10. LIQUEFACTION AND GROUND FAILURES

10.1. Liquefaction and Its Effects

Liquefaction was widely distributed and caused some of the more striking and damaging effects of the earthquake occurred in the region between Adana and Ceyhan. Those effects included fissures, as much as several meters wide, accompanied by sand boils that vented water and sediment covering areas up to tens of square meters in extent. Liquefaction phenomenon was wide-spread for a length of 50 km almost along Ceyhan River (Figures 10.1, 10.2, 10.3 and 10.4). Although two weeks already passed over the earthquake, the incidents of sand volcanos, sand blows were still clearly visible at various localities.

Figure 10.1 Liquefaction near Asmali bridge

Figure 10.2 Liquefaction in a school yard in Abdioğlu village

Figure 10.3 Liquefaction in a school yard in Abdioğlu village

Figure 10.4 Trace of liquefied soil on a fracture crevasse of soil slope failure along Ceyhan River near Mercimek village

It is interesting to note that the liquefaction sites ranged in the alluvium along the Ceyhan River and on its flood plains as shown on the map given in Figure 10.5. The general distribution of the ground fissures and sand boils on the floodplains were surveyed. Liquefaction fissures and sand boils are evidently observed in Abdioğlu, Nacarlı, Geçitli, Misis, Çakıldere, Çokça, Toktamış, K. Burhaniye, SW of Ceyhan town, Büyük Mangıt, Mercimekköy, Hamitbey, Adapınarı, İnceyar and Dikilitaş settlement areas. The general trends of the eruption fissures are N 50-70 E and N 60-70W of the southern and northern parts of Ceyhan town, respectively (Figure 10.5). Liquefaction trends appear systematically along the extansion fractures developed during this earthquake. According to local people, liquified soil and water rised up to 7-8 m above the surface during the main schock. Ground fissures and sand boils were the most widely distributed permanent surface effects generated by Adana-Ceyhan earthquake. Besides, damages beneath the structures were also observed in the earthquake area. The most spectacular damage to structures at Abdioğlu settlement area was the tilting of a fountain in the garden of primary school (Figure 10.6), and a differential settlement of about 5 cm beneath the water-storage tower at the same location (Figure 10.7). Furthermore, uplifting of a concrete water tank was observed beneath the same tower. Similarly, a crack developed through a concrete water pipe near a home at the entrance of Abdioğlu (see Figure 7.48), and goal pillars in the garden of Kazime Özler Primary School between Misis and Abdioğlu, tilted about 8^o (Figure 10.8).

Observations of the investigation team indicated that dark gray fine sands with an ignorable amount of fines (silt and clay) form the liquified soil through the zone of liquefaction. This soil lies 3 to 5 meters below the ground surface generally at the level of Ceyhan River. But its thickness cannot be determined. It is overlain by light brown non-liquefied alluvial soil mainly consisting of fines with a thickness of 3 to 5 m. The liquefied and non-liquefied soils and their relative positions can be directly observed on the banks of Ceyhan River in Mercimekköy where lateral spreading has occurred during the earthquake. At this location, sandy soil, during liquefaction, rised through the fissures and coated the non-liquefied soils (see Figure 10.4). Therefore, it is evident that both the presence of thin silty and clayey layers above sand layers susceptible to liquefaction and high groundwater levels (generally 3 to 5 m) generate a condition favorable for the occurence of liquefaction.

Slope failures observed along the embankments of Ceyhan River were as a result of lateral spreading of ground rather than ordinary slope failure. Very large ground movements were observed. Luckily since there was not any structure of great importance, the lateral spreading of the earthquake could not cause any major damage. Neverthless, the extent of liquefaction and lateral spreading observed in this earthquake will undoubtedly have a great effect on the design of engineering structures in Turkey following this earthquake.

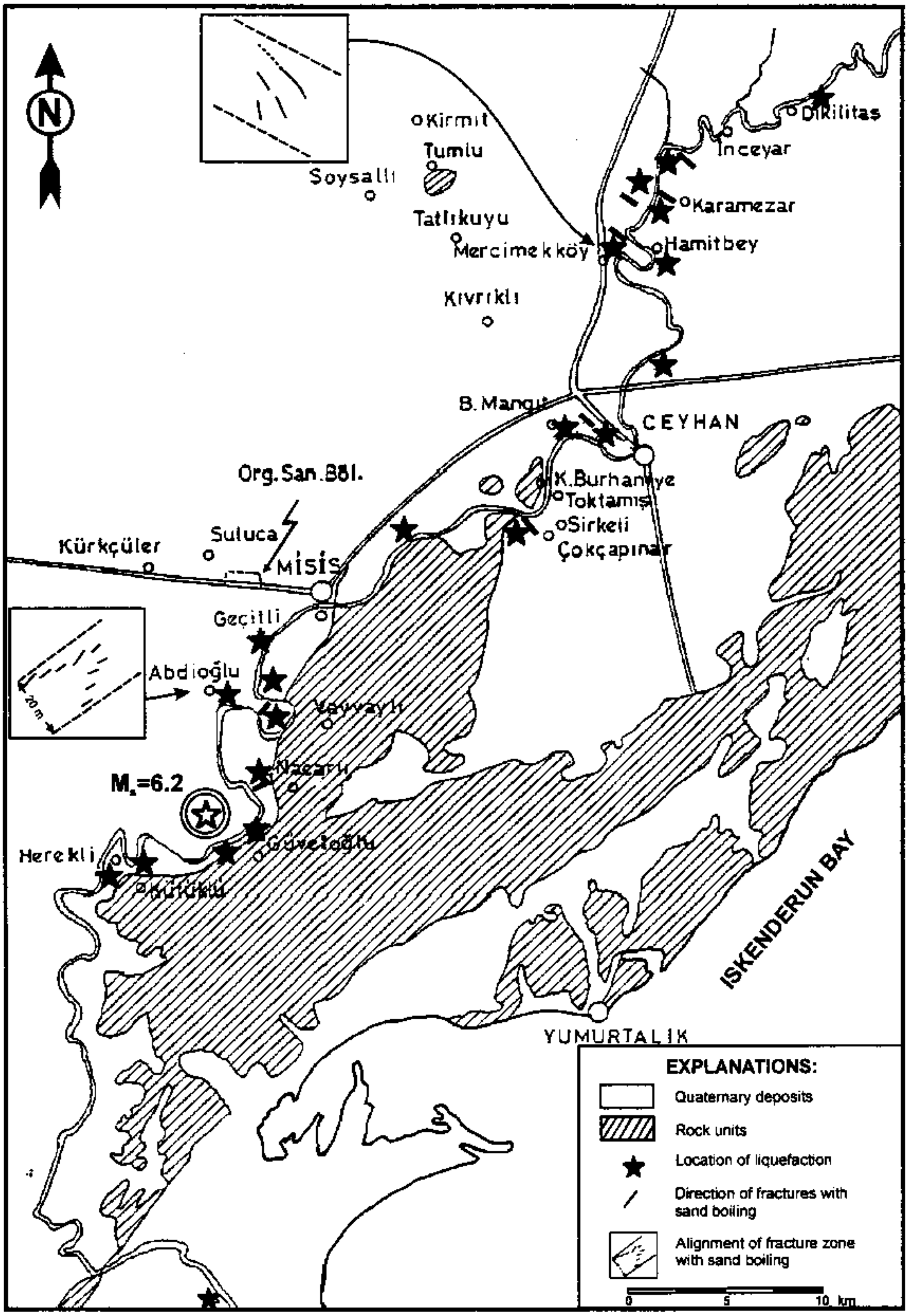


Figure 10.5 Locations of liquefaction sites

Figure 10.6: Tilting of a fountation in the garden of a primary school at Abdioğlu Village due to liquefaction

Figure 10.7: Differential settlement of 5 cm beneath the water-storage tower at Abdioğlu

Figure 10.8: Tilted pole and goal pillars in Abdioğlu

10.2 Sampling and Soil Properties

During the field investigations, soil sampling was carried out at some typical liquefaction locations for laboratory testing to characterize the physical and engineering properties of the liquefied and non-liquefied soils from the uppermost two zones in the alluvium. For the purpose, disturbed bag samples, tube samples (7 mm in diameter and 13 mm in height; Figure 10.9) and one block sample were collected from four different locations. Tube samples were taken from the sand boils of the liquified soil. But sampling with tubes from the uppermost non-liquefied fine grained soil could not be possible, because its very stiff nature.

Laboratory testing consisted of the determination of moisture content, unit weight, specific gravity, grading, porosity, permeability, Atterberg limits and static shear strength parameters. Shear strength parameters were determined on the test specimens prepared from the tube samples of the liquefied soil. The physical characteristics of two soil types were compared and assessed from the liquefaction potential point of view.

Figure 10.9: Tube and bag sampling at a liquefaction site

10.2.1. Physical and Index Properties

The unit weights were determined 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. However, they do not show a significant scatter. Because the liquefied soils were sampled two weeks after the earthquake, probably the most moisture-representative samples were the block sample taken from the bank of Ceyhan River (Sample No.2c) and the samples from the non-liquefiable soil which lies above the groundwater level. The range of specific gravity obtained was 2.59-2.70, and 2.39-2.57 for the liquefied and non-liquefied soil layers, respectively.

Although most of the liquefied soils lost most of their natural moisture content just after the boiling, they have greater moisture content values (2.8-15.95 % ; except sample 2c) than those of the samples from the non-liquefied soil (2.39-2.57 %). The value of 37.4 % obtained from block sample 2c, represents a more realistic moisture content.

Grain size analyses were conducted on 8 specimens from both liquefied and non-liquefied soils. Figure 10.10 shows particle size distribution curves of liquefied soils from previous earthquakes in Turkey. Figure 10.11 shows that fine-to-medium sand sized material ranging between 82 and 94 % is the dominant in the liquefied soils in Çukurova basin. The grain size distribution of these liquefied soils fall between the well known upper and lower limits for liquefaction (see Figure 10.11). It is evident that all the samples from the liquefied layers do not meet the requirements of the Unified Soil Classification System where a well-graded sandy soil should both C_u>6 and C_c between 1 and 3. Their properties indicate that these soils are poorly-graded fine-to-medium sands with a very low percentage of fines. By employing the procedure suggested in the Unified Soil Classification the soil samples from this zone fall into SP group. The D_{50} of the soil grains of this sand does not show a scatter and ranges between 0.11 and 0.3 mm indicating that the soil is highly susceptible to liquefaction (Iwasaki, 1986). Both the partical 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 occurence of the liquefaction.

Based on the results obtained from three specimens (Figure 10.12), the uppermost soil overlying the sandy liquefiable level is a fine-grained soil (40-84 % silt and clay with some sand (16-60%)). D_{50} values obtained from this level vary between 0.019 and 0.07 mm. Except one specimen (2b) which is non-plastic, the index properties of this fine-grained soil indicate that the liquid limit (LL) and the plasticity index (PI) range from 27.4-35.7 % and 6.4-8.8 %, respectively. Evidently all samples have liquid limits less than 50 %, suggesting low plasticity. These soils are classified as ML group soil and defined as silty clay. The reason for not occurring liquefaction in this layer could be its fine grained composition, mean grain size, its position with respect to groundwater table and the amplitude of acceleration vawes. It is also noted that the grain size distribution of the non-liquefied soils do not fall within the well known liquefaction range and they are consistent with non-liquefaction based on grain size (see Figure 10.12).

The permeability coefficients of the liquefied soils determined in the laboratory range between $1.77x10^{-5}$ cm/s and $5.22x10^{-4}$ cm/s. Porosity of the same samples is about 46%.

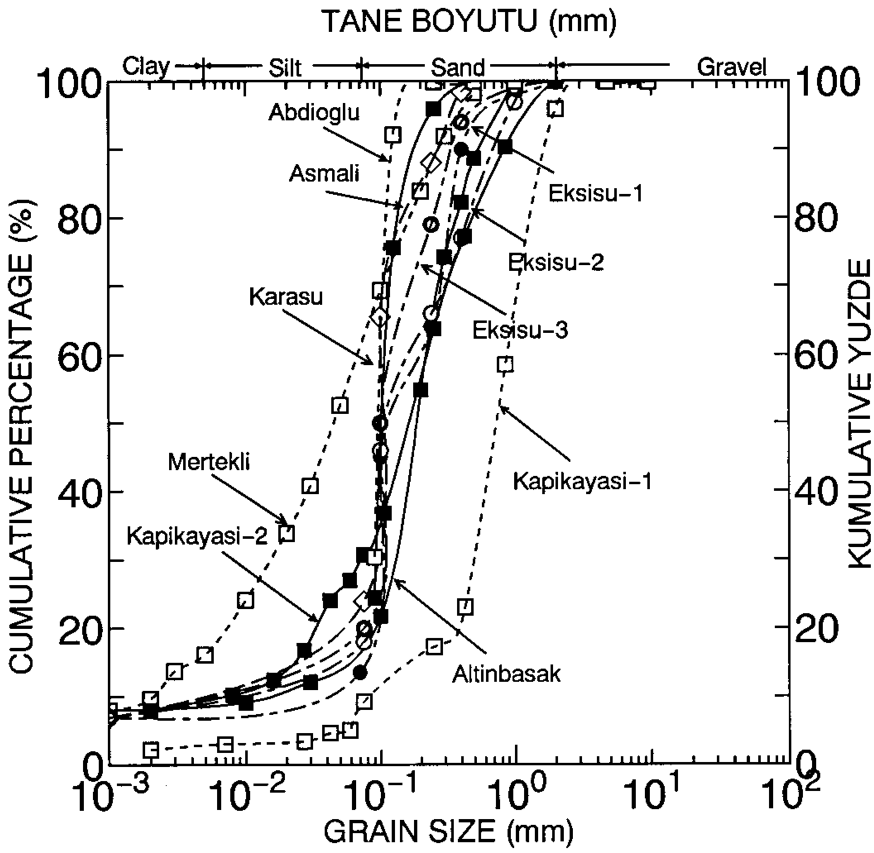


Figure 10.10: Grain size distribution curves of the soil samples taken from the non-liquefied uppermost layers of the allivium in Ceyhan Basin

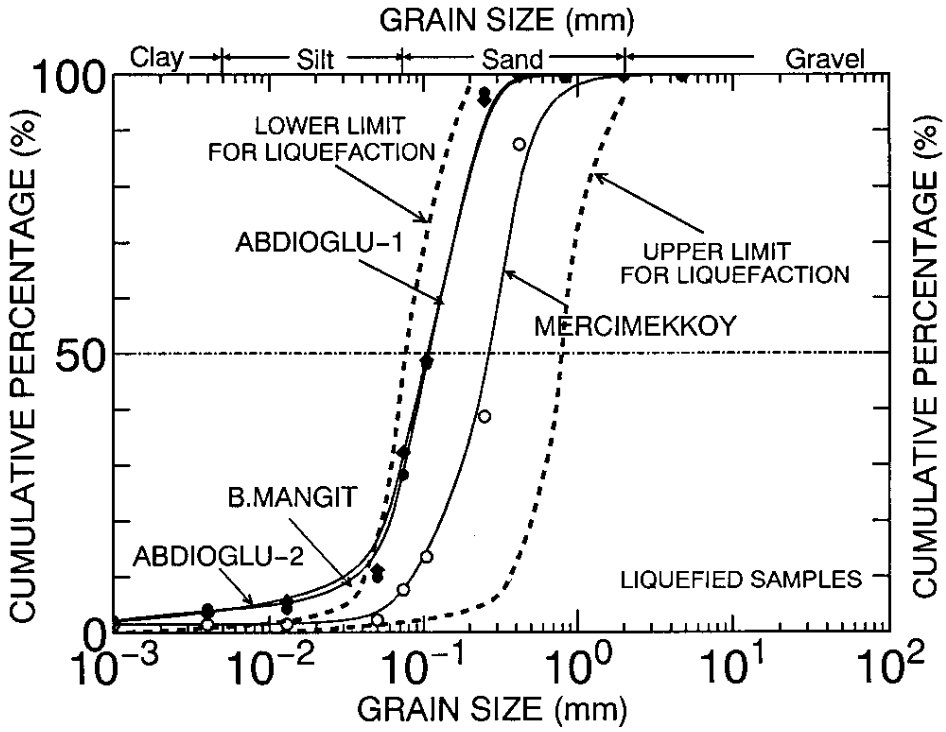


Figure 10.11: Grain size distribution curves of the soil samples taken from the non-liquefied uppermost layers of the allivium in Ceyhan Basin

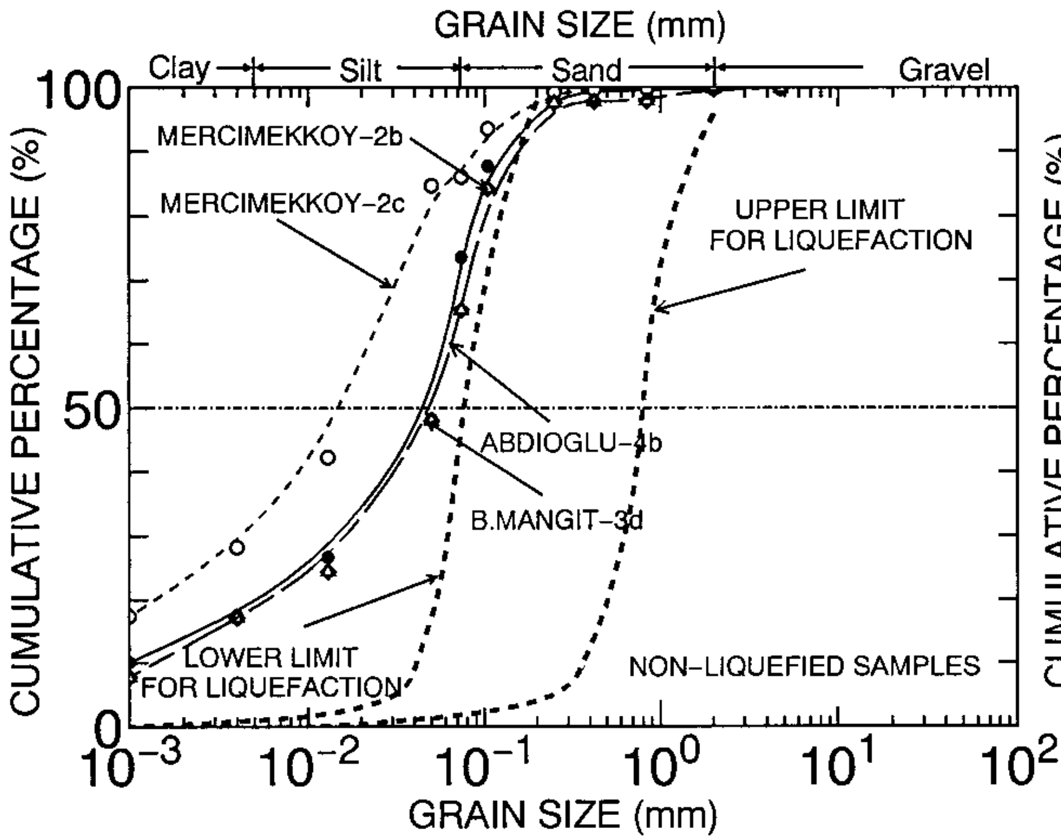


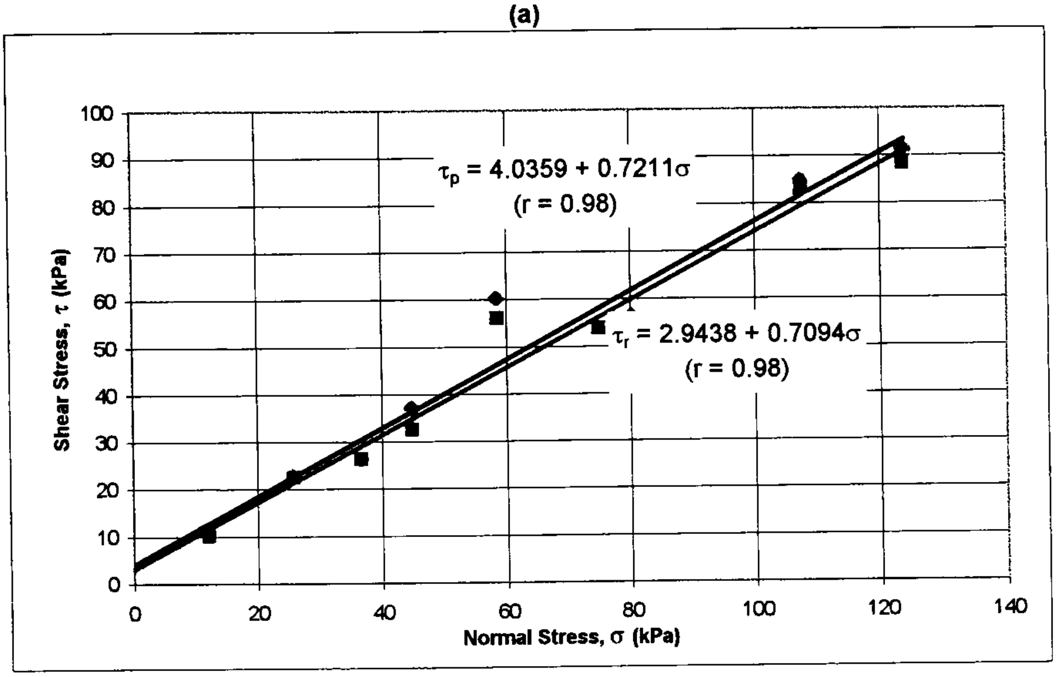
Figure 10.12: Grain size distribution curves of the soil samples taken from the non-liquefied uppermost layers of the allivium in Ceyhan Basin

10.2.2. Static Shear Strength of the Liquefied Soils

Static shear strength parameters, cohesion (c) and internal friction angle (ϕ) of the liquefied soil layers were determined employing motorised direct/residual soil shear test device. Totally 9 specimens from the block sample (2c) and from tube samples (Sample 1 and 3a) were prepared to fit the shear box. Tests were carried out on three test sets consisting of 3 specimens of each to achieve representative failure envelopes for each set. All the tests were run at a strain of 0.25 mm/min.

Shear strength parameters from the failure envelopes based on the linear and geometric regression analyses show a consistency and yield similar coefficients of correlation. Considering this agreement, shear strength parameters obtained from the linear envelopes can be used. Peak cohesion and peak internal friction angle of the specimens vary between 0 and 8.7 kPa and 33.7^{o} and 36.4^{o}, respectively. It is also noted that the residual parameters are very close to peak parameters. The cohesion intercept obtained from two samples (samples 1 and 3a) is probably due to the presence of low amount of fines. To obtain general failure envelopes of peak and residual strength representing the liquified soil, all test data were plotted on a single σ-τ graph (Figure 10.13).

(a)



(b)

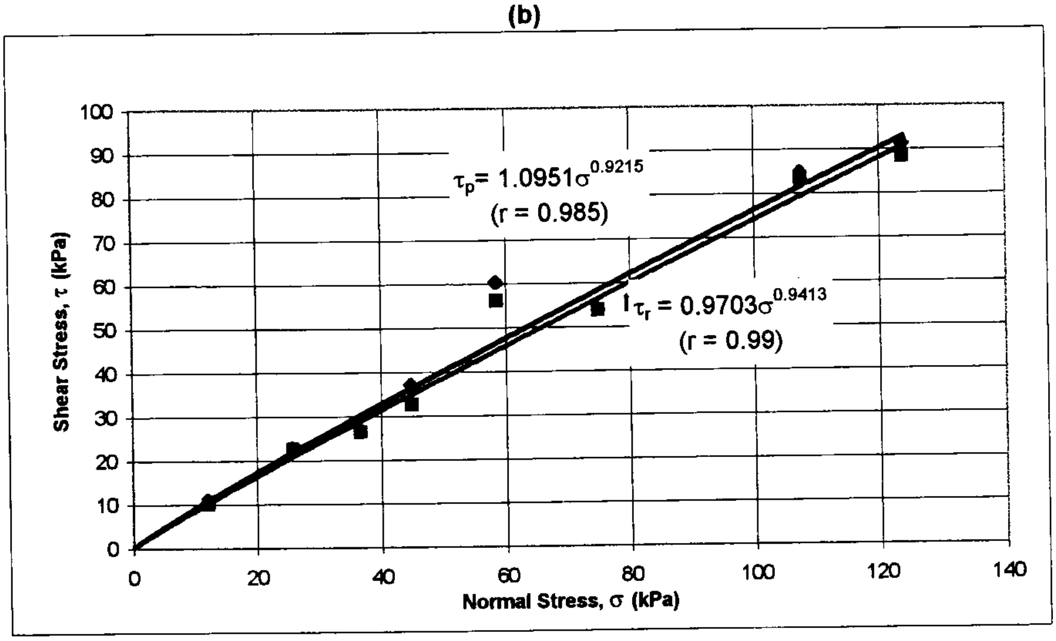


Figure 10.13: Generalized linear (a) and non-linear (b) failure envelopes of the liquefied soils

10.3 Comparison of Adana-Ceyhan Earthquake with Other Earthquakes Occurred in Turkey

Aydan and Kumsar (1997) compiled some data on the locations of earthquakes and developed some empirical relations between magnitude of earthquake and hypocenter distance for liquefaction - non-liquefaction states. Figure 10.14 compares data obtained in this earthquake with the data from other Turkish earthquakes. The data gathered in this earthquake are within the empirical bounds.

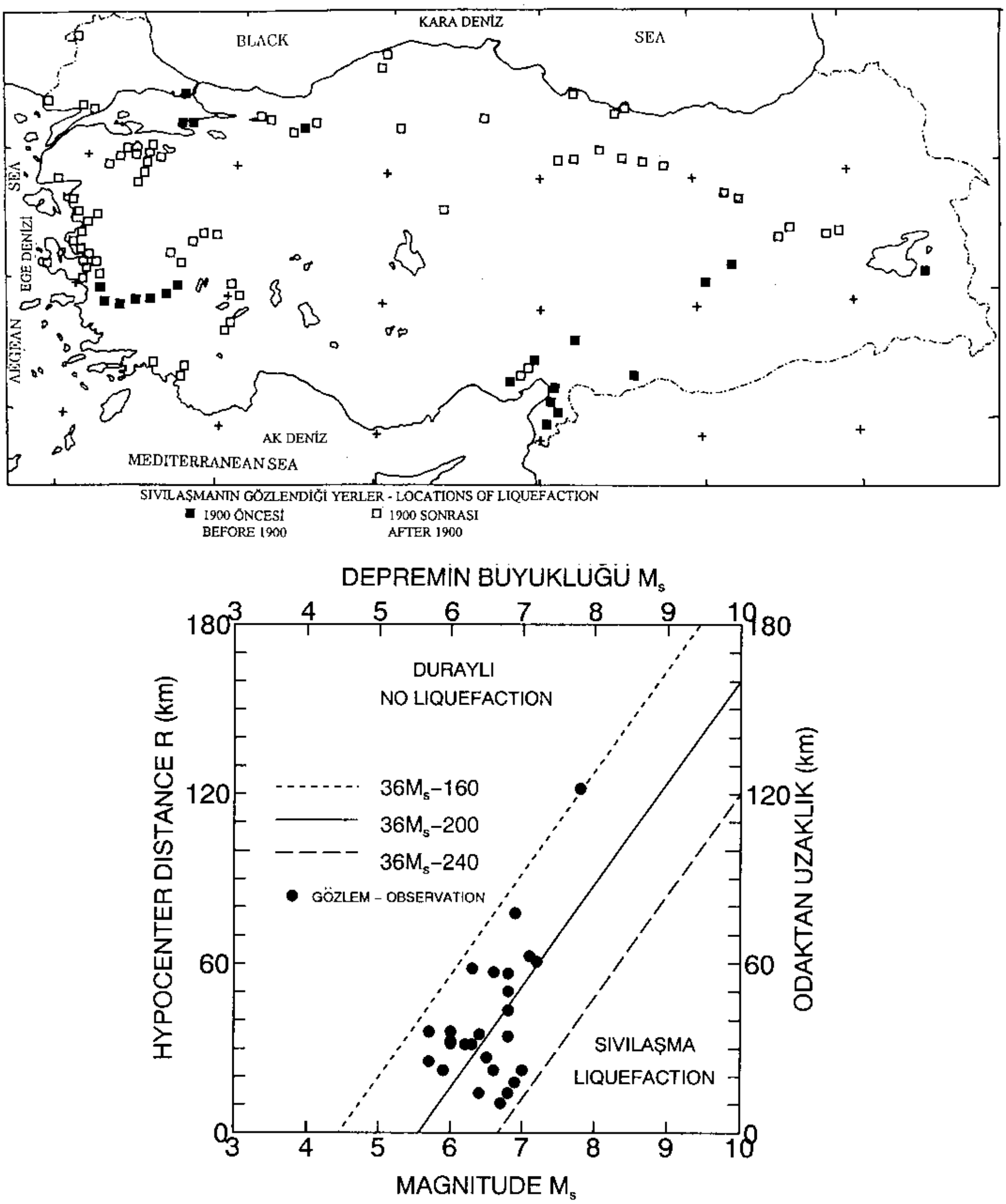


Figure 10.14 Locations of liquefaction in Turkey and comparison of data from this earthquake with other Turkish earthquakes