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The Effect of Soil Type and Different In-situ Test Results on Soil Amplification Analysis

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ABSTRACT

The effect of local soil conditions is taken into consideration in the evaluation of ground motion properties in seismic design of structures. One of the most important effects on the ground surface due to strong ground motion is soil amplification resulted in the structural damage. Soil amplification can be determined both by dynamic analyses performed according to analytical methods based on local site conditions and obtained with investigations based on the results of in-situ testing methods. Therefore, the effects of local site conditions are considered to evaluate the properties of ground motion for seismic design of structure. In this study, soil properties of İnönü district are evaluated based on Standard Penetration Test (SPT) and Multi-Channel Analysis of Surface Wave (MASW) method which is one of the geophysical methods. İnönü is located at the west of Eskişehir surrounded with numerous active fault systems and subjected to very intensive tectonic activities in geological history. The studies related to seismic activity have been made on the basis of probabilistic seismic hazard analyses. Soil amplification analyses are performed with Shake2000 software comparatively by taking into considerations data from in-situ testing methods.

Introduction

The aim of planning the settlements is to increase the quality of life and welfare of the society [1]. To this end, planning requires an interdisciplinary approach to meeting different human needs [2]. However, geological and geotechnical studies constitute an important stage in the protection and control of possible natural disasters [3]. As a result, earthquake, which is one of the most important natural disasters, creates a dynamic movement effect on buildings by creating a displacement movement depending on time.

Therefore, in predicting the behavior of the structures to be constructed and constructed under earthquake loads, it is necessary to know how the foundation system and the foundation soil will act under earthquake loads in the regions where earthquake is likely to occur. The major damages in the 1964 Nigata and Great Alaska earthquakes have demonstrated the importance of soil behavior during the earthquake. In the earthquake of Adapazarı on August 17, 1999; it is stated that the main cause of damages in Adapazarı, Gölcük and Yalova is due to soil problems [4, 5, and 6].

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Damages caused by past earthquakes indicate that local soil conditions in a region have a major impact on the earthquake impact [7, 8, and 9]. Therefore, the effect of local soil conditions is taken into consideration in the evaluation of ground motion properties in seismic design of important structures.

The estimation of the ground motion created by the energy arising in the crust region of the earth can be made by interpreting the information that is developed in different disciplines such as geotechnical and structural engineering, seismology, geophysics and geology. Although the relevant information has a very rapid upward trend, there are still some uncertainties.

There is a significant effect of the soil response to repeated loads on the distribution and character of damages caused by earthquakes. In other words, only low level unit deformations occur on the ground in many cases and especially in cases where wave propagation effects are dominant and large unit deformations occur when the stabilization of the soil mass is evaluated. In this sense, different methods have been developed to measure and evaluate the soil behavior under low and high unit deformation under repeated loads [10].

Various laboratory and field methods are used to measure dynamic soil properties. Standard Penetration Test (SPT) method is widely preferred in field applications but geophysical methods are used in very special projects due to application costs and difficulties. On the other hand, multi-channel analysis of surface waves (MASW), which is cheaper and more functional compared to other geophysical methods, has been increasingly used in geotechnical engineering applications [11, 12].

It has long been known that earthquake damage is generally greater on soft sediments than on bedrock. Many settlements including Eskişehir-İnönü district were formed along river beds on such newly deposited soft and young surface deposits. Therefore, in the seismic design of buildings or other structures, the effect of local soil properties is taken into consideration in the evaluation of ground motion properties.

In this study, it is aimed to determine the dynamic soil properties of the region, which also includes the settlement area of İnönü district, located in the west of Eskişehir, under the influence of nearby sources, and to investigate its behavior under earthquake conditions. Within the scope of the study, the geological structure of the region has been evaluated by examining the lithological and stratigraphic characteristics of the region, and experiments have been conducted on the basis of SPT and MASW method which is one of the geophysical methods. Experimental studies were carried out to determine the physical and engineering properties of the samples in the laboratory. The studies related to seismic activity have been made on the basis of probabilistic seismic hazard analyzes considering the source zones affecting the region and the maximum ground acceleration values have been reached for different earthquake conditions. Afterwards, dynamic analyses were carried out using two different in-situ test results (SPT and MASW) using SHAKE2000 [13] package program.

Materials and Methods

Soil Profiles

In this context, geological structure of the study area was evaluated first. State Hydraulic Works (DSI) [14], by the purpose of revealing the hydrogeological characteristics of the region (Eskişehir-İnönü) made electrical resistivity measurement. The cross-sectional line taken near the study area is given in Figure 1. Resistivity data indicate the presence of faults that limit the study area from north and south, as well as buried faults. There are valleys hanging along the southern edge of the İnönü-Dodurga segment. Existing earthquake records, geophysical data and the presence of hanging valleys on the Eskişehir fault zone indicate that the İnönü-Dodurga segment is active and plays an important role in the development of current morphology [15].

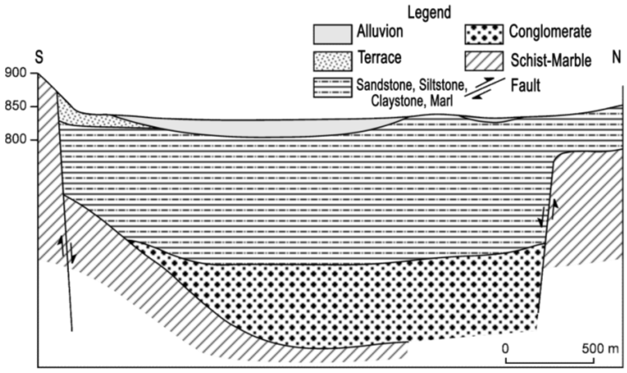

Figure 1. Electrical resistivity measurement from the study area [14]

Paleozoic schists and marbles, Neogene limestone and Quaternary alluvium are observed in the study area (Figure 1). Alluvium is observed in the east-west direction along the İnönü plain. This unit, which has a thickness of 20-30 m, consists of clay and silt at the upper levels and consists of sand and gravel at deeper levels. Field studies carried out within the scope of this study were conducted in two stages. The first stage field study was carried out on the basis of Standard Penetration Test (SPT), which is also considered as high deformation test. SPT was performed every 1.5 m to a depth of 30.5 m and undisturbed (UD) soil samples were provided at depths suitable for sampling. In the second stage of the study, geophysical field test (MASW), which are defined as low deformation tests, were carried out considering the relevant drilling locations. Intensive experimental studies were carried out in order to identify alluvial soil units in the study area.

MASW is a geophysical method, which generates a shear wave velocity, Vs, profile by analyzing Raleigh-type surface waves on a multichannel record. A MASW system consisting of a 24 channels Geotech model, Lakkolit 24M-3 seismograph with 24 geophones of 4.5 Hz frequency were used in this investigation. The recording sampling interval of 1.0 ms and the recording length of 2048 ms were applied. The recorded Rayleigh wave is analyzed using SurfSeis software. SurfSeis is designed to obtain Vs data using a three-step procedure. These steps are: i) preparation of a multichannel recording, ii) distribution curve analysis and iii) inversion. More detailed information on the MASW method and its applications is available in the literature [16, 17].

A large part of the study area is covered with fine grained material at the top and coarse grained material at the bottom as defined Alluvium. The soil profiles, SPT numbers and shear wave velocity (Vs) profiles of the two selected locations are presented in Figure 2.

Site Specific Seismic Hazard Analysis

Seismic-tectonic map proposed by Seyrek [18] was taken as a basis for the seismic hazard analyses to be performed for the study area and its surroundings. Seismic source zones within the boundary of 100 km radius of the study area, which is the center of İnönü district, were determined to be under the influence of 5 different seismic source zones (Figure 3). Within the scope of this study, the northern branch of the North Anatolian Fault Zone is shown as Zone 1 and the southern branch as Zone 2. The other source zone controlling the seismic hazard in the study area is defined as Zone 3. It is stated that this fault zone called İnönü-Eskişehir fault zone extends between İnegöl and Tuz Gölü and consists of successive segments [19, 20]. The Kutahya Fault Zone is situated in the Southwest of Inonu. Simav fault zone is evaluated as Zone 5.

In this study, the resource zones considered during the seismic hazard analysis and each segment were evaluated separately. In the determination of maximum earthquake magnitude, which is one of the most important stages of seismic hazard analysis, the relationship between surface fracture (L) and earthquake magnitude (Mw) proposed by Wells and Coppersmith [21] was used.

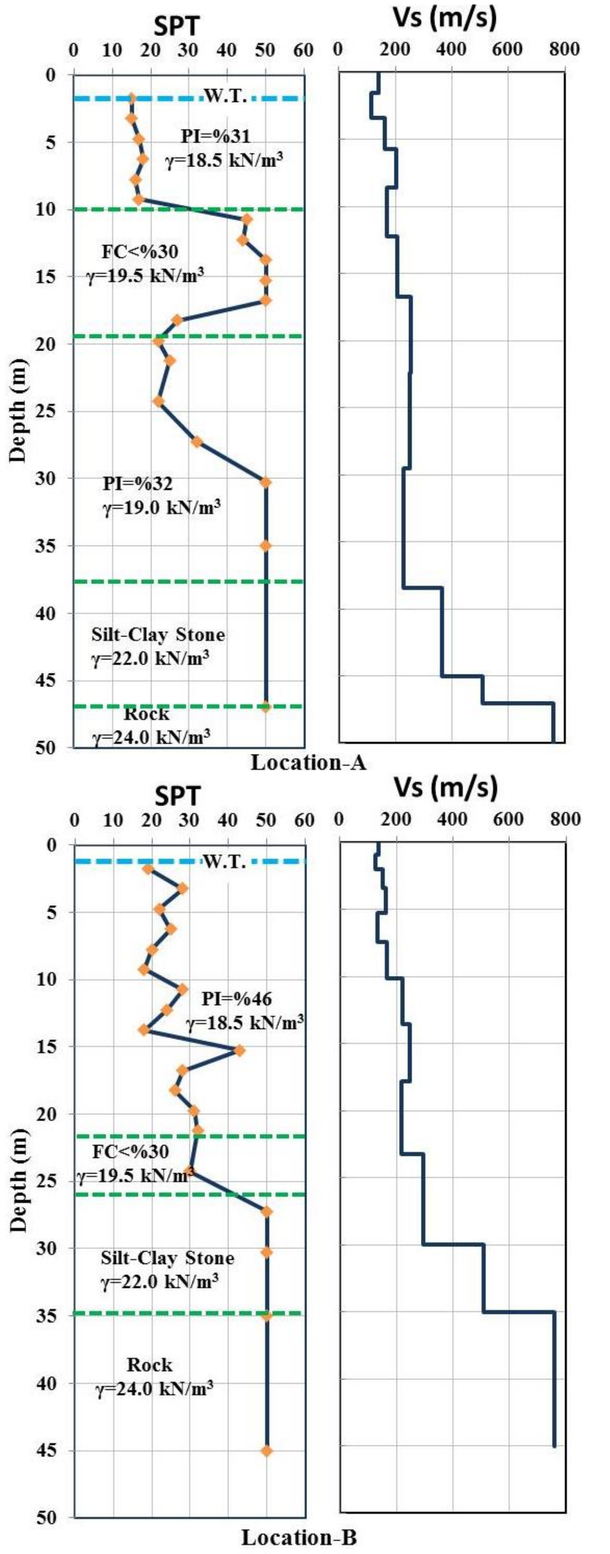

Figure 2. Representative soil profiles, SPT numbers and shear wave velocity (Vs) profiles for two selected locations.

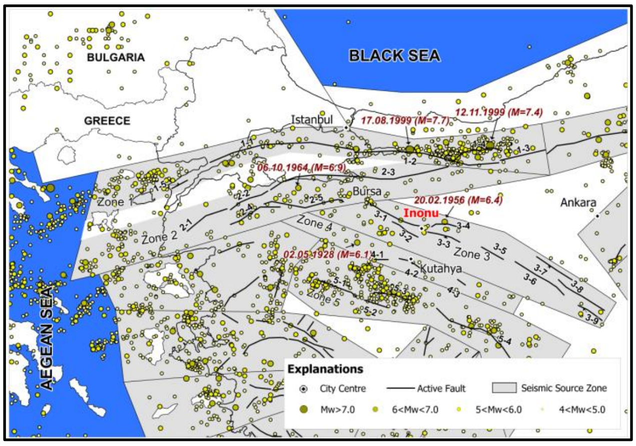

Figure 3. Distribution of source zones and earthquakes affecting the study site and its surroundings.

Table 1. Probabilistic seismic hazard analysis results for the study area.

Attenuation relationship	PGA (g)
Boore et al., [22]	0.26
Gulkan and Kalkan, [23]	0.35
Kalkan and Gulkan, [24]	0.34
Mean	0.32

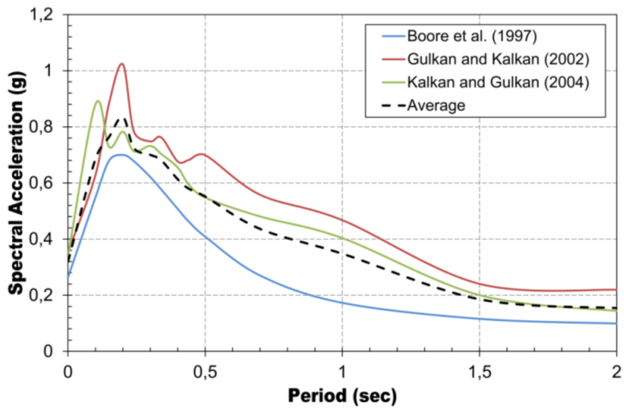

Figure 4. Average response spectrum in the rock for the study area ($V_{s,30}$= 760 m/s)

In the absence of strong ground motion recordings in and around the project site, multiple attenuation relationships are required to estimate the ground motion parameters to be created by the design earthquake. In this study, three different attenuation equations were used [22, 23, and 24].

Table 2. List of earthquake records used in this study

EARTHQUAKE		DATE	STATION	COMPONENT	MAGNITUDE	CLOSEST DISTANCE (km)	PGA (g)
ERZINCAN	**ERZ92**	92/03/13	Erzincan	E-W	M_L=6.1	16.8	0.480
DUZCE	**DUZ99**	99/11/12	Duzce	N-S	M_w=7.2	9.7	0.416
KOCAELI	**KOC99**	99/08/17	Duzce	E-W	M_w=7.4	46.1	0.321
LOMA PRIETA	**LOP89**	89/10/18	Gilroy Array #3	E-W	M_w=6.9	12.8	0.367

The most important criterion in the selection of the attenuation relationships is that they are compatible with the existing tectonic structure. Probabilistic seismic hazard analysis was performed for the study area using the software developed by Seyrek [18]. It should be noted that the hazard analyses are performed for rock environment ($V_{s,30}$ = 760 m/s). Table 1 presents the results of the ground motion level, expressed as the design earthquake, corresponding to the probability of exceeding 10% in 50 years. When Table 1 is examined, it is understood that the maximum ground acceleration (PGA) value for the rock environment in Inönü city center is 0.32 g. Figure 4 shows the average response spectrum on the rock level obtained using the estimation equations developed by Boore et al. [22], Gülkan and Kalkan [23] and Kalkan and Gülkan [24]. In engineering applications, the response spectrum is a parameter required for the design of structures that reflects the dynamic properties of the soil during an earthquake.

In seismic design specifications, since the seismic hazard in a field is defined by the design acceleration spectrum, it is necessary to use acceleration records compatible with the design acceleration spectrum in linear elastic or non-elastic earthquake calculations in the time domain of structures. Acceleration records can be obtained from synthetic (simulated), simulated or real earthquake recordings. Although it is preferred to use real ground motion records, there are difficulties in finding strong ground motion data banks that are compatible with seismic source and local ground conditions and source-field distance affecting the project site [25]. For this reason, both synthetic records can be produced and real earthquake records can be selected to meet the conditions specified in the regulations and scaled to match the design acceleration spectrum. Acceleration-time graph is used which is compatible with the hazard spectrum in soil amplification analysis.

For this purpose, four different real earthquake records are selected as seen in Table 2. The abbreviations given in Table 2 will be used in this way for soil amplification analyses. The selected earthquake records were scaled in the time domain to be consistent with the average acceleration spectrum given in Figure 4. For this purpose, SeismoMatch software was utilized using the wavelets algorithm proposed by Abrahamson [26] and Hancock et al. [27] .In addition, an artificial acceleration recording compatible with the response spectrum was created using SeismoArtif software. Figure 5 shows the scaled and non-scaled states of real and artificial acceleration recordings that are harmonized with the average response spectrum. As seen in Table 3, for the material parameters used in the analyses, Vucetic and Dobry [28], considering the plasticity index of clayey soils, and Seed et al. [29], for alluvial and the sanded soil, relations were used.

Results and Discussion

The most reliable way to obtain the soil amplification is the result of spectral analysis of the accelerations recorded during strong ground motions [30].

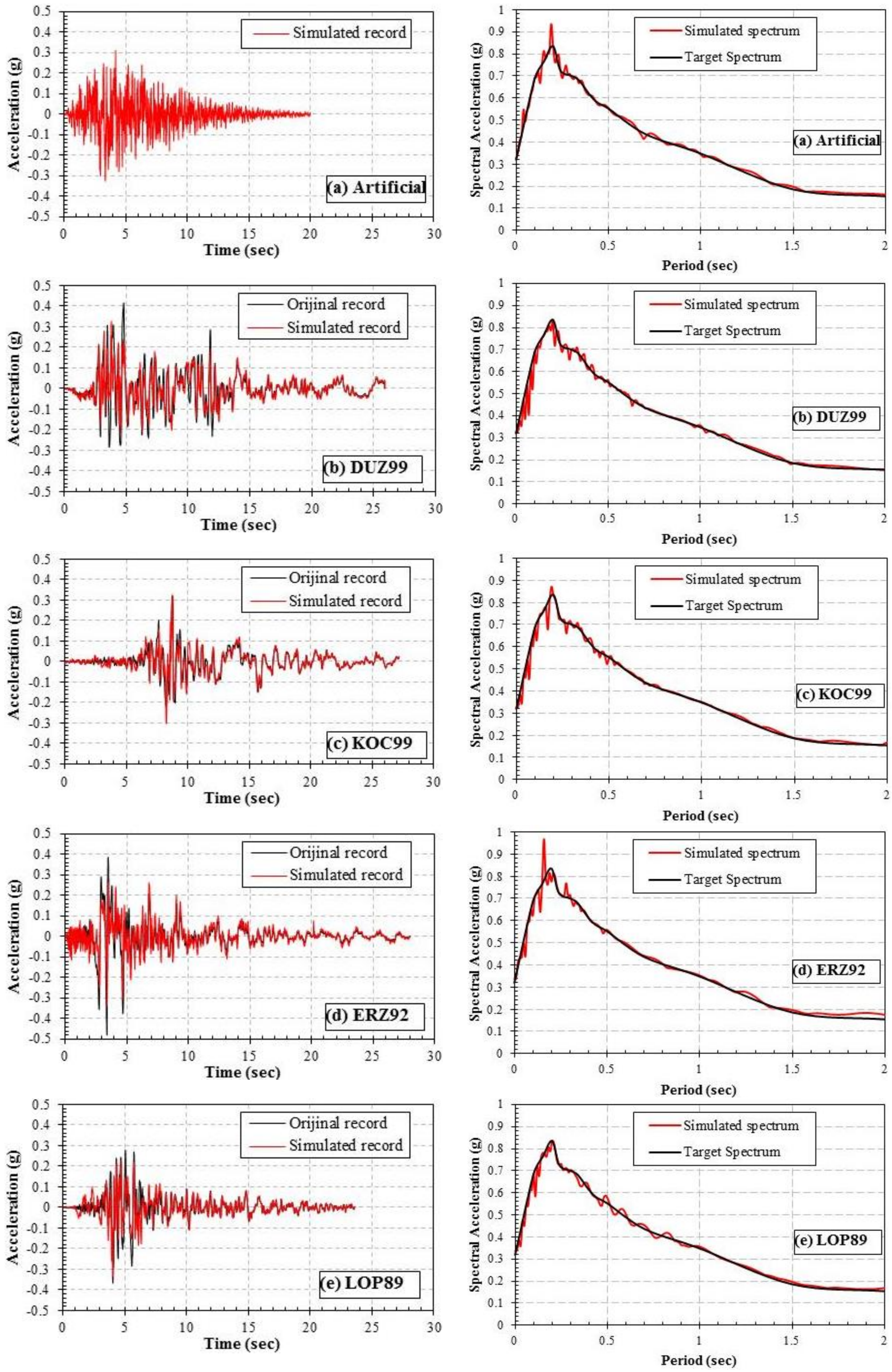

Figure 5. Scaled and non-scaled states of real and artificial acceleration recordings that are harmonized with the average response spectrum

Table 3. Material parameters used in analyses

Soil		Soil classification	Dynamic behavior model
Alluvial	High plasticity clay and silt	CH, MH	Based on Plasticity Index, Vucetic and Dobry [28]
	Low plasticity clay and silt	CL, ML	Based on Plasticity Index, Vucetic and Dobry [28]
	Clay silty sand (gravel)	SM, SC, GC, GM	Fine content <30%, Seed et al. [29] Fine content >30%, depending on PI, Vucetic and Dobry [28]
Neogene	Sandstone	-	EPRI Rock 2 [13]
	Silt-Clay stone	-	EPRI Rock 2 [13]

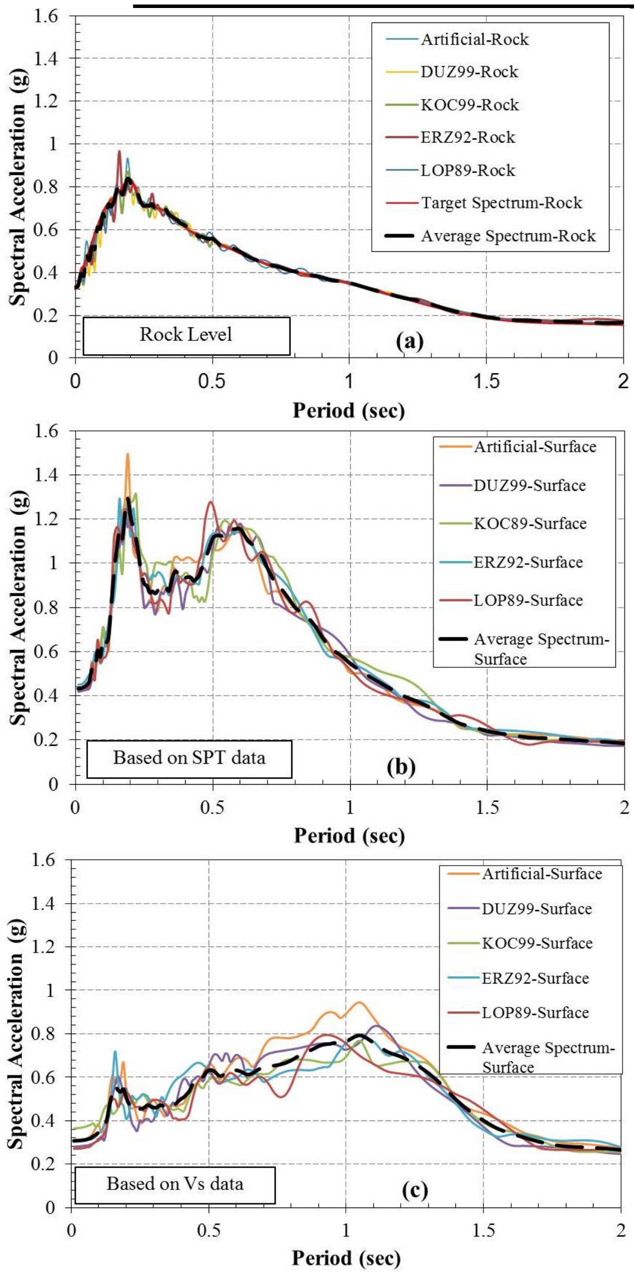

Figure 6. Variation of the spectral values of the acceleration-time recordings obtained on the soil surface using SPT and Vs data at location-A (5% damping)

The spectral values of the acceleration-time recordings obtained on both the rock and the soil surface for the relevant locations selected within the scope of the study were obtained using SPT and MASW test results under different earthquake conditions.

The variation of spectral accelerations obtained for the location-A is presented in Figure 6 as a result of analyses on rock level and soil surface. As can be seen from Figure 2, there is a 10m thick sand layer between the two clay layers under groundwater in the location-A profile. Comparing Figures 6b and 6c, the spectral acceleration values obtained using SPT data yielded greater acceleration values at a lower period than those obtained using Vs. When the spectral acceleration obtained as a result of the analysis using Vs data in Figure 6c is observed, it is seen that there is no change in acceleration magnitude compared to the rock level but the greater period value is effective. In addition, in this study in which earthquake recordings with different frequency contents are used as input, the scattering of spectral accelerations on the soil surface in SPT basis is in a narrower range than the spectral accelerations on ground surface in Vs basis. In other words, the scattering of spectral accelerations on the ground surface was found in a wider range as a result of the analyses using Vs data.

Figure 7 shows the variation of the spectral acceleration obtained as a result of the analyses for location-B. In the representative soil profile of the location-B, a sand layer of approximately 4 m thickness was observed under the 22 m thick clay layer (Figure 2).

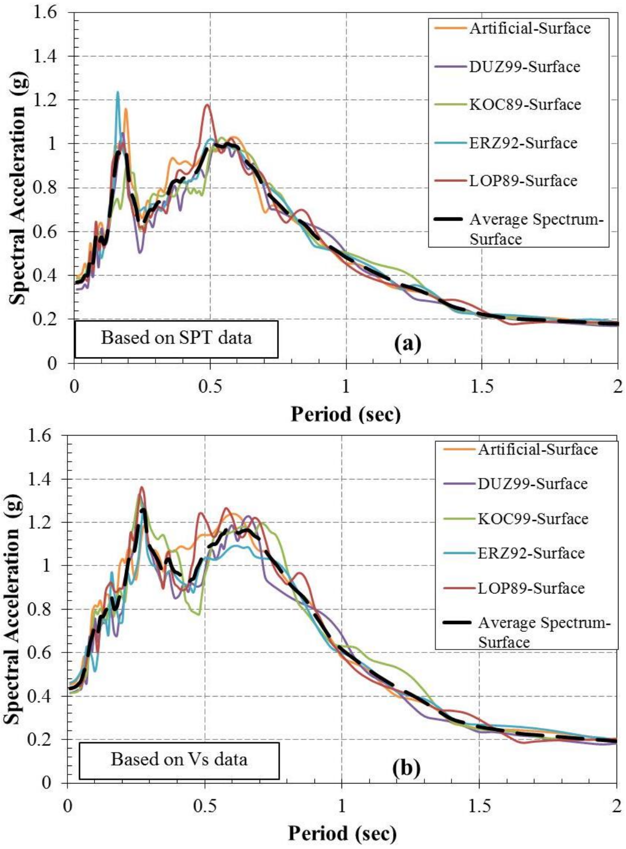

Figure 7. Variation of the spectral values of the acceleration-time recordings obtained on the soil surface using SPT and Vs data at location-B (5% damping)

The thickness of the sand layer observed in the representative soil profile of the location-B is less than the location-A. Due to the decrease in the thickness of the sand layer in the soil profile defined in Location-B, the spectral accelerations on soil surface found as a result of the analysis based on Vs data were greater than those found using SPT data. In other words, higher spectral acceleration values were obtained as a result of the analysis using Vs data in this profile (Location-B) dominated by clay soil layer. Spectral values between 0.2 sec and 1 sec (short period and long period, respectively) are very important in determining the design spectrum which plays an important role in the earthquake behavior of the structures.

For this reason, spectral acceleration values corresponding to these periods are mapped in the seismic hazard maps produced for different regions and presented to the use of relevant experts.

The evaluation of the analysis results as a whole is presented in Table 4. The average of the spectral accelerations values on soil surface presented in Figure 6 and 7 was reached by taking the average of the values between 0.2 sec and 1 sec period.

Table 4. Comparison of soil amplification analysis results

Location	Earthquake	Spectral Acceleration on Soil Surface (g)			
		Based on SPT Data		Based on Vs Data	
		Mean	Max.	Mean	Max.
A	Artificial	0.930	1.495	0.615	0.900
	DUZ99	0.917	1.247	0.596	0.757
	KOC99	0.960	1.312	0.563	0.694
	ERZ92	0.942	1.293	0.586	0.757
	LOP89	0.943	1.278	0.560	0.794
B	Artificial	0.809	1.160	1.038	1.234
	DUZ99	0.761	1.047	0.975	1.326
	KOC99	0.783	1.028	1.016	1.322
	ERZ92	0.786	1.235	0.956	1.284
	LOP89	0.799	1.178	1.039	1.363

When the effects of soil conditions on the results are examined, the acceleration values obtained at the location-A where the sand layer thickness is higher are higher than the results at the location-B where the sand layer thickness is less. When the different earthquake records are examined separately, similar results are obtained and the dominant effect of the earthquake records on the results can be seen in Table 4.

Conclusions

When the average spectral acceleration values obtained on the surface of the soil were compared, in the analyses made on the basis of Vs data obtained from MASW method, large average spectral acceleration values were calculated on the soil profiles composed of clay and weathered rocks under the this clay layer. In the analyses made using SPT data, generally large average spectral acceleration values were calculated in profiles consisting of approximately 10 m thick clay on the surface, 10 m thick sand below and a clay layer below this layer. In other words, large average spectral acceleration values were calculated in the analyses using the SPT test results at the locations where the sand layers are dominant and using the MASW test results at the locations where the clay layers are dominant.

The fact that the groundwater level in the study area is quite high is thought to be effective on the results.

In addition, in this study in which earthquake recordings with different frequency contents are used as input, the scattering of spectral accelerations on the soil surface in SPT basis is in a narrower range than the spectral accelerations on ground surface in Vs basis. In other words, the scattering of spectral accelerations on the ground surface was found in a wider range as a result of the analyses using Vs data.

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