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EXPERIMENTAL STUDIES ON THE CAISSON TYPE QUAY WALL DAMAGED BY HYOGOKEN-NANBU EARTHQUAKE 1995

M. MITO[1], T. SUGANO[2], T. INATOMI[2] and H. INAGAKI[3]

1)Institute of Technology,PENTA-OCEAN Construction Corp. LTD.,Tochigi, Japan
2)Port and Harbour Research Institute,Ministry of Transport, Yokosuka, Japan
3)Costal Development Institute of Technology, Tokyo, Japan

ABSTRACT

Hyogoken-Nanbu earthquake 1995 damaged of the facilities at Kobe port and almost paralyzed their function. Typical form of the damage of caisson type quay was that caisson slided, leaned toward the sea and sank and the ground behind it subsided. This report shows the outline of the shaking table test to analyze the mechanism of the collapse of caisson type quay and the result. So long as the settlement of the ground surface and the displacement of the caisson are concerned, the result of the experiment and the measurement were in good agreement.

KEYWORDS

Experimental study; Hyogoken-Nanbu Earthquake; Shaking Table Test; Caisson; Damage

INTRODUCTION

Hyogoken-Nanbu earthquake 1995 damaged of the facilities at Kobe port and almost paralyzed their function. The form and the extent of the damage of a quay depended largely on the seismic coefficient and type of the structure. First we investigated the damage according to the seismic coefficient. Most of structures with small seismic coefficients were damaged while three berths at Maya area, which are earthquake-proof reinforced quays with the largest seismic coefficient at the Port of Kobe, suffered almost no damage. Secondly we compared the type of the structure. Gravity-type quays such as caisson and block-type suffered heavier damage than relatively lighter structures such as piers. Typical form of the damage of caisson type quay was that caisson slided, leaned toward the sea and sank and the ground behind it subsided. This report shows the outline of the shaking table test to analyze the mechanism of the collapse of caisson type quay and the result.

OUTLINE OF THE SHAKING TABLE TEST

We uesd a shaking table with a water depth of 2 m to model the behavior of the quay, which are constructed in the water, under earthquake more faithfully. The cross-section of the caisson type quay test model is shown in Fig.-1. This test model is -12 m quay of container wharf in Port Island with a scale of 1 to 17 in longitudinal direction. we gathered Masa soil in Port Island, sieved the particles smaller than 30 mm and used them as replaced and reclaimed soil. We used crushed stone # 4 as rubble foundation and # 6 as stone backfill. we mounted four earth pressure gauges and four pore pressure gauges behind the caisson in order to measure the dynamic earth pressure and dynamic water pressure acting on the caisson. We installed pore pressure gauges and accelerometers in the replaced soil directly under the caisson and in front of the caisson. Pore pressure gauges and accelerometers were also installed in the reclaimed soil. Photo-1 shows experiment model on the shaking table with water tank.

The input motion used in the experiment was a strong motion record of Hyogoken-Nanbu earthquake collected at GL. -32 m in Port Island. Fig.-2 shows the input motion in two horizontal components and a vertical component.

RESULT OF THE EXPERIMENT

Response Acceleration

Fig.-3 shows response acceleration in horizontal component measured by the accelerometers AH6 to AH9, mounted in reclaimed soil behind the cassion. AH9 was installed at the ground surface and AH6, AH7, AH8 are installed at the depth 100, 66 and 33 cm respectively. At AH6, the deepest point, the maximum response acceleration was about 344 Gal while at AH9, the ground surface, it was about 190 Gal. This figure shows that the maximum response acceleration gets smaller as the depth becomes smaller. Looking at frequency characteristic, we find that in AH9, the surface, long period component is more dominant than in AH6, the deepest point. Therefore, as the depth becomes smaller, the maximum response acceleration becomes smaller and long period component get more dominant. This is because near the surface excess pore pressure becomes high and reclaimed soil becomes soft.

Fig.-4 shows response acceleration in vertical component measured by the accelerometers AV6 to AV9, mounted at the same depth as AH6 to AH9. Unlike in the horizontal component, the maximum response acceleration gets larger as the depth becomes smaller and there is no tendency that long period component becomes dominant near the surface.

Excess Pore Water Pressure. Fig.-5 shows the time history of the excess pore water pressure by pore pressure gauges W3 to W5, mounted in the reclaimed soil behind the caisson, W1 and W2, mounted in the replaced soil directly under the caisson and W6 and W7 in front of W1 and W2. The time history of W3 to W5 shows that in the reclaimed soil behind the caisson, the maximum excess pore water pressure becomes larger as the depth becomes larger. The pore pressure gauge W3, which is mounted at the deepest point, shows that its maximum excess pore water pressure is 100 gf/cm^2 and the ratio of the excess pore water pressure to the vertical effective overburden pressure is about 0.8. The same tendency was observed in other pore pressure gauges in the reclaimed soil behind the caisson. Therefore, the excess pore water pressure in the reclaimed soil behind the caisson becamed as large as cause full liquefaction at whole area.

We show the time history of the pressure gauges W1 and W2, under the caisson, at the middle. The maximum excess pore water pressure of W1 is about 54 gf/cm^2 and the excess pore water pressure ratio is about 0.45. From this we can conclude that replaced soil directly under the caisson was stable. The maximum excess pore water pressure of W2 indicated the same result. However, the vertical movement of the caisson changed the effective stress and it also changed the excess pore water pressure.

We show the time history of the pore pressure gauge W6 and W7, mounted in the replaced soil in front of the caisson, at the bottom. The pore pressure gauge W6 shows that its maximum excess pore water pressure is about 47 gf/cm^2 and the excess pore water pressure ratio is about 0.8. Therefore, this part of replaced soil became a little less stable than directly under the caisson. Fig.-6 shows comparison of effective overburden pressure and maximum excess pore water pressure.

Displacement of the Caisson Body and Settlement of Ground Surface. In order to check the relation between the observed deformation after the earthquake and results of experiment, we studies the investigation result of the damage. Fig.-7 shows the deformation of the ground surface and the caisson of -12 m quay at container wharf after the earthquake. In this Figure, observed deformation after the earthquake is shown by broken line. From the observed deformation, the top of the caisson moved about 3.0 m to the sea. In vertical direction the caisson moved about 1.6 m downward. The settlement of ground surface behind the caisson was about 1.6 m same as the vertical movement of caisson body. The residual displacement of the ground surface and the caisson obtained by the experiment was converted into the actual scale following the similarity law considering non-linearity of soil and these results are given by solid line in Fig.-7. The settlement of the ground surface and the displacement of the caisson are relatively in good agreement.

CONCLUSIONS

We performed the shaking table test of the caisson type quay damaged by Hyogoken-Nanbu Earthquake 1995 and analyzed the mechanism of the collapse. In this experiment the excess pore water pressure in the reclaimed soil and a part of replaced soil increased as high as to cause full liquefaction. So long as the settlement of the ground surface and the displacement of the caisson are concerned, the result of the experiment and the measurement were in good agreement. We will carry out more experiments under various conditions and analyze the mechanism of the collapse in detail.

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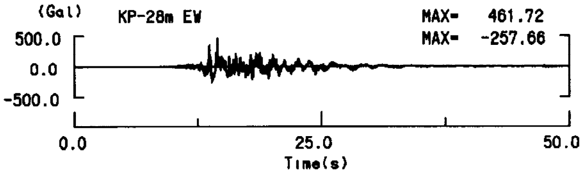
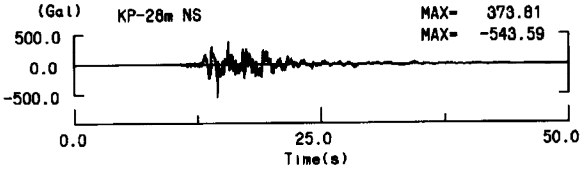
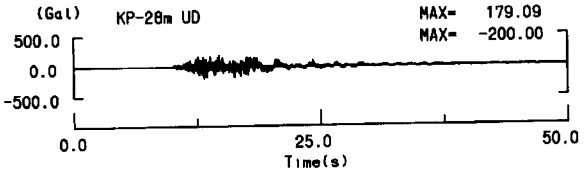


(1)EW Component



(2)NS Component



(3)UD Component

Fig.-2 Strong Motion Recorded at the Port Island

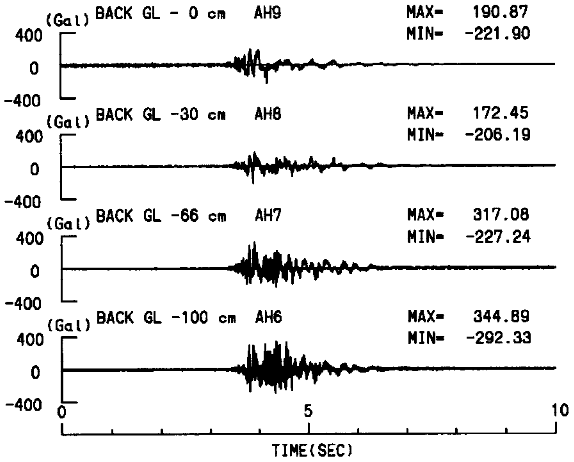


Fig.-3 Horizontal Response Acceleration for the Reclamied Soil

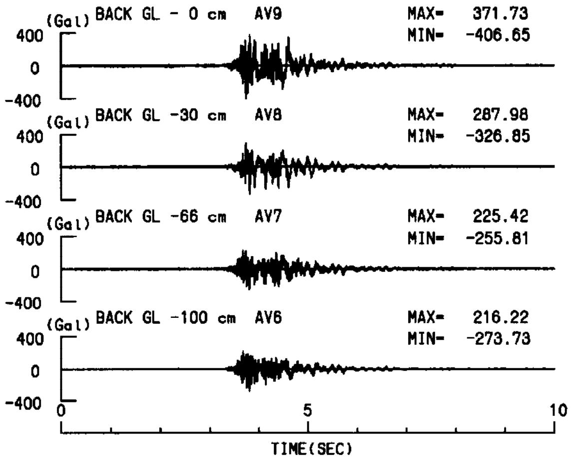
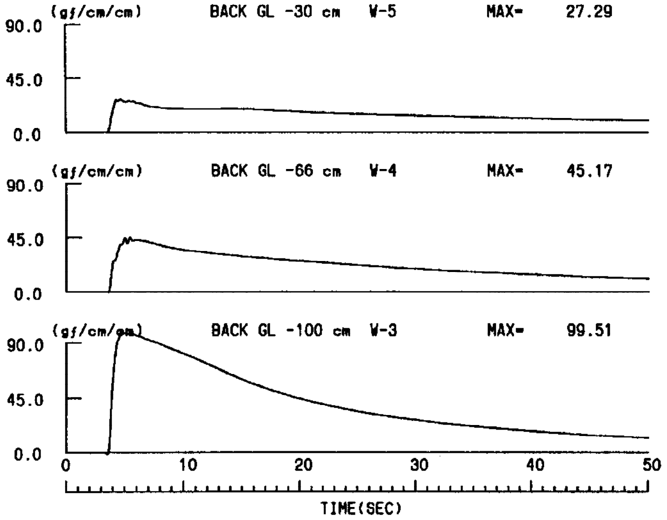
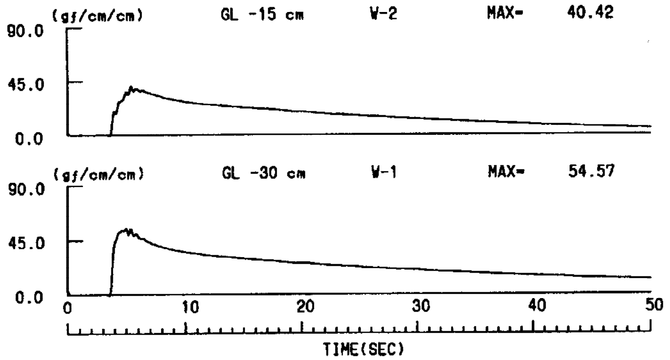


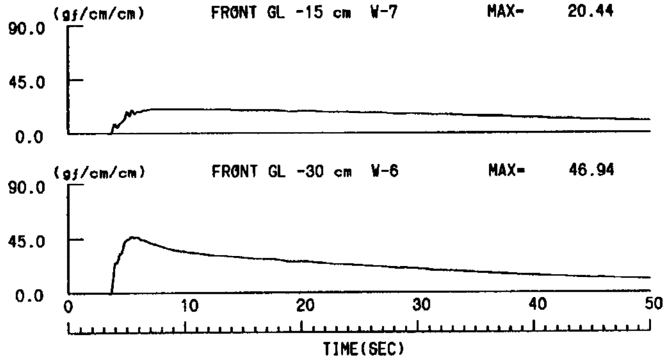
Fig.-4 Vertical Response Acceleration for the Reclamied Soil



(1) Reclaimed Soil(w3～w5)



(2) Replaced Soil under the Caisson(w1,w2)



(3) Replaced Soil in front of the Caisson(w6,w7)

Fig.-5 Time history of Excess pore water pressure

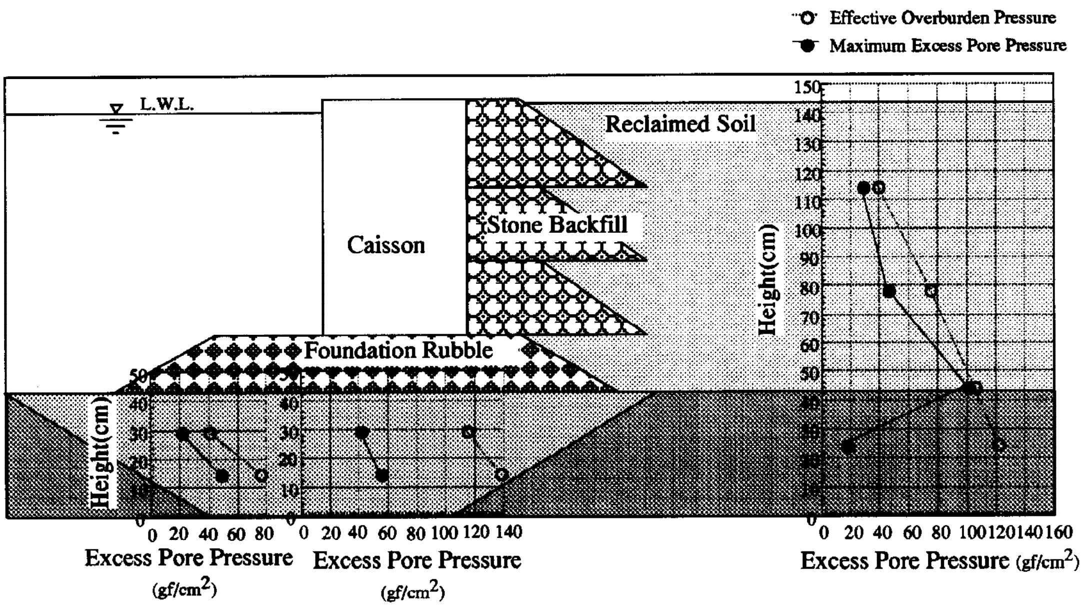


Fig.-6 Comparison of Effective Overburden Pressure and Maximum Excess Pore Pressure

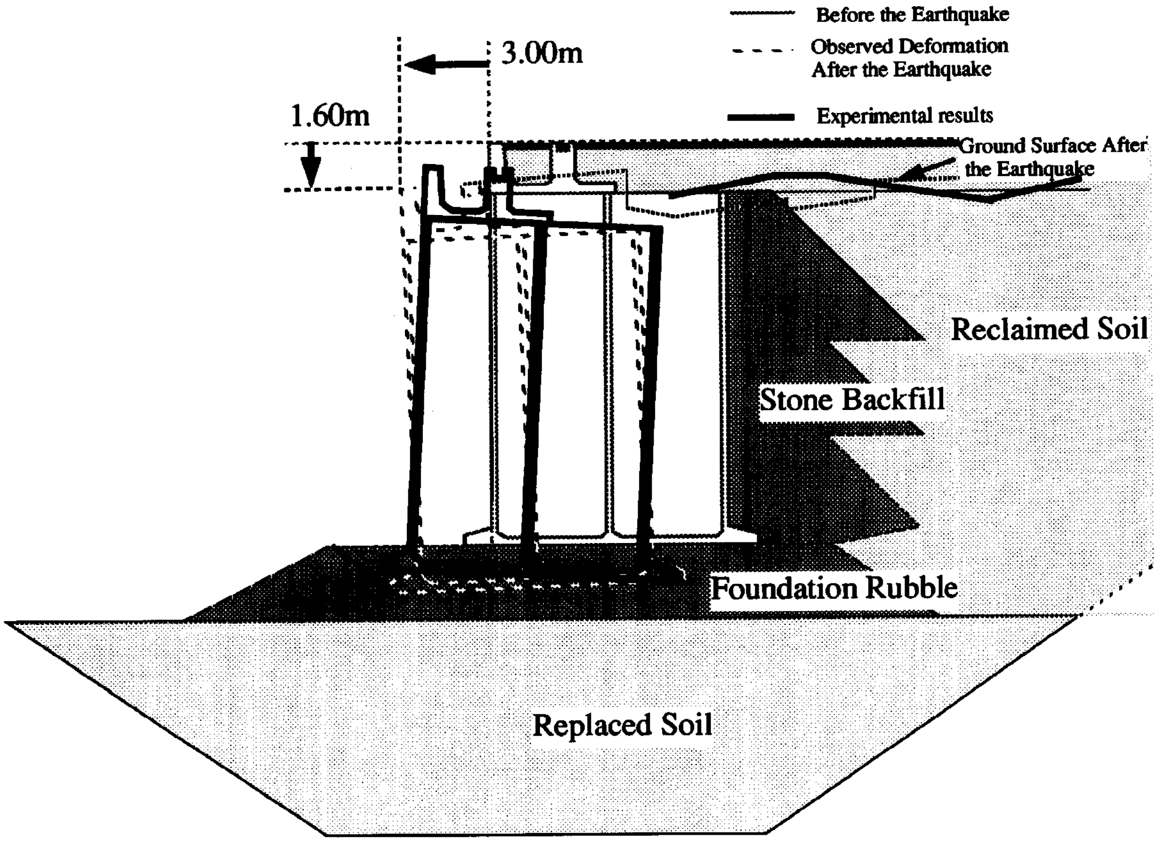


Fig.-7 Comparison of Observed Deformation after the Earthquqke and Experiment