Underwater Shake Table Test for Seismic Response of Caisson Type Seawall with Sloped Seabed

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SUMMARY:
The liquefaction-induced ground displacement in sloped ground occurred during past earthquakes. Therefore, if liquefaction occurs in a seabed in front of a seawall, the slope may make displacement of the seawall increase. A shake table test of a large scale model was conducted in order to study seismic response of the seawall and the sloped seabed during an earthquake. As a result, displacement at the top of the seawall was not received influence of the sloped seabed but the seabed moved greatly to sea side by movement of the seawall and displacement of the seabed was increased by the slope.

Keywords: liquefaction, liquefaction-induced flow, shake table test, seawall

1. INTRODUCTION

An approach lighting system is one of air navigation facility which allows pilots to visually identify a runway central line and the direction of approach. In the example of the standard type approach lighting system shown in Fig. 1.1, since approach lights are installed on a runway extension, a 900m space is needed from the end of a runway. It is difficult, however, to secure a space for approach lights at an airport, which constructed as man-made island in the sea, from the end of runway to seawalls surrounding the island. Therefore, a bridge is often constructed in the sea to secure the space of approach lights with an abutment on a seawall top or behind seawall and approach lights are fixed position. This bridge is called as approach light bridge.

A type of many substructures of approach light bridge is jacket or pile bent pier which does not have a footing and a pier shares piles. Since the approach light bridge is installed on the abutments on seawall, if seawall moves to the sea side in case of an earthquake, the damage in which a bridge is also pushed out to the sea side is assumed (Ohya et al, 2011). In case of the seismic performance evaluation of

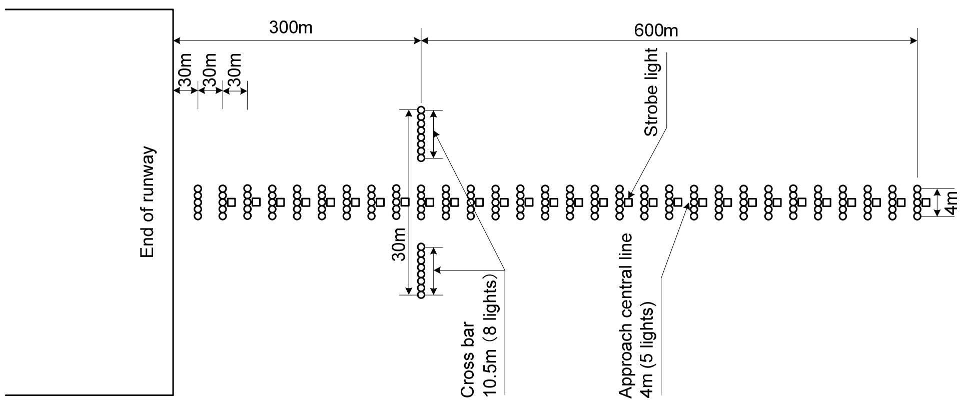


Figure 1.1. General arrangement of the approach light system (SCOPE, 2008)

such an approach light bridge, it is necessary to take into account the influence by the displacement of the seawall and the seabed located in front of the seawall in addition to its own inertia force. For example, prediction of displacement of the ground is important in the seismic response displacement analysis because this method applies maximum displacements of the ground which calculated by a seismic response analysis through Winkler type springs.

By the way, if the base of the seawall which the approach light bridge has connected liquefies in the level 2 earthquake, the seawall may move to the sea side several meters. The seabed in front of the seawall is pushed out by movement of such seawall and liquefaction-induced flow of backfill accompanying the movement of the seawall to the sea side, and the influence of displacement may reach to the bridge piers which separated distantly. Probably the amount of displacement of the seabed will be large, and the zone of influence will become large, since the base will flow if the sloped seabed liquefies at this time. On the other hand, the resistance to the displacement by the side of the sea becomes small by flow of the seabed, and it is thought that the seawall and its base can move easily to the sea side.

In this study, the influence caused by the existence of the sloped seabed in front of the caisson type seawall of reclaimed man-made island during an earthquake was investigated by a large scale shake table test.

2. TEST PROCEDURE

2.1. Apparatus of test and model

The experiment was conducted using with 1.5 m in height, 4.0 m in width, and a depth of 2.5 m steel rigid box installed in the large scale underwater shake table. By installing an inside partition board in the steel rigid box, 2 division (1.25 m of one section) of the depth direction was carried out.

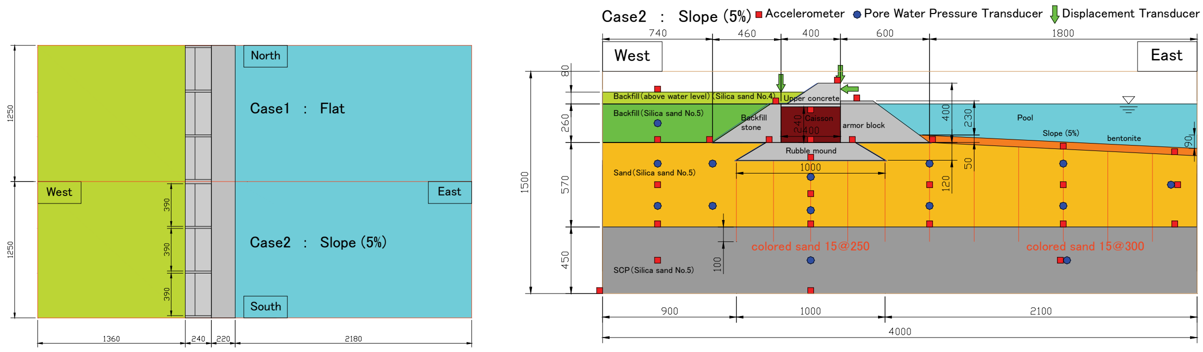
The examination object was assumed a caisson type seawall surrounding the man-made island where the airport was built and the approach light bridge was installed. The space which can produce an about 2m slope in front of the seawall could be secured. The scale ratio (= prototype scale / model scale) of length was set to 30 so that the seawall of the composition near a real structure could be produced.

The base of the seawall was made from loose sand which can liquefy and set to 0.45m in thickness referred to a soil profile. The SCP improvement for soft soil was produced as dense sand layer under the sand layer. From the result of the bathymetric survey, although the slope of the actual surface of the seabed for examination was about 3%, since it was thought that displacement became small by the rigid box, it was set up to 5%. This value referred to research of liquefaction-induced flow in a sloped ground (Hamada and Wakamatsu, 1998).

2.2. Model preparation

Schematic illustration of the model is shown in Fig. 2.1 and the appearance of the model before shake test is shown in Photo 2.1. Although only the section with a slope (case name is 'slope') is shown in the figure, a seabed is level from the toe of an armor block to the east side of the box in a case without a slope (case name is 'flat'). The similitude in 1g gravitational field proposed by Iai (1988) and applied to this experiment is show in Table 2.1. This similarity rule was derived by the basic equations which govern the equilibrium and the mass balance of 2-phase material (pore water and soil skeleton). Henceforth, experimental conditions and results are denoted by the model scale

The sand layer, backfill sand and SCP layer were made from Soma sand (ρ_s=2.647g/cm^3, $e_{\max}$=1.084, $e_{\min}$=0.722) pluviated through air after setting of accelerometers and pore water pressure transducers. The relative densities of the sand layer and SCP layer as a result were 43% and 110%, respectively. In



(a) plane view (b) cross section view (slope)

Figure 2.1. Schematic illustration of the model

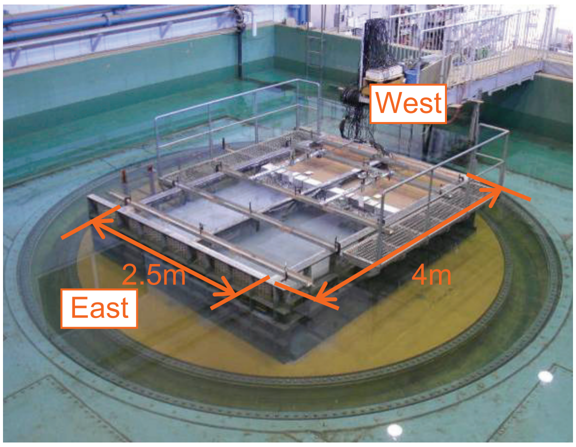


Photo 2.1. Photo of model before shake test

Table 2.1. Similitude for shake test in 1g gravitational field

items	prototype / model	scale ratio
length	λ	30
density of saturated soil	1	1
time	$\lambda^{0.75}$	12.82
stress	λ	30.00
pressure of pore water	λ	30.00
displacement	$\lambda^{1.5}$	164.32
acceleration	1	1.00
strain	$\lambda^{0.5}$	5.48
stiffness	$\lambda^{0.5}$	5.48

order to confirm deformation of the sand layer, the colored sand dyed by black ink was installed at intervals of 30cm in the seabed and 25cm under the seawall in the vertical direction. Acrylic boards were installed parallel to rigid box and we can observe the cross section of the model. Caisson models consist of steel box assembled by 20mm-thick steel plate and concrete block on it. Moreover, three caissons installed per section in the rigid box depth direction. After preparation of the ground and caissons, in order to imitate sea water, tap water was poured in.

Input seismic waves were taken as a 5Hz sine wave (20 waves except taper parts, maximum acceleration 500Gal).

3. TEST RESULTS

3.1. Histories of displacement and acceleration

Time histories of horizontal and vertical displacements at the upper seaside corner of the caisson and accelerations recorded by main transducers are shown in Fig. 3.1. The residual seaward displacement and settlement in the slope-less case (flat) were 71mm and 40mm, respectively. And in the slope case (slope), these were 72mm and 37mm, respectively. If its attention is paid to time histories, displacement of the caisson will become proportional relationship between time and displacement. That is, in proportion to the number of seismic waves, the amount of displacement is increasing. Moreover, after the end of shake test, displacement stopped and settlement of the caisson caused by dissipation of excess pore water pressure was not seen. The difference between two cases was small about displacement.

In all the measurement positions, after the shake start 4 waves, the acceleration time histories showed the pulse-like waveform of bigger amplitude than an input value, and became smaller than input amplitude after that. The degree to which acceleration amplitude became small changed with measurement positions. On the backfill sand surface (A1-05), after becoming a little smaller than an input, it recovered to the same amplitude. On the caisson (A1-14), it was small in approximately the half of an input. In the seabed ground (A1-23), it became small to about 100 Gal, and it must have liquefied. These tendencies were common in two cases from which the slope of the seabed differs.

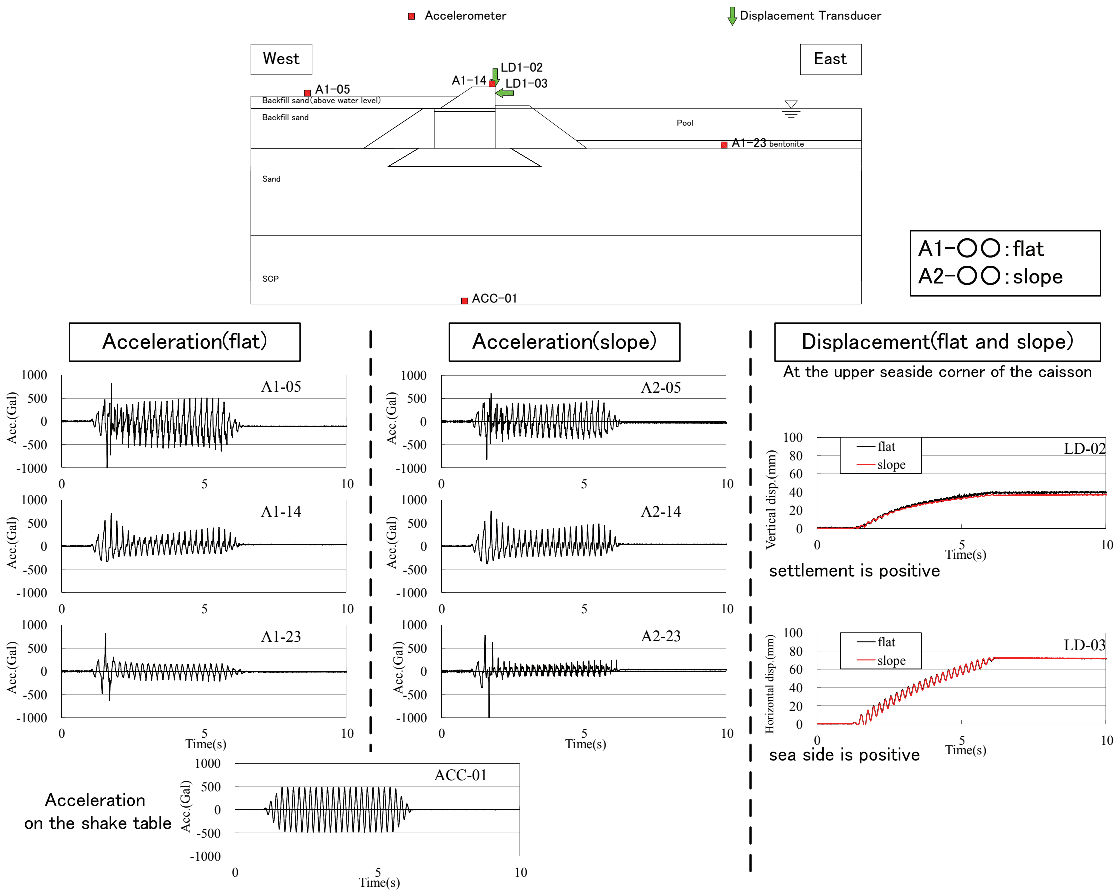


Figure 3.1. Time histories of displacements and accelerations

3.2. Distribution of excess pore water pressure

A distribution of the maximum ratio of excess pore water pressure is shown in Fig. 3.2. This ratio divided measurement pore pressure by initial effective overburden pressure. And it is the maximum value of the time history which carried out low pass filter processing. The ratio of excess pore water pressure was 0.8 or less in the backfill sand and the base of the caisson. On the other hand, in the seabed ground of front of the caisson, the excess pore water pressure ratio became one or more, and liquefaction occurred.

The generating degree of such excess pore water pressure corresponded with the degree of decrease of the acceleration of ground surface. Although acceleration showed the decrease of amplitude after the pulse-like waveform as mentioned above, the tendency for acceleration amplitude to become small after that was seen. On the surface of the seabed ground in which liquefaction occurred, the reduction in acceleration amplitude appeared remarkably. The reduction degree had small on the backfill sand surface in which excess pore water pressure ratio raise up to about 0.7.

The influence of the slope of the seabed ground did not confirm from distribution of the excess pore water pressure ratio. An important result is that only the seabed ground liquefied and the base of caisson did not liquefy. The phenomenon in which the base under caisson does not liquefy is seen in other experiments (i.e. Ohya et al., 2010). In addition to large overburden load caused by the caisson, initial deviator stress and a boundary condition about deformation in the lateral direction are also considered as reason.

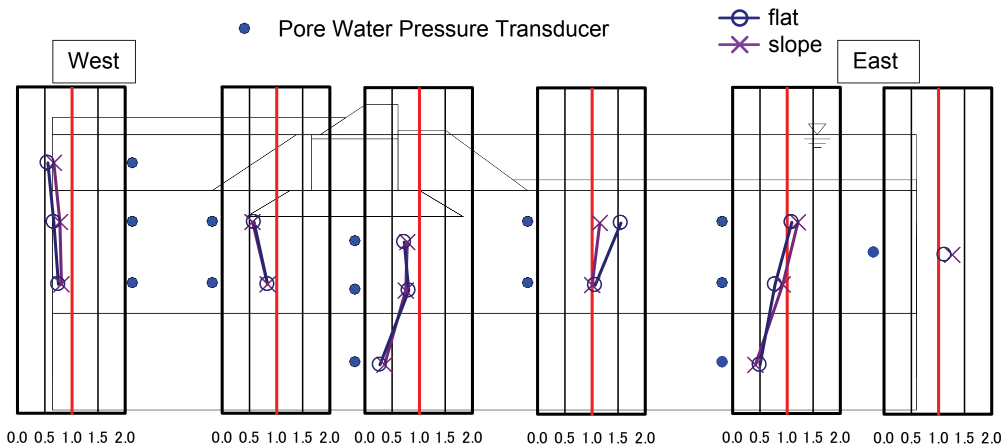


Figure 3.2. Distribution of the maximum ratio of excess pore water pressure

3.3. Deformation of the model

After dissipation of excess pore water pressure, the water in the pool was drained. After that, positions, such as colored sand installed in the sand layer, the rubble mound and the caisson were observed from the acrylics wall. The sketch of the model outline and colored sand before and after the experiment is shown in Fig. 3.3. Deformation of the colored sand was large in the east side under the rubble mound and whole area under the armor block. Deformation was also large in the seabed ground and displacement was converged on the steady value in the place shallower than the middle of the sand layer. The maximum displacement of the colored sand is 98mm which occurred in the sand layer under the toe of the armor block, and it was larger than 72mm of residual displacement at the upper seaside corner of the caisson.

The amount of displacement which became the maximum value under the toe of the armor block was small as it approached the wall of the east side of the rigid box. Moreover, the depth in which displacement began to become large is shallow as it approached the wall too. It is clear that the wall of the rigid box was suppressing displacement of the seabed ground. Differences of deformation were seen under the rubble mound and the seabed by comparison with two cases. However, since the displacement near the boundary of the sand layer with the rubble mound was almost the same, it can be said that there is no difference between two cases under the rubble mound.

Fig. 3.4 shows the ratio of residual displacement of flat case and slope case (slope / flat) in the depth direction in each line of the colored sand. The number in the figure is equivalent to the number of the colored sand line shown by Fig. 3.3. Since the amount of displacement is small in the deep place of the sand layer, the ratio of displacement is large. In the number 4 and 5 located in the middle of the armor block and east wall of the rigid box, the ratio had become about two.

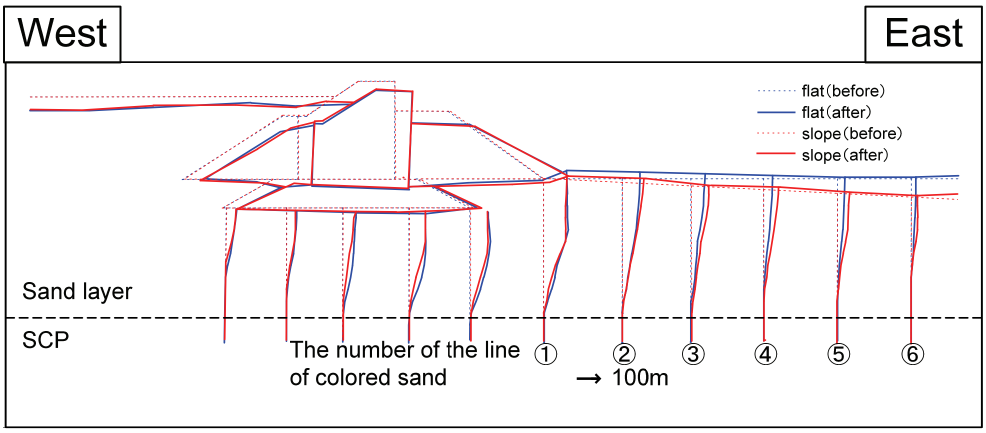


Figure 3.3. Sketch of the model outline and colored sand

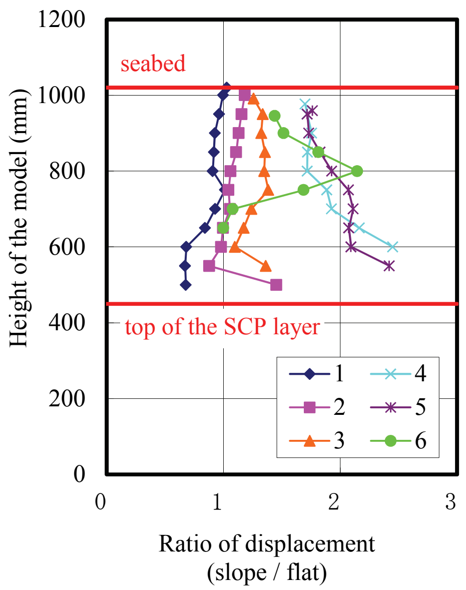


Figure 3.4. Ratio of residual displacement

4. CONCLUSION

An underwater shake table test was conducted to investigate influence caused by the existence of the sloped seabed. By the seabed 5% slope, displacement of the seabed ground became large about twice. On the other hand, displacement on the top of the seawall was changeless. Although the ratio of excess pore water pressure went up to one and liquefaction occurred in the seabed ground, it did not go up to one in the backfill sand and the base of the seawall. That is, the seabed and base of the seawall did not liquefy continuously. Therefore, behavior of seismic response of the seawall did not change by the sloped seabed.

The result to which displacement of the seabed became large twice could never be disregarded by seismic performance evaluation of such an approach light bridge. The examination in the numerical analysis (i.e. finite element method) will be required to confirm a possibility that the steel boxes is suppressing displacement and influence of the boundary conditions and model size.

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