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SEISMIC MICROZONATION OF URMIA CITY BY MEANS OF MICROTREMOR MEASUREMENTS

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SUMMARY

In order to perform seismic microzonation of Urmia city, northwest of Iran, microtremor measurements were carried out in more than 200 points. Simultaneous measurements were done at soil and rock stations in the city. To make use of the measured data two commonly used methods, i.e. Hs/Hr and H/V spectral ratios, were employed. Conclusions were displayed in term of transfer function shape, fundamental frequency and amplification factor. Sites on sediment categorized into two near and far from their reference sites. It's shown that in the far case sites, H/V method gives better results. However, in the near case sites, H/V method achieves very good results too. Comparison between these two methods showed that H/V technique is more applicable to microtremors. In addition H/V method was attempted using different spectral analysis. The advanced segmental cross-spectra method was compared with the conventional methods of Fourier spectra, power spectra, and cross spectra. Results showed that H/V method with segmental cross spectra gives more accurate and reliable results especially in the case of amplification factor. In order to evaluate the results obtained from microtremor method, they were compared with those calculated based on geotechnical borehole information. For this reason, one-dimensional ground response analysis was carried out for different locations. Comparison between the results of the direct analysis and that of the microtremor method showed that the microtremor method could accurately determine the dynamic characteristics of the surface ground. Especially this method accurately suggests fundamental frequency. Finally based on the obtained results, the seismic microzonation maps of the city including, iso-period and iso-amplification factor maps were presented.

INTRODUCTION

Damages occurred in recent earthquakes showed that local site conditions have a significant effect on ground motion. Therefore, site response studies play an important role in seismic microzonation studies. The application of microtremors to determine dynamic characteristics (predominant period and amplification factor) of sediment was pioneered by Kanai and Tanaka [1], [2]. Nowadays microtremor measurements are generalized in site characterization due to their simplicity, low cost and minimal disturbance to other activities.

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Techniques for analyzing microtremors are generally divided into two main categories: non-reference site (H/V) and reference site (Hs/Hr) techniques. In Hs/Hr method, assumptions are that at nearby sites, source and path effects are believed to be identical and reference site is free of any site effect. Therefore, motion recorded at the reference station is representative of the excitation arriving at the interface sediments under the soft soil site and spectral ratio, Hs/Hr, constitute a reliable estimate of site response. This technique, introduced first by Borcherdt [3], is still widely used and is very popular for the analysis of weak or strong motion records. It has been applied to microtremor measurements by Kagami et al. [4] with good results.

In the traditional spectral ratio method, Hs/Hr, site and source effects are estimated from observations at a reference site. In practice, adequate reference site are not always available especially in flat areas. Therefore, methods have been developed that do not need reference sites [5]. A technique using horizontal to vertical spectral ratios (H/V) of the microtremors, which was first applied by Nogoshi and Igarashi [6], [7] and popularized by Nakamura [8], has been widely used to estimate the site effects. Several recent applications of this technique have proved to be effective in estimating fundamental periods ([9], [10]) as well as relatively amplification factors ([11], [12]).

Several methods have been proposed for spectral calculation of ground motions including microtremors. Fourier spectrum is the most convenient one that is used widely. Some investigations showed that different methods give similar results [13]. However some researchers declare that a suitable spectral method gives more reliable results [14].

Ghayamghamian and Kawakami [14] introduced segmental cross-spectrum (SCS), as an effective tool for compensating unknown effects like source effects and noise in input and output measurements. They evaluated the performance of SCS in contrast with the conventional methods, i.e. Fourier or power spectra through the mathematical modeling and numerical simulations. Results of their studies indicated that SCS gives more reliable results for both amplification factor and predominant resonance frequency of the site than the conventional methods.

MICROTREMOR MEASUREMENTS

The ground is always vibrating at minute amplitudes. Microtremors are ambient vibrations of the ground caused by natural or artificial disturbances such as wind, sea waves, traffic, and industrial machinery. The amplitude level of the microtremor is typically less than several microns. Seismometers of high sensitivity are used for microtremor measurements [15].

Microtremor measurement was carried out in 200 sites in Urmia city (Fig. 1). MT and RT respectively show sites on sedimentary zone and rock outcrop reference sites. The equipment used to record the microtremors were five seismometers with 1-second natural period and 70% of critical damping ratio by Kinematic. Seismometers comprise three components, which can record the horizontal motion (in longitudinal and latitudinal directions) and the vertical motion. These were coupled by PDAS-100 digital seismograph with a link cable (Fig. 2). Sampling rate was 100 Hz. At each site 4 to 8 records with a 120 second duration were obtained. In addition, measurements were carried out from 12:30 pm to 5:30 am in order to minimize artificial noises due to traffic and human activities. Several windows were selected from these records, for the analysis. The criterion for selecting time histories was visual. Time histories that consisted noise were excluded from calculation. Figure 3 shows a typical record at site MT103. The motions were simultaneously recorded on both soil and reference sites. Three reference sites were considered in the measurements shown in Figure 1: Bagh Rezvan, Band and Sheikh Tappeh stations. All of reference sites are located on the rocks outcropping on some hills around the city.

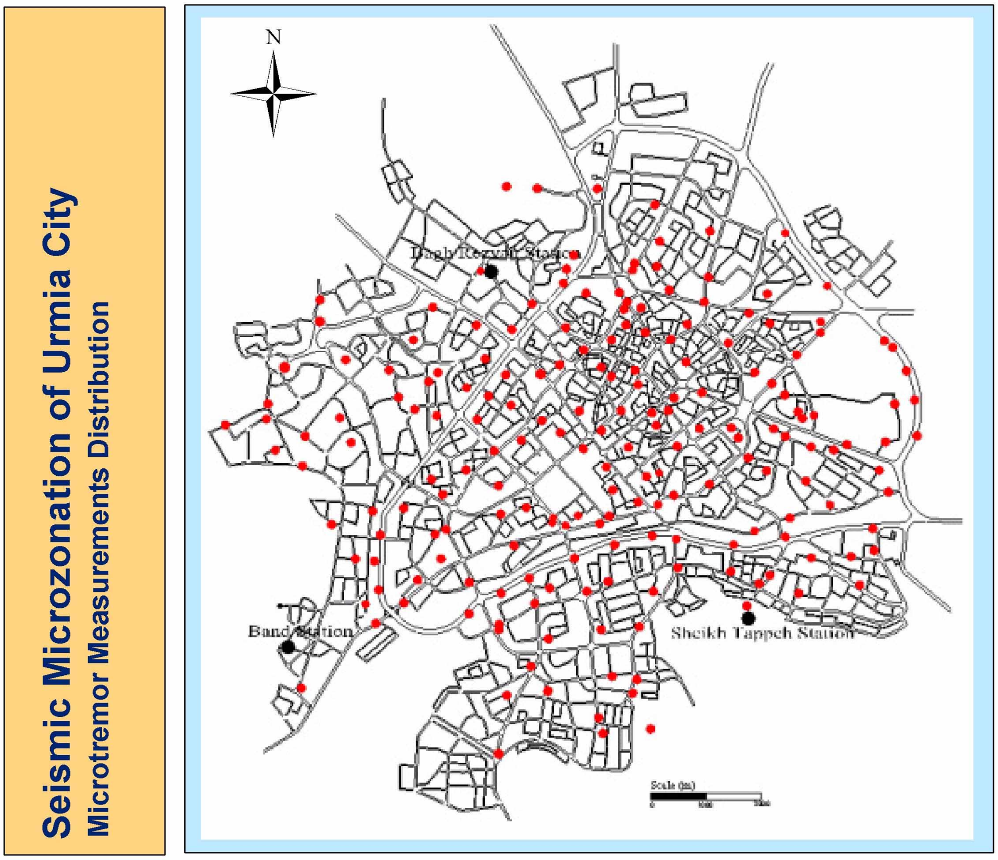


FIGURE 1: LOCATION OF 200 MICROTREMOR MEASUREMENT SITES IN URMIA CITY

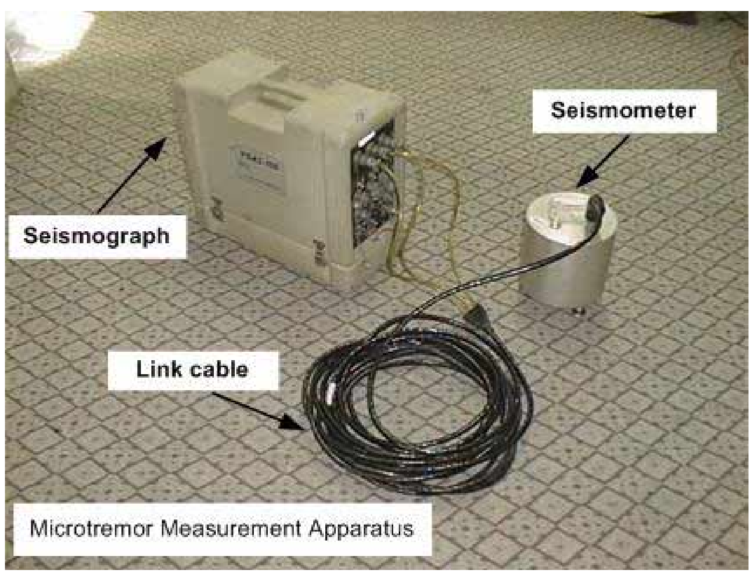


FIGURE 2: MICROTREMOR MEASUREMENT APPARATUS

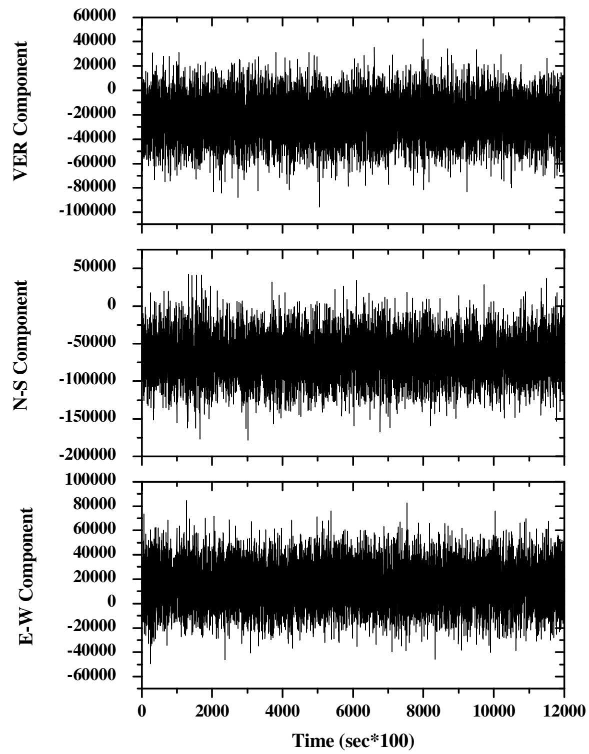


FIGURE 3:TYPICAL RECORD AT SITE MT103

COMPARISON OF H/V AND HS/HR TECHNIQUES

In this section, two methods that are used for analyzing the data provided by microtremors are evaluated including Hs/Hr and H/V techniques. Among the measured sites, 37 sites were selected from different geological conditions around the city. Sites were categorized into two groups. The distance of near sites to their reference site is less than 2500 meters, while far sites on sediment are located in a distance larger than 2500 meters from reference site. All the recorded data were used and presented curves are based on mean values.

Regarding the authors previous studies [16], a time window length of 20 seconds, with an overlapping value of 10% and a Hamming window type were considered to process microtremors.

Sites near the reference site

In this section, sites located in a distance less than 2500 meters from their reference site, are investigated. Both H/V and Hs/Hr techniques were applied to analyze the data of 21 sites, which are located in this category. Spectral ratio curves, which are supposed to be the transfer function of soil layer, are calculated. Some of the results of spectral ratio are shown in the Figure 4. In addition, parameters including FF (Fundamental Frequency), AF (Amplification Factor) and SD (Standard Deviation) values at resonance peak are studied separately. In Figure 5, these values calculated using two mentioned techniques, are shown. Subsequently, the following results are concluded on the near sites:

1- in all cases, the spectral ratio curves calculated using H/V method is sharper and FF and AF values can be estimated easily and accurately. In some cases like MT60 and MT66, without H/V curves, dynamic soil parameters could not be estimated accurately.

2- regarding Figure 5, it's evident that FF values calculated using both methods are similar.

3- amplification factors calculated using both methods are almost close. Generally speaking AF results are similar. Nevertheless, there are some exceptions.

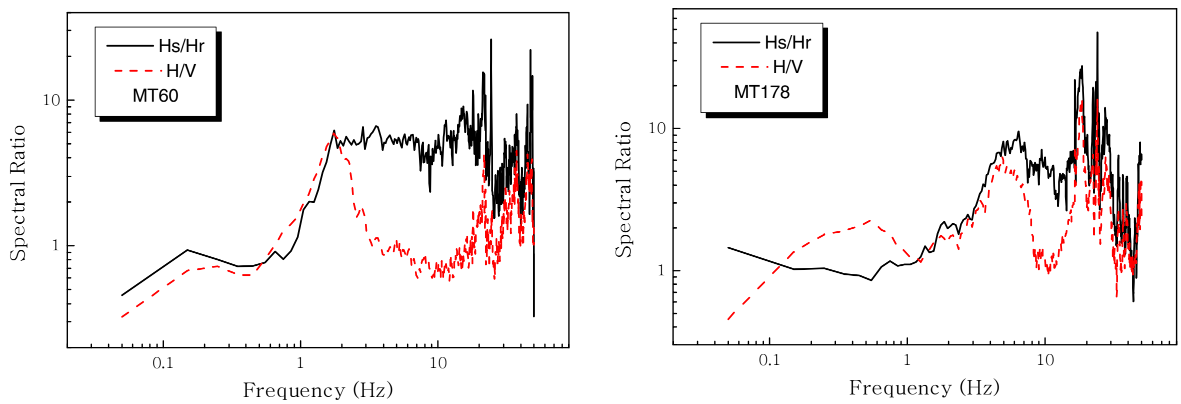


FIGURE 4. SPECTRAL RATIO CURVES CALCULATED USING H/V AND HS/HR TECHNIQUES IN NEAR SITES

4- SD values using H/V method are definitely smaller than the results of Hs/Hr. It's clear that in all cases, H/V method results are more accurate with less dispersion in soil dynamic parameters.

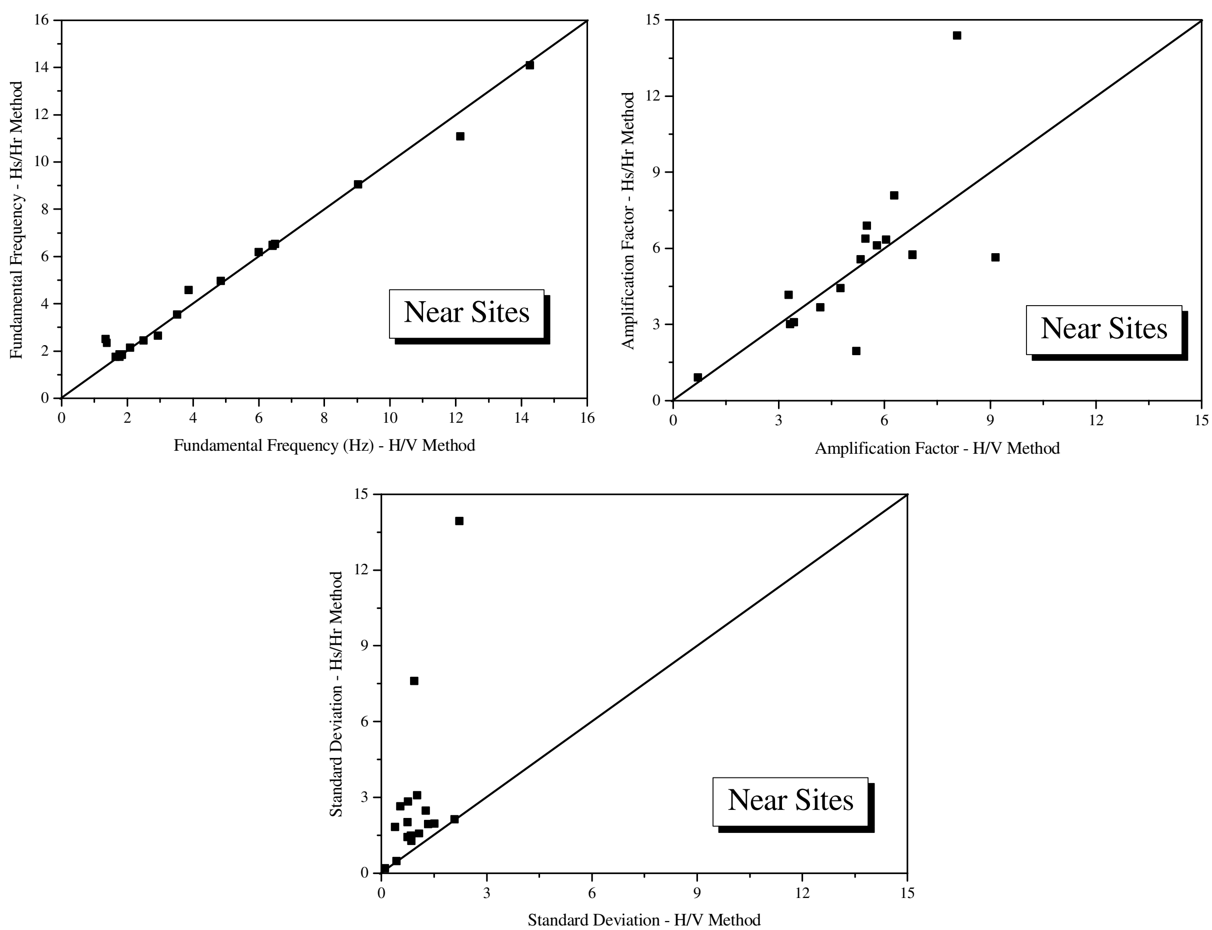


FIGURE 5. RESULTS CALCULATED BY H/V AND HS/HR TECHNIQUES IN NEAR SITES

Sites far from the reference site

Sites situated in a distance more than 2500 meters to their reference will be discussed in this section. Two common spectral techniques are applied to the 16 sites. In Figure 6, two of the calculated spectral ratio curves are shown. A special emphasis is given to FF, AF, and SD values at resonance peak. Therefore, they are shown graphically in Figure 7. Finally, the following results are obtained from analyzed sites:

1- the spectral ratio curves calculated using Hs/Hr method could not demonstrate the resonance peak obviously. Dynamic soil parameters shown in Figure 7, are mostly determined by H/V curves. If there is no H/V curve, conclusion might be a difficult task. H/V curves are able to demonstrate sediments dynamic characteristics effectively.

2- considering Figure 7, it can be concluded that resulting FF values using Hs/Hr method are almost larger than H/V method results. Although their estimation are performed based on H/V curves. Differences in FF values increase while the distance to the reference site increases. In some cases no resonance peak detected by Hs/Hr approach.

3- amplification factors determined by Hs/Hr method have almost high values. It seems that applying Hs/Hr technique increases the uncertainty behind the data provided by microtremors for estimating sediments amplification factor.

4- standard deviation values calculated using Hs/Hr method definitely represent high values except MT34. It means that in H/V method parameters can be estimated more accurately.

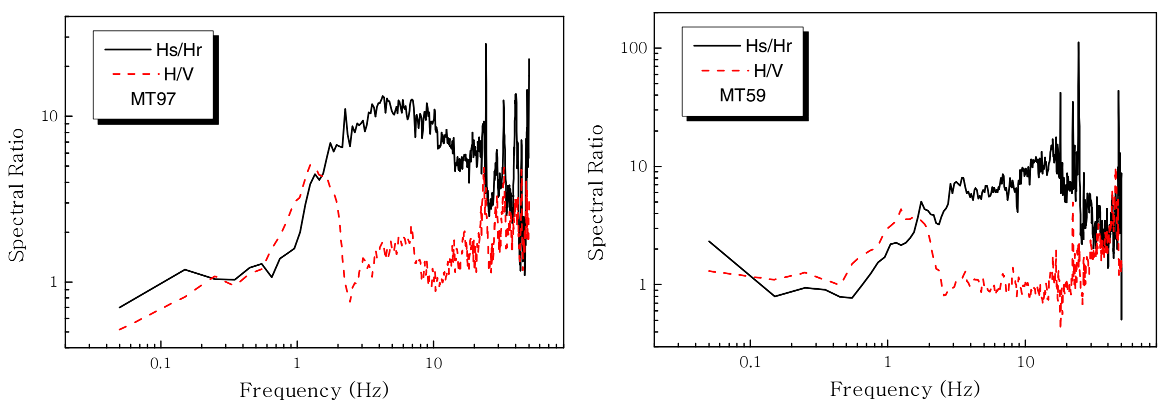
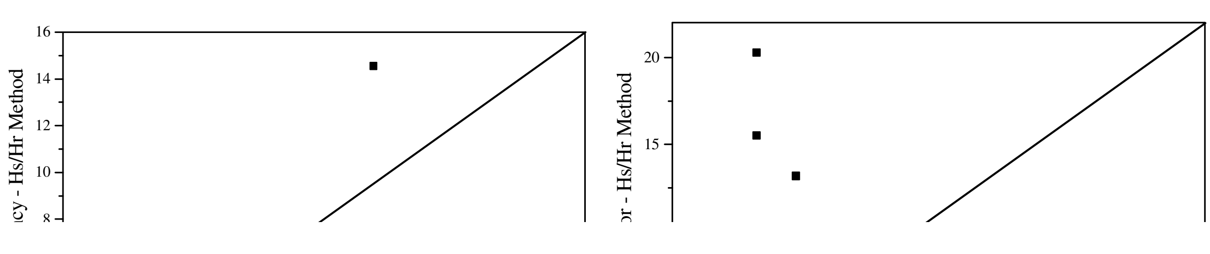


FIGURE 6. SPECTRAL RATIO CURVES CALCULATED USING H/V AND HS/HR TECHNIQUES IN FAR SITES

Comparison between Hs/Hr and H/V methods shows that nevertheless, in near cases, reference sites are close but H/V technique gives reasonable results in all sites. In far cases, again the H/V method's results are more stable. By increasing distance to the reference site, Hs/Hr technique cannot be applied effectively. The distance of 2500 meters is introduced as an allowable upper limit of Hs/Hr approach.



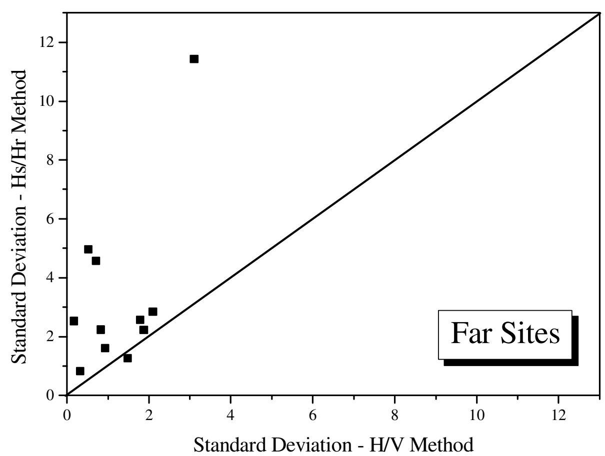


FIGURE 7. RESULTS CALCULATED BY H/V AND HS/HR TECHNIQUES IN FAR SITES

MICROTREMORS SPECTRAL ANALYSES

In order to evaluate different spectral methods, 10 measured sites were selected in the Urmia city and the following methods were applied: 1- Fourier spectrum (FS), 2- power spectrum (PS), 3- cross spectrum (CS), 4- segmental cross spectrum (SCS).

Four methods mentioned above were used to analyze data. For instance in Figure 8, H/V spectral ratio mean curve for a site are shown. Calculations show that in a frequency range between 0.1 to 10 Hz, the results of H/V spectral ratio using FS method represents higher amplitude values. It increases the uncertainty of the amplification factor resulting from microtremors. Investigated sites with the number of used data are shown in Table 1. Note that curves shown in the following figures have mean values.

TABLE 1. INFORMATION OF STUDIED SITES

Site	Number of 120 seconds data used
MT105	5
MT103	5
MT18	7
MT28	3
MT1	7
MT55	5
MT47	6
MT7	6
MT63	6
MT13	10

However, three other methods give close values. It's important to note that differences decrease when frequency increases. On the other hand, higher the fundamental frequency of the site, less the differences between different methods.

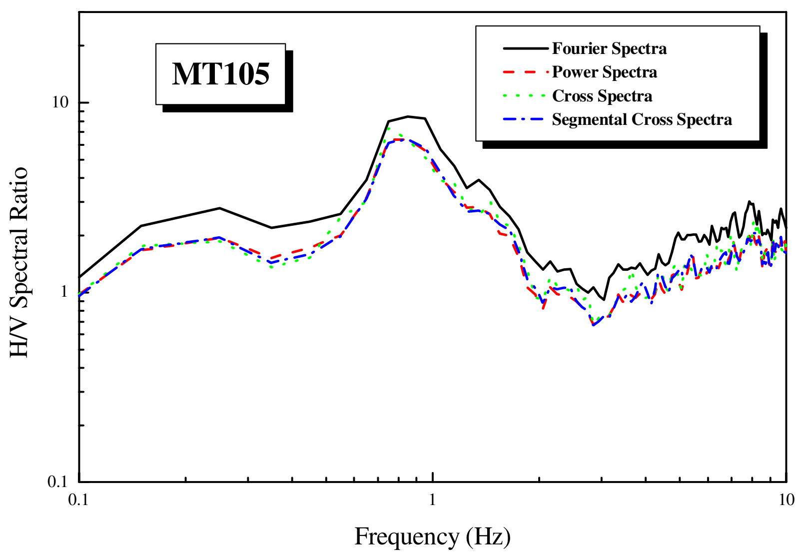


FIGURE 8. H/V RATIO CURVE USING DIFFERENT SPECTRAL TECHNIQUES

Since fundamental frequency and amplification factor are two important factors that are concluded using H/V spectral ratio curves, special emphasis is given to these two parameters. Therefore, FF and AF values are reviewed and discussed more due to their important role.
In Figure 9, FF values are shown which were calculated in different sites using several spectral techniques. It's apparent that different methods give very close values.

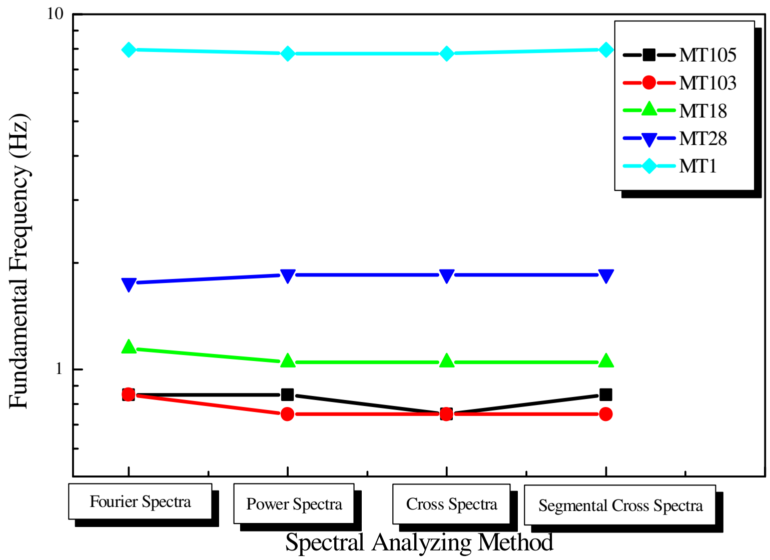


FIGURE 9. FF VALUES USING DIFFERENT SPECTRAL APPROACHES

Amplitude values of H/V spectral ratio that are supposed to be the sediments amplification factors are shown in Figure 10. It's clear that amplification factors resulted from FS method are higher and the ones calculated using SCS technique are less. Considering the uncertainty behind the microtremors, it can be stated that the amplification factor obtained from the SCS technique is more reliable.

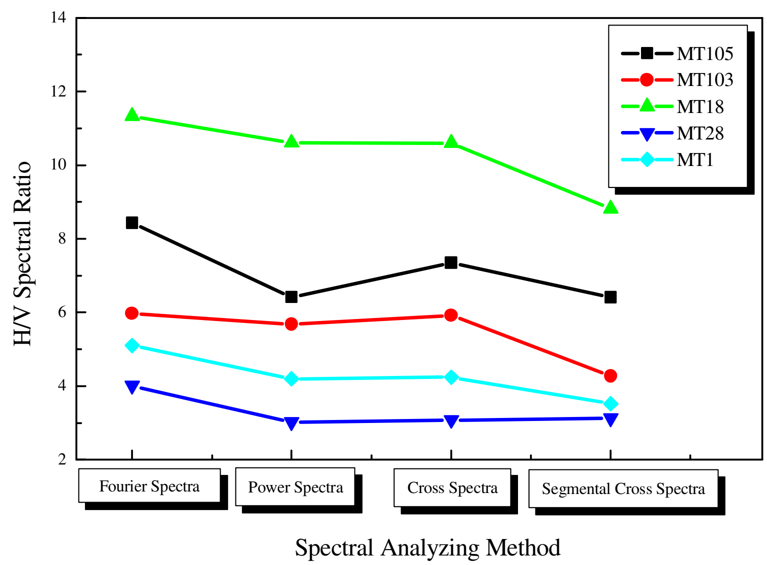


FIGURE 10. AF VALUES USING DIFFERENT SPECTRAL APPROACHES

Standard deviation values at the resonance peak are compared in the Figure 11. It's evident that, SCS results have the minimum dispersion among different methods and the resulted data are more stable.

Regarding mentioned results, it's apparent that SCS approach is the most reliable and efficient method in spectral calculation of microtremor data and obtained parameters are more reliable due to their minimum error.

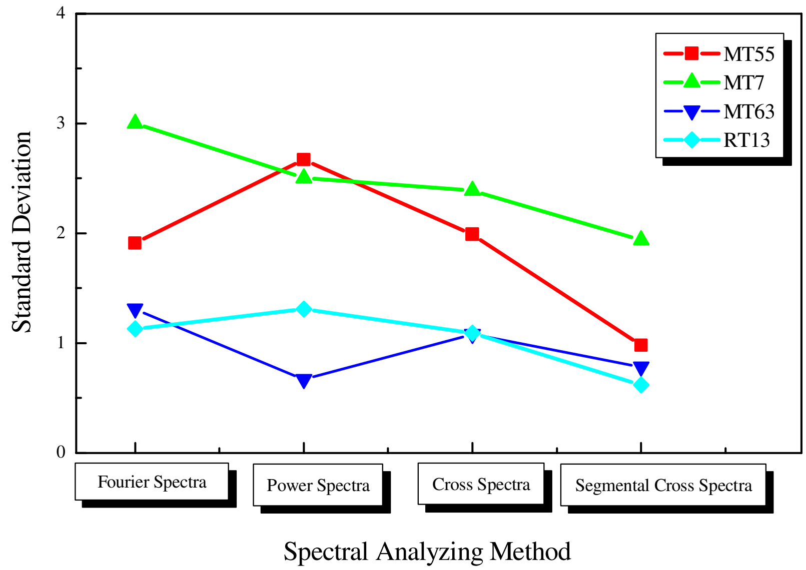


FIGURE 11. SD VALUES USING DIFFERENT SPECTRAL APPROACHES

EVALUATION OF MICROTREMORS WITH GEOTECHNICAL DATA

In order to verify obtained results from microtremors, a limited geotechnical investigation was conducted. In five different sites, 200 meters of geotechnical logging was performed. By performing SPT logs and some complementary laboratory tests, the geodynamical and geotechnical profiles were defined for each borehole. SHAKE type analysis was performed to achieve the fundamental dynamic characteristics of these sites. EERA computer program [17] was used to analysis the borehole data. Adjacent every borehole, some microtremor measurements were conducted. Microtremors were analyzed by the results obtained in previous sections. In Table 2, depth of boreholes and their location are shown. Wash boring was used as the boring method and was continued to reach the bedrock or stiff soil.
10 intact samples by shelbi and 113 SPT tests were done in different depths and boreholes. Regarding SPT values, soil type, mechanical and physical characteristics determined by laboratory tests, dynamic properties of soil layers in each borehole were extracted. Shear modulus and damping ratio values were selected according to the available curves in literature [18] for different soil types.

TABLE 2. INFORMATION OF GEOTECHNICAL BOREHOLES

Borehole No.	Location	Depth (m)
1	Bonyad Maskan	50
2	Varzesh St.	40
3	Markaz Modiriat Dolaty	40
4	Khane Javan	40
5	Bakery St.	33

Maximum shear modulus was determined using the relationship between shear wave velocity and SPT values. Baziar's relation [19] that is based on Iranian data was used to calculate shear wave velocity.

Site response analysis

Site response analysis was done to obtain the fundamental dynamic characteristics of the mentioned sites. For this purpose, equivalent linear method was applied using the EERA computer program [17]. Transfer function at borehole 3 is shown in Figure 12. Results of microtremors and site response analysis of boreholes are shown in Table 3. As it is shown, microtremors were measured at least at two sites near every borehole.

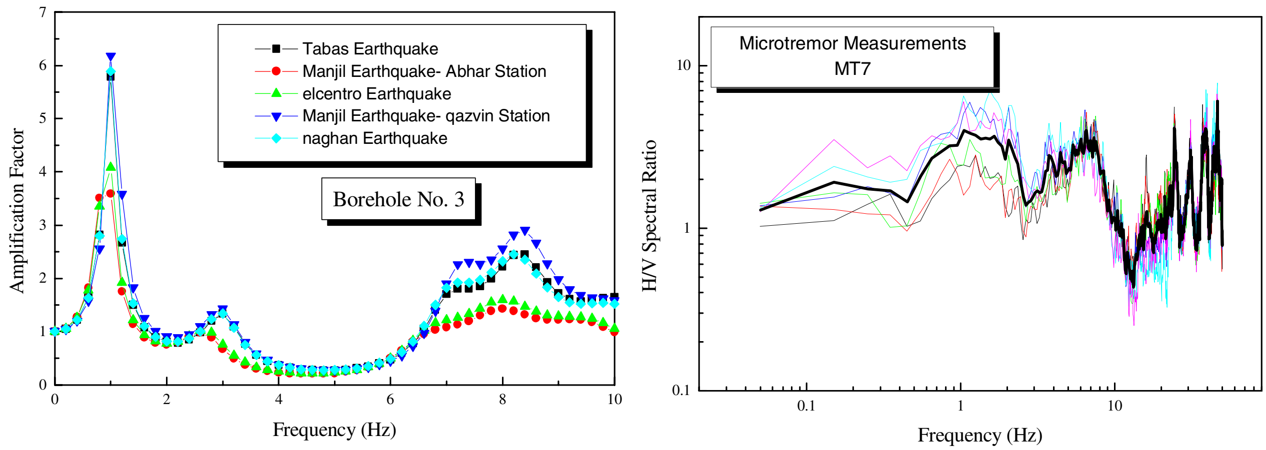


FIGURE 12. TRANSFER FUNCTION OF BOREHOLE NO. 3 AND H/V SPECTRAL RATIO IN MT7

It's clear that microtremors can estimate the fundamental frequency of the soil sediment effectively. Nevertheless, for the amplification, the results are somehow complicated. In some cases, microtremors give higher amplification values and in others represents smaller values. H/V spectral ratio of MT7 site, which was near borehole 3, is shown in Figures 12.

TABLE 3. COMPARING THE RESULTS OF GEOTECHNICAL BOREHOLES AND MICROTREMORS

Borehole No.	Microtremor Site	Microtremor		EERA Analysis	
		FF (Hz)	AF	FF (Hz)	AF
1	MT62	1.74	4.76	1.8	3.23
	MT66	1.85	5.53		
	MT74	1.65	2.88		
2	MT39	1.04	3.84	0.95	3.99
	MT40	0.5	6.96		
3	MT7	1.05	3.99	1.0	5.78
	MT94	1.10	7.01		
	MT95	0.95	3.63		
4	MT15	1.15	9.05	1.2	4.84
	MT51	1.65	2.45		
	MT52	1.55	2.78		
5	MT85	1.65	13.09	1.7	7.39
	MT86	1.74	2.82		
	MT89	1.70	3.63		
	MT90	1.65	3.52		

SEISMIC MICROZONATION MAPS OF URMIA CITY

Finally based on the results obtained in previous sections, two microzonation maps of Urmia city are presented. Iso period and iso amplification maps of city are presented in Figures 13 and 14 respectively. At 200 sites in the city, resonance period and amplification factor of sediment were calculated using H/V technique. In addition, segmental cross spectrum was applied to the data for spectrum calculations.

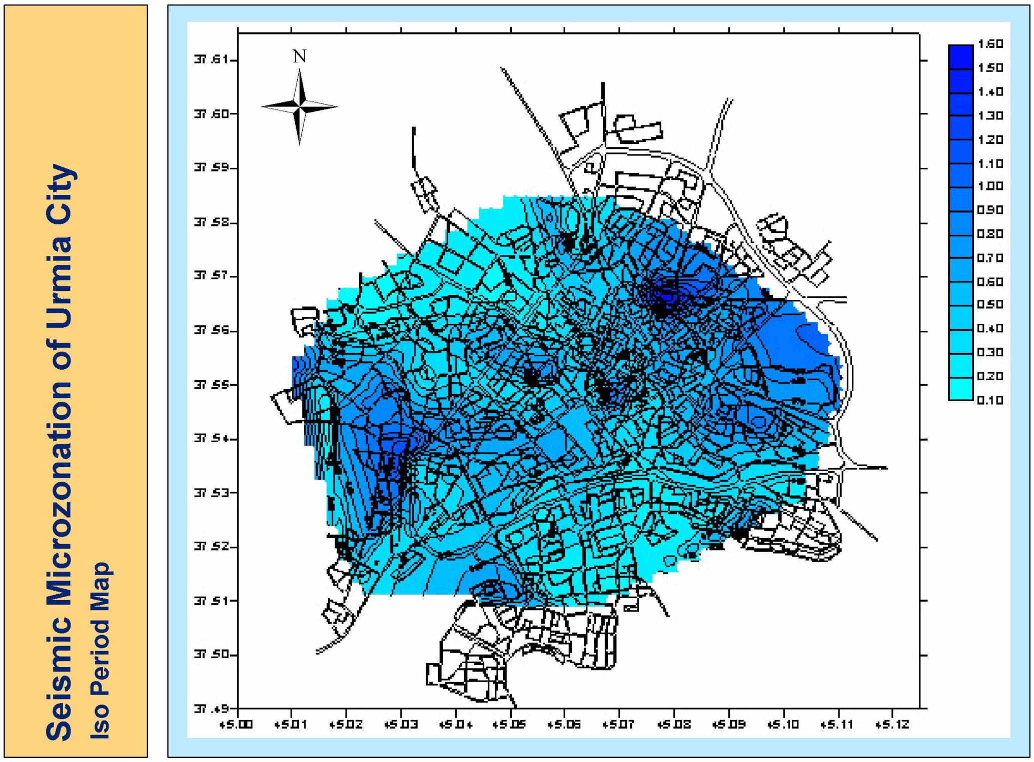


FIGURE 13. ISO PERIOD MAP OF URMIA CITY

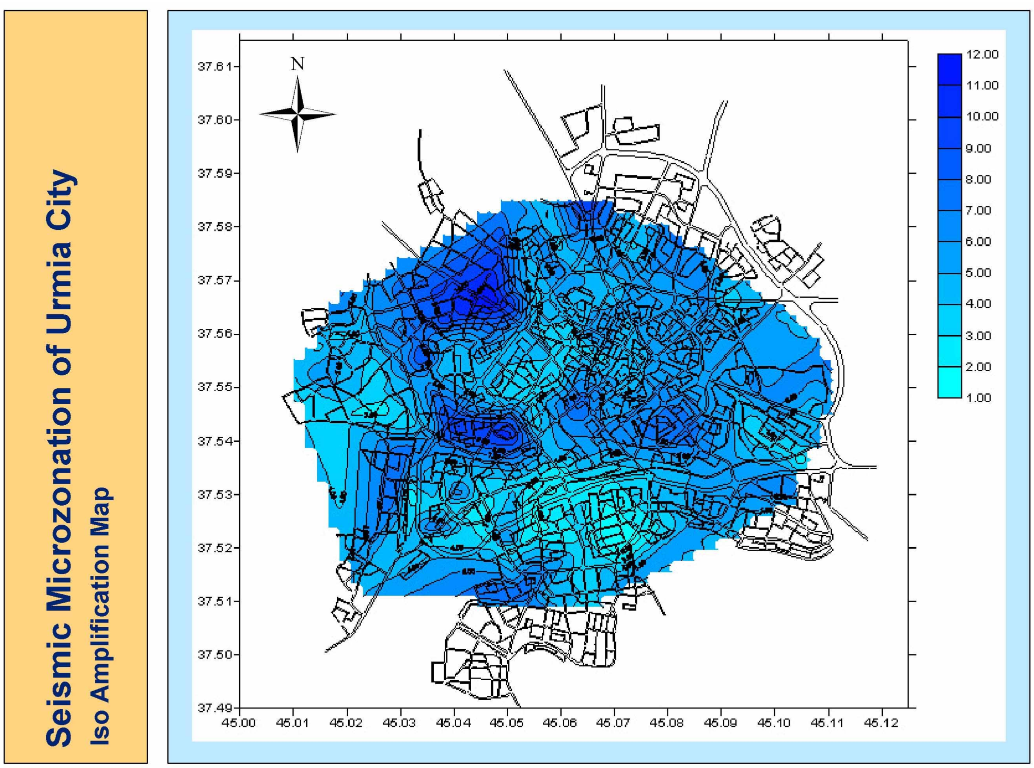


FIGURE 14. ISO AMPLIFICATION MAP OF URMIA CITY

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