

12 LIQUEFACTION, GROUND SUBSIDENCE AND SLOPE FAILURES

12.1 Liquefaction and Its Effects

Liquefaction was widely distributed and caused damage to structures and lifelines in the region between Adapazarı and Yalova. Liquefaction was observed for a length of 120 km almost along the earthquake fault break within a band of about 10 km (Figure 12.1). The most devastating effect of liquefaction was observed in Adapazarı which was about 6 km away from the fault break on the northern block. According people interviewed, the liquefied sand and water came out of ground gradually. Figure 12.2 and 12.3 show some typical examples of liquefaction in Adapazarı.

Along the coastline of the Sapanca Lake liquefaction-induced lateral ground displacement was observed and a hotel building moved towards the lake and sunk as shown in Figure 12.4.

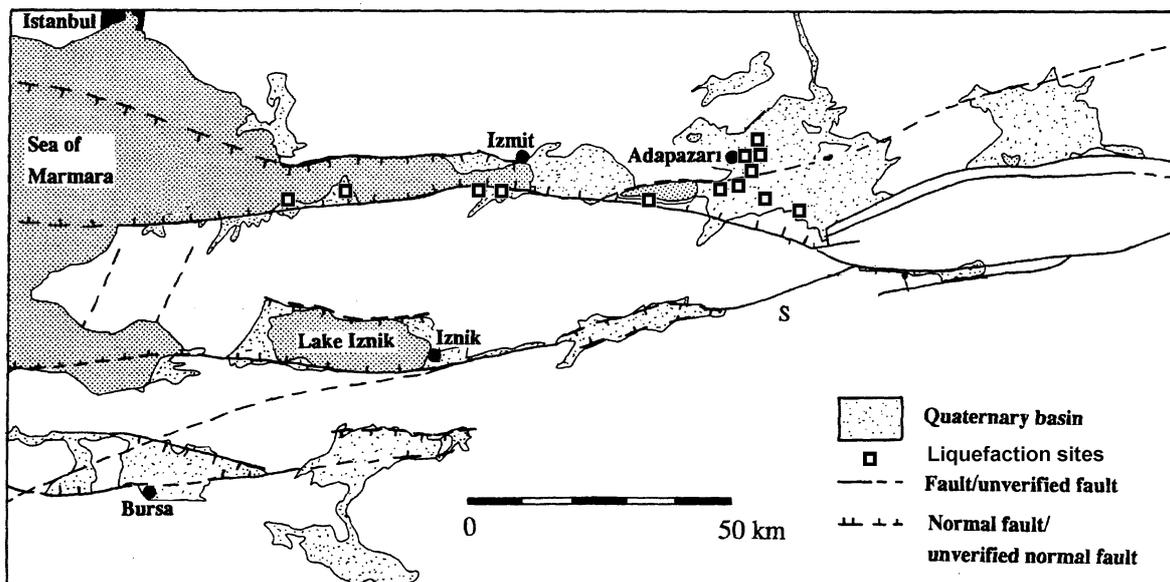


Figure 12.1 Distribution of liquefaction sites observed in this earthquake



Figure 12.2 Sand volcano observed on Aug. 18, 1999 in Erenler (Adapazar)



Figure 12.3 Wide-spread sand ejection and lateral spreading along souther shore of Sapanca Lake near Sapanca town (note the settlement and separation of the wall in the background)

Liquefaction fissures and sand boils are evidently observed along the Sakarya River in Adapazar City and Akyaz , the southern shore of Sapanca Lake and zmit gulf as far as Yalova whenever saturated quaternary loose deposits exist.

The most severest damage to structures due to liquefaction was observed in Adapazar City. Many buildings were settled, tilted or totally collapsed. The settlement of buildings up to 110 cm were observed. The building shown in Figure 12.5 showed one of typical examples of severe tilting resulting from the loss of bearing capacity of the foundation ground. This type of failure is quite similar to that observed in the 1964 Niigata earthquake and the 1983 Nihonkai-Chubu earthquake.



Figure 12.4 Lateral spreading and settlement of a hotel along the shore of Sapanca Lake (details of liquefaction site is shown in Figure 12.3)



Figure 12.5 Tilted and collapsed buildings (Adapazar)

The heaving of ground occurred as a result of settlement of buildings and the uplift of sewage pipes as shown in Figure 12.6. Electric poles were either sunk or inclined as a result of the liquefaction of the ground.



Figure 12.6 Heaving of a roadway as a result of settlement of adjacent buildings and the uplift of sewage pipe

12.1.1 Properties of Liquefied Soil

The unit weights were obtained in the laboratory using tube and block samples with known dimensions and bouyancy method for the liquefied and non-liquefied samples, respectively. The values of unit weight vary between 13.1 kN/m^3 and 18 kN/m^3 according to soil composition. The range of specific gravity obtained was 2.56-2.74, for the liquefied soil layers (Ulusay et al. 1999).

Grain size of the liquefied soils was examined on specimens collected from the sand volcanoes. Figure 12.7 shows cummulative particle size distribution curves of the liquefied soils from previous earthquakes in Turkey (Hamada and Aydan 1992, Aydan and Kumsar 1997). Figure 12.8 shows that fine-to-medium sand is dominant in the liquefied soils obtained

from various locations in the Kocaeli earthquake. The grain size distribution of these liquefied soils fall between the well known upper and lower limits for liquefaction (see Figure 12.8). Both the practical characteristics of the soil and high groundwater levels in conjunction with active seismic features of the region result in a condition which is favorable for the occurrence of the liquefaction. Porosity of the same samples is about 30-46%.

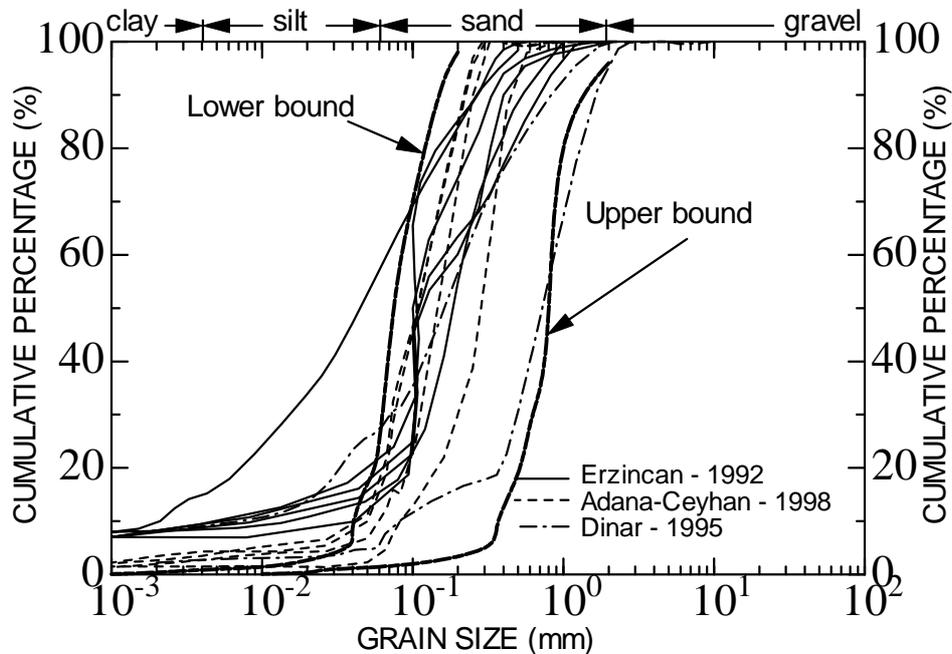


Figure 12.7 Grain size distribution curves of the soil samples taken from the liquefied at various locations of liquefaction in the previous earthquakes of Turkey

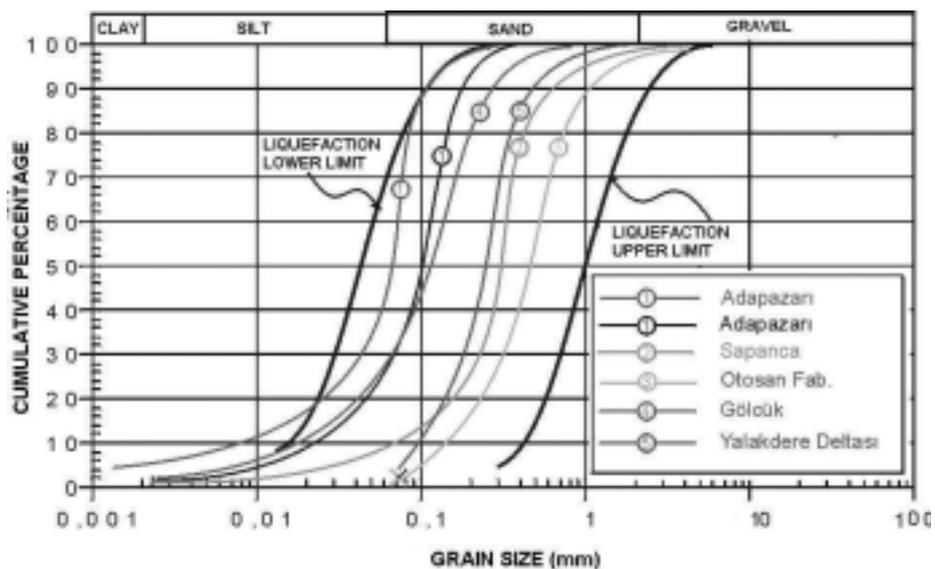


Figure 12.8 Grain size distribution curves of the soil samples taken from the liquefied at various locations of liquefaction in the Kocaeli earthquake (after Kasapo lu et al. 1999)

12.1.2 Comparison of Kocaeli Earthquake Data with Those of Other Earthquakes Occurred in Turkey

Although many liquefaction related damage occurred in the past Turkish earthquakes, the liquefaction phenomenon has not received much attention in Turkey until the Erzincan earthquake of March 13, 1992. Aydan et al. (2000) investigated many reports and catalogues of past Turkish earthquakes to identify the locations and extent of liquefaction. From this investigation, a data-base was developed to study the liquefaction characteristics of Turkish earthquakes. The parameters of the data-base involve the geometrical condition of the sites, the magnitudes of earthquakes, the hypocentral distance to the site and soil parameters. Figure 12.9 shows the liquefaction locations observed until 1998. It is also of great interest that the locations almost coincide with quaternary deposits 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.

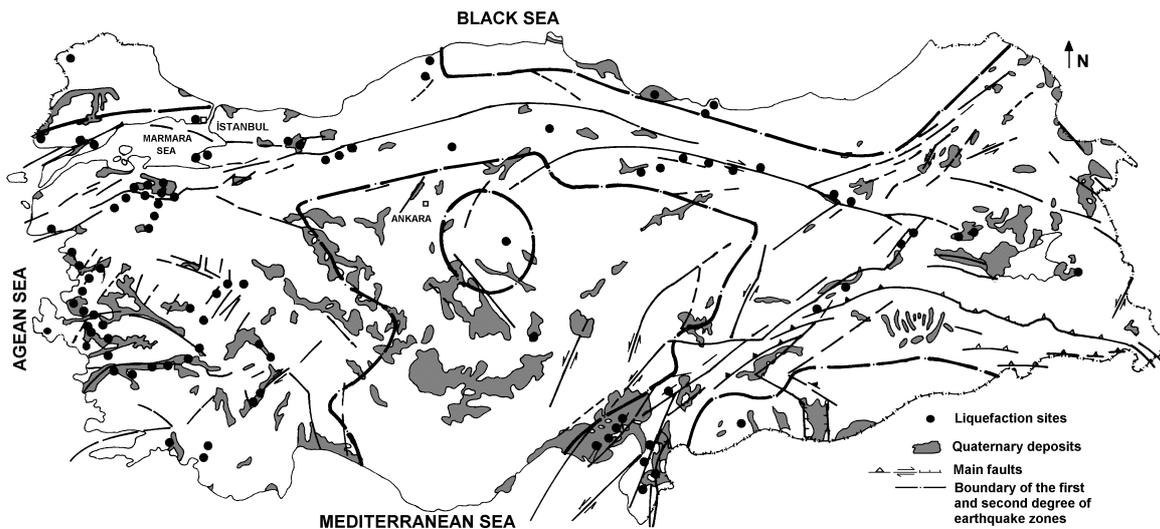


Figure 12.9 Distribution of the Quaternary alluvial deposits and liquefaction sites, and main structural features of Turkey with 1st and 2nd degree seismic risk zones (After Aydan et al. 2000)

It is of great interest that the locations shown in Figure 12.1 are almost the same as those shown in Figure 12.9. The figure implies that the grounds at the locations of liquefied ground were again liquefied in this earthquake.

Aydan and Kumsar (1997) compiled some data on the locations of earthquakes and developed some empirical relations between magnitude of earthquake and hypocentral distance for liquefaction - non-liquefaction states. The relation between the magnitude of the earthquake and the hypocentral distance to the site of liquefaction is given in Figure 12.10. The following three functions are fitted to the observed results (Aydan et al. 1998):

$$R = 36M_s - 160 \quad (\text{upper bound}) \quad (11.1)$$

$$R = 36M_s - 200 \quad (\text{mean}) \quad (11.2)$$

$$R = 36M_s - 240 \quad (\text{lower bound}) \quad (11.3)$$

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. Figure 12.9 compares data obtained in this earthquake with the data from previous Turkish earthquakes. The data gathered in this earthquake are within the empirical bounds.

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.

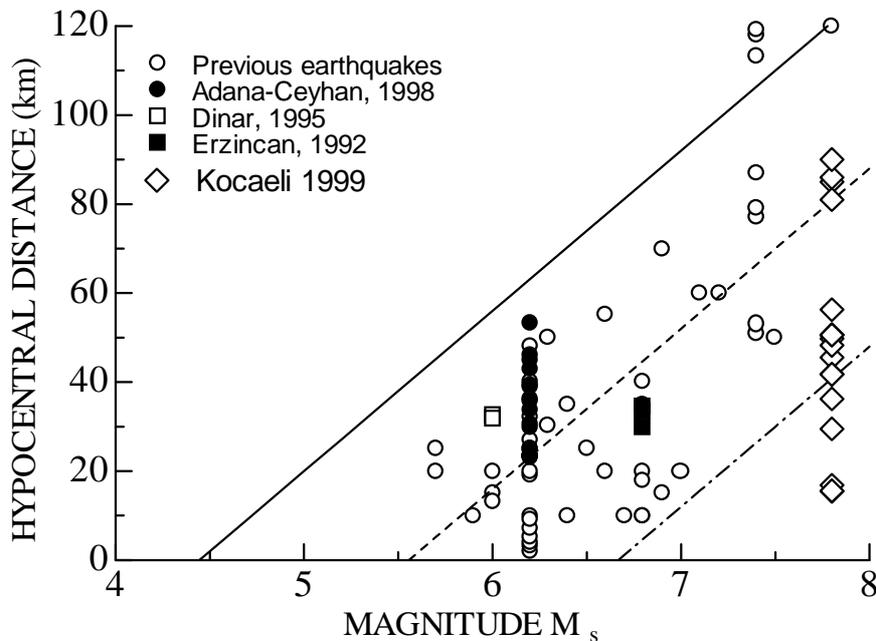


Figure 12.10 Comparison of the observed relation between the magnitude and distance of liquefied sites with empirical relations

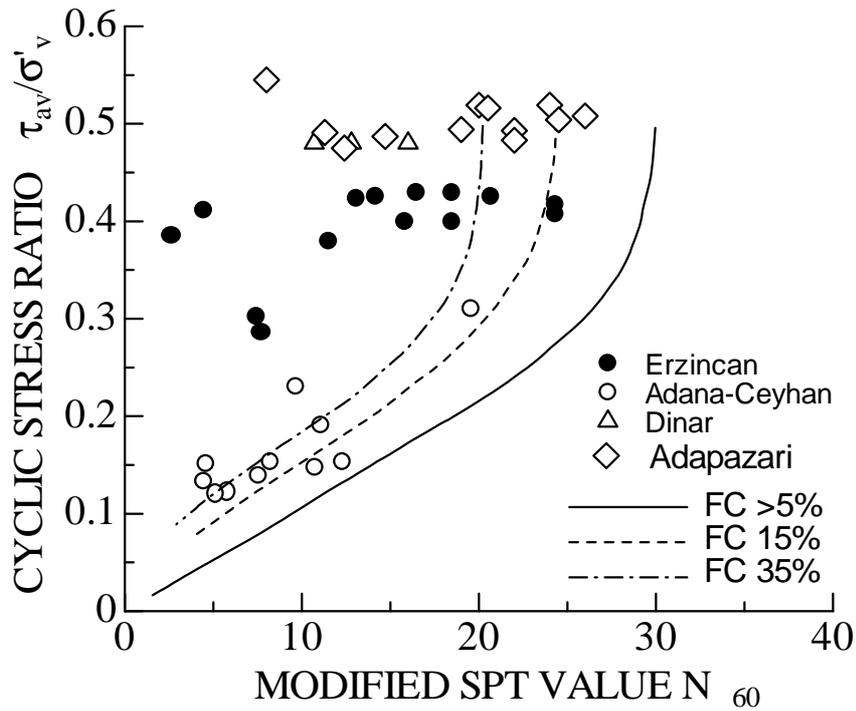


Figure 12.11 The relation between modified SPT value N_{60} and cyclic stress ratio CSRE together with bounds for liquefaction/non-liquefaction proposed by Seed and DeAlba (1986)

Figure 12.10 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 12.11. are taken from the work of Ansal et al. (1994) and Erken et al. (1998) and Ülker et al. (1998) and the investigations of the author (Aydan and Kumsar, 1997; Aydan et al., 1998; Aydan et al. 2000a). The data of liquefied soils fall generally within the range of liquefiable soils.

12.2 Ground Subsidence

A huge scale ground subsidence occurred at Kavaklı district of Gölcük town (Figure 12.12). This ground subsidence took as a result of normal faulting associated with the main lateral strike slip event. The normal fault could be traced from Kavaklı shore up to Hisareyn village along the main highway where the fault terminated. The vertical throw of the fault was more than 2m at several locations. The land on the overhanging block of the fault subsided into the sea so that a large part of Kavaklı district became submerged. In this location, very fine soil

was ejected as a result of ground liquefaction. Nevertheless, the ground liquefaction is not thought to be the main cause of the subsidence.



Figure 12.12 Submerged Kavakl District of Gölcük town

12.3 Slope Failures

12.3.1 Soil Slope Failures and Submarine Landslides

There were some soil slope failures on the banks of roadways and along Sakarya rivers (Figures 12.13). Most of soil slope failures are seemingly circular sliding. The failures were mainly observed on the slopes facing west and east. This observation was quite consistent with the maximum acceleration observed in the strong motion records.



Figure 12.13 Soil slope failure at Yalova



Figure 12.4 Location of sub-marine land slide at De ĭrmendere

The most publicised sub-marine slide took place at De ĩrmedere where a 5-story hotel slides into the sea together with two adjacent buildings (Figure 12.14). The site investigation showed that there were tension cracks extending into the land for an 80 m distance from the post-failure seashore. The spacing of these tension cracks was quite consistent. The bathymetry of the seabed indicates that the slope angle was quite steep at the sliding location.



Figure 12.15 Rock falls along the shore of Black Sea near ĩle

12.3.2 Rock Slope Failure

Rock slope failures were mainly observed along Tran-Europe Motorway (TEM) on the northern shore of Marmara Sea, D-100 highway passing along the northern shore of Sapanca Lake, Karamürsel, Black Sea coast near ĩle and the valley between Akyaz ĩ and Düzce (Figures 12.15 and 12.16). The slides and rock fall along the TEM were of limited scale as the slope angle was quite small. The large scale rock slides occurred along D-100 highway near Kocaeli-Sakarya provincial boundary where secondary normal faulting events took place. Although the discontinuities of rock masses at those locations were quite favorable for the stability of rock slopes, the vertical and horizontal accelerations must have been quite large to

cause the failure of the rock slopes. Rock falls were observed between Gökaya and Akyaz along the D-100 highway and the highway between Karamürsel and Yalova. The rock slopes are quite steep near the Karamürsel Army base along the highway.



Figure 12.16 Rock slope failure at Kocaeli-Sakarya provincial boundary along D-100 highway (note that the car on the left-hand side of the highway was hit by the fallen debris)

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