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Seismic microzonation of Bursa/Güzelyalı in Turkey: A study on the compatibility of 1D dynamic analysis and microtremor measurements

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ABSTRACT: Estimation of soil behavior under dynamic loading has great importance in reducing the damage that may occur in an earthquake. For this reason, microtremor measurements were performed in a specific site to define dynamic behavior in terms of shear strain. The study area was divided into square shaped cells with 200m'X'200m dimensions in order to implement the seismic microzonation criterion. Within the scope of microzonation studies, to 75 separate single station microtremor measurements, 7 microtremor array measurements were carried out and 75 boreholes data are collected. These field measurements were analyzed according to the Nakamura Method and estimated effective shear strain. One-dimensional (1D) equivalent linear seismic ground response analyses were performed for the sites where the microtremor array measurements were conducted. The results of microtremor analyses and 1D dynamics analysis were presented by Geographic Information System (GIS) and compared for research area.

1 INTRODUCTION

Ground motion induced shear strain in the near surface soil layers is one of the most critical factors affecting the structures. Ground motion attenuation, usually expressed in terms of peak ground acceleration (PGA), is a function of the source type and magnitude of the earthquake, site distance from the epicenter, and the soil properties through which seismic waves travel. Consequently, the reason of seismic damage on structures should be investigated by the feature of source components, local site conditions and superstructure characteristics. In combination with local site conditions, the intensity of the seismic bedrock motion plays a governing role in the variation of shear strain levels of the near surface soil layers and the local variation of structural damage distribution.

In order to estimate the shear strains that will occur in the soil layers near the surface during the strong ground motion, one, two and three dimensional seismic site response analyses were developed using by different material models and calculation methods. In one-dimensional analysis, it is sufficient to determine thickness, the dynamic properties of soil layers and depth of the seismic bedrock, while two and three dimensional analysis require two or three dimensional geometry and boundary conditions etc. On the other hand, microtremor measurements are also considered as an alternative estimation method for evaluation of shear strains in the soil layer near the surface. The use of microtremor measurements have been widely used for prediction of the effects of local soil conditions. The reasons why microtremor measurements are mostly preferred are: *i)* easy to apply at anytime and anywhere, *ii)* the instruments and analysis are simple, *iii)* it does not generate any environmental problem (Atakan et al., 2004). Moreover, the microtremors contain significant amount of surface waves. For his reason, the dynamic behavior of soil layer parameters can be estimated by microtremor analysis (Bard, 1999). Three component single station microtremor recordings which is performed on the ground surface were analyzed according to the horizontal to vertical spectral ratio technique (HVSR). The HVSR method depend on the ratio between the Fourier amplitude spectra of the horizontal to vertical components of ambient vibrations recorded at a single station. As a result of HVSR analyses predominant period and spectral amplification can be obtained for investigation site (Haghshenas et al., 2008). Using by predominant period and spectral amplification, the effective shear strain values (γ_e) within surface layers were calculated by combining the Seismic Vulnerability Index (K_g) values with peak rock outcrop acceleration values (Nakamura 2008). In the literature, there are many studies that are based on the analysis of microtremor measurements by HSRV method and by comparing the soil amplification values obtained from the microtremor recordings with the analysis of strong ground motion or by the one-dimensional dynamic analysis of the soil layers (Chavez and Tejeda, 2010). By considering the results of the microtremor analyses, predominant periods, site amplifications and vulnerability indices were determined throughout the region (Fäh et al., 2001; Bonnefoy-Claudet et al., 2006). In order to determine the shear wave velocity profile; array microtremor measurements consisting of passive surface wave data was analyzed by using the Spatial Autocorrelation Method (SPAC) with a hybrid genetic simulation algorithm (Yamanaka, 2007; Karagoz et al., 2015)

In this study, dynamic behavior of soil layer for a residential area in the Marmara Region has been investigated by both analysis of microtremor and one-dimensional (1D) equivalent linear dynamic analyses. Initially, local site amplifications and predominant periods were calculated by using the HVSR method. Afterwards for each single station microtremor measurement, the effective shear strain values within surface layers were calculated by combining the Seismic Vulnerability Index (K_g) values with peak rock outcrop acceleration values ranging from 0.10 g to 0.40 g by using the Nakamura Method. In order to obtain shear wave velocity profile within the study region, microtremor array measurements were performed at seven different sites. The 1D equivalent linear seismic ground response analyses were executed for the sites having predetermined shear wave velocity profile by using six different rock out-crop motion records with peak acceleration values varying between 0.1 g and 0.4 g. The shear strain values were calculated within the near surface soil layers. Finally, the shear strains were visualized by using Geographic Information System (GIS) according to two different methods and compared.

2 FIELD INVESTIGATIONS

The study region is located at the southeastern side of Marmara Sea in Bursa city in Turkey. It lays along the southwestern part of Gemlik Bay with an average width of 0.8 km and has an approximate area of 2 km^2. There was most of streambed in research area. Therefore, the soil type of the region is represented as alluvium. Moreover, plain areas that extend parallel to coastline have coastal sediments and covered with alluvium. There was conglomerate, sandstone, clay stone which are part of Paleogene aged Eocene series and show lateral and vertical transitions in northwest of investigation field. The sediments that located the eastern and western direction of the region and in the southern parts of the region includes conglomerate, sandstone, claystone, limestone and marl. The alluvium layer on the shore extends from east to west. This alluvium layer includes clay and is described as sandy clay, sandy gravel and silty (Akyürek, 1987).

Southern Marmara part of North Anatolian Fault Line that is the most active fault in Turkey, placed on the border of the working area and surroundings. When historical earthquakes are examined around Bursa, the most severe earthquakes occurred 28 February (Mercalli intensity:IX) and 11 April (Mercalli instensity:X) 1855. Ulubat and Bursa Faults that are parts of North Anatolian Fault Line are most active faults. İznik-Gemlik Fault that is placed

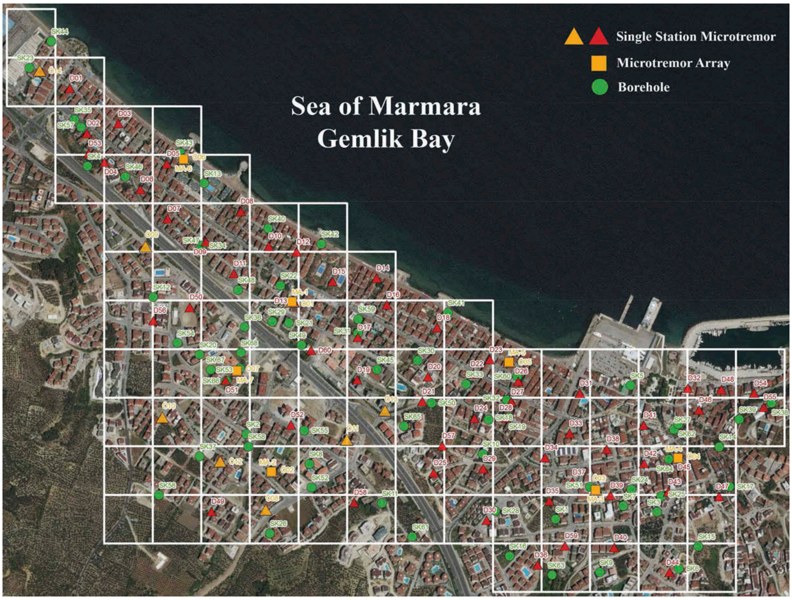

Figure 1. Location of the geotechnical and seismic in situ tests.

Located 3 to 7 m north of the coast and extending east-west and Gençali Fault that is passing through the lake of Iznik and Eskişehir Faults that came from Eskişehir and reached to Marmara Ereğli, are the most significant fault for working area (Kepçeoğlu, 2008). In our research, the expected maximum surface acceleration value is 0.4g according to Turkey Earthquake Regions Map (TBEC, 2019).

In this study, pre-conducted 75 boreholes and 60 single station microtremor records are compiled. In addition to pre-field studies, 21 single station and 7 microtremor array measurements are executed close to the geotechnical drillings that had already been carried out. In this Figure 1, red triangles points show pre-conducted single station microtremor and yellow triangles show single station microtremor measurements that are performed in the field, rectangular points describe microtremor array measurements and boreholes shown with green circular points.

2.1 *Boreholes and geotechnical tests*

In the study area, the depths of pre-conducted 75 boreholes vary between 15 m and 35 m. The alluvium is composed of alternating layers of clayey/silty sand and silty clay with thickness values changing from 5 m to 20 m. The SPT-N values in silty/clayey sand layers generally range from 10 to 20 until the depth of 15 m from the surface, then increase to 20 ~ 40. Groundwater level is measured at an average depth of 5 m. SPT-N values used for determined V_s and site classification map (Iyisan, 1999). The example boreholes and site classification map shown in Figure 2.

In this studies area, according to Eurocode 8, shear wave velocity changing with depth that is determined by using SPT-N values is used for developing seismic site classification microzonation map and corresponding V_{S30} values for each borehole location. Only a small part of the study region classifies as Eurocode 8 Site Class A. In the west of investigation area, there was a Class D that is a deep alluvium. There is Site Class E in the middle and south east of the region. The rest of the region consists of Site Class B and C.

2.2 *Microtremor measurements*

Microtremor studies were performed in two different methodologies, single station and array microtremor measurements. For single station microtremor measurements GMG-40T-1

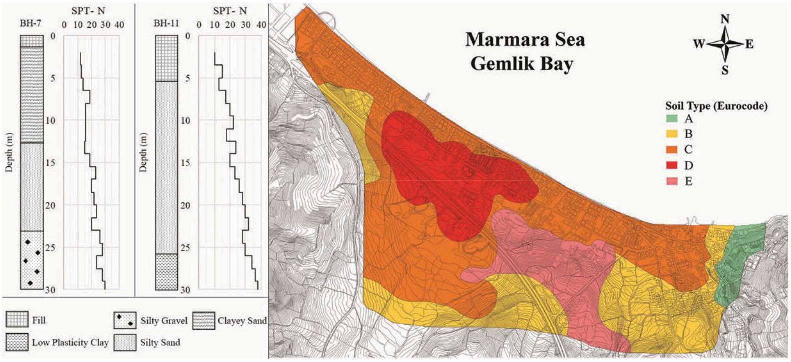

Figure 2. Example of boreholes and seismic site classification microzonation map.

(Güralp) 3 component seismometer with frequency range between 0.5-80 Hz was used and microtremor array measurements were carried out with V243S (Mitsutoyo Corp.) accelerometers with a flat characteristic frequency range of 0.20 and 25 Hz. Seven vertical sensors were used. All microtremor measurements were taken minimum 15 minutes. Array observations are performed with wavelengths exceeding 10 m by taking a 15 minutes long observation of vertical component of microtremors using a circular array with a changing radius. Sizes of arrays can be 10 m to 50 m and 2 Hz geophones are enough for estimating the shear wave velocity of the soil layers in most of the sites (Okada, 2003). Microtremor array and single station mikrotremor measurement technique is illustrated in Figure 3.

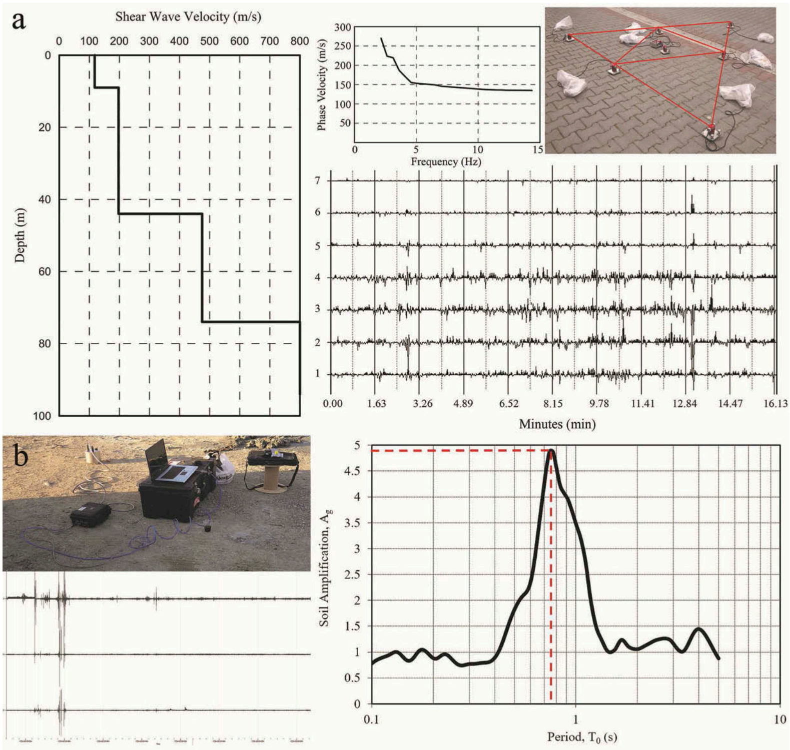

Figure 3. a) Microtremor array measurement b) Single station microtremor measurement

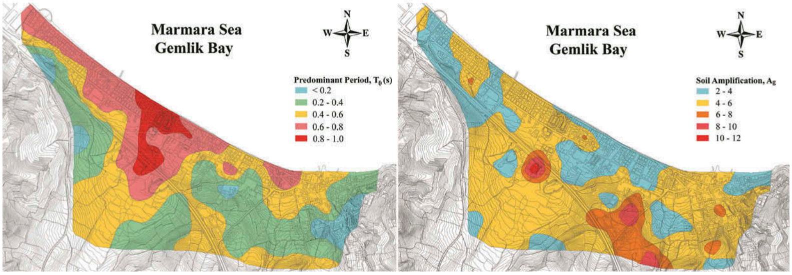

Figure 4. Predominant period and soil amplification maps for the study area.

3 THE SEISMIC VULNERABILITY INDEX

In this study, single station microtremor records were analyzed according to the HVSR method (Nakamura, 2008) and microtremor array measurement were used by the SPAC method for determining the shear wave velocity profile (Yamanaka, 2007).

There is a theoretical difference between microtremors and the characteristics of strong ground motion, it is known that the predominant period values obtained from single microtremor measurements and numerical analysis of strong ground motion are compatible with each other (İyisan et al., 2013). The predominant period and the soil amplification were determined according to HVSR method. The distributions of the predominant period and soil amplitudes for research area show in Figure 4.

In the seismic vulnerability index method that was proposed by Nakamura (2008), the deformation characteristics of the ground under earthquake excitation is approximated based on the amplification and natural frequency information determined by microtremor measurements. The Nakamura Index (K_g) is defined in Equation 1 in which A_g and T_0 denote soil amplification and predominant period values and obtained index for each point on the site.

$$K_g = A_g^2 T_0 \tag{1}$$

Nakamura Index method was developed to estimate the shear strain value (γ_e) that will occur within the surface soil layer during earthquake excitation. In this method, the seismic vulnerability index value (K_g) is multiplied by the peak seismic bedrock acceleration value ($a_{\text{max-bedrock}}$) and the coefficient C, in order to estimate the effective shear strain of the surface layer as given in Equation 2.

$$\gamma_e = K_g C a_{\max\_bedrock} \tag{2}$$

C is a coefficient depending on both the shear wave velocity of the seismic bedrock (V_b) and the term, e, which describes the efficiency of the strong ground motion. The units of the $a_{\text{max-bedrock}}$ and shear wave velocity of the seismic bedrock (V_b) are selected as gal (cm/s^2) and m/s, respectively. Efficiency term (e) is described as the ratio of the dynamic force generated during the earthquake to the static force, which is given equal to 0.60 (Nakamura, 2008). In this equation, the $a_{\text{max\_bedrock}}$ were selected equal to half of the maximum absolute acceleration values of the rock-outcrop accelerograms used in the 1D-site response analyses in order to provide the comparability of the findings. Rock outcrop is picked soil type B and V_b is accepted as 800 m/s in accordance with Eurocode 8.

4 SITE RESPONSE ANALYSES

The data from in situ penetration tests, boring logs, laboratory experiments and results of the microtremor array analyses were compiled for seven different sites and 1D shear wave velocity

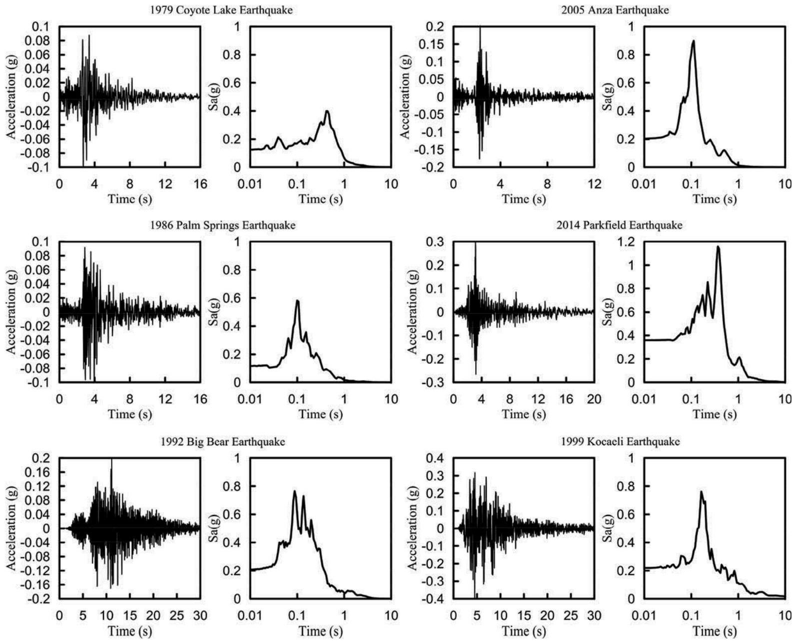

Figure 5. Strong ground motion records used in 1D dynamic analysis

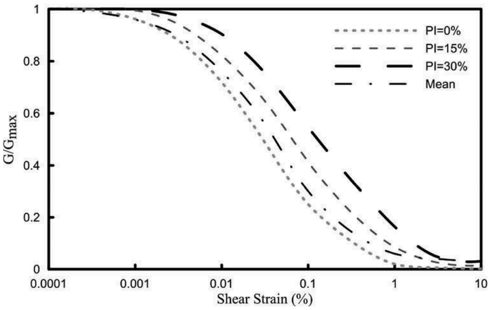

Figure 6. Examples of stiffness degradation curves used in dynamic analyses

profiles were constituted for each site. The 1D seismic site response analyses were carried out for each site by using six different rock outcrop acceleration time histories with peak absolute acceleration values ($a_{\max}$) varying between 0.1 g and 0.4 g. The accelerograms used in one-dimensional site response analyses show in Figure 5. 1D site response analyses were performed by using DeepSoil software based on equivalent linear method (Hashash et al., 2016). Seed and Idriss (1970), Vucetic and Dobry (1991) relations were used to simulate the material behavior under cyclic loading for coarse and fine-grained soils. Stiffness degradation ($G/G_{\max}$) curves that were used in analyses are shown in Figure 6.

5 COMPARISON OF SHEAR STRAIN VALUES

Nakamura Method was used to calculate the shear strains (γ_e) within surface soil layers after HVSR analysis of the three-component microtremor measurements conducted in the study area. Besides, the data from in situ penetration tests, boring logs, laboratory experiments and

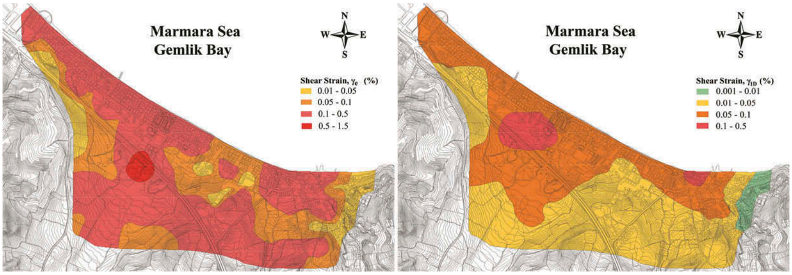

Figure 7. Spatial distributions of the shear strain values estimated by different analysis methods for 0.4 g

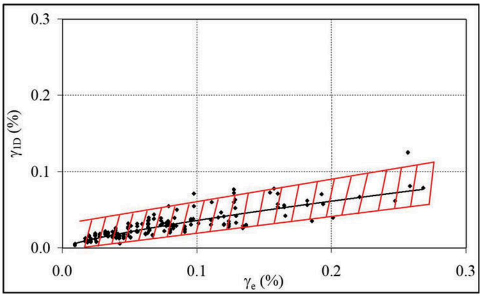

Figure 8. Distributions of the shear strain for 0.4 g on a graph.

results of the microtremor array analyses were compiled for seven sites and 1D shear wave velocity profiles were constituted for each site. Afterwards, by using rock outcrop acceleration time histories with different intensity values, 1D equivalent linear analyses were performed for each site to estimate the maximum shear strain values (γ_{1D}) approximately at 5 m below the ground surface. To calculate peak absolute acceleration values ($a_{\max}$) 0.4 g, both the spatial distribution of the shear strain values that were obtained from microtremor measurement analyses and the spatial distribution of the shear strain values that were estimated by 1D dynamic analysis are illustrated in Figure 7.

When both of the shear strain maps are considered together, it can be observed that comparable and similar results were obtained for the same regions. In our research area, the expected maximum surface acceleration value is 0.4g according to Turkey Earthquake Regions Map (TBEC, 2019). Therefore, in our study the shear strains are compared with both methods for 0.4 g. If all the results were evaluated on the graph, it is observed that the shear strains changed in certain value ranges. This result is illustrated in Figure 8.

6 CONCLUSION AND DISCUSSION

Stress-strain properties under earthquake excitation has great impact to identification of soil behavior in engineering practice. Therefore, comprehensive evaluation of site and laboratory test should be performed to get realistic deformation on the soil. The cyclic shear strain levels not only control the stress strain behavior, also pore water pressure generation, volume change, stiffness degradation, post-cyclic strength in soil layers. As a result, the level of shear strains occurring in near surface soil layers during strong earthquakes affects the spatial distribution of structural damage. In this study, the behavior of the soil layers under earthquake motion for a residential area in the Marmara Region has been investigated by both analysis of small amplitude ambient vibration data and 1D equivalent linear site response analyses. The shear strain values obtained from microtremor data analysis by using Nakamura Index method were compared with the values estimated by 1D dynamic analysis methods. As a result of analyzes for 0.4 g, it is observed that the shear strains changed in certain value ranges. This indicates that there may be a relationship between the microtremor data analysis based shear strain value (γ_e) and 1D site response analysis based shear strain value (γ_{1D}) for the strain levels at which elastic and elasto-plastic behavior occurs. The aim of future studies is to determine the relationship between γ_e and γ_{1D} by increasing the number of field studies.

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