SHAKING TABLE TESTS ON FLOATATION OF BURIED PIPES DUE TO LIQUEFACTION OF BACKFILL SANDS

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ABSTRACT

Many manholes and sewage pipes were floated due to liquefaction during the 1993 Kushiro-oki earthquake in Japan To study the mechanism of the floatation, several shaking table tests were carried out under several conditions of soil densities, specific gravities of pipes, water levels and diameters of pipes Tests were also conducted on the model grounds in which a trench was excavated and then backfilled with loose sands Test results show that the speed and the height of floatation are affected by soil density, the specific gravity of the pipe or manhole, water level, and width and depth of the trench

INTRODUCTION

Many manholes and buried pipes were elevated in the ground during the 1993 Kushiro-oki earthquake in Japan. Soil investigations and seismic response analyses revealed that this floatation was due to the liquefaction of backfill soils and alluvial sands To study the mechanism of the floatation, shaking table test were carried out under several conditions.

FLOATATION OF MANHOLES AND PIPES DURING THE 1993 KUSHIRO-OKI EARTHQUAKE

On January 15, 1993, the Kushiro-oki earthquake of magnitude 7 8 occurred near Kushiro City in the northern Japan The earthquake caused severe damage to sewage facilities, gas pipelines, road embankments, houses, harbor facilities, etc. In the sewage facilities, many sewage pipes, manholes, sewage disposal plants and pump stations were damaged in and around Kushiro City. In the city, 7,744m of sewage pipes were damaged and in the adjacent town, 10,838m of sewage pipes were damaged The main patterns of pipe damage were meander, bends and joint failure. Moreover, about 20 manholes were raised in the Kiba and Katsuragi districts of Kushiro Town. The maximum amount of the floatation was 1.3m.

The Ministry of Construction's PWRI (Public Works Research Institute) and Kushiro Town officials inspected the floated manholes by excavating them and carried out soil investigations, including borings and laboratory tests According to the boring data, an artificially filled layer with a thickness of about 2m and a peat layer with a thickness of 1 to 2m were deposited from the ground surface, as shown in Fig.1 Alluvial sand layers underlay them. As the bottom of the floated manholes was almost 4m below the ground surface, sand had been back filled to this depth around the manholes in excavated trenches during construction The alluvial sands and the backfill sand were silty fine sands with SPT N-values of less than 10 and clean sand with SPT N-values of 0 to 11, respectively Based on analyses of liquefaction, it is estimated that the backfill sand liquefied during the Kushiro-oki earthquake. Though it is difficult to judge whether the alluvial layers were liquefied or not, the authors

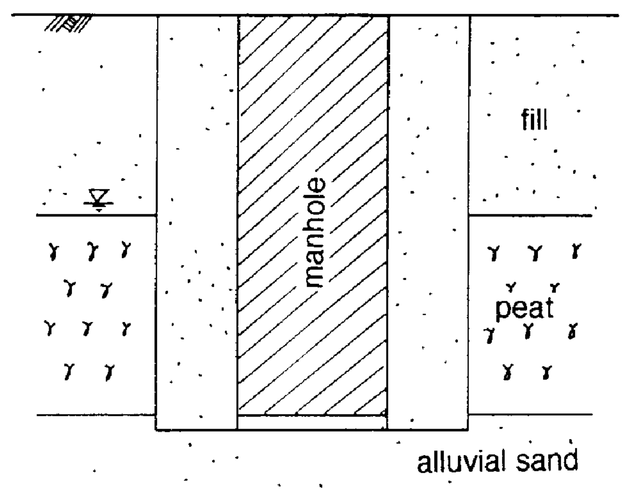


Fig.1 Schematic diagram of soil conditions

estimated that the alluvial sand layers did not liquefy during the earthquake.

Figure 2 shows the locations of damaged sewage pipes in Kushiro City and Kushiro Town. In geomorphological condition, Kushiro City and Kushiro Town are separated into four areas: (1) several artificially reclaimed lands are formed along the Pacific Ocean, (2) a sand dune runs along the Pacific Ocean, (3) peat ground extends widely behind the sand dune, and (4) hills exist in the east. As shown in Fig.2, most of the damaged sewage pipes were in the third and fourth areas. In the fourth area, damage probably occurred due to the sliding of slopes. In the third area, pipe damage was most likely induced by liquefaction, because many pipes were raised, as shown in Fig.2. The soil conditions to a depth of about 10m seemed to be similar to the soil conditions at the Kiba and Katsuragi district, as described before. Therefore, the authors concluded that the damage to pipes in the fourth area was also caused by the liquefaction of backfill sand.

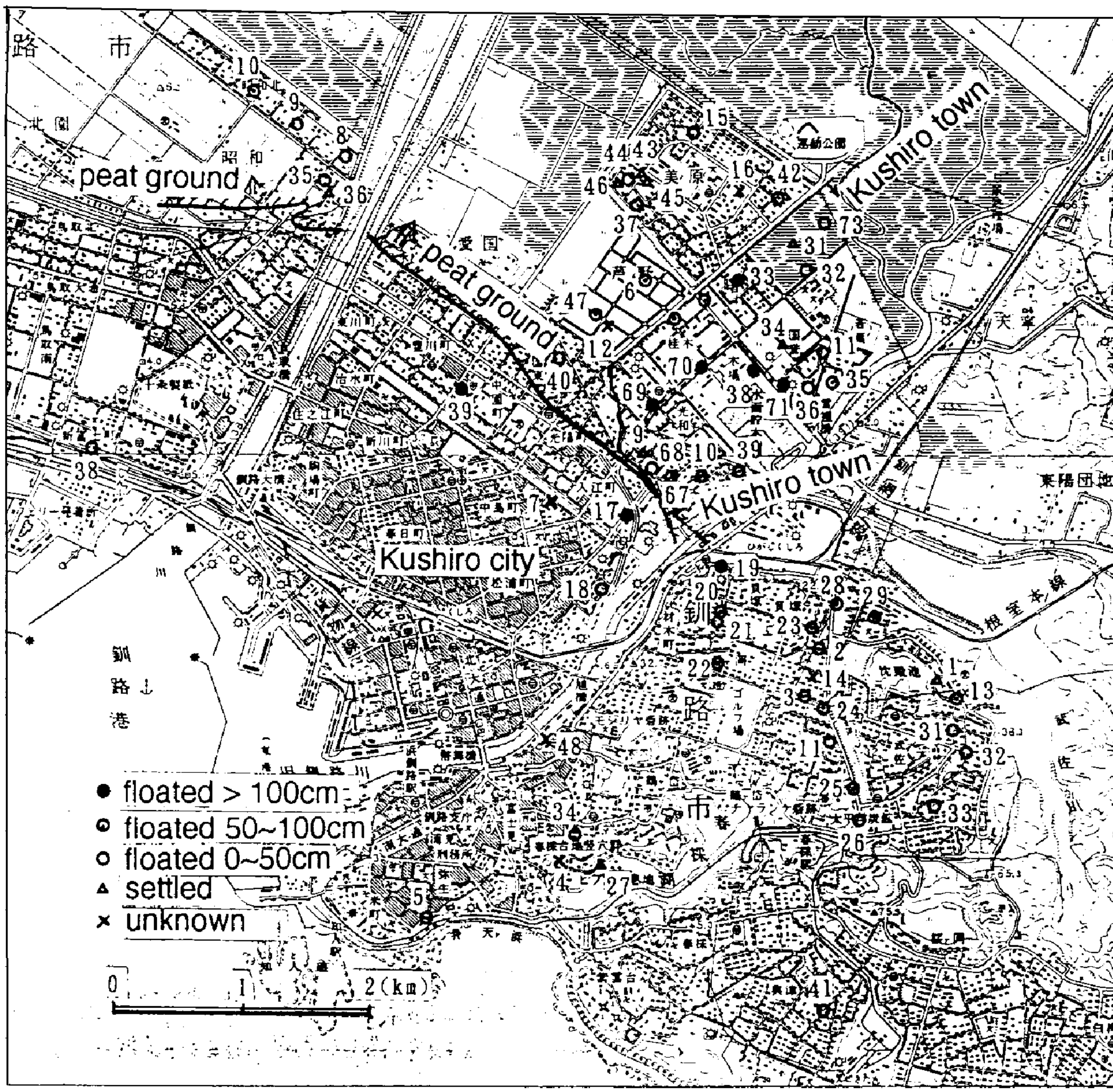


Fig.2 Locations of damaged sewage pipes

The possibility of floatation of buried pipes or manholes due to the liquefaction of backfill sand only had not been studied Therefore, several shaking table tests were conducted to prove it. Fundamental tests to ascertain the mechanism of floatation of buried pipes and some factors which affect floatation were carried out before the tests on the possibility of floatation due to the liquefaction of backfill sands

SHAKING TABLE TESTS ON THE MECHANISM OF FLOATATION

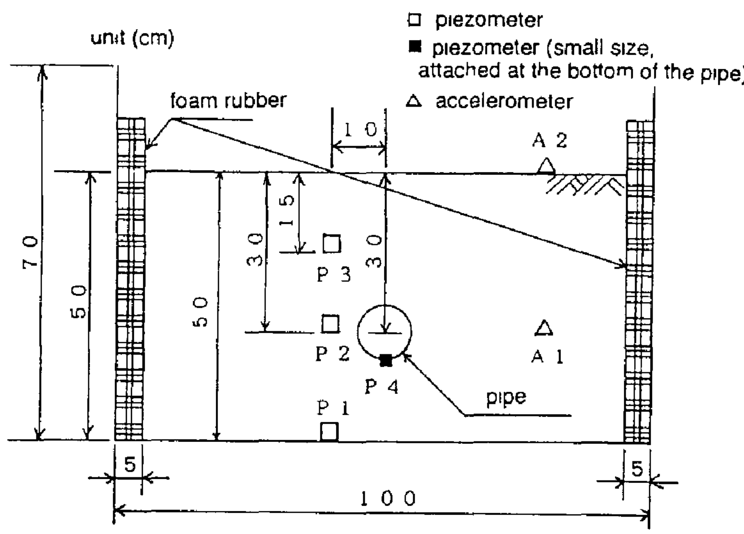


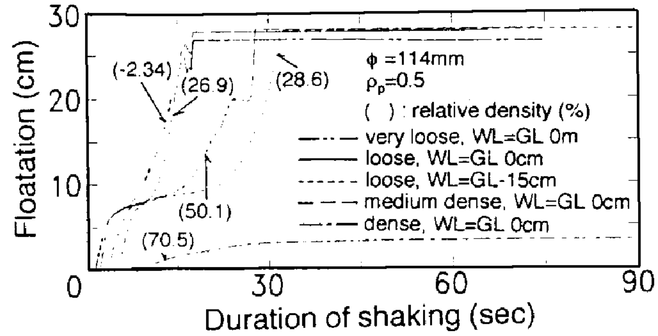
Fig.3 Diagram of apparatus for shaking table test

The shaking table used was 1m in length and 1m in width in plane The soil container used was 100cm in length, 70cm in depth and 60cm in width, as show in Fig.3. A form rubber of 5cm in thickness was inserted inside both walls to induce uniform cyclic shear strain in a soil model during shaking. Very clean Toyoura sand with a mean diameter of 0.175mm was used The soil was arranged in four grades very loose, loose, medium dense and dense The relative densities of these grades were about 0%, 30%, 50% and 70% Two scales of model pipes (1) 11 4cm in diameter and 55cm in length and (2) 6cm in diameter and 55cm in length, were buried in the soil to a depth of 30cm, as shown in Fig.3. The pipes were filled with clay to achieve five specific gravities, ρ_p, : 0.5, 1 5, 1.7, 1.8 and 1 9 One pair of rings was attached to both ends of the pipes, and two strings stretched in the vertical direction were passed inside the rings to float the buried pipes horizontally

Four piezometers and two accelerographs were installed in the model ground, as shown in Fig.3. The floatation of the pipe was measured by the displacement of a string which was connected to the pipe. The water level was adjusted to a depth of 0cm or 15cm from the ground surface Shaking motion was applied in one direction parallel to horizontal axis in Fig.3, at a frequency of 3 Hz and with an acceleration of 250 gals, until the floatation of the pipe is terminated Moreover one series of tests were conducted under the higher acceleration of 400 gals, to know the effect of severity of liquefaction on the speed of floatation.

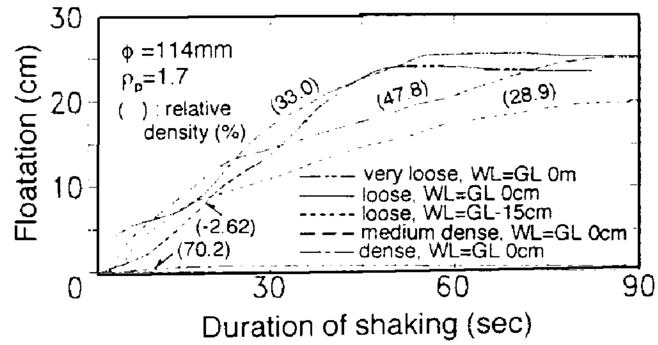
Figures 4 and 5 show relationships between the duration of shaking and the floatation of pipes with a specific gravity of 0.5 and 1.7, respectively, under different densities of soils. The speed of floatation decreased with soil density, the specific gravity of the pipe and water level in the case of ρ_p = 0.5. However, the effect of the specific gravity of the pipe is not clear in the case of ρ_p = 1.7. This may be due to the small difference between ρ_p and soil density. In dense sand, the pipes did not rise to the ground surface. Figures 6 and 7 compare the excess pore pressure ratio measured at the bottom of the pipe in loose sand with the ratio measured in dense sand, each pipe having a specific gravity of 1.7. As shown in these figures the excess pore pressure ratios increased to almost 1.0 due to shaking in both densities. Therefore, it may be said that some amount of resistance to floatation remained in the dense soil, even though the soil was liquefied.

Figures 8 and 9 show relationships between the



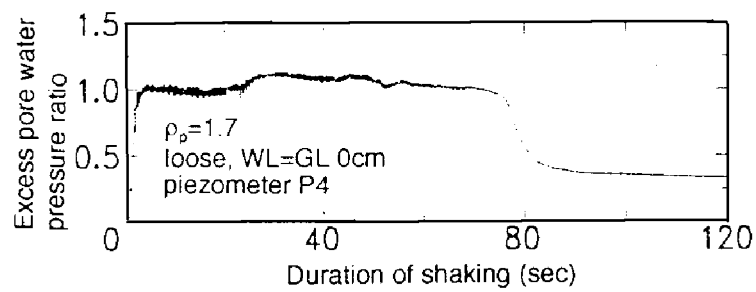
ρp: specific gravity of a pipe

Fig.4 Relationships between duration of shaking and floatation of a pipe with a specific gravity of 0.5



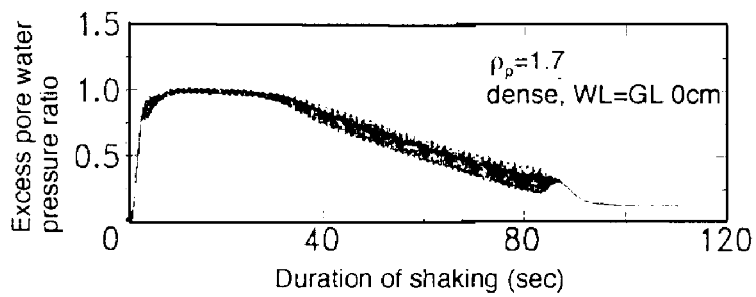
ρp: specific gravity of a pipe

Fig.5 Relationships between duration of shaking and floatation of a pipe with a specific gravity of 1.7



ρp: specific gravity of a pipe

Fig.6 Excess pore water pressure ratio in loose sand



ρp: specific gravity of a pipe

Fig.7 Excess pore water pressure ratio in dense sand duration of shaking and the floatation of pipes with diameters of 6cm and 11.4cm, respectively. It is clear again that the speed of floatation deceased with the specific gravity of the pipe. Moreover, the speed of floatation decreased slightly with the diameter of the pipe. As the unit weight of the soil in loose sand was about 1.88 tf/m^3, the pipe with the specific gravity of 1.9 was not floated to the ground surface.

Figure 10 shows test results for severe shaking with the acceleration of 400 gals on the shaking table. By comparing Fig.10 and Fig.5, which are the same test conditions except the acceleration, the speeds of floatation in Fig.10 were higher than those in Fig.5. As shown in Fig.6 and Fig.7, fully liquefaction had already occurred when the floatation began. Therefore, the difference of the speed must be attributed to the difference of the severity of liquefaction. This means that the friction between pipe and liquefied soil or the stress-strain relationships of liquefied soil is affected by the severity of liquefaction, as same as the torsional test results on post liquefaction behavior (Yasuda et al. 1994c). And, it implies the necessity of consideration of the severity of liquefaction into the design of floatation or settlement of structures due to liquefaction.

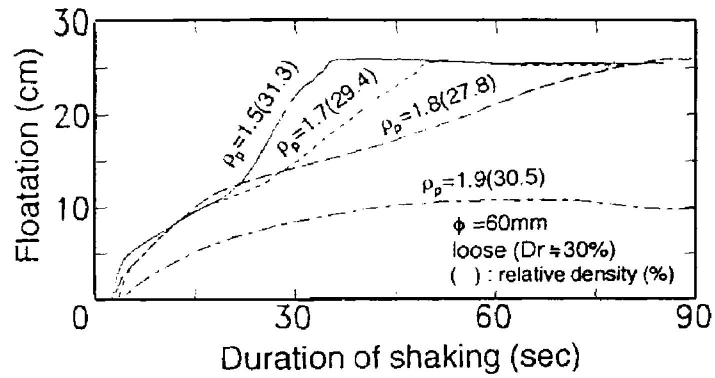


Fig.8 Comparison of the speed of floatation among different ρ_p for a small pipe

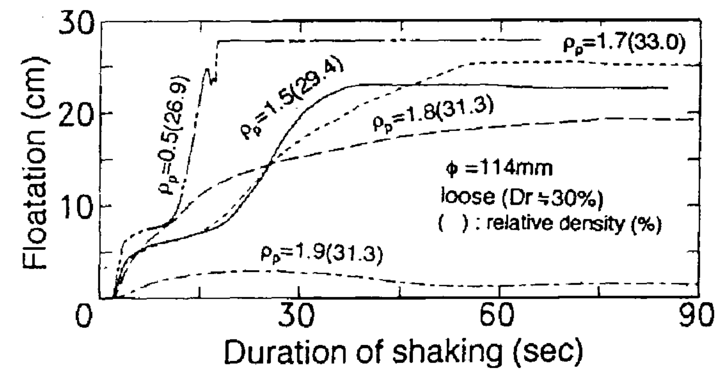


Fig.9 Comparison of the speed of floatation among different ρ_p for a large pipe

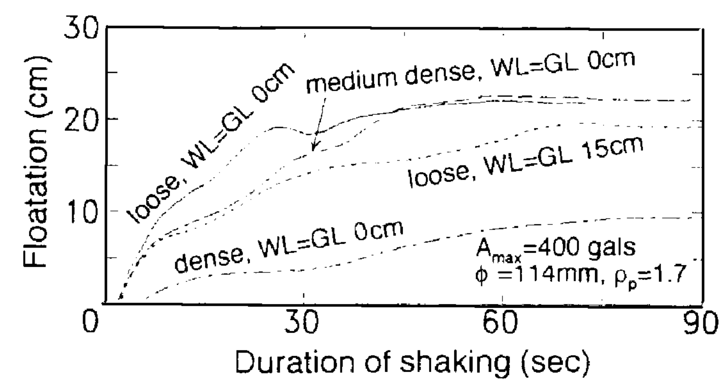


Fig.10 Test results for severe shaking with an acceleration of 400 gals

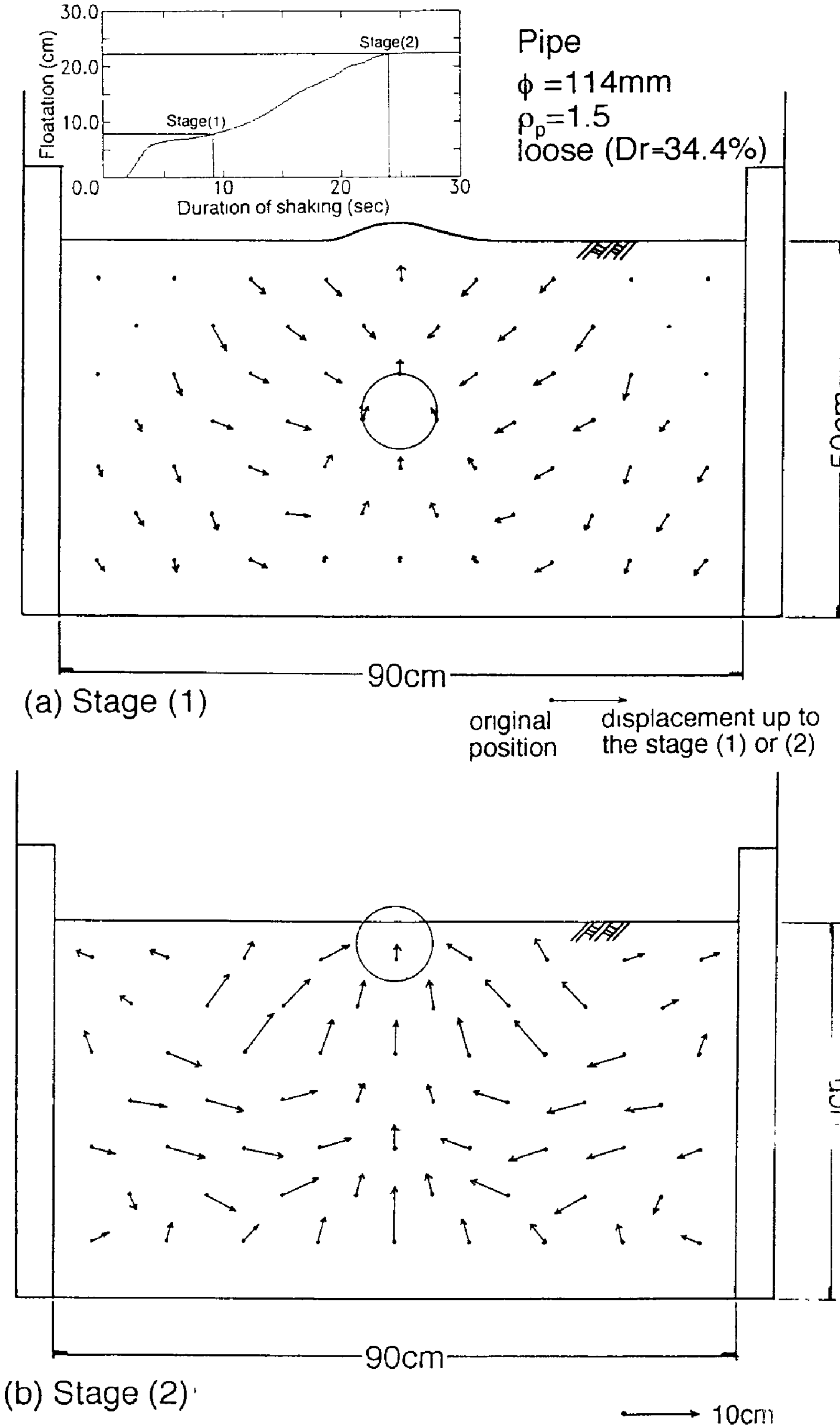


Fig.11 Observation of the movement of soil grains during the floatation of a buried pipe (ϕ=114mm, ρ_p=1.5)

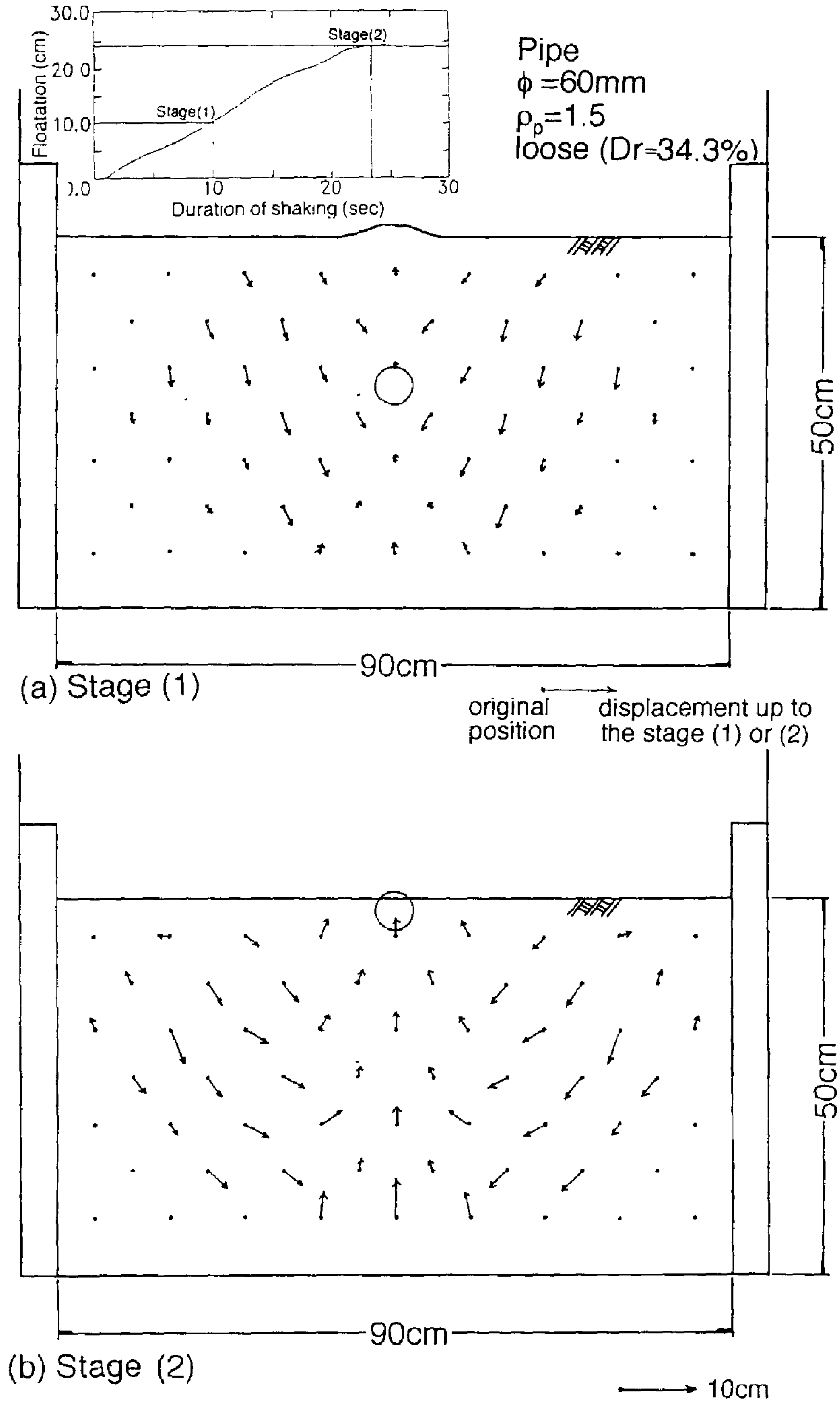


Fig.12 Observation of the movement of soil grains during the floatation of a buried pipe (ϕ=60mm, ρ_p=1.5)

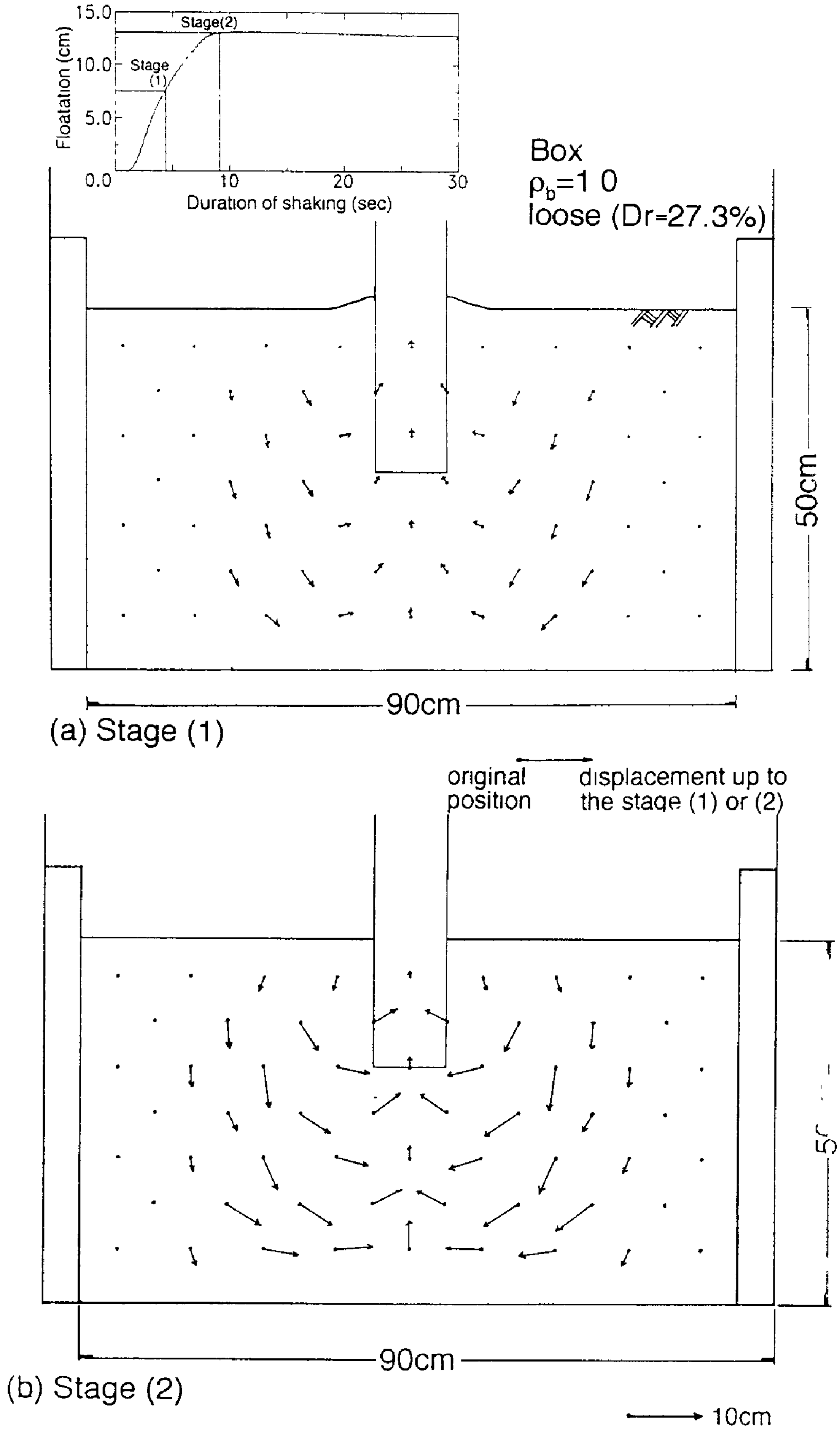


Fig.13 Observation of the movement of soil grains during the floatation of a buried box (width of the box is 35cm, ρ_b=1.0)

As shown in Fig 4, the speed of floatation was not constant in low-density soil and with pipes of low specific gravity. The speed slowed when the floatation reached almost 6 to 7cm., and after several seconds, the speed accelerated again. In the pipe of small diameter, though this phenomenon was also observed, it was not as clear. It was observed during shaking that a small mound appeared on the ground surface when the speed of floatation slowed. It is not clear why the floatation slowed, because the movement of the soil grains around the pipe was not measured. However, it is surmised that several minutes were required to move the upper or lateral soil toward the bottom of the pipe

Then, the detailed observation of the movement of soil grains during the floatation was carried out by using a video camera, for better understanding. The movement was estimated by measuring the displacement of chips of noodles which were installed between soil and front glass with an interval of 10cm in horizontal and 6.25cm in vertical. Figure 11, Fig.12 and Fig.13 show the measured displacements during the floatation of the large pipe (ϕ =114mm), the small pipe (ϕ = 60mm) and a box, describes later, respectively, from the beginning of shaking to the two stages (1) and (2) Stage (1) and (2) are corresponded to the times when the speed of the pipe or the box was accelerated again and when the pipe or the box was elevated up to the ground surface. As shown in Fig.11 and Fig 12, soil upper and below the pipe moved to up during the floatation. Soils right and left sides of the pipe moved toward the bottom of the pipe. It is noted that the soil grain 30 cm far from the pipe moved also toward the bottom of the pipe. In the case of the box also, soils below and both sides of the box moved to up and toward the bottom of the box, respectively, as shown in Fig 13.

SHAKING TABLE TESTS ON THE EFFECT OF BACKFILL SOIL

In the tests to determine the effect of backfill soil on the floatation of buried pipes, the same shaking table, soil container and sand as mentioned above was used. Figure 14 shows the model tested After filling the soil, the ground was densified to 90% relative density, so it would not liquefy during shaking Then a trench with a depth Z and a width B was excavated, and while suspending a pipe or a box, the trench was backfilled with sand. The relative density of the backfilled sand was fixed at 30%, which is easy to liquefy due to 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 backfill soil during shaking. However, a test without the vinyl sheet was also conducted to know the effect of permeability. The diameter and the specific gravity of the pipe was 11 4cm and 0.75, respectively. The width and the specific gravity of the box, which is the model of a manhole, was 11 4cm and 1.0, respectively The depth of the

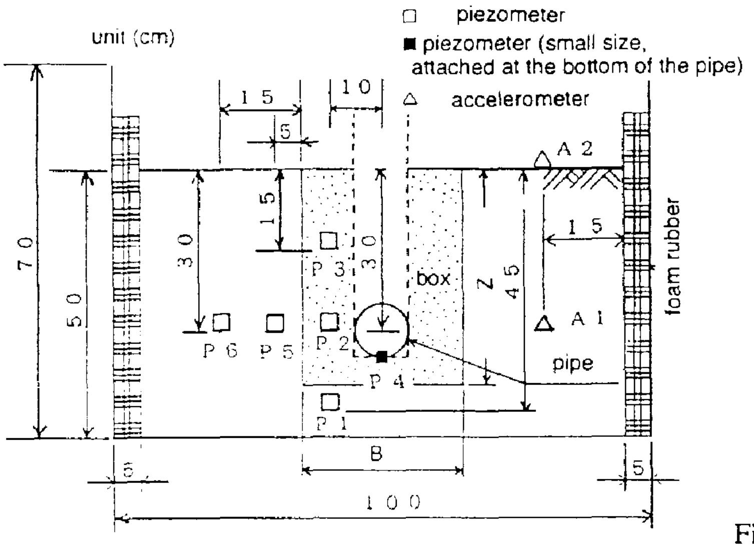


Fig.14 Diagram of apparatus for tests on the effect of backfill soil

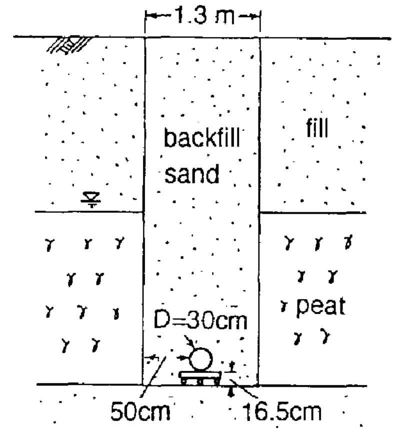


Fig.15 Diagram of a trench to bury a pipe

bottom of the pipe or the box was GL-35.7cm.

Figure 15 shows an example of a trench due to bury a sewage pipe in Kushiro Town. As shown in the figure, backfill sand with a thickness of 16.5cm and a width of 50cm existed below and around the pipe, respectively. As it was expected that the thickness and the width affect the floatation of the pipe due to liquefaction of the backfill sand, tests were conducted under several depths and widths of the trench in the model.

Figure 16 compares the relationships between the duration of shaking and the

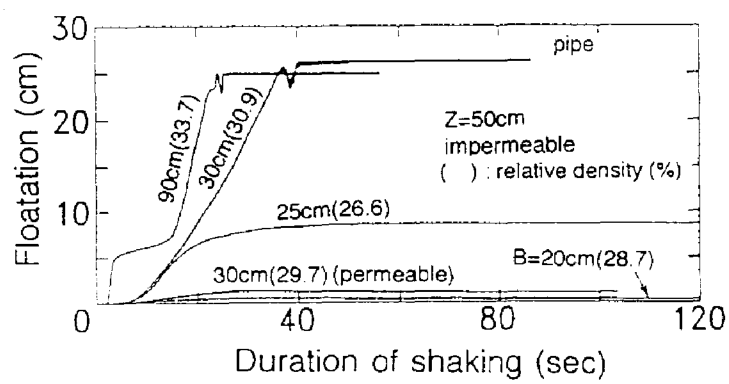


Fig.16 Effect of the width of a trench on the floatation of a pipe

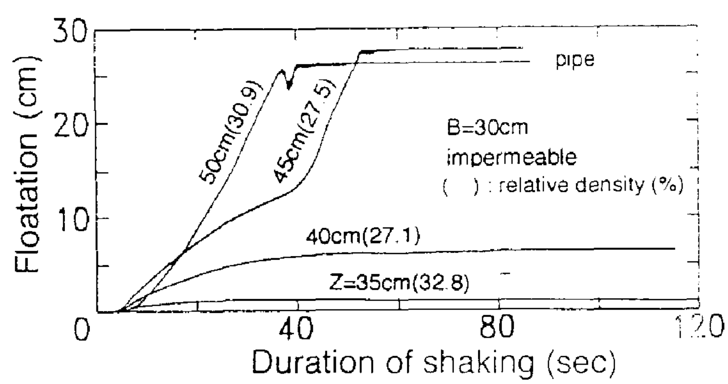


Fig.17 Effect of the depth of a trench on the floatation of a pipe

floatation of the pipe among different widths at a depth of 50cm The speed and the maximum height of floatation increased with width The pipe no longer rose when the width was limited to 20cm Figure 17 compares the relationships between the duration of shaking and the floatation of the pipe at different depths when the width was kept at 30cm. It is clear that the speed and the maximum height of floatation increased with depth. When the pipe was placed on the bottom of the trench, at a depth of 35cm, the pipe did not rise. These two figures imply that a buried pipe can be floated even if liquefaction occurs only in backfill soil, and the floatation is affected by the width and depth of a trench

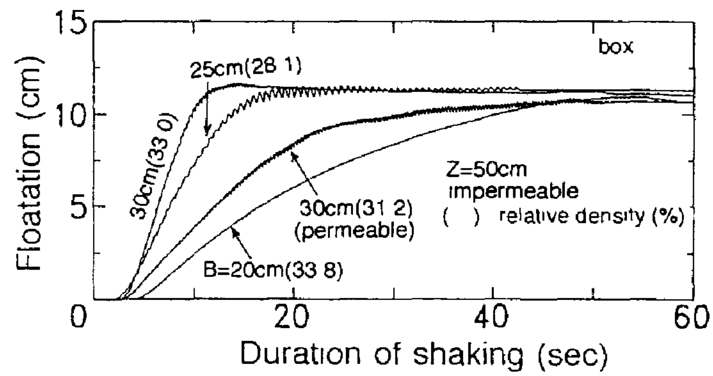


Fig 18 Effect of the width of a trench on the floatation of a box

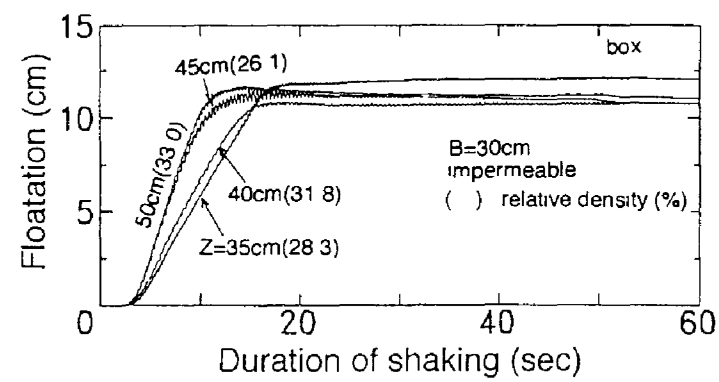


Fig. 19 Effect of the depth of a trench on the floatation of a box

The effect of permeability at the boundary between the trench and the surrounding ground on floatation is also shown in Fig 16 Without the vinyl sheet at the boundary, the pipe was not floated because the excess pore water pressure induced in the backfill sand dissipated into the surrounding ground

Figure 18 and 19 show relationships between the duration of shaking and the floatation of the box Floating speed increased also with the width and depth of the trench By comparing these results with the results of tests on the pipe, shown in Figs. 16 and 17, it can be seen that the box was floated more rapidly than the pipe

CONCLUSIONS

By conducting shaking table tests on the floatation of a buried pipe or box due to liquefaction, the following conclusions were reached

1 A pipe and a box can be floated due to the liquefaction of a backfill sand only.

2. The speed and the height of floatation are affected by soil density, the specific gravity of the pipe or box, water level, severity of liquefaction and width and depth of a trench. Grain size of the soil and shape of the pipe also must be affected to the floatation.

ACKNOWLEDGEMENTS

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