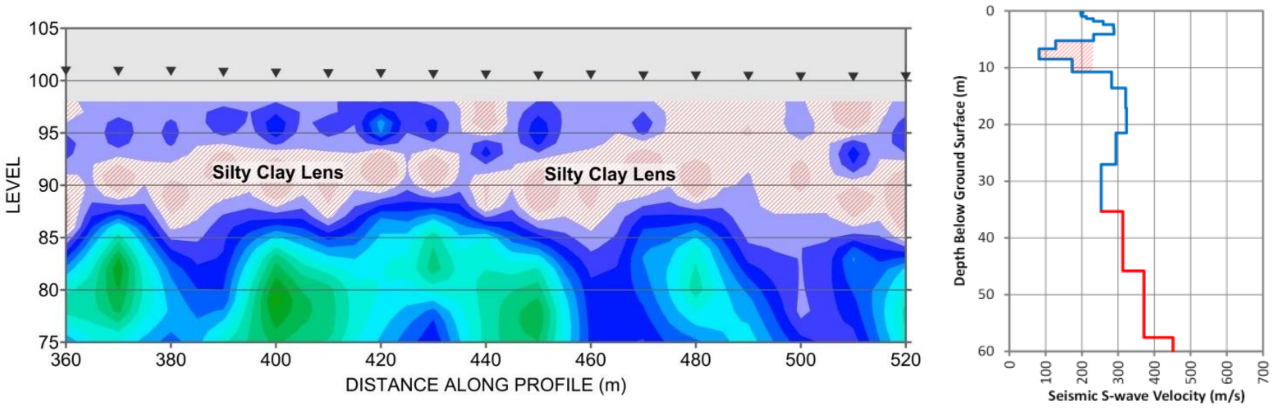

Figure 5: Sub-section of a generated S-wave velocity section (Figure 4) showing areas of low modelled Vs corresponding to interpreted silty clay lenses. Vs sounding through one of the lenses is shown on the right.

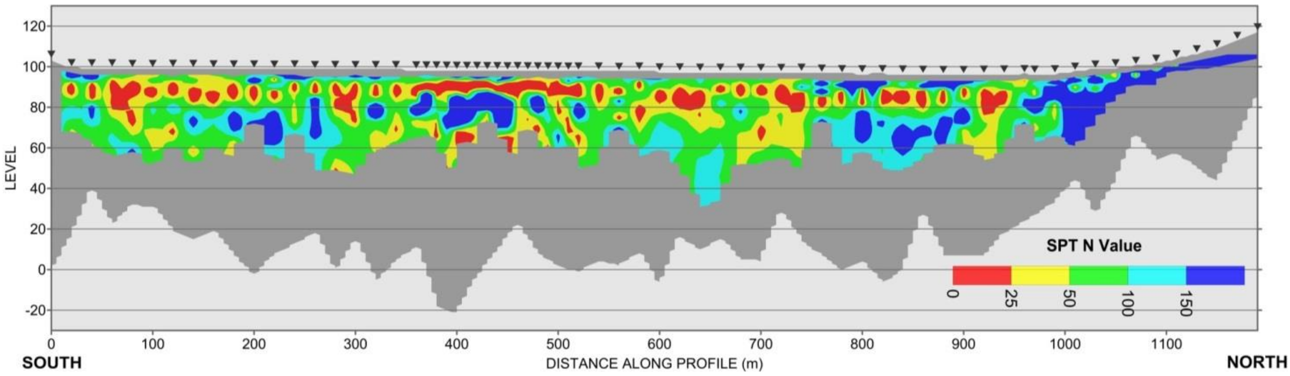

Figure 6: Modelled SPT value generated with correlation to the ReMi S-wave velocity sections.

CONCLUSIONS

The geophysical investigation of the proposed Tailings Storage Facility at Finchif in the Morobe Province PNG was completed during a50 day site programme. Processed and initial interpreted datasets were provided to the client on a daily basis in order to modify the investigation scope as required.

The ReMi data quality was observed to be good to excellent where ambient seismic noise was sufficient and when calibrated with the down hole and cross hole geophysics and geotechnical testing provided a robust subsurface model in which the overall geotechnical assessment could be carried out with confidence. In addition the client's supportive approach in regards to trialling various acquisition parameters while on site, led to a more efficient investigation whilst improving the overall data quality.

The results of the investigation, including the modelled S-wave velocity sections, the analysis of clay lenses and the bedrock topography, were shown to provide valuable information to the client during the overall feasibility assessment of the site for the proposed Tailings Storage Facility.

ACKNOWLEDGMENTS

GBG Australia would like to acknowledge Newcrest Mining, Advisian, Morobe Mining Joint Venture, GBGMAPS and the Papua New Guinea Government for their assistance with this project.

REFERENCES

Basavanagowda, G. M., Govindarahu, L., & Ramesh Babu, R. (2012). *Application of Refraction Microtremor (ReMi) for Seismic Site Characterisation.*

Rucker, M. L. (2003). *Applying the refraction microtremor (ReMi) shear wave technique to geotechnical characterization.* .