LIQUEFACTION PHENOMENON IN THE EARTHQUAKES OF TURKEY, INCLUDING RECENT ERZINCAN, DINAR AND ADANA-CEYHAN EARTHQUAKES

Ömer AYDAN[1], Reşat ULUSAY[2] And Halil KUMSAR[3]

SUMMARY

Liquefaction phenomenon were observed in almost all earthquakes occurred in Turkey when the reports of the past earthquakes are carefully examined. Nevertheless, it did not receive any attention until the recent March 13, 1992 Erzincan earthquake . Following this earthquake, the liquefaction phenomenon was also observed in Dinar earthquake of October 1, 1995 and Adana-Ceyhan earthquake of June 27, 1998. The recent Adana-Ceyhan earthquake caused widespread liquefaction along the banks of Ceyhan river. The farthest site of liquefaction was 50 km from the hypocenter. The main purpose of this study is to investigate the liquefaction phenomenon in Turkey and clarify its characteristics, which have not been well studied yet. The distributions of locations of liquefaction observed in the earthquakes of Turkey until 1998 are described in the lights of the geology of Turkey, and some empirical relations between magnitude versus the hypocenter distance for liquefaction limit with the use of a data-base system developed for this purpose are presented. Liquefaction prone regions in Turkey are identified. A review of geotechnical characteristics of soils susceptible to liquefaction are given together with those obtained from detailed geotechnical tests on samples from liquefied sites in the last three earthquakes.

INTRODUCTION

Turkey is a well-known earthquake prone country with its well-documented historical seismicity (Ergin et al., 1967; Eyidogan et al., 1991). It has been shaked numerous times and many devastating earthquakes occurred, causing huge losses of human lives and properties and destruction of many historical cities. The reasons for such casualties may be both associated with geological conditions beneath human settlements and the existence of active fault systems causing earthquakes of in-land type which are more destructive and deadly as compared with off-shore earthquakes in subduction zones. Many settlements in Turkey are located on elongated ovas or plains, which are also the products of strike-slip faulting and normal faulting. The ovas (plains) cause geological structures beneath settlements, which may easily amplify and prolong seismic waves as observed in recent earthquakes such as Erzincan earthquake of March 13, 1992, Dinar earthquake of October 10, 1995 and Adana-Ceyhan earthquake of June 27, 1998 (Hamada and Aydan, 1992; Aydan and Kumsar, 1997a; Aydan et al., 1998). It is believed that the complete and/or partial liquefaction of ground is one of the important factors of huge devastation in the earthquakes of Turkey. Although there are many documents reporting some indications of liquefaction in Turkish earthquakes, the liquefaction started to receive some attention after the Erzincan earthquake of March 13, 1992. Therefore, the characteristics of liquefaction phenomenon in Turkish earthquakes are not well studied. The authors will try to fill this gap in the seismic history of Turkish earthquakes and summarise the characteristics of liquefaction through a study of past records of earthquakes for a period of 2000 years as well as the recent earthquakes. Specifically, regions susceptible to liquefaction throughout Turkey are identified on the basis of geological mapping. Then a location map of liquefaction prepared from the records of past earthquakes is given and some empirical relations between the earthquake magnitude and the hypocenter

[1] *Tokai University, Dept. of Marine Civil Eng., Shimizu, Japan, aydan@scc.u-tokai.ac.jp*
[2] *Hacettepe University, Dept. of Geological Eng., Ankara, Turkey, resat@hacettepe.edu.tr*
[3] *Pamukkale University, Dept. of Geological Eng., Denizli, Turkey, kumsar@mailexcite.com*

distance for liquefaction occurrence are developed. In addition, several examples of liquefaction observed in recent earthquakes such as Erzincan, Dinar and Adana-Ceyhan are described in order to illustrate the characteristics of liquefaction in the lights of investigations with modern technology in geotechnical engineering.

LIQUEFACTION SUSCEPTIBILITY OF TURKEY

Liquefaction is generally associated with non-cemented sedimentary deposits. It can take place in any soil as long as the pore-pressure due to seismic shaking is sufficient to cause liquefaction. Although sand deposits are much more easily liquefiable than other types of soils, liquefaction can both theoretically and experimentally take place in gravelly or clayey soils as also observed in the Hyogo-ken Nanbu earthquake of January 15, 1995. (Aydan and Kumsar, 1997b). Turkey is situated on Alpine seismic belt and it has many active faults. Some of them are North Anatolian Fault (NAF), East Anatolian Fault (EAF) and West Anatolian Fault System (WAFS) (Figure 1). As a result of tectonics motions along these faults, many elongated deep basins are developed. These basins are named Ovas by Sengör (1979) after a Turkish noun "Ova". The ovas have generaly ovaloidic shape having loose sedimentary non-cemented deposits with a high groundwater level. Sometimes these deposits are covered by partially or non-saturated thick silty or clayey top soil. Figure 1 shows the distribution of alluvial or diluvial deposits throughout Turkey. These deposits are susceptible to liquefaction. It is also of great interest that many historical and modern cities and towns exist on these deposits. This fact emphasis the importance of liquefaction problem for Turkey.

LIQUEFACTION CHARACTERISTICS FROM PAST TURKISH EARTHQUAKES

Although many liquefaction related damages occurred in the past Turkish earthquakes, the liquefaction pheno-

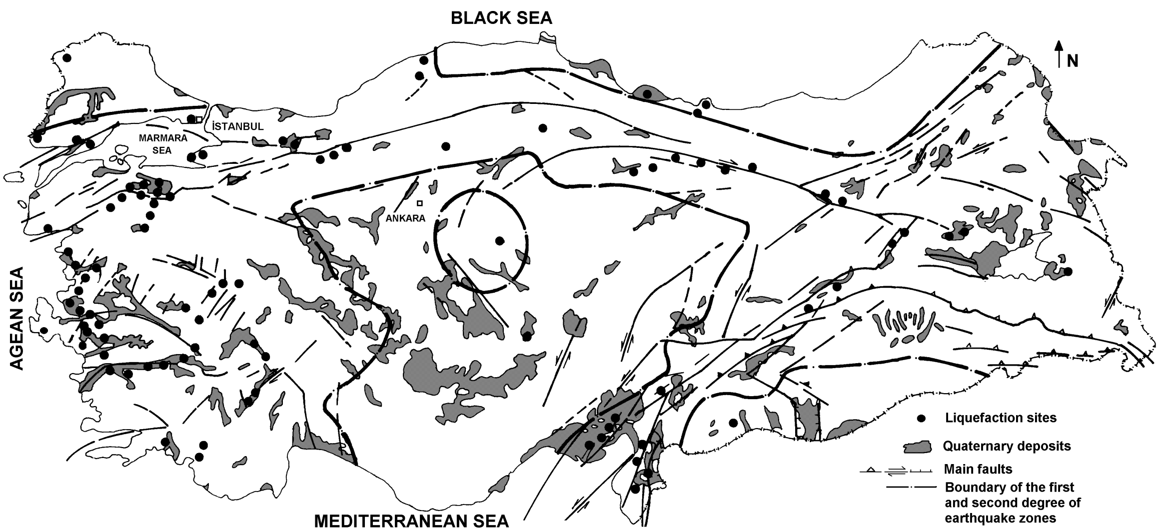

Figure 1 Distribution of the Quaternary alluvial deposits and liquefaction sites, and main structural features of Turkey with 1st and 2nd degree seismic risk zones

menon has not received much attention in Turkey until the Erzincan earthquake of March 13, 1992. The authors investigated many reports and catalogues of past Turkish earthquakes to indentify the locations and extent of liquefaction. From this investigation, a data-base system was developed to study the liquefaction characteristics of Turkish earthquakes. The parameters of the data-base involve the geometrical location of the sites, the parameters of earthquakes, the hypocentral distance to the site and some soil parameters. Figure 1 shows the liquefaction locations observed until 1998. It is also of great interest that the locations almost coincide with Ovas along the active faults of Turkey. Although some liquefaction locations were observed along the shores of Kara Deniz (Black Sea), they were away from the North Anatolian Fault in the Erzincan earthquake of 1939.

The relation between the magnitude of the earthquake and the hypocentral distance to the site of liquefaction is given in Figure 2. The following three functions are fitted to the observed results (Aydan et al. 1998):

$$R = 36M_s - 160 \quad \text{(upper bound)} \tag{1}$$

$$R = 36M_s - 200 \quad \text{(mean)} \tag{2}$$

$$R = 36M_s - 240 \quad \text{(lower bound)} \tag{3}$$

These three empirical lines may also be regarded as non-liquefaction to light, light to moderate and moderate to severe liquefaction boundaries in Turkish earthquakes. The theoretical studies by Aydan and Kumsar (1997b) for such boundaries support the functions presented here.

When earthquakes occur in dry seasons, the water table is generally low. As a result, liquefaction may be observed on the ground surface in a very limited sense. In addition, if the top soil is partially saturated or non-saturated silty or clayey, the liquefaction phenomenon may also be observed in a limited sense. However, the existence of such a top soil may act as a non-pressure releasing lid, resulting in the prolongation of shaking.

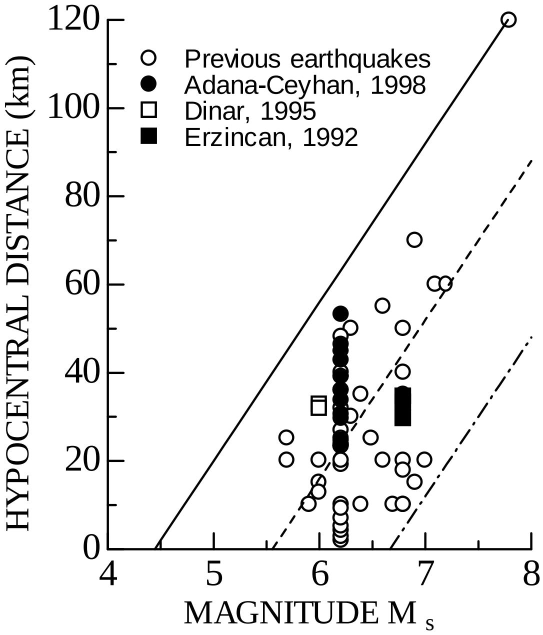

Figure 2 The relation between the magnitude of the earthquake and the hypocentral distance to the site of liquefaction

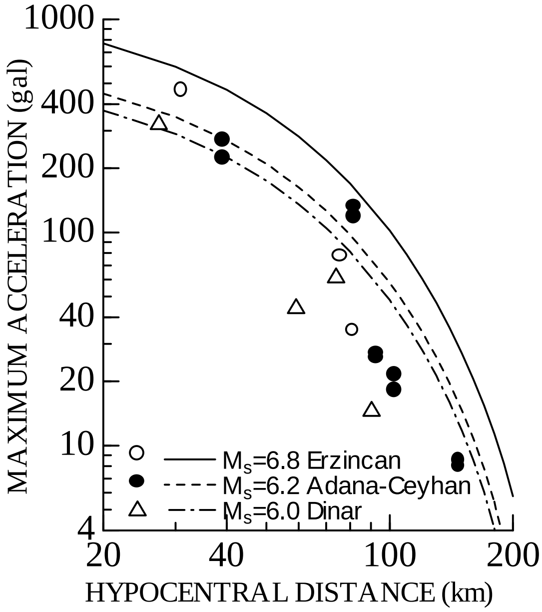

Figure 3 The relation between the hypocentral distance and maximum acceleration for different surface magnitudes based on data from Turkish earthquakes

Aydan et al. (1996) proposed the following function for the relation among maximum acceleration a_{max}, hypocenter distance R_0 and surface magnitude M_s of the earthquakes of Turkey for soil-like grounds (Figure 3):

$$a_{\max} = 2.8(e^{-0.025R_0} e^{0.9M_s - 1}) \tag{4}$$

This equation found to be yielding good estimates to the peak ground accelerations in the recent Erzincan, Dinar and Adana-Ceyhan earthquakes (Aydan and Kumsar, 1997a, Aydan et al., 1998) as also seen in Figure 3.

LIQUEFACTION CHARACTERISTICS FROM RECENT TURKISH EARTHQUAKES

Following the Erzincan earthquake of March 13, 1998, many detailed investigations on the liquefaction phenomenon in Turkey were initiated (Ansal et al., 1994; Erken et al., 1996; Ülker et al., 1998; Tosun and Ulusay, 1997). The authors were also able to investigate the recent three earthquakes, namely, Erzincan earthquake of March 13, 1992, Dinar earthquake of October 10, 1995 and Adana-Ceyhan earthquake of June 27, 1993 (Aydan and Hamada, 1992; Hasgür and Aydan, 1996; Aydan and Kumsar, 1997a; Aydan et al., 1998). The authors studied the liquefaction phenomenon and its characteristics in these last three earthquakes. Figure 4 shows the grain size distributions of samples collected at several sites affected by these earthquakes together with bounds of liquefaction (Ishihara, 1985). Although most of grain-size distribution curves of samples from liquefied sites fall within the empirical bounds, some of distributions may also be beyond the bounding curves. Therefore, the bounds should only be regarded as the most likely range of liquefaction for earthquakes having a surface wave magnitude less than 6. Clayey or gravelly soils may also liquefy as long as the circumstances are suitable for generating pore-pressures to cause liquefaction as observed in the Hyogo-ken Nanbu earthquake of January 15, 1995.

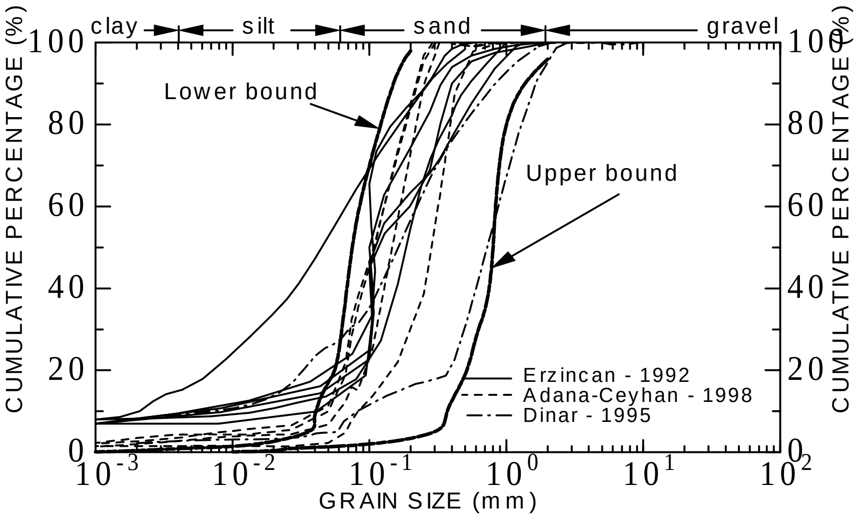

Figure 4 Grain size distributions of liquefied soils from the earthquakes occurred in Turkey

Figure 5 shows the relation between the dry unit weight and porosity of soils collected from liquefied sites. The unit weight of liquefied soil ranges between 9 and 20 kN/m^3, while the porosity ranges between 25-65%. The mean values for the unit weight and porosity are 15 kN/m^3 and 40%, respectively.

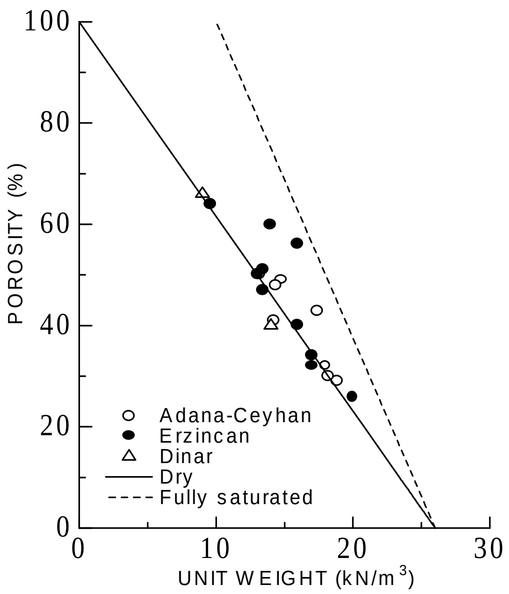

Figure 5 The relation between the unit weight of liquefied soils and their porosity

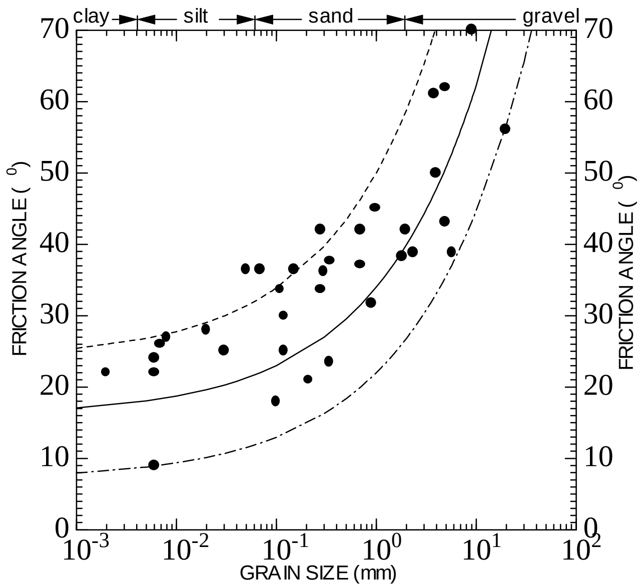

Figure 6 The relation between friction angle and mean grain size

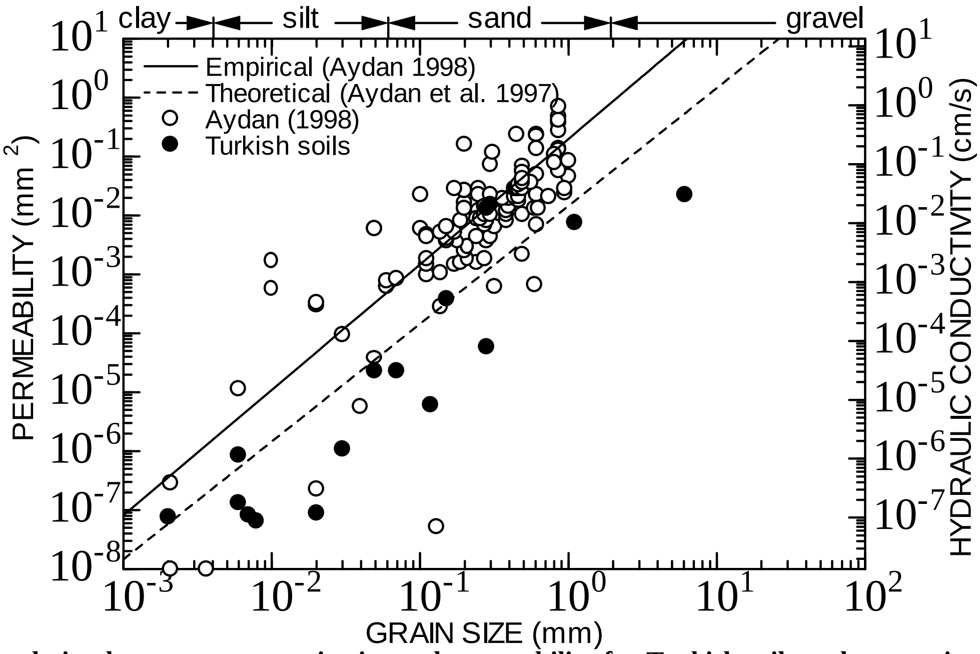

Figure 7 The relation between mean grain size and permeability for Turkish soils and comparisons with the soils of other countries

Figure 6 shows the relation between the friction angle versus mean grain size for soils of Turkey, including those of Adana-Ceyhan region. As seen from the figure, the friction angle increases as the mean grain size increases. Nevertheless, the data are scattered. This may be associated with the relative density difference among samples. The data for gravelly soils are still insufficient and further tests are felt to be necessary to have a better extrapolation for this range.

The permeability of soils is also an important item in the assessment of liquefaction by numerical methods (Ekşioğlu et al., 1989). Recently, Aydan and Kumsar (1997b) developed a liquefaction assessment method in which the soil permeability is also taken into account. With this in mind, the authors gathered some data on the permeability of soils of Turkey and compared with those obtained from a data-base system developed by Aydan (1998) in Figure 7. As seen from the figure, the permeability of Turkish soils are in good agreement with the previously obtained empirical and theoretical relations (Aydan, 1998; Aydan et al. 1997.

Figure 8 shows the relation between modified SPT value N_{60} and cyclic stress ratio CSRE together with bounds for liquefaction/non-liquefaction proposed by Seed and DeAlba (1986). The data shown in Figure 5 are taken from the work of Ansal et al. (1994) and Erken et al. (1998) and Ülker et al. (1998) and authors investigations (Aydan and Kumsar, 1997a) and Aydan et al., 1998). The data of liquefied soils fall generally within the range of liquefiable soils.

Using the method proposed by Aydan and Kumsar (1997b) and Eq. (4) for the peak ground acceleration, the relation between surface magnitude of earthquakes and hypocentral distance for liquefaction limit are plotted in Figure 9 for various specific weight G_s. The plotted relations are quite similar to those in Figure 2, and observations can be closely simulated by the relations computed by the method of Aydan and Kumsar (1997b).

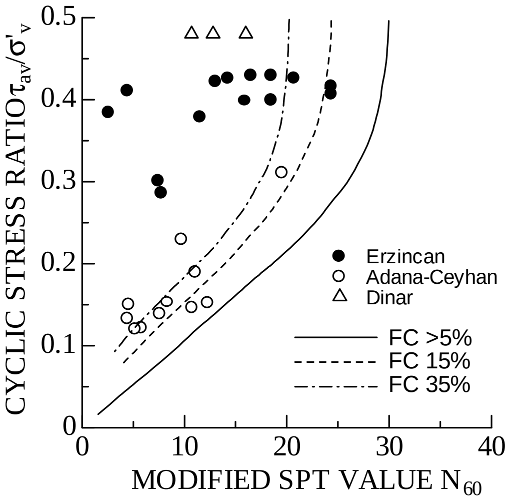

Figure 8 The relation between modified SPT value N_{60} and cyclic stress ratio CSRE together with bounds for liquefaction/non-liquefaction proposed by Seed and DeAlba (1986)

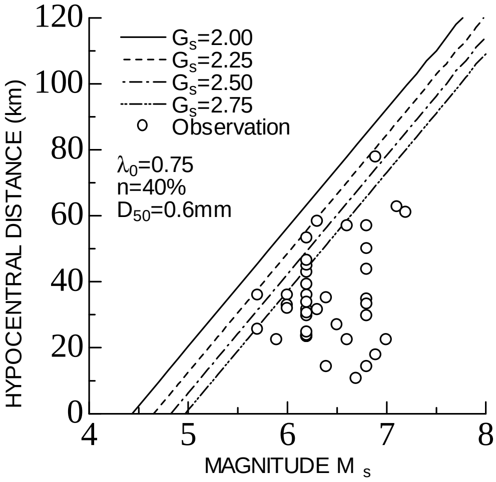

Figure 9 Comparison of computed magnitude versus hypocentral distance relations with observations

CONCLUSIONS

The distributions of locations of liquefaction observed in the earthquakes of Turkey until 1998 and geotechnical properties of the liquefied soils are described, and some empirical relations for magnitude versus the hypocenter distance for liquefaction limit with the use of a data-base system developed for this purpose are presented. Liquefaction sites are generally well coincided with the alluvial Quaternary deposits throughout Turkey. The grain size distributions of liquefied soils generally fall within the empirical bounds of grain size distribution of liquefiable soils. The geotechnical characteristics of soils of Turkey for liquefied ground are quite similar to those observed in other countries. The data of the liquefied sites observed at the recent three earthquakes are within the empirical bounds suggested by Seed and DeAlba. Furthermore, the empirical relations between the surface magnitude of earthquakes and hypocentral distance, developed for Turkish sites of liquefaction can be also theoretically obtained using the procedure proposed by Aydan and Kumsar (1997b). It should be however noted that this study could not fully cover the liquefaction characteristics of soils in Turkey and the authors feel the necessity for further studies on this problem.

REFERENCES

Ansal, A.M., Lav, A.M., İyisan, R. and Erken, A. (1994), "Effects of geotechnical factors in March 13 1992 Erzincan Earthquake", *The 13th Int. Conf. on Soil Mechanics and Foundation Engineering*, NewDelhi, 49-54.

Aydan, Ö. and Hamada, M. (1992), "The site investigation of the Erzincan (Turkey) Earthquake of March 13, 1992", *The 4th Japan-US Workshop on Earthquake Resistant Design of Lifeline Facilities and Countermeasures Against Soil Liquefaction*, Honolulu, 17-34.

Aydan, Ö., Sezaki, M., Yarar, R. (1996), "The seismic characteristics of Turkish Earthquakes", *The 11th World Conf. on Earthquake Eng.*, CD-2, Paper No:1270.

Aydan, Ö. and Kumsar, H. (1997a), "A site investigation of October. 1, 1995 Dinar Earthquake", *Turkish Earthquake Foundation*,TDV/DR 97-003**,** 116p.

Aydan, Ö. and Kumsar, H. (1997b), "A new liquefaction assessment method and its applications", *The 2nd Symposium on Geotechnical and Earthquake Problems of Izmir and its Environement*, Izmir, Turkey, 1-10.

Aydan, Ö., Ücpirti H. and Ulusay, R. (1997). Theoretical formulation of Darcy's law for fluid flow through porous and/or jointed rock and its validity (in Turkish). *Kaya Mekaniği Bülteni*, **13**, 1-18.

Aydan, Ö. (1998). A data-base system for seepage characteristics of geomaterials. *Int. Symp. on Environemental Issues and Waste Management in Energy and Mineral Production*, Ankara, 209-213.

Aydan, Ö., Ulusay, R., Kumsar, H., Sönmez, H. and Tuncay, E. (1998), "A site investigation of June 27, 1998 Adana-Ceyhan Earthquake", *Turkish Earthquake Foundation*, TDV/DR 006-03**,** 131p.

Eksioglu, S., Aydan, Ö., Ichikawa, Y. and Kawamoto, T. (1989). Wave propagation in saturated porous media. *The 3rd Symposium on Computational Mechanics of Japan*, 381-387.

Ergin, K., Güclü, U. and Uz, Z. (1967), "The catalogue of earthquakes of Turkey", *ITU, Yer Fiziği Enstitüsü*, Yayın No. 24, Istanbul.

Erken, E., Ansal, A. M., Yildirim, H., Kiliç, C. and Kara, B. (1996), "Erzincan-Eksisu'da kumlu siltli zeminlerin sivilasma potansiyeli", *Zemin ve Temel Mühendisligi 6. Ulusal Kongresi*, Cilt 2, 533-541.

Eyidogan, H., Güclü, U., Utku, Z. and Değirmenci, E. (1991), "Türkiye büyük depremleri makrosismik rehberi", İTÜ.

Hamada, M. and Aydan, Ö. (1992), "A report on the site investigation of the March 13 Earthquake of Erzincan, Turkey", *ADEP, Association for Development of Earthquake Prediction*, 86p.

Hasgür, Z. and Aydan, Ö. (1996), "Liquefaction, lateral spreading, slope and embankment failures during the march 13 earthquake of Erzincan, Turkey", *The 11th World Conf. on Earthquake Eng.,* Acapulco, CD-1, Paper No: 1025.

Ishihara, K. (1985), "Stability of natural deposits during earthquakes", *The 11th Soil Mechanics and Foundation Engineering Confrence*, San Francisco, Vol. 1, 321-376.

Seed, H., and DeAlba, P. (1986), "Use of SPT and CPT tests for evaluating the liquefaction resistance of sands", *In Use of In-situ Tests in Geotechnical Engineering,* ASCE Geotechnical Special Publication, Vol. 6, 281-302.

Sengör, A. M. C, (1979), "The north Anatolian transform fault: its age, offset and tectonic significance", *Journal of Geological Society of London*, 136, 269-282.

Tosun, H. and Ulusay, R. (1997), "Engineering geological characterization and evaluation of liquefaction susceptibility of foundation soils at a dam site, Southwest Turkey", *Environmental and Engineering Geoscience,* Vol. 3, No. 3, 389-409.

Ülker, R., Celep, Z., Hasgür, Z., Eyidogan, H., Erken, A. and Kaypak, B. (1998), "27 Haziran 1998 Adana-Ceyhan Depremi Hakkında", *ITU Yapı ve Deprem Uygulama Araştırma Merkezi*, Istanbul. observations