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NEW DEVELOPMENTS IN THE APPLICATION OF UNDERWATER MASW

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ABSTRACT

The underwater multichannel analysis of surface waves (U-MASW) can be used to obtain the soil stiffness profile below seafloor. The conventional method utilizes a streamer of low frequency hydrophones and an acoustic source resting on the sea floor. Scholte waves are generated at the seafloor by means of the acoustic source. Records are processed to obtain the Scholte wave dispersion curve, and the soil stiffness profile is computed by means of an inversion process. This paper deals with a data acquisition method to improve survey results: two streamers with different spacing of the hydrophones are used to simultaneously record the seismic data. Such configuration allows for both a sufficient penetration below seafloor (long streamer) and considerable data accuracy in the shallow layers (short streamer). An example case of a site investigation in Sicily is presented. Data shows good agreement with the stratigraphy encountered in the adjacent geotechnical boreholes, confirming the reliability of the underwater multichannel analysis of surface waves (U-MASW). The new method proved particularly useful in site investigation on seismic sites where nearshore developments are planned.

Keywords: Nearshore Surveys, Scholte Waves, Shear Wave Velocity

INTRODUCTION

A nearhsore geophysical and geotechnical campaign was performed to collect data for seismic design and foundation engineering. The soil stiffness profile was a fundamental parameter for geotechnical engineering. The soil stiffness is usually computed from the shear wave velocity (V_s) and soil density. Common methods to evaluate V_s include laboratory testing on high quality samples, Seismic Cone Penetration Testing (SCPT), downhole measurements, and the analysis of surface waves. Each method presents a series of advantages and shortcomings. Surface waves are particularly attractive as they provide in-situ values and are cost effective. This paper presents a new methodology for the application of surface waves underwater. For an introduction about theory of surface waves, the reader may refer to the extensive literature, e.g. Richart et al, 1970, and Stokoe et al, 2004.

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APPLICATION OF UNDERWATER SURFACE WAVES

Scope of Work

The purpose of the survey was to obtain the shear wave velocity profile along the proposed jetty, in water depths between 9 and 23 m. The field operations were performed in three days, including mobilization and presurvey. Following the U-MASW survey, eight geomechanical boreholes were drilled from a self elevating platform. Figure 1 shows the borehole positions and the start/end of the streamer across the locations.

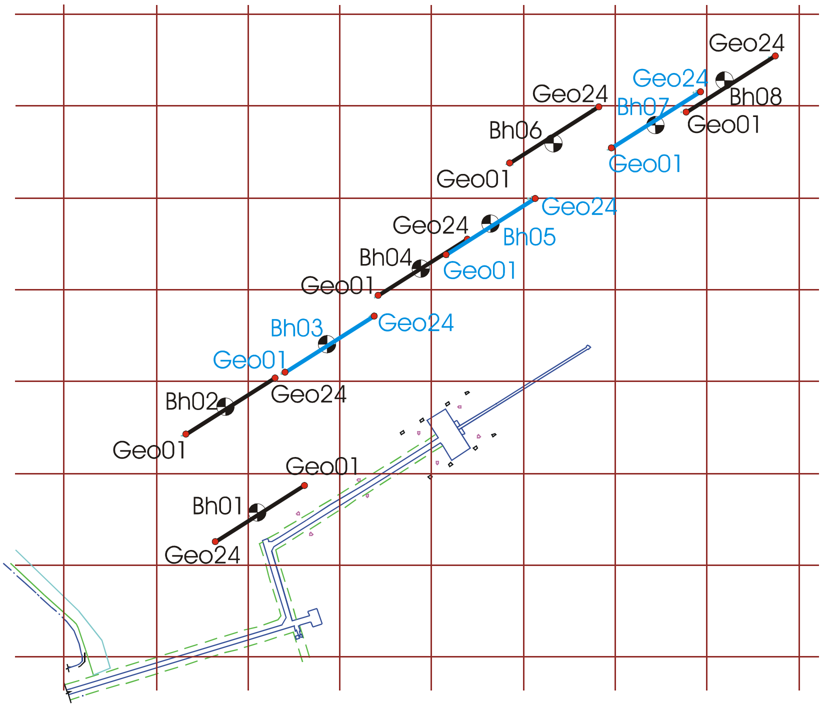


Figure 1 - Survey area and streamer orientation - 100 m square grid

Equipment

The following equipment was utilized for the survey:

- one main boat, length overall 12 m, and one support boat;
- one streamer of 24 low frequency hydrophones at 5 m intertrace, distance source to first receiver 5 m;
- one streamer of 24 low frequency hydrophones at 2 m intertrace, distance source to first receiver 10 m;
- airgun Sodera of 20 cubic inch, fed by air bottles of 18 liters at 220 bars;
- umbilical of 100 m length;
- seismic recorders with 24 channels.

The mobilization of equipment and pre-survey took one day.

Methodology for the fieldwork

The methodology utilized for the survey consisted in the following:

- the main boat was anchored at each location and the support boat utilized to deploy the streamers on the seafloor;
- a series of air gun shots was executed while the streamer and airgun were resting on the seafloor;
- the data was logged and dispersion patterns obtained in real time for quality control.

The following figure shows the layout during survey.

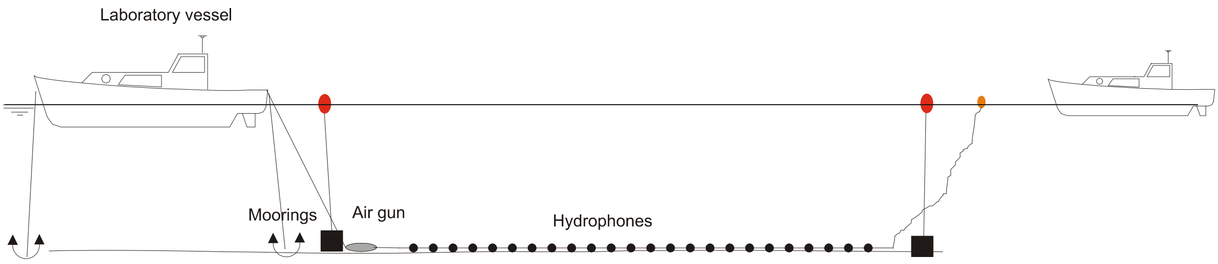


Figure 2 - Layout of equipment during operations

Data Processing

Processing of seismic surface waves data consisted of the following steps:

- data filtering;
- transformation of data from *x-t* plane to *v-f* plane, where *x* is distance, *t* is time, *v* is surface wave velocity, and *f* frequency by means of slant staking and FFT;
- the signal in the *v-f* plane generally shows the fundamental mode and higher modes. Only the fundamental mode, the slowest, was considered and picked as dispersion curve $v = v(f)$;
- inversion from $v = v(f)$ to $v = v(z)$ where z is the depth below seafloor. For this purpose, the stratigraphy is modeled as a series of layers of uniform seismic properties. The inversion process is repeated until the model and picked dispersion curve show a good match. The water layer is modeled considering the speed of sound, the density of water, and the water depth. The soil is modeled as a series of uniform horizontal layers and a substrate of infinite thickness.

Details about inversion methods are available in the literature (e.g. Foti, 2000; Strobbia 2003).

Results of the survey

The use of the two streamers provided useful information about the stratigraphy. The wavelength domain is controlled by the dimensions of the streamer and the hydrophone spacing. The shortest wavelength is approximately equal to the hydrophone spacing, while the greatest wavelength is approximately equal to the full length of the streamer, i.e. the hydrophone spacing times the number of hydrophones. As a consequence, the 5 m intertrace streamer, 115 m long, achieves greater penetration but has less accuracy, while the 2 m intertrace streamer, 46 m long, provides greater detail at shallow depths, but achieves lower penetration.

The dispersion patterns of the survey at one central location are shown in Figure 3 for the two streamers. At that location, the stratigraphy consisted of medium stiff to stiff soil followed by weakly cemented sand / sandstone below 14 m penetration.

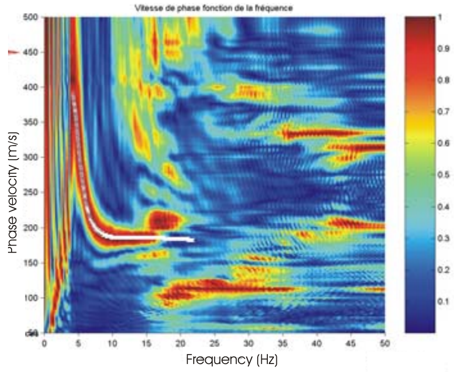
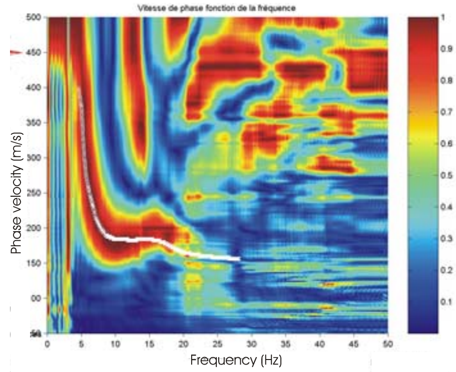
5 m intertrace streamer	2 m intertrace streamer
	

Figure 3 - Dispersion Pattern at Location BH4

Figure 4 shows the dispersion curve picked from the processed signal (blue line) and the dispersion curve of the model stratigraphy (red line). The dashed line represents the standard deviation of the analysis, which is correlated to the convergence obtained in the inversion.

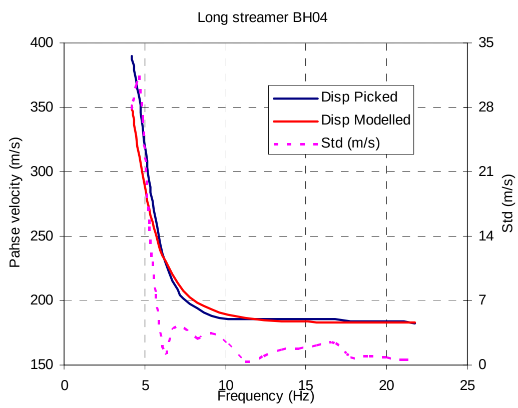
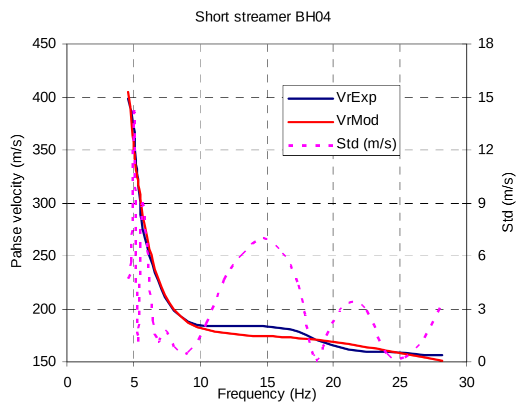
	5 m intertrace streamer	2 m intertrace streamer
Dispersion (picked/modelled)		

Figure 4 - Comparison of the Picked and Model Dispersion Curves

The stratigraphic model corresponding to the dispersion curve that best matched the picked dispersion curve is presented in Figure 5. The blue step-like line represents the shear wave velocity of each seismic layer, assumed uniform in the analyses. The magenta continuous line is the trend line passing through the middle of the seismic layers. Considering that the maximum wavelength that can be measured is function of the streamer length and that the depth of a wave is approximately 1/2 to 1/3 of the wavelength, the interpretation of the 2 m intertrace streamer is cut below 17 m.

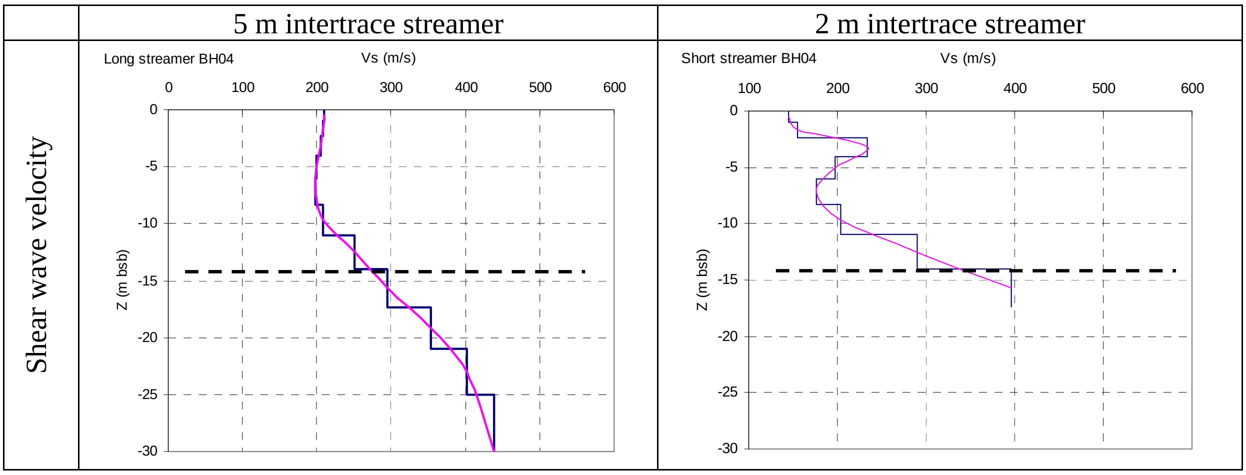


Figure 5 - Processed data and Shear Wave Velocity Profiles
(The dashed line shows approximate soil / rock interface)

The following observations can be made:

- the average shear wave velocity is about 200 m/s in the first 10 m. The short streamer (2 m intertrace) captures more detailed information in the shallow layers;
- at the soil/rock interface the shear wave velocity rapidly increases from about 250 to 350 m/s.

CONCLUSIONS

This paper presents a new application of multichannel spectral analysis of surface waves for underwater sites (U-MASW). Data was collected by means of two streamers of 24 low frequency hydrophones at 5 and 2 m spacing, respectively. The data was processed to obtain the dispersion curve that is the function of the phase velocity of the surface wave with frequency. Numerical inversion was used to derive the shear wave velocity profile with penetration below the seafloor. The use of two streamers allowed to simultaneously capture detailed results at shallow depths (short streamer) and ensure adequate penetration of the investigation (long streamer). The results of the survey are consistent with the findings of geotechnical boreholes drilled at the site. The U-MASW can be successfully used to obtain the in-situ soil stiffness profile for local amplification studies, liquefaction potential evaluation, and stratigraphic interpretation with the aid of geotechnical boreholes.

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