EVALUATION OF SITE CONDITIONS FOR THE ANKARA BASIN OF TURKEY BASED ON SEISMIC SITE CHARACTERIZATION

M.K. Koçkar[1], H. Akgün[2], E.M. Rathje[3]

[1] *Ph.D., Earthquake Research and Implementation Center, Gazi University, Ankara, Turkey*
[2] *Professor, Dept. of Geological Engineering, Middle East technical University, Ankara, Turkey*
[3] *Assoc. Professor, Dept. of Civil, Architectural and Environmental Engineering, University of Texas at Austin, Texas, USA*
Email: mkockar@gazi.edu.tr, hakgun@metu.edu.tr, e.rathje@mail.utexas.edu

ABSTRACT: Regional site conditions relevant for seismic hazard studies can be derived from various geologic, seismologic, and geotechnical sources. In this study, site conditions are derived for the Ankara Basin in Turkey by merging in-situ seismic measurements of dynamic properties, geologic information, and some geotechnical boring information. Field seismic surveys were performed at 259 sites in the project area to classify and characterize Plio-Pleistocene fluvial deposits and Quaternary alluvial and terrace deposits. The average shear wave velocities in the upper 30 m ($V_s(30)$) of the near-surface geologic units were used to characterize site classes according to the International Building Code (International Code Council, ICC 2006). The measured shear wave velocities of the near-surface geologic materials were utilized to develop a regional $V_s(30)$ model for identifying local site conditions and for differentiating the characteristics of the geologic units in the western part of the Ankara basin. However, these data show that the geologic units cannot be directly assigned to site classes; hence, the distribution of shear wave velocity within a geologic unit may spread across multiple site classes, making site class determination based on geologic unit alone inaccurate.

KEYWORDS: Site characterization, Seismic zonation, Seismic hazard assessment, Shear wave velocity, Ankara basin, Turkey

1. INTRODUCTION

This paper presents regional information regarding the site conditions within the Ankara basin of Turkey, an area adjacent to the Turkish capital of Ankara. Evaluation of the site conditions within the Ankara basin started with an assessment of the local geologic formations and mapping of the surface geology based on available sources of information. Geologic units were defined and mapped on the basis of depositional characteristics with the purpose of determining the boundaries between units and the characteristics of each formation. The data from the geologic map were augmented with the data from detailed site investigations and in-situ seismic surveys performed as part of this study. Specifically, shear wave velocity measurements were performed, particularly in the Quaternary alluvial sediments of the Ankara basin (Koçkar, 2006), and these shear wave velocities are used to characterize the geologic units for evaluating local site conditions. Therefore, the average shear-wave velocity in the upper 30 m ($V_s(30)$) were used to classify a soil profile into one of the site classes defined in the International Building Code, IBC (ICC, 2006). Defining the geographic distribution of $V_s(30)$ and site classes has proved to be useful for future zonation studies because site amplification factors were defined as a function of these parameters, such that the effect of site conditions on ground shaking could be taken into account. Using the shear wave velocity data within each of the mapped geologic units, the relationships between geologic unit, thickness of Quaternary deposits, $V_s(30)$, and site class were investigated. The collected data and relationships were used to develop maps of $V_s(30)$ and site class that could be used in zonation studies.

2. STUDY AREA

2.1. General Setting and Seismicity

Ankara, the capital city of Turkey with a population of about 5.1 million, is located at an intersection point of highways connecting east to west and north to south of Anatolia. The study area is located in the Ankara basin towards the west of the center of the city in an approximately ENE-WSW-trending, 25-30 km long, and 10-15 km wide fault-bounded depression that drains from east to west direction through the Ankara River. The study area lies within the major growth potential for Ankara and has been moderately to densely populated with mostly residential structures and small to large industrial buildings (Fig. 1).

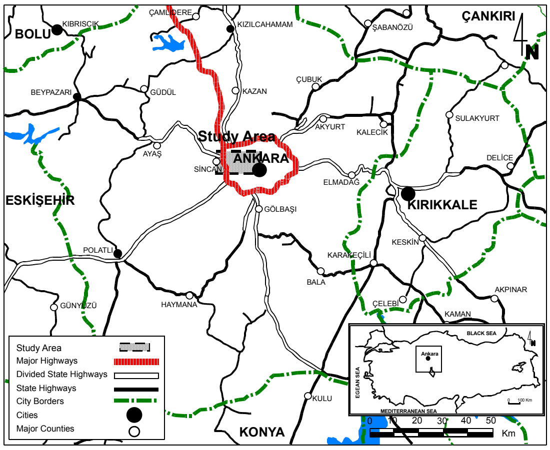

Figure 1 Location map of the research area situated towards the western part of the city center of Ankara

The faults in the Ankara basin are seismically active but are only capable of producing smaller earthquakes (M < 5). Recent seismic activity within about 50 to 75 km of Ankara includes the June 6, 2000 Orta earthquake and its aftershocks (M_D=5.9, 5.2 and 5.0; KOERI, 2006); the July 31-August 9, 2005 Bala earthquake series (M_L=5.3, 4.8 and 4.6; KOERI, 2006); and the December 12 - 27, 2007 Bala earthquake series (M_L=5.7 and 5.5; DEPAR, 2007). These earthquakes are relatively moderate seismic events that might affect Ankara. On a regional scale, the Ankara region can be affected by the surrounding large-scale fault systems, particularly the North Anatolian Fault System (NAFS), Salt Lake Fault Zone (SLFZ) and Seyfe Fault Zone (SFZ), which are capable of producing large destructive earthquakes (M > 7.0; Koçyiğit, 1991; Koçkar, 2006). Some of the prominent examples of major events that have occurred along these systems around the Ankara region are the November 26, 1943 Kastamonu earthquake (M_L=7.3), the February 1, 1944 Gerede earthquake (M_L=7.3), and the August 13, 1951 Çankırı earthquake (M_L=6.9) along the NAFS, and the March 19, 1938 Taşkovan-Akpınar earthquake along the SFZ (M_L=6.6).

2.2. Geology and Subsurface Sediment Characteristics

The geologic units outcropping in the region range from Pre-Upper Miocene to Quaternary in age. The developed 1:25,000 geologic map subdivides the surface geology into four main units: (1) Pre-Upper Miocene to Lower Pliocene basement rocks, (2) Plio-Pleistocene fluvial deposits, (3) Quaternary terrace deposits, and (4) Quaternary alluvial deposits (Fig. 2). This study focuses on the characteristics of the three younger sedimentary units, known collectively as Ankara Clay (Ordemir et al., 1965).

2.2.1. Plio-Pleistocene fluvial deposits

The Plio-Pleistocene fluvial deposits show a continental origin and have accumulated in and near the fault-bounded basins of the study area (Fig. 2). The fluvial sediments generally reflect the source of their basement rock type and their physical appearance varies from one location to another. Fine lacustrine interlayers are encountered within these units and calcareous concretions occur near the surface (Erol, 1973; Erol et al., 1980; Kasapoğlu, 1980). The geologic unit appears to be preconsolidated in the upper layers due to desiccation

(Ordemir et al., 1977), and is observed to be intercalated with Quaternary sediments (particularly terrace sediments) at outlets of the basin. The activity and clay content of the Plio-Pleistocene fluvial sediments are relatively higher than the Quaternary sediments, and they display higher swelling potential (Birand, 1963; Lohnes, 1974; Sürgel, 1976). Index properties of these deposits are highly heterogeneous, as they contain silt, sand and gravel particles in forms of layers and lenses, but they are classified generally as high-plasticity clay (CH) according to the USCS. Their thicknesses range from a few meters to 200 m based on their stratigraphic position (DSİ, 1975; Erol et al., 1980). Water-bearing strata are not encountered most probably due to the considerable clay content of the sediments.

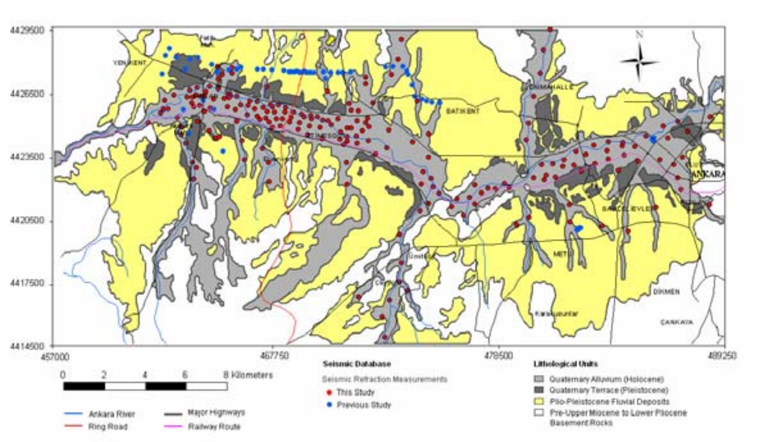

Figure 2 Study area with geologic units and locations of seismic measurements (geological features modified from Akyürek et al. (1997) and Erol et al. (1980) by field studies performed and reported in Koçkar, 2006)

2.2.2. Quaternary alluvial and terrace deposits

The Quaternary alluvial and terrace sediments were deposited by flood waters on the flat flood plains of the Ankara River in the fault-bounded Ankara basin (Fig. 2). The Quaternary deposits are differentiated as terrace deposits, present at the margins, and alluvium (Holocene), present at the stream beds. The outcrops of Quaternary terrace deposits comprise a relatively small area and cover several step-like river terraces along the margins of the Ankara basin (Fig. 2). It is difficult to differentiate the terraces from the Plio-Pleistocene fluvial sediments, especially at higher terraces which show similar sediment characteristics but are relatively less stiff. Therefore, step-like terraces are differentiated geomorphologically based on their elevations relative to the surrounding younger alluvium deposits (Erol et al., 1980). In this sense, the lowest terraces that are grey colored without calcareous concretions of gravels are differentiated as end of Quaternary (Pleistocene). The terraces are classified generally as high-plasticity clay (CH) with some low-plasticity clay (CL). The estimated thicknesses of these sediments generally vary from 5 to 10 m (DSİ, 1975; Koçkar, 2006). The Quaternary (Holocene) alluvial sediments are relatively thick and normally consolidated, soft deposits that are relatively more homogeneous than the other geologic units (Lohnes, 1974; Sürgel, 1976). The Quaternary alluvium sediments are classified predominantly as CL, with some CH and clayey sand (SC). The groundwater level ranges between 2 to 6 m (DSİ, 1975) and is gradually deeper beneath the terrace and older deposits bordering the basin. Generally, the thickness of the alluvial deposits range between 5 m and 30 m (Erol, 1973; Kasapoğlu, 1980; Koçkar, 2006).

3. FIELD TESTING AND DATA ANALYSIS

During the subsurface geologic exploration and engineering site characterization study, seismic refraction testing was conducted predominantly in the Quaternary alluvial and terrace sediments, with some sites located in the Plio-Pleistocene fluvial sediments. Near-surface shear-wave velocities were measured at a total of 204 project site locations (Fig. 2; Koçkar, 2006). The data collected as part of this study were expanded by compiling results from seismic testing conducted previously towards the west of the city center of Ankara. These existing data include 55 locations that were tested in connection with municipal and private construction projects in the study area. A Geographic Information System (GIS) was used to merge the various data, assess the spatial extent of soil characteristics, and classify the sites for seismic zonation and site-condition evaluations. The shear wave velocity profiles developed from the refraction surveys were used to calculate $V_s(30)$ based on the travel time of a shear wave through the top 30 m of material using:

$$V_s(30) = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \frac{d_i}{V_{si}}} \tag{1}$$

where V_{si} is shear wave velocity (m/s) of layer i and d_i is the thickness of layer i. Ultimately, the values of $V_s(30)$ were used to assign site classes from the site classification system of IBC (2006), as shown in Table 1.

Table 1 IBC Site Class Definitions Using the Average Shear Wave Velocity to 30 m (ICC, 2006)

SITE CLASS	SOIL PROFILE NAME	AVERAGE PROPERTIES IN TOP 30 m
		Soil shear wave velocity, V_s (30), (m/s)
A	Hard rock	V_s *(30)* > 1,500
B	Rock	7,600 < V_s *(30)* ≤ 1,500
C	Very dense soil and soft rock	360 < V_s *(30)* ≤ 760
D	Stiff soil profile	180 ≤ V_s *(30)* ≤ 360
E	Soft soil profile	V_s *(30)* < 180

4. SHEAR-WAVE VELOCITY RESULTS

4.1. General Site Conditions across Study Area

To analyze the site classification results, the distribution of $V_s(30)$ for the Quaternary deposits and Plio-Pleistocene fluvial deposits were compiled and statistically investigated. The general distribution of site class according to the geologic descriptions and $V_s(30)$ is shown in Fig. 3. It is clear from Fig. 3 that the Plio-Pleistocene fluvial deposits are generally found at the upper end of the IBC site class D range, while the Quaternary deposits are generally found at the lower end of the IBC site class D range (Table 2).

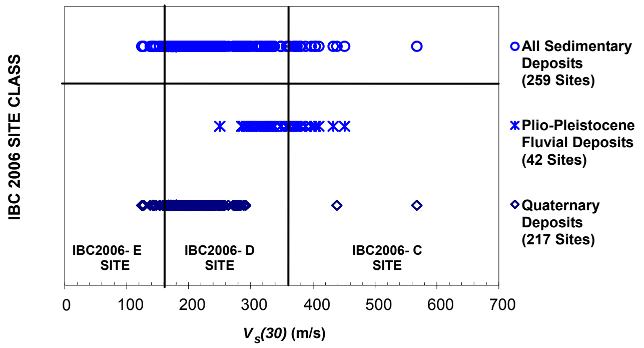

Figure 3 The general distribution of $V_s(30)$ and site classes for the different geologic units

Table 2 Description of the characteristics of generalized geologic units and their IBC site classes based on $V_s(30)$ data

Geologic Unit	Avg $V_s(30)$ (m/s)	Std Dev (m/s)	COV	# of Data	Percentage (%)	SITE CLASS (IBC 2006)
Quaternary alluvial and terrace deposits	202	34	0.17	0	-	CLASS B
				2	0.9	CLASS C*
				134	61.8	**CLASS D**
				81	37.3	**CLASS E**
Plio-Pleistocene fluvial deposits	343	42	0.12	0	-	CLASS B
				14	33.3	**CLASS C**
				28	66.7	**CLASS D**
				0	-	CLASS E

* Two sites with site class C in the Quaternary were not consistent with the other results due to artificial fill at these locations and hence were not included in the interpretation for site characterization.

It is observed in Fig. 3 and Table 2 that the distributions of $V_s(30)$ and the resulting site classes for the geologic units are variable. A major contributor to this variability is differences in sediment textures within a geologic unit due to differences in depositional environments. An interesting observation from Fig. 3 and Table 2 is that the majority of sites from both the Quaternary and Plio-Pleistocene deposits fall into site class D, despite the fact that the average $V_s(30)$ values for these geologic units are statistically very different. In fact, Fig. 3 indicates a more natural boundary between the Quaternary and Plio-Pleistocene deposits may be around 280 to 300 m/s. Additionally, both geologic units cross site class boundaries making direct relationships between geologic unit and site class difficult. Because the code-based site classes do not adequately distinguish these geologic units, it is important to maintain the geologic description along with the site class when developing information for ground motion studies.

4.1.1. Site conditions for Quaternary alluvial and terrace deposits

Average shear wave velocities for the Quaternary deposits were calculated for a total of 215 testing locations (Table 2). The mean shear wave velocity is 202 m/s, which is slightly larger than the velocity at the boundary between IBC site classes D and E, and the standard deviation is 34 m/s resulting in a coefficient of variation (COV) of 0.17. There are some reasons for this variability in the $V_s(30)$ results. The shear wave velocity of unconsolidated deposits depends on material properties, including grain size, depth, density, and ground water levels (Fumal, 1978), and as previously noted, these characteristics vary across a geologic unit. However, perhaps more important, is the fact that most of the testing points with younger (Holocene) alluvium at the surface are underlain by stiffer terrace deposits within the upper 30 meters of the site. For instance, some areas shown on a geologic map as alluvium may have only a thin layer of younger alluvium, which in turn is underlain by a different, stiffer material. Yet, the velocity of the stiffer material is used in the $V_s(30)$ calculation (Wills and Silva, 1998). Holocene alluvium in the Ankara basin is rarely more than 30 m thick and the transition from Holocene to Pleistocene or Holocene to terrace deposits is difficult to differentiate using surface seismic methods alone without any other supportive site characterization information (e.g., boring log with engineering geology descriptions). For this study, an attempt was made to identify the thickness of the Holocene alluvium using adjacent borehole data, where available (Koçkar, 2006). Because the Plio-Pleistocene fluvial deposits contain calcareous concretions, the presence of these concretions was used along with the stiffness of these sediments to identify the transition from Quaternary alluvium to Plio-Pleistocene deposits. The Quaternary terraces are generally stiffer than the Quaternary alluvium. However, the terraces prove difficult to differentiate from the Plio-Pleistocene fluvial sediments due to similar soil texture, especially for terraces at higher levels. However, the lowest terraces may be differentiated from the Plio-Pleistocene deposits because they do not contain calcareous concretions of gravel. Additionally, the terrace sediments are partly consolidated and tend to be softer than the surrounding older sediments. These lower terrace deposits were not observed to be more than 10 m thick; hence, considerable amounts of stiffer and more consolidated Plio-Pliocene sediments were encountered within the top 30 m and the resulting values of $V_s(30)$ are relatively higher when compared with the Quaternary alluvium. The mean shear wave velocity was 251 m/s and the $V_s(30)$ values ranged from 218 to 284 m/s. All of these sites are classified as site class D. Table 3 summarizes the statistical distribution of $V_s(30)$ for the Quaternary terrace and Quaternary alluvium test locations. It can be inferred from the Quaternary $V_s(30)$ results that the terraces are all IBC site class D, while the alluvium is at the boundary between IBC site classes D and E. The distribution of $V_s(30)$ within the alluvium is significantly influenced by the thickness of the surficial Quaternary alluvium sediments, which complicates the ability to assign site classes within this sedimentary unit based on geologic description alone.

Table 3 Summary of the statistical results of $V_s(30)$ for Quaternary deposit and each three site categories within these deposits

Geologic Unit	No. of Data	Percentage (%)	V_s (30) (m/s)				SITE CLASS (IBC 2003)	General Descriptions
			Mean	Std. Dev.	COV	Range		
Quaternary Deposits	215	100	202	34	0.17	125-292	D to E	Holocene-Upper Pleist.
Quaternary Alluvium (E-Sites)	81	37.7	169	13	0.08	125-180	E	Holocene
Quaternary Alluvium (D-Sites)	119	55.3	217	26	0.12	181-292	D	Holocene
Quaternary Terrace Deposits	15	7.0	251	24	0.10	218-284	D	Upper Pleistocene

4.1.2. Site conditions of Plio-Pleistocene fluvial sediments

The Plio-Pleistocene fluvial deposits are represented as an undifferentiated single unit on the general geologic map, and $V_s(30)$ data were calculated at a total of 42 testing locations (Table 2). At most of the testing locations where these Plio-Pleistocene fluvial deposits were observed at the surface, their thicknesses were determined to be more than 30 m and bedrock was not encountered within the top 30 m. At some locations, the Plio-Pleistocene deposits appeared to be intermixed with uplifted Quaternary terrace deposits at the outlets of the basin. Therefore, relatively younger and partly consolidated fluvial deposits may sometimes get confused with the Quaternary terrace deposits, especially at higher terrace elevations. The mean $V_s(30)$ for this unit is 343 m/s, while the standard deviation is 42 m/s and the COV is 0.12. This COV is smaller than that observed in the Quaternary deposits, and is most likely a result of the fact that the Plio-Pleistocene deposits extend beyond 30 m in depth. The velocity data reveal that the $V_s(30)$ values for this geologic unit range across the boundary for site classes C and D. As noted for the Quaternary deposits, this creates a problem when trying to assign site classes based solely on geologic mapping. Note that the number of $V_s(30)$ data for the Plio-Pleistocene deposits is small compared with the Quaternary deposits because the seismic testing was mainly aimed at Quaternary deposits that are more susceptible to seismic hazards. Therefore, there is more uncertainty in the assignment of site classes for the Plio-Pleistocene deposits than for the Quaternary deposits.

5. SEISMIC ZONATION MAP OF THE ANKARA BASIN

The shear wave velocity data assembled as part of this study have been synthesized for both Quaternary and Plio-Pleistocene sedimentary units in an effort to construct a map of $V_s(30)$ that can be used to assess site conditions for site response evaluations of the Ankara basin. The $V_s(30)$ data were contoured between testing locations to develop a map of $V_s(30)$ (Fig. 4). In general, smaller values of $V_s(30)$ are found towards the center of the alluvial valley, where the depth of alluvium is greatest. Larger values of $V_s(30)$ are observed within the alluvial tributaries and outside the alluvial basin. The $V_s(30)$ data can be used to develop a zonation map of IBC (2006) site classes. However, it is important to utilize geologic mapping and $V_s(30)$ data when developing this site class map because of the observed variability in velocity (e.g., Fig. 3). For instance, site class D Quaternary alluvium (average $V_s(30)$ = 217 m/s) displays different velocity characteristics than the Quaternary terraces (average $V_s(30)$ = 251 m/s) or the Plio-Pleistocene sediments (average $V_s(30)$ = 343 m/s). Fig. 5 displays the developed site class zonation map that incorporates geologic and $V_s(30)$ information. The majority of the study area is underlain by site class D, although these D sites have been separated into Plio-Pleistocene fluvial, Quaternary Terrace, and Quaternary Alluvium deposits to distinguish their unique velocity characteristics. The issue related to distinct geologic units with overlapping site class assignments, despite significant differences in the velocity characteristics within each geologic unit, was also mentioned by Holzer et al. (2005) and Wills et al. (2000) as a deficiency in the definition of $V_s(30)$ boundaries of the code-based site classes. Outside the areas identified as site class D are some small areas of site class C within the Plio-Pleistocene fluvial sediments. Locations of site class E are concentrated within the center of the alluvial basin, but they do not systematically appear throughout the basin. Again, this demonstrates the importance of field measurements of shear wave velocity to supplement geologic mapping when developing site class zonation maps.

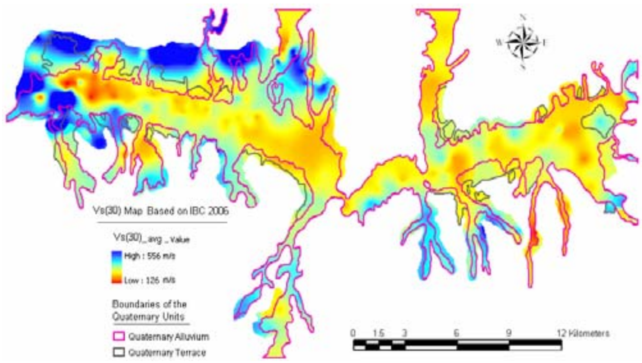

Figure 4 The regional seismic zonation map based on measured values of $V_s(30)$

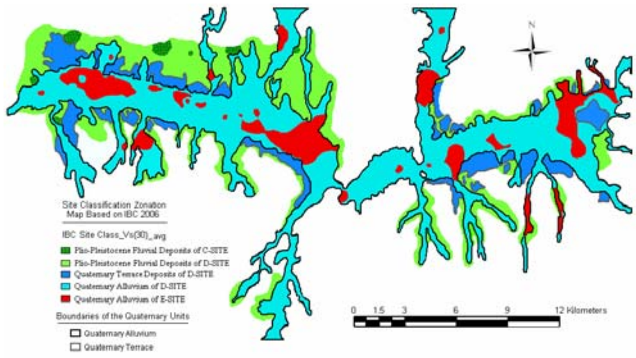

Figure 5 Regional IBC (2006) site class zonation map of the Ankara basin based on measured values of $V_s(30)$ and geologic units

6. CONCLUSION

Site-specific geologic and geotechnical site information were used to develop site class information for the western part of the Ankara basin in Turkey. The study area lies within the major metropolitan growth areas in the province of Ankara. Significant seismic events have taken place around the Ankara basin, implying that Ankara and its surroundings are susceptible to future seismic events. Therefore, this study is important for the capital of Turkey for preliminary seismic hazard evaluations, general land-use and urban planning, and delineation of special study zones where additional geo-engineering site characterization studies may be required. The geologic character of the sedimentary units were investigated and compared, along with seismic site characterization studies to interpret the sediment characteristics and classify the soil deposits. Quaternary sediments were differentiated into two units, namely Quaternary Alluvium at the boundary between site classes D and E, and terrace Deposits of site class D. Similarly, measurements for the Plio-Pleistocene deposits in the Ankara basin led to a classification at the boundary between site class C and D. However, it must be noted again that although sites may be placed in the same site class, their $V_s(30)$ values may be significantly different based on the geologic unit. For example, Quaternary deposits of site class D and fluvial deposits of site class D display significantly different $V_s(30)$ characteristics, and thus these sites are identified separately in (Fig. 5). In addition, as observed from Fig. 3, it appears that there is a natural delineation between these geologic units at about 280-300 m/s. Both seem to be normally distributed, but not within the IBC class definitions. Therefore, $V_s(30)$ distribution of geologic units may seem to separate themselves differently than IBC site classes and need to be revised in code-based site classes to utilize geological mapping units more effectively. Finally, the developed site classification map is suitable for assessing local site conditions only for regional design purposes. This study shows that the areas which are classified as site class E will be subjected to the largest level of amplification potential at lower levels of shaking and will be the most adversely affected areas during a future seismic hazard event. However, additional site-specific studies should be performed in these areas to accurately describe the potential level of ground shaking. In the future, the developed zonation maps may be used with more elaborate and detailed geo-engineering studies, particularly microzonation studies such as in areas of site class E and areas that have higher urbanization potential.

ACKNOWLEDGMENT

The financial support of this study was provided by the Middle East Technical University Research Fund Project (BAP-2004-03-09-01). We would like to express our appreciation to many others who are not mentioned here but who have contributed this paper.

REFERENCES

Akyürek, B., Duru, M., Sütçü, Y.F., Papak, İ., Şaroğlu, F., Pehlivan, N., Gönenç, O., Granit, S. and Yaşar, T. (1997). The surrounding geology of the city of Ankara and natural resources project (the geology group studies in 1994), MTA compilation no. 9961 (in Turkish, unpublished).

Birand, A.A. (1963). Study characteristics of Ankara clays showing swelling properties. MSc. Thesis, Middle East Technical University, Department of Civil Engineering, Ankara, 39 p.

DEPAR (2007). Gazi University, Earthquake Research and Implementation Center. Earthquake Records. http://www.deprem.gazi.edu.tr

DSİ. (1975). Hydrogeological Report of Hatip Plain. General Directorate of the State Hydraulic Works, Geotechnical Service and Groundwater Chief Office Publication, 40 p.

Erol, O. (1973). Geomorphological outlines of the Ankara area (Summary). Map 1:100.000. Ankara University, D.T.C.F. Publication, No:16, Geomorphology Maps, Ankara, No.1, 29 p.

Erol, O., Yurdakul, M.E., Algan, Ü., Gürel, N., Herece, E., Tekirli, E., Ünsal, Y. and Yüksel, M. (1980). Geomorphological map of Ankara. MTA report no: 6875, 300 p (in Turkish).

Fumal, T.E. (1978). Correlations between seismic wave velocities and physical properties of near-surface geologic materials in the southern San Francisco Bay region, California. U.S. Geol Surv Open-File Rept., 78-1067.

Holzer, T.L., Padovani, A.C., Bennett, M.J., Noce, T.E. and Tinsley, J.C. (2005). Mapping NERPH V_S30 site classes. *Earthquake Spectra* **21:2**, 353-370.

International Code Council, ICC. (2006). International Building Code. Structural and fireand life-safety provisions (seismic, wind, accessibility, egress, occupancy and roof codes), Whittier, CA.

KOERI. (2006). Kandilli Observatory and Earthquake Research Institute. Earthquake Records. http://www.koeri.boun.edu.tr/sismo/map/tr/index.html

Kasapoğlu, K.E. (1980). Geo-engineering properties of the city of Ankara foundation soils. Associate Professorship Thesis, Hacettepe University, Geological Engineering Department, Beytepe, Ankara (in Turkish).

Koçkar, M.K. (2006). Engineering geological and geotechnical site characterization and determination of the seismic hazards of Upper Pliocene and Quaternary deposits situated towards the west of Ankara. Ph.D. Dissertation, Middle East Technical University, Ankara, 401 p.

Koçyiğit, A. (1991). Changing stress orientation in progressive intercontinental deformation as indicated by the neotectonics of Ankara Region, NW Central Anatolia. *TAPG Bulletin* **31**, 43-55.

Lohnes, R. (1974). Geological report on Ankara Clay. METU Department of Civil Engineering, Ankara (unpublished).

Ordemir, İ., Alyanak, I. and Birand, A.A. (1965). Report on Ankara Clay. Middle East Technical University Publication, No.12, Ankara, 30 p.

Ordemir, İ., Soydemir, C. and Birand, A. (1977). Swelling Problems of Ankara Clays. In: 9th Intentional Conference of Soil Mechanics and Foundation Engineering, Tokyo, Vol.1, 243-247.

Sürgel, A. (1976). A survey of the geotechnical properties of Ankara soils. M.S. Thesis, METU Civil Engineering Department, 96 p.

Wills, C.J., Petersen, M., Bryant, W.A., Reichle, M., Saucedo, G.J., Tan, S., Taylor, G. and Treiman, J. (2000). A site-conditions map for California based on geology and shear wave velocity. *Bull Seism Soc Am*. **90: 6B**, S187-S208.

Wills, C.J. and Silva, W. (1998). Shear wave velocity characteristics of geologic units in California. *Earthquake Spectra* **14**, 533-56.