ERRATUM

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ORIGINAL ARTICLE

Development of a geotechnical and geophysical database for seismic zonation of the Ankara Basin, Turkey

Mustafa K. Koçkar · Haluk Akgün

Abstract Engineering geological and geotechnical site characteristics were assessed and seismic hazard studies performed for the Upper Pliocene to Pleistocene fluvial and Quaternary alluvial and terrace deposits for a site west of Ankara, Turkey. Sediment conditions were determined and a soil profile was characterized by surface geophysical methods. These studies were integrated with existing in-situ characterization studies to create a seismic and geo-technical database for the site. A seismic zonation map of the site was then prepared. Site classification systems were assigned to account for site effects in relation to seismic hazard assessments. The consequences of the seismic hazards were investigated and recommendations were presented.

Keywords Seismic zonation · Seismic hazard assessment · Seismic and geotechnical site characterization · Correlations of in-situ measurements · Quaternary sediments · Ankara · Turkey

Introduction

To perform seismic hazard assessments, sufficient engineering geological, geotechnical and geophysical information must be available for the analyses and characterization of earthquake hazards. Various seismic hazard evaluations must be combined with site specific geo-engineering information to develop seismic zonation studies. The objective of this study, the first prototype research in the sedimentary deposits in the western part of Ankara, was to integrate a variety of databases with invasive and non-invasive field testing results to identify and map seismic hazards (Koçkar 2006). The study started with assessment of local site conditions by distinguishing the geological formations based on information complied from previous studies; including topographic maps, geologic maps, geo-morphologic maps and boring data. Geologic units were mapped to determine boundaries and characteristics on a 1:25,000 scale. The geotechnical seismic database was intended to evaluate areal differences and characterize local site conditions of sediments. Hence, Upper Pliocene to Pleistocene fluvial and Quaternary alluvial and terrace deposits were differentiated based on geotechnical seismic data obtained from boreholes (i.e., standard penetration test results, along with the laboratory testing studies) and seismic refraction testing (i.e., shear wave velocity measurements) (Koçkar 2006). The average shear wave velocities and standard penetration test results in the upper 30 m of near-surface geologic units were assessed to characterize geological units according to the design code of the IBC 2006 (International Code Council; ICC 2006). Accurate depictions of near-surface shear wave velocity useful for predicting site response were taken into account by correlating shear wave velocity with the standard penetration resistance of the sediments through regression equations. In particular, surface wave velocities were measured to develop a regional V_s model for the site classes. Finally, a seismic hazard assessment map was developed to summarize the potential for hazards and to indicate areas that require further detailed geo-engineering investigation.

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Location

The seismic hazard assessment studies investigated the earthquake hazard potential of an area of about 300 km^2 west of Ankara, the capital city of Turkey. Ankara has a population of about 3.69 million and is at an intersection of highways connecting east to west and north to south. The study area lies in the Ankara basin and 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 includes zones with population growth potential, as well as settled zones in the province of Ankara. The area is generally moderately to densely populated, mostly residential, but with some small to large industrial buildings (Fig. 1).
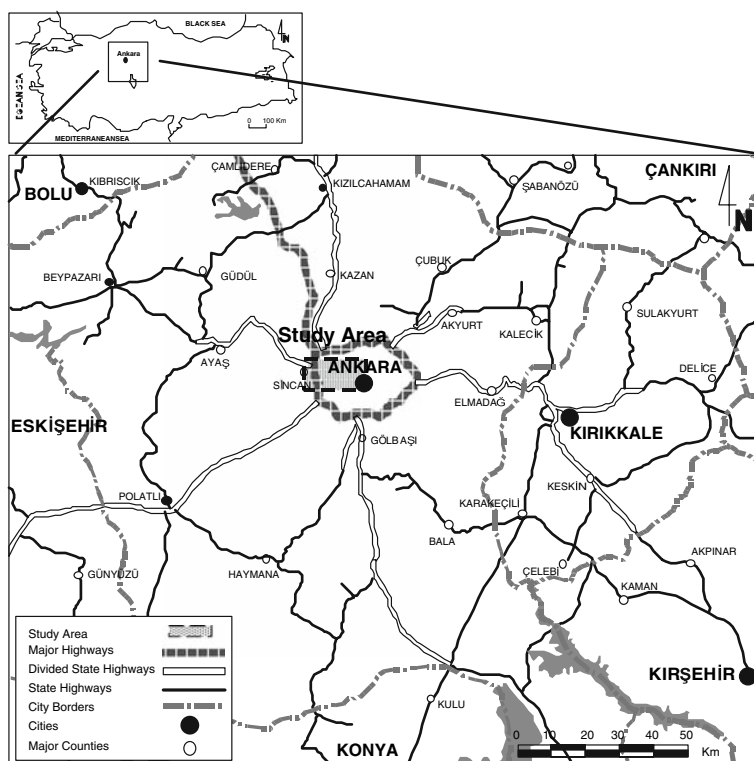
Geology and subsurface sediment characteristics

Rock units outcropping range from the Triassic to Quaternary. The older rock units in the Ankara region are highly deformed pre-Upper Miocene basement rocks and Upper Miocene–Lower Pliocene rocks (Fig. 2). They are overlain unconformably by the Triassic schists and grey-wackes with carbonate blocks, Liassic clastics and Upper Jurassic–Lower Cretaceous limestones and the Upper Miocene–Lower Pliocene volcanics, fluvial–lacustrine

sedimentary rocks from bottom to top (Akyürek et al. 1997). The younger stratigraphic rock units in the region are overlain uncomformably by the neotectonic Upper Pliocene to Pleistocene fluvial red clastics and Quaternary alluvial and terrace deposits (Fig. 2). In this study, the geological and depositional characteristics of the sedimentary units known as Ankara Clay (Ordemir et al. 1965) were described in detail.

The Upper Pliocene to Pleistocene fluvial sedimentary units with an areal extent of about 200 km^2 cover a major part of the western part of the Ankara basin. These fluvial sediments have a continental origin near the fault-bounded basins (Fig. 2). Their slope gradually increases towards the older deposits and ranges between 3° and 8° in slope. These fluvial sediments generally reflect the source of their basement type. Their physical appearance changes from one location to another. Fine lacustrine interlayers are encountered and calcareous concretions occur near the surface of the basins (Erol 1973; Erol et al. 1980; Kasapoğlu 1980). They appear to be preconsolidated in the upper layers due to desiccation (Ordemir et al. 1977) and are intercalated with Quaternary sediments (particularly terrace sediments) at outlets of the basin. However, relative activity and clay content of these sediments are higher than the Quaternary sediments. Index properties of these deposits possess a highly heterogeneous structure and appearance, as they contain silt, sand and gravel particles in the forms of layers and lenses. Fluvial deposits have higher

Fig. 1 Location map of the research area that is situated towards the western part of the city center of Ankara
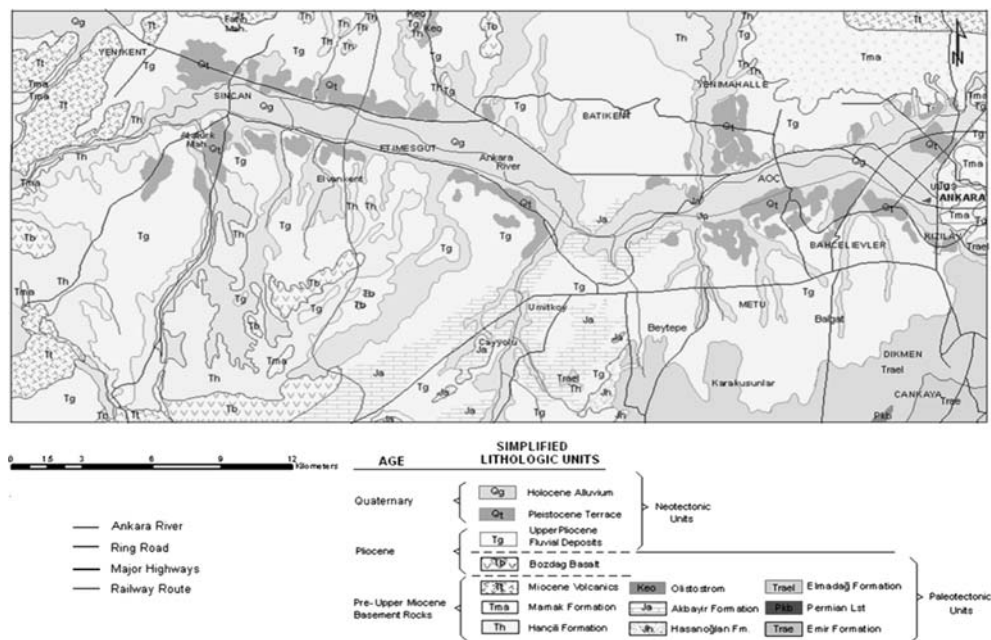
Fig. 2 Major geological features of the study area (modified from Akyürek et al. 1997; Erol et al. 1980 by Koçkar 2006)

swelling potential than the Quaternary sediments (Birand 1963; Lohnes 1974; Sürgel 1976). These indurated stiff sediments are classified as generally CH according to the Unified Soil Classification System. Water-bearing strata are not encountered owing to the considerable clay content of the sediments. Their thicknesses range from a few meters to 200 m based on their stratigraphic position (DSİ 1975; Erol et al. 1980).

The Quaternary alluvial and terrace sediments cover a flat area of about 105 km^2 in the Ankara basin (Fig. 2). They are differentiated as older terrace deposits in the margins and younger alluvium in the stream beds (Erol 1993). The slope of the Quaternary deposits is generally less than about 3° towards the older terrace deposits. The outcrops of Quaternary terrace deposits which are Upper Pleistocene in age comprise a relatively smaller area and cover several step-like river terraces along the margins of the Ankara basin (Fig. 2). It is difficult to differentiate the terrace sediments from the Upper Pliocene to Pleistocene fluvial sediments, which show similar sediment characteristics but are relatively less stiff due to their depositional and geomorphological character. The estimated thicknesses of these sediments generally vary from 5 to 10 m (DSİ 1975; Koçkar 2006). The Quaternary alluvial sediments are rather thick and Holocene in age (Fig. 2). These are normally consolidated deposits and their parent materials vary as in Upper Pliocene to Pleistocene and Quaternary terrace deposits, but are relatively more homogeneous, depending on the nature of the rock and soils (Lohnes 1974; Sürgel 1976). These softer sediments are classified as generally

CL and partly CH according to the Unified Soil Classification System. The groundwater level in the inner basin is close to the surface in general, though it varies within the alluvium. It is gradually deeper beneath the terrace and older deposits bordering the basin and ranges between 2 and 6 m (DSİ 1975). The thickness and width of the recent alluvial deposits along the Ankara River and its major tributaries range between 5 and 30 m and between 0.2 and 3 km, respectively (Erol 1973; Ordemir et al. 1977; Kasapoğlu 1980; Koçkar 2006).

Seismotectonics

The N-S trending, approximately 150 km wide and 250 km long Ankara region includes various earthquake centers related to the northern and southern Anatolian ranges and faults (Koçyiğit 1991; Fig. 3). It delineated by the right lateral strike-slip fault systems Kesikköprü Fault Zone and Seyfe Fault Zone (SFZ) in the east, the oblique-slip normal Salt Lake Fault Zone (SLFZ) in the southeast, the İnönü-Eskişehir Fault Zone in the west–southwest, and the right lateral strike-slip North Anatolian Fault System (NAFS) in the north. The seismic events associated with the faults around Ankara are of rather short extent and seismically active but are capable of producing frequent small earthquakes. These fault zones (FZ) and fault are the Ilıca FZ, Çeltikçi FZ, Dodurga FZ, Kesikköprü FZ, Çubuk FZ, Balaban FZ, Kızılırmak FZ and Kalecik Fault (Fig. 3). However, some of the recent seismic activities in this
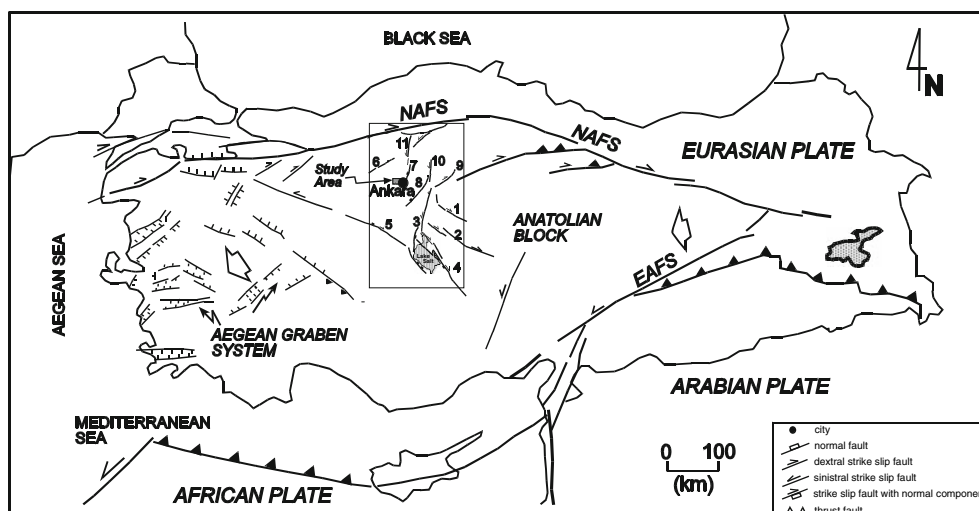
Fig. 3 Simplified seismotectonic map showing the outline of the Ankara region and its vicinity (*rectangle* magnifies the area) and some of the major neotectonic structures of Turkey [*1* Seyfe FZ, *2* Salanda FZ, *3* Kesikköprü FZ, *4* Salt Lake FZ, *5* Eskişehir FZ (Ilıca FZ), *6* Çeltikçi FZ, *7* Çubuk FZ, *8* Balaban FZ, *9* Kızılırmak FZ, *10* Kalecik FZ, *11* Dodurga FZ (compiled from Koçyiğit 1991, 2003)]

region, namely the 6 June 2000 Orta earthquake ($M = 5.9$ and two aftershocks of $M = 5.2$ and 5.0; Kandilli Observatory and Earthquake Research Institute, KOERI 2005) along the Dodurga FZ; and 31 July 2005–9 August 2005 series of Bala earthquake (particularly Ml = 5.3, 4.8 and 4.6; KOERI 2005) along the southern end of the Kesikköprü FZ indicate that some of these fault zones are capable of producing relatively moderate seismic events that might affect Ankara (Fig. 4). On a regional scale, the Ankara region might be affected from the surrounding large-scale fault systems, especially the North Anatolian Fault System (NAFS), Salt Lake Fault Zone (SLFZ) and Seyfe Fault Zone (SFZ) that have the capability to produce large, destructive earthquakes ($M > 6.0$). Hence, significant seismic events along these systems might affect Ankara and its surroundings and have to be considered in seismic hazard assessment. Some of the prominent examples of major events that have occurred along these systems around the Ankara region are the 26 November 1943 Kastamonu earthquake (Ml = 7.3); 1 February 1944 Gerede earthquake (Ml = 7.3) and 13 August 1951 Çankırı earthquake (Ml = 6.9) along the NAFS, and 19 March 1938 Taşkovan-Akpınar earthquake along the SFZ (Fig. 4; KOERI 2005).

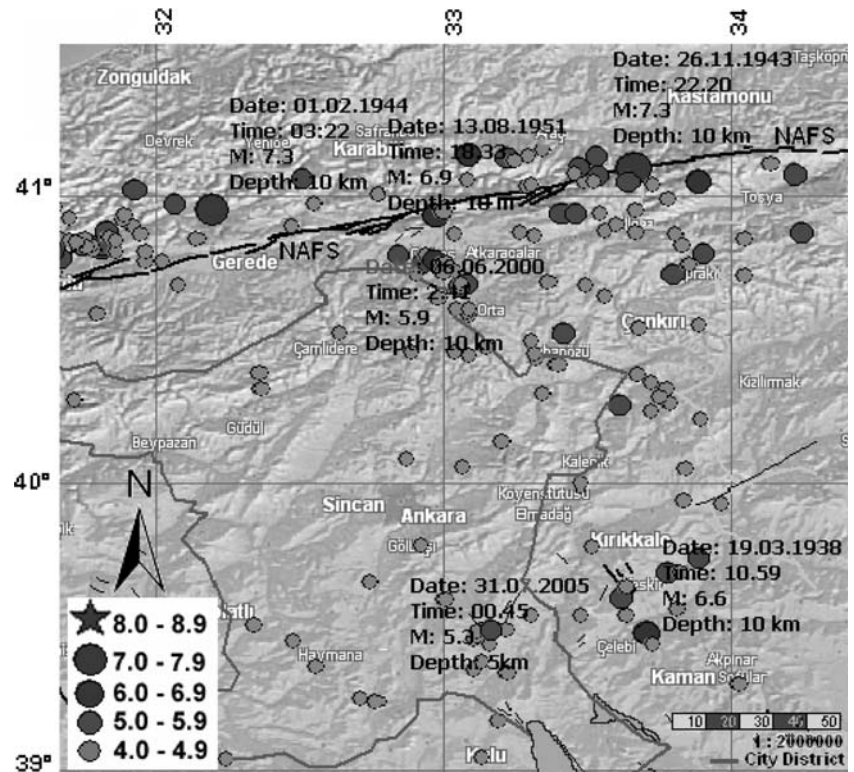## Geotechnical and seismic site characterization studies

Methodology

The distribution of damage caused by ground movement reflects local geology and soil conditions. Site conditions are one of the important parameters for assessment of seismic shaking hazard (Wills et al. 2000). Shear wave velocity is a critical factor to identify stiffness of the sediment in determining the amplitude of ground motion (Joyner and Fumal 1985; Boore et al. 1993; Anderson et al. 1996) and might be a useful parameter to characterize local geologic conditions quantitatively for calculating site response (Tinsley and Fumal 1985; Park and Elrick 1998; Wills et al. 2000). As an alternative, relations between shear wave velocity and several other physical properties (i.e., standard penetration resistance) can be identified, which can be mapped more readily on a regional scale (Fumal 1978; Fumal and Tinsley 1985). By using the method of assigning shear wave velocities to the mapped geologic units, the engineering geological and geotechnical parameters that show correlations with shear wave velocity are texture and standard penetration resistance for unconsolidated sedimentary deposits. These correlations can be applied to areal distribution, physical properties and thickness of the geologic units to estimate and map shear wave velocity potential that is useful for seismic zonation studies.

The method herein identifies soil profiles in site characterization and merges in-situ measurements of dynamic properties with geologic information, especially surface seismic methods according to design code of IBC 2006. Recent seismic code provisions have adopted site classification using average shear wave velocity and standard penetration results in the upper 30 m of a site as the sole parameter for site classification (Borcherdt 1994; Borcherdt and Glassmoyer 1994; Dobry et al. 2000). The site conditions specified by IBC 2006 (Table 1) are identical to the provisions of IBC 2003, and practically distinguishes soil profiles in five main categories. Each category is

Fig. 4 The distribution of
epicenters for major
earthquakes in the Ankara
region and its surroundings
since 1900 with magnitudes
greater than 4.0 (seismic data
were obtained from KOERI
2005)

assigned factors appropriate for the site conditions. The
average shear wave velocity and correlated index mea-
surements of the average standard penetration resistance to
30 m [$V_s(30)$ and $N(30)$] have been calculated in accor-
dance with Eqs. (1) and (2) below, and then used to
develop categories for local site conditions.

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

$$N(30) = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \frac{d_i}{N_i}} \tag{2}$$

where V_{si} is the shear wave velocity (m/s), N_i is the standard
penetration resistance (ASTM D 1586–84) not exceeding
100 blows/0.3 m as directly measured in the field without
corrections and d_i is the thickness of any layer between 0
and 30 m.

During the site characterization study, near-surface
seismic refraction measurements of shear waves were per-
formed at 204 locations and compiled with existing data
from 55 locations by previous studies in Quaternary alluvial
and terrace and Upper Pliocene to Pleistocene fluvial sedi-
ments (Koçkar 2006; Fig. 5). A total of 191 seismic profiles

extended to at least 30 m, while 68 profiles (8% of the
conducted data and 95% of the compiled data) penetrated
between 20 and 30 m. The extrapolation method entitled
"extrapolation assuming constant velocity" as proposed by
Boore (2004) was utilized for shear wave velocity data that
did not reach down to a depth of 30 m. The general distri-
bution of the site characterization data according to
geological settings and average shear wave velocity in the
upper 30 m [$V_s(30)$] are shown in Fig. 6. The engineering
geological and geotechnical site characterization study was
accomplished by in-situ tests. Data from 913 borings,
including standard penetration test results for depths equal
to or greater than 20 m, were compiled from previous
subsurface engineering studies by credible public and pri-
vate sources cited in Koçkar 2006 (Fig. 5). About one-third
of the profiles (298 profiles) extended less than 30 m deep.
The general distribution of site characterization data
according to geological settings and average standard pen-
etration results in the upper 30 m [$N(30)$] are shown in
Fig. 7. The compiled standard penetration test data was not
as well distributed as the seismic testing studies over the
project area and included different geologic materials with
relatively larger volumes of data in the Upper Pliocene to
Pleistocene fluvial deposits. Hence, surface wave mea-
surements have been conducted primarily in the Quaternary
alluvial sediments to develop a consistent and well-dis-
tributed database for seismic hazard calculations.

Table 1 IBC 2006 site class definitions using the average shear wave velocity and the average standard penetration resistance to 30 m (ICC 2006)

Site class	Soil profile name	Average properties in top 30 m	
		Soil shear wave velocity, V_s (m/s)	Standard penetration resistance, N (blows/0.3 m)
A	Hard rock	$V_s > 1{,}500$	N/A
B	Rock	$7{,}600 < V_s \le 1{,}500$	N/A
C	Very dense soil and soft rock	$360 < V_s \le 760$	$N > 50$
D	Stiff soil profile	$180 \le V_s \le 360$	$15 \le N \le 50$
E	Soft soil profile	$V_s < 180$	$N < 15$

Site conditions based on average shear wave velocity measurements of the sedimentary units

The database for site evaluation was generalized from shear wave velocity measurements at individual sites to broad shear wave velocity classes that include sedimentary mapping units. Sedimentary units were briefly subdivided and interpretation of the distribution of $V_s(30)$ results of these distinct units were investigated statistically. Resulting distribution of data and site classes are given in Table 2. A histogram (Fig. 8) shows the distribution of site classes based on $V_s(30)$.

During the interpretation of the $V_s(30)$ data, it was observed that Quaternary sediments and fluvial deposits showed variable velocity ranges generally occurring at the boundary between the existing shear wave velocity categories of younger fluvial and older geologic units, respectively (Fig. 6). This distribution was attributed primarily to variability of sample textures, which is an indicator of the range of depositional environments within each geological unit. These units may be differentiated into two different categories. The units of Upper Pliocene to Pleistocene fluvial deposits and Quaternary deposits have $V_s(30)$ distributions that lie at the boundary between site categories D and C, and E and D, respectively (Table 2). Considering the geological and depositional character of these sedimentary units, they probably possessed different depositional or erosional characteristics at the time of setting.

$V_s(30)$ results were calculated for a total of 215 testing locations in the Quaternary deposits. These results show two units with different shear wave velocity characteristics, Quaternary Alluvium of E-Site (38%; mean $V_s(30)$: 169 ± 13 m/s), Quaternary Alluvium and Terrace Deposits (Older Quaternary) of D-Site (62%; mean $V_s(30)$: 221 ± 27 m/s). The Upper Pliocene to Pleistocene fluvial
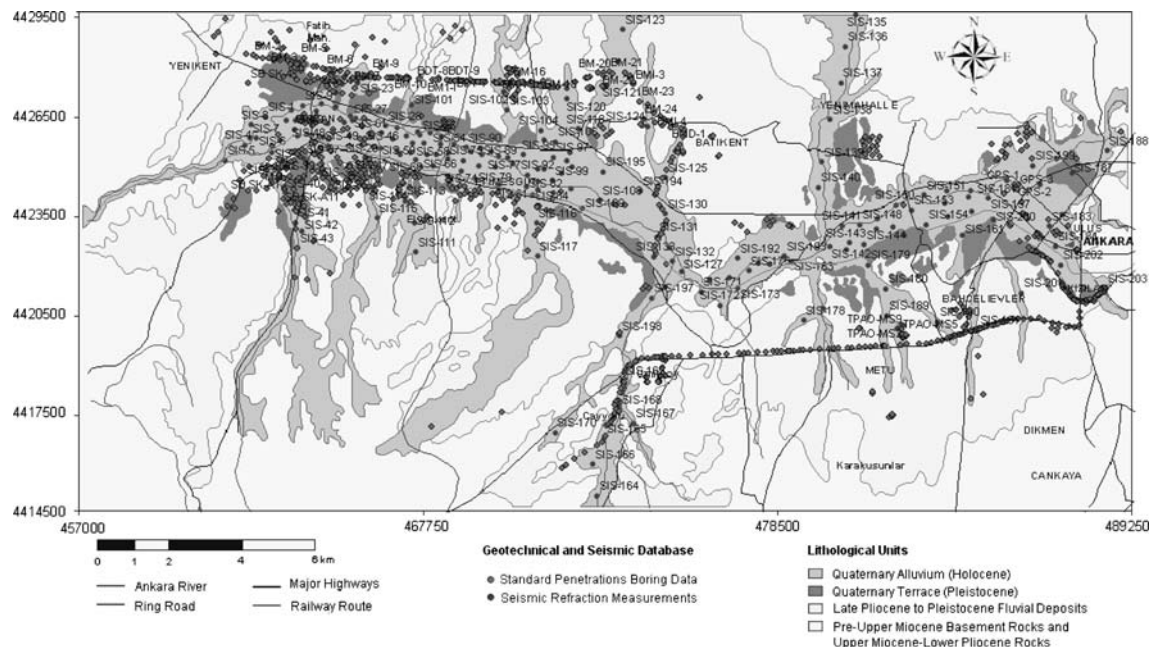

Fig. 5 The spatial distribution of the standard penetration testing data compiled and the shear wave velocity measurements performed for the study area in the western part of the Ankara basin
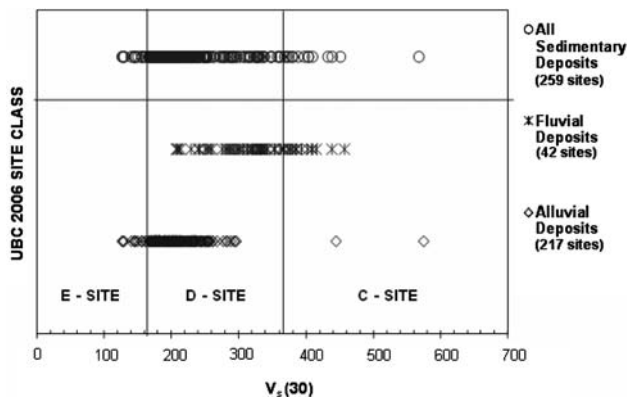
Fig. 6 The general distribution of site characterization data in regards to geological setting and $V_s(30)$ results
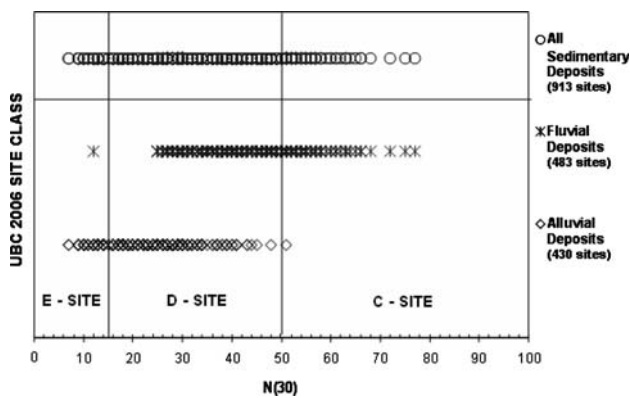

Fig. 7 The general distribution of site characterization data in regards to geological settings and $N(30)$ results

sediments are described as an undifferentiated single unit on the general geologic map. $V_s(30)$ results were calculated at 42 testing points (Table 2). These results led to a decision to classify them as relatively less dense fluvial deposits of D-Site (67%; mean $V_s(30)$: 319 ± 23 m/s) and denser fluvial deposits of C-Site (33%; mean $V_s(30)$:

392 ± 27 m/s) based on the depositional environment (Table 2; Fig. 8).

Site conditions based on average standard penetration test results of the sedimentary units

A similar site classification and statistical interpretation scheme was used for the site characterization study. $N(30)$ results showing the data distribution obtained in the sedimentary units and their IBC 2006 site classes are given in Table 3. The histogram (Fig. 9) shows distribution of site classes for sedimentary deposits based on $N(30)$.

During the interpretation of the $N(30)$ data, it was observed that the distribution of the penetration results and site classes for some geologic units showed variable ranges of $N(30)$. The $N(30)$ ranges overlapped with existing standard penetration categories, which was also observed for the $V_s(30)$ results, especially in Quaternary sediments and fluvial deposits of D-Sites. The distribution of $N(30)$ was more uniform for Quaternary deposits of E-Sites. These had a relatively narrow range of penetration results (Table 3). The depositional environments generally had a wider range of physical soil properties and a variety of soil textures that could influence standard penetration, as well as shear wave velocity results. Sedimentary units of Upper Pliocene to Pleistocene fluvial deposits and Quaternary alluvial deposits resulted in a $N(30)$ distribution that crossed the boundary between IBC 2006 site categories D and C, and E and D, respectively (Table 3).

In the Quaternary deposits, $N(30)$ results were calculated for 429 testing points. They were classified within two different units showing similar depositional characteristics with shear velocity results, and then characterized with respect to these three units, Quaternary Alluvium of E-Site (25%; mean $N(30)$: 13 ± 2 blows/0.3 m), Quaternary Alluvium and Terrace Deposits (Older Quaternary) of D-Site (75%; mean $N(30)$: 25 ± 6 blows/0.3 m). The Upper

Table 2 Description of the characteristics of generalized geologic units and their IBC 2006 site classes based on $V_s(30)$ data

Geologic unit	Number of data points	Data percentage (%)	Mean $V_s(30)$	±SD	SITE CLASS (IBC-2006)
Quaternary alluvial and terrace deposits	0	–	–	–	CLASS B
	2[a]	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	0	–	–	–	CLASS B
	14	33.33	392	27	CLASS C
	28	66.67	319	23	CLASS D
	0	–	–	–	CLASS E

[a] Two of the C site in Quaternary sediments were not consistent with the other results due to the presence of an artificial fill (pre-emplaced fill material) at those locations, and so were not included in the site characterization evaluation

Quaternary Geologic Units (E and D Sites) - 215 Data Points

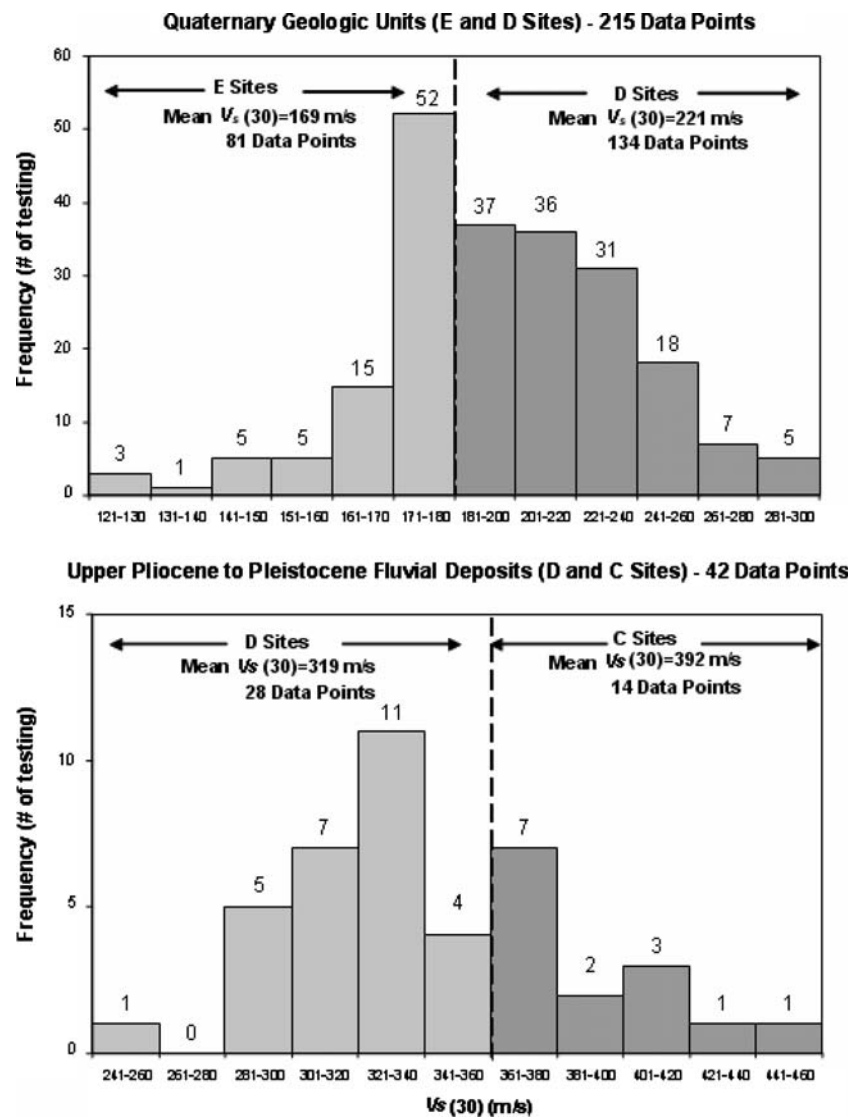Upper Pliocene to Pleistocene Fluvial Deposits (D and C Sites) - 42 Data Points

Table 3 Description of the characteristics of generalized geologic units and their IBC 2006 site classes based on N(30) data

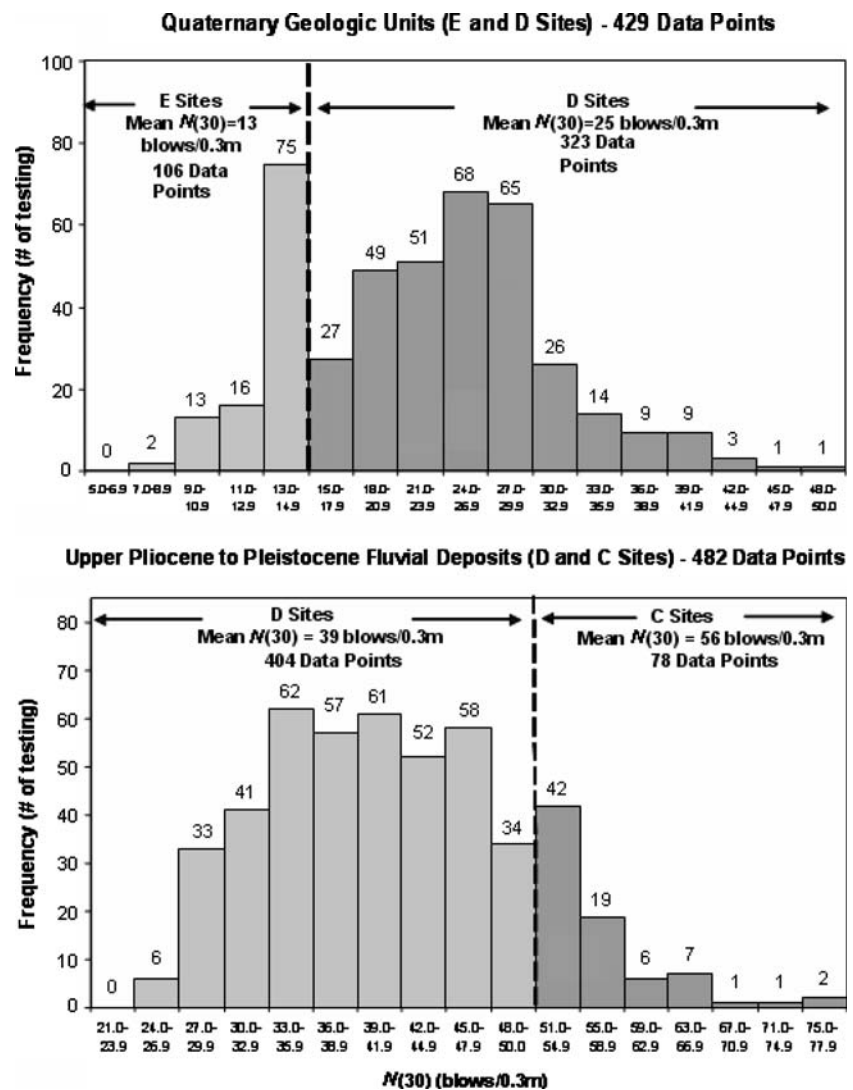| Geologic unit	Number of data points	Data percentage (%)	Mean N(30)	±SD	SITE CLASS (IBC-2006)
Quaternary alluvial and terrace deposits	0	–	–	–	CLASS B
	1[a]	0.23	52.0	–	CLASS C
	323	75.12	25.4	6.2	CLASS D
	106	24.65	12.7	1.8	CLASS E
Upper Pliocene to Pleistocene fluvial deposits	0	–	–	–	CLASS B
	78	16.15	55.8	5.8	CLASS C
	404	83.64	38.5	6.4	CLASS D
	1[b]	0.21	12.0	–	CLASS E

[a] One C site in Quaternary sediments was not consistent with the other results due to the presence of artificial fill (pre-emplaced fill material) at this location; and so was not included in the site characterization evaluation

[b] One E site in fluvial deposits was not consistent with the remainder of the data; therefore, the data point was omitted

Pliocene to Pleistocene fluvial sediments which are generally intercalated with Quaternary older terrace deposits were investigated at a total of 482 test locations. Since they are particularly cemented, deformed and uplifted (situated in higher elevations) compared to the surrounding environment of Quaternary alluvial and sometimes terrace

Fig. 9 Histogram of $N(30)$ data for distribution of site classes for Quaternary alluvial and terrace deposits and Upper Pliocene to Pleistocene fluvial deposits

deposits, their $N(30)$ results gave relatively stiffer results. These site categories were classified as the fluvial deposits of D-Site (84%; mean $N(30)$:39 ± 6 blows/0.3 m) and the fluvial deposits of C-Site (16%; mean $N(30)$: 56 ± 6 blows/0.3 m) based on environment of deposition (Table 3; Fig. 9).
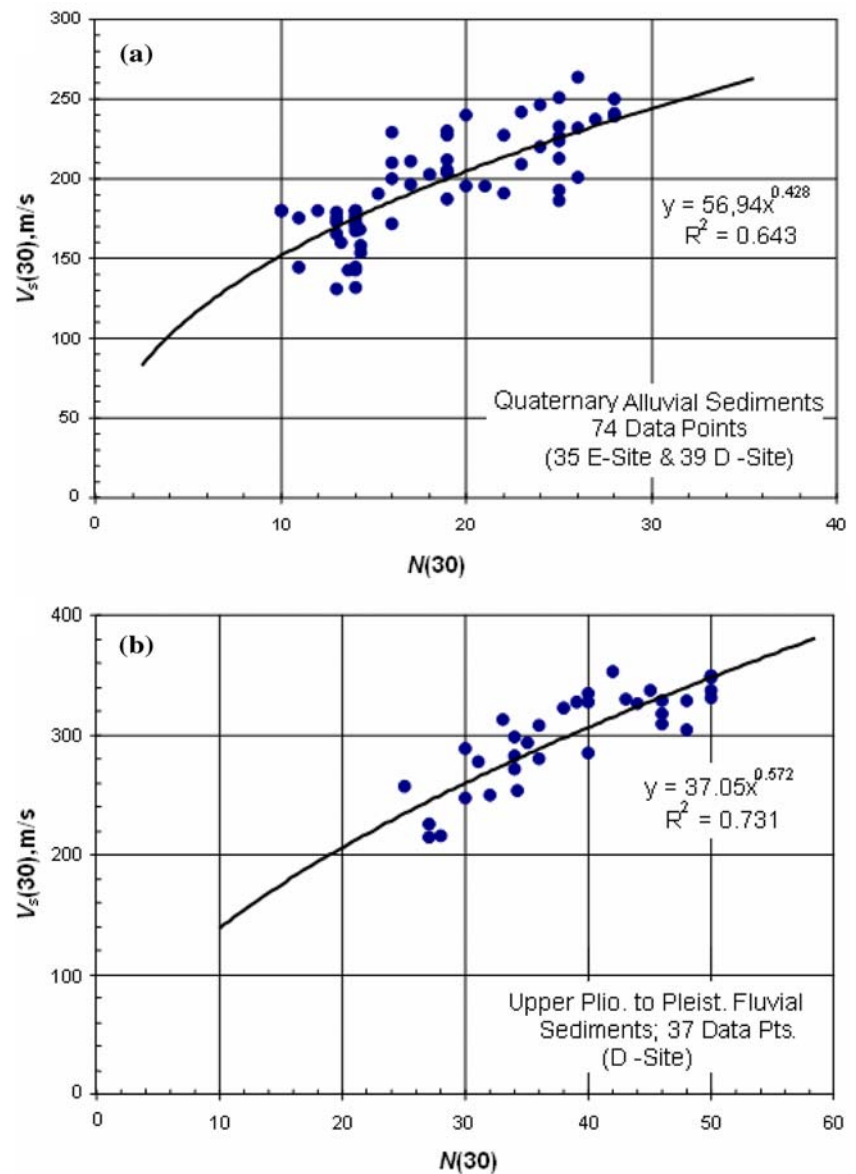
Correlations between shear wave velocity and standard penetration resistance for regional seismic site characterization

A study was conducted to evaluate the effects of utilizing shear wave velocity correlations for constructing a seismic hazard map. Many empirical equations have been proposed for estimating the shear wave velocity from reliable index measurements (i.e., standard penetration resistance, depositional setting and soil type) to avoid the problems of in-situ measurements and to investigate the physical

relationships between these soil indices and shear wave velocity. The success of this study depends in a large part on the selection of the shear-wave velocity correlation and the more reliable index measurements, particularly standard penetration resistance. Due to the variability and large volume of data in various sedimentary materials in the rather large research area, some of the index parameters were not included in this correlation study (i.e., soil type). Some of these parameters had less effect on these types of correlations (e.g., Imai 1977; Fumal and Tinsley 1985; Sykora and Stokoe 1983).

Regression equations were developed between shear wave velocity and site characterization index measurements of penetration resistance and depositional setting. Available data from 123 sets of $V_{\mathrm{S}}(30)$ and $N(30)$ at the same locations were studied for correlation (Koçkar 2006). Seventy-four data pairs fell within the Quaternary alluvial and 37 data pairs fell within the Upper Pliocene to Pleistocene fluvial sediments. The correlated $V_{\mathrm{s}}(30)$ and $N(30)$

Fig. 10 $V_s(30)$ and $N(30)$ regression equation developed for this study for Quaternary alluvial sediments (**a**), Upper Pliocene to Pleistocene fluvial sediments (**b**)

data pairs for alluvial and fluvial sediments are tabulated in Fig. 10a, b, respectively. The regression equations are presented by the following relationships:

$$V_s(30) = 56.94(N(30))^{0.428};$$
$$R^2 = 0.643 \text{ for alluvial soil deposits} \qquad (3)$$

$$V_s(30) = 37.05(N(30))^{0.572};$$
$$R^2 = 0.731 \text{ for fluvial deposits} \qquad (4)$$

The coefficients of determinations (R^2) for alluvial and fluvial deposits are 0.643 and 0.731 and probable errors (SDE) are ±18.9 and ±17.1%, respectively. The estimated $V_s(30)$ results compare well with the measured $V_s(30)$ results for both the Quaternary alluvial and Upper

Pliocene to Pleistocene fluvial sediments. The results assembled from the estimated and measured $V_s(30)$ studies have been synthesized and aggregated to construct the site classification map of $V_s(30)$ (Fig. 11). Quaternary terrace deposits were classified along with fluvial deposits of D-Site having similar site characterization results, as well as depositional characteristics. There is more consistency with respect to surface geology and accurate soil categorization when using seismic site characterization studies.

Conclusions

Methods and procedures from various engineering fields used in the course of this research included hazard
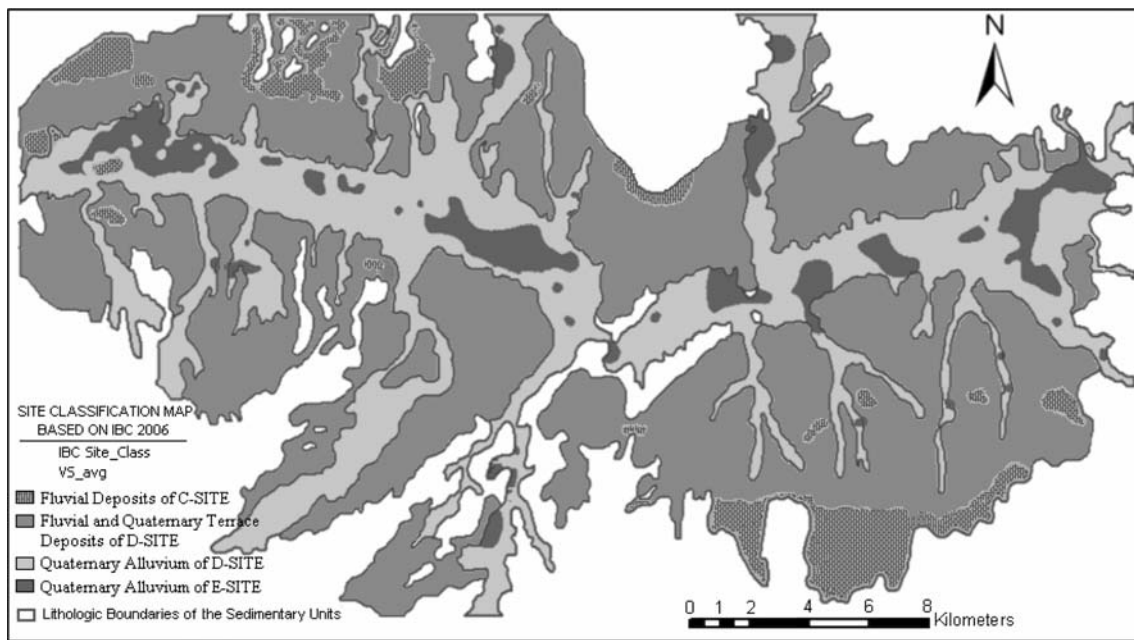
Fig. 11 Regional site classification zonation map of the Ankara Basin in regards to the site classes as specified by IBC 2006 based on measured and estimated $V_s(30)$ measurements

evaluations combined with site-specific engineering geological, geotechnical and geophysical information to develop zonation studies for seismic hazard calculations in the western part of the Ankara basin. The study area lies within the major growing potential, present and future settlement province of Ankara. Past examples show that significant seismic events have taken place around the Ankara basin, implying that Ankara and its surroundings are susceptible to future seismic events. The study developed in this research is important for the capital city 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 before major development is approved.

The geological character of the Upper Pliocene to Pleistocene fluvial and Quaternary alluvial and terrace sedimentary units were investigated and compared with engineering geological, geotechnical and seismic site characterization studies to interpret sediment characteristics and classify the soil deposits. Average shear wave velocity, $V_s(30)$ and average standard penetration resistance, $N(30)$ were used to develop site categories according to design code of IBC 2006.

Quaternary sediments were differentiated into two units: Quaternary alluvium of E-Site, Quaternary alluvium and terrace deposits of D-Site, based on the environment of deposition. Measurements on the Upper Pliocene to Pleistocene fluvial deposits in the Ankara basin led to a decision

to classify them as fluvial deposits of D-Site and fluvial deposits of C-Site. Site characterization depending on $V_s(30)$ along with $N(30)$ results is an appropriate measure of soil conditions and may give valuable evidence to define local site conditions. This methodology may be helpful in differentiating characteristics of the generalized sedimentary mapping units into more detailed sub-classes consistent with geological age and depositional character. Note that some geologic units may not be directly assigned to site classes (i.e., Quaternary deposits and Upper Pliocene to Pleistocene fluvial deposits do not easily assign themselves to D-Sites).

The $V_s(30)$ and $N(30)$ data pairs, along with other characteristic indices, were studied to derive the regression equations. A regional site classification map of the Ankara Basin as specified by the IBC 2006 was prepared. Areas which are classified as E-Site will be the most adversely affected during a seismic event, and additional site-specific studies may be required. Areas classified as D-Site will be moderately affected, and areas classified as C-Site are least likely to be affected during seismic events. These results may be applied to more elaborate and detailed geo-engineering studies, particularly microzonation studies in E-Site and other areas that have high urbanization potential. The methodology for integrated analysis presented is suitable for seismic hazard analysis on a regional scale to give general estimates of potential damage distributions and to indicate areas that require more detailed investigations.

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