Source Assisted Marine Refraction Microtremor (ReMi) for Marine Material Strength Assessments – New Ireland Province, Papua New Guinea

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SUMMARY

Refraction Microtremor (ReMi) is a relatively new technique which utilises ambient noise generated from urban infrastructure in addition to the natural seismic energy to generate shear wave models of the subsurface. This paper presents the geological setting, field acquisition parameters, problems and limitations of data collection and results of a survey conducted in a shallow marine harbour in Papua New Guinea. The primary objective was to undertake an assessment of the viability of Marine ReMi to obtain subsurface parameters to assist in an overarching geotechnical study taking place on site. The subsurface parameters that the investigation was aiming to define included shear strength and stratigraphy. The environment in which this trial was undertaken was a shallow marine environment containing paleochannels, coral, marine sediments and landslide material.

The field setup used was designed to target shallow features and establish their shear wave velocities. The setup consisted of using 10Hz Hydrophones at 2m separation, with a record length of 20 seconds stacked 8 times. During collection it was found that relying on ambient noise alone was insufficient to gain the required data resolution. To provide additional energy a controlled source in the form of a bolt airgun was utilised with shots being taken at arbitrary locations off the line and up to three times each stack. Inversion of the data was undertaken as per standard passive seismic inversion.

The results of the investigation show that through careful processing and analysis accurate models of S-wave velocities beneath the ocean floor can be successfully achieved using ReMi. We were able to cross correlate the results with traditional marine geophysical techniques, land based geophysics and physical observations to gain a better understanding of the accuracy of the modelled Marine ReMi data compared with other data streams. This correlation shows that the results are comparable in both structures and velocities to the other data streams.

Key words: Ambient seismic, refraction microtremor, ReMi, Papua New Guinea, Shallow Marine

INTRODUCTION

The development of geophysical techniques to determine shear wave seismic velocities (Vs) is relatively new, with MASW being introduced in 1999 (Park et al, 1999) as a method of evaluating the stiffness of the subsurface, specifically for use in geotechnical and engineering investigations. As shear wave velocity is an elastic constraint, under a majority of circumstances it is a direct indicator of shear strength of the subsurface material. The majority of early Vs surveys suggested the use of either a swept source (such as a vibrator) or a sledgehammer as an impulsive source (Park et al, 1999). Both of these sources generate ground roll which is necessary for undertaking active MASW surveys. The development of passive dispersion based methods such as Refraction Microtremor (ReMi) allows the operators to utilise the background or ambient noise available at the investigation site and ideally precludes the requirement to have an active source. Utilising the available ambient noise is particularly useful for sites such as mines or areas of construction where a large amount of energy is available through external factors, factors which normally limit the use of more traditional seismic techniques (Kaiser & Smith, 2005, Sirles et al, 2013). In addition, surface waves provide the highest signal to noise ratio which lends itself well to environments such as the one in which this survey was undertaken (Mohamed et al, 2013).

Much of the development into surface wave methods has been undertaken with land based surveys in mind, with only limited investigations being undertaken to determine the suitability of the technique within marine environments. As part of a combined land and marine geophysical investigation within a shallow marine environment off the Island of Lihir, Papua New Guinea, Marine ReMi was undertaken to evaluate the viability of the technique to determine the Vs of the subsurface for calculations indicating the liquefaction potential of the natural marine sediments and material deposited from a nearby drainage pipe. The aim of this trial investigation was to undertake the survey using hydrophones deployed on the sea floor and attempt to define a set of collection parameters which future investigations can utilise. It was found during the investigation that the ambient noise present on the site was insufficient to provide enough signal strength within the data. As a result, it was necessary to supplement the available ambient noise with bolt air-gun shots at arbitrary locations during collection.

Geological Setting

Lihir Island is part of the Bismarck Archipelago, which is located in north-east PNG. Lihir Island is one of four volcanic island groups that form a chain parallel to the New Ireland coast line called the Tabar to Feni Chain. The islands in this chain are volcanic of predominantly Pliocene to Recent age rising from a submarine platform. The island chain has a varied but predominately shoshonitic composition (Moorhead, 2013).

The island itself consists of the remains of five volcanoes with the site being located within the Luise Caldera on the eastern side of the Island (Moorhead, 2013). The high geothermal activity within the area has lead to a large number of alterations of the subsurface materials found on site. The initial porphyry alteration was followed by an epithermal event which produced the argillic clays that can be observed extensively on site (Moorhead, 2013). The other major subsurface materials found in the investigation area have been identified as mostly marine sediments and waste material from mining operations on site.

METHOD AND RESULTS

Collection Methodology

The fieldwork was carried out between 12 to the 22 of January 2017 with a two-person geophysical crew plus two local boats. All marine survey operations were carried out aboard "Banana Boat" vessels operated by the local crews. The vessels were launched and moored during the survey at the local wharf. A total of three marine ReMi survey lines were conducted across the harbour: a single north-south line and two east-west transverse lines.

Marine ReMi data was acquired utilising GBG Australia's marine refraction system comprising a Bolt airgun source, 24 channel hydrophone array, Geometrics Geode seismograph and real time source triggering system. The array was deployed on the sea floor by utilising two vessels with the array being weighted to the sea floor using lead weights. Owing to the enclosed nature of the harbour there were no significant currents present ensuring that the array could be deployed as close to inline as possible. At each survey location a total of 8 soundings were taken with a single stack being collected for each sounding. A record length of 20 sections was utilised to allow for a sufficient amount of ambient noise to be recorded for each sounding. In previous ReMi surveys various record lengths had been trialled and from the results of those trials a 20 second record length was deemed to provide the best combination of depth and data quality.

Seismic response was recorded via an array of 24 hydrophones at 2 m separations. Data from the hydrophone array was acquired utilising a Geometrics Geode seismograph and a field computer running Seismodule Controller Software (MGOS, Geometrics, 2013) which allows for digital recording in standard seismic format (i.e. SEG2) as well as real time visual output of each shot for quality control.

While ReMi utilises ambient noise as the main energy source it was found that there was not sufficient background noise to determine the fundamental dispersion curve. Therefore in addition to monitoring the background seismic energy, additional energy was introduced using an artificial source. Seismic energy was produced via a 20 cubic inch Bolt airgun firing at a distance off the end of each profile. The airgun was powered by compressed air from storage tanks located on the deck of the vessel. The gun was operated at 900 – 1000 psi for the entirety of the survey with at least three airgun shots off the end of the spread being deployed to supplement the ambient seismic energy.

Once each sounding location had been completed the array was retrieved off the sea bed and moved 50m down the survey line where the collection was repeated in the exact same method. By undertaking a number of soundings along the survey line a 2D pseudosection could be developed during processing in addition to the independent 1D soundings created at each survey point.

Processing Methodology

Through recording the dispersive phase velocities of Rayleigh surface waves, shear wave velocities can be determined. By utilising the principle that velocities will be directly related to the frequency of the wave a dispersion curve can be created to determine the shear wave velocities of the subsurface (Xia et al 1999).

Processing of the Marine ReMi data was undertaken using industry standard techniques for processing of passive seismic data. Surfseis 5.0 by KGS was utilised for processing which allows for the creation of dispersion curves and inversions of the data.

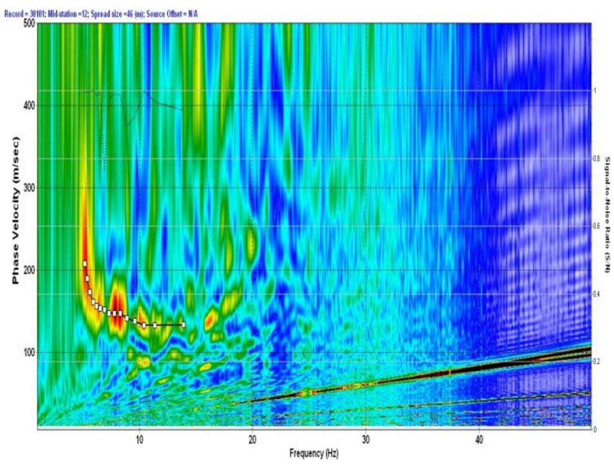

Figure 1: Example Dispersion curve from Line 3 showing a fundamental curve between 5 Hz to 15 Hz.

For each sounding location, the eight shots were imported and combined within the software to effectively stack the shots into a single data file. After importation and conversion of the SEG2 data to a Surfseis specific data format, the geometry of the array was applied to the passive data file for accurate computation of the dispersion curves and later inversions.

For the creation of the dispersion curve images used for picking and inverting the marine ReMi soundings a roadside passive MASW setup was applied to the imported data. A frequency range of 1Hz to 50Hz was used at a 0.1Hz increment, this allowed for a wide range of frequencies to be analysed while still maintaining high resolution across the frequency range.

Based on initial observations a phase velocity range of between 10 m/s to 500 m/s with an increment of 1 m/s was used. A contrast setting of 1 was used in Surfseis to better highlight the fundamental frequency within the collected data.

For inversion of each sounding the standard automatic settings were utilised in Surfseis 5. The soundings were constrained to a 10 layer model, which is the industry standard. The average RMS errors of the soundings were generally good with an error of between 3.5% to 4.5% for the majority of the soundings.

Once each collection point had been inverted as a 1D sounding Surfseis was used the combine the files based on horizontal location to create a 2D Vs profile. At the same time elevations based on a bathymetry survey done at the same time as the ReMi survey were applied to the data to correct for elevation and ensure that the 2D profile could be compared easily to other data sets nearby. These 2D profiles were exported from Surfseis in Surfer .grd format so that the final combined inversions could be displayed in Surfer 13 developed by Golden Software. Surfer 13 was used to display the inversion results in addition to displaying interpreted sections and overlaying any addition information available which would assist in the interpretation process.

Velocity Analysis Results

The results of all three lines show what was expected for this marine environment with unconsolidated marine or alluvial sediments overlaying more compact marine sands. Beneath the marine sediments the results of the ReMi profiles show what has been interpreted as weathered clay which possibly progresses onto argillic clays as depth increases. These interpretations of the layers observed within the Marine ReMi data were developed through the use of nearby, land based boreholes. By comparing a number of bore logs with the layers within the ReMi inversions fairly accurate assumptions can be made about the characteristics of the layering with the adjacent shallow marine environment.

Line 1

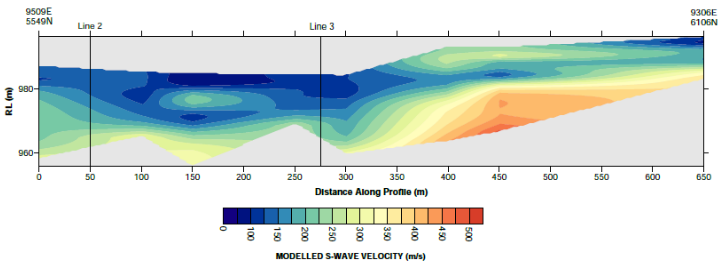

Figure 2: Line 1 2D profile showing the variations of Vs within the subsurface. The line starts in the south and ends in the north.

Line 1 was surveyed from the south to the north with a total length of 650m being collected. It is clear from the ReMi 2D profile that there are significant amounts of unconsolidated Silt and Sands in the south of the survey area. This appears to thin as you progress north towards the mouth of the harbour with the thickness decreasing from 23m in the south to only 9.2m at the north of the survey line. There is a clear rise in the more competent material as you progress north as well as a general shallowing of the sea floor as seen in the associated bathymetry data. This would indicate more competent material in the north of the harbour which is backed up by the results seen in the ReMi data. There is a clear increase in the velocities observed within the survey line with velocities exceeding 400 m/s in the north.

The shallowing of more competent material is mirrored within associated seismic reflection data collected on site where a local reflector was observed at approximately the same RL as shown by the inverted marine ReMi survey.

Line 2

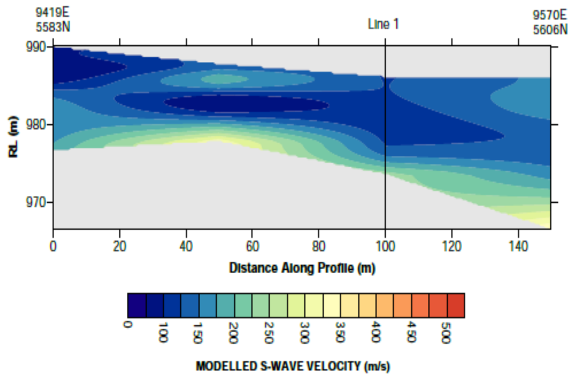

Figure 3: Line 2 2D profile showing the variations of Vs within the subsurface. The line starts in the west and ends in the east.

Line 2 was located to the extreme south of the survey area and shows typical responses as observed in Line 1. There appears to be a thick layer of unconsolidated silts and sands which overlays a slightly more competent layer beneath it. The thickness of the unconsolidated layer also appears to increase to the east of the line with the thickness ranging from 8.7m in the west to 13m in the east. The south of the site contains a number of outlet pipes removing water and sediment from other sections of the site which would account for the increased thickness of the unconsolidated material. The limited depth of penetration in Line 2 has been attributed to the unconsolidated seafloor attenuating the seismic signal resulting in signal from the lower frequencies having a high enough amplitude to be detected in the created dispersion curves.

Line 3

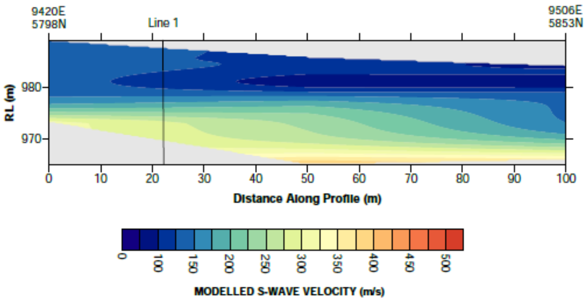

Figure 4: Line 3 2D profile showing the variations of Vs within the subsurface. The line starts in the west and ends in the east.

Line 3 was located to the north of the survey site and approximately half the way along the length of Line 1. The results of the ReMi inversion show the same three layers as seen in the previous lines with similar patterns observable. As with Line 2 there is a slight increase in thickness of the unconsolidated material to the east of the survey line however this is not as significant as Line 2 with the thickness only ranging from 11m in the west to 13.1m in the east. The middle saturated sand layer is fairly consistent along the line with only a slight thinning of the layer in the eastern end of the line. In addition to this the most competent layer is observable in the profile from approximately chainage 30m to 100m which is in line with the observations in Line 1 and the associated reflection data.

CONCLUSIONS

It has been found that Marine ReMi described in this paper allows for the determination of shear wave velocities within a shallow marine environment if paired with a source capable to supplementing the low frequency ambient noise found within the environment. By utilising a 2m separated hydrophone array and a 20 cubic inch Bolt airgun the technique has been shown to be viable for defining the strength characteristics of shallow marine environments.

By utilising the collection and processing methodology outlined above, a three layer model was established across three lines in a shallow harbour off the coast of Lihir, Papua New Guinea. The results of this initial investigation were compared with other geophysical investigations performed on site and compared with borehole information gathered on the adjacent beach and harbour walls. The result of this comparison was that the inverted profiles showed good correlation with the more established techniques leading us to determine the the source assisted marine ReMi has been successful in gaining an understanding of the strength properties of the marine sediments within the harbour.

As this was an initial trial, further investigations should be undertaken to further refine the process of collection and processing of Marine ReMi data, in addition to gaining better understandings of the effectiveness of the technique in other marine environments with varying degrees of ambient noise.

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