Digest 2009, December 2009 1313-1336

Microzonation Study in Balıkesir†

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ABSTRACT

A microzonation methodology is developed for Balıkesir based on available geological and geotechnical data and applied for microzonation of the areas defined as BPH (the area covering Bahcelievler, Plevne and Hasan Basri Cantay districts) and 18-02 in Balikesir. Acceleration records are simulated compatible with target acceleration spectra estimated for Balıkesir design earthquake. Representative soil profiles are modelled by a grid system for each cell based on geotechnical data. Spectral accelerations on the ground surface are calculated by two different approaches using site response analysis and NEHRP amplification factors. Microzonation maps are produced with respect to ground shaking intensity taking into account the variation of the spectral accelerations calculated based on these two procedures.

Keywords: *Microzonation, spectral acceleration, ground shaking intensity.*

1. INTRODUCTION

Microzonation is a multi-dimensional issue that considers the interaction between earthquake source properties, path effects, and site conditions in the estimation of earthquake characteristics on the ground surface during a probable earthquake. Consequently, possible earthquake characteristics and effects must be taken into consideration for microzonation. This case study is based on the analysis of response of soil layers under earthquake excitations and thereby the variations of earthquake characteristics on the ground surface.

The design earthquake characteristics were determined based on a probabilistic approach taking into account existing data related to the seismic history and previous earthquakes around Balıkesir. The uniform hazard response spectrum at the bedrock level was calculated using different attenuation relationships compatible with regional seismic hazard and simulated acceleration time histories compatible with this spectrum were generated using the Rascal (Response Spectra and Acceleration Scaling) software [1]. Rascal is a semi-empirical procedure which is one of the spectral matching methods in the frequency domain that was developed based on random vibration theory using Fourier phase spectrum of real ground motion records. Program generates acceleration time records by stochastic

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† Published in Teknik Dergi Vol. 20, No. 1 January 2009, pp: 4583-4607

approach based on simple functional form for source characterisation and wave propagation to achieve compatibility with the target response spectrum.

The geotechnical data within Balıkesir residential area boundaries were provided from two different sources. The first data source contains boring and SPT test results that were conducted for the Balıkesir Municipality [2]. These borings have a homogeneous distribution in the study areas defined as BPH (the area covering Bahcelievler, Plevne and Hasan Basri Cantay districts) and 18-02 Regions. The other data source was created by compiling 802 soil investigations conducted by private companies within the municipality boundaries. Based on these databases, in the geotechnical modelling stage, the study areas were divided by a grid system with a cell size of 250m × 250m. Cell size was determined in accordance with the existing geotechnical data and based on the scale of study depending on the selected location. Representative soil profiles were determined for each cell. Thus, it was possible to achieve more comprehensive and reliable information about soil stratifications in the investigated areas. The effects arising from different distances between borings are eliminated in the mapping phase by assuming that representative soil profiles are located at the centre of each cell [3].

The site response analyses for the modelled representative soil profiles were conducted using Shake91 software [4]. The microzonation parameters were determined as spectral accelerations calculated based on the results of site response analysis and using the empirical amplification relationships proposed by Borcherdt [5]. The superposition of the spectral accelerations calculated with two different approaches are taken into consideration to define the microzonation map based on three levels of relative shaking intensity for the entire Balıkesir residential area.

2. DESIGN EARTHQUAKE AND SIMULATED GROUND MOTION RECORDS

The seismic activity ($M \geq 3$) within the radius of 100km around Balıkesir generally took place around Yenice-Gönen, Manyas, Sarıköy fault zones on the north, Edremit fault zone on the west, Zeytindağ, Bergama fault zones on the southwest, Soma-Akhisar fault zone on the south and Simav fault zone on the southeast. The fault mechanisms observed in these fault zones during the past earthquakes were normal faulting with strike-slip components. In this seismotectonic area, it was observed that 29 earthquakes took place during the historical era (26 B.C. to 1900) and 164 earthquakes in the instrumental era (1900 to 2000) as shown in Figure 1.

The seismic hazard analysis was conducted based on these data to evaluate exceedance probabilities. The Gutenberg-Richter recurrence relationship was calculated by one stage regression analysis separately for historical era ($I > VI$) and instrumental era ($M \geq 4$). At this stage, the intensities for the historical records were converted to M_s magnitude by using the relation developed for Turkey by Ansal [6];

$$M_s = 0.594\ Io + 1.36 \qquad (1)$$

In the analyses performed for determining the exceedance probabilities in terms of earthquake magnitudes, a weighted averaging procedure was adopted by assigning weights of 40% and 60% for historical and instrumental records, respectively. Thus, the magnitude of a probable earthquake corresponding to the average exceedance probability of 10% for a period of 50 years in Balıkesir was estimated as M_s=7.5 [7].

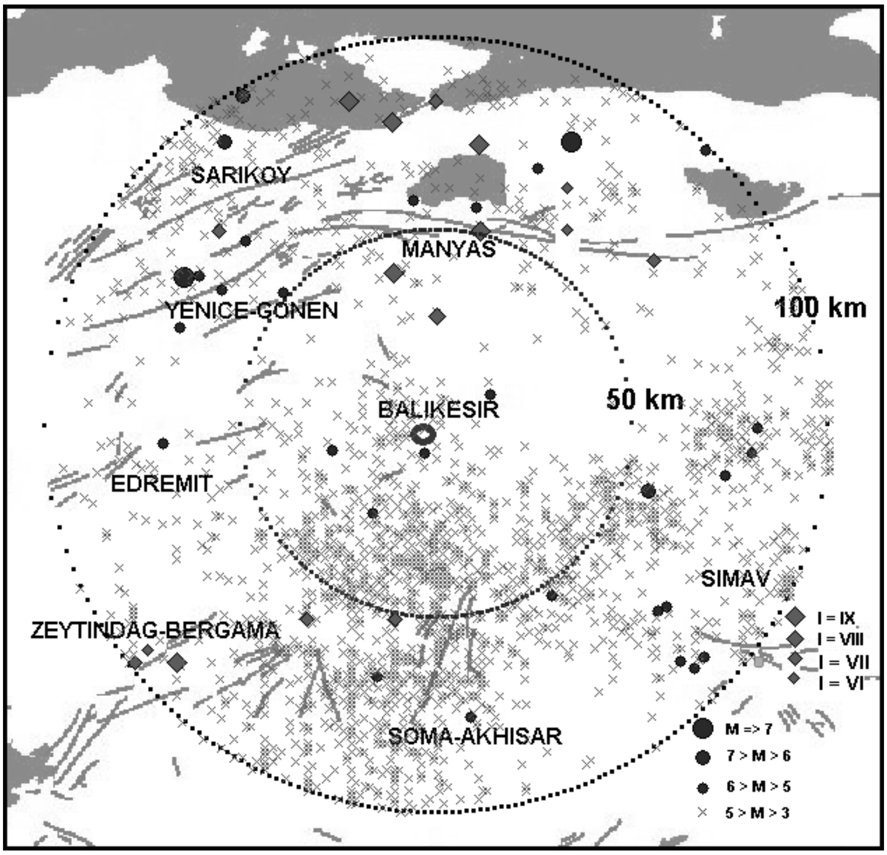


Figure 1. Distribution of earthquakes from the historical and instrumental era within the aerial radius of 100km around Balıkesir

Studies on the geological and tectonic formations in the region indicate that active faults in the investigated area have a complex structure. Therefore, it was assumed that the possible epicentre and related fault for a probable strong earthquake will be within 100km radius of Balıkesir and probabilistic approach was adopted in the estimation of possible epicentre location for the probable earthquake by using the same exceedance probability. Statistical analyses were conducted by assuming that all epicentres of instrumentally recorded earthquakes with magnitude M≥2 around Balikesir are possible epicentres for future earthquakes. By this approach, the epicentre distance for M_s=7.5 earthquake corresponding to 10% exceedance probability was determined as R=40km [7].

Acceleration response spectrum at the bedrock level is estimated based on two attenuation relationships compatible with the regional seismic hazard proposed by Boore et al. [8] and

Ambraseys et al. [9]. The faulting mechanisms for the previous earthquakes in the Balıkesir region were generally normal with strike-slip components. However, the fault type parameters for the selected two attenuation relationships are different due to the differences in the respective databases. Boore et al. [8] relationship is based on selected strong motion data from western North America. In this relationship, the fault type factors are used to indicate the difference between reverse and strike-slip fault mechanisms. In the Ambraseys et al. [9] relationship, data from Europe and the Middle East were used and strike-slip and normal earthquake mechanisms are compiled as different fault types. Both attenuation relationships were used and three uniform hazard spectra were calculated for Rascal simulations (Figure 2). At this stage, the variability and scatter in attenuation relationships were evaluated based on probabilistic approach in terms of exceedance probabilities to maintain the same hazard level adopted for the design earthquake.

Input acceleration records to be used for Rascal simulations were selected from earthquakes with magnitude M≥5 and with epicentre distance of 20 km ≤ R ≤ 60 km that took place in Turkey as given in Table 1, from the data set compiled by Ambraseys et al. [9]. The purpose was to maintain the compatibility with the selected design earthquake parameters for Balıkesir with respect to the frequency content and magnitude. The regional source and path parameters were assumed as; the stress drop of $\Delta\sigma$=100 bar, the frequency-dependent Q model of $Q(f)=300\ f^{0.5}$ and the high frequency spectral decay factor of κ=0.035. In the simulations, two different real acceleration records were used for each target spectrum and thereby six acceleration records were simulated (Table 2). These six acceleration time histories simulated by Rascal are shown in Figure 3 and ground motion parameters calculated for these simulated records are summarised in Table 3. It is observed that the range of variation for some of these calculated ground motion parameters are relatively large.

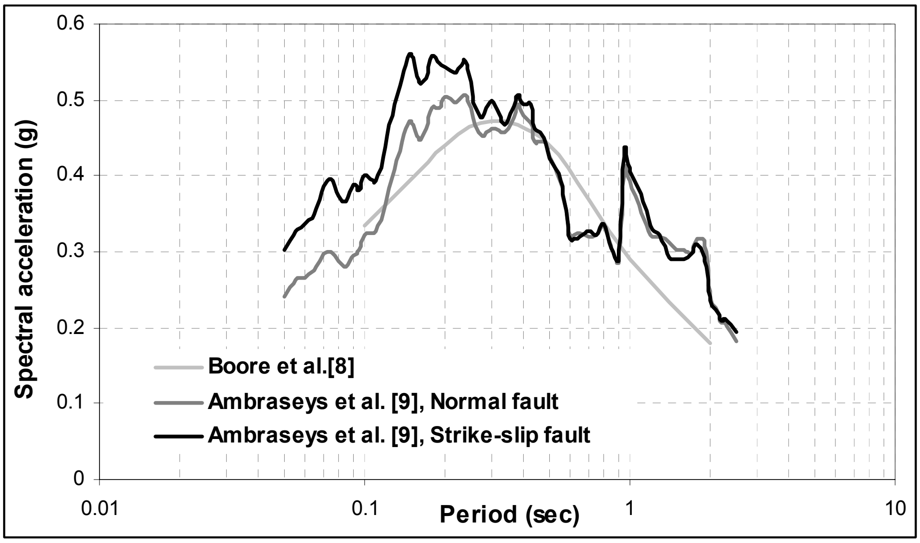


Figure 2. Uniform hazard acceleration spectrum determined at the bedrock level for Balıkesir corresponding to 10 % exceedance probability in 50 years

Table 1. Input real acceleration records used in simulations by Rascal

Earthquake	Date	Time	M_W	Faulting mechanism	Record code	Station	Distance to fault
Kocaeli	17.08.1999	00:01:40	7.6	Strike-slip	**gbz**	Gebze-TMAM	30 km
Kocaeli	17.08.1999	00:01:40	7.6	Strike-slip	**ist**	İstanbul-B.İ.M.	61 km
Biga-Çanakkale	05.07.1983	12:01:27	6.1	Odd	**edc**	Edincik-Kan.Göz.İst.	56 km
Doğanşehir-Malatya	05.05.1986	03:35:38	6	Odd	**gol5**	Gölbaşı-Dev. Has.	27 km
Doğanşehir-Malatya	06.06.1986	10:39:47	5.8	Strike-slip	**gol6**	Gölbaşı-Dev. Has.	34 km
Amasya	14.08.1996	01:55:03	5.7	Strike-slip	**ams**	Amasya-Bay. Müd.	33km

Table 2 . Simulated acceleration records for the three target spectrum

Simulated acceleration records by Rascal	Input of Rascal code	
	Real record	Target spectrum
gbzlb	Record of Gebze-Component L	Boore et al. [8]
edclb	Record of Edincik-Component L	Boore et al. [8]
gol5ln	Record of Gölbaşı/5-Component L	Ambraseys et al. [9] for normal fault
gol6ln	Record of Gölbaşı/6-Component L	Ambraseys et al. [9] for normal fault
Istls	Record of İstanbul-Component L	Ambraseys et al. [9] for strike-slip fault
amsts	Record of Amasya-Component T	Ambraseys et al. [9] for strike-slip fault

Table 3. Ground motion parameters for acceleration records simulated by Rascal

	Maximum Acceleration g	Maximum Velocity	Arias Intensity	Acceleration RMS g	Acceleration Spectrum Intensity	Velocity Spectrum Intensity	Bracketed Duration	Significant Duration
gbzlb	0.2079	54.759	0.467	0.0385	0.166	91.43	20.43	8.06
edclb	0.2079	62.366	0.523	0.0407	0.172	99.529	20.40	7.59
gol5ln	0.2108	78.988	0.827	0.0512	0.212	148.61	20.48	9.63
gol6ln	0.2108	52.726	1.532	0.0493	0.202	154.09	40.95	24.56
istls	0.2317	52.106	0.907	0.0379	0.206	145.25	40.67	14.56
amsts	0.2317	59.318	1.301	0.0514	0.223	153.28	31.94	16.32

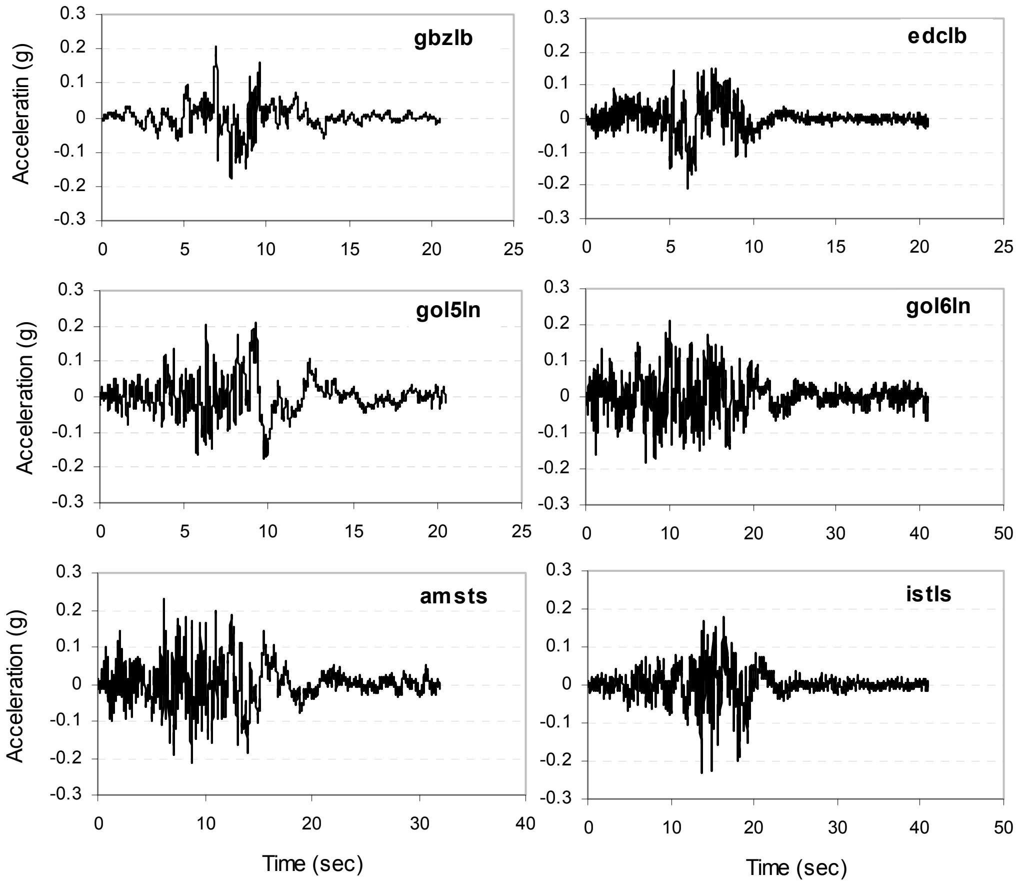


Figure 3. Acceleration time histories simulated by Rascal

3. GEOTECHNICAL MODELLING

Major part of the Balıkesir residential areas have relatively flat topography covered with Neocene aged sediment formations according to the 1/25000 scale geological studies [2]. These formations are composed of conglomerate, sandstone, marl, claystone, clayey limestone and limestone. Among these sediments, Neocene aged tuffs, agglomerates and lavas are encountered horizontally and vertically. The areas with higher elevations were defined as Neocene aged volcanic rocks. In 1/2000 scale geological studies [2], the entire BPH region and a large portion of the 18-02 region (except alluvial zones in the Ayşebacı area) are identified as tuffite formations. In another 1/5000 scale study [10], the entire 18-02 region is defined as alluvium.

Geotechnical data is based on two different databases. Most of the soil investigations conducted by private companies within the residential area include soil boring with depth of 5-10m, SPT tests mostly for the top 5-6m, soil classification tests for 3-4 points and very few unconfined compression and/or consolidation tests. In the other survey conducted for the Balıkesir municipality for BPH and 18-02 regions, soil borings have a relatively homogeneous distribution with approximately 250-500m spacing. The average depths for these soil borings are around 15m with very few laboratory and SPT tests. BPH region different from the 18-02 region includes data from both databases (Figure 4). Therefore, there are differences between the databases used for microzonation for different areas.

The geotechnical modelling phase requires an approach that enables the integration of field and laboratory test results obtained by different methods. However, even in studies based on extensive field and laboratory investigations, different criteria and interpretation of the geotechnical data may cause changes in soil response models and may lead to different modelling results [11, 12]. Besides, insufficient database may require trials based on different approaches during the geotechnical modelling stage [13, 14].

In this study, the geotechnical data compiled from different sources in BPH region were evaluated and interpreted together. Based on distribution of 58 soil borings and 227 soil investigations in the region (Figure 4), the most appropriate cell size was estimated as 250m × 250m.

As a natural result of the differences between the data sets, the information about soil layers in two sets are different in detail. While in one data set very limited laboratory tests are available for soil layers to support the field interpretations, there are a large number of laboratory tests for soil classification in the second data set. Soil borings that are homogeneously distributed in the study area were conducted by a single working group, whereas soil explorations with inhomogeneous distribution were conducted by different companies and by different people. Thus, after determining the soil layers in the top 5-8m based on large number of laboratory tests, data concerning deep soil borings with homogeneous distribution were evaluated in a relative manner to estimate the remaining depth for the representative soil profiles.

The insufficient soil explorations by private companies in the database for the 18-02 district eliminated the need for relative interpretation of the soil profiles. However, the deep borings with homogeneous distribution were conducted by a single working group for both regions and soil profile in the BPH district were modelled based on these borings. Considering this situation, a relative approach was adopted taking into account regional geological differences.

Soil investigations in the BPH region include 362 laboratory tests mostly limited to the upper layers. These experiments consist of basic soil classification tests as grain size analysis and consistency limits. According to the results of these tests, 70% of the soils in the region are silts and elastic silts (ML, MH), lean and fat clays (CL, CH), 26% of the soils are clayey sands (SC) and 4% of the soil are clayey gravels (GC) according to the Unified Soil Classification System (Figure 5). In general the fines content in the sandy soils are more than 30% and around 50%, while the sand content in silt and clay soils is between 30% and 50%. Consequently, the soil layers in the region are composed of 71% clays and silts and 26% sands containing more than 30% fines with plasticity indices between 10 and 50 (Figure 5).

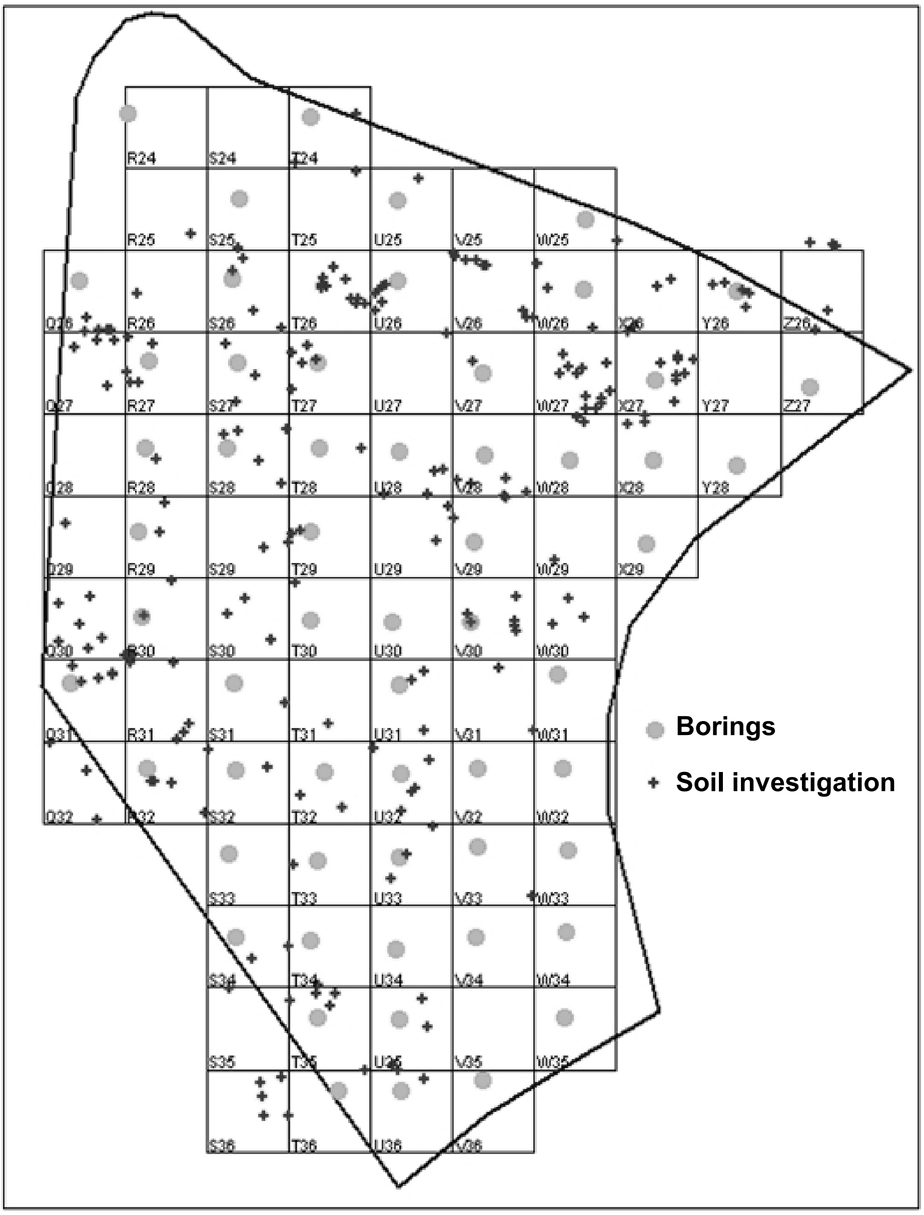
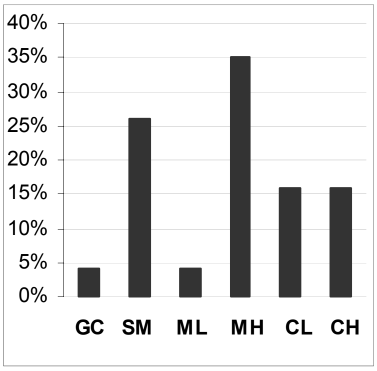


Figure 4. The distribution of borings and soil investigation locations in the 250m×250m dimensional cell system for BPH region

For sandy soils in this area, fines content is more than 30% and plasticity indices vary between 20 and 50. However, the plasticity index for sands is maximum 15 for the modulus reduction and damping curves used for modelling dynamic behaviour of sands in the literature [15, 16]. On the other side, the sand content in clays and silts vary between 30% and 50%. Considering this situation for the soils in the region, a different soil classification for the encountered soil types and different modulus reduction and damping models would be more suitable.



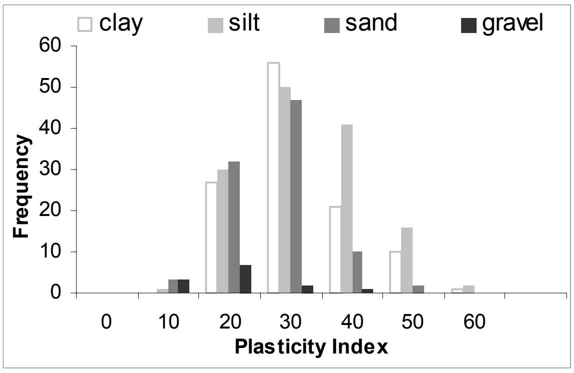


Figure 5. The frequency distribution of soil types according to the Unified Soil Classification System and plasticity index in the BPH region

In the classification system proposed by Seed et al. [17] for seismic analysis, soils are evaluated under two different groups; soils with fines content more than 30% (15%≤ PI ≤90%, cohesive) and soils with fines content less than 30% (cohesionless). Similarly, according to the British Soil Classification System, if the fines content remains between 35% and 100%, the soils are classified as silts and clays. Besides, in the early years of geotechnical earthquake engineering, the stress-deformation behaviour of soils was treated separately for coarse and fine grained soil. However, recent research has revealed a gradual transition between the stress-deformation behaviour of nonplastic coarse grained soil and plastic fine grained soil [18].

Vucetic and Dobry [15] proposed a model for the shear modulus reduction and damping curves as a function of plasticity index based on results of the study conducted to evaluate the performance of Mexico City clay during the 1985 Michoacan earthquake (Figure 6). In another study conducted to investigate the dynamic behaviour of four different soil groups (SM-ML, SM, MH and ML), the results obtained were compatible with the curves proposed by Vucetic and Dobry [15, 19].

The model developed by Sun et al. [20] contains five different modulus reductions and damping curves based on the plasticity index. Especially, because shear modulus and damping properties of low plastic soils are affected by the effective confining pressure, model curves proposed by Ishibashi and Zhang [21] were based on these two parameters. In another study based on undisturbed soil samples (MH, CL and CH) taken from different regions of Turkey, an empirical relationship based on the plasticity index is recommended for G/G_{max} curve [22]. In addition, there are curves developed by Seed and Idriss [16] for sands for three different cases and there are curves developed by Seed et al. [23] for gravel and by Schnabel et al. [24] for rock.

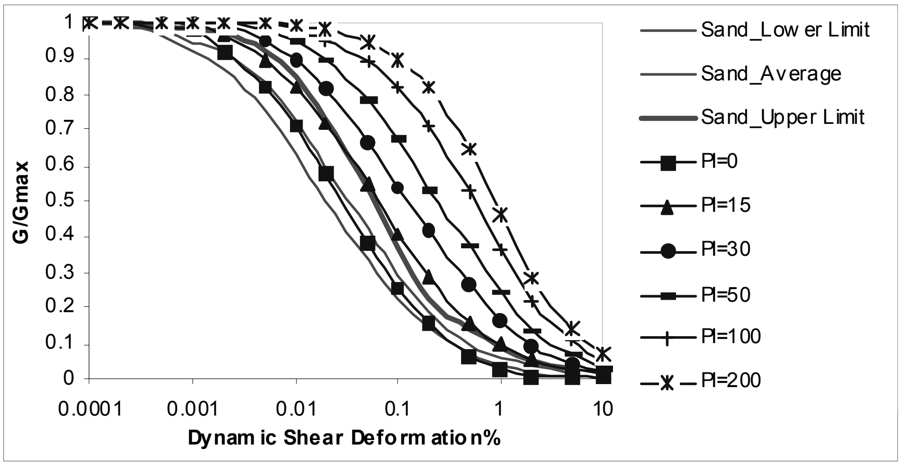


Figure 6. Comparison of the modulus reduction curves proposed by Vucetic and Dobry [15] for soils with different plasticity and the curves proposed by Seed and Idriss [16] for sands

Table 4. Soil groups specified for Geotechnical modelling

Soils defined according to the Unified Soil Classification System		**Soil group**	**Dynamic Behaviour Models**
SM-SC / GM-GC	(FC< %30)	Sand / Gravel	Seed and Idriss LB [16] / Seed et al. [23]
SM-SC / GM-GC	(%30≤FC≤%49)	Sandy clay / gravelly clay	Vucetic and Dobry [15] based on the plasticity Index
CL-CH	(S>%30 / G>%30)		
ML-MH	(S>%30 / G>%30)		
CL-CH	(S<%30 / G<%30)	Clay	Vucetic and Dobry [15] based on the plasticity Index
ML-MH	(S<%30 / G<%30)		

Taking into consideration the dynamic soil models in the literature, the approach to be applied during to modelling of the representative soil profiles for BPH region were determined. In Table 4 and Table 5, the resulting soil groups based on this approach and the selected dynamic soil models are presented. Soils with fines content more than 30% were modelled as clays and these soils were grouped according to their plasticity indices.

In the modelling stage of the representative soil profiles for each cell based on the adopted approach, whether or not the laboratory test results are compatible with the estimations based on field observations, there are two alternatives. In the first alternative, modelling has been performed for the cells with laboratory test results from different databases that are compatible with the field soil definitions. In the second alternative, the cells with no laboratory tests to verify field observations or if boring data were incompatible with laboratory tests, interpretations were re-evaluated in comparison with the nearby soil profiles. The cell S27 containing one of the 3 deep borings in the region can be given as an example to modelling with limited number of soil borings (Figure 7).

Table 5. Dynamic behaviour models of soil groups used for geotechnical modelling

Soil number	Soil group	Dynamic Behaviour Models
1	Fill	Vucetic and Dobry [15] PI=0
2	Clay-sandy clay $10 \leq PI \leq 20$	Vucetic and Dobry [15] PI=15
3	Clay-sandy clay $20 \leq PI \leq 40$	Vucetic and Dobry [15] PI=30
4	Clay-sandy clay $PI \geq 40$	Vucetic and Dobry [15] PI=50
5	Sand	Seed and Idriss [16] LB
6	Gravel	Seed et al. [23]

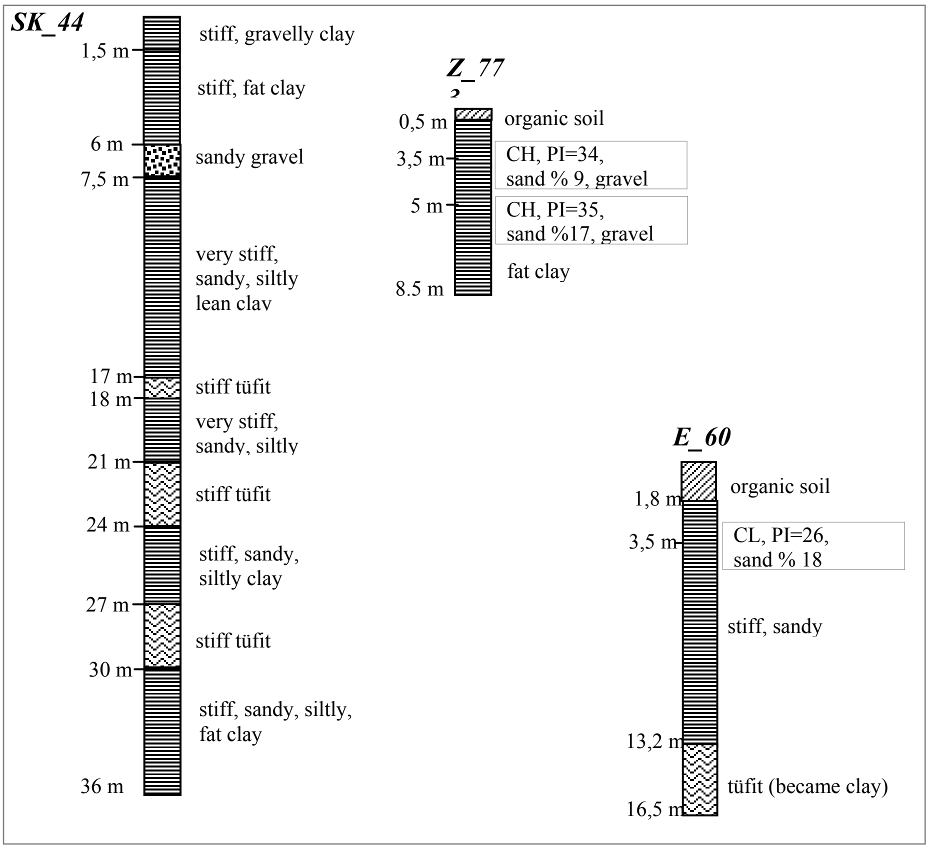


Figure 7. Database of cell S27

Soil layers in the soil boring SK_44 can be defined as clays except the gravel layer encountered between the depths of 6-7,5m and 1-3m thick tufiite bands located at various depths. There are no laboratory tests for this boring, but layers at depths of 1,5-6m and 30-36m have been defined as fat clay. This interpretation is supported by the laboratory tests results on the samples obtained from the top 5m in the borings Z_773 and E_60. However, the soil stratification observed for the shallowest boring with depth of 8,5m is not compatible with the soil stratification in the other borings. Even though this can be due to the different locations of the three soil borings, it is not possible to have a comprehensive assessment since all three borings extend to different depths. Consequently, S27 representative soil profile was modelled based on a relative approach taking into account deepest soil boring SK_44 and assuming that tufite layers have been transformed to clays as mentioned in E_60 soil boring (Figure 8).

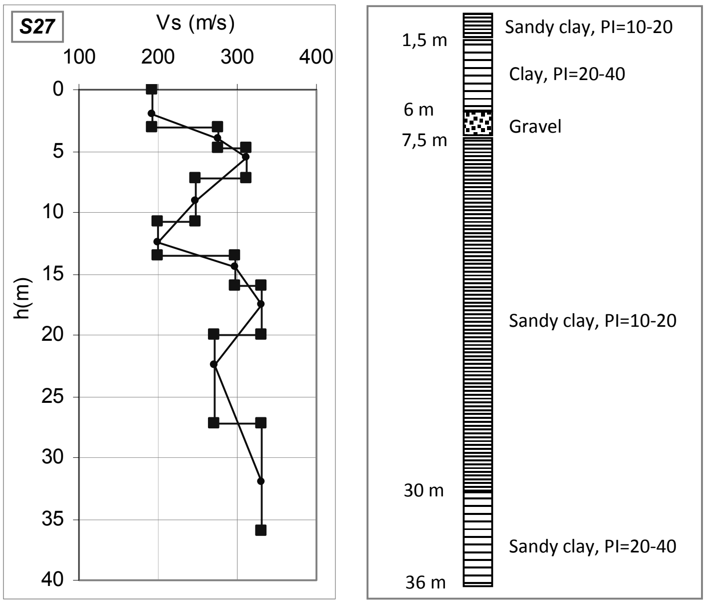


Figure 8. Representative soil profile for S27 cell

The shear wave velocities for the representative soil profiles were determined based on the SPT-N blow counts using the formula proposed by İyisan [25];

$$V_S = 51.5\ N^{0.516} \quad \text{(m/sec)} \tag{2}$$

where N is uncorrected SPT blow counts. This relationship is valid for all soil types. In general, it was observed that the calculated shear wave velocities vary between 200 and 400m/sec down to depths of 10-15m. For the shear wave velocities below 15m depth, the calculated velocity profiles of the two deep borings in the region were taken into account. In these two borings, the shear wave velocity at depths of 30 and 36m are 332m/sec and 341m/sec respectively. Accordingly, the shear wave velocities of representative soil profiles at 10-15m depths have been assumed as constant down to 30m. The equivalent shear wave velocities calculated for the representative soil profiles are observed to vary between 223 and 392m/sec in the BPH region and 261 and 423m/sec in the 18-02 region.

4. SITE CLASSIFICATION ACCORDING TO THE TURKISH EARTHQUAKE CODE AND NEHRP

The vast majority of the BPH and 18-02 regions were classified as Z1 and Z2 site class according to the Turkish Earthquake Code [26] based on the representative soil profiles. While the cells defined as Z3 site class have a scattered distribution in the BPH region (Figure 9), they are restricted to a small and limited zone in the 18-02 region. The classifications according to NEHRP (National Earthquake Hazards Reduction Programme) [27] show even distribution for C and D site classes in the 18-02 region, while almost the entire BPH region is classified as D site class (Figure 10).

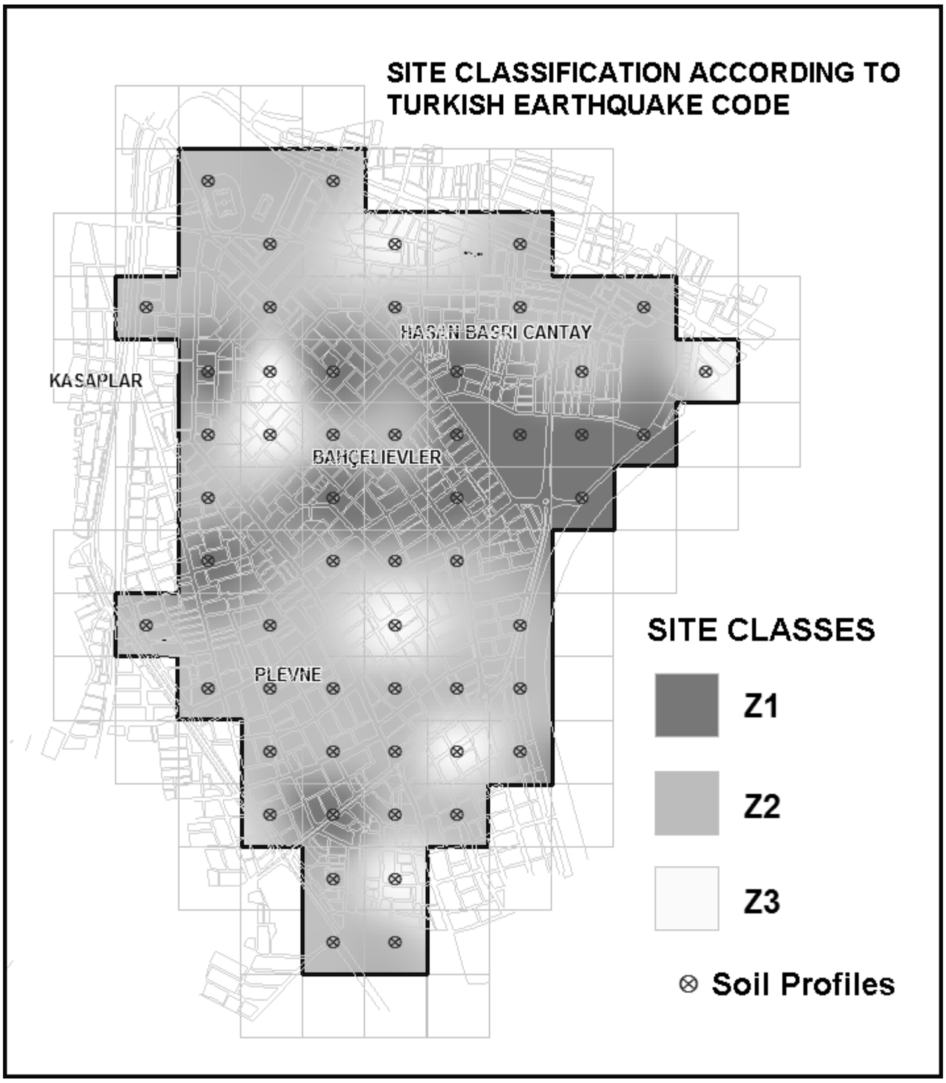


Figure 9. Site classification according to Turkish Earthquake Code for BPH region

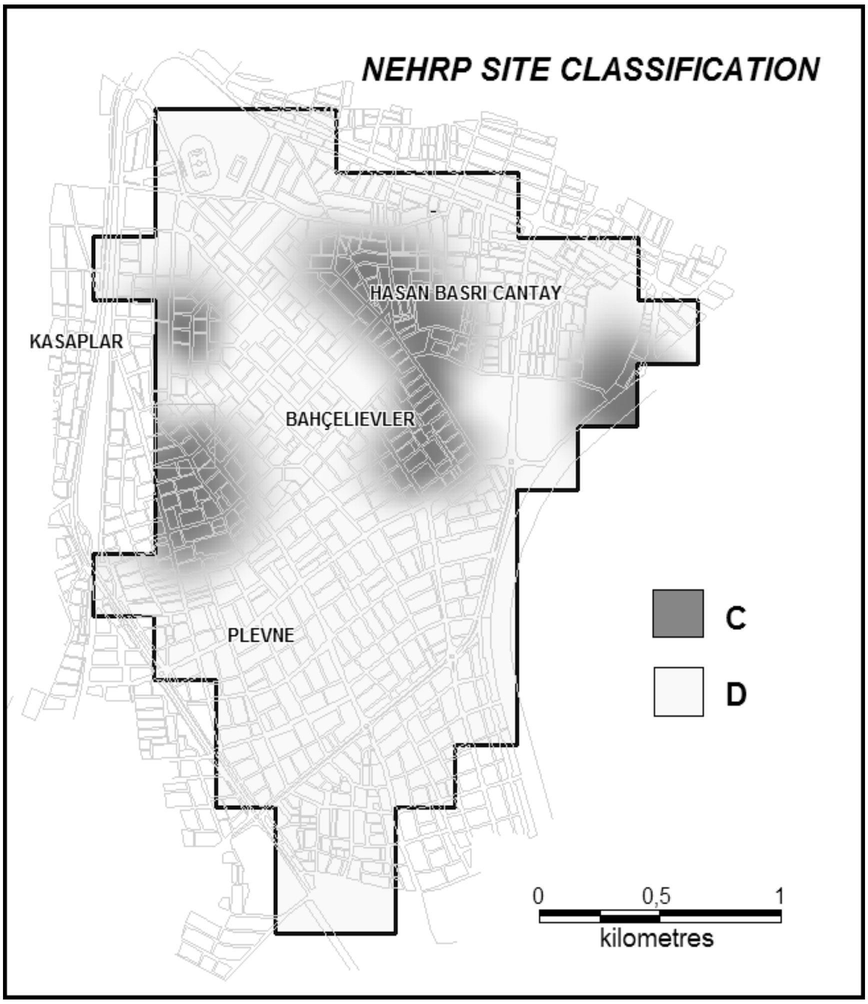


Figure 10. Site classification according to NEHRP for BPH region

The classification of local soil layers according to Turkish Earthquake Code and NEHRP, in fact, is a first grade microzonation method. From this perspective, as can be seen in Figure 9 and Figure 10, Turkish Earthquake Code provides a more comprehensive approach in comparison to NEHRP site classification. However, these maps, nevertheless, should not be evaluated as comprehensive seismic microzonation maps. As observed in many studies in the literature, since these maps were developed only based on site conditions, they contain no information concerning possible response variations under earthquake excitations. Therefore, it is essential to account for the probable earthquake characteristics and the effects of local soil conditions on the earthquake characteristics on the ground surface to generate realistic microzonation maps with respect to ground shaking intensity.

5. SITE RESPONSE ANALYSIS AND MICROZONATION PARAMETERS

The site response analyses for representative soil profiles were conducted using one dimensional wave propagation program, Shake91. The program is based on the equivalent linear method for the calculation of nonlinear behaviour of soils with an iterative procedure to obtain shear modulus and damping values compatible with the equivalent uniform strain in each layer. The response of horizontal soil layers is calculated under the influence of propagating shear-waves in the vertical direction [11].

The bedrock depth varies between 50m and 70m according to opinion of experts who were involved with the geological database of the region. Accordingly, it was assumed that the depth of bedrock is 70m and the shear wave velocity of the bedrock is Vs=700m/sec in the site response analysis. The shear wave velocity profiles defined down to 30m depth have been extended linearly to 70m depth for the representative soil profiles.

Six acceleration records generated by Rascal were used in the site response analysis for a total of 105 representative soil profiles in the regions of BPH and 18-02. As a result of these analyses, the geometric mean of the six response spectra obtained on the ground surface for each cell were determined and the arithmetic means of these average spectra between 0.1-1s periods were calculated. This calculated average spectral acceleration is one of the microzonation parameters suggested for microzonation applications in Turkey [3]. These average spectral accelerations were compared with the maximum spectral accelerations and the acceleration spectrum intensity for the geometric mean spectra at the ground surface and the correlation between these parameters was observed to be very high (Figure 11). Thus , it is possible to conclude that the use of average spectral acceleration between 0.1-1s periods as a microzonation parameter is a realistic approach.

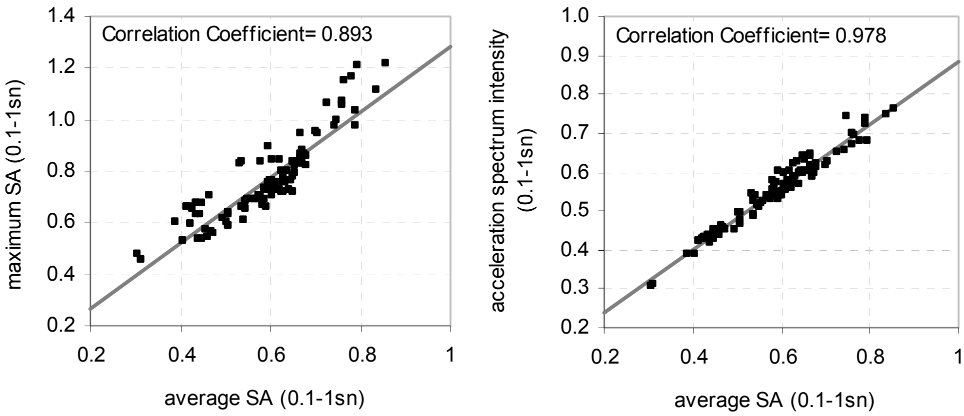


Figure 11. Comparison of average spectral accelerations with maximum spectral accelerations and acceleration spectrum intensities

The use of relative grouping of these average spectral accelerations with respect to frequency distribution in the investigated region is recommended as one microzonation parameter for mapping in the recent studies [3, 28, 29].

The approach adopted in the assessment of microzonation maps involves the division of the area into three zones as (A, B and C) based on the relative values of the selected microzonation parameter. Since the site characterizations, as well as all the analysis performed, require various approximations and assumptions, it was preferred not to present the numerical values for any parameter since their relative values are more important then their absolute values. In this approach, the frequency distributions for calculated values of parameters are obtained to determine the 33 and 67 percentiles to define the boundaries between the three zones. Thus zone A shows the most unsuitable 33 percentile (i.e. high spectral accelerations), zone B shows the medium 34 percentile and zone C shows the most favourable 33 percentile (i.e. low spectral accelerations).

For the Balıkesir study areas, the frequency distribution of the average spectral accelerations between 0.1-1second periods is shown in Figure 12. The relative zoning map generated considering this distribution is composed of two zones based on the 50% percentile of the statistical distribution in accordance with the proposed approach [3]. According to the proposed approach, it was recommended to define only two zones with 50% percentile value as the boundary if the difference between the corresponding values of 33% and 67% percentiles is less than 20%.

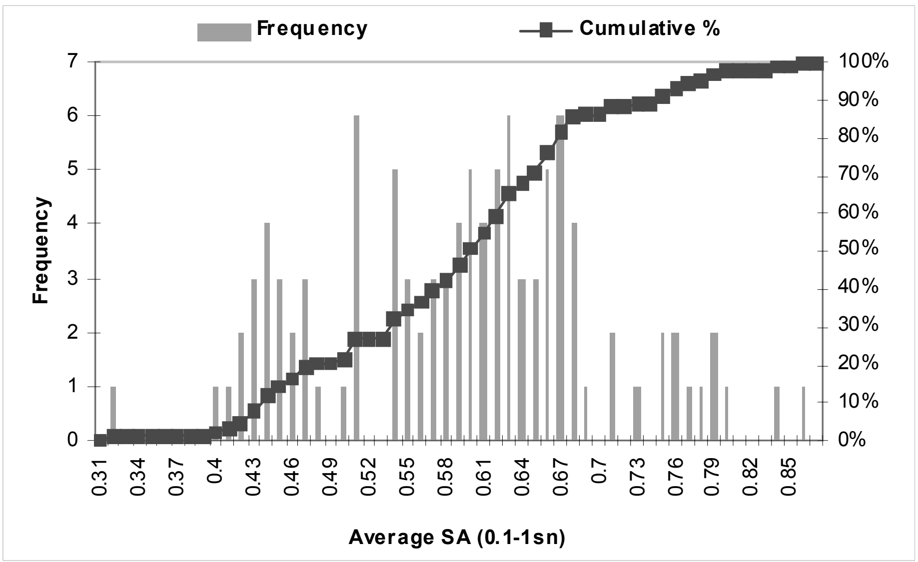


Figure 12. The frequency distribution of the average spectral acceleration in the study areas

In general, the results of site response analyses are evaluated together with the parameters calculated based on empirical amplification equations. In accordance with this approach, the maximum spectral accelerations calculated using the relationship proposed by Borcherdt [5] based on average shear wave velocities, is defined as the second microzonation parameter. The maximum spectral accelerations in the range of short periods are calculated based on the amplification factor F_a defined as;

$$F_a = (v_0 / v)^{m_a} \tag{3}$$

where v_0 is the bedrock shear wave velocity; v is the average (equivalent) shear wave velocity for the top 30 meters of soil profile. Exponential coefficient m_a is determined based on the level of the ground motion intensity on the bedrock.

In this study, the peak ground acceleration on the bedrock level was determined by taking the maximum value calculated based on the selected attenuation relationships [8, 9]. For this acceleration value determined as 0.23g, the exponential coefficient proposed by Borcherdt [5] was determined as m_a=0.21. Shear wave velocity of the bedrock has been assumed as the v_0=700m/sec as used in site response analyses. As a result, for each cell, amplification factors were calculated based on average (equivalent) shear wave velocities using the relationship;

$$F_a = (700 / v)^{0.21} \tag{4}$$

These amplification factors were multiplied with the average bedrock spectral acceleration calculated as SA=0.56g using the same attenuation relationships that were adopted to estimate the spectral accelerations on the ground surface.

In microzonation with respect to ground shaking intensity, the preferred approach is to compare and utilize multiple parameters [28, 29, 30]. There are two primary reasons for such an approach. Firstly, site response analysis is a numerical procedure and the results are significantly affected by the soil and earthquake properties used in analysis. The reliability of the results obtained from site response analysis is very dependent on the selected soil properties and on the characteristics of acceleration time records used in analysis. Secondly, in contrast to being empirical, Borcherdt [5] method may yield consistent results due to its empirical nature that was formulated based on observational data.

6. MICROZONATION WITH RESPECT TO GROUND SHAKING INTENSITY

The average spectral accelerations between 0.1-1s periods calculated based on site response analysis and evaluated relatively with respect to the frequency distribution in the study area were proposed as one of the microzonation parameters in the literature [3, 28, 29]. However, in this study, an approach was preferred that would be applicable for the entire residential area in Balıkesir. For this purpose, in accordance with the proposed approach; first, the regions within Balıkesir residential area but outside of the areas with site response analyses, were classified according to NEHRP [27] based on the soil investigations conducted by private companies. Even though these soil investigations do not contain detailed geotechnical data, they reflect the variations in site conditions for all residential areas. According to the NEHRP site classification, areas within Balıkesir residential boundaries may be classified as B, C and D.

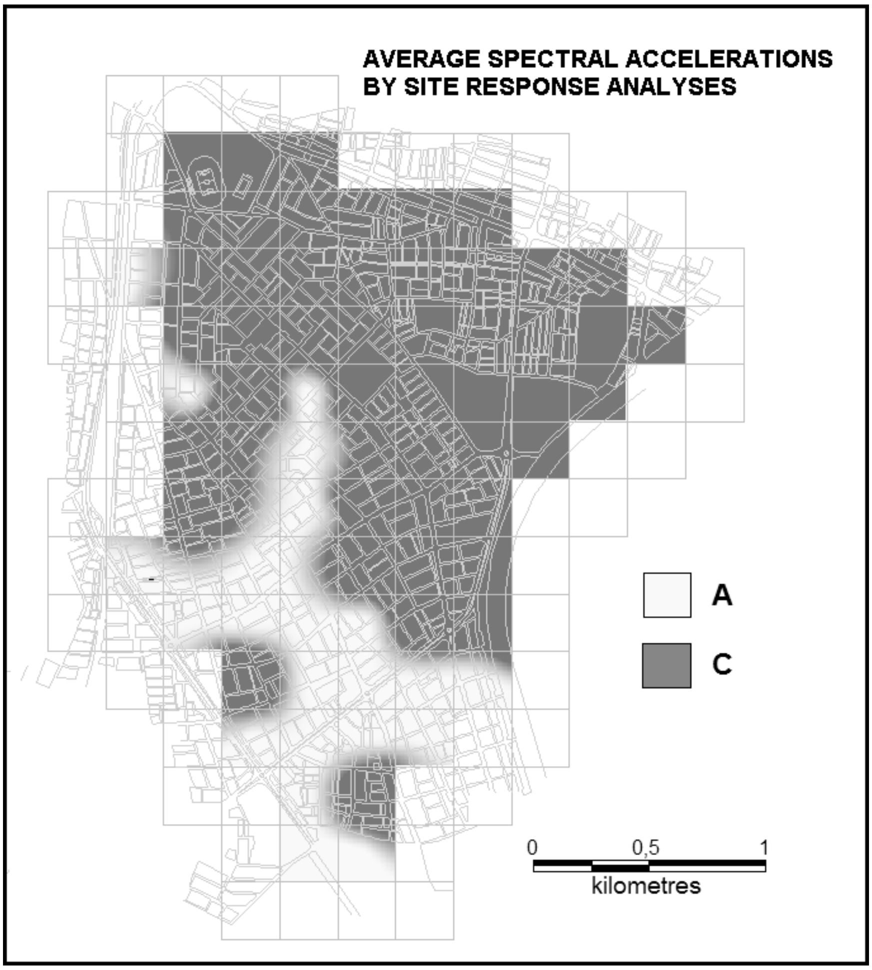


Figure 13. Microzonation with respect to the average spectral accelerations calculated based on site response analyses for BPH region

Afterwards, based on the site classes according to NEHRP, spectral accelerations on the ground surface were calculated using spectral amplification factors proposed in NEHRP code. At this stage, for the determination of spectral acceleration at 0.2s period at the bedrock level in Balıkesir corresponding to the exceedance probability of 10% in 50 years, similar to the previous approach, different attenuation relations [8, 9] were used and the maximum calculated value was selected. For this spectral acceleration determined at the bedrock level, amplification factor varies based on the site class. Accordingly, the spectral accelerations calculated on the ground surface within Balıkesir residential area vary between 0.56g and 0.76g. The average value of 0.66g was defined as the boundary value for microzonation and accordingly two zones have been identified at this stage for microzonation of the study area. Thus, cells with spectral accelerations higher than 0.66g were identified as zone A (where higher ground shaking is expected) and cells with spectral accelerations less than 0.66g were identified as zone C (where lower ground shaking is expected).

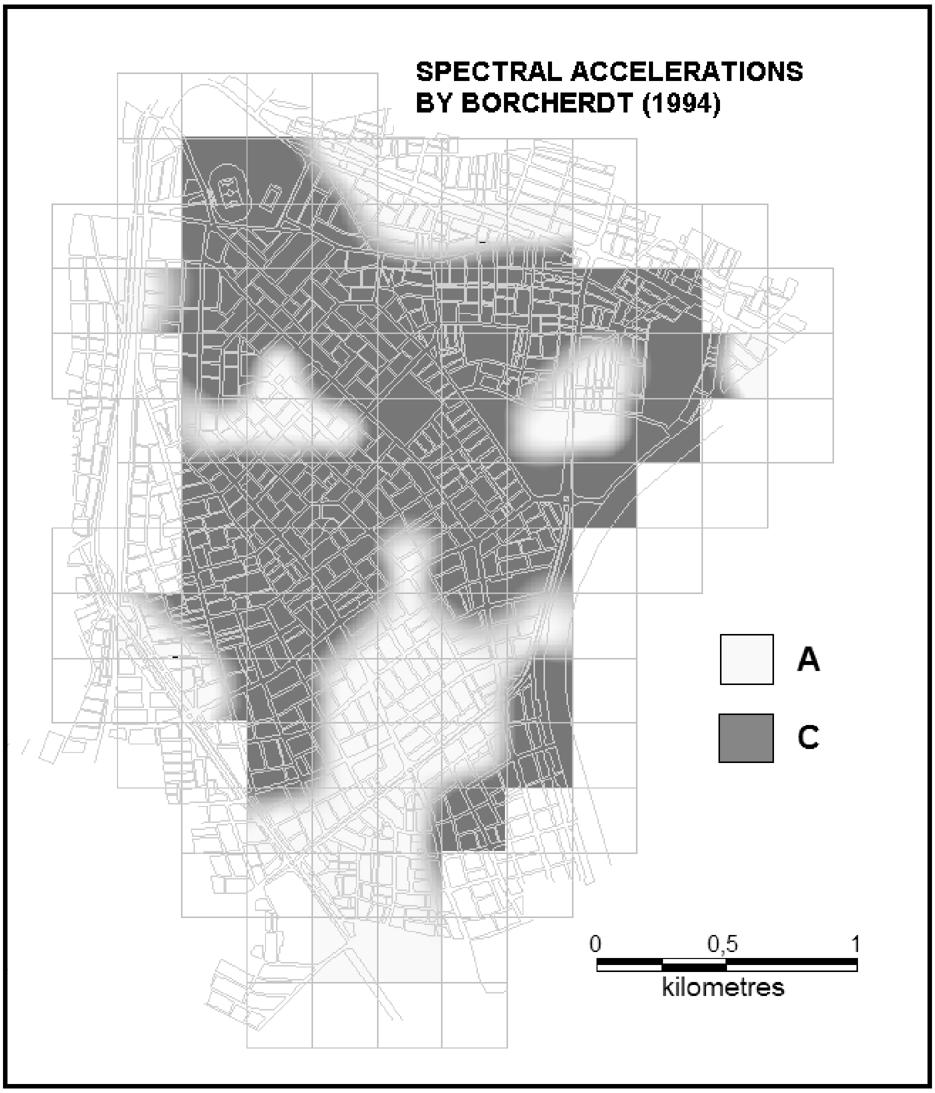


Figure 14. Microzonation with respect to spectral accelerations calculated using Borcherdt [5] relationship based on equivalent shear wave velocity in BPH region

Similar approach of relative mapping according to the frequency distribution of the two microzonation parameters was applied to the BPH and 18-02 regions and microzonation maps were generated with respect to the average spectral accelerations between 0.1-1s periods based on site response analysis (Figure 13).

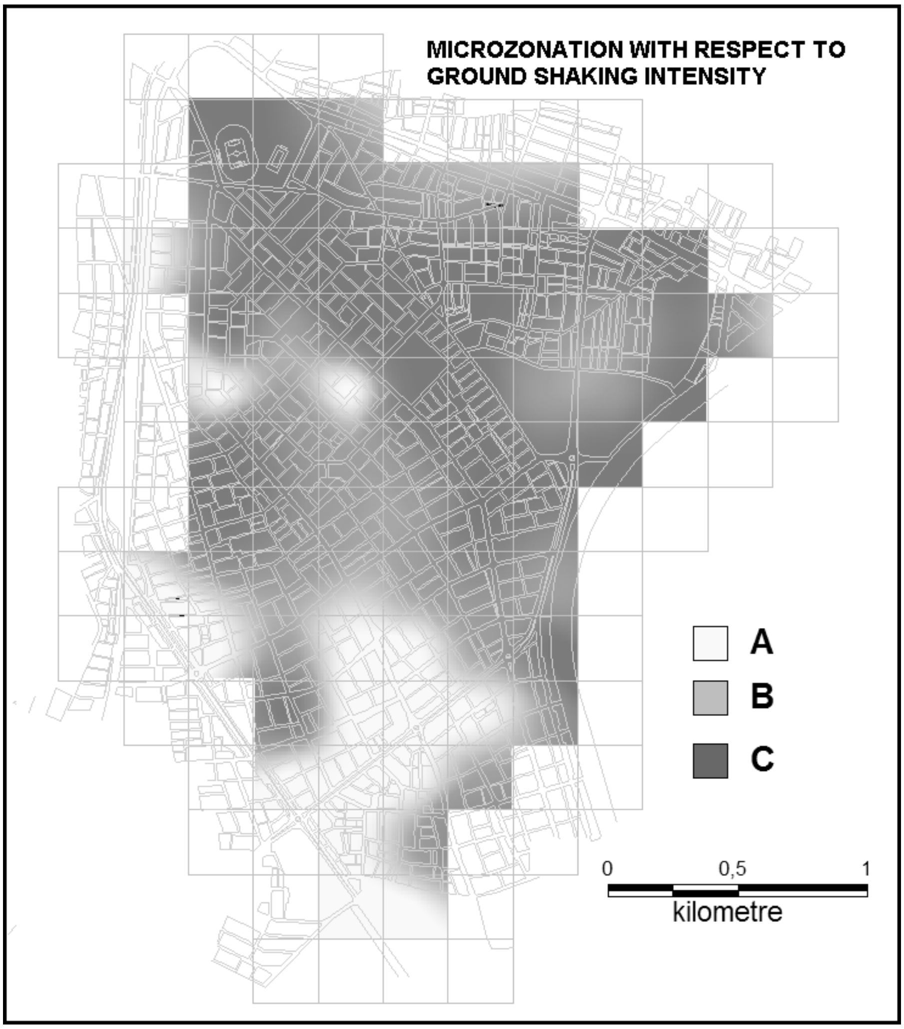


Figure 15.Microzonation with respect to ground shaking intensity for BPH region

Microzonation maps based on relative mapping procedure were also generated with respect to spectral accelerations calculated using the empirical relationships proposed by Borcherdt [5] for BPH and 18-02 regions. Similar to the case of average spectral accelerations, cells located in zone A is expected to experience higher ground shaking intensity and cells located in zone C is expected to experience lower ground shaking intensity (Figure 14).

When the microzonation maps generated for both microzonation parameters are compared, it is possible to observe that the distribution of zones defined as A and C have some differences as well as similarities. Finally, microzonation map with respect to the ground shaking intensity was generated by the superposition of the microzonation maps obtained based on the spectral accelerations calculated by two different approaches. At this stage, in case of the overlapping of cells with different microzonation levels such as A and C, these cells are identified as zone B (Figure 15). Accordingly, zone A shows areas with highest ground shaking intensity, zone B shows the areas with medium ground shaking intensity and zone C shows the areas with low ground shaking intensity during a probable future earthquake.

7. CONCLUSIONS

An approach compatible with the recent advances in microzonation methodology was developed that can be applicable for Balikesir. The proposed methodology was applied to two areas defined as BPH and 18-02 within the boundaries of the residential area.

Simulations are performed based on the Rascal code for establishing probabilistic design earthquake characteristics using different attenuation relationships compatible with the earthquake hazard of the region using real acceleration records. Thus, the variations based on the interaction among earthquake characteristic and soil properties were taken into account in site response analyses.

The cell size compatible with the distribution of existing data in the study areas and the criteria used for modelling the representative soil profiles were determined based on the interpretation of geotechnical data compiled from two different datasets. Soil classification and dynamic soil models in the region were represented with a gradual transition based on the plasticity index for cohesive and cohesionless soils. However, in determining the soil stratification in the region and response of these soil layers under cyclic stresses, it was taken into account that existing data is not necessarily accurate enough for microzonation applications. In representing local geotechnical conditions in a realistic way for the microzonation studies, field and laboratory experiments need to be applied at least for depths of 30m.

Based on the results of the site response analysis, the average spectral accelerations between 0.1-1s periods calculated for each cell were compared with the acceleration spectrum intensities and the maximum spectral accelerations for average spectrum and it was observed that these comparisons yielded high correlation coefficients. The maximum spectral acceleration reflects only one characteristic of the ground motion. However, the acceleration spectrum intensity reflects two ground motion characteristics as magnitude and frequency content. The average spectral acceleration between 0.1-1s periods is considered as a suitable parameter for microzonation since it also reflects a more comprehensive ground motion characteristic.

The spectral accelerations determined numerically and empirically for each cell were interpreted considering the range of spectral accelerations that varies according to NEHRP within the Balıkesir residential area and combined for microzonation parameter according to ground shaking. With this approach, microzonation maps of the study areas reflect the relative results that may be valid for the whole of the Balikesir residential area

References

[1] Silva, W., RASCAL, Response Spectrum and Accelerogram Scaling Manual, WES Rascal Code for Synthesizing Earthquake Ground Motions, US Army Corps of Engineers State-of-the-Art for Assessing Earthquake Hazards in the United States, Report 24, 1987.

[2] Tufan, A., ve Çona, A., Balıkesir Belediyesi, Bahçelievler, Plevne, Hasan Basri Çantay, Akıncılar Mahalleleri ve 18-02 Konut Bölgelerinin Temel ve Zemin Araştırması Etüd Raporları, 2000.

[3] DRM-World Institute for Disaster Risk Management, Belediyeler için Sismik Mikrobölgeleme, Türkiye Cumhuriyeti Bayındırlık ve İskan Bakanlığı, Afet İşleri Genel Müdürlüğü, 2004.

[4] Idriss, I. M., Sun, J.I., SHAKE 91-A Computer Program for Conducting Equivalent Linear Seismic Response Analyses of Horizontally Layered Soil Deposits, 1992.

[5] Borcherdt, R.D., Estimates of Site Dependent Response Spectra for Design Methodology and Justification, Earthquake Spectra, **11**, 173-, 1994.

[6] Ansal, A., İstanbul İçin Tasarım Deprem Özelliklerinin Belirlenmesi, Prof. Dr. Rıfat Yarar Sempozyumu Kitabı, 1, 233-244, 1997.

[7] Ansal, A., Balıkesir Şehri Bahçelievler, Plevne, Hasan Basri Çantay, Akıncılar Mahalleleri ve 18-02 Konut Bölgesinin Yerleşime Uygunluk Çalışmalarının, Depremsellik ve İnşaat Mühendisliği Açısından Değerlendirilmesi, İTÜ Geliştirme Vakfı, Uygulamalı Araştırma Raporu, 2001.

[8] Boore D.M., Joyner W. B., Fumal T.E., Equations for Estimating Horizontal Response Spectra and Peak Acceleration from Western North American Earthquakes: A Summary of Recent Work, Seismological Research Letters, 68-1, 1997.

[9] Ambraseys, N. N., Douglas, J., Sarma, S. K., Smit, P. M., Equations for estimation of strong motions from shallow crustal earthquakes using data from Europe and the Middle East: Horizontal peak ground acceleration and spectral acceleration, Bulletin of Earthquake Engineering, 3, 1–53, 2005.

[10] MTA, Balıkesir Belediyesi 1802 nolu İmar Sahasının İmar Planlarına Esas Jeolojik Etüd Raporu, Kuzey Batı Anadolu Bölge Müdürlüğü, Balıkesir, 1999.

[11] Pitilakis, K., Raptakis, D., Lontzetidis, K., Tika-Vassilikou, Th. & Jongmans, D., Geotechnical and Geophysical Description of Euro-Seistest, Using Field, Laboratory Tests, and Moderate Strong Motion Recordings, Journal of Earthquake Engineering, 3/3, 381-, 1999.

[12] Raptakis, D., Chavez-Garcia, F.J., Makra, K. & Pitilakis, K., Site Effects at Euroseistest-I. Determination of The Valley Structure and Confrontation of

Observations with 1D Analysis, Soil Dynamics and Earthquake Engineering, 19, 1-, 2000.

[13] Khaled, A., Jun, K., Ryoji, I., Estimation of Uncertainties in The Dynamic Response of Urban Soils in Japon, Eleventh World Conference on Earthquake Engineering, 736- , 1996.

[14] Destegül, U., Sensitivity Analysis of Soil Site Response Modelling in Seismic Microzonation for Latitpur, Nepal, Thesis of Master of Science, International Institute for Geo-Information Science and Earth Observation, The Netherlands, 2004.

[15] Vucetic, M. and Dobry, R., Effect of soil plasticity on cyclic response, Journal of Geotechnical Engineering, ASCE, 117-1, 89-107, 1991.

[16] Seed, H.B. and Idriss, I.M., Soil moduli and damping factors for dynamic response analyses, Report No. EERC 70-10, Earthquake Engineering Research Center, University of California, Berkeley, 1970

[17] Seed, R. B., Çetin, K. O., Moss, R.E.S, Kammerer, A.M., Wu,J., Pestana,J.M., Riemer, M.F., Recent Advances in Soil Liquefaction Engineering and Seismic Site Response Evaluation, Geotechnical Earthquake Engineering and Microzonation Seminar, Istanbul, 2001.

[18] Kramer, S.L., Geotechnical Earthquake Engineering, ed. William J. H., Prentice-Hall International Series in Civil Engineering and Engineering Mechanics, New Jersey, USA, 1996.

[19] Schneider, J.A., Hoyos, L., Jr., Mayne, P.W., Macari, E.J., and Rix, G.J., Field and Laboratory Measurements Of Dynamic Shear Modulus of Piedmont Residual Soils, GSP 92, ASCE, Reston, VA, 12-25, 1999.

[20] Sun, J.I., Golesorkhi, R., and Seed, H.B., Dynamic moduli and damping ratios for cohesive soils, Report No. EERC-88/15, Earthquake Engineering Research Center, University of California, Berkeley, 1988.

[21] Ishibashi, I. and Zhang, X., Unified dynamic shear moduli and damping ratios of sand and clay, Soils and Foundations, 33-1, 182-191, 1993.

[22] Okur,V., Ansal, A., Dynamic Characteristics of Clays under Irregular Cyclic Loading, Lessons Learned from Recent Strong Earthquakes, Earthquake Geotechnical Engineering Satellite Conference, 267-270, 2001.

[23] Seed, H.B., Wong, R.T., Idriss, I.M., and Tokimatsu, K., Moduli and damping factors for dynamic analyses of cohesionless soils, Journal of Geotechnical Engineering, ASCE, 112-11, 1016-1032, 1986.

[24] Schnabel, P. B., Lysmer, J., and Seed, H. B., SHAKE: A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites, Report No. UCB/EERC-72/12, Earthquake Engineering Research Center, University of California, Berkeley, December, 1972.

[25] İyisan, R., Zeminlerde Kayma Dalgası Hızı ile Penetrasyon Deney Sonuçları Arasındaki Bağıntılar, İMO Teknik Dergi, 1187-1199, 1996.

[26] Deprem Bölgelerinde Yapılacak Binalar Hakkında Yönetmelik, TMMOB, İnşaat Mühendisleri Odası, İstanbul Şubesi, 2007

[27] BSSC- Building Seismic Safety Council, NEHRP (National Earthquake Hazards Reduction Program) Recommended Provisions for Seismic Regulations for new buildings and other structures, 2000 Edition, Part 1: Provisions (FEMA 368), CH.4, Washington, D.C., 2001.

[28] Ansal, A., Özaydın, K., Erdik, M., Yıldırım, H., Kılıç, H., Adatepe, Ş., Özener, P.T., Tonaroğlu, M., Şeşetyan, K., Demircioğlu, M., Seismic Microzonation for urban planning and vulnerability assessment, Kobe, (2005)

[29] Ansal, A., Biro, Y., Erken, A., Gülerce, Ü., Seismic Microzonation: a case study, Recent Advances in Earthquake Geotechnical Engineering and Microzonation, ed. by A. Ansal, Kluwer Academic Publishers, 253-, 2004.

[30] Ansal, A., Springman, S., Studer, J., Demirbaş, E., Önalp, A., Erdik, M., Giardini, D., Şeşetyan, K., Demircioğlu, M., Akman, H., Fah, D., Christen, A., Laue, J., Buchheister, J., Çetin., Ö, Siyahi, B., Fahjan, Y., Gülkan, P., Bakır, S., Lestuzzi, P., Elmas, M., Köksal, D., Gökçe, O., Adapazarı ve Gölcük için Mikrobölgeleme çalışmaları, 5. Ulusal Deprem Mühendisliği Konferansı, İstanbul, 2003.