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Shaking table tests on floatation of buried pipes in backfilled sand layer reinforced with geotextiles

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ABSTRACT: Several series of shaking table tests were performed to investigate the effectiveness of geotextiles in reducing the floatation of buried pipes during earthquakes. The tests were conducted on model ground in which a trench with a width of 30 cm was excavated and then backfilled with loose sand. The model soil around the backfilled sand was composed of a dense sand layer which would not liquefy during shaking. In the tests, three kinds of geotextiles were installed right above the buried pipe, consecutively. Consequently, it was observed that the floatation of a buried pipe diminished as the mesh size of the geotextile decreased and as the bending stiffness of the geotextile increased.

1 INTRODUCTION

Many sewage pipes and manholes were floated in the ground and severely damaged by the 1993 Kushiro-oki earthquake in Japan. According to a soil investigation and seismic response analyses by the JSSMFE, it was clear that this floatation was induced by the liquefaction of backfilled soils and alluvial sands below them. Yasuda et al. (1995) conducted several series of shaking table tests to study the mechanism of the floatation. The test results showed that the speed and height of floatation of the buried pipe are affected by soil density, the specific gravity and diameter of the pipe and the dimensions of the trench in which the pipe is buried.

In the present study, the floatation characteristics of a buried pipe in a backfilled sand layer reinforced with geotextiles, which were installed right above the buried pipe horizontally, were investigated by several series of shaking table tests, in order to develop a new measure to counter the floatation of buried pipes. In the tests, the specific gravity and diameter of buried pipe were 0.75 and 6 cm, and the width and depth were 30 and 50 cm, respectively. Three kinds of geotextiles were used to prevent the buried pipe from being lifted in the backfilled sand layer. The effectiveness of the geotextiles in reducing floatation will be discussed in this paper.

2 TEST PROCEDURE

Fig.1 shows the soil model tested using a soil container which is 100 cm in length, 70 cm in depth and 60 cm in width. The shaking table used was 1 m in length and 1 m in width in plane. A form rubber of 5 cm in thickness was inserted inside both walls to induce uniform cyclic shear strain in the model soil during shaking. Six pore pressure gauges, two accelerometers and one earth pressure transducer were installed in the model ground, as shown in Fig.1. The pipe buried in the model soil was 6 cm in diameter and 51 cm in length, and its specific gravity was 0.75. Two iron wires were vertically stretched through small rings at both edges of the pipe, to prevent the pipe from tilting in the ground during floating. The floatation of the pipe was measured by the displacement of a string connected to the pipe.

Toyoura sand was used as the test material. The grain size distribution curve is shown in Fig.2. This sand has a subangular grain shape and has a specific gravity of 2.637. The maximum and minimum void ratio were measured to be 0.973 and 0.609, respectively. The soil model shown in Fig.1 was made by the following method. (1) The sand was filled in the soil container, and then the ground was densified to a relative density of 90 % , so that it would not liquefy during shaking. (2) A trench with a depth of 50 cm and a width of 30 cm was excavated. (3) The trench was backfilled with the sand, setting buried pipe and geotextile at the specified position. The relative density of the backfilled sand was 30%, which would easily liquefy during shaking. A vinyl sheet was placed at the boundary between the trench and the surrounding ground to prevent the dissipation of excess pore water pressure induced in the backfilled sand layer during shaking. Shaking motion was applied at a frequency of 3Hz and with an acceleration of 500 gal until the buried pipe was uplifted to the ground surface.

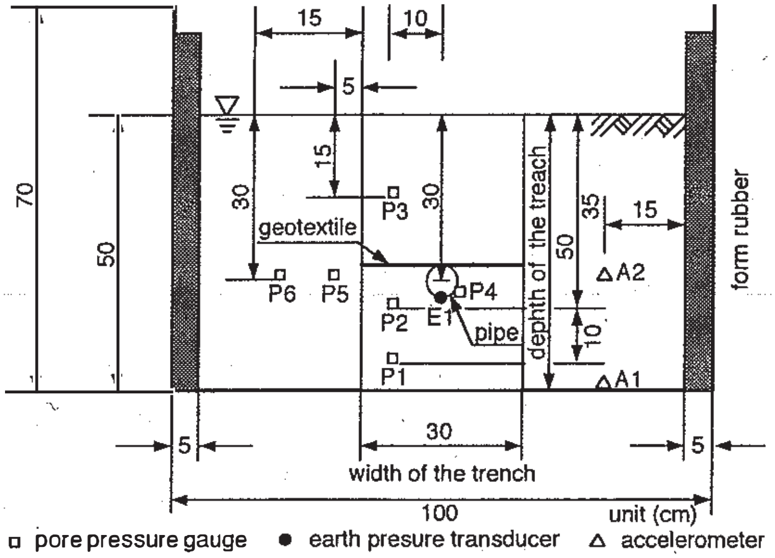
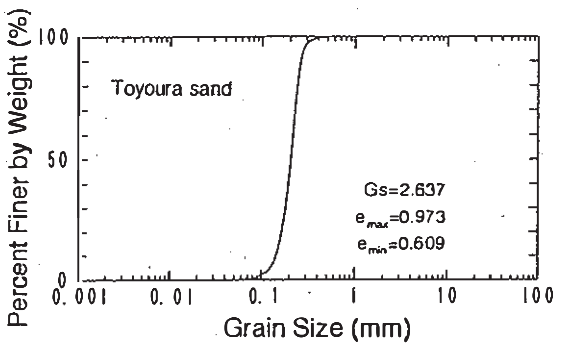


Fig.1. Soil model for shaking table test.



ig.2. Grain size distribution curve of Toyoura nd.

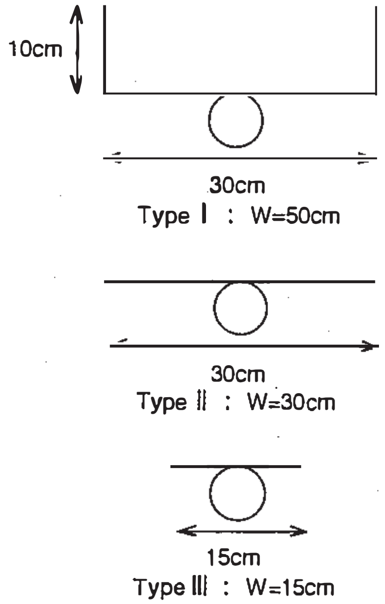


Fig.3. Widths of installed geotextile.

Table 1. Properties of geotextiles used in shaking table tests.

	Mesh Size (mm)	Bending Stiffness (Nm^2)	Materials
Geotextile A	zero	—	nonwoven fabrics
Geotextile B	2	2.00×10^{-6}	plastic net
Geotextile C	5	6.27×10^{-6}	plastic net

Three kinds of geotextiles were used in the tests. Table 1 indicates the properties of the geotextiles used. These are called geotextiles A, B and C. The values of bending stiffness shown in Table 1 were measured by a test in which dead weight was gradually applied to a cantilever beam made of the geotextile. Geotextiles with widths of 15, 30 and 50 cm, called Type I, II and III, respectively, were installed right above the buried pipe horizontally, as shown in Fig.3. Moreover, several shaking table tests were also conducted using the soil model shown in Fig.1, which was reinforced with wire nets instead of geotextiles, in order to study the effects of bending stiffness on the floatation characteristics of buried pipe. The mesh sizes of wire nets used were 2 and 4 mm, and their bending stiffnesses were 2.97×10^{-4} and 1.13×10^{-4} Nm^2, respectively.

In the present tests, the effectiveness of geotextiles with different mesh sizes and bending stiffnesses in reducing the floatation of buried pipe was measured.

3 TEST RESULTS

Figs.4 and 5 indicate time histories of the accelerations of shaking motion, the excess pore water pressure ratios and total stresses at the bottom of buried pipe and the amounts of the floatation, obtained from the tests without countermeasures and with geotextile A with a width of 50 cm, respectively. In the test without countermeasures, the pipe was lifted to the ground surface for about 20 seconds, while the excess pore water pressure at the bottom of buried pipe suddenly decreased to 0, after its value almost reached 1.0. It may be seen that the decrease of the excess pore water pressure is due to dilation of sand soil near the ground surface, which is induced by the approach of the pipe to the surface. The total stress at the bottom of the buried pipe is almost equal to the value calculated by multiplying saturated unit weight, γ_{sat}, by the depth of the bottom of buried pipe, z. On the contrary, in the case of the test using geotextile A, the floatation did not increase to a value of more than 5 cm, while the excess pore water pressure ratio was kept at almost 1.0. Therefore, it can be seen that liquefaction occurred in the backfilled sand layer reinforced with geotextile A in a similar manner to the test without countermeasures, but the floatation of the pipe was prevented by the resistance of the geotextile. The value of total stress fluctuated considerably, while the mean value did not change much. It may be seen from the result that the earth pressure transducer at the bottom of the buried pipe was vibrated during shaking since the pipe could not move upward.

Fig.6 indicates time histories of the floatation of buried pipe in tests in which the width for installation of geotextile A was set at 15, 30 and 50 cm, as shown in Fig.3, and the deformation features of geotextiles after the shaking tests are demonstrated in Fig.7. It is clear from the result in Fig.6 that the pipe was floated to the ground surface for about 20 seconds in the tests without countermeasures and with geotextile A in widths of

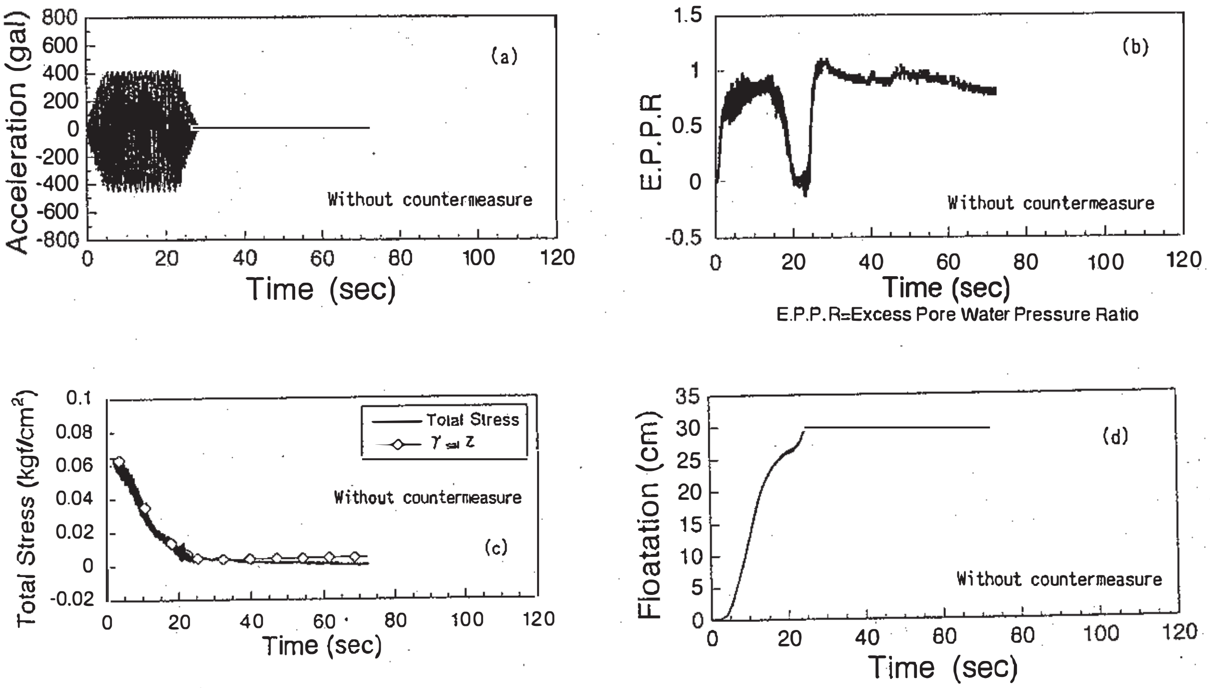


Fig.4. Time histories of acceleration of shaking motion, excess pore water pressure, total stress and floatation without countermeasure.

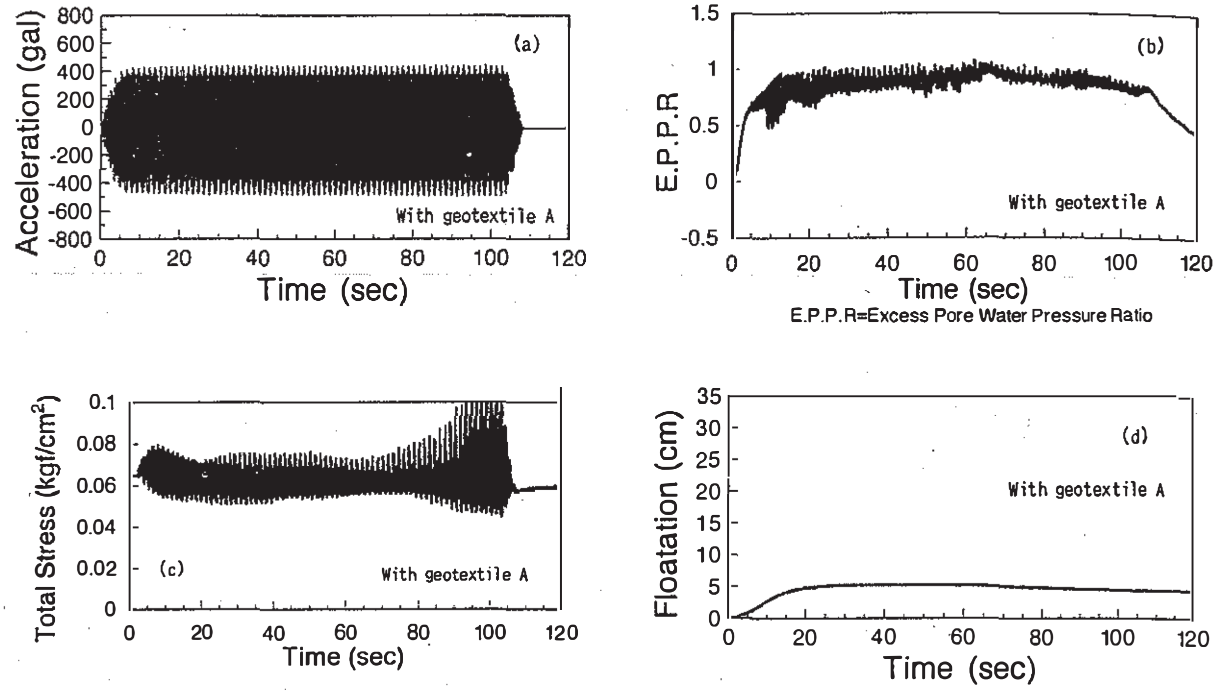


Fig.5. Time histories of acceleration of shaking motion, excess pore water pressure ratio, total stress and floatation with geotextile A.

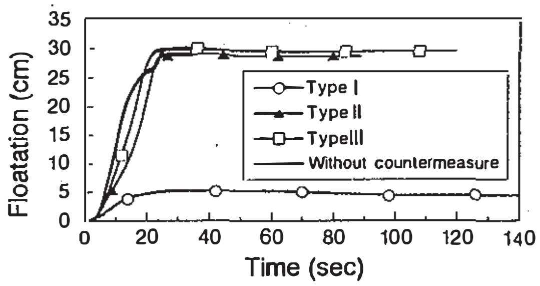


Fig.6. Time histories of floatation of buried pipe in tests with geotextile A in widths of 50, 30, 15cm and without countermeasure.

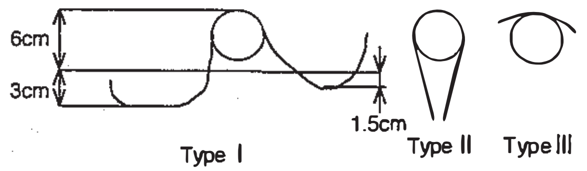


Fig.7. Deformation feature of geotextile A after shaking.

15 and 30 cm. The geotextile of 15 and 30 cm in width was not effective in reducing the floatation, for two reasons; (1) Since there was a space of 15 cm between geotextile A with a width of 15 cm and the surrounding ground densified to 90 % relative density, the liquefied backfill sand soils above the installed geotextile was able to easily move to the bottom of the pipe. (2) Using the geotextile C 30 cm in width, which is the same as the width of the trench, the liquefied sand particles above the buried pipe moved toward the bottom and pushed the installed geotextile downward. Then, the pipe was wrapped by the geotextile at the final state of the test, as shown in Fig.7. On the contrary, it was observed in Fig.7 in the test using a geotextile of 50 cm in width that the geotextile near the edge of the trench was settled by the movement of liquefied sand to the bottom of the pipe and the center part of the geotextile was uplifted by the floatation of the pipe. Therefore, it can be concluded that the movement of liquefied sand from the upper part of the pipe to its bottom part was limited by the geotextile of 50 cm in width. It can also be noted that a geotextile of at least 50 cm in width is needed if the countermeasure is effective in reducing the floatation of the buried pipe in the present tests. Therefore, a geotextile of 50 cm in width was used in other tests.

The time histories of the floatation of buried pipe in the tests without countermeasures and with three kinds of geotextiles A, B and C are compared in Fig.8, and the amounts of floatation, indicated in

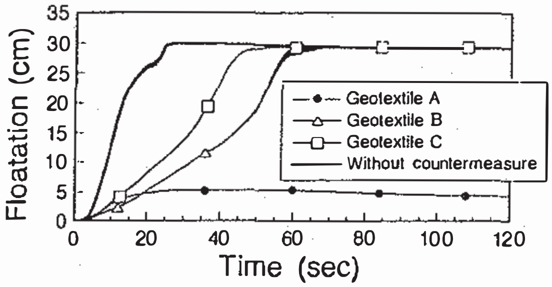


Fig.8. Time histories of floatation of buried pipe in tests with geotextile A, B and C and without countermeasure.

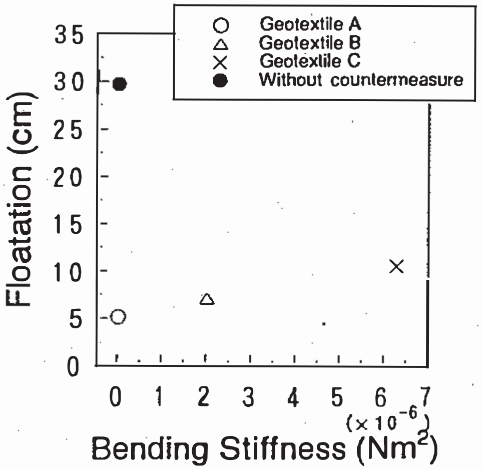


Fig.9. Relationships between floatation and bending stiffness.

Fig.8, at the instant when the buried pipe was lifted to the ground surface without countermeasures are plotted versus the bending stiffness of the geotextiles in Fig.9. The value of bending stiffness of geotextile A and without countermeasures was considered to be zero. It can be seen from the result in Fig.8 that the speed and the maximum height of floatation of buried pipe decreased as the mesh size of geotextile decreased. It may be seen in Fig.9 that the speed of floatation did not depend only on the bending stiffness if the data obtained in the test without countermeasures is included in this discussion. Therefore, it can be considered that the difference of floatation characteristics is not only due to the bending stiffness but due to the mesh size, because it is difficult for liquefied sand particles to go through geotextile with a fine mesh size and the amount of liquefied sand particles moving to the bottom of a buried pipe decreases as the mesh size decreases.

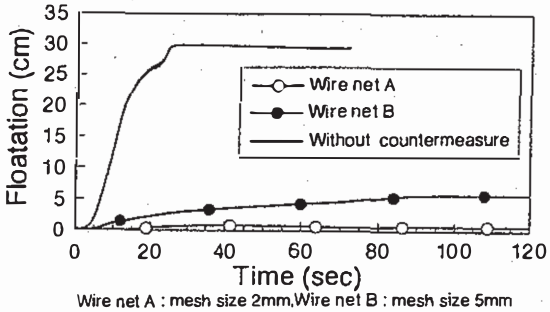


Fig.10. Time histories of floatation of buried pipe in tests with wire net A and B and without countermeasure.

Effects of the bending stiffness of installed material on the floatation of buried pipe were also investigated by some shaking table tests using two kinds of wire nets with mesh sizes of 2 and 4 mm, which are named wire nets A and B, respectively. Both nets had a width of 50 cm. Fig.10 compares the time histories of floatation of a buried pipe in tests without countermeasures and with wire nets A and B. The buried pipe was little floated using wire net A, while the pipe was lifted by about 6 cm in the case of wire net B, which moved upward without being deformed. It can be assumed that the liquefied sand particles more easily went through wire net B than wire net A. This would be the reason why the floatation was larger with wire not B than with wire net A. Moreover, it is realized by comparing the results shown in Figs. 8 and 10 that floatation using geotextiles was larger than the floatation using wire nets. This reason may be that the liquefied sand particles above the buried pipe could not easily move to the bottom of the pipe using the wire nets, because the bending stiffness of wire nets A and B was considerably larger than that of geotextiles A, B and C.

4 CONCLUSIONS

Several series of shaking table tests were carried out to study the effectiveness of geotextiles in reducing the floatation of buried pipe. The following behaviors were observed.

(1) The floatation of a buried pipe decreased as the mesh size of geotextile decreased and its bending stiffness increased.

(2)To prevent floatation, a geotextile must be wider than the trench it is covering and both edges of the geotextile must be in touch with the surrounding ground.

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