Applied MASW Technique for Detecting Soil Condition underneath the Packing Unit in Helwan Cement Factory

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Abstract: The packing unit of Helwan cement factory encountered a partial failure at the beaching walls that surrounds the platform together with differential subsidence of the concrete floor. These signs indicated that the unit is in danger and a swift interruption to restore the working condition is needed. Thus present research work was carried out to define the situation of the soil beneath the concrete floor using the passive multichannel analysis of surface wave (MASW) method was thus used. The experiment was carried out using an array of 24 geophones with 1 m interval with the total length of 23 m. Nineteen roadside experiments (linear array) is carried out at the site to deduce the shear wave velocity model underneath the unit. The shear wave velocity models obtained shows that there exist a low shear velocity layer between 2 m and 4 m deep. The research results showed that the soil layers below the concrete plateau lost its strength due to the high dynamic load exerted from the overlying industrial activities. This study helped to point out the problem, which, in turn, helped in choosing the suitable engineering solution.

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Introduction

The objective of the present work is to determine the soil shear wave velocities underneath the packing unit at Helwan cement factory. The packing unit area is one of the important facilities in the factory. The site is characterized by dense activities of heavy trucks for loading the products of the factory. These types of high activities usually exert dynamic loading and henceforth greatly affect the soil just beneath the floor of the packing unit.

Recently, it was discovered that parts of the beaching stones that bound the site, are suffering from minor to intermediate cracks. The risk of site crackdown becomes higher and approaching. Since soil flow through any part of the beaching stones will result in the subsidence of parts of the concrete plateau and thus the packing unit will become inaccessible.

The engineering geophysics community has recently focused on the use of Rayleigh wave methods, such as Multichannel Analysis of Surface Waves (MASW) to detect underground cavities and subsurface soil structures through the modeling of S-wave velocity (Miller et al, 1999). Successful applications of this method have been reported (Tallavo et. al, 2008), however further experimental and analytical investigations are required to comprehend the observed data (Zhang *et al.*, 2004; Xu and Butt, 2005; Tallavo *et al.* 2008).

MASW technique is dependent on the dispersion nature of the surface waves either using Rayleigh waves or Love waves. Thus, the backbone of the technique is the determination of surface wave dispersion curve, which, in turn, is inverted for the shear wave velocities of the soil layers.

The determination of elastic parameters relies on the modeling and evaluation of shear wave structures of the soil layers. The conventional seismic methods are generally active in nature, *i.e.*, it requires seismic sources to produce the seismic energy used in the analysis. In some locations, the use of seismic sources is impossible due to high noise activities (*e.g.*, heavy machinery or traffics that produce high seismic noise). As a result, the use of passive seismic method becomes vital. Fortunately, the passive version of MASW represents reliable supplement to conventional techniques. However, due the non-linear nature of the inversion of dispersion curves the method requires extensive work to determine reliable shear velocity model.

Due to all of these circumstances, the present work aims at capturing the soil structure that caused the observed problems. The results are then adopted to find better solution to current situation.

Location

The site is a facility that belongs to Helwan Cement Factory. It is located about 25 km to the south of Cairo (fig. 1). The area is characterized by the presence of several industrial projects in addition to dense dwelling slums used by the workers and employees. From the geological point of view, the packing unit is located at an area near the contact between the alluvial deposits of the Nile valley and the surrounding limestone plateau. The soil is composed of recent alluvial sediments with hard limestone below.

Fig.1: Location of the study area prepared using open street map (OSM) data.

Multi Channel Analyses of Surface Waves (MASW)

The multichannel analysis of surface waves method (MASW) is a nondestructive seismic method designed to investigate the shallow part (<150 ft) of the earth utilizing the Rayleigh type surface waves (Park et al., 1999; 2004; 2005). It analyzes dispersion properties of certain types of seismic surface waves (fundamental-mode Rayleigh waves) propagating horizontally along the surface. The method gives shear-wave velocity (Vs) -or stiffness- information in either 1-D (depth) or 2-D (depth and surface location) format in a cost-effective and time-efficient manner.

The fundamental framework of the MASW method is based on a multichannel recording and analysis approach long used in seismic exploration surveys. Thus it can discriminate a useful signal against all other types of noise by utilizing the pattern-recognition techniques (e.g. F-K or SPAC). The method can be applied in two modes active mode and passive one. The passive mode uses no active sources but depends on the recording and analysis of ambient noise.

Surface-wave velocities depend on the elastic properties of the layers underneath the line of transducers employed for the measurements. The stiffness profile of a layered medium can thus be inverted from the dispersion curve of surface waves. The multichannel analysis of surface wave (MASW) method is a relatively new technique.

MASW technique (according to Park et. al, 1999) consists of (1) a portable, repeatable, seismic source with sufficient energy to provide broadband Rayleigh waves in case of active mode; (2) a robust, flexible, user friendly, and accurate set of algorithms organized in a straightforward data processing sequence designed to extract and analyze 1D Rayleigh wave dispersion curves; (3) stable and efficient algorithms incorporating the minimum number of assumptions necessary to obtain 1D near-surface S-wave velocity profiles which are iteratively inverted using the generalized linear inversion (GLI) method; and (4) construction of the 2D S-wave velocity field.

The MASW method uses this dispersion curve to determine the shear-wave velocity profile of the medium. As the frequency increases, penetration of surface waves decreases. Thus, the high frequencies propagate through shallow layers. For practical purpose, the maximum depth of penetration of surface waves can be considered as equal to its wavelength. The seismic source in MASW tests is located at known distances or offsets from the array of transducers. The offset of the source together with the length of the array affect the largest reliable wavelength in the measurements (near field effects).

The array of transducers measures the surface response in terms of velocity or acceleration. Velocity transducers or geophones are normally used to collect low-frequency data (4–100 Hz), whereas accelerometers are used for higher frequencies (100 – 500 Hz), (Tallavo et al., 2008).

The time signals are recorded and transformed into the frequency domain using Fourier transform. From the frequency domain records, the cross spectrum and coherence function are computed to extract the phase information for each frequency component. The surface-wave velocity and the corresponding wavelength are computed using the distance and the phase difference between transducers, or as the ratio of frequency and wave number obtained from the 2D-Fourier transform of the time signals.

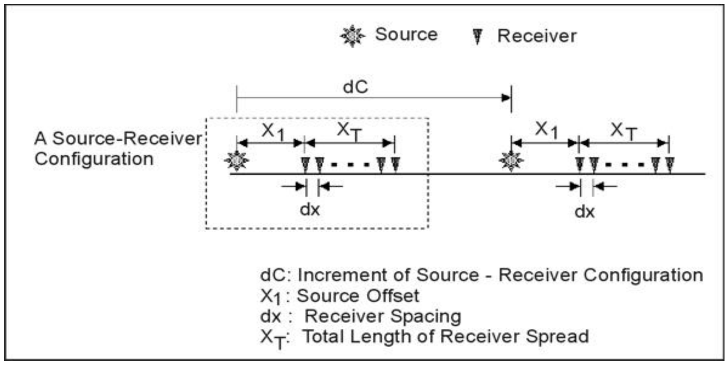


Fig. 2: MASW layout and acquisition parameters

A multiple number of receivers (usually 24 or more) are deployed with even spacing along a linear survey line with receivers connected to a multichannel recording device (seismograph) (fig. 2). Each channel is dedicated to recording vibrations from one receiver. One multichannel record (commonly called a shot gather) consists of a multiple number of time series (called traces) from all the receivers in an ordered manner.

Data processing consists of three steps; 1) preliminary detection of surface waves, 2) constructing the dispersion image panel and extracting the signal dispersion curve, and 3) back-calculating Vs variation with depth. All these steps can be fully automated. The preliminary detection of surface waves examines recorded seismic waves in the most probable range of frequencies and phase velocities. Construction of the image panel is accomplished through a 2-D (time and space) wave field transformation method that employs several pattern-recognition approaches. This transformation eliminates all the ambient noise from human activities as well as source-generated noise such as scattered waves from buried objects (building foundations, culverts, boulders, *etc*.). The necessary dispersion curve, such as that of fundamental-mode Rayleigh waves, is then extracted from the energy accumulation pattern. The extracted dispersion curve is finally used as a reference to back-calculate the Vs variation with depth below the surveyed area. This back-calculation is called inversion and the process can also be automated.

Data Analysis

MASW method is carried out here to get 1-D of the shear wave velocity in the vicinity of the plateau of the packing unit. To do so, acquisition array of 24 geophones were used. Passive MASW technique was applied due to the situation in the site where heavy machinery and traffics coexist. The total length of the array is chosen to be 23 meters. Figures 3 and 4 are samples of the data collected for MASW application. The total length of both array were 1000 s and 250 s respectively. Prior to the next step called generation of dispersion image or overtone data some of the traces were removed due to recording problem.

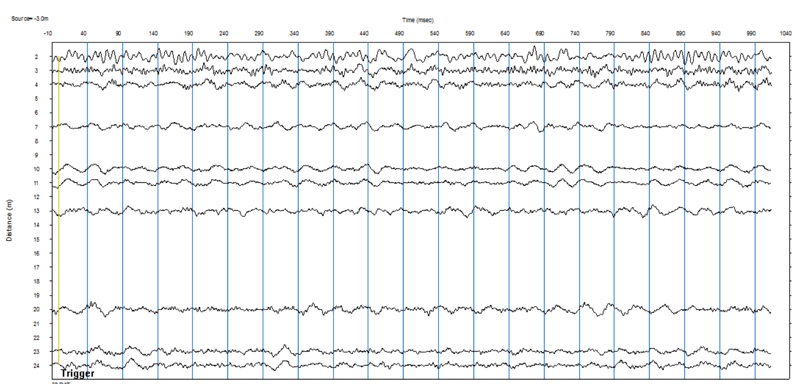


Fig. 3: Sample MASW data

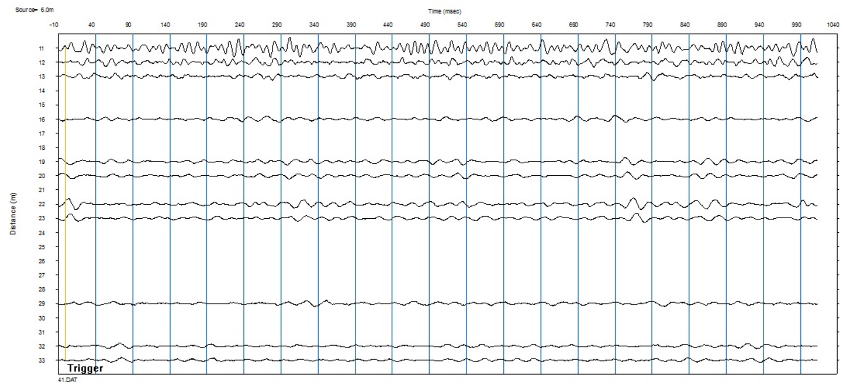


Fig. 4: Sample MASW data

The dispersion image data is presented in figure 5, while the phase velocity curve is shown in figure 6. Analyses and modeling adopted the fundamental mode approach only as higher modes were poorly determined.

The inversion for the surface wave dispersion curves is non-linear. Hence, iterative technique is used for the inversion and modeling. The inversion yielded that there exist low shear wave velocity layer at depths between 2 and 4 meters. This layer is most likely responsible for the swelling. The rest of the deeper layers have shear wave velocities that are normal to the study area.

Discussion

The study site which is important to a cement factory exhibited signs of deterioration and potential for damages (Pictures 1 thru 3). The beaching stone walls were fractured and the stone fences were partially collapsed. As a result, worries were tightening as the inaccessibility of the site would result in high economic loss for the firm. Such situation was the motivation to conduct the present work.

The conditions of the site are not suitable for applying active seismic methods or conventional SPT and CPT since heavy machinery and trailers are present and could not be stopped or shut down. Passive MASW is thus chosen as it gives reliable estimates of the shear wave velocity of soil beneath the floor of the study area. The method starts by recording the ambient noise using linear geophone array. Geophone interval is chosen to be 1 m with a total length of 23 m. Unfortunately, due to some technical problems only 10 traces were used as the rest of geophones produced bad data quality.

Determination of surface wave dispersion curve is the core of the method. For passive MASW the dispersion curve is obtained using spatial autocorrelation (SPAC) method. This method was first introduced by the work of Aki (1957). Afterward, the method is enriched and modified by numerous researchers (e.g. Okada, 2003; Bettig *et al*. 2001; Chávez-Gárcia *et al*. 2006; Köhler *et al*. 2007). The dispersion curve obtained is thus iteratively inverted to yield the shear wave velocity model of the soil. Recent work is carried out in order to simplify the problem (Pelekis and Athanasopoulos, 2011).

The best fit model is shown in fig 7. It shows high velocity layer at the surface which is related to the concrete plateau of the packing unit. Below this layer the shear wave velocity tends to decrease sharply to about 150-200 m/s. At deeper depths the velocity tends to increase again due to the expected presence of rocks with higher stiffness.

As An interpretation to the model, the soil layers below the concrete plateau lost its strength due to the dynamic load exerted from the overlying industrial activities. This situation is responsible for the partial damage features observed.

Conclusion

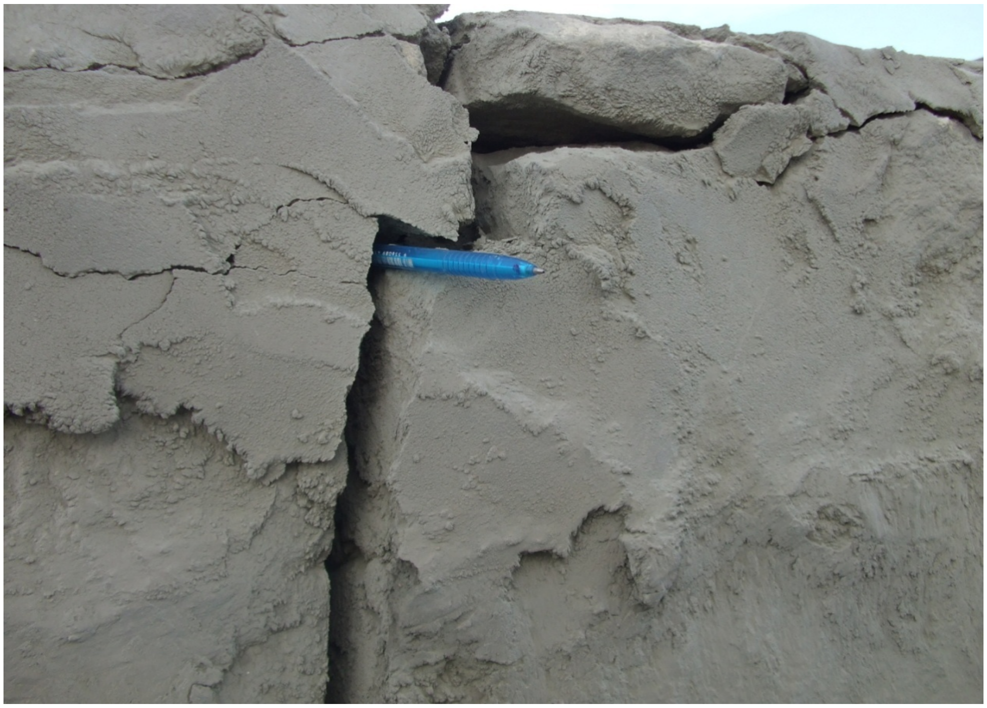
The problem at hand represent complicated situation where signs of damages pop up at the packing unit of cement factory, yet the unit cannot be stopped to investigate the causes and solve the problem. At this conditions conventional seismic and SPT methods fails as the activities at the site prohibit their application. To overcome such problems, Passive MASW method with SPAC pattern recognition algorithm is applied.

Nineteen roadside arrays of 24 geophones are used to study the soil conditions below the floor of the unit to find out the causes of the partial failure. The geophone interval is set to 1m, thus the total length of the array is 23 m.

The data analysis and modeling showed the presence of low shear velocity zone between 2 and 4 meters depth. This zone is most likely lost its strength as a result of the dynamic loads above. Thus the concrete floor begins to slide producing the damages reported. Such results are used to fix the situation by the structural engineers successfully. As a result passive MASW method might be used with different other acquisition layouts to solve similar problems efficiently.

Pict.1: Partial collapse of stone fence of the packing unit.

Pict.2: Partial damage of beaching stone wall extending upward to the fence.



Pict.3: Minor cracks of the stone wall.

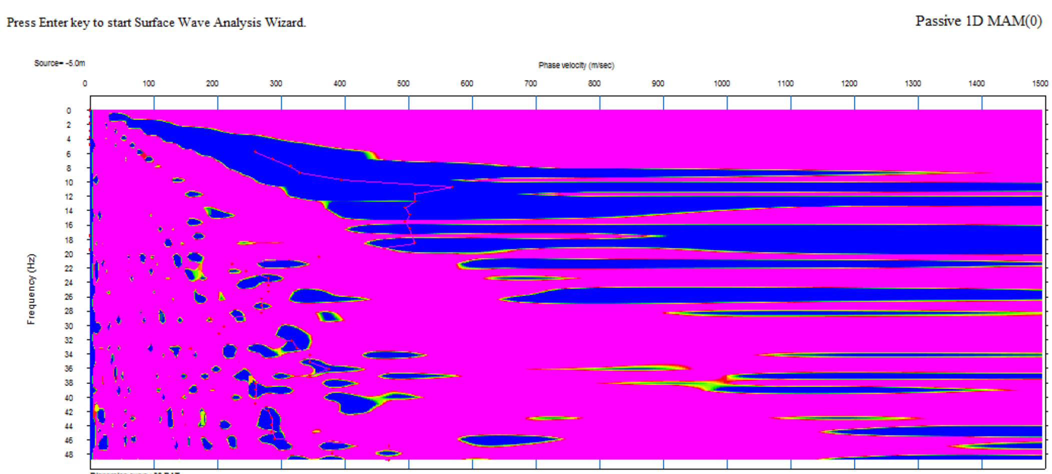


Fig. 5: Dispersion image of the data produced adopting by applying SPAC algorithm to the recorded data.

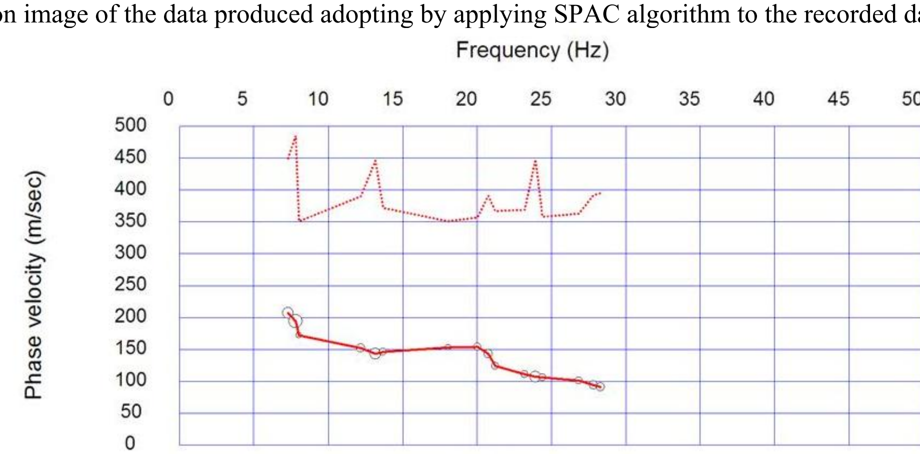


Fig. 6: Phase velocity curve obtained after the analysis of the data.

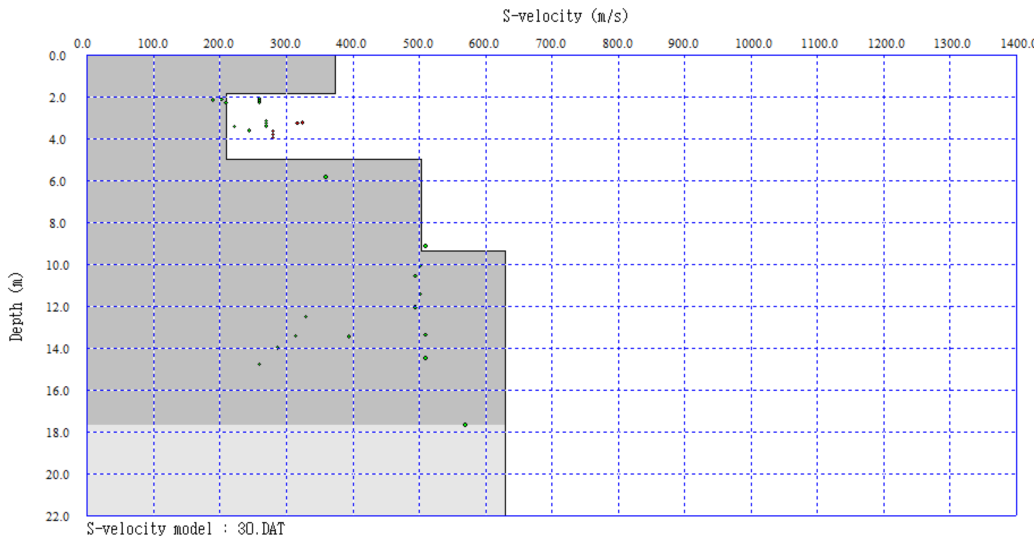


Fig. 7: Best fit shear wave velocity model of the area.

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