The southern area of Ashiya-hama, where liquefaction effects were significant, was reclaimed by the sands both from the sea and from Awaji Island[13]. Figure 8 (a) shows a typical boring log in the southern area of Ashiya-hama, indicating that marine sand having an SPT N-value of around 10 underlay about 5 meters below the ground surface. On the contrary, the northern area of Ashiya-hama where less effects of liquefaction occurred was reclaimed mostly by decomposed granite as shown Figure 8 (b). Areas underlain by these different profiles may behave differently during the earthquake. Actually the sand erupted from the ground surface was not yellow decomposed granite but gray marine sand.

Low-rise reinforced concrete residential buildings supported by pile foundations generally behave well. However, in the areas facing the water, foundation piles of several buildings were found to be broken and/or be cracked due to lateral displacement of the liquefied ground[14]. In the south end of Ashiya-hama, residential buildings complex 14-29 story high did not suffered any settlement and tilt, although sand boils and large ground displacements more than 2 meters were observed in the neighborhood. These buildings were supported by steel pipe piles 110 cm in diameter and about 30 meters in length. The piles had been driven in to Pleistocene soil layer through fills improved by sand compaction piles for remedial measure against liquefaction[15].

Extensive liquefaction was also observed in Minami Ashiya-hama located south of Ashiya-hama. Fortunately, no building and facility had been constructed in the area by the time of the earthquake.

4.6 Nishinomiya City

Traces of soil liquefaction were evident both in Nishinomiya-hama and in Koshien-hama. A girder neighboring to Nishinomiya-ko Bridge spans between Koshien-hama and Nishinomiya-hama fell down as described later. A sewage treatment plant used from 1991 in Koshien-hama suffered differential settlements of buildings and facilities, floating up of underground structures, cracks of pile head, and separation of concrete joints of basins.

Naruo-hama was reclaimed during 1967-1975, almost in same period as Ashiya-hama, using decomposed granite from Awaji Island. Thickness of the fill ranges 10-14 meters, with ground surface 5 meters above sea level. Greater part of the fill was untreated, nevertheless, liquefaction traces such as sand boils, ground fissures and subsidence were considerably less than those in other reclaimed areas described previously. Photo 27 shows a quaywall of the northeastern end of Naruo-hama, where no major damage was observed. One of the reasons why the liquefaction effects were slight in this area is that the intensity of the ground motion is smaller because of the longer epicentral distance.

Photo 27 Qauywall of Naruo-hama where no major damage was observed (W in Figure 4)

4.7 Osaka City

In Osaka City, east of Hyogo Prefecture, soil liquefaction sporadically occurred along the coastal area facing the Bay of Osaka as shown in Figure 3. The severest liquefaction occurred along the lower reaches of the Yodo River, approximately 35 km east from the epicenter, damaging river dikes and a substantial number of wooden private houses. The heavily damaged areas are Konohana-ku, Nishi-yodogawa-ku, Fukushima-ku and Yodogawa-ku[6].

Dikes of the Yodo River were seriously damaged over a total length of 6,590 meters: the concrete parapet of the levees tilted, settled and slid about 8 meters into the river; the embankment cracked and settled maximum of 3 meters[16]. Sand erupted from the fissures along the dikes as shown Photo 28.

The liquefaction also occurred in the residential areas along the river. Many residence, which were typically 2-story wooden houses with low foundation rigidity, and several low-rise buildings sustained severe settlement and tilting (Photo 29). According to Osaka City Government[6], damage to houses in Osaka was heavily concentrated in Nishi-yodogawa-ku and Konohana-ku; 47 houses were totally damaged and 912 were partially damaged among a total of 18,840 houses in Nishi-yodogawa-ku, while 115 houses were totally damaged and 620 were partially damaged among 12,248 houses in Konohana-ku. Exact number of houses damaged due to liquefaction were unknown, however the most of the damage to houses is assumed to be related liquefaction since they were located in the liquefied areas.

The severely damaged areas along the Yodo River were originally reclaimed from the sea in the period of 17-19 centuries, having been used for paddy field[17]. After the excavation of the present channel of the Yodo River in 1910, the areas were gradually developed for residential areas by reclamation. The area around Denpoji Water Gate, where the embankment

settled 3 meters, located within the abandoned channel of the old Yodo River and had been a swamp until forty years before the earthquake. Figure 9 shows soil profile along the Yodo River. Loose fill and alluvial sand with SPT N-value of 10 or less extend from ground surface to a depth of 15 meters. These alluvial sand and fill beneath the water level are considered to have liquefied.

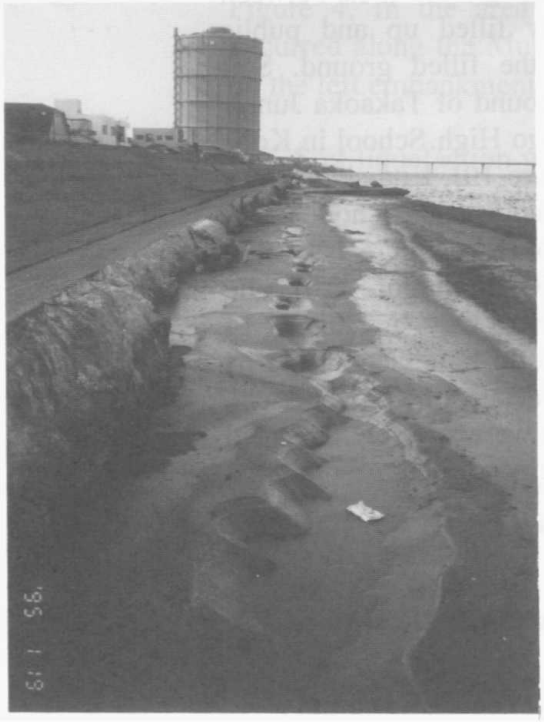

Photo 28 Sand boils along Torishima Dike of Yodo River (Courtesy of Mr. R. Isoyama)

Photo 29 Liquefaction-induced settlement of stores near Torishima Dike18)

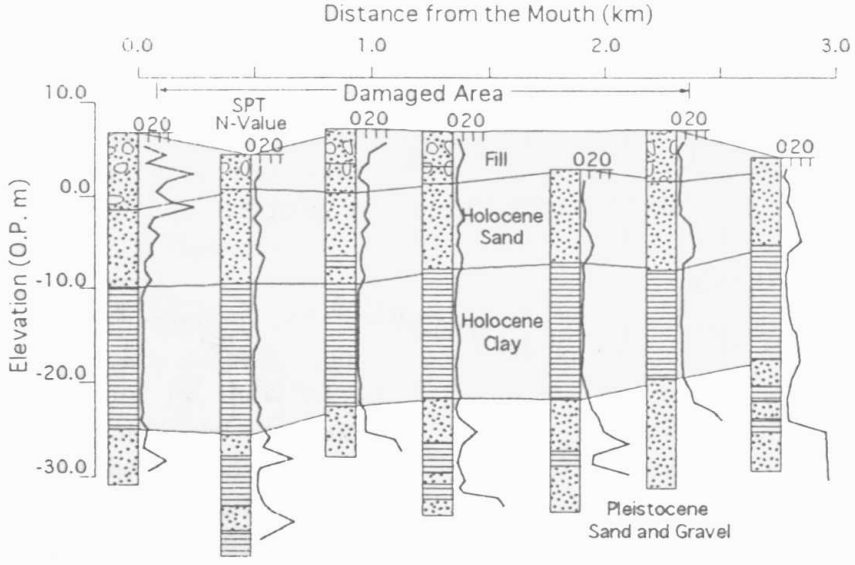

Figure 9. Soil profiles along the left bank of Yodo River[19]