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EVALUATION OF SITE CHARACTERIZATIONS AND SITE EFFECTS OF THE ANKARA BASIN, TURKEY

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ABSTRACT

The purpose of this study is to assess the in-situ site characteristics and to perform seismic hazard studies of the Upper Pliocene to Pleistocene fluvial and Quaternary alluvial and terrace deposits located towards the west of Ankara. Based on a general engineering geological, geotechnical and seismic characterization of the site, site classification systems were assigned for seismic hazard evaluations. Then, short-period noise recordings of the microtremor measurements at the ground surface have been used to estimate the site response of the site. This research mainly focuses on the development of a methodology to integrate the various components necessary for a regional multi-hazard seismic risk assessment that includes consideration of hazards due to local site effects. These tasks have been fulfilled through the development of an engineering database that was obtained from invasive and non-invasive explorations at the study area. Hence, the engineering geological and geotechnical site characterization studies have been compiled; and geophysical site characterization studies have been performed, particularly in the Quaternary sediments of the Ankara basin. By using all of these studies, hazard assessment maps (i.e., site classification map and site period map) and a seismic zonation map of Ankara basin, Turkey were developed along with discussing the consequences of the seismic hazards.

Keywords: Site Characterization, Site Effects, Seismic Hazard Assessment, Ankara

INTRODUCTION

The objective of this study is to integrate a variety of databases coupled with invasive and non-invasive field testing results obtained from this study in regards to identifying and mapping seismic hazards. This research mainly focused on the development of a methodology to integrate the various components necessary for a regional hazard study that started with the assessment of the local site conditions through distinguishing the local geological formations and the mapping of surface geology based on available sources of information and database. Then, these geologic units were differentiated according to the physical properties; and maps of these properties were also prepared by site characterization studies obtained from boreholes and geophysical testing studies. Hence, the engineering geological and geotechnical site characterization studies have been compiled; and geophysical site characterization studies have been performed to enable the assessment of local site conditions along the sedimentary deposits of the Ankara basin (Koçkar, 2006). By using all of these studies, a seismic hazard assessment map was developed to summarize the potential for the respective hazards, and to indicate areas that require further detailed investigation within the study area. Finally, the consequences of the seismic hazards were investigated and mitigation recommendations were presented. Since the models chosen to be included in the information analysis are suitable to be used

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with regional spatially-distributed data, a hazard model for each of the hazard components listed above was developed and implemented in the GIS environment.

This seismic hazard assessment project was conducted as the first prototype study for Ankara (Koçkar, 2006). Ankara, the capital city of Turkey with a population of about 3.69 million and area of approximately 300 km^2, is located at an intersection point of highways connecting east to west and north to south of Anatolia (Figure 1). The research area situated in the Ankara basin and located towards the west of the center of the city of Ankara is an approximately E-W-trending, 25-30 km long and 10-15 km wide fault-bounded depression that is drained in the east-west direction through the present-day course of the Ankara River. The study area that covers the major growing potential, present and future settlement province of Ankara is moderately to densely populated with mostly residential settling and significant portion of small to large industrial buildings. A location map of the research area that is situated within the western part of the city center of the Ankara province is shown in Figure 1.

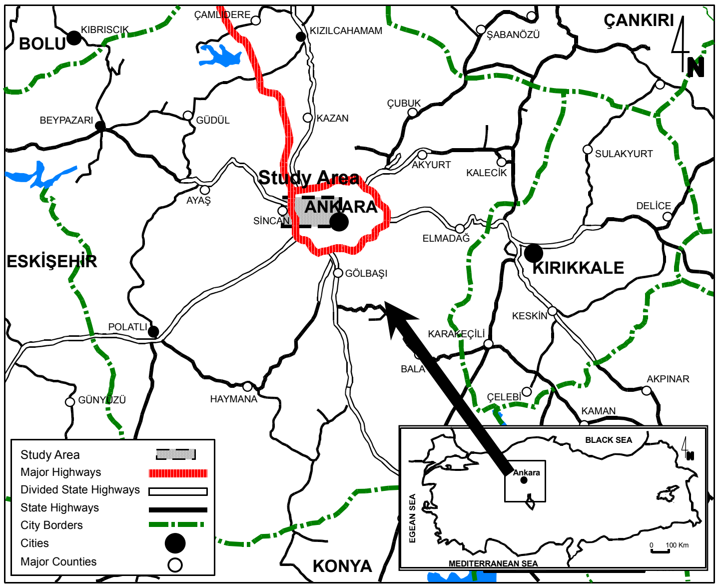

Figure 1. Location map of the research area

GEOLOGY AND SEISMOTECTONICS OF THE STUDY AREA

In the Ankara Region, the rock units cropping out in the region range from Triassic to Quaternary in age. The older rock units in the Ankara region are highly deformed pre-Upper Miocene basement rocks and Upper Miocene-Lower Pliocene rocks. The younger stratigraphic rock units in this region are encountered uncomfortably by the Upper Pliocene to Pleistocene fluvial red clastics and Quaternary alluvial and terrace deposits (Akyürek et al., 1997; Erol et al., 1980) (Figure 2). In concordance with the aim of this study, the geological characteristics of the basin fill types of these younger sedimentary units will be emphasized in detail.

The basin fill types of the Upper Pliocene to Pleistocene sedimentary unit is widely exposed and covers the major part of the study area in the western part of the Ankara basin. These fluvial sediments showing a continental origin have accumulated in and near the fault-bounded basins of the study area (Figure 2). These deposits possess highly heterogeneous structure and appearance in respect to their rock pieces, grain size distributions and colors. Their thicknesses range from a few meters to 200 m based on their stratigraphic position (State Hydraulic Works, DSİ, 1975; Erol et al., 1980). Regarding the hydrogeological conditions, considerable water-bearing strata were not encountered due to presence of clay-bearing sediments. Quaternary alluvial fill and terrace sediments were deposited by flood waters in the fault-bounded Ankara basin throughout the flood plains in the east-west direction of Ankara River and its tributaries (Figure 2). These deposits are differentiated as older terrace deposits that are present at the margins and younger alluvial sediments that are present at the stream beds of the Ankara Basin. The outcrops of Quaternary terrace deposits which are Upper Pleistocene in age and mostly formed by erosional setting is well-exposed at different elevations as several step-like river terraces along the margins of fault-bounded depressions of the Ankara basin. The Quaternary alluvial sediments that are rather thick and Holocene in age, have been deposited by flood waters along both side of the recent river beds. These are normally consolidated soft deposits and their parent materials vary similar to the fluvial deposits, but are relatively more homogeneous, depending on the nature of the rock and soils in the areas drained by the streams (Sürgel, 1976). The groundwater level varies within the alluvium and ranges between 2 to 6 m (DSİ, 1975). Generally, the thickness and width of the recent alluvial deposits observed along the Ankara River and its major tributaries relatively range between 5 m and 45 m and from 0.2 to 3 km, respectively (Erol, 1973; DSİ, 1975; Kasapoğlu, 1980; Koçkar, 2006).

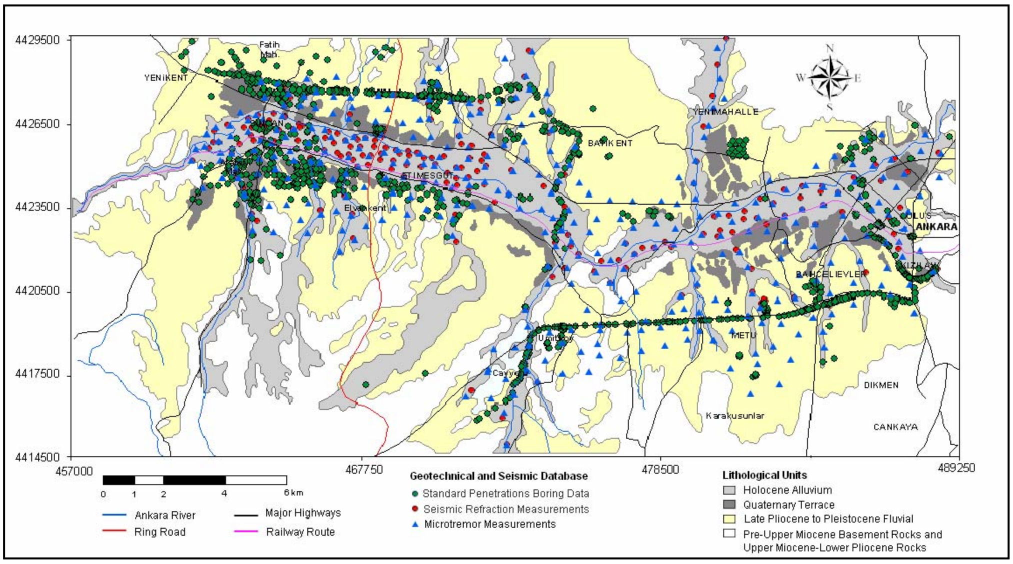

Figure 2. The spatial distribution of the SPT borings compiled from previous studies; and the seismic refraction and the microtremor measurements performed for the study area. Note that geological map were modified from Akyürek et al. (1997), Erol et al. (1980) and Koçkar (2006)

The study area that lies in the Ankara Region is a broad and structurally triangular area delineated by the right lateral strike-slip fault zone, namely, the Seyfe Fault Zone (SFZ) in the east, the oblique-slip normal fault zone, namely, the Salt Lake Fault Zone (SLFZ) in the southeast and the right lateral strike-slip fault system, namely, the North Anatolian Fault System (NAFS) in the north. The seismic events that are associated with the faults in the Ankara basin are seismically active but have rather short extent. Hence, these are capable of producing frequently occurring small and occasionally occurring moderate seismic events. On a regional scale, whereas, the Ankara region might be affected from the surrounding large-scale Fault Systems and Fault Zones, especially NAFS, SLFZ and SFZ that have capability to produce large destructive earthquakes (M > 6.0). Hence, significant seismic events that might take place along these large-scale Fault System and Fault Zones might affect Ankara and its surroundings and thus have to be considered seriously in regards to earthquake hazard assessment.

DEVELOPMENT OF A GEOTECHNICAL AND SEISMIC DATABASE

Initial sources of information and the database that was used in this study included topographic, geologic, engineering geologic and geomorphologic maps, and deep boring data. These studies may provide a reasonably well first approximation of the characterization of geologic units. Regarding the geotechnical and engineering geological site characterization, the research area was explored by in-situ tests that were conducted in previous studies towards the west of the Ankara. These existing databases contained about 913 of the boring data of SPT results, N values (blows/m) from penetrometer studies which were added to the database in the Upper Pliocene to Quaternary sediments (Koçkar, 2006; Figure 2). There were also previously performed surface wave refraction measurements at 55 locations that have been compiled for the research area. It should be noted that the compiled data was not as well distributed as the conducted seismic testing studies over the project area and included a spectrum of different geologic materials. Hence, for the sake of consistency, the surface wave measurements have been conducted primarily in the Quaternary alluvial and terrace sediments to develop a relatively consistent and well distributed database. Hence, the surface geophysical site characterization study was conducted for this research in an attempt to interpret the local site conditions (Koçkar, 2006). Therefore, near-surface shear wave velocities were measured at a total of 204 project site locations, particularly, in the Quaternary sediments (Figure 2). In addition, short-period noise recordings of microtremor measurements were conducted at 352 project site locations on the Upper Pliocene to Quaternary sediments in regards to study the seismic response of the Ankara basin and its close vicinity (Figure 2). During the evaluation of the ambient noise records, the recording files have been processed and analyzed by using MicPlot (Motoki, 2002). Hence, the measured frequency values were compared with existing geotechnical and seismic information that were obtained from collected and performed site investigation studies to check the accuracy and hence the reliability of the results.

EVALUATIONS OF SEISMIC AND GEOTECHNICAL SITE CHARACTERIZATIONS

By using the concept of assigning shear wave velocities to the mapped local geologic units that were developed by Tinsley and Fumal (1985), and modified by Park and Elrick (1998), it could be inferred that the geological and geotechnical parameters that show useful correlations with shear wave velocity are standard penetration resistance and texture for unconsolidated sedimentary deposits. These correlations can be applied to the research area by using data concerning the areal distribution and physical properties of the geologic units to estimate and map shear wave velocity that is useful for hazard assessment study. Therefore, presented herein is a method for identifying soil profiles in regards to site characterization that merges in-situ measurements of dynamic properties with geologic information and especially surface seismic methods according to design code of IBC-2003 (International Code Council, ICC, 2003). Consequently, recent seismic code provisions adopted the site classification using mean shear wave velocity and also standard penetration results in the upper 30 meters of a site as the sole parameter for site classification (Borcherdt 1994; Borcherdt and Glassmoyer, 1994; Dobry et al., 2000). Hence, geotechnical and seismic investigations were conducted in the project area to classify and characterize Upper Pliocene to Quaternary sediments in the Ankara basin along with calculating the mean shear wave velocity and correlated index measurements of the standard penetration resistance to 30 m to develop site categories to account for site conditions according to the design code of IBC-2003.

In order to perform a site evaluation, the database has to be generalized from shear wave velocity measurements at individual sites to broad shear wave velocity classes that include sedimentary mapping units. Interpretation of the distribution of shear wave velocity results of soil layers in the upper 30 meters [$V_s(30)$] was included for each unit. Regarding the classification scheme, sedimentary units were briefly subdivided into the two units, and then the mean shear wave velocity results of soil layers in the upper 30 meters of these statistically distinct units were investigated. According to the seismic testing database, a summary of the results showing the distribution of data that describe the characteristics of generalized sedimentary geologic units and their IBC-2003 site classes based on $V_s(30)$ are given in Table 1. During the standard penetration based site characterization study, a similar site classification scheme that was outlined in the mean seismic wave velocity measurements above was used to mainly assemble the results of a consistent and well distributed site classification scheme. In addition, useful correlations between each test were performed to idealize the site characteristics for a more thorough site classification in regards to assessing site classes. A summary of the results of soil layers in the upper 30 meters [N(30)] showing the data distribution obtained in the sedimentary geological units and their IBC-2003 site classes based on N(30) are given in Table 2.

Table 1. Description of the characteristics of generalized geologic units and their IBC-2003 site classes based on $V_s(30)$ data

Geologic Unit	Number of Data Points	Data (%)	$V_s(30)$ (mean)	± Std	SITE CLASS (IBC-2003)
Quaternary alluvial and terrace deposits	2*	0,92	504	91	CLASS C
	134	61,75	221	27	CLASS D
	81	37,33	169	13	CLASS E
Upper Pliocene to Pleistocene fluvial deposits	14	33,33	392	27	CLASS C
	28	66,67	319	23	CLASS D
	0	-	-	-	CLASS E

***C** sites were erroneously encountered due to the presence of pre-emplaced fill material at those locations; therefore, the data points were omitted

Table 2. Description of the characteristics of generalized geologic units and their IBC-2003 site classes based on N(30) data

Geologic Unit	Number of Data Points	Data (%)	N(30) (mean)	±Std	SITE CLASS (IBC-2003)
Quaternary alluvial and terrace deposits	1*	0,23	52,0	-	CLASS C
	323	75,12	25,4	6,2	CLASS D
	106	24,65	12,7	1,8	CLASS E
Upper Pliocene to Pleistocene fluvial deposits	78	16,15	55,8	5,8	CLASS C
	404	83,64	38,5	6,4	CLASS D
	1**	0,21	12,0	-	CLASS E

***** C site was erroneously encountered due to the presence of pre-emplaced fill material at this location; therefore, the data point was omitted
****** One E site in fluvial deposits was not consistent with the remainder of the data; therefore, the data point was omitted

During the interpretation of the $V_s(30)$ and N(30) data, it was observed that the distribution of the mean shear wave velocity and penetration results and hence, the site classes for some geologic units were relatively variable, especially in Quaternary alluvial and Upper Pliocene to Pleistocene fluvial deposits of D-Sites, whereas the distribution of $V_s(30)$ and N(30) was more uniform for Quaternary deposits of E-Sites that had a relatively narrow range of shear wave velocity and penetration results. Therefore, these deposits had quite variable ranges of $V_s(30)$ and N(30) that crossed boundaries between the existing shear wave velocity and standard penetration categories of younger and older sedimentary units. A major contributor to this crossing was attributed to the variability of sample textures which is an indicator of the range of depositional environments included within each geological unit. As a result, since some sedimentary units did not exactly fit into the code-based penetration result categories, these units could have been differentiated within different site categories. For example, Quaternary alluvium deposits in the Ankara basin were differentiated into three units, namely Younger Alluvium of E-Site, Younger Alluvium of D-Site and Older Terrace Deposits of D-Site, respectively. Similarly, measurements on the Upper Pliocene to Pleistocene Fluvial Deposits in the Ankara basin led to a decision to classify them as relatively less dense or stiff Fluvial Deposits of D-Site and stiffer or denser Fluvial Deposits of C-Site. Considering the engineering geological character of these sedimentary units, it might be that they also include different depositional or erosional characteristic themselves at the time of setting. Hence, it can be pointed out that site characterization depending on the $V_s(30)$ and N(30) results is an appropriate measure of soil conditions and may give valuable evidences to define the local site conditions, which might be helpful in differentiating the characteristics of the generalized sedimentary mapping units that are consistent with geological age and depositional character.

Finally, a regional seismic map of $V_s(30)$ was developed to evaluate the effects of using shear wave velocity correlations that is to be used to construct a map for assessing site conditions specified in the IBC 2003 according to this study based on the actual data developed through improved regression equations between $V_s(30)$ and N(30). Regarding the general variability of the characteristics of the sedimentary units and considering the amount of the suitable data pairs in the success of this correlation study, the data were briefly classified within two different sedimentary environments as Quaternary alluvial and Upper Pliocene to Pleistocene fluvial deposits. The $V_s(30)$ and N(30) data pairs with the characteristic indices were analyzed to derive regression equations for alluvial and fluvial deposits which may be presented by the following relationships (Koçkar 2006; Koçkar and Akgün, 2006):

$$V_s(30) = 59.94\left(N(30)\right)^{0.428} \quad \text{for Alluvial Deposits} \tag{1}$$

$$V_s(30) = 37.05\left(N(30)\right)^{0.572} \quad \text{for Fluvial Deposits} \tag{2}$$

It may be inferred from the results presented by Equations (1) and (2) that the estimated V_s results compare well with the measured V_s results and provide the best estimates of V_s for both alluvial and fluvial sediments. This could be due to the generated regression results that are based on the actual data sets representing local site conditions of our research area. Consequently, the results assembled from the estimated and measured $V_s(30)$ studies have been aggregated for both Quaternary alluvial and Upper Pliocene to Pleistocene fluvial sediments to construct the regional site classification map of $V_s(30)$ for assessing site conditions to be utilized in predicting the site response of the Ankara basin (Figure 3). It is anticipated that this study will be quite useful in preparing regional seismic hazard map in which V_s characteristics can be used as part of a site-condition term.

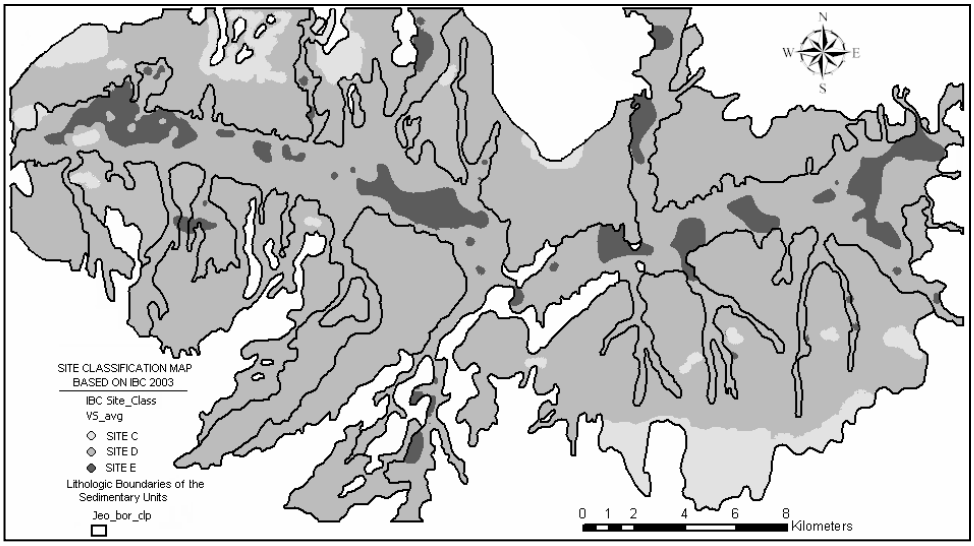

Figure 3. Regional site classification map of the Ankara basin in regards to the site classes as specified by IBC-2003 based on measured and estimated $V_s(30)$ measurements (Koçkar, 2006)

EVALUATION OF SITE EFFECTS

An understanding of site effects due to sedimentary deposits near the ground surface using ambient noise measurements to estimate the seismic response has been one of the main goal of this study. Therefore, regarding the use of ambient noise measurements to estimate the local site conditions, the Horizontal-to-Vertical Component (H/V) spectral ratio of the Nakamura technique has proven to be a more reliable method that produces more correlative results (Nakamura, 1989; Lermo and Chavez-Garcia, 1994; Field and Jacob, 1995; Field et al., 1995). It is well adapted in the urban environments to be of great interest for site effects and to establish the seismic zonation, noting that a thorough understanding of subsurface heterogeneities and non-linear effects at the study site is essential to a reliable interpretation of the data (Finn, 1991 and Bour et al., 1998). In the study of the Ankara basin, different lithologies associated with typical amplification factors have been identified and surveyed using the field approach of short-period noise recordings. In general, the results showed a good correlation between thickness and/or the type of soft soil and the fundamental period obtained with the H/V method. Regarding the results obtained from the microtremor study, each measurement point provides a spectral ratio and enables an estimation of the fundamental period and the maximum value of the amplification at the site studied. Through performing spatial interpolation between these points, one can deduce a map of resonance periods over the Ankara basin given as an example in Figure 4 (Koçkar, 2006).

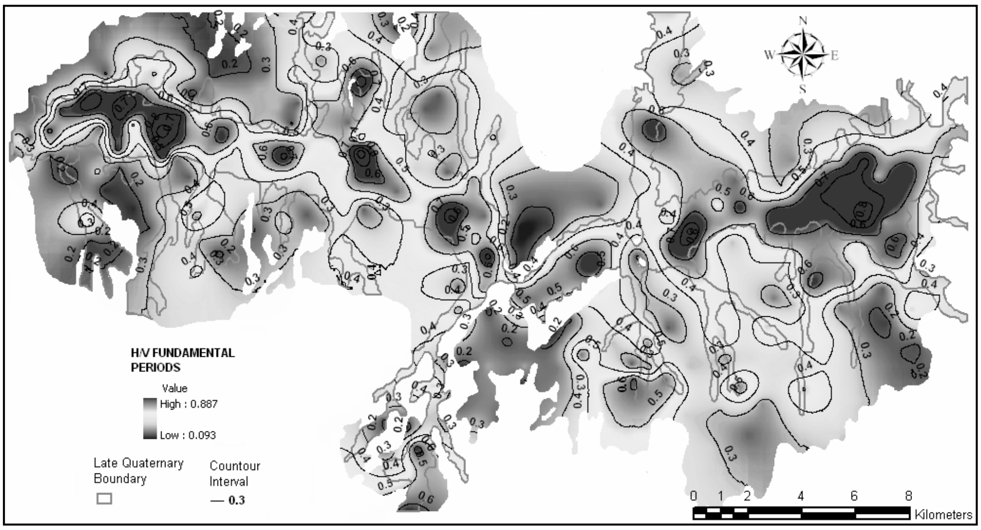

Figure 4. Map of fundamental resonance periods obtained with the H/V method over the Quaternary alluvial and Upper Pliocene to Pleistocene fluvial sediments of the Ankara Basin

From the processed microtremor results, the H/V fundamental periods were consistent with the geological setting of the research site. The fundamental periods that ranged from about 0.2 to 0.9 s relatively increased along the Quaternary deposits of Ankara basin throughout the flood water plains of the Ankara River and its main tributaries (Figure 4). These ranges of the fundamental periods also appeared to be variable for this unconsolidated deposit. The possible reasons for the variability of fundamental periods were attributed particularly to the variability of material properties including thickness of the alluvial sediment and density that led to the variability of the shear wave velocities of the sediments. It can also be concluded that the maximum amplifications observed at these fundamental periods were also relatively consistent with the geological setting of the research site. Considering the general distribution of site amplifications (H/V), the presence of the Quaternary sediments relatively amplified the ground motion larger than that in the surrounding older geologic units by a factor relatively ranging from 2 to 4. This confirmed the thickening of the unconsolidated alluvial sediments covering the seismic substratum which appeared to increase maximum amplification at some locations in the Younger Quaternary sediments throughout the flood water plains of the Ankara River.

EVALUATION OF THE RESULTS AND CONCLUSIONS

Methods and procedures from various engineering fields that were used in the course of this research included seismic hazard evaluations combined with site specific engineering geological, geotechnical and geophysical information to enable the development of seismic zonation studies for assessing the potential for respective hazards within the specified area. The study area lies within the major growing potential, present and future settlement province of Ankara. The sources of the past recent examples proved that significant seismic events have taken place in and around the Ankara basin that might affect Ankara and its surroundings. Therefore, the earthquake hazard assessment developed in this study proves to be important for one of the biggest cities and also the capital city of Turkey for preliminary seismic hazard evaluations, general land-use planning, and delineation of special study zones.

Along the purpose of this research, the geological properties of the sedimentary units in the Ankara basin have been investigated. Then, these sedimentary units were compared with the engineering geological, geotechnical and seismic site characterization studies to classify and characterize the soil deposits and the mean shear wave velocity and standard penetration resistances were used to develop site categories to account for site conditions according to design code of IBC-2003. Consequently, the regional site classification map of the Ankara Basin in regards to the site classes were prepared based on shear wave measurements resulting from this study to characterize the local site conditions. Regarding the site effects, the H/V spectrum results at the ground surface have been used to estimate the fundamental periods and amplification factors of the site. The processed Fourier spectrum results identified several factors that influences site response. Younger Quaternary sediments amplify ground motions at longer periods more than older Fluvial sediments due to the low-velocity deposits in the near-surface. Regarding the comparison of geotechnical and seismic data along with the H/V spectral ratios in Ankara basin, variation of the fundamental period map agreed with the maximum value of the amplification as well as with the seismic site characterization results (Figure 3). The higher amplification results at fundamental periods were observed along the Younger Quaternary sediments of the studied region which generally corresponded to the thicker unconsolidated materials that had low shear wave velocity characteristics in this unit. Hence these results appeared to complement and correlate seismic site characterization studies used in microzonation studies for reliably determining the local site character.

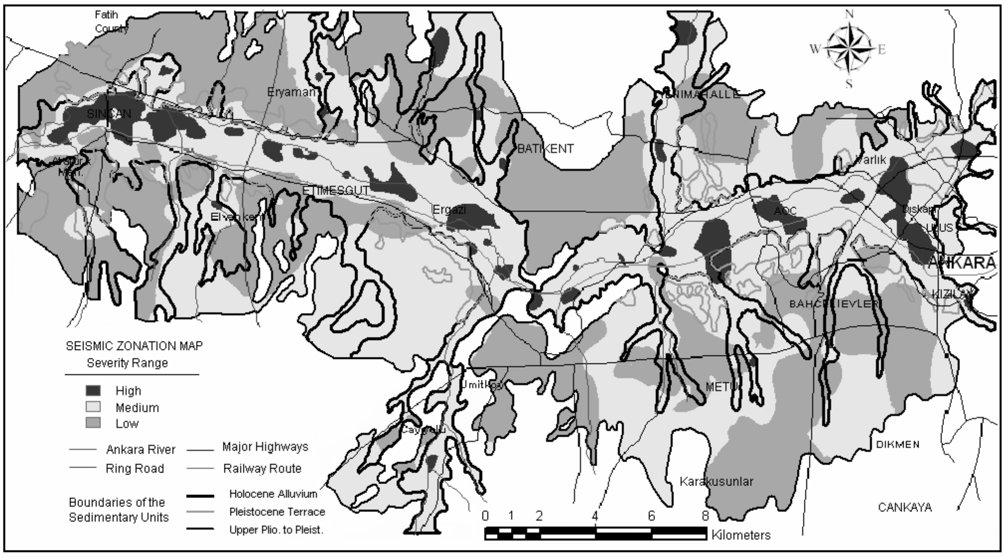

Figure 5. Seismic zonation map of the estimated seismic hazards in the Quaternary alluvial and Upper Pliocene to Pleistocene fluvial sediments towards the western part of the Ankara basin.

Finally, a regional seismic zonation map of the Ankara Basin was prepared to give preliminary seismic hazard evaluations based on site classification map of $V_s(30)$ resulting from this study; and the maps of H/V spectral ratios for the resonance periods and maximum amplifications observed at these fundamental periods over the Ankara basin (Koçkar, 2006; Figure 5). The final seismic zonation mapping study showed that the areas which are classified as a severity range of "High" would be most adversely affected during a probable seismic hazard event where additional site-specific studies might be required before major development is approved. The areas which are classified as a severity range of "Medium" would be the moderately affected and the areas which are classified as a severity range of "Low" are the areas that would be less affected with probable seismic hazard events and these areas could be considered to be more suitable for urbanization. Then, these results may be applied to more elaborative and detailed studies, particularly microzonation studies such as in areas of "High Severity"

Sites that are seismically more critical than the areas of "Medium Severity" and "Low Severity" Sites and also areas that have higher urbanization potential. It is important to stress that these results were based on the extensive research that were estimated by using the available in-situ data based on the site characterizations and evaluation of the site effects studies and this particular seismic zonation procedure could be considered to be one of the best methodologies for assessing the local site conditions that is to be solely used for regional seismic design purposes.

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