MASW and Microgravity – a novel approach to investigating Karstic features in a large Tailings Storage Facility.

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SUMMARY

Multi-channel Analysis of Surface Waves (MASW) is a non-destructive seismic method which uses the elastic properties of subsurface materials to determine the subsurface structure. By analysis of the dispersive properties of varying frequencies from a single seismic source, shear-wave velocity (Vs) and associated geotechnical parameters can be determined. Microgravity is a potential field technique used to accurately record localised variations in the earth's gravitational field. The variations in gravitational readings are caused by density contrasts of the rocks and sediments beneath the reading location. Both methods are therefore an indicator of low velocity and low-density subsurface units, a common characteristic of karstic features or voiding. When individual readings from both methods are combined, a scientist can interrogate the subsurface in a detailed manner outlining both low velocity and corresponding low-density areas. Through careful interpretation, an accurate image of the subsurface can be inferred. Although both methods have been used independently for karstic investigations, they have not been combined for a large-scale geotechnical investigation and used to constrain the overall 3D geotechnical model.

This paper presents an alternative way of using seismic and gravity investigations with the primary objective to target unconsolidated subsurface strata or voiding, within limestone terrains. The way data is collected and combined within this paper is specifically designed and applicable for Tailings Storage Facilities. The paper introduces the reader to automated GPS corrected MASW data collection, while handling large datasets in excess of 85,000 shots. The paper also covers 3D inversion and display of the MASW data, and how modelled data can be interrogated to use results and findings to plan a Gravity campaign over anomalous areas. Finally, the paper will outline how all datasets can then be used to constrain final 3D models for target anomalies associated with unconsolidated subsurface strata or voiding.

Key words: Tailings Storage Facility, MASW, Gravity

INTRODUCTION

Karstic features, liquefaction, subsidence issues, low density areas, and many more critical terms, are all ways of describing risks that multiple industries face when building infrastructure. Mitigating risks when building in areas of risk is typically the most important factor in the site feasibility and establishment phase. As Matthew supposes, 'only a foolish man builds on sand'.

This paper explores common issues encountered when building upon limestone dominant karstic environments and introduces the reader to novel ways of investigating this problematic substratum using multiple geophysical methods. Nichols (2009) outlines a karstic geological province as a limestone dominated area that is primarily affected by dissolution weathering, developing karstic patterns. These patterns evolve over geological time through denudation creating larger areas of risk, introducing specific ground failure issues. The reader would be aware of the phrases like dolines, karsts, sinkholes, and depressions all of which are typically found in limestone strata and created from localised weathering. Once the diagenesis process of the local limestone is within human timescale it is then generally covered by local regolith. These environments create locations of unconsolidated materials at shallow depth and areas of weakness. These areas sometimes open at surface creating caverns and sinkholes.

GBG was commissioned from 2018 to 2020 to consult on identifying karstic terrains providing an alternate method to a large-scale drilling program. The site was characterised as a tailing storage facility (TSF) build with active simultaneous operations over the site. The investigation area was within a known limestone terrain with nearby open caverns and voids appearing at surface. The survey conditions were typically over areas of flat terrain although the area was subject to extreme weather patterns and ambient noise from local machinery. As with many projects, the client was confronted with two options; a comprehensive drilling program at random locations based off broad and sometimes vague geological sheets, or a proactive geophysical investigation validated with physical ground truthing. Through consultation GBG recommended a program consisting of; GPS synchronised seismic data collection, 3D modelling of seismic data, target generation, target validation from physical testing, a gravity survey campaign over nominated targets, followed by final input of all datasets into a 3D model. These decisions were based off detailed understandings from the work of Sharma (1997) and intellectual property attained over GBG's long history of similar projects.

The program was setup in a way to deliver risk mitigating results by identifying karsts, voids, or areas of weakness within the TSF footprint. Results provided a 3D model integrating shear wave (Vs) velocities and density (mGal) values. By relating the datasets to each other, it was shown the whole model increased in accuracy, directly due to each geophysical dataset restraining the other. By achieving this restrained model, we found that increased confidence was attained and accurately identified, basement, velocity profiles, areas of weakness, dipping structure, regional trends and most importantly locations of potential voids.

METHOD AND RESULTS

Primary method data collection.

Multi-Channel Analysis of Surface Waves MASW is a non-destructive seismic method which uses the elastic properties of subsurface materials to determine the subsurface structure. By analysis of the dispersive properties of varying frequencies from a single seismic source, shear-wave velocity (Vs) and associated geotechnical parameters can be determined. GBG proposed 65 lineal kilometres of seismic data acquired using the (MASW) method targeting areas of low shear wave velocities (Vs). Lines were specifically designed to be collected over the tailings dam wall footprint. Therefore, thirteen concentric polygons spaced 10m apart would make up the 3D block model. Seismic datasets were collected with a base station setup, providing a GPS string corrected to local grids, with accuracy assured to always be sub 50mm. High accuracy GPS data was used for multiple reasons:

1. Provided a high accuracy move along for the shot spacings needed.
2. Locations were synced to provide layback positions of the ute.
3. A constant feed was recorded in the seismic software and included on every file for redundancy purposes (QAQC).

Typically, MASW datasets would be collected with a staff member walking beside a ute recording data or supplying the source impulse, the ute would be towing a seismic cable. Our MASW system was setup to be continuously automated with two staff in one ute with a live video feed sent to the driver and passenger.

Table 1 – Summary of MASW acquisition parameters:

Source	36kg accelerated weight drop system
Seismograph	Geometrics Geode
Acquisition Software	Seismodule controller
Geophone centre frequency (Hz)	4.5
System	Towed 24 channel rig
Geophone interval (m)	2
Source offset (m)	4
Spread length (m)	46
Record length (s)	2
Sample interval (s)	0.5
Number of records (stacks)	5
Array type	Linear
Shot point density (m)	One file every 4
Line type	Parallel lines, 10 m spacing
Total files	14082

Once MASW data had been collected, it was processed with dispersion curve picking software, inverted and input into 3D modelling software. Vs values were modelled as singular vertically elongated blocks (20-layer Vs readings combined into a 30 m vertical sounding), constrained by the shot and line spacing. At this stage, individual blocks were 1D readings which were then input into Geosoft, aggregated and 3D gridded into 3D voxels.

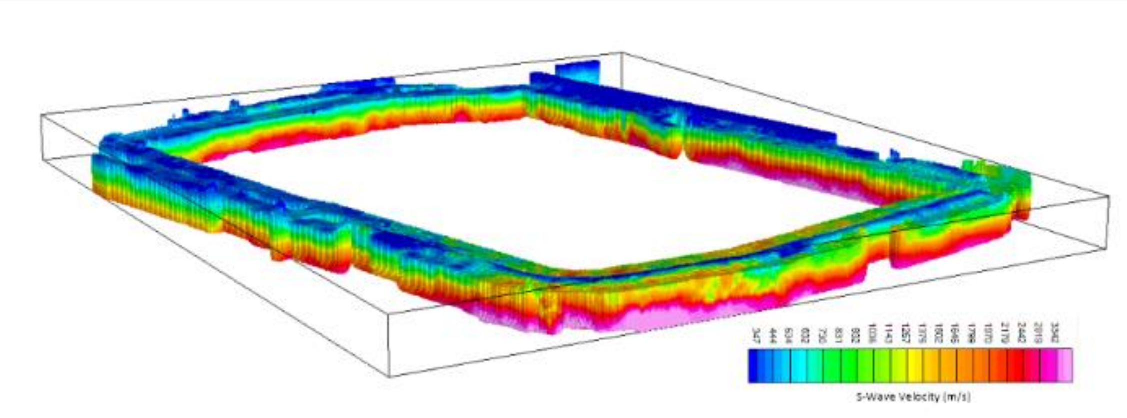

Figure 1. 3D voxel outlining all modelled seismic velocities (Vs) to 30m. Low velocities (250m/s) are shown in blue, increasing velocities are stretched to pink (2800m/s)

Interrogation of the 3D model was completed by clipping velocities above 650m/s. By doing this we could better understand any areas of interest that would exhibit known void or doline characteristics and/or extend with depth. MASW was used as the primary evaluation method, highlighting areas shown by the example in Figure 2. From these outlined areas, gravity targets were tabulated and quantified.

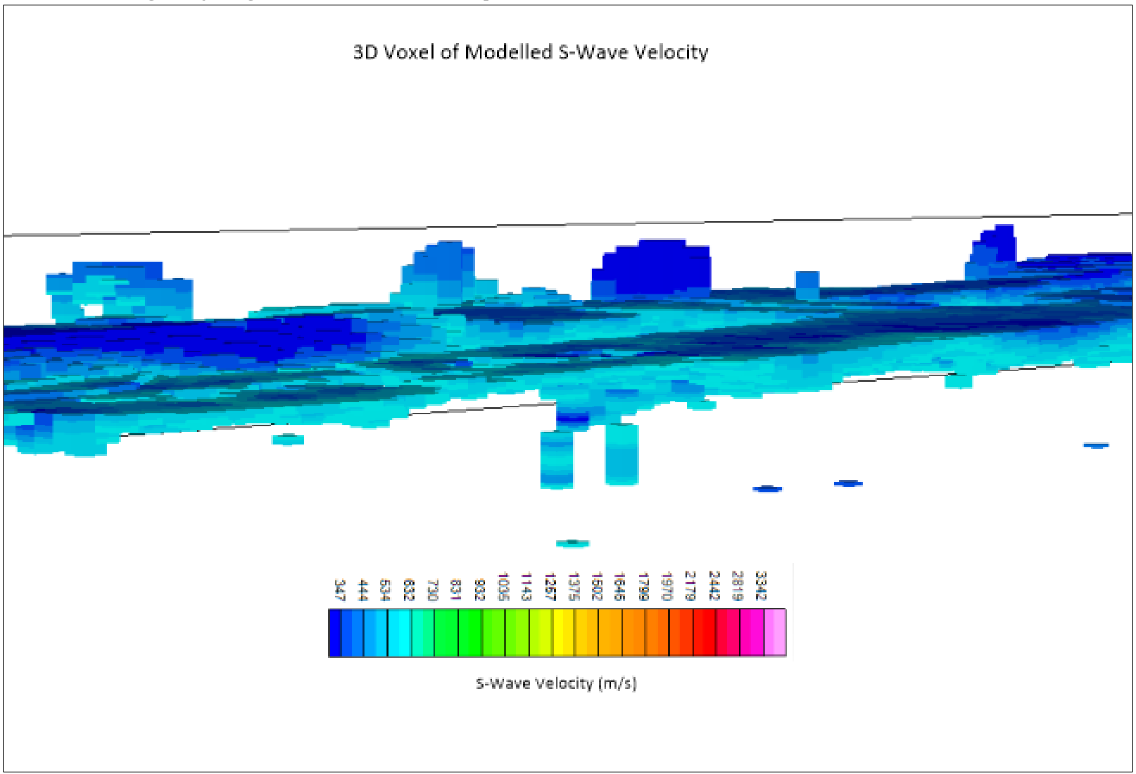

Figure 2. Modelled examples of low velocity areas extending with depth. Velocity cut off is shown at 650m/s.

The results of the MASW survey showed variations in shear wave velocities site wide. Shear wave velocity is an integral component of both Youngs and the Shear elastic moduli. Variations in S-wave velocity can therefore be used as indicators of variations in material stiffness. A low S-wave velocity reflects weaker material, and a high S-wave velocity indicates a stiffer, more competent material (basement or competent limestone). As S-wave velocity is calculated as the square root of stiffness over density, the latter property has a large influence over the observed S-wave velocity.

Secondary method target proofing.

Microgravity is a potential field technique used to accurately record localised variations in the earth's gravitational field. The variations in gravitational readings are caused by density contrasts of the rocks and sediments beneath the reading location. Gravity was used as the secondary method based on the targets acquired from the MASW data, and importantly used to constrain the size and extent of the targets. Target generation for the gravity locations were achieved by extracting single XY points and completing a 4 m x 4 m grid around the area of interest. Grids were increased or decreased in size based on field results and user discretion. Once gravity data was processed to ISBA267 (Infinite Slab Bouguer Anomaly 2.67 g/cm3) data was then imported into Geosoft for inversion modelling. Initial models were then based off the MASW results which were then constrained by geological data (depth to top of rock from physical testing). The resulting dataset was then inverted to create a gravity model. Details could then be understood around the shape and extent of the gravity anomaly, therefore supplying a higher certainty, and increased accuracy for later physical inspections.

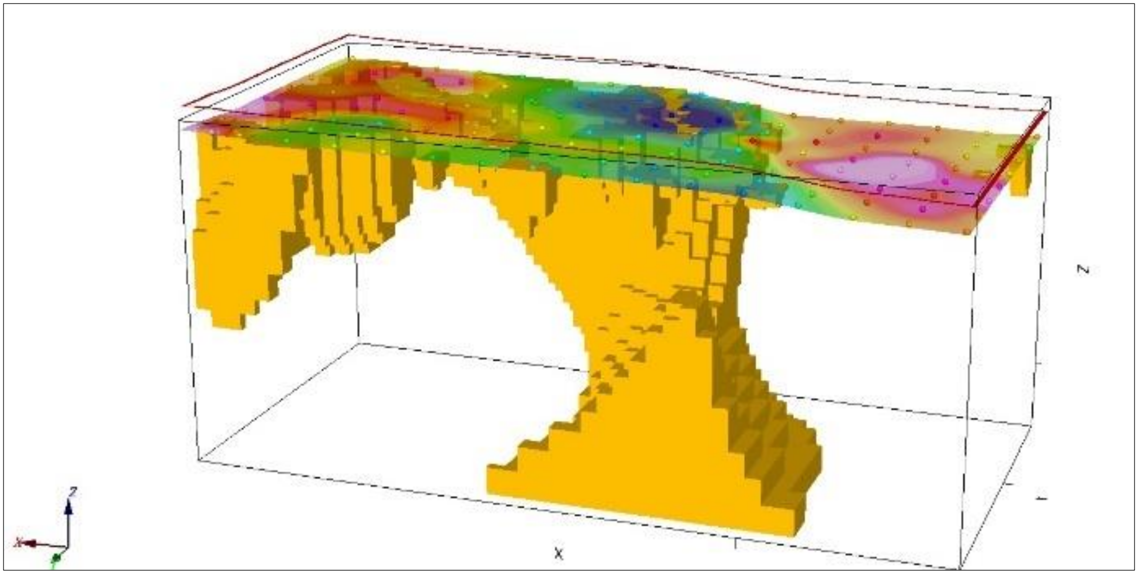

Figure 3. Modelled example of a low velocity area extending along the Y scale, draping a gravity anomaly on the X scale. Correlation of both datasets outlines an area of interest extending with depth.

At any given point on Earth's surface, the measured gravity is directly related to the density of the subsurface. A measurement above a region of low-density material will therefore indicate a lower gravitational field when compared to a measurement over a denser subsurface. It is important to understand that the measurements made in the field are not of the absolute gravitational field but rather, relative individual measurements that are later corrected and tied back to absolute measurements. Gravity data when acquired and modelled is displayed as differences in milligals (mGal). Variations of milligals can be broad (regional or site wide) and discrete (individual locations), therefore concentrating on discrete variations provides higher accuracy target information. When interpreting microgravity data in respect to possible voiding, a cavity could be identified by a distinct region of relatively low gravity amongst relatively higher gravity measurements.

CONCLUSIONS

MASW and gravity have long been considered 'go-to' techniques to identify karstic voids. However, used together, both methods provide a resulting dataset of high confidence. MASW alone identifies areas of low shear strength which include cavities, sand lenses, unconsolidated sediments, and gravels. Each of which show a lower S-wave velocity than competent rock. Similarly, gravity data outlines features with a lower density than surrounding rock. For example, a gravel lens will have a lower magnitude negative gravity response (smaller variation in milligals) than an air-filled void of the same dimensions. We can then infer that a large negative response seen in gravity data may indicate an area of interest to be further investigated. As gravity targets were identified by low S-wave velocity areas, it follows that coincident low velocity zones and distinct, high-amplitude negative gravity responses warrant significant further investigation. Due to the competent limestone bedrock beneath the survey site, areas of low velocity and low-density contrast strongly against the response from the background subsurface in each dataset. In the case of this investigation, a positive correlation between the two methods would be characterised by a negative gravity anomaly identified above the target low velocity zone. Overall, there was a good correlation between the locations of the low velocity zones identified via MASW and subsequent local negative gravity anomalies identified in the microgravity survey. The correlation between the datasets proves the effectiveness of this combination of techniques.

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