Determination of S-Wave structure via Refraction Microtremor Technique in Urban Area: a Case Study

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Abstract

Geological conditions of Tabriz, a growing city in NW-Iran, are strongly influenced by North Tabriz fault (NTF). North Tabriz Fault is a major seismogenic fault in NW-Iran. So, for a correct seismic microzonation, shear wave velocity (Vs) structure in different part of city should be determined. But urban conditions, such as ambient noise due to cultural activity, restrict the general application of conventional geophysical techniques for determination of Vs. This study proposes Refraction Microtremor (ReMi) technique for determination of shallow shear wave velocity in urban area. The ReMi data were collected by standard refraction equipment at the part of Tabriz city. We used ambient noise including energy from cultural activities and traffic. Also in processing of ReMi, resistivity data, as auxiliary information, are used. At the end for evaluation of results the estimated Vs profile was compared with downhole data that are available around of study area. The findings show that ReMi method is a suitable approach to obtain the Vs structure in urban areas.

Keywords: ReMi, Resistivity, Shear Wave, Microzonation.

1– Introduction

Tabriz is the biggest city of North West of Iran having 1.5 million people, great commercial cores, political centers, social and cultural centers, from one side, and the likelihood of earthquake occurrence from the other side requires a well-done evaluation of seismic hazard analysis. Tabriz has been destroyed under many catastrophic earthquakes that the oldest one happened in 8th century. Shear-wave velocity is one predictor of earthquake ground-motion amplification in alluvium-filled basins, and it is the basis of site hazard assessment. The calculation of the depths and the elastic properties of sedimentary deposits is an important goal in various scientific and technical fields. For example, the velocities profile and the geometry are necessary information for geophysicists and seismologists for modeling The seismic response of sedimentary basins (Almendros *et al*., 2004). The depths of the sediments in a deposit can provide valuable geomorphologic information, the velocities profile together with the depth of the basement below the sediments are useful data in geotechnical studies for the correct construction of buildings (García *et al*., 2008). 1-D shear wave velocity structure is important for site effect studies and geotechnical engineering, but it is quite difficult and expensive to derive from the conventional geophysical techniques (Mahajan *et al*., 2012). Current techniques of estimating shallow shear velocities for assessment of earthquake site response are too costly for use at most construction sites. They require large sources to be effective in noisy urban settings, or specialized independent recorders laid out in an extensive array (Louie, 2001).

The ReMi method, introduced by Louie (2001), has widely been used to determine shear wave velocity profiles using ambient noise recordings. The ReMi method provides an effective and efficient means to obtain general information about large volumes of the subsurface in one dimension per setup, where appropriate setup length is related to desire the depth of investigation (Rucker, 2003). ReMi is based on obtaining the dispersion curve of the Rayleigh waves, but in this case using ambient seismic noise or microtremor. For processing procedure as other surface wave methods, after construction of dispersion curves next step is inversion of the dispersion curve to obtain a single VS profile or a vertical slice. The inversion stage in processing of ReMi data, because of its nonlinearity and multi dimensionality, is an important issue to obtain a reliable near-surface Vs profile. In current study for decrease the non-uniqueness of inversion results the resistivity data (Wenner array) as auxiliary information are applied. The Wenner configuration is a robust array that in general, is suitable for resolving vertical changes. In this study we used swarm intelligence base algorithm for inversion of ReMi data. At the end the obtained S-wave structure from ReMi is compared with downhole measurements. In general the results proved the ability of ReMi approach in estimation of Vs profile in shallow depth. Moreover the ability to collect data in a noisy environment and quick data acquisition are the important benefits in application of the ReMi technique.

2– ReMi method

The ReMi technique is a cheaper and quicker “passive” geophysical technique. This method is based on ambient noise measurements that are carried out with seismic arrays to obtain information on surface wave velocity dispersion. There are a number of geophysical techniques commonly applied in near surface study to the task of estimating the Vs structure at a site (e.g. SASW, MASW, reflection, refraction, borehole seismics and array Microtremor). Urban conditions, such as existing underground facilities and ambient noise due to cultural activity, restrict the general application of conventional geophysical techniques (Cha, 2006). The ReMi method combines the urban utility and ease of microtremor array techniques with the operational simplicity of Spectral Analysis of Surface Waves (SASW) technique and the shallow accuracy of Multi Channel Analysis of Surface Waves (MASW) technique. By recording urban microtremor on a linear array of a large number of lightweight seismometers, the method achieves fast and easy field data collection without any need for the time-consuming heavy source required for SASW and MASW work. As SASW technique ReMi is based on obtaining the dispersion curve of the Rayleigh waves, but in this case using ambient seismic noise or microtremor. Configurations of 12 to 48 single vertical, 8-12 Hz exploration geophones can give surface-wave phase velocities at frequencies as low as 2 Hz, and as high as 26 Hz. This range is appropriate for constraining shear velocity profiles from the surface to 100 m depths (Louei, 2001). After Louei (2001), reliability and accuracy of ReMi method was investigate in different case studies. Rucker (2003) applied the ReMi shear wave technique to geotechnical characterization and several geotechnical applications have been shown in his publication. Scott *et al*. (2004) performed measurement of shear-wave velocity to 30 m depth (Vs30) for hazard assessment of Reno basin. They were successful in obtain detailed shallow shear-wave velocity transect across an entire urban basin with minimum effort. Cha *et al*. (2006) introduced Application of ReMi surveys for rock mass classification in urban tunnel design, and they showed that evaluating the Rock Mass Rating (RMR), using shear-wave velocity information from ReMi in urban area is possible truly. Stephenson *et al*. (2005) conducted a blind comparison of MASW and ReMi results with four boreholes logged to at least 260 m for shear velocity in Santa Clara Valley, California, to determine how closely these surface methods match the downhole measurements. They suggested MASW and ReMi surface acquisition methods can both be appropriate choices for estimating shear wave velocity and can be complementary to each other in urban settings for hazards assessment. Moreover they state ReMi data acquisition is easier and more time efficient, requiring less equipment than MASW. Coccia *et al*. (2010) used ReMi technique for determination of 1-D shear wave velocity in a landslide area and concluded that in marginally stable slope areas the ReMi method can provide the data needed to calculate shear-wave velocity vertical profiles down to depths of few tens of meters. This can be achieved even using array shorter than the commonly recommended minimum value of 100 m.

Panzera and Lombardo (2013) successfully used MASW and ReMi techniques to investigate on the dynamic properties of main lithotypes outcropping in Siracusa region and their relationships with the local seismic response. The comparison of two methodologies clearly shows the prevailing of high frequencies components contribution in the definition of the MASW dispersion curves whereas, the phase velocity–frequency curves obtained through the ReMi approach appear better defined at lower frequency.

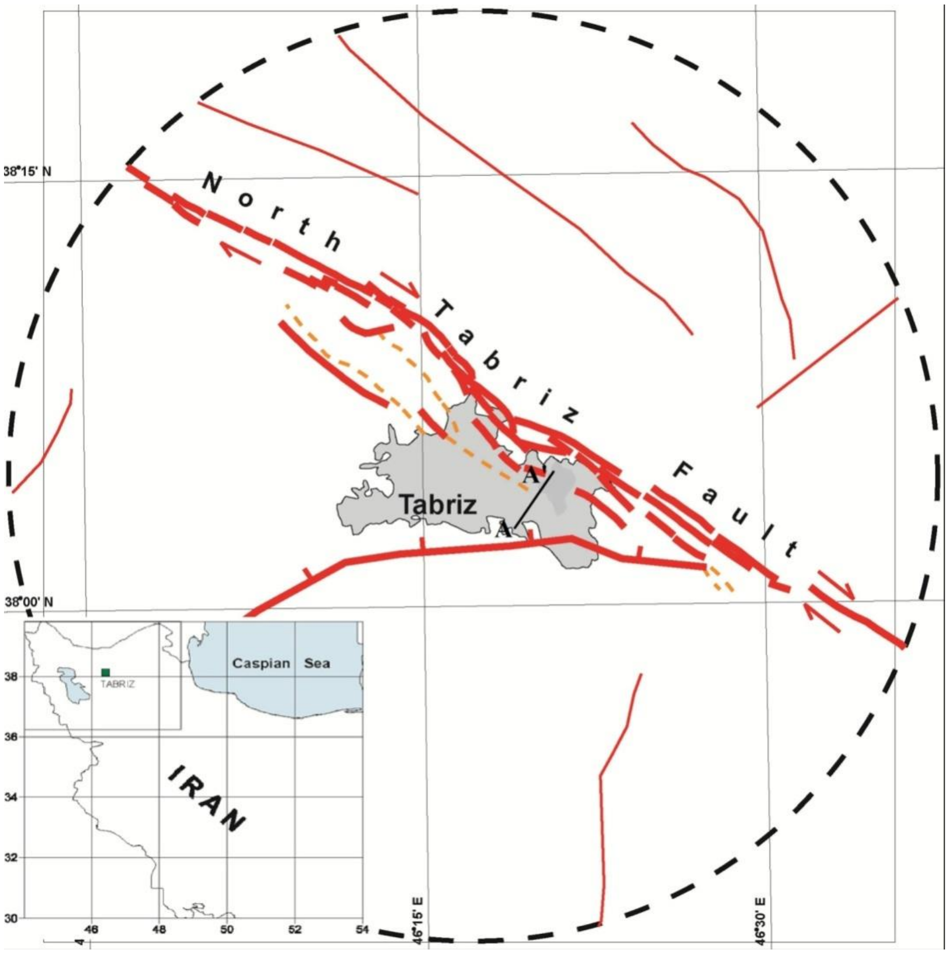


Figure 1) Structural map of Tabriz and location of study area.

3– Geological setting

Tabriz city, the centre of east Azerbaijan province, is one of the biggest industrial cities of Iran. Iran has been divided into several structural units (Ghorbani, 2013), that Tabriz is belonging to Central Iran unit. Tabriz area is underlain by recent alluvium in central urban area and a complex of conglomerate, fine sediments, red sand stone and alteration of greenery and dark grey marl is the general bed rock in this region (Sadrkarimi *et al*., 2006). The North Tabriz Fault is the most prominent tectonic structure in the immediate vicinity of Tabriz city (Fig. 1).

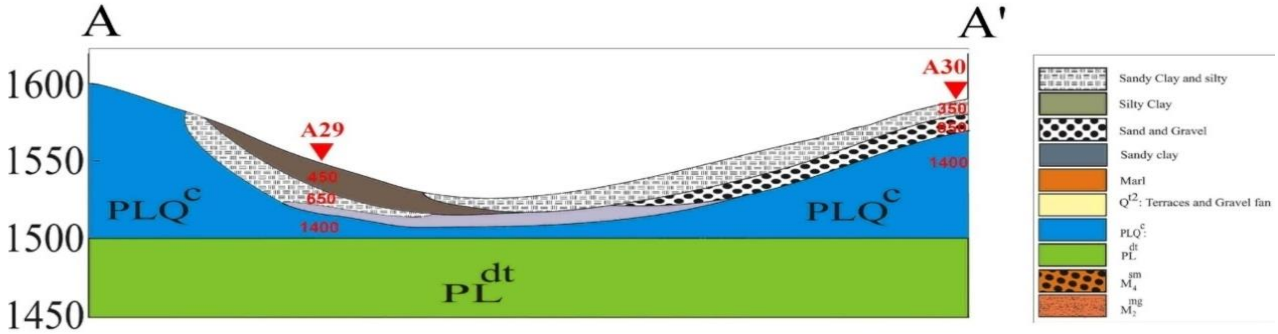


Figure 2) Geology section of profile A-A', in study area (Zarean, 2013).

It should be pointed out that this fault (i.e. NTF) is one of the big and active faults in Iran that has an obvious surface appearance. It has an average strike of NW-SE over a length of about 150 km and its dip is vertical (Berberian and Arshadi, 1976). The North Tabriz Fault is an old geological fault which has been reactivated during different movements. But on the basis of historical studies (Berberian and Arshadi, 1976), it would appear that the Tabriz region has not experienced any major destructive earthquakes since the end of the 19th century. This seismic quiescence has continued to the present day. The absence of any field evidence of significant creep along the fault may indicate that the North Tabriz Fault is capable of sudden seismic slip.

4– Methodology

In this study the ReMi data were collected in a line at the part of Tabriz city (near the Azad University of Tabriz) in NW-Iran. The geological and geotechnical studies show upper layer, made up of soil consisting of alluvium and sandy clay, and the second layer, made up of mix clay soil, Gravel and Tuff. For the more description of local geological condition of study area in figure 2 a geology section near to the study area is shown that this section is based on microzonation study of Tabriz city by Zarean (2013). The ReMi method was performed with using an OYO 12-channal seismograph and 4.5Hz geophones with a receiver spacing of 4m. Unfiltered 17 second records were collected at study site. Also fourteen records were gathered. ReMi Data processing consists of three steps: 1) preliminary detection of surface waves, 2) extracting the dispersion curve, and 3) back-calculating Vs variation with depth (i.e. inversion stage). The linear configuration in ReMi approach has the advantage of simplicity, the test configuration is the same as might be used for refraction testing, but it has the drawback that the predominant noise-arrival azimuth is unknown (Jin *et al*., 2006). In the presence of a single source, and a single plane wave, the apparent velocity detected by a linear array depends on the angle between the array direction and the source azimuth, that interpreter cannot just pick the phase velocity of the largest spectral ratio at each frequency as a dispersion curve, as MASW analyses effectively do (Strobbia and Cassiani, 2011; Louie, 2001). In linear array as the angle of propagation increases from parallel to perpendicular, the apparent phase velocity increases. In reality, sources of microtremors vary and energy radiates from many directions at unknown angles to the geophones. Since angles of propagation are unknown, with a linear array, the calculated phase velocity may be higher than the actual phase velocity unless a method independent of the source locations such as spatial autocorrelation (SPAC) method (Wathelet, 2005) is applied. In this study ReMi data processing except inversion step is performed using the module Pickwnin/SW of the commercial software package SeisImager v.3.14. The fundamental assumption of microtremor data analysis using the SPAC method of SeisImager/SW is that the signal wavefront is planar, stable, and isotropic making it independent of source locations (SeisImager/SW Manual, 2009). Processing flows of ReMi dataset of experimental dataset is shown in Figure 3.

Table 1) Mean model obtained from experimental dispersion curve and search space

layer number	S-wave velocity(m/s)	thickness(m)	search space	
			S-wave velocity(m/s)	thickness(m)
1	296	4.1	150- 450	2-6
2	386	4.7	250- 700	1-6
3	425	4	300-800	1-6
4	491	Half-space	350-900	-

For calculation of phase velocity of experimental data the minimum and maximum of velocity that expected from study area are needed. For these values we used auxiliary data, resistivity and geological information about study area. In next step dispersion curve by picking the maximum amplitudes on the phase velocity-frequency plot will be determined.

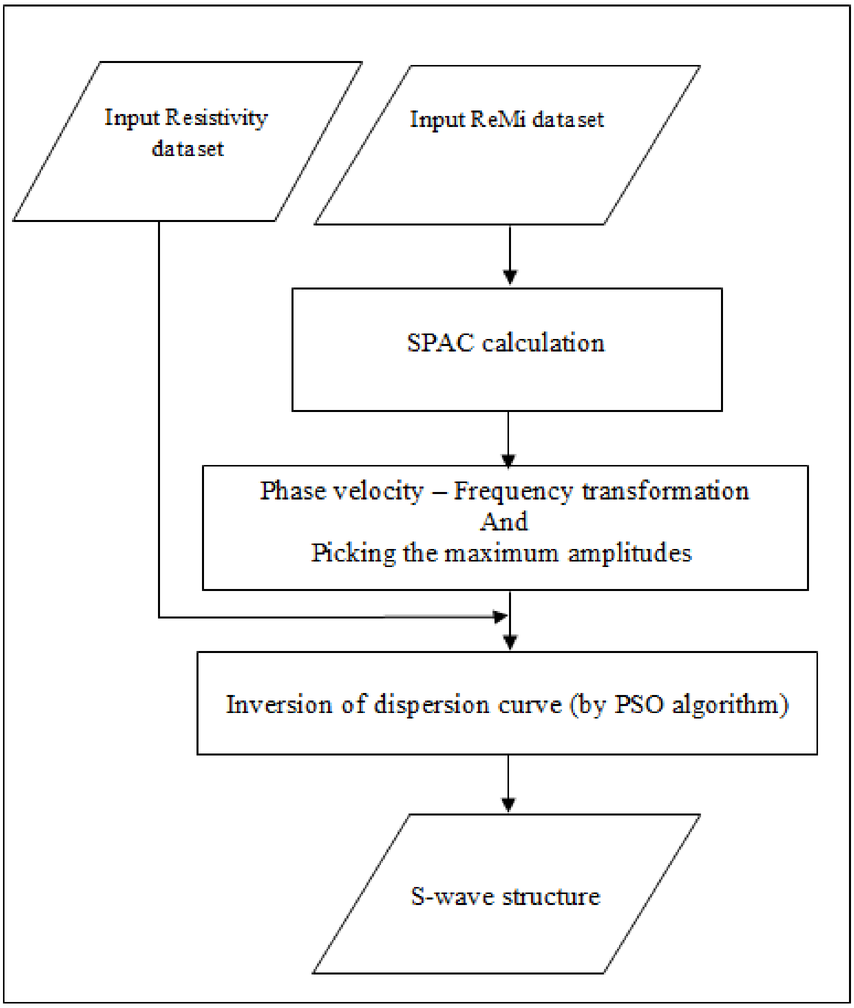


Figure 3) Flowchart of processing procedure of experimental dataset.

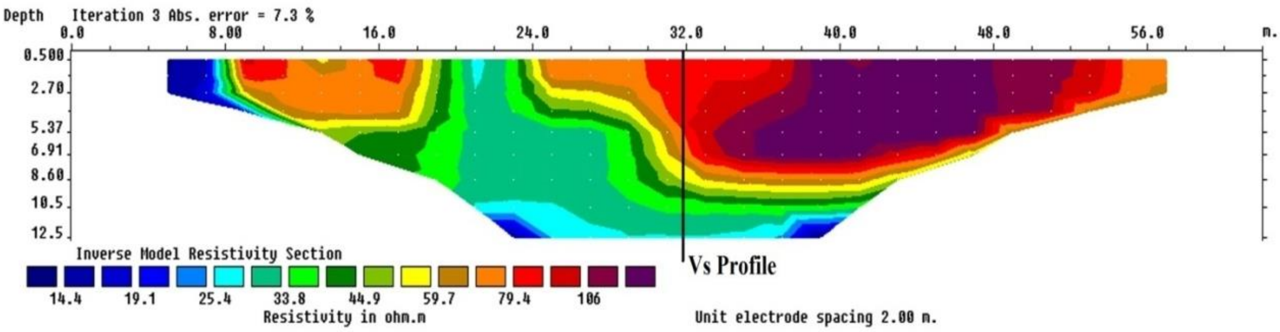
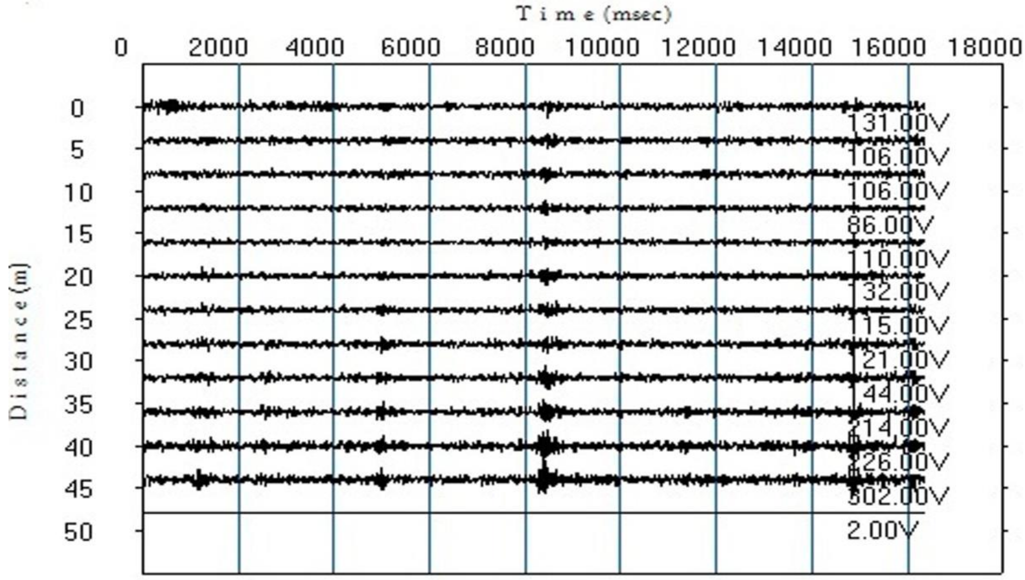


Figure 4) Resistivity section of study area.



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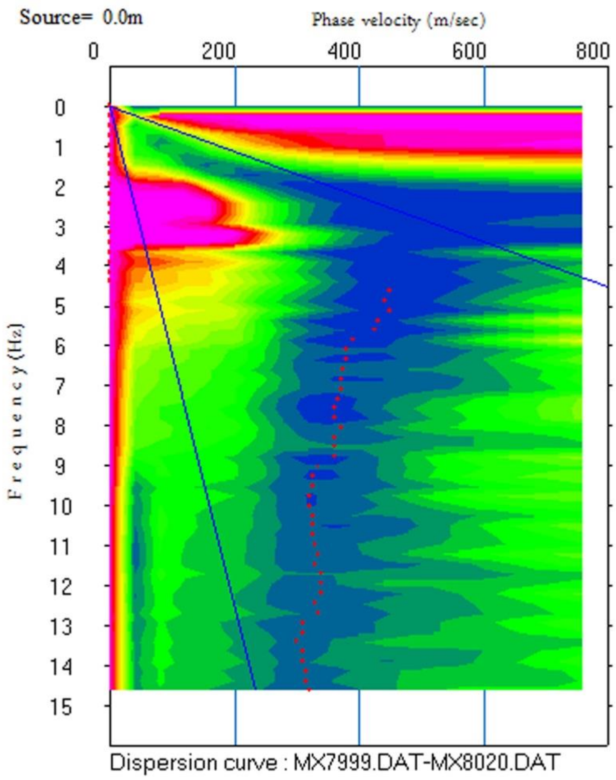

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Figure 5) experimental dataset: a) a record of ReMi data, b) Dispersion curve.

In this study the minimum and maximum frequency value are 4.5 Hz and 15Hz respectively. The final step of processing flows is inversion of dispersion curve. But dispersion curve inversion in fact is a highly nonlinear problem that severely challenges any inversion algorithms. In this study an inversion algorithm based on Particle Swarm Optimization approach (Poormirzaee *et al*., 2014) is used. Particle swarm optimization (PSO) is a stochastic evolutionary computation technique for optimization in many different engineering fields, which is inspired by the social behavior of individuals (called particles) in groups in nature, such as a flock (swarm) of birds searching for food. The PSO code for inversion of ReMi data was written and processed in Matlab.

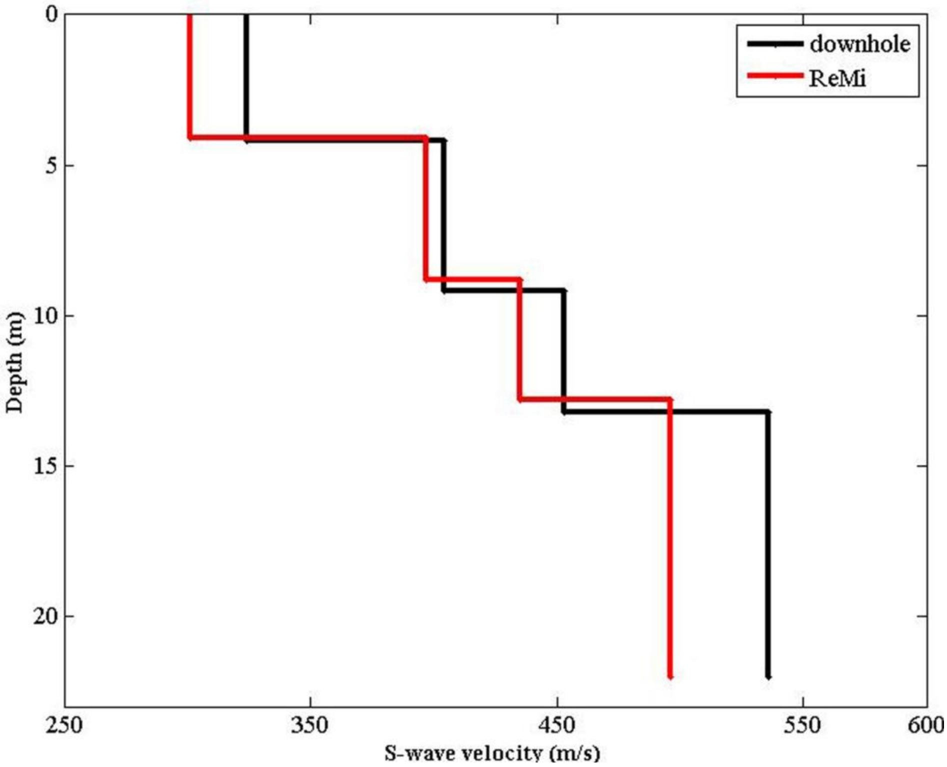

Figure 6. Obtained S-wave structure from experimental dataset.

Using resistivity data in processing of ReMi are for constraining the interpretation and removing the ambiguity in the reconstruction of structures. Panzera and Lombardo (2013) pointed out that the use of combined different methods provides a robust way to characterize the investigated soils and to reduce the problems linked to the non-uniqueness of solutions during the interpretation of geophysical data. Synergies of surface wave tests with other geophysical tests can be useful to improve the reliability of the final result and to obtain a more consistent soil mode (Foti, 2005). Resistivity method can provide information about bed rock and water table in study area. For this goal, resistivity measurements were carried out by using high-resolution RESECS resistivity meter system. In this study Wenner array, with 32 electrodes (2m unit electrode spacing), for measurements of 1-D resistivity imaging profile is used. That the obtained resistivity model is presented in figure 4. After obtained dispersion curve (Fig. 5), to invert ReMi data we considered Vs and thicknesses (H) of layer as variables. Also by attention to observed dispersion curve and also according to priori information (i.e. resistivity and geological information) a 3layer model overlying a half-space was adopted. The search space of algorithm to invert the dispersion curve is shown in the Table 1. For inversion of experimental data the Poisson's ratio (ν), regarding to priori information, was set between 0.2 and 0.4. Also the compressional velocity (Vp) is considered as a dependent variable to the assumed Vs and *ν*. Moreover the parameter of density was fixed according to the classical Gardner *et al.* (1974) empirical V_p–ρ relationship:

$$\rho = log(0.23 + (kVp)^{0.25}) \quad (1)$$

Where $K = 1/0.3048$ is a constant to convert feet into meter. For evaluation of results, the obtained Vs profile from experimental dataset was compared with the Vs profile from downhole seismic survey, which is available around the study area (Fig. 6). The results of experimental dataset show a good correlation with downhole survey. Moreover the thicknesses that estimated by inversion of ReMi data are like to layers that detected by the observed resistivity section.

5– Conclusions

The determination of S-wave velocity structure is a very important issue in geotechnical and earthquake engineering because of its direct relationship with the stress and strain properties of soils. Conventional techniques of estimating shallow shear velocities for assessment of earthquake site response are too costly for use at most construction sites. In current study by ReMi approach we obtained a detailed shallow shear-wave velocity profile across an urban area (i.e. Tabriz city), with the minimal effort and time. The study area is located in developing part of city that included a low thickness alluvium. After acquiring ReMi data and construction dispersion curve as other surface wave methods, inversion of the dispersion curve, to obtain a single VS profile or a vertical slice, has been done. For improve the reliability of the final result and removing ambiguity in the reconstruction of structures, resistivity data in inversion of dispersion curve as auxiliary information is used. The applied array (i.e. Wenner array) is relatively sensitive to vertical changes in the subsurface resistivity below the center of the array. As in figure 4 is shown relatively a high resistivity anomaly is detected, which is probably a gravel deposit in sandy layer. The deep layers formed clay and mixed clay and sand formation. Resistivity information in inversion, for adjusting the limit of search space for Vs and thicknesses of layers are significant. After inversion of dispersion curve the downhole data confirmed the estimated Vs profile from experimental data. Also the estimated thicknesses are in a good correlation with observed resistivity section. The ReMi data acquisition is easier and more time efficient, requiring less equipment than other geophysical methods and is suitable method for study areas that suffer from restriction such as urban noise and cultural activities. Also in complicated geological conditions joint interpretation of ReMi and other geophysical data, such as resistivity, is a successful strategy to achieve a correct interpretation and reducing the non-uniqueness of solutions.

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