8 GEOTECHNICAL DAMAGE

8.1 Soil Liquefaction and Lateral spreading

Soil Liquefaction was widespread all over the epicentral area. The soil liquefaction was observed from on both sides of Shinano River from Tokamachi to Nagaoka plain. Liquefaction was also observed at Joetsu city, Teradomari, Kashiwazaki along Japan Sea shores in north and Koide and Muikamachi in south. Since the soil layers are inclined towards Shinano-River, the lateral spreading and permanent displacement of ground induced by soil liquefaction took place. The soil liquefaction and associated lateral spreading caused extensive damage to linear structures such as railways, highways, embankments and viaducts of expressway and Shinkansen railways. The topsoil is mostly silty or clayey layer, which may act as a lid to prolong shaking and excess pore-pressure dissipation. Therefore, the sand volcanoes sometimes were missing although ground rupturing and ejection of mud were observed. Liquefied soil ranged from clayey soil to gravelly sand, including sand. Some sampling was done at several locations nearby Shinkansen line (Katada) where Shinkansen TOKI No: 325 derailed and Takiya. The physical and geotechnical properties of these soil samples are given in Table 8.1 and grain-size distributions are shown in Figure 8.1. Figure 8.2 shows the relation between the hypo-central distance and earthquake magnitude for liquefied sites together with liquefaction state limits developed for Turkish earthquakes (Aydan et al. 1999). Figure 8.3 shows several views of soil liquefaction in the earthquake-affected area. As it is noted from pictures, the ejection of gravels and clayey material was observed in the epicentral area and beneath Shinkansen line where the train was derailed. Furthermore, the splashing of muddy material on the columns of viaducts of Shinkansen line was 4m high in some places.

Table 8.1: Properties of liquefied soil samples collected from sand volcanoes

Soil Sample Location	Dry Unit Weight (kN/m^3)	Porosity (%)	Mean Grain Size D_{50} (mm)	Friction Angle (^{o})
Katada-manhole	11.0-12.5	37.3	0.610	30-32
Katada-Shinkansen	13.2-13.3	42.7	0.533	29-31
Takiya-field	13.2-13.8	40.0	0.247	27-31

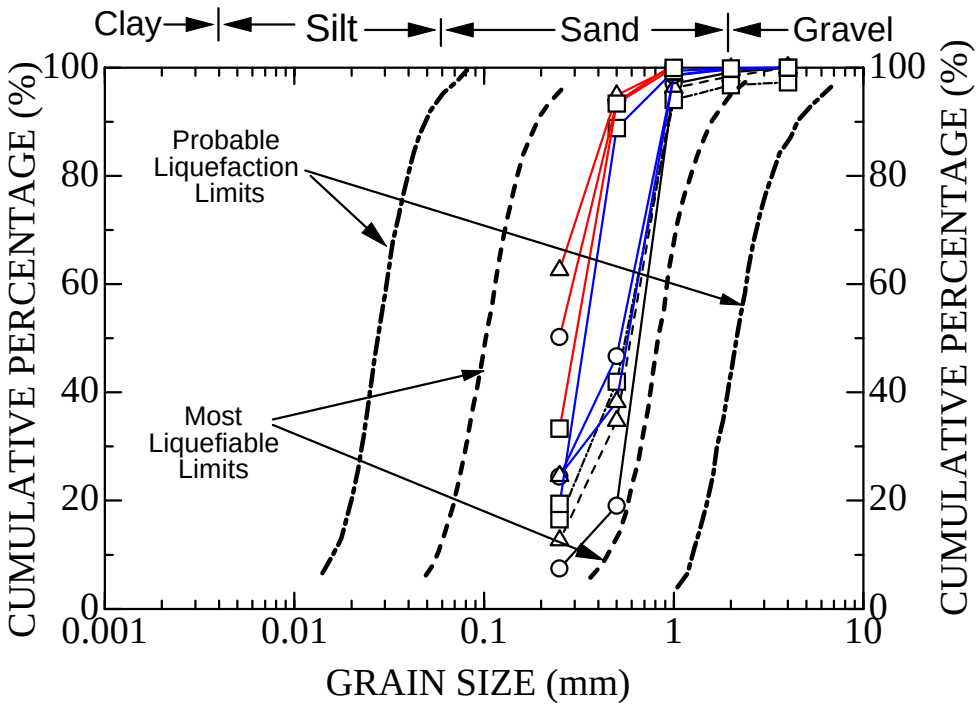

Figure 8.1: Grain size distribution of samples collected from sand volcanoes

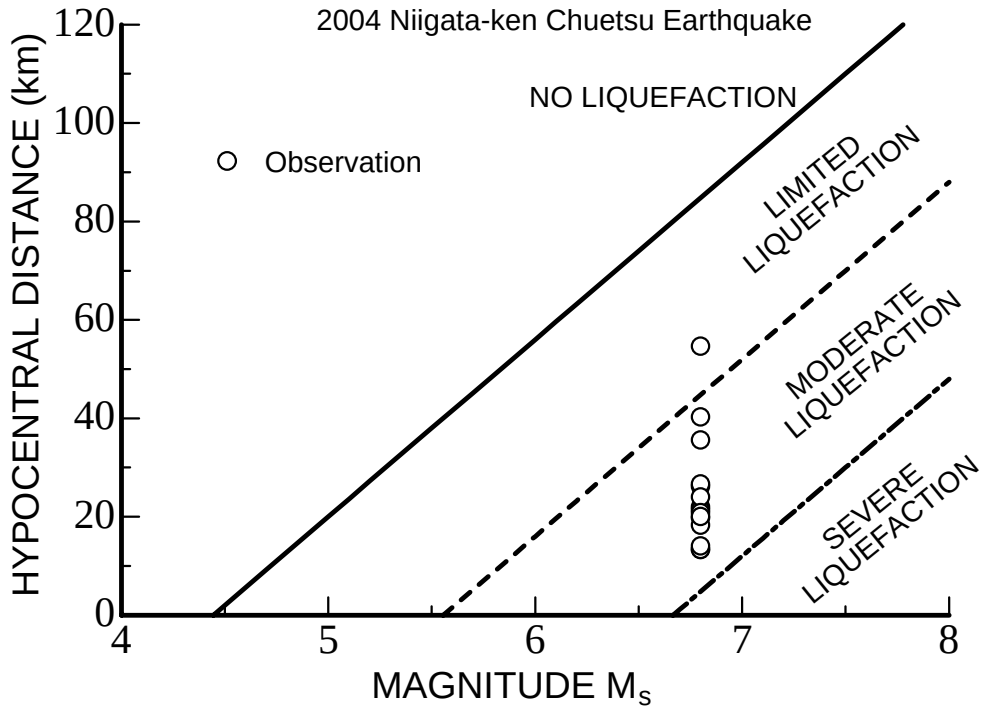

Figure 8.2: The relation between the hypo-central distance and earthquake magnitude together with liquefaction state limits for Turkish earthquakes

Figure 8.3: Examples of liquefaction (pictures by Aydan and Niigata University)

Figure 8.4 shows two aerial photographs taken nearby Ojiya and Nagaoka along Shinano River. In these pictures taken by several Aerial Surveying Companies, the sand volcanoes and ground ruptures associated with lateral spreading are clearly visible.

(a) Nagaoka

(b) Ojiya

Figure 8.4: Aerial photographs of liquefaction and lateral spreading (from Aerial Surveying Companies)

8.2 Slope Failures

One of the most striking characteristics of this earthquake is extensive slope failure. The slope failures caused extensive damage on roadways, railways, and expressways as well destroying homes. The most extensive slope failures were observed in Yamakoshi village. The area mainly consists of Neogenic mudstone. This mudstone near ground surface is highly weathered and it had become clayey soil. The slope failures in this area are associated with bedding planes which dips NE with an inclination ranging between 10-25 degrees. Before the earthquake, Typhoon No.23 passed over the earthquake epicentral area and resulted in very heavy rainfall. Therefore, rock mass and soil layers are expected to be fully saturated at the time of earthquake. The slope failures may be categorized as illustrated in Figure 8.5

a) Curved deep-seated slope failures (shear or sliding – Figure 8.6)
b) Shallow seated slope failures (flexural toppling, combined sliding and shearing – Figure 8.7)
c) Sliding failure (plane sliding, wedge sliding – Figure 8.8)
d) Rock-falls (toppling, bending failure – Figure 8.9)

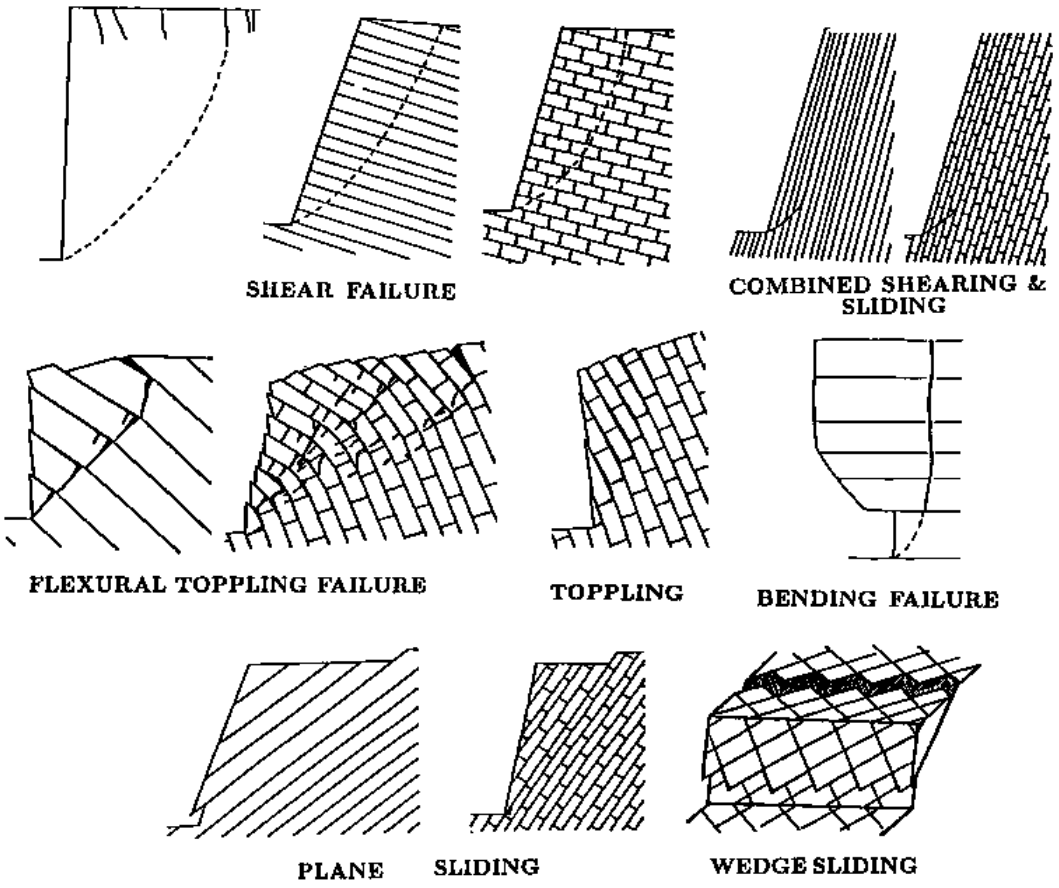

Figure 8.5: Classification of slope failures (arranged from Aydan 1989)

Figure 8.6: Aerial photographs of slope failure at Yamakoshi and along Shinano River

Figure 8.7 Slope failures

Figure 8.8: Planar Rock Slope failures

Figure 8.9: Wedge, toppling and combined rock slope failures

8.3 Embankment Failures and Settlements

Embankment failures and settlements were widespread. Several typical examples are shown in Figure 8.10. The highways, Kanetsu expressway and railways are mainly built on the embankments. The embankments mostly failed in the form of curved sliding. Some failures were associated with the liquefaction of soil beneath the embankments.

Figure 8.10: Embankment failures

There are also some earth dams built for irrigation and drinking water purposes. The failure and settlement characteristics of embankments of these structures are basically the same. Some examples are shown in Figure 8.11.

Figure 8.11: Embankment failures associated with earth dams