# LIQUEFACTION, GROUND DEFORMATION AND THEIR RELATED DAMAGE TO STRUCTURES*

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*This paper introduces an outline of liquefaction, its induced ground deformation and damage to lifeline facilities and foundations of buildings and bridge piles during the 1995 Hyogoken-nambu (Kobe) earthquake. Characteristics of ground displacement and strain measured by aerial survey are described. Some typical examples of large ground displacements are presented and a casual relationship of damage to buried pipes and foundation piles with the ground displacements is investigated. In addition, the present paper introduces several examples of foundations proved to have resisted against the liquefaction and its induced ground displacements during the earthquake.*

*Key Words: Earthquake, earthquake damage, liquefaction, ground displacement, site investigation, case history, sand, sandy soil, measurement, decomposed granite.*

## 1. INTRODUCTION

The 1995 Hyogoken-nambu earthquake caused significant soil liquefaction in an extensive area of reclaimed land in Kobe and its neighboring cities. The soil liquefaction also induced large ground displacements in the horizontal direction, which resulted in serious damage to buried lifeline facilities and foundations of bridges and buildings. The authors have investigated the liquefaction during the earthquake and its caused damage to various kinds of civil engineering structures. They also measured the liquefaction-induced ground displacements in reclaimed lands along the waterfront of Hanshin area by an aerial survey using both pre- and post-earthquake photographs and by referring to the results from field surveys. Typical examples of damage related liquefaction-induced ground

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displacements were presented. In addition, the authors discussed the performances of foundations in the area of the liquefaction and large ground displacements, by referring the types of the foundation, and sought effective countermeasures in the liquefied ground.

## 2. GEOLOGICAL AND GEOMORPHOLOGICAL SETTINGS

Hanshin area, the heavily damaged area by the Hyogoken-nambu earthquake, is located at the southern foot of the Rokko Mountains, is approximately 5 km wide in the north-south direction and 25 km long in the east-west direction. The Rokko Mountains, with elevations of more than 900 meters in the eastern part and about 400 meters in the western part, are comprised of granite formed by igneous activities in the Cretaceous period. The granite easily weathers and decomposes known as "Masado", which is characterized by low plasticity, low cohesion and ease of erosion.

Figure 1 shows schematic diagram illustrating geological and geomorphological cross section in Hanshin area. Many small rivers originating in the mountains have formed terrace comprising of Pleistocene fan deposits, alluvial fan and coastal plains of Holocene deposits in the south. The area south of the plains comprises reclaimed lands, which were mainly filled with decomposed granite from Rokko Mountains and Awaji Island, and Pliocene deposits of tuff, conglomerate, sand stone and mud stones of Kobe Group from western Kobe. They were partially filled with Pleistocene marine clay and gravel of Osaka Group and dredged marine sands. The fill also contains rubble and waste from construction sites. The materials and work periods of the reclamation are summarized in Table 1.

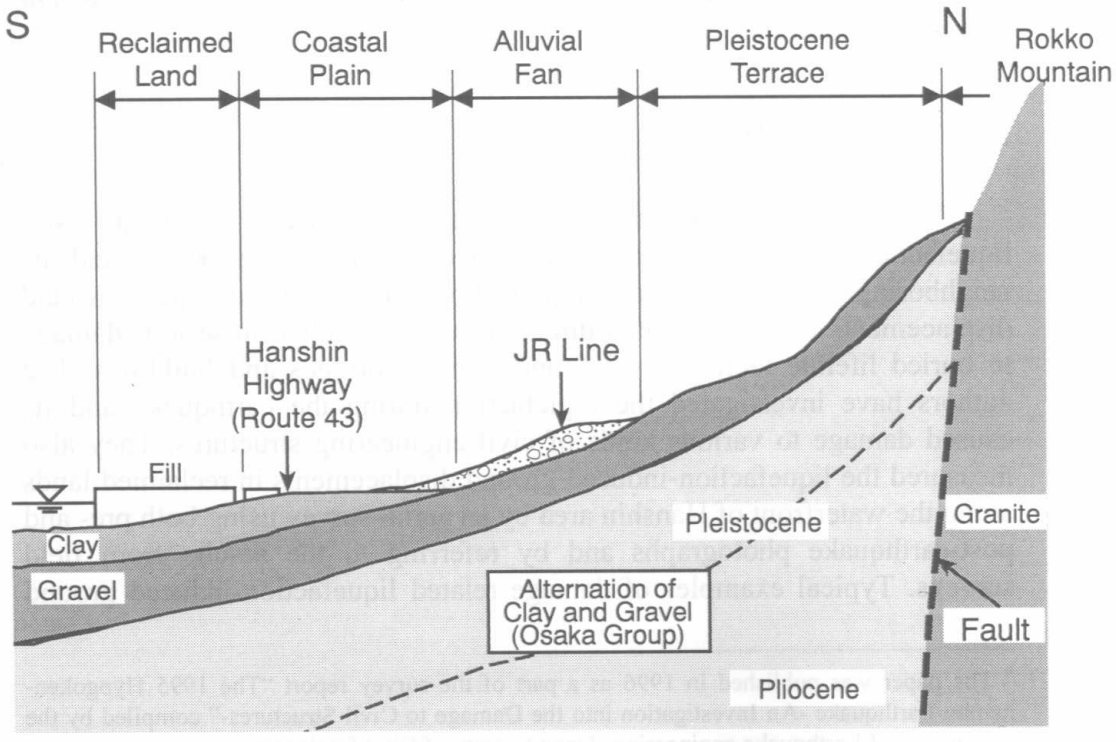


*Figure 1. Schematic diagram showing geological and geomorphological aross section in Hanshin area*

TABLE 1. SUMMARY OF RECLAMATION IN KOBE, ASHIYA AND NISHINOMIYA[1)]

| Area | | Project Organization | Work Period | Source of Fill | Geology of Fill |
|---|---|---|---|---|---|
| First Stage | Sotohama, Komagabayashi-minami | Kobe City | 1957-1967 | Suma ward, Kobe | Rokko Granite*1 |
| | Karimojima | ditto | 1963-1968 | ditto | ditto |
| | Tohya-hama | ditto | 1960-1966 | Suma ward, Kobe | ditto |
| | Nada-hama-higashi | ditto | 1953-1967 | Nada ward, Kobe | ditto |
| | Mikage-hama, Sumiyoshi-hama | ditto | 1960-1968 | ditto | ditto |
| | Uozaki-hama | ditto | 1961-1968 | Higashi-Nada ward, Kobe | ditto |
| | Fukae-hama | ditto | 1964-1970 | Suma ward, Kobe | ditto |
| Second Stage | Port Island, Phase I | ditto | 1966-1980 | ditto | ditto |
| | Rokko Island | ditto | 1972-1990 | Suma and Nishi wards, Kobe | Rokko Granite, Kobe Group*2 , Osaka Group*3 |
| | Port Island, Phase II | ditto | 1986-1996 | Nishi ward, Kobe | Kobe Group , Osaka Group |
| Maya Wharf | | Ministry of Transport | 1959-1967 | Nada ward, Kobe Kobe port | Rokko Granite Marine sand |
| Ashiya-hama | | Hyogo Prefecture | 1969-1975 | Okayama Prefecture, Awaji Island | Marine sand Ryoke Granite*4 |
| Minami-Ashiya-hama | | Hyogo Prefecture | 1971-1996 | Awaji Island | Ryoke Granite |
| Nishinomiya-hama | | Hyogo Prefecture | 1971-1992 | ditto | ditto |
| Koshien-hama | | Hyogo Prefecture | 1971-1994 | ditto | ditto |
| Naruo-hama | | Private Enterprise | 1967-1975 | ditto | ditto |

*1: Granite including decomposed granite (Late Cretaceous)

*2: Mainly consists of lacustrine mudstone, sandstone, and conglomerate embedded with intermediate layers of tuff (Miocene)

*3 Mainly consists of marine clay embeded with intermediate layers of gravel and volcanic ash Early Pleistocene)

*4: Granite including decomposed granite (Early to Late Cretaceous)

Figure 2 shows the ranges of the grain size distribution curve for the fill materials comparing with that for liquefied sands during the 1964 Niigata earthquake. It should be noted that the actual fill material contain gravel particle over 50 mm, cobbles and /or boulders. The figure shows that the fill materials are well-graded and contain a significant amount of fines as well as large gravel, which had been considered to be resistant to liquefaction. As described later, these materials were unexpectedly liquefied during the 1995 earthquake.

## 3. DISTRIBUTION OF SOIL LIQUEFACTION

Figure 3 shows the location of liquefied sites found by several reconnaissance teams[4)-6)] as well as by the authors. Sand boils occurred in many locati ons along an 83 km long zones along the Bay of Osaka that stretched from Takasago, west of Kobe, to Kishiwada, south of Osaka. Most of the liquefied sites in the figure lie on recently reclaimed land areas from the sea, but some of them located at natural ground and fill on the

former pond. Soil liquefaction was also observed coastal areas of Awaji Island and northeastern part of Tokushima Prefecture, Shikoku Island as shown in the figure.

The most distant liquefied site from the epicenter is Yabashi, Kusatsu City located at the shore of Biwa Lake, the epicentral distance of which is about 90 km[4]. Minor sand boils, however, had occurred at more distant sites during the past inland-type earthquakes whose magnitude was the same as the 1995 earthquake. For example, during the 1895 Kasumigaura and the 1896 Riku-u earthquakes, sand boils were observed at the sites about 160 km and 100 km from the epicenters, respectively[7].Therefore, soil liquefaction may have occurred at more distant sites than Yabashi.

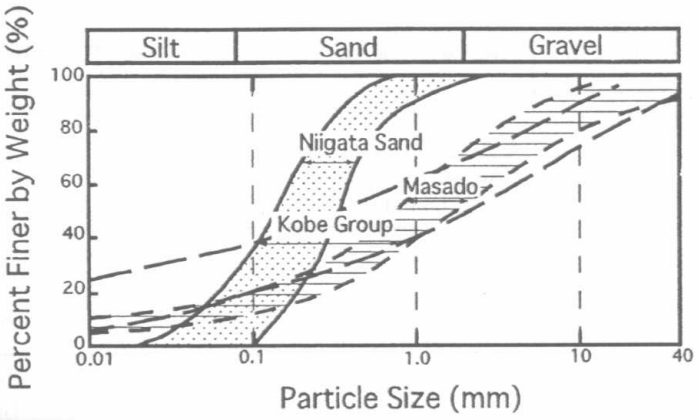


*Figure 2. Grain size distribution curves for the fill materials in Kobe[2] and Niigata sand[3]*

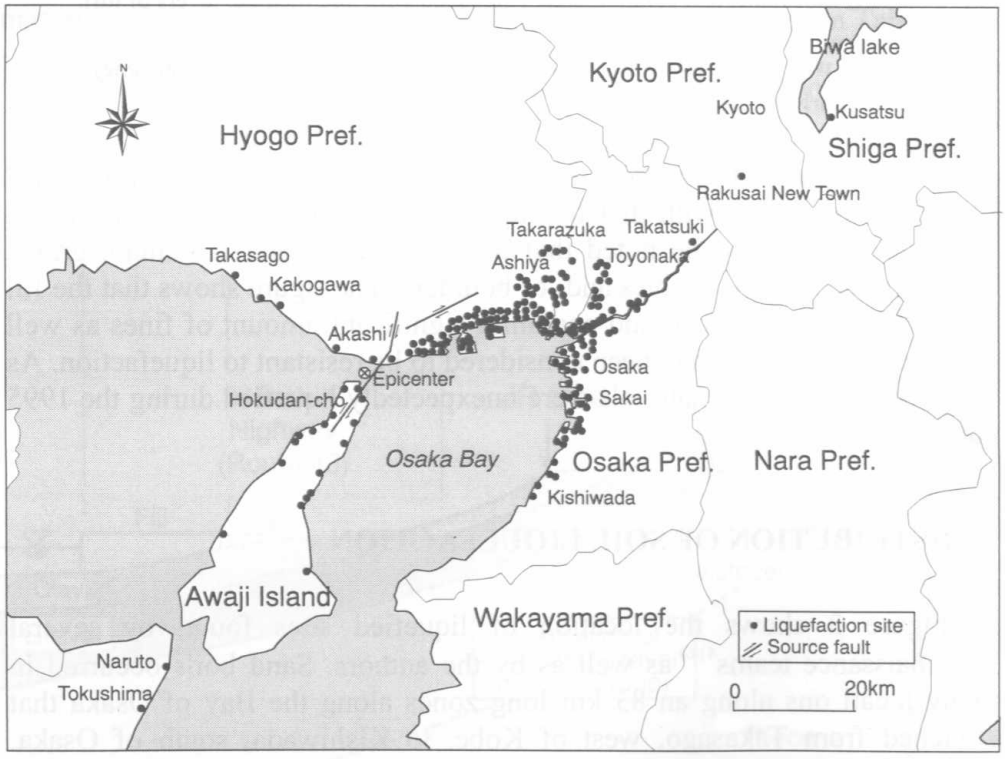


*Figure 3. Distribution of liquefied sites*