An application of multi-channel analysis of surface waves (MASW) to hydrological study: A case history

Koya Suto
Terra Australis Geophysica Pty Ltd
koya@terra-au.com

SUMMARY

The multi-channel analysis of waves (MASW) is a seismic survey method, in which the seismic data are analysed in the frequency-phase velocity domain to estimate underground S-wave velocity structure. It is used in a variety of engineering projects from large to small at various stages.

An MASW survey was carried out to investigate palaeochannels which is suspected to provide passage to leakage of a dam. For the condition peculiar to the dam site, three different methods of data acquisition were used: spiked geophones; landstreamers and unspiked geophones supported by play dough. These methods of placing geophones provided comparable data quality.

The result was presented in section form along the survey lines and interpolated depth slices in plan view of S-wave velocity distribution. The plan view maps showed a pattern of low S-wave velocity anomaly which is interpreted as drainage. This result was correlated with the other geotechnical tests and used in the subsequent hydrological study.

Key words: MASW, hydrology, palaeochannel, dam

INTRODUCTION

The Multi-channel Analysis of Surface Waves (MASW) (Park, et al, 1999) is widely used in many different facets of engineering projects. In an early stage of construction projects, it is commonly used to estimate the hardness of the ground for excavation and cutting. In a later stage, when a construction site has been prepared, the MASW survey may be used to check the quality of the prepared ground: competence of the ground of compacted site for example. The application includes large scale project such as roads, railways and pipelines and small surveys under a house (Suto, 2007). As the output of MASW is spatial distribution of S-wave velocity, there is a possibility of other applications where variation of S-wave velocity is associated with geological or geotechnical features sought.

In this study, the MASW method is used for hidrogeological investigation at a dam site where small leaks are suspected through buried palaeochannels. A low S-wave velocity anomaly is anticipated over the palaeochannels.

The study took place at one of the water reservoir dams in the north of Melbourne, Victoria.

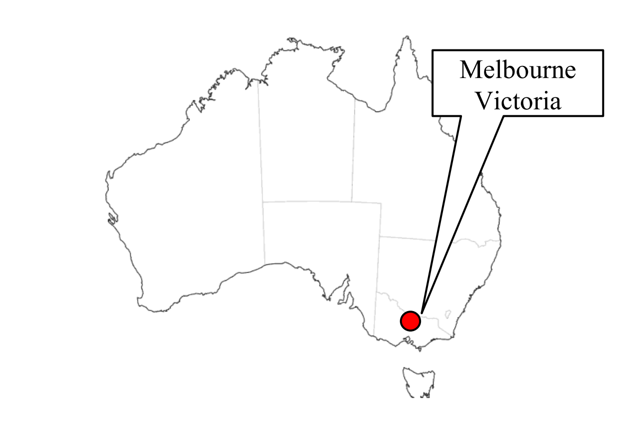

Figure 1. Location map

DATA ACQUISITION

In this survey, seismic data along four parallel lines and one tie line were collected. From the nature of the dam, there are different surface conditions for data acquisition: hard flat surface on the top, grassed area at the bottom, steep slope across the bank and sloped cement surface inside of the dam. Three different methods of receivers were deployed for different surface and data of comparable quality were acquired.

A landstreamer was a used on the hard surface of the top of the dam wall for maximum efficiency in data acquisition. It could be used in the grassed area where vehicle access was possible. However the grass under each geophone sledge of the landstreamer must be removed or pushed aside to ensure good ground coupling of the receiver. Conventional spiked geophones were used on the slope of the wall, where the landstreamer could not be used due to the difficulties in keeping the geophones vertical and of vehicular access (Figure 2).

But the real difficulty in the data acquisition was on the slope on the water side of the bank. Its concrete surface forbade the spikes of the geophones, and the landstreamer slipped sideways to the water. Paste made of flour, or “play dough” as used in kindergarten children to make figures, was used to stabilise the geophones the spikes of which were removed (Figure 3). This held the geophones vertical without “cushioning” to attenuate the seismic signal. It is totally organic and biodegradable; no environmental concern was

Figure 2. Data acquisition methods used in different environments: Landstreamer on the top of the bank (Left); Landstreamer pushed in the grass (Middle) and Spiked geophones on the slope of the bank (Right).

Figure 3. Line A with geophones placed with play dough (left) and detail (right)

caused. In fact, soon after the most of the dough was removed, ants started to clean up the remains.

DATA ANALYSIS

Data Quality

The data of the three different receiver systems were comparable and of good quality. Figure 4 shows some examples of the seismic records collected with three different modes of receivers.

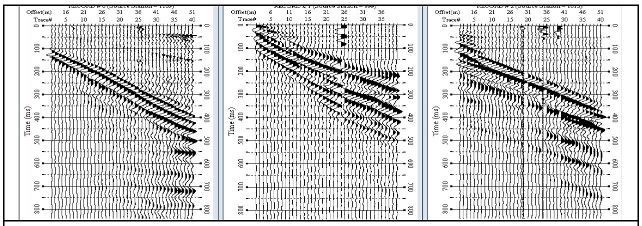

Figure 4. Typical data records: By landstreamer (left); by spiked geophones; and geophones fixed with dough.

Overtone Analysis

The overtone analysis is the process to transform the acquired seismic data in the time-distance domain to the frequency-velocity domain. Most of the seismic records transformed into this domain showed clear trend of dispersion curve of the fundamental mode Rayleigh wave to 30-40Hz (Figure 5).

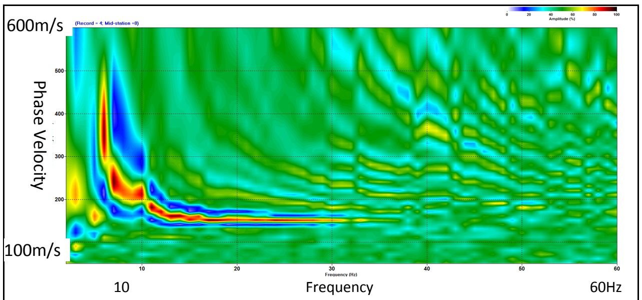

Figure 5. A typical overtone analysis display

Several trials of top muting of the data were sometimes required to obtain a confident dispersion curve of the fundamental mode Rayleigh wave as seen in Figure 5. Regular higher mode trends were also seen in the overtone display.

1D Inversion

The dispersion curves obtained from the overtone analyses at every 12 metres underwent iterative inversion to reach 1-dimensional S-wave velocity profiles.

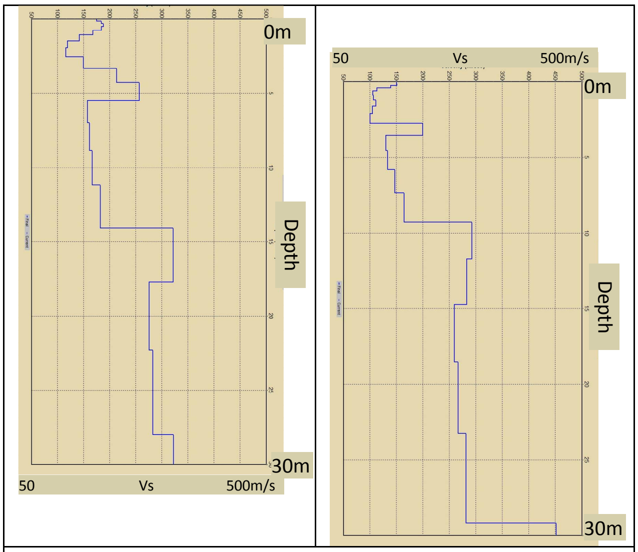

Figure 6. Two examples of inversion result: One point on the top of the dam bank (left) and point at the bottom of the bank; displayed with offset by the height of the bank.

Figure 6 show two S-wave velocity profiles from the top and the bottom of the dam bank. The profiles are displayed with an offset by the height of the bank of the dam. The S-wave velocity profile at the top of the bank (left) shows the base of the bank is well compacted to have S-wave velocity over 200m/s, while the material of the bank itself is less competent with slower S-wave velocity. The S-wave velocity profile at the bottom of the bank (right) shows a soft surface layer above a thin hard layer. The bed rock has an S-wave velocity about 300m/s, which is clearly distinguishable from the layer above with slower S-wave velocity, and is seen at the similar level in both profiles.

2D Sections

From the series of 1D profiles, S-wave velocity sections were drawn colour-coding the velocity. The surface topography was incorporated in the section to adjust to the common datum of elevation.

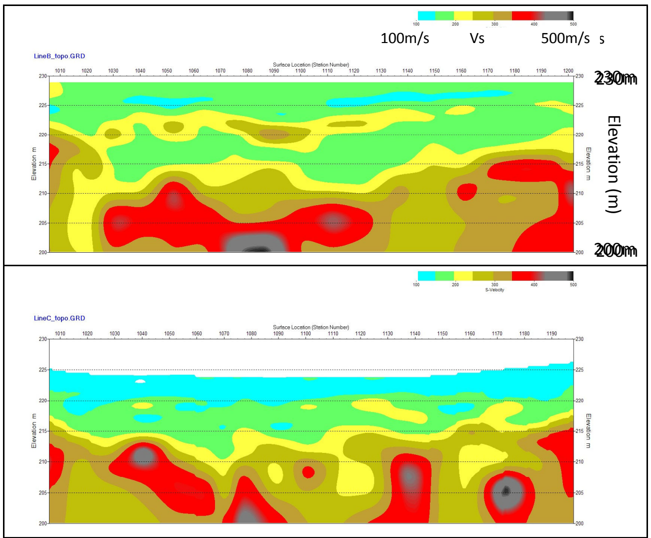

Figure 7. 2D S-wave velocity section corrected to elevation: the line on top of the dam bank (top) and the base of the bank (bottom). Lines are approximately 200m long.

Figure 7 shows two S-wave velocity sections of two parallel lines at the top and base of the bank of the dam. In this section the top of the bedrock which is considered to have *Vs*= 300m/s is expressed by the boundary of two shades of brown. Its elevation is about 215m at the shallowest, consistently appearing in both sections. Note the velocity within the bedrock is not uniform but there are spots with anomalously low S-wave velocity expressed in yellow.

Horizontal Slices

The S-wave velocity data from the 1D inversion were interpolated in the three-dimensional space and displayed at every 2m elevation. Figure 8 shows the horizontal slices of S-wave velocity at every 10 metres.

These horizontal slices show somewhat similar but not exactly the same pattern of velocity distribution. The areas with low S-wave velocity below 210m elevation are suspected to be the places where the bed rock is incised and subsequently filled with softer sediments. The different pattern of the S-wave distribution at different levels suggests that the drainage changed over the time by meandering.

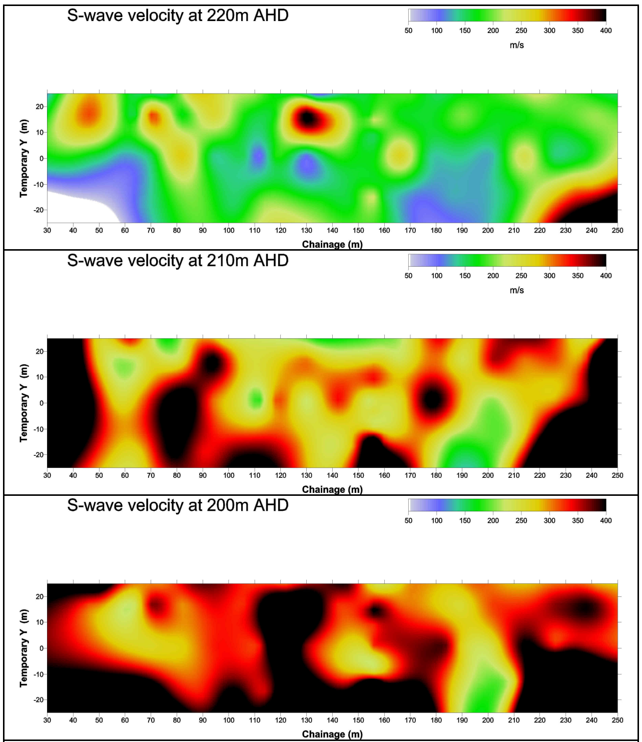

Figure 8. Horizontal slices of S-wave velocity at three levels.

DISCUSSION

Correlation

Together with the MASW survey, an intensive geotechnical investigation was carried out in the area. Figure 9 shows a summary of the correlation between the geotechnical data and S-wave velocity section along the survey line at the bottom of the bank. The points of significant events in the geotechnical data are marked by green, yellow and red dots and were transferred onto the S-wave velocity section. Then the corresponding features in the S-wave velocity are traced and transferred onto the geotechnical section. A good agreement between the S-wave velocity and geotechnical sections is noted.

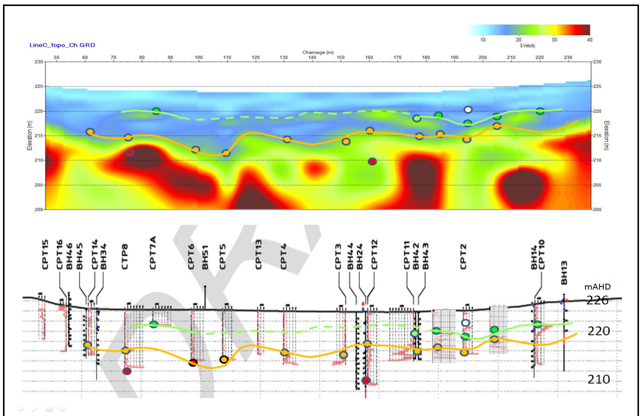

Figure 9. Correlation between S-wave velocity and geotechnical

Interpretation

One of the horizontal slices (at 202m AHD) was chosen for interpretation of palaeochannels (Figure 10). The colour scale was adjusted to enhance the visibility of the low velocity trend. Two trends with a meandering pattern and one isolated low-velocity anomaly ("?" in Figure 10) are recognised. The meandering trends are interpreted as a palaeochannel at this level. Examining the horizontal slice maps of other levels, this isolated anomaly is considered as a branch of the palaeochannel to the east.

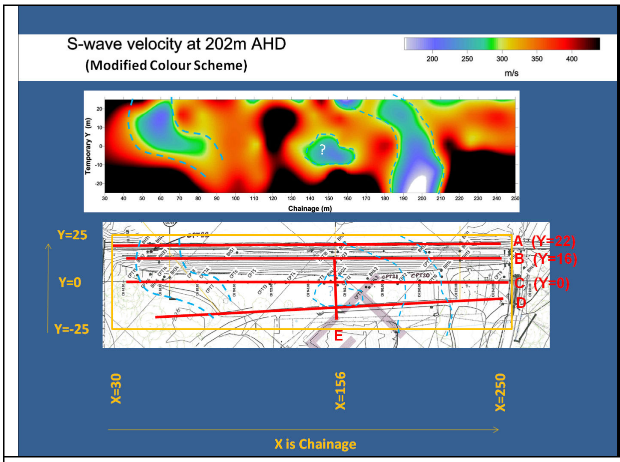

Figure 10. Horizontal slice at 202m elevation with tentative location of the palaeochannel at that level.

CONCLUSION

An MASW survey was carried out to aid hydrogeological study at a reservoir dam near Melbourne. Three different modes of receivers were deployed and comparable data were acquired.

The data were inverted to 1D S-wave velocity profiles, then expressed in sections and horizontal slices. The S-wave velocity distribution correlated well with the geotechnical data collected at the same area. The result showed anomaly with low S-wave velocity areas at the level of the bed rock, which were interpreted as drainage pattern of buried palaeochannels.

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The software used for the MASW processing is SurfSeis 2.05 by Kansas Geologica Survey and mapping software used is Surfer 7 by Golden Software.

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