MASW-MULTICHANNEL ANALYSIS OF SURFACE WAVES: A NEW GEOPHYSICAL METHOD FOR FOUNDATION ENGINEERING

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Resumo

O método MASW trabalha com o registro de ondas de superfície, com frequências entre 1 e 30 Hz, e investiga profundidades entre poucos metros até algumas dezenas de metros. A fonte de geração pode ser ativa (marreta) ou passiva (ruído do tráfego de veículos). É uma técnica da metodologia sísmica que permite determinar a variação da velocidade das ondas S com rapidez e qualidade, mesmo em locais urbanos onde o tradicional ruído, que normalmente atrapalharia a sísmica convencional, funciona como sinal (fonte passiva). Os dados obtidos, após o processamento, fornecem as informações necessárias para a obtenção dos módulos dinâmicos de elasticidade do meio, que são parâmetros importantes para os projetos de engenharia de fundações. Uma das suas mais importantes aplicações tem sido a avaliação de locais para implantação de torres eólicas.

Abstract

The multichannel analysis of surface waves (MASW) method deals with surface waves in the lower frequencies (e.g., 1-30 Hz) and uses a much shallower depth range of investigation (e.g., a few to a few tens of meters). Several key characteristics of surface waves and surface-wave imaging make application of this technique possible in areas and at sites where other geophysical tools have failed or provided inadequate or questionable results. The MASW method generates surface waves actively through an impact source like a sledge hammer, whereas the passive method utilizes surface waves generated passively by cultural (e.g., traffic) activities. The acquired data provides the necessary information to determine engineering parameters, such as dynamic stiffness moduli of a soil. One of the most important applications of MASW have been conducting soil sites assessment to set up wind turbine towers.

Key Words – Foundation, Engineering, Geophysics, Seismic, MASW

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1 - INTRODUCTION

The multichannel analysis of surface waves (MASW) method deals with surface waves in the lower frequencies (e.g., 1-30 Hz) and uses a much shallower depth range of investigation (e.g., a few to a few tens of meters). Several key characteristics of surface waves and surface-wave imaging make application of this seismic technique possible in areas and at sites where other geophysical tools have failed or provided inadequate or questionable results. The MASW method generates surface waves actively through an impact source like a sledge hammer, whereas the passive method utilizes surface waves generated passively by cultural (e.g., traffic) activities. The acquired data provides the necessary information to determine engineering parameters, such as dynamic stiffness moduli of a soil. (Tezcan *et al*., 2006).

In 2010 AFC Geofisica Ltda conducted its first geological survey applying the MASW technique in a project to set up 50 wind turbine towers in the countryside of the state of Bahia, utilizing active source (sledge hammer) in order to determine the dynamic stiffness moduli at each area designed for wind turbine installation.

In 2013 AFC Geofísica Ltda. applied the MASW technique combining active and passive surveys in the city of Porto Alegre - RS, in order to determine the depth to bedrock. The results of these surveys will be presented here.

2 - METHODOLOGY

The propagation velocity of the surface waves is mainly determined by the S-wave velocity (secondary or transverse) of the medium. Seismically, shear-wave velocity (VS) is its best indicator. Shear modulus is directly linked to a material's stiffness and is one of the most critical foundation engineering parameters.

Surface waves, commonly known as ground roll, are always generated in all seismic surveys, have stronger energy compared with other registered waves (refracted and reflected).

The sampling depth of a particular frequency component of surface waves is in direct proportion to its wavelength, and this property makes the surface wave velocity frequency dependent, i.e., dispersive.

The multichannel analysis of surface waves (MASW) method utilizes the dispersion property of surface waves for the purpose of VS profiling in 1D (depth) or 2D (depth and surface location) format. Basically it is an engineering seismic method dealing with frequencies in a few to a few tens of Hz recorded by using a multichannel (24 or more channels) recording system and a receiver array deployed over a few to a few hundred meters of distance, being recorded by the geophones and specific processing software.

There are basically two types of survey modes: active, passive and active-passive combined. The active MASW method adopts the conventional mode of survey using an active seismic source (e.g., a sledge hammer) and the maximum depth of investigation usually ranges of 10–30 m. The passive MASW method utilizes surface waves generated passively from ambient cultural (and natural) activities such as traffic (and thunder, tidal motion, atmospheric pressure change, etc.), ranging up to hundred meters along the surface and depth directions.

The main advantage of the MASW method is to take a full account of the complicated nature of seismic waves that always contain harmful noise waves such as higher modes of surface waves, body waves, scattered waves, traffic waves, etc. The MASW is operationally easier to apply, although methods like shear-wave refraction, downhole, and crosshole surveys can be used, they are generally less economical than any other seismic methods in terms of field operation, data analysis, and overall cost.

The MASW method consists of recording surface waves and construction of the dispersion curve image displayed as a function of phase velocity versus frequency, then analyzes the propagation velocity pattern of surface waves with 1-D (depth). When multiple records are acquired moving their position along a line, the resulting 1-D Vs profiles can be assembled into a 2-D (surface and depth), then a map is constructed through an appropriated interpolation scheme. Field procedures and data processing steps can be illustrated in Figure 1 Park et al. (2007):

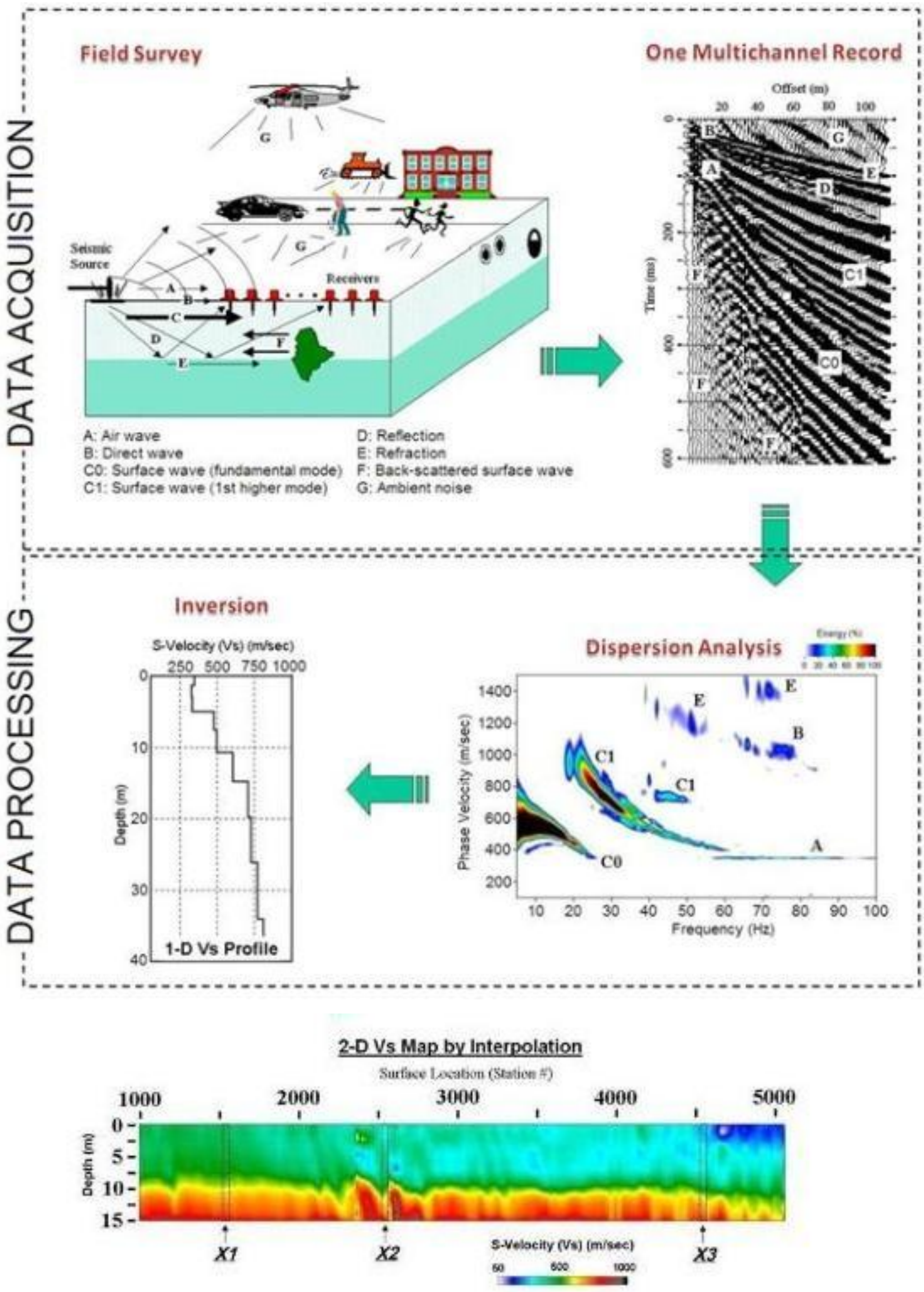

Figure 1- Data Acquisition and data processing for MASW surveys

3 - RESULTS

Two experiments were performed using the MASW method. The first one was developed using active source in the countryside of the State of Bahia, with the purpose of investigating potential sites for wind turbine tower installation. The second experiment was carried out combining active and passive survey in the urban zone of the city of Porto Alegre, RS to determine the depth of bedrock.

3.1 – Case Study of Active MASW

The first method was performed in the countryside of the State of Bahia with the purpose of determining the S-wave velocity profile at 50 sites selected to install wind turbine towers. Figures 3 and 4 illustrate the work performed in the area. The Information obtained has allowed to investigate depths around 25-30m, determining dynamic stiffness moduli of the soils in order to support the wind tower foundations plan to be implemented in the area.

Figure 2 – Data Acquisition

Figure 3 - Data Acquisition

Figure 4 illustrates an example of record gathered in one of the sites where the wind turbine will be installed. Figure 5 illustrates the wave dispersion image of acquired data. Figure 6 illustrates the velocity model for the PS waves. A summary of data acquisition parameters is displayed in table 1.

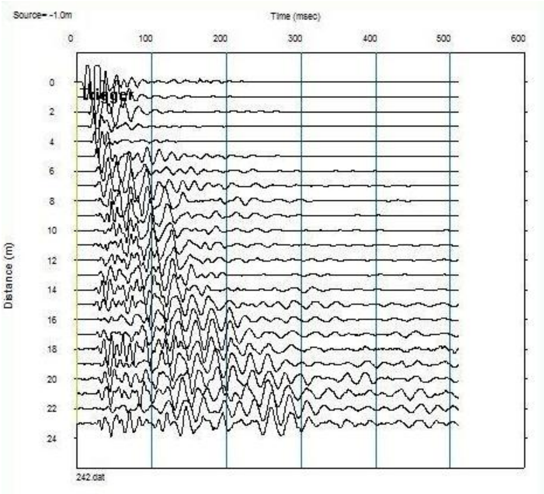

Figure 4 – Record

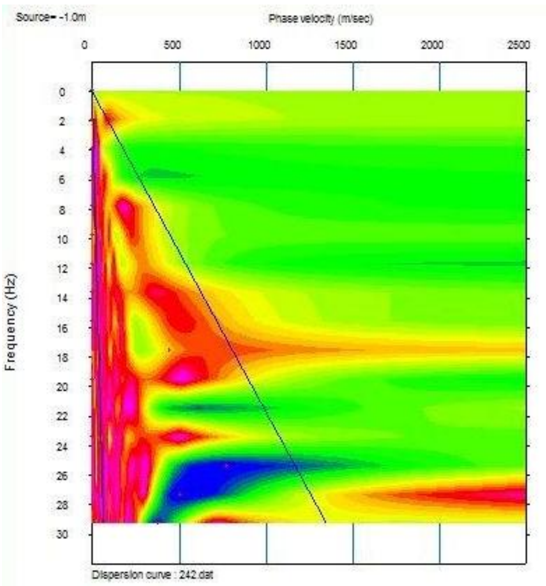

Figure 5 – Wave Dispersion Image

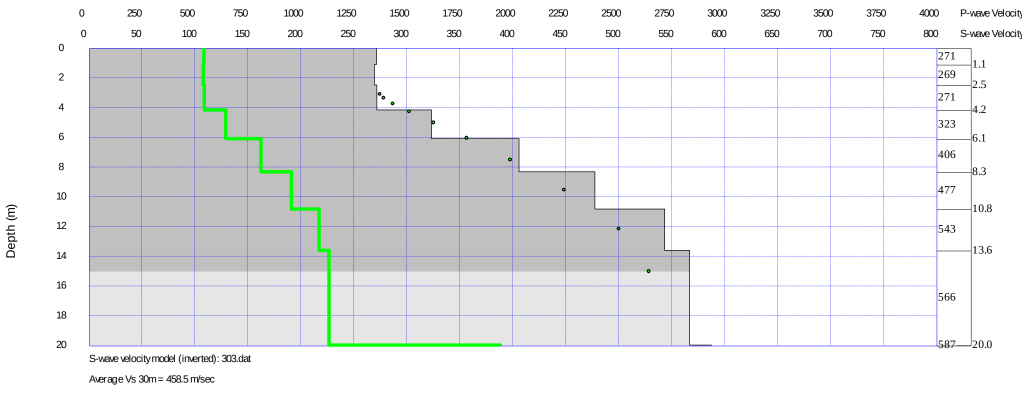

Figure 6 – Velocity model for the PS waves

Table 1 – Summary of MASW data acquisition parameters

Depth (m)	Vs (m/s)	Vp (m/s)	Density (g/cm³)	N (IBC)	µ	Gdyn, Gmax (MPa)	Gdyn, 0 (MPa)	Edyn (MPa)	Esdyn (MPa)
0.0	271	542	1.45	26.50	0.33	426	64	1136	1136
1.1	269	539	1.45	25.92	0.33	421	63	1124	1130
2.5	271	543	1.45	26.62	0.33	428	64	1141	1146
4.1	323	646	1.49	46.21	0.33	622	93	1658	1658
6.1	406	812	1.55	95.53	0.33	1022	153	2725	2725
8.3	477	955	1.60	160.24	0.33	1459	219	3893	3904
10.3	543	1087	1.65	241.84	0.33	1950	292	5200	5213
13.6	566	1133	1.66	276.48	0.33	2131	320	5684	5698
20.0	587	1942	1.92	310.12	0.45	7241	1086	20995	69599
26.6	594	1949	1.92	321.15	0.45	7293	1094	21133	68795

3.2 - Case study of Active and passive combined survey

The method has been applied in an urban road (figures 7,8,9,10) in the city of Porto Alegre/RS, with the aim of estimating the thickness of the loose sedimentary cover and the depth of bedrock.

Figure 7 – Data acquisition obtained in urban zone

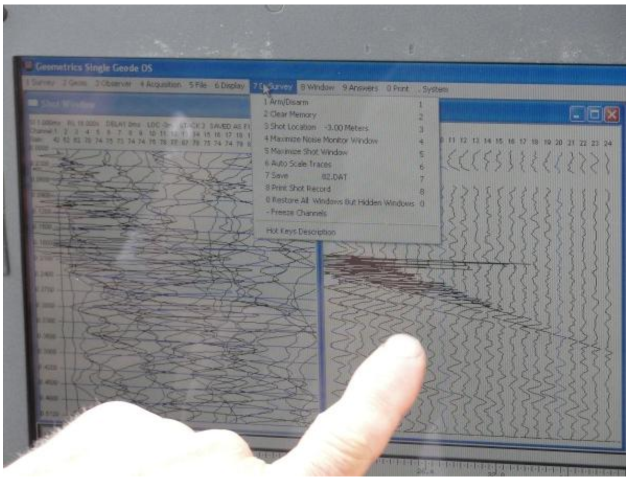

Figure 8 – Data acquisition record

Figure 9 – Geophone in position on the ground

Figure 10 - Data acquisition obtained in urban zone

Figures 11,12 and 13 illustrated record data acquired, dispersion image and velocity model for the PS waves. To perform the MASW survey a borehole 48 meters deep was drilled and geophysical logging (gamma ray, resistivity and sonic velocity) were carried out using a variety of probes. Figure 13 borehole logs and geophysical data are illustrated along with velocity model for the PS waves in a MASW survey. In the description, the first 20 meters correspond to the unconsolidated material such as sand and clay, underneath a granitic rock occurs. Gamma ray log allows for a more precise definition for the texture of the sediment / granite related to borehole description provided from samples of basalt rocks indicating the depth of 18,5m, which coincides impressively with the prediction made on MASW survey carried out previously.

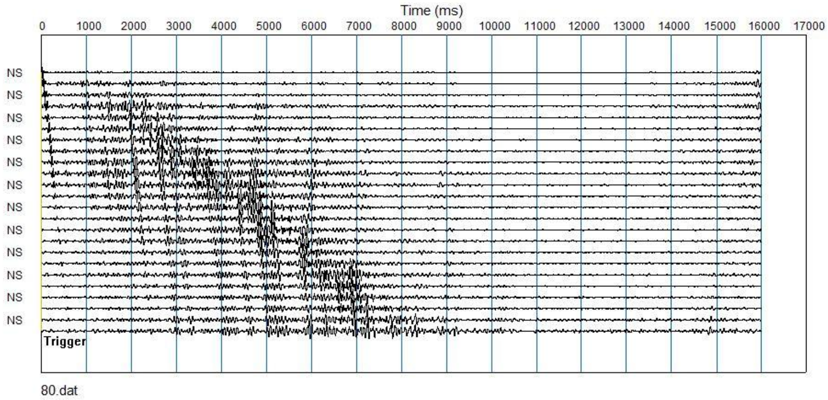

Figure 11 – Data acquired on MASW survey

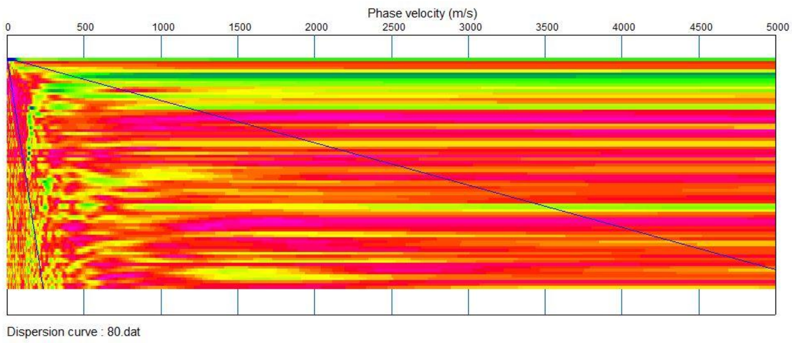

Figure 12 – Dispersion image

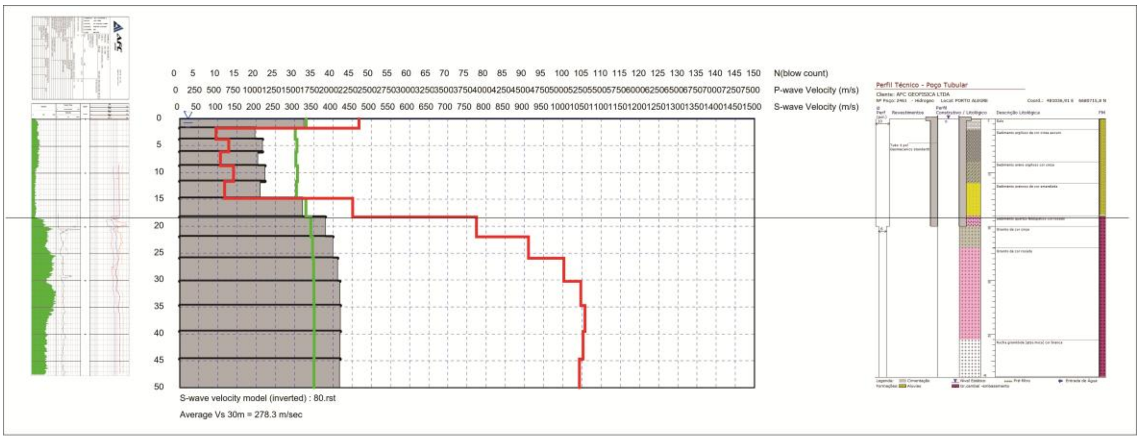

Figure 13 –Velocity model for the PS waves

4 - CONCLUSION

The MASW method is extremely easy and fast to implement. The main advantage of the MASW method is to take a full account of the complicated nature of seismic waves that always contain harmful noise waves such as higher modes of surface waves, body waves, scattered waves, traffic waves, etc. The MASW is operationally easier to apply, although methods like shear-wave refraction, downhole, and crosshole surveys can be used, they are generally less economical than any other seismic methods in terms of field operation, data analysis, and overall cost.

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