ABSTRACT

The 1995 Hyogoken-Nambu earthquake severely damaged coastal facilities and reclaimed land in the Hanshin area. This report summarizes the outline of the reclaimed land at Naruohama on the basis of the previous investigations. And then this report discusses the damages caused by the earthquake to the reclaimed land at Naruohama by means of the leveling and the grain size analysis conducted by the authors. A summary of the damage is as follows; Sand boil due to liquefaction occurred mainly in the western part of the reclaimed land area, as well as in the part of the reclaimed land near the original shoreline. The degree of settlement caused by the earthquake ranged from 0.3 to 42.5 cm, and averaged 13.3 cm. The ratio of the degree of settlement due to the earthquake to the thickness of the sand stratum above the alluvial clay stratum ranged from 0.03 to 4.12%, and averaged 1.14%. No significant settlement caused by the earthquake was observed in buildings supported by approximate 30 m-long piles.

Key words: earthquake, earthquake damage, grain size, liquefaction, settlement, site investigation (IGC: C7/C6/E2)

INTRODUCTION

The 1995 Hyogoken-Nambu earthquake severely damaged coastal facilities and reclaimed land in the Hanshin area. Until now, reports have focussed mainly on the damage to Kobe port, Port Island and Rokko Island. The authors work at an institute in the Naruohama reclaimed land and have conducted previous investigations concerned with the reclaimed land at Naruohama. This report summarizes the outline of the reclaimed land and the damage caused by the earthquake.

OUTLINE OF RECLAIMED LAND

As shown in Fig. 1, the present reclaimed land, with an area of approximate 1,880,000 m², is located in the southeastern part of Nishinomiya City, at the mouth of the Muko River.

Process of Reclamation

The land reclamation was planned and begun before World War II. Reclamation was suspended, however, due to the war and unfavorable social conditions. It was resumed in 1967, and was completed in 1975.

Pit sand collected from Awaji Island was used for the reclamation. The sand was directly dumped by bottom door type hopper barges in order to reclaim land up to a level 2 m below sea level. After reaching this level, it became impossible for the barges to enter the area. Additional reclamation was therefore done by temporarily placing sand, and then pumping sand with water.

Figure 2 shows the progress of reclamation. The numeral in this figure shows the date of completion.

Stratification in the Reclaimed Land Area

The stratification of the reclaimed land area, with depth, comprises the landfill, upper alluvial sand stratum, alluvial clay stratum, lower alluvial sand stratum, and diluvial gravel stratum.

The landfill consists mainly of gravel. During reclamation, the landfill materials thrust into the soft clay or sank to the bottom ground. This caused intrusion of clay into the landfill. As a result, the stratification has become complex in some sections of the reclaimed area, as shown in Fig. 3. Accordingly, the interface between the landfill and the original sea bottom is extremely irregular, and landfill thickness varies widely according to location.

As shown in Fig. 4, the upper alluvial sand stratum extends along the original coastline. This stratum becomes thinner as it extends toward the open sea; and therefore, it is found only in part of the reclaimed area near the original shoreline.

Figure 5 shows the contour lines of the uppermost level of the alluvial clay stratum. This level corresponds with the original bottom level where the upper sand stratum does not exist. Except for the eastern end of the reclaimed land area, the original bottom depth increases in proportion to the distance from the original shoreline.

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Fig. 1. Location map (Matsuo et al., 1995)

Fig. 2. Progress of land reclamation (Toyo Construction, 1987)

Fig. 3. Cross section (NEW JEC, 1976)

Fig. 4. Contour lines (Thickness of upper alluvial sand) (Nisiki Consultant et al., 1985)

Fig. 5. Contour lines for the uppermost level (Nisiki Consultant et al., 1985)
The rate of increase is uniform. The sea-bottom depth ranges from D.L.-5.0 to -9.0 m, indicating that the bottom is mostly level.

Figure 6 shows the contour lines for the alluvial clay stratum. The thickness ranges from 10.0 to 15.0 m, and increases as the stratum extends from the northern part of the reclaimed area to the south.

**STATUS OF DAMAGE REGARDING THE RECLAIMED LAND**

**Ground Liquefaction**

Figure 7 shows the areas of reclaimed land in Naruohama, where sand boils occurred due to liquefaction caused by the 1995 Hyogoken-Nambu earthquake. This figure indicates that sand boils due to liquefaction occurred mainly in the western part of the reclaimed area, as well as in part of the reclaimed land near the original land (shoreline). Sand boils did occur in large areas in playgrounds, parking lots and in open space. Sand boils originated mostly from cracks in the ground surface. Sand in linear areas also boiled from cracks in asphalt pavements of roads, and boundaries between roads and gutters or curbs.

Boiled sand was collected at five locations (No. A~E) as marked by closed circles in Fig. 7, and subjected to the grain size distribution tests. Figure 8 shows the results of these tests. According to the figure, the grain size distribution for all the sand samples falls within the category.

![Fig. 6. Contour lines (Thickness of alluvial clay) (Nisiki Consultant et al., 1985)](image)

![Fig. 7. Liquefaction area map in Naruohama](image)
Ground Settlement
The authors investigated the reclaimed land area with a level survey on March 27, 1995. The degree of settlement measured by the leveling includes the degree of consolidation settlement. The degree of settlement caused by the earthquake was determined by subtracting the degree of consolidation settlement from the degree of settlement measured by the level survey. The degree of consolidation settlement on March 27, 1995 was estimated using the hyperbolic method (JSSMFE 1982), based on data obtained prior to the earthquake.

a) Reclaimed Land in Naruohama
Figure 9 shows examples of the relationship between time and the degree of settlement based on the level survey. This figure indicates that the earthquake caused large settlement at point (4), while the influence of the earthquake was not apparent at other points. Figure 10 shows the degrees of settlement due to the earthquake. This figure indicates that the degree of settlement caused by the earthquake ranged from 0.3 to 42.5 cm, and averaged 13.3 cm. The land has heaved at four points, by up to 6.5 cm (noted by the minus sign in Fig. 10). The degree of settlement tends to be larger in the northeastern part (near the original shoreline) than in other parts. Large degrees of settlement were observed in areas where relatively extensive sand boils occurred.

In the present level survey, stormwater sewer manhole levels were regarded as ground surface elevation; there-
fore, it can be discussed that the results do not correspond exactly with those at actual ground surface level. It was assumed, however, that the results indicated the status of the settlement of the reclaimed land with satisfactory precision, since the protrusion of manholes above the ground was not observed in the reclaimed land area.

Ground settlement presumably occurred due to compaction of the sand stratum caused by vibration, and to the discharge of soil caused by sand boils. The parenthesized value in Fig. 10 is the ratio of the degree of settlement caused by the earthquake to the thickness of the sand stratum, based on the assumption that ground settlement was due only to the compaction of the sand stratum caused by vibration. In calculating the ratio, the stratum was limited to the sand stratum located above the alluvial clay stratum. The ratio ranged from 0.03 to 4.12%, and averaged 1.14%.

b) Naruo Technology Center, Toyo Construction Co., Ltd.

The site of the Toyo Construction Technology Center is located in the southwestern corner of the reclaimed land area (see Fig. 10). Figure 11 shows the results of the measurement of settlement of the structure at the site. At points (a) to (e), (1) to (8) and (13) to (16), the degree of settlement caused by the earthquake was calculated by predicting the degree of consolidation settlement by using the hyperbolic method (JSSMFE 1982); as explained above. Only three sets of data on settlement were available for points (17) to (40), and the authors were unable to estimate the degree of consolidation settlement by this method. For these points, therefore, the degree of settlement caused by the earthquake was determined by linearly approximating the degree of consolidation settlement (see point (25) in Fig. 11). Figure 12 shows the degree of settlement caused by the earthquake at the site of the Toyo Construction Technology Center.

Points (c) to (e) and (1) to (8) are located at buildings (see St. 1 and St. 2 in Fig. 12) supported by approximate 30 m-long piles. The building (St. 1) has two stories and, there is a two-storied portion in the area of points (1), (2), (7) and (8) in building (St. 2). No significant settlement caused by the earthquake was observed at these points. Points (a) and (b) are located in a concrete pit (St. 3 in Fig. 12) with an embedded depth of 1 to 1.5 m. The degree of settlement at point (a) was almost equal to that at point (b). Points (13) to (16) are located at another building (St. 4) with a raft foundation. Points (13) and (16) are located in the two-storied portion of the build-
ing, which occupies approximately 1/3 area of the building area. The degree of settlement at these points was larger than those at the other points due to the weight of the building second floor. Points (17) to (20) and (21) to (40) are located at other buildings (St. 5 and St. 6) with a raft foundation. There are three-storied portions at the site of points (19) and (20) in the building (St. 5) and at the site of points (21), (39) and (40) in the building (St. 6). The degree of settlement at points for building sections heavier and located closer to the revetment than other sections tend to be larger.

Figure 13 shows a comparison between the results of a standard penetration test at point C' and those at point C". The test at point C' was conducted on January 12, 1984, and the test at point C" on July 14, 1995, after the earthquake. These points are located only approximate 5 m apart from each other. Generally, no significant differences were found between the measurements at points C' and C". Measurements at point C", however, were slightly less than those at point C'.

CONCLUSIONS
A summary of the damage is as follows;
1) Sand boils due to liquefaction occurred mainly in the western part of the reclaimed land area, as well as in part of the reclaimed land near the original land (shoreline).
2) The degree of settlement caused by the earthquake in Naruohama ranged from 0.3 to 42.5 cm, and averaged 13.3 cm.
3) The ratio of the degree of settlement due to the earthquake to the thickness of the sand stratum above the aluvial clay stratum ranged from 0.03 to 4.12%, and averaged 1.14%.
4) No significant settlement caused by the earthquake was observed in buildings supported by approximate 30 m-long piles.

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REFERENCES