

GROUP INSTALLATION OF PLASTIC BOARD DRAINS AT EMBANKMENT TOES FOR LIQUEFACTION AND LATERAL FLOW COUNTERMEASURES

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ABSTRACT

In order to prevent catastrophic liquefaction failure of embankment caused by a large lateral flow of its foundation soils, the authors have been studying a ground improvement technique that utilizes group installation of PBD (Plastic Board Drains) to increase a liquefaction resistance of ground. This paper deals with experimental studies to examine the effects of the PBD group installation in reducing the lateral flow of ground. PBD group installation at the toes of embankment shows its effect of constraining lateral spreading of liquefied ground beneath the embankment. It is however necessary to constrain the horizontal movement of PBD installation head through the use of either longitudinally spaced geo-grid or similar tie-rod system that are to be placed beneath the embankment. The soil mass confined within such geo-grid and PBD fingers boundaries does not seem to escape or flow out from such system. The PBD installation should however be made in triangular spacing.

Keywords: Liquefaction, embankment, lateral flow of ground, countermeasures, PBD group installation

INTRODUCTION

One of the most profound effects of ground liquefaction would be the damage due to lateral spreading of liquefied ground. During the Great Hanshin-Awaji Earthquake of 1995, extensive damage of quay walls occurred along the shoreline of many reclaimed lands at Kobe Port, Ishihara et al. (1996) and also a river embankment near Osaka failed due to the liquefaction of foundation soil, Matsuo (1996). Fortunately the failure of the embankment was not so extensive enough to cause a river to breach, which would have been a catastrophe for low lying residential area behind the embankment.

In order to prevent catastrophic liquefaction failure of embankment caused by a large lateral flow of its foundation soils, various ground improvement techniques have been proposed in the past. Examples of such liquefaction countermeasures involving ground improvement may be a) soil densification using sand compaction piles, or b) creating cement grouted soil mass at the toe of embankment. Authors have been studying a ground improvement technique that utilizes group installation of PBD (Plastic Board Drains) to increase a liquefaction resistance of ground, and several series of model tests using 1G type shaking table have been performed to identify the optimum installation to maximize the

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liquefaction resistance of ground, Mizoguchi and Tanaka 2004. This paper deals with experimental studies to examine the effects of the PBD group installation in reducing the lateral flow of ground.

GROUP INSTALLATION OF ANCHORED PBDs

Figs. 1 (a) & (b) show examples of the ground improvement using PBD group installation. A large number of PBD are installed through a liquefaction prone soil stratum from the ground surface where a sheet of geo-grid is placed over the target improvement area prior to the installation. The bottom tip of PBD with anchor metal is driven firmly into bearing strata to provide anchoring effect, while the top PBD end is tied to the top surface geo-grid to confine the movement of soil mass. Group installation of PBDs into the ground thus provides the countermeasures against liquefaction by utilizing the following two functions of PBD; a) dissipation of excess pore water pressure to reduce

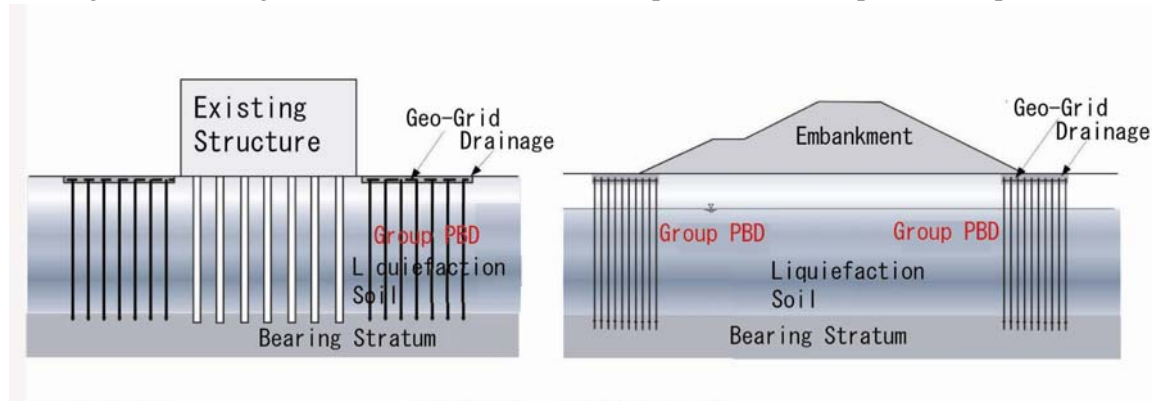


Fig. 1a PBD installation under existing Structures

Fig. 1b PBD installation for embankment

the pressure built-up, and b) tensile force of PBD member to confine the soil movements against horizontal shaking as well as lateral spread of liquefied mass under the earthquake force.

Previously some studies have already been made on the relationship between the installation density and the liquefaction resistance of improved ground by performing a series of model shaking table tests with a level ground having various installation densities of PBD. The model test has shown that the increase of PBD installation density increased the liquefaction resistance of ground. However, the effectiveness of the PBD group installation against the lateral flow of ground has not yet been examined. Thus it was decided to carry out a series of model shaking table test with embankment load to examine the optimum installation method of PBD to reduce the lateral spreading of foundation soil beneath the embankment.

SHAKING TABLE TEST

Configuration of Model Embankment and PBD Installation

The model test was carried out by constructing a reduced size embankment of 100mm height on a 400mm thick foundation soil in a simple shear box having a size of 700mm width x 1500 mm breadth x 700 mm height as shown in Fig.2. The model embankment had 45 degree inclined slope on each side, and the slope was formed by stacking two layers of sandbags that contained coarse gravels. The foundation soil was formed by pulverizing air-dried silica sand into a thin layer of water in the simple shear box, and by keeping the height of sand fall to be constant the foundation soil having about 50% relative density was formed. Table 1 summarizes the variation of five model tests conducted for this study. Case 1 is a benchmark test without any ground improvement, and other four cases represent the

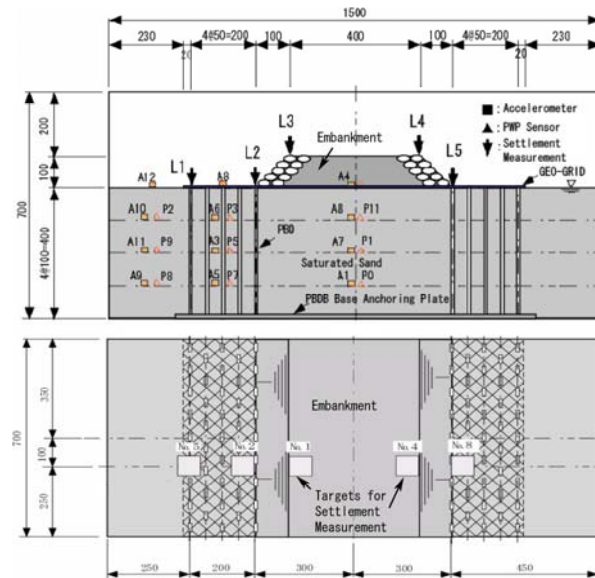


Fig.2 Model Test Configuration with PBD

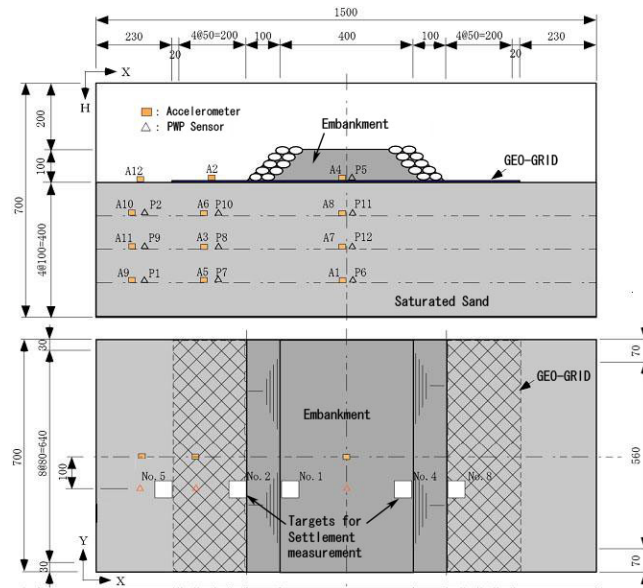


Fig.3 Model Test Configuration with Geo-Grid Only

Table 1 List of model test configuration

No.	Configuration	Dr(%)		Shaking Intensity (gal)
		Founda tion	Embank ment	
1	No Treatment	52.4	100	50,70,100,130
2	GeoGrid only at base	51.0	100	50,70,100,130,150,180
3	17 PBDs at toes without tie	46.2	100	50,70,100,130,150,180
4	17 PBDs at toes tied with base geo-grid sheet	45.5	100	50,70,100,130,150,180,210,250
5	17 PBDs at toes tied with base geo-grid strips	52.2	100	50,70,100,130,150,180,210,250

ground improvement cases having various combinations of geo-grid reinforcement and the group PBD installation. Case 4 represents the most heavily reinforced case that had 5 rows of PBD installations at both toes of the embankment with a geo-grid sheet completely underlying the embankment base and connecting the heads of PBD group installations, of which configuration is shown in Fig.2.

On the other hand, Case 2 represents the least improvement only with a sheet of geo-grid underlying the embankment base, of which configuration is shown in Fig.3. In Case 3, the PBD installations at both embankment toes were not connected by the geo-grid while the 5 rows of PBDs were connected locally by a geo-grid. In Case 5, the PBD group installations at the both toes were connected by strips of geo-grid sheet, instead of a continuous complete geo-grid sheet. It may be noted that the model PBD had a size of 20mm width x 2 mm thickness and they are installed in triangular spacing against each other. This triangular spacing proved to be the best to prevent the liquefied soil to flow through the rows of PBD fingers.

Instrumentation Monitoring and Shaking

A number of pore water pressure sensors and accelerometers were installed in the foundation soils and embankment as shown in Figs. 2 & 3, and the surface settlement was monitored at 5 locations as shown also in the figures. The model embankment and ground was shaken by increasing the acceleration in stepwise increments starting from 50gal and in each shaking a twenty cycles of shaking was applied to the model ground. In each step, monitoring was made on the excess pore water pressures until they have dissipated and the next step of shaking was applied. In addition to these monitoring, miniature cone penetration tests to examine the soil density changes and video recoding of ground movements are made at suitable intervals.

TEST RESULTS

Five model tests have been performed in this test series, and the liquefaction occurred at 100-130 gals for No.1, and 100 gal for No.2. Since these two tests have no ground improvement except for placing a geo-grid beneath the embankment for No.2, there was no significant difference between the two. The soil density for No.1 was slightly higher than 50%, and this probably caused higher liquefaction resistance in Case 1.

On the other hand, for Cases 3 to 5, the liquefaction resistance increased to 150 gal because of having the toe improvement by PBD group installation. In the followings, the test results of Cases 2 to 3 will be described as there was no difference between Cases 1 & 2 and also between Cases 4 & 5.

Ground Surface Settlements

Figures 4 to 6 presents the sequences of surface settlements as observed during the shaking steps for Cases 2 to 4 respectively. For Case 2, the embankment has settled rapidly as the liquefaction developed, and at the end of 130 shaking there is almost no more trace of embankment, leaving nearly a flat liquefied ground that was the same situation for Case 1 at the end of shaking. Since there is no reinforcing member in the ground to restrict the horizontal movement of soil, the toes of embankment have slid freely in horizontal direction. It may be noted that the same situation existed for the ground improvement by soil densification at the toes once the liquefaction had occurred both in the ground and the sand compaction zone, although the level of shaking is higher than the case without any soil densification. This observation was made through one of experiments that had been performed prior to this model test study herein.

Figures 5 and 6 demonstrate the effectiveness of geo-grid connection between the toe PBD group installations at both ends. Case 3 that is the case without geo-grid connection have resulted in a similar amount of embankment settlement, while in Case 4 the shape of embankment has remained even when the liquefied ground waves at 250gal of shaking. In Figures 7 to 9, the shape changes of embankment section among Cases 2, 3 and 4 are depicted using the measurements at the start and at the end. Again the effectiveness of connecting the toe PBD installation together via geo-grid is clearly seen. It is also shown in these figures the settlement profile of geo-grid beneath the embankment for

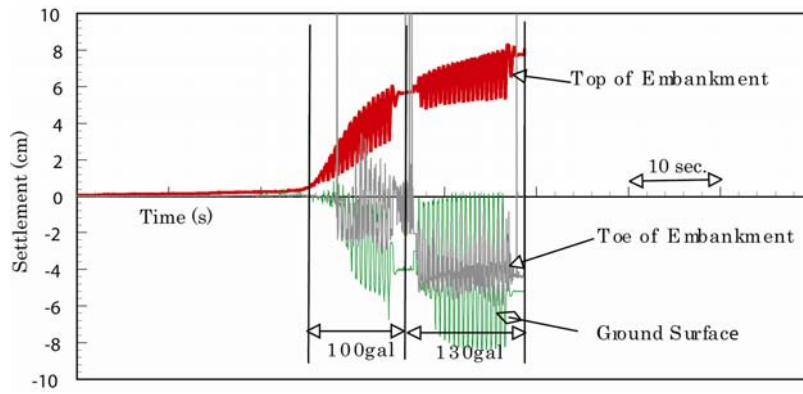


Fig. 4 Sequence of embankment settlement for Case 2

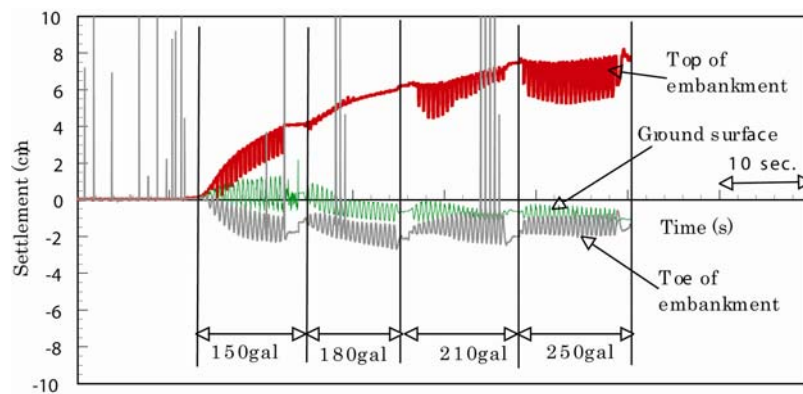


Fig. 5 Sequence of embankment settlement for Case 3

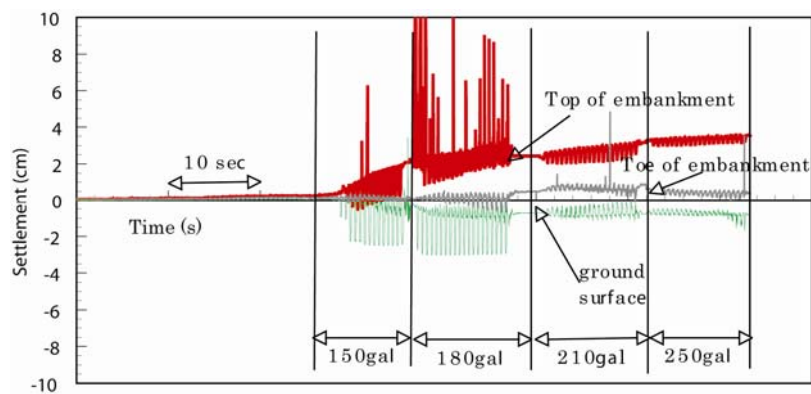


Fig. 6 Sequence of embankment settlement for Case 4

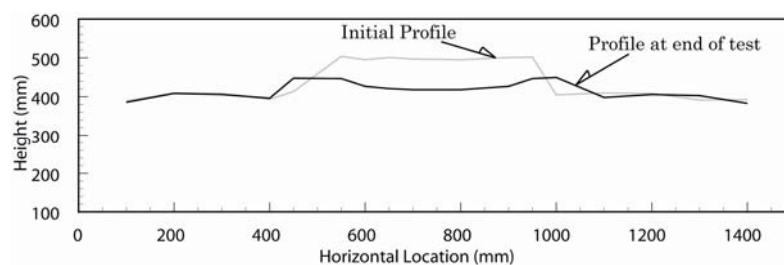


Fig.7 Surface profile at end of test, Case 2

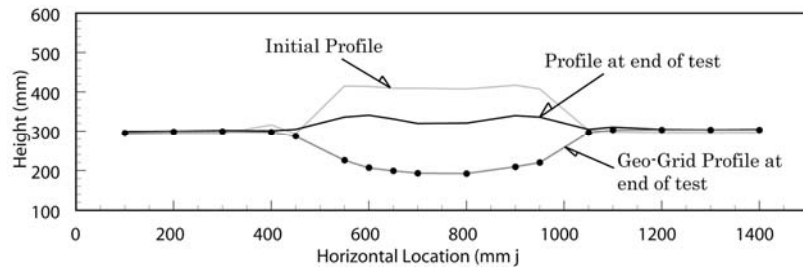


Fig.8 Surface profile at end of test, Case 3

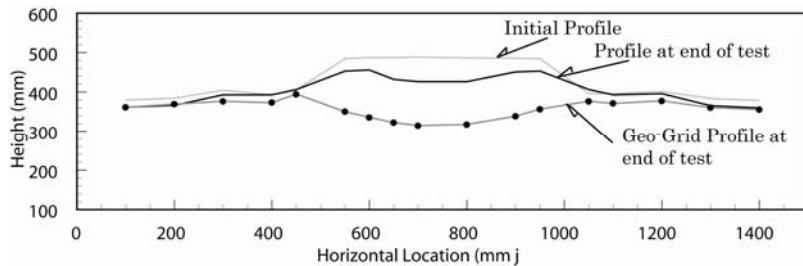


Fig.9 Surface profile at end of test, Case 4

Cases 2 & 4 and these measurements was taken after excavating the embankment section at the end of test.

Ground Movements Beneath the Embankment

Although there is clearly an effect of geo-grid connection to reduce the embankment settlement, the amount of settlement is still large and the mechanism of causing such ground movement beneath the embankment is needed to be understood. In order to examine the ground movements beneath the embankment, excavations of ground and various sensors in the ground were carefully made after each model test to observe the ground movements. It may be noted that attempts are made to calculate the horizontal dynamic movements of ground using the accelerometer data, but it was not possible obtain reliable results as these sensors have been tilted during the shaking.

Figures 10 to 12 illustrate the ground movements as measured by such excavation process respectively for Cases 2 to 4, and the horizontal and vertical displacements of accelerometers and pore pressure sensors are shown. Case 2 as in Fig. 10 shows the largest horizontal displacement of ground beneath the toe (i.e., 450mm in horizontal location), particularly towards the surface, while Case 3 in Fig.8 shows some reduction in the displacement at the same toe location because of toe PBD installation. For Case 3, the largest horizontal movement of ground occurred at mid height of ground. Although

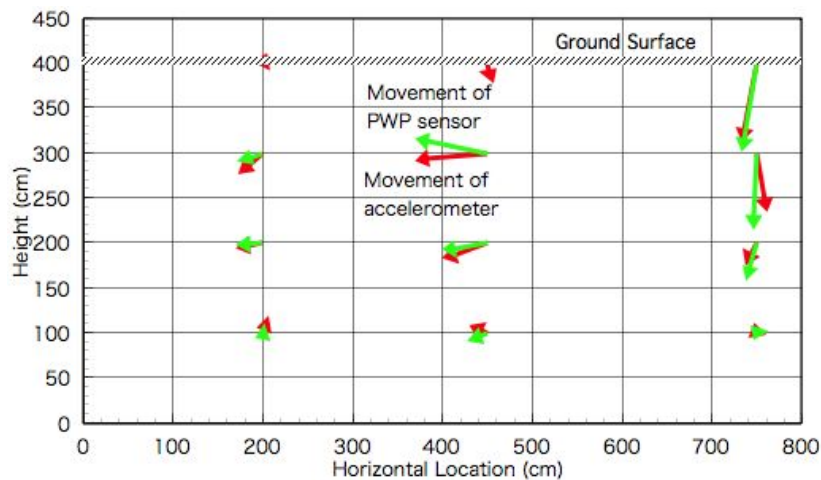


Fig. 10 Ground movements based on sensor location, Case 2

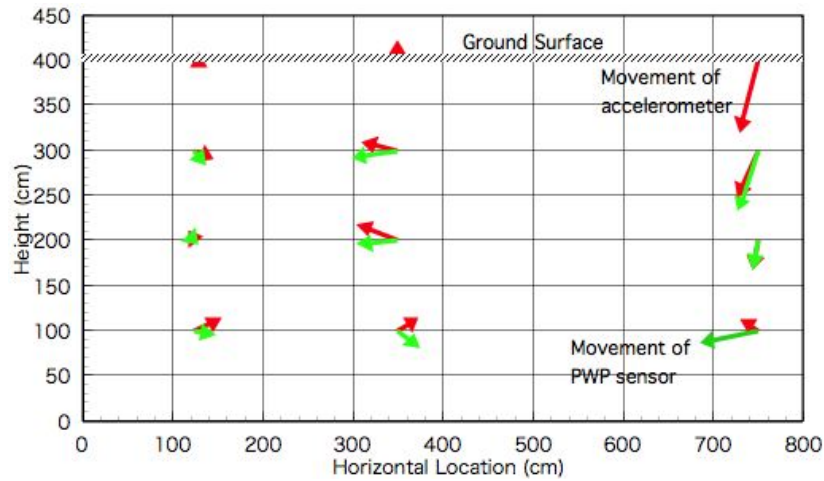


Fig. 11 Ground movements based on sensor location, Case 3

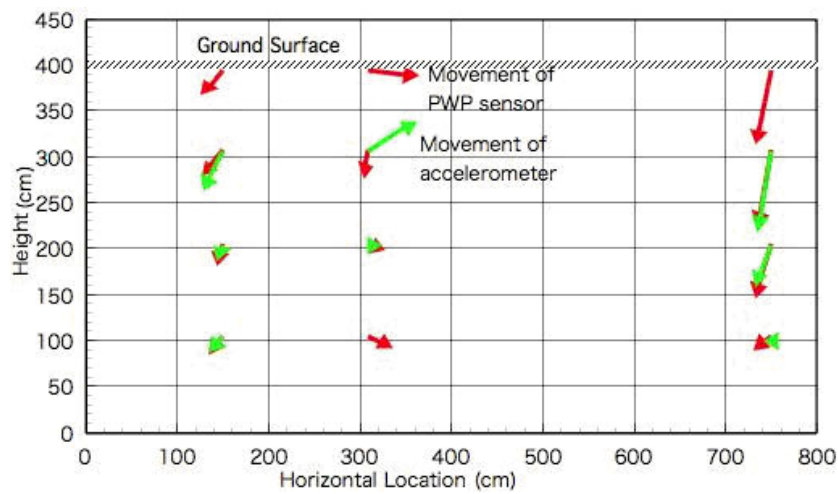


Fig. 12 Ground movements based on sensor location, Case 4

Fig. 11 does not show any horizontal displacement at the ground surface, the video record shows that there was about 35mm outward displacement of the toe. Case 4 in Fig. 12 shows the least horizontal movement of ground, but the vertical movement near the center of embankment is very significant.

The significant amount of embankment settlement has occurred for Case 4, and this mechanism was

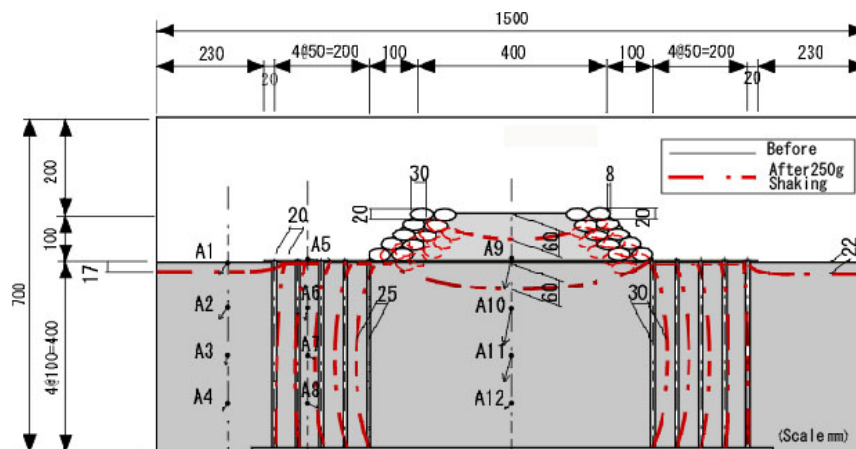


Fig. 13 Movements of geo-grid and PBD, Case 4



Fig. 14 Movements of PBD, Case 4

further investigated by measuring the deformation pattern of PBD at the toe. Fig. 13 and 14 show the outlines of PBD deformation and the excavated surface of PBD for Case 4. It is seen that the soil mass beneath the embankment spread horizontally and the maximum displacement at mid height of PBD is about 25-30mm. By using the measured geometry of soil mass surrounded by the geo-grid at top and by the PBDs at both sides, the amount of soil compression was estimated to be 6%. This amount of soil compression is very likely to occur due to the consolidation after the liquefaction, and therefore there would not have been escape or flow out of liquefied soil through the fingers of group PBD installations. This in turn indicate that in order to reduce the settlement of embankment due to liquefaction it is necessary to reduce the horizontal outward movement of PBD installed, especially at mid height of PBD. Further improvement is needed to reduce the PBD outward movement by increasing the rigidity of PBD installed soil mass.

CONCLUSIONS

In this paper, experimental work was performed to examine the mechanism of a ground improvement method that utilizes group installation of PBD into liquefaction susceptible ground. The following conclusions may be summarized through the results presented herein;

- 1) PBD group installation at the toes of embankment shows its effect of constraining lateral spreading of liquefied ground beneath the embankment.
- 2) It is however necessary to constrain the horizontal movement of PBD installation head through the use of either longitudinally spaced geo-grid or similar tie-rod system that are to be place beneath the embankment.
- 3) The soil mass confined within such geo-grid and PBD fingers boundaries does not seem to escape or flow out from such system. The PBD installation should however be made in triangular spacing.

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