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Convergence of shear wave velocity structure models obtained from ellipticity analysis of surface waves of ambient vibrations

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Abstract

Shear wave velocity structure of the surficial layer of the earth is one of the requirements in many of site investigation programs. Conventional methods, especially in sites with thick alluvial layers, have limitations for this purpose. In this study, single-station measurement of micro-tremors and surface-wave ellipticity inversion were used to identification of soil structure. The study site is located in the south of Tehran and has a considerable thickness of soft alluvial layers. The ellipticity ratio was obtained using Geopsy software employing the time-frequency analysis method. Due to the uniformity of the sub-surface layers of the site, the mean ellipticity ratio curve of the four seismic measurements stations was used to inversion and extraction of the shear wave velocity structure. Due to the uncertainty in the inversion process and to investigate the convergence and stability of the solutions, five different initial models are considered and the inversion process has been repeated 3 times in each model. There is a very little error in inversion results, where they show that the seismic bedrock exists at a depth of about 100 meters. Also, different models have good convergence indicating the reliability of the method used to derive the shear wave velocity structure.

Keywords: *Velocity structure, micro-tremor, inversion, ellipticity, ambient vibration.*

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Extended Abstract:

1. Introduction

Determining soil sub-surface layers have been always an important issue in seismic hazard investigations. One of the most worthy parameters to characterize the sub-surface soil situation is shear wave velocity. Both excavation and geophysical measurements face considerable practical limitations in dealing with deep sub-surface structures. On the other hand, the relationship between soil structure and ambient noises frequency content has resulted in developing some novel methods for sub-surface characterizations based on single station micro-tremors vibrations. These methods have not only beneficially overcome the aforementioned approaches limitations, but also make it possible to achieve much deeper layers with lower costs. It has been shown that the spectral ratio of horizontal to vertical components of micro-tremors vibrations perfectly presents the amplification frequency of soil layers. Fah et al (2001) have shown that for a structural model with a strong contrast between sediments and bedrock, horizontal to vertical spectral ratio is well correlated with the ellipticity ratio of the first mode of Rayleigh wave. Studies conducted as a part of the NERIES project have led to the development and advancement of the method for characterizing the structure of soil layers based on the ellipticity ratios of Rayleigh waves (Hobiger et al., 2009; Poggi et al., 2012). This method is being developed and has been used in some recent site characterization and zoning projects (Fazlavi and Haghshenas 2015). In this study, the shear wave velocity structure of the soil layer at a site in the south of Tehran has been derived using the inversion of the ellipticity ratio of Rayleigh waves. The main aim of the study is to investigate the convergence of different initial models and the feasibility of the method for velocity structure characterization in deep alluvial sites.

2. Site Geology and Data Acquisition

The studied site is a structural project which has been located on southern Tehran plain, adjacent to the Behesht-e-Zahra highway. Evaluation of the sub-surface situation was based on some excavations which are performed earlier (Omran-Rahvar consultant, 2019). The sub-layers mainly consist of fine-grain soils (silt and clay). Two down-hole measurements were also performed in the site which has yielded shear and compressional wave velocities. Geophysical investigations represent relatively low shear wave velocities up to 500 m/s in 50 m depth. Velocity profiles for deeper soils have been achieved according to four single station micro-tremors data acquisition in the site. Two of these stations are positioned on previous down-hole measurement locations. In order to reduce noise effects, measurements are performed from midnight to approximately 3 A.M. Data acquisition is performed by a Gural-6TD broad-band instrument with a sampling frequency of 100Hz for a minimum duration of 20 minutes.

3. Data Processing and Results

Preliminary data analysis has been carried out employing Geopsy package software. The spectral ratios show a considerable similarity which is reasonable according to limited variations of sub-layer in the studied site. All four stations show an amplification peak on the H/V spectral curve between 0.5 to 1.0 Hz. Azimuthal spectral ratios indicate that there is no dependency in amplification ratios to any specific direction and accordingly these ratios could be confidently attributed to sub-surface layers. Moreover, low amplitudes of the H/V ratios represent a gradual velocity increase without sharp contrasts between different layers.

There are two different insights available for extracting the ellipticity ratio curve of Rayleigh waves, including time-frequency analysis and random decrement technique (Hobiger et al, 2009; 2012). In the first approach, with time-frequency analysis, Rayleigh wave amplitude is considered as times carrying the highest vertical component energy content, and a horizontal component corresponding to that would be achieved by transferring the horizontal component equal to one-fourth of the wavelength. In this way, the ellipticity ratio can be calculated by dividing the maximum amplitudes of the vertical component to the amplitude of the horizontal component. This process eliminates other surface and volumetric waves, especially out of plane shear wave and love wave. The second approach considers time windows according to Rayleigh wave frequency, in which vertical component amplitude shift between negative to positive values are considered as Rayleigh wave arrival. Then the horizontal component would be transferred equal to one-fourth of the wavelength regarding the Rayleigh wave frequency. This process is repeated for a high number of time windows and the summation or average of transferred vertical and horizontal windows will be calculated to achieve a graph for vertical and horizontal components. In this approach, the ellipticity ratio is equal to the square root of the ratio of vertical signal energy to the horizontal signal.

In this paper, to evaluate the ratio of ellipticity of Rayleigh waves in acquired data, the time-frequency analysis approach has been employed. Although methods like Short-time Fourier transform are available for signal evaluation in time-frequency analysis, some advantages such as variable time windows, make wavelet transform method more desirable. After wavelet transform in each frequency, the maximum values in the vertical component will be found and accordingly, the ellipticity ratio will be calculated. Figure 1 shows average ellipticity ratios for the studied stations. As can be seen due to negligible variations of sub-surface conditions the ellipticity curves for all four studied stations show a considerable similarity; average ellipticity ratio of the stations has been presented in the figure as well.

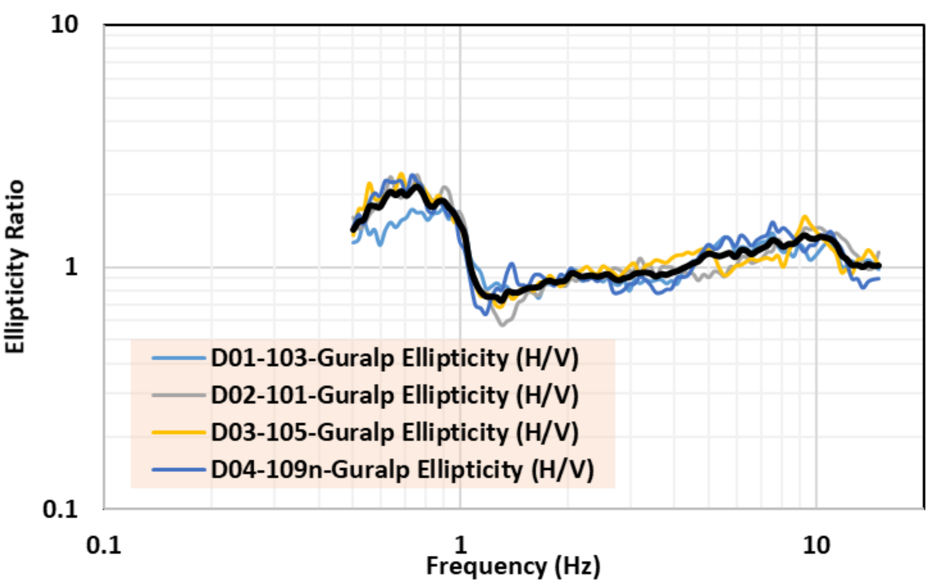

Figure 1. Average and standard deviations of the ellipticity curve for four studied sections.

The average ellipticity ratio is used to achieve the shear wave velocity structure. To this aim, DINVER add-on of Geopsy software package (Wathelet et al, 2004; Wathelet, 2008) is employed. This add-on uses the neighborhood algorithm to invert different data including surface wave dispersion curves and Rayleigh waves ellipticity curves in order to extract the sub-surface structure of soil layers. Several different models have been analyzed which finally resulted in 15 shear wave velocity profiles. Figure 2 presents the achieved velocity structure of soil layers with the lowest misfit values for different initial models. The convergence of different analyses can be followed in this figure which indicated the reasonable viability of the results.

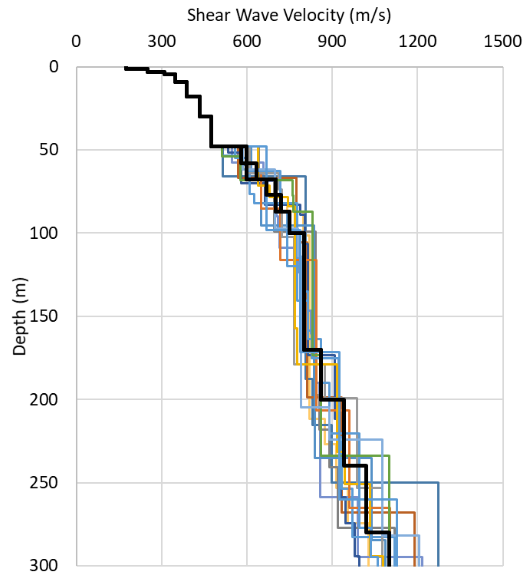

Figure 2. Comparison of shear wave velocity structures for different initial models.

4. Conclusion

The results indicate that the seismic bedrock located in depths about 100m for the studied site, moreover, consistency and convergence of the results for different initial models for the analyses suggest that ellipticity inversions can be used with enough reliability to extract velocity structure, where other conventional geophysical approaches are unable to achieve such data in deep alluvial sites. Alongside this, Ease of use and rapid data acquisition process with considerably lower costs make this approach much more favourable.

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