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SITE CONTROL USING SEISMIC TECHNOLOGY

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ABSTRACT

Geophysics, in particular seismic technology, gives engineers a test that can provide 2D and 3D visualization of sub-surface profiles as well as providing a comprehensive array of drained material properties. This gives the geotechnical engineer a framework to build the geotechnical model of the site. It reduces assumptions and leads to sub-surface site control.

KEYWORDS:

Seismic technology, MASW, Refraction, Young's Modulus, Geophysics, Geotechnical Investigations

1 INTRODUCTION

The modern day client has high expectations of the geotechnical engineer, to design a cost effective and constructible solution. However, most geotechnical engineers, at some point, have been left inadequately equipped to design solutions when given a AS1726 compliant geotechnical report. AS1726 compliant reports are based on the current analogue methods. These methods can give good results (if soil conditions are favorable) at the test point. However, even with numerous test points the engineer is left to assume the soil profiles in between these points. These assumptions regularly leave the engineer exposed to missing vital sub-surface data, such as the presence of boulders, soft spots, a spike and or a depression in the rock line. This often results in an overly conservative design and/or redesigning during the excavation stage, leading to delays and cost overruns that are unacceptable to the modern day client.

Seismic technology gives the geotechnical engineer another tool to compile the geotechnical model for the site. The data obtained from one seismic line is infinitely more than could be obtained by the current analogue methods. It is ideal for sub-surface profiling with 2D and 3D imagery of virtually any layer. It can pick up soft layers, hard layers, the water table, and probably the most impressive output the drained Young's modulus of the sub-surface materials.

In Australia there has been many papers written on the application of geophysics, notably by Professor Bob Whitely. These papers generally focus on large complex projects, out of the realm of the typical geotechnical engineer. This paper will provide an overview of the seismic technology most appropriate to near surface applications (less than 50m deep) that can be adopted to all construction sites, as well as some typical applications and examples.

2 SEISMIC OVERVIEW

2.1 HISTORY

Seismic theory and methods were first published in the early 1900s, with the first patent on what we would call a seismograph in 1917. However there are indications that the theory had been around for some 300 years prior to this but was never developed for practical use. The origins of seismic technology are firmly in the mining industry that continually developed the technology for mineral exploration. However it was limited till the digital revolution in the 1960s in which computers were able to calculate the complex algorithms required. Since this time the evolution of seismic technology has been exponential and its application has been broadened from the elite in the mining industry to obtaining site control of building lots.

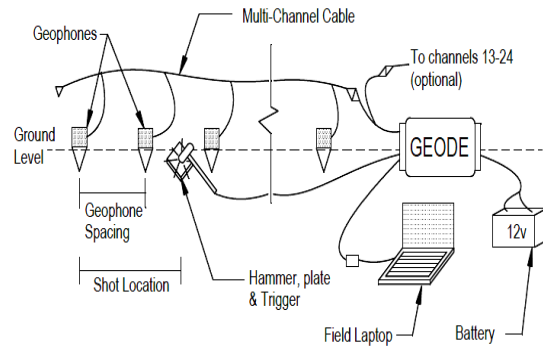
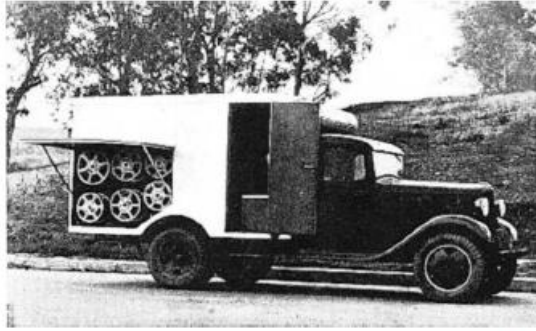


Figure 1 (left), Rieber's 1936 instrumentation truck, used before the digital revolution
 Figure 2 (right), Shows a current field set up

2.2 SEISMIC TECHNOLOGY

Seismic technology is the interpretation of the how seismic waves travel through different sub-surface materials. In broad terms, the manner that seismic waves travel through a material can give information on the sub-surface material properties.

There are three main seismic methods used to image sub-surface materials.

1. Reflection
2. Refraction
3. Multi channel analysis of surface waves (MASW)

Reflection method is generally used for deep investigations mainly for the mining industry and mineral exploration. Since this paper's focus is site control of construction sites with relative shallow investigation depth, less than 50m, reflection will not be covered further.

2.2.1 REFRACTION

Refraction has been in use since the early 1900s and was used in conjunction with reflection in the mining industry through these early years. The refraction method analyses the velocity and the time of arrival of the compression wave (V_p), to develop sub-surface V_p profile. The V_p profile is a good indication of the strength of the sub-surface material but only empirical relationships exist between V_p and typically used geotechnical properties such as Young's modulus. It is a good sub-surface imaging tool and has been used by industry to indicate sub-surface strengths, rock depth and the rock rippability for the past century.

However, as with all geotechnical methods it has its limitations, as follows;

- A. Cannot image soft layers within a stronger soil matrix,
- B. Cannot image soft layers below a stronger soil matrix,
- C. Depth of image on small sites is restrictive (practically 10m),
- D. The method typically cannot image below a water table, and
- E. It is very sensitive ambient noise.

The author believes that these limitations have given the method a poor reputation. Engineers who initially trialed seismic refraction, were left with little results and a disappointing outcome. However, when it is applied correctly it can give very good results.

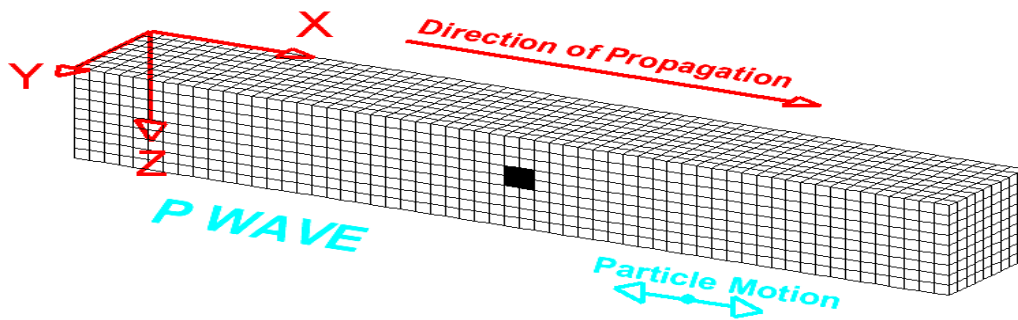


Figure 3, Shows a how the compression wave (P wave) propagates through a medium

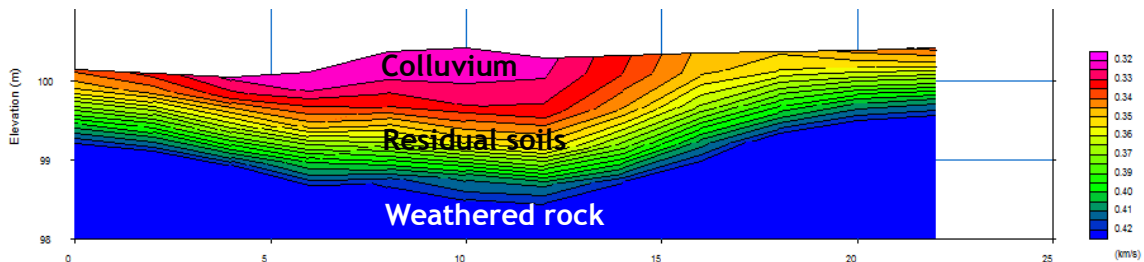


Figure 4, Shows a typical refraction V_p profile, Note, the softer tongue of Colluvium material

2.2.2 MASW

MASW method is a relatively young method. It was first used in the early 1980's in the Netherlands but its origins go back to the 1950s. The MASW approach uses the Amplitude, Frequency and velocity of the surface wave to develop the shear wave velocity (V_s) profile.

In contrast to the refraction method, MASW method is not restricted by the same limitations. It has the following benefits;

- A. Can image voids,
- B. Can image boulders and soft layers,
- C. The depth of image is five times greater than the refraction method (40m depth is easily achievable on a standard house site),
- D. The water table has no effect, and
- E. It is not as sensitive to ambient noise.

The MASW method is a much more robust method than refraction. It is more practical and renders better results in most situations. However, the most impressive feature of the MASW method is that a mathematical relationship between V_s and drained Young's modulus, which will be covered further.

The MASW method has been used in a variety of applications, such as pier depth determination, settlement calculations, slope stability remediation, slope stability risk assessment and fill compaction.

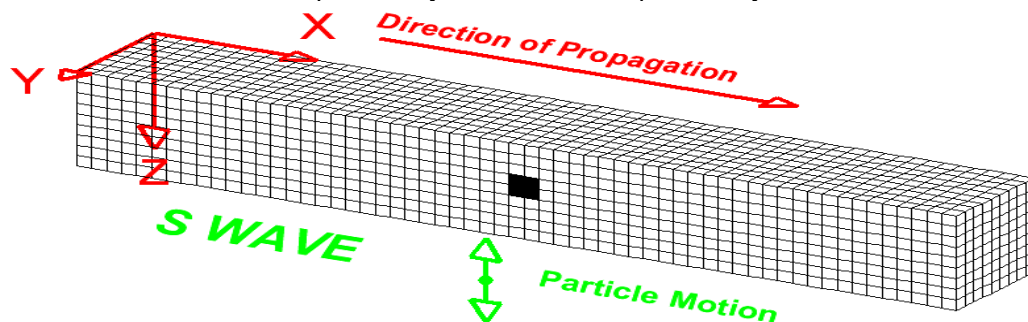


Figure 5, Shows a how the shear wave (S wave) propagates through a medium

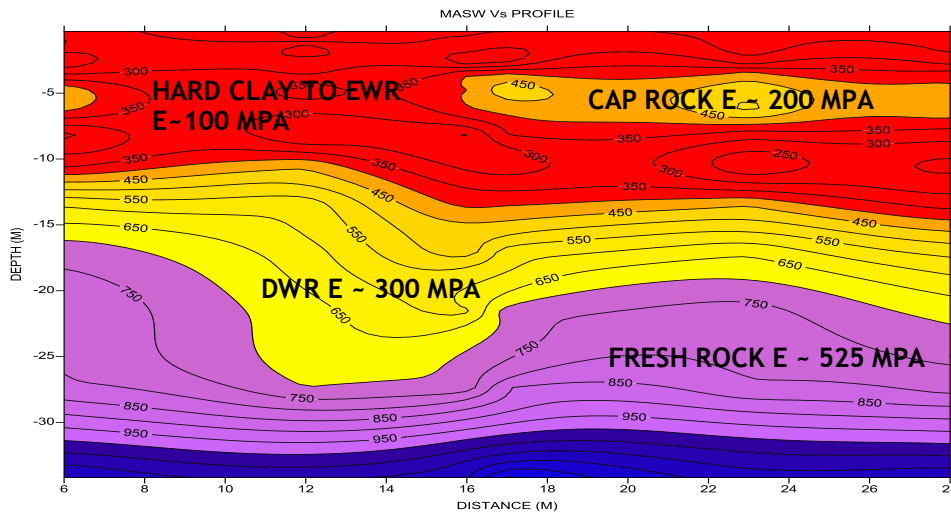


Figure 6, Shows a typical MASW V_s profile, Note, the cap rock layer

Figure 6 shows how MASW can be used to image through a cap rock layer. Often, traditional methods are unable to penetrate this strength rock and give a description like “Unable to penetrate (UTP)”. However, this is not a true indication of the site and can lead to construction issues. MASW gives the engineer an overall image of the site enabling site control.

By using either the refraction or MASW methods, we are able to produce a 2D section through the block. By taking at least two seismic sections, we can input the data into imaging software, to produce a 3D image of sub-surface layers.

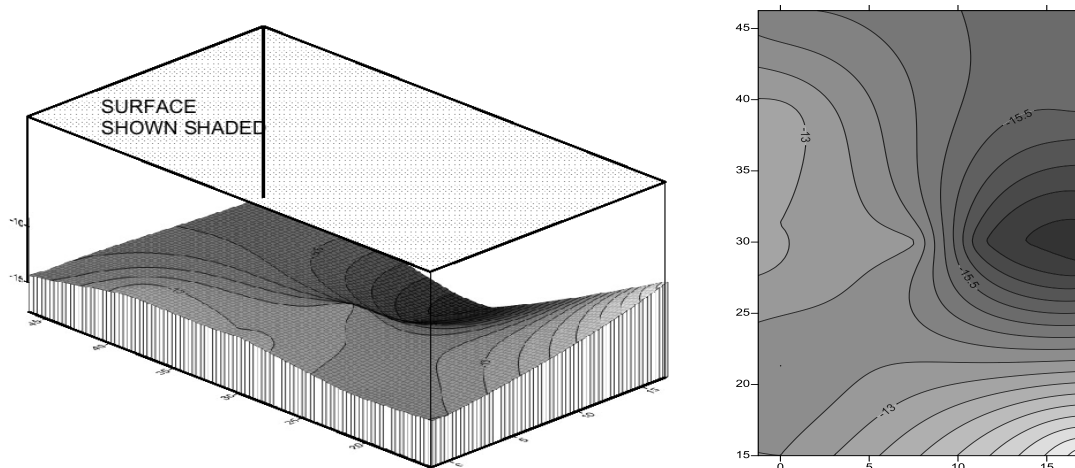


Figure 7, Shows a typical MASW 3D and contour plan of $V_s=350$ (foundation strength) profile.

The 3D images shown in figure 7 show the proposed foundation depths for screw piers for a factory. The screw pier installer’s logs show that 46 of the total 47 piers installed were within 0.5m of the seismic predicted depths.

Without the seismic results, the screw pier installer would be left to certify founding depths. By conducting the seismic survey the engineer is able to design screw piers depths, provide the client with accurate cost estimates and maintain site/project control.

3.0 SEISMIC ADVANTAGES

Most engineers have had an AS1726 compliant soil test fail to supply adequate sub-surface information to design a solution. Utilizing seismic methods in conjunction with traditional methods is an efficient way to overcome these short comings.

Seismic methods have many advantages over traditional methods;

- A. The results are averaged between geophones
- B. There is a mathematical relationship to drained Young's Modulus ($V_s = [E/2(1+\nu)\rho]^{1/2}$)
- C. Gives insitu soil properties, (shear and compression wave velocities)
- D. Doesn't rupture the soil matrix
- E. Non – destructive
- F. The depth of investigation is effectively infinite for construction work
- G. Cost is not a function of depth, enabling investigations to greater depths to gain overall site control
- H. Can image underwater, through boulders, under watertable etc.
- I. Requires limited access
- J. Is cost effective

However, the author is not proposing the total replacement of traditional methods as they still have a function. Each seismic investigation should be augmented with at least one borehole to identify the type of material and to confirm the seismic results. The author is encouraging the geotechnical community to embrace this technology as well as other geophysical methods to deliver more comprehensive services to the community.

4.0 SEISMIC APPLICATIONS

The author has applied this technology to many geotechnical problems over the past couple of years. They include;

- A. Bearing capacity evaluation
- B. Screw pier foundation depth prediction
- C. Soil depth and strength evaluation
- D. Earthquake site classification as per AS1170.4
- E. Slope stability investigation
- F. To issue compaction certificates
- G. Subsidence investigations
- H. Settlement calculations

The author has comprehensively applied this technology over a wide range of geotechnical situations with great success and expects that in the future there will be many more.

5.0 BRIEF SEISMIC CASE STUDY

This case study is a landslide investigation and remediation project. Boreholes, DCP testing, Atterberg limits and shear box testing were carried out in addition to the seismic surveying. The access was very poor which meant that only hand tools could be used for the investigation.

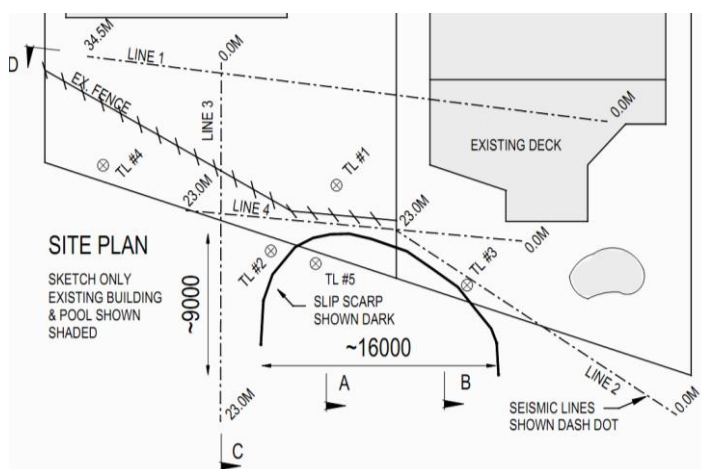


Figure 8, Shows the site plan & part of the DCP record for TL#3

Depth in meters	TL#3	Converted DCP*
0.1	4	5
0.2	5	6
0.3	5	5
0.4	5	2
0.5	4	2
0.6	4	5
0.7	7	6
0.8	8	8
0.9	12	11
1.0	12	
1.1	8	
1.2	9	14
1.3	8	
1.4	9	
1.5	10	15
1.6	7	
1.7	7	
1.8	20	
1.9	31	15
2.0	B	

*Converted DCP, $V_s = (60N^{0.4})/3$ (Koya Suto, 2010)

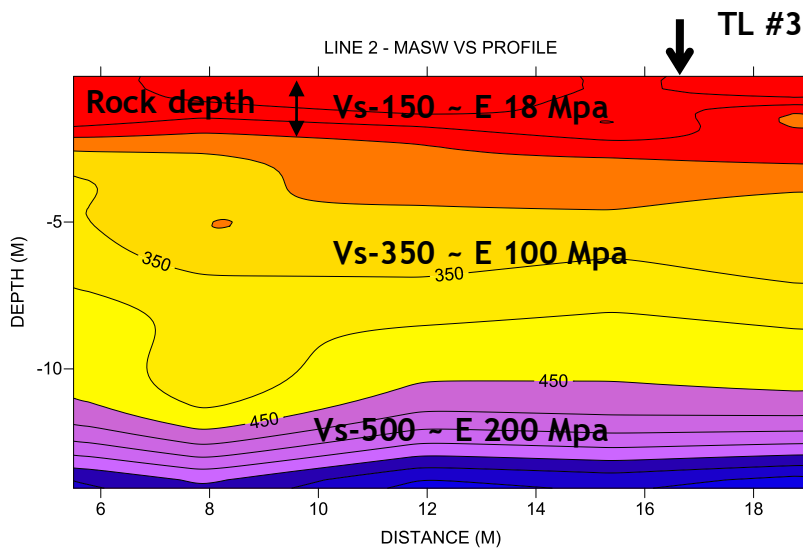


Figure 9, Shows line 2, 2D V_s profile; note, red indicates clays – yellow EWR and purple & blue fresh rock

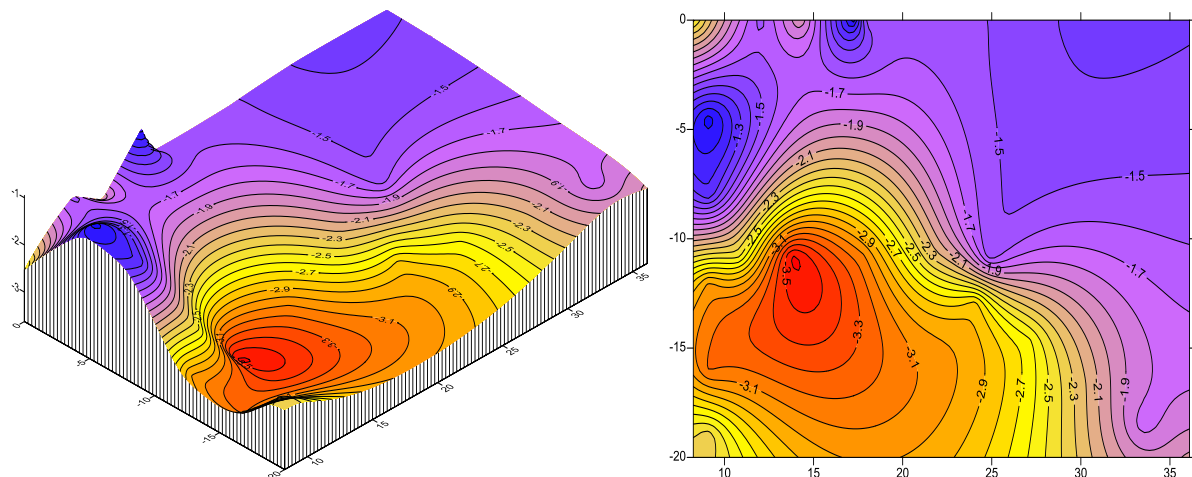


Figure 10, Shows the MASW 3D and contour plan of $V_s=250$ (rock line) profile. Note slip occurred in the depressed zone.

In this case, the seismic survey gave a clear indication how the rock profile varied over the site. It clearly shows that the rock profile is deeper within the slip zone, overlaid by weaker clays. The analogue testing confirmed this result. However, if only analogue testing had been carried out the design engineer would have had to assume the sub-surface profile between the test locations. The seismic survey gave the engineer confidence to design an economical solution and gain site control.

6.0 CONCLUSION

In conclusion, the world has evolved since the digital revolution. However, soil investigations within Australia have remained similar. Seismic surveying techniques offer the geotechnical engineer another tool to build the geotechnical model for the site. The sheer depth of penetration and Young's modulus correlation gives the engineer an overall view of the site. The results clearly illustrate how the soil and rock profiles vary across the site. The seismic results reduce assumptions and give the engineer site control.

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