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GROUP EFFECTS OF RIGID CIRCULAR FOUNDATIONS ON POST-LIQUEFACTION SETTLEMENT

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ABSTRACT

A series of large-scale shaking table tests are conducted, where models of rigid circular foundations are founded on the surface of saturated clean fine sand, and seismically excited. The settlements of model foundations and the distributions of excess pore water pressures induced around the model foundations are observed. The influence of spacing between adjacent model foundations is examined and discussed in connection with the development and dissipation of excess pore pressures.

Keywords: Soil liquefaction, Foundations, Settlement, Shaking table test

INTRODUCTION

The structures resting upon the surface of saturated sand deposits are subjected to settlement and tilt following liquefaction during earthquakes. The two to four stories buildings with flat foundations led to significant sinking and tilting during 1964 Niigata earthquake in Japan and also during 1990 Luzon earthquake in Philippines, (Ishihara et al. 1993, Kishida 1966, and others). The pile-supported tank farms for storage of liquefied propane gas have suffered from tilt and differential settlement during 1995 Kobe earthquake in Japan, though fatal consequences such as leakage of gas and breakout of fire have been avoided, (Ishihara 1999).

From the experiences gained from such recent earthquakes, there have been several issues of concern regarding the seismic response of rigid foundations founded on the surface of saturated sand deposits. One issue of concern is associated with group effects of rigid foundations. In fact, it was observed during 1990 Luzon earthquake that most of the buildings had two to four stories on shallow footings without piles, and most significantly settled were found among the buildings with greater separation from adjacent structures. In the tank farms which suffered from liquefaction-induced settlement and tilt during 1995 Kobe earthquake, some of the tanks were situated close to one another. It is not known what effects the spacing between adjacent foundations would exert on the seismic response of rigid foundations following liquefaction during earthquakes.

In the present study, a series of shaking table tests are conducted, where models of rigid circular foundations are founded on the surface of saturated clean fine sand deposit, and seismically excited. The settlements of model foundations and the distributions of excess pore water pressures induced around the model foundations are observed. The influence of spacing between adjacent rigid foundations is

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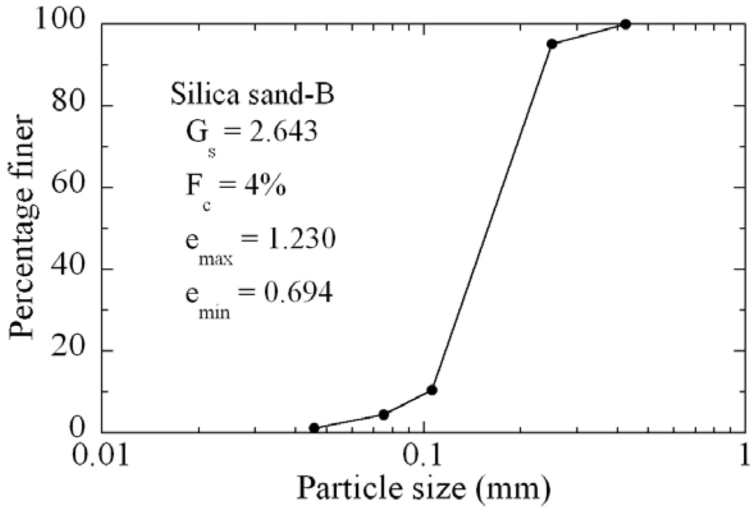

Figure 1. Grain size distribution of soil

Figure 2. Model rigid circular foundation

particularly examined. The following is the description of these tests and their consequences.

TESTING DETAILS

The large-scale shaking table test apparatus located at the technical research centre of Obayashi Corporation is used in the present study. The model saturated sand deposits are prepared in the large shear box container consisting of 24 steel frames stacking up with one another via bearings, which is 2.5 metres long, 1.5 metres wide and 2.0 metres deep. The soil material used in the present study is silica sand, herein denoted as “Silica sand-B”. The basic properties and grain size distributions of this sand material are indicated in Fig. 1. At the beginning of each test, the model of a saturated sand deposit with the relative density of D_r = 60 % is prepared as follows. The sand deposit is boiled up with water by inserting the nozzle from the surface into the sand deposit, and the excess water is then removed from the surface. The density of the sand deposit is controlled by achieving the pre-determined depth of sand deposits within the

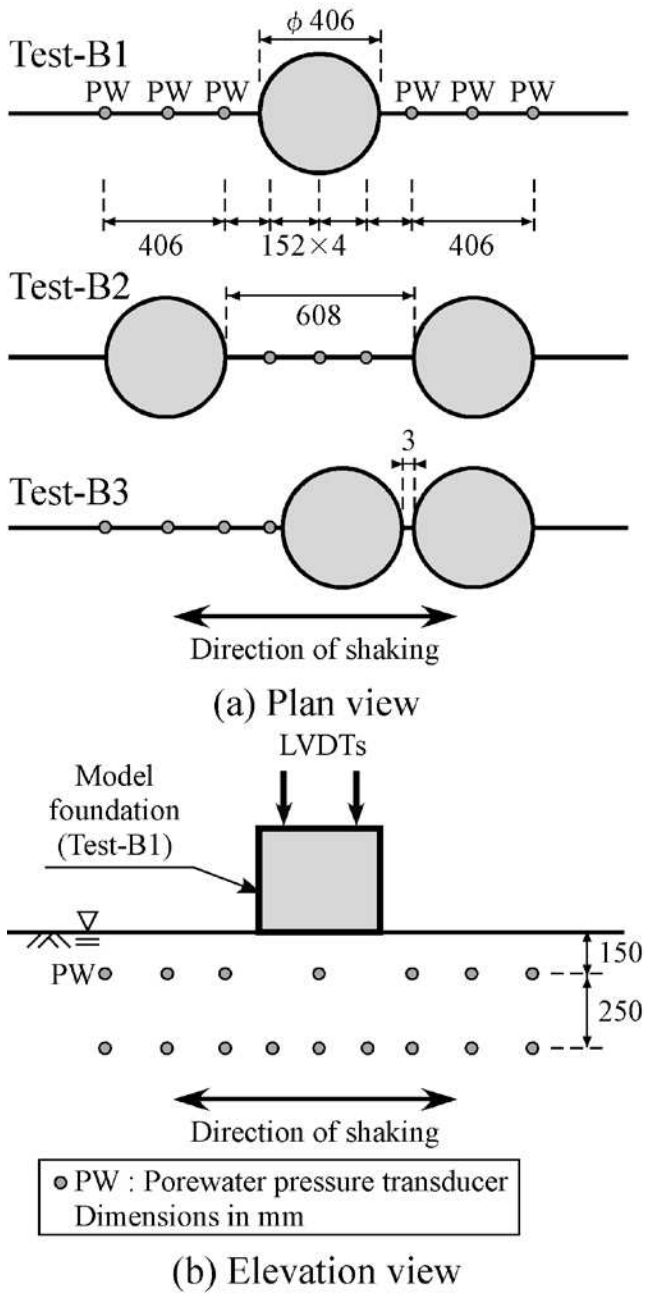

Figure 3. Positions of transducers

shear box container. In so doing, the shear box is shaken if necessary. The model rigid circular foundation used in the present study is a steel cylinder with a steel flat bottom as shown in Fig. 2, which is 40.6 in diameter, 40.6 cm in height and 41.75 kg in weight. The model foundation weighing a total of 73 kg is then prepared by filling up the silica sand inside the model, producing the contact pressure of 8.7 kPa under the model resting on the saturated sand deposit. The accelerometers and pore-water pressure transducers are installed within the model of the saturated sand deposit. Prior to the preparation of a model sand deposit within the shear box container, the transducers are attached along a series of long phosphor copper plates. These long plates are hung from over the shear box container for the transducers to be placed within the container at appropriate locations. The model sand deposit is then prepared by pouring

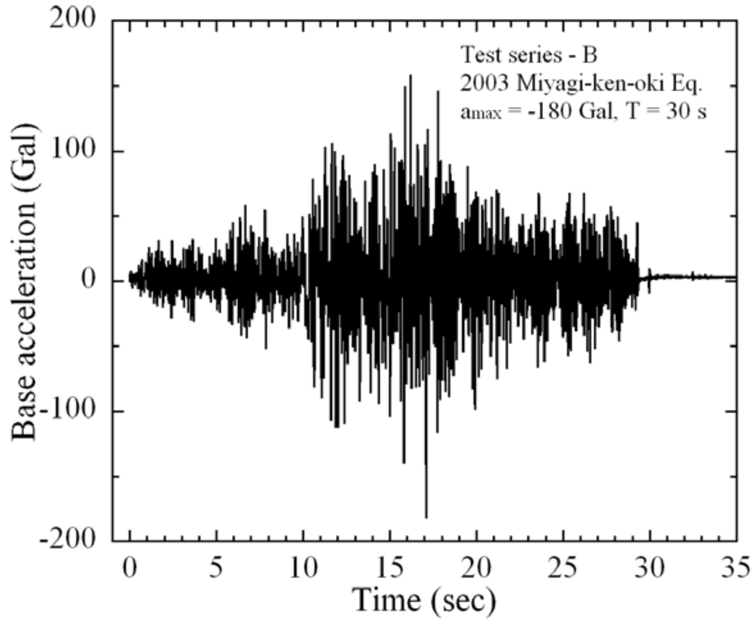

Figure 4. Time history of a base acceleration

the sand into the container. The transducers are then embedded into the sand deposit.

In the present study, the influence of group effects of rigid foundations, in other words, the effects of spacing between adjacent rigid foundations are examined. Three tests, B1 to B3, are conducted. The positions of transducers embedded in the model of the saturated sand deposit are shown in Fig. 3, together with the positions of the model rigid foundations placed upon the surface of the saturated sand deposit. In the test-B1, a single model rigid foundation is used. In the test-B2, two model rigid foundations are placed with a spacing of 1.5B, where B is the diameter of the model rigid foundation. In the test-B3, two model rigid foundations are placed with a spacing of 3 cm. The time history of a base input acceleration used in the present study is shown in Fig. 4. This is one of the acceleration records observed during 2003 Miyagi-ken-oki earthquake, which occurred on May 26, 2003, and registered the magnitude of 7.1.

EXCESS PORE PRESSURES AND SETTLEMENT OF FOUNDATION

The distributions of excess pore pressures around the model rigid foundations are shown in Figs. 5(a) and (b) at different depths of GL = -150 and -400 mm for the test-B1. The duration of shaking is 30 seconds as shown in Fig. 4. It is seen that the excess pore pressures are fully developed at the free field away from the rigid foundation, however the development of excess pore pressures beneath the rigid foundation tends to be suppressed at the shallowest depth of GL-250 mm until about t = 10 seconds. It is then found that the excess pore pressures increase due probably to the dissipation of excess pore pressures at greater depths followed by the upward migration of excess pore water thus induced. The similar observations can be made for the test-B2, where two model rigid foundations are placed with a spacing of 1.5B, as shown in Figs. 6(a) and (b). However, when it comes to the test-B3, where two model rigid foundations are placed as closely as with a spacing of 3 cm, the development of excess pore pressures tends to be suppressed even at the locations between the two rigid foundations, as shown in Figs. 7(a) and (b). Therefore, the development of excess pore pressures tends to be suppressed at the entire area enclosed by the two model rigid foundations. The settlements of rigid foundations observed in the tests are plotted against the values

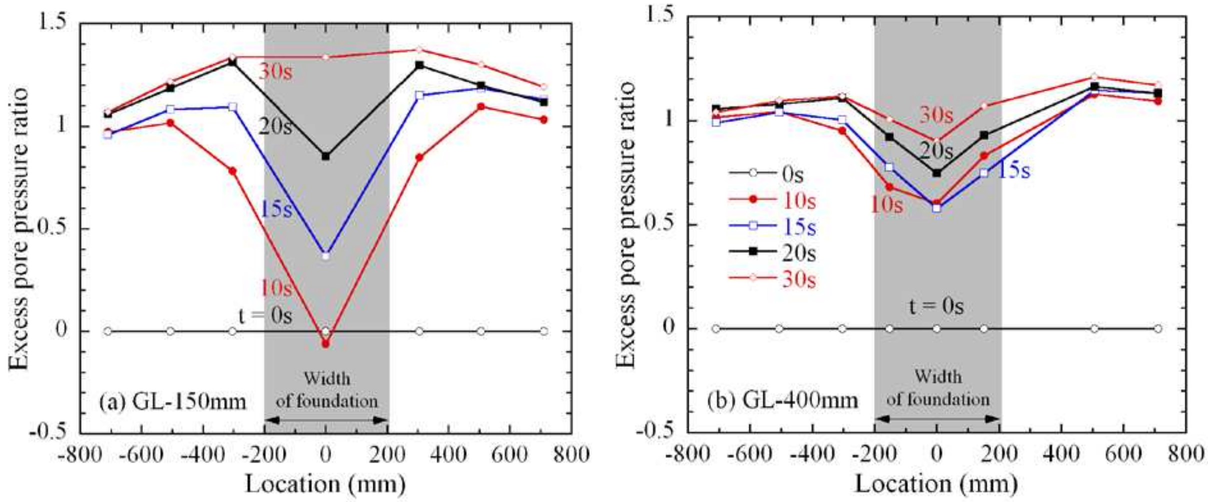

Figure 5. Distributions of excess pore pressures, (a) GL-150mm, (b) GL-400mm, (Test-B1)

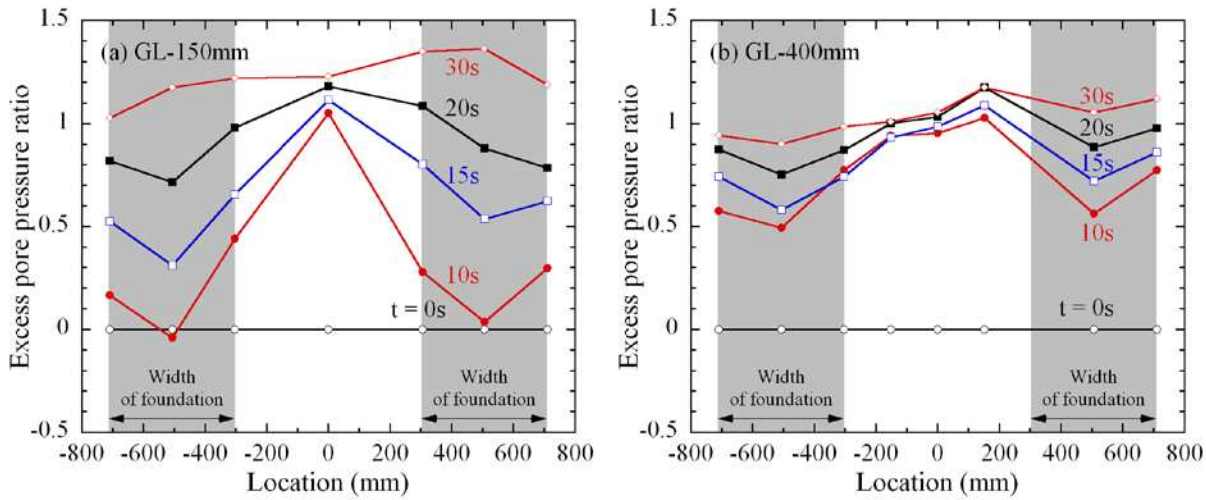

Figure 6. Distributions of excess pore pressures, (a) GL-150mm, (b) GL-400mm, (Test-B2)

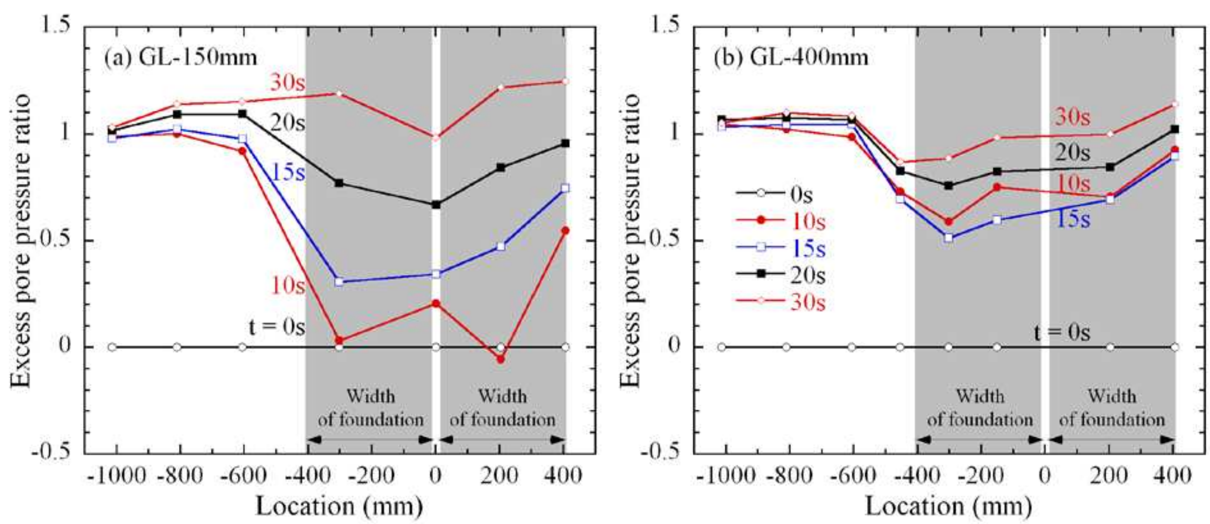

Figure 7. Distributions of excess pore pressures, (a) GL-150mm, (b) GL-400mm, (Test-B3)

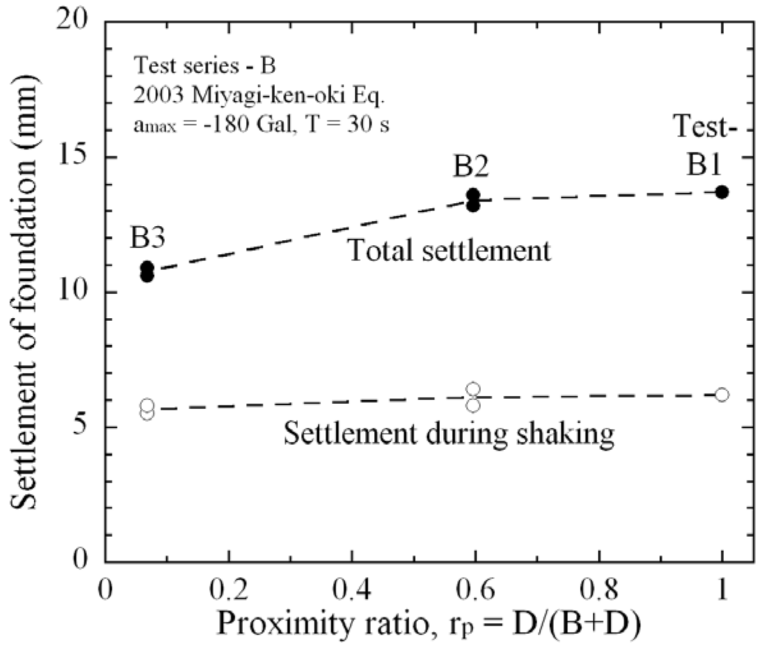

Figure 8. Plots of settlement of foundation against proximity ratio r_p

of the proximity ratio r_p in Fig. 8. Herein, the proximity ratio is defined as $r_p = D/(B+D)$, where D is the spacing between the two model rigid foundations and B is the diameter of the model rigid foundation. In case of the test-B1 with a single model rigid foundation, the spacing is assumed as $D = \infty$, and therefore $r_p = 1$. It is found that the settlements observed during shaking are similar to one another. However, the total settlement for the closed spaced model rigid foundations in the test B1 is smaller than the other widely spaced model rigid foundations in the tests B2 and B3. Therefore, the difference in the behaviours of model rigid foundations appears to emerge at the phase where the dissipation of excess pore pressures occurs.

CONCLUSIONS

A series of large-scale shaking table tests were conducted to examine the post-liquefaction settlement of rigid circular foundations founded on the surface of saturated clean fine sand. The influence of spacing between adjacent foundations was particularly examined in the present study. It was found that the settlements occurring during shaking remained almost the same regardless of the spacing between adjacent foundations, however the settlements occurring after the end of shaking were different. The closely spaced foundations were subjected to smaller settlement occurring after the end of shaking.

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