EXPERIMENTAL AND ANALYTICAL STUDY OF THE FLOATATION OF BURIED GAS STEEL PIPE DUE TO LIQUEFACTION

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SUMMARY

This paper investigated the floatation of the gas steel pipe and its effect on road surface pavement when the ground was liquefied by the earthquake and the pipe was loaded of floatation force.

The objective of the study is to know whether there is a possibility for the gas pipe float up to the road surface, causing traffic problems after an earthquake, because most of the gas pipelines in Japan are buried underneath public roads.

The floatation of gas pipes due to liquefaction was investigated by a real-scale shaking table experiment. The ground was made of uniformly graded liquefiable Gifu sand . The gas pipe of 600mm in diameter was buried in the ground. In four experimental cases out of five, the gravel and asphalt were paved at the thickness of 35 cm and 5 cm, respectively and other one is without pavement. The analytical simulations were carried out by means of dynamic effective stress analysis.

The experimental and simulation results showed that, if pipe was back filed by the sand used in the actual pipe construction site and compacted according to the manual, the floatation of the pipeline was small and had less effect on the damage of pavement surface of the roads above it. And the analytical simulation are coincident with the experimental results.

INTRODUCTION

This paper investigated the floatation of gas steel pipe and its effect on road surface pavement when the ground liquefied by the earthquake motion and the pipe was loaded of floatation force. The effect on the pavement was investigated because most of the gas pipelines in Japan are buried underneath public roads and it is important to know whether there is a possibility of gas pipeline floatation above the road surface, causing traffic problems after an earthquake.

The experiment in this paper was done in real scale. and the ground surface was paved by base course gravel and asphalt. As the backfill material, the sand used at actual pipe construction site was employed and it was compacted according to a manual issued by the public road management authorities.

METHOD OF EXPERIMENT

2.1 Experiment condition

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The test ground was made in the large shear box of 3.0 m in depth, 4.3 m in length and 2.8 m in width, and the earthquake motion was given to the box on the shaking table. The buried steel pipe was 600 mm in nominal diameter. It was 60.96 cm in outside diameter, 220 cm in length and 0.397 in apparent specific gravity.

Five experiments were done in total. Figure 1 shows key sketches in each experiment. Table 1 shows experiment conditions. Exp.1 was the standard model most equivalent to the actual pipe construction site. The pipe was buried at the

depth of 180 cm to the top. In Exp.2, the test ground structure was the same as that in Exp.1, however, the pipe depth was 120 cm. In Exp.1, it was feared that the thickness of the layer beneath the pipe was too small for the liquefied sand to intrude in to it from above and beside the pipe. In Exp.3, sine curve shaking motion was applied. The Intensity was set to be equivalent to that of the strongest earthquake which should be considered. In Exp.4, the sand above and beside the pipe was not compacted. This experiment was prepared to show that the compaction of the backfill sand restrained the floatation of the pipe. In Exp.5, there was no pavement at the test ground surface. This experiment was to study the effect of pavement on the floatation of the pipe.

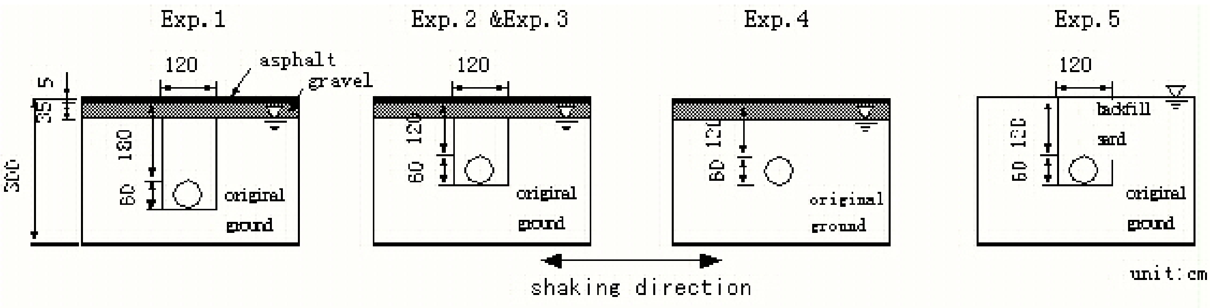

Figure 1 Key sketches of the vertical section in experiment

Table 1 Experiment condition

	Exp.1	Exp.2	Exp.3	Exp.4	Exp.5
Pavement	Asphalt 5cm Gravel 35cm	Asphalt 5cm Gravel 35cm	Asphalt 5cm Gravel 35cm	Asphalt 5cm Gravel 35cm	None
Water table	GL-40cm	GL-40cm	GL-40cm	GL-40cm	GL-0cm
Ground material	Gifu sand & Backfill sand	Gifu sand & Backfill sand	Gifu sand & Backfill sand	Only Gifu sand	Gifu sand & Backfill sand
Backfill	Compacted	Compacted	Compacted	Uncompacted	Compacted
Relative density (Dr)					
Original ground	59%	57%	53%	57%	53%
Backfill	79%	81%	94%	57%	76%
Depth top of pipe	180cm	120cm	120cm	120cm	20cm
Input seismic wave	Hachinohe*	Hachinohe*	5Hz sine curve 65sec	5Hz sine curve 65sec	5Hz sine curve 65sec

*Seismic wave in NS direction recorded at Hachinohe Hardor during the 1968 Tokachioki earthquake.

Table 2 Physical properties of sand

	Gifu sand	Backfill sand
Soil particle density(g/cm^3)	2.65	2.65
Maximum dry density(g/cm^3)	1.64	1.65
Minimum dry density(g/cm^3)	1.22	1.26
Coefficient of permeability (cm/sec)	$9.1*10^{-3}$	$4.0*10^{-3}$

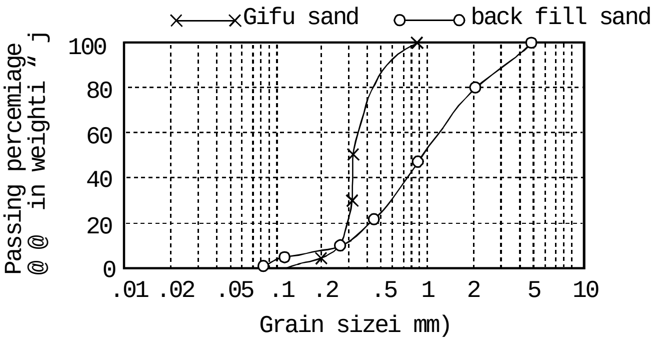

Figure 2 Grading curves of sand

The groundwater was at the same level as the bottom of the gravel layer in Exp.1 to Exp.4, and at the surface level in Exp.5. The pavement structure was decided according to the asphalt pavement design manual(Japan Road Association 1988). The thickness of base course gravel and asphalt was 35 cm, respectively, based on consideration of the design example of the class L traffic in which large vehicles pass less than 100 times per one day in one direction.

2.2 Ground material

Gifu sand was used to make the original ground. It was uniformly graded easy to liquefy. For the backfill of the pipe, the sand used in the actual pipe construction site was employed. Table 2 shows physical properties of sand, and Figure 2 show grading curves of sand.

2.3 Preparation of test ground

The original ground was made by scattering dry Gifu sand at a certain height from the mobile apparatus. The thickness of one layer was about 10 cm. When the pipe was backfilled, a steel frame was used. The backfill sand was put into the frame, and the sand was compacted by a rammer at every 30 cm. According to a manual issued by the public road management authorities. The sand beside and beneath the pipe was carefully compacted by thrusting a bar. After the sand was backhilled and compacted to the same height as that of the original ground, the steel frame was pulled up, and covered. Then, the work to make the original ground was carried out. This procedure was repeated. In Exp.4, the pipe was backfilled by Gifu sand without compacting it by rammer; however, even in this case, the sand was carefully put into beside and beneath the pipe by hand.

In Exp.1 to Exp.4, in which the test ground was paved, the base course gravel at optimum moisture content was put on the ground and compacted to 35 cm in thickness, after the test ground was made to the level 40 cm below the planned surface. Then, asphalt of 5 cm in thickness was paved within steel frame so as to allow the ground to settle freely.

After the test ground was made, the pore air in the ground was replaced by carbonic dioxide by inserting it from the bottom of the box. Lastly, the water, which did not contain gas, was inserted from the bottom. It took about 50 hours to get the water to the planned water level.

The water content and the weight of the sand taken into the box were measured. From these data, dry densities and relative densities were obtained. Densities of base course gravel and asphalt were calculated by the weight of used material and the volume in the ground.

3. EXPERIMENT RESULTS CONSIDERATINS

3.1 Examples of measured acceleration, pipe movement, etc.

For reference, time histories of acceleration, pipe movement, excess pore water pressure in Exp.3, are shown in Figure 3. The ground below 120 cm liquefied completely, as shown in the acceleration time histories and the maximum excess pore water pressure distribution. The backfill sand above GL-100 cm did not liquefy completely. Particularly, the excess pore water pressure ratio of the backfill sand above GL-60 cm, was less than 50%. The comparison of the excess pore water pressure at GL-80 cm between the original ground and the backfill sand indicates that the water pressure in the latter grew more slowly than that in the former. The pipe settled 2 to 3 cm with the settlement of the surface, and then, started moving upward in about 50 second. The final absolute upward movement of the pipe was about 2 cm. As the surface settled at about 4 cm, the floatation of the pipe relative to the surface was 6 cm. This floatation did not crack or damage the asphalt surface at all.

3.2 Summary of experiment results

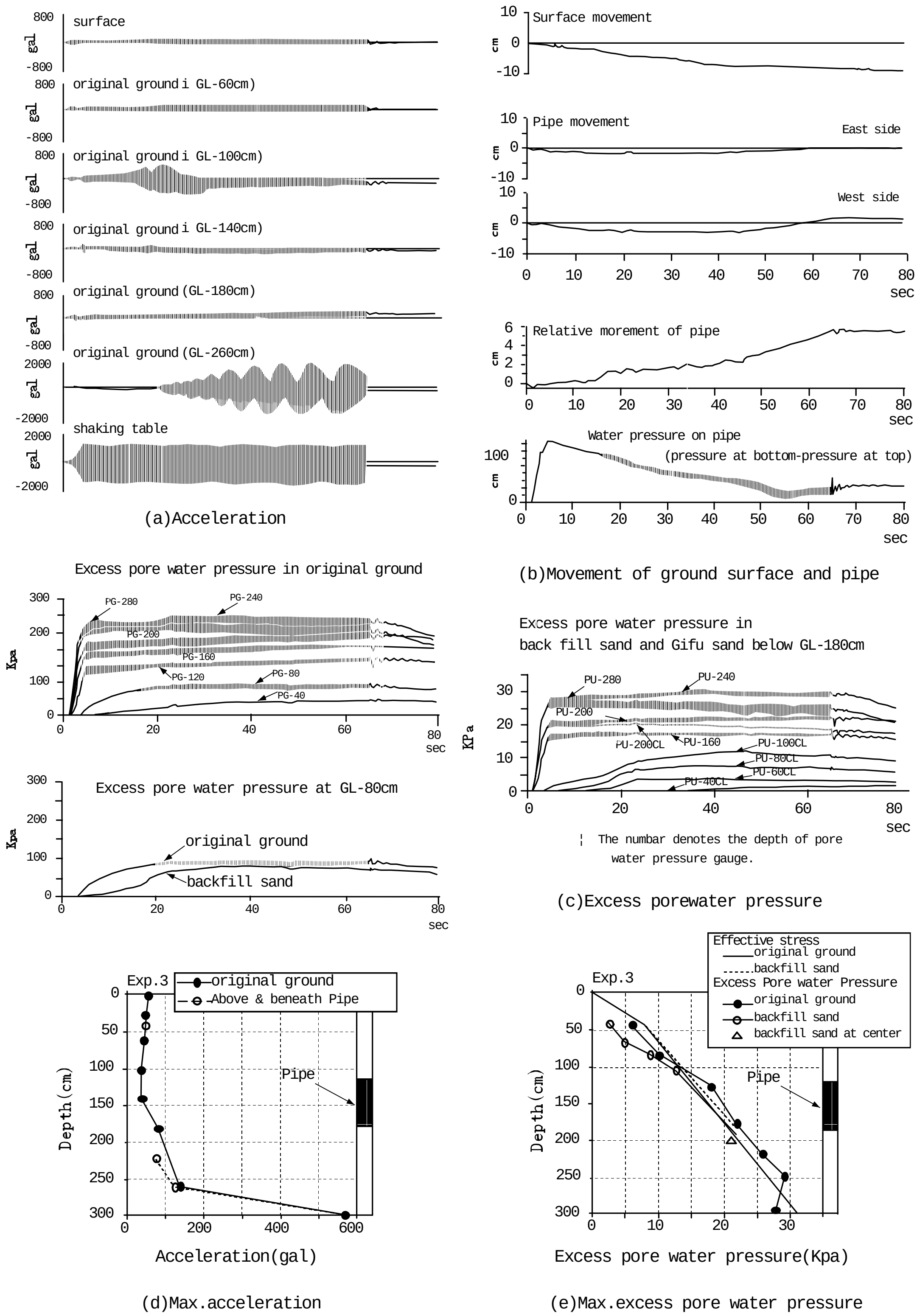

Figure 3 Time histories of acceleration, pipe movement, excess pore water pressure, etc. in Exp.3

Table 3 Summary of experiment results

Exp. No.	Liquefaction level* Ground shallow	Ground deep	Backfill	Pipe movement p(cm)	Surface movement q(cm)	Relative movement p+q(cm)	Asphalt
1	C	B	C	0.5 down	3.6 down	3.1 up	No damage
2	C	A	C	0.2 down	5.5 down	5.3 up	No damage
3	B	A	C	1.6 up	4.0 down	5.6 up	No damage
4	A	A	B (Gifu sand)	16 up	4.0 down	20 up	No damage
5	A	A	C	3.9 up	Ground 3.9down Backfill 3.3 up	6.7 up** 0.2 up**	-----

*A; completely liquefied, B; almost completely liquefied, C; not completely liquefied.
**not equal to p+q because p and q took their maximum at different time.

the backfill was compacted, the floatation of the pipe was 7 cm. In this experiment, the movement of the pipe was nearly equal to that of the backfill sand. They moved together.

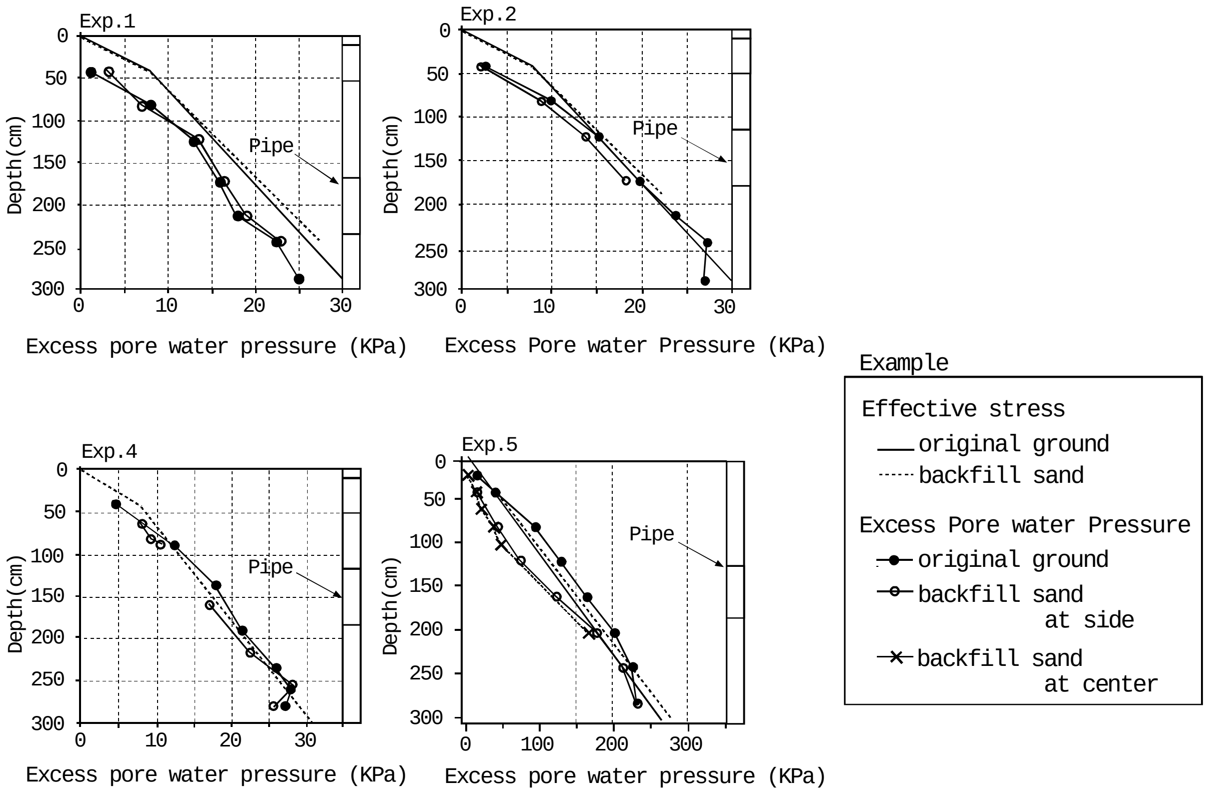

Figure 4 Maximum excess pore water pressure distribution

4. ANALYTICAL METHOD

Simulation analyses were conducted to clarify the liquefaction mechanism of original ground and back-fill sand, and to investigate the floatation mechanism of gas pipes.

These analyses comprised one- and two-dimensional effective-stress analyses for Exp. 3. Figure 5 shows the analysis model for each analytical model. The inputs to the ground employed in the simulation analyses were determined from experimental values and soil test results. The following soil test were conducted: a triaxal CD test, a permeability test, a liquefaction test and a dynamic deformation test. The test specimens were of Gifu sand and backfill sand, and their relative densities were made about the same as those used in Exp. 3. However, the bulk modulus used in the two-dimensional effective stress analysis was decreased to allow for the possibility that perfect saturation is not achieved in the ground during the experiment and that the shear box expanded slightly during the experiment.

The input wave refers to the waveform(5 Hz,, sine wave. 500 gal) of the shaking table used in Exp. 3.

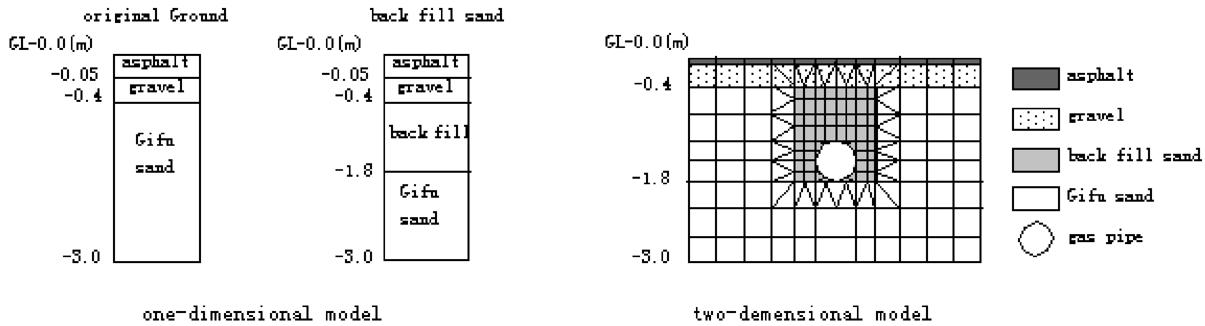

Figure 5 Analytical model

ANALYTICAL RESULTS

Figures 7 and 8 snows the results of one-and two-dimensional effective-stress analysis. Figure 6 and 7 shows the maximum excess pore water pressure distribution and the excess power water pressure ratio distribution obtained from one-dimensional effective- stress analysis, respectively.

In these figures, left side is original ground, and right side is backfill sand, and solid line (—) is effective- stress line, circle (•) is experimental values, dot (•) is analytical values.

From the one-dimensional effective-stress analysis, It can be seen from this figure that the depth where liquefaction occurred in the analysis generally agreed with the experimental results.

Figure. 8 show the waveform of excess pore water pressure ratio obtained from two-dimensional effective-stress analysis. Solid line (—) and dotted line (---) denote the experimental and analytical values, respectively.

From these figures, it can be seen that the analytical values generally agree with the experimental values and that the increasing pore water pressure could be simulated to some extent.

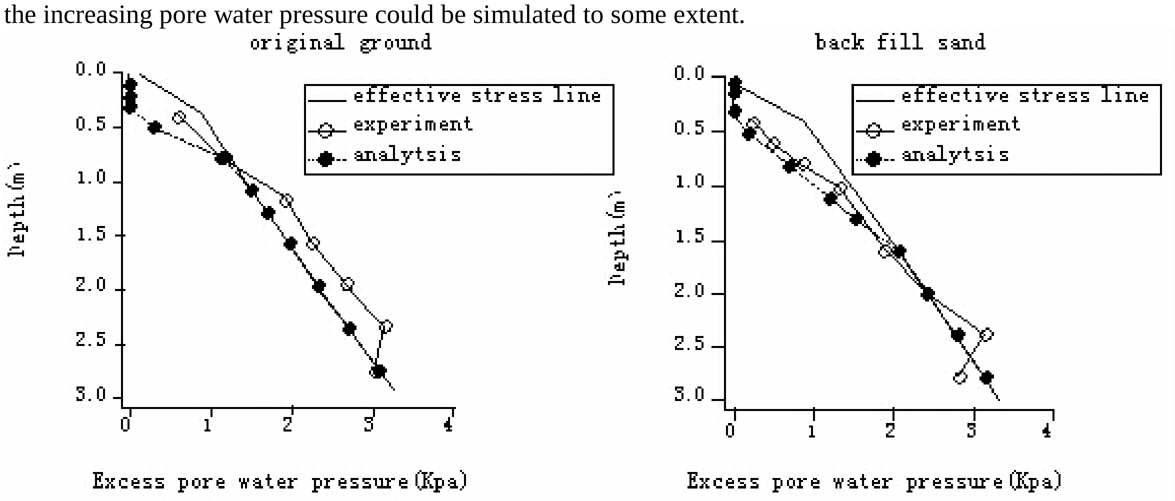

Figure 6 Maximum excess pore water pressure distribution in Exp.3

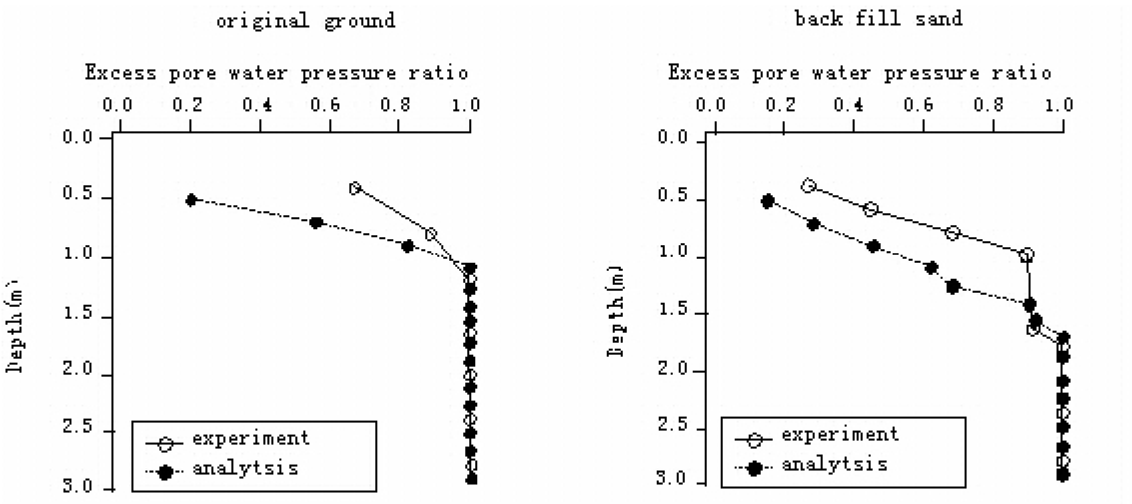

Figure 7 Maximum excess pore water pressure ratio in Exp.3

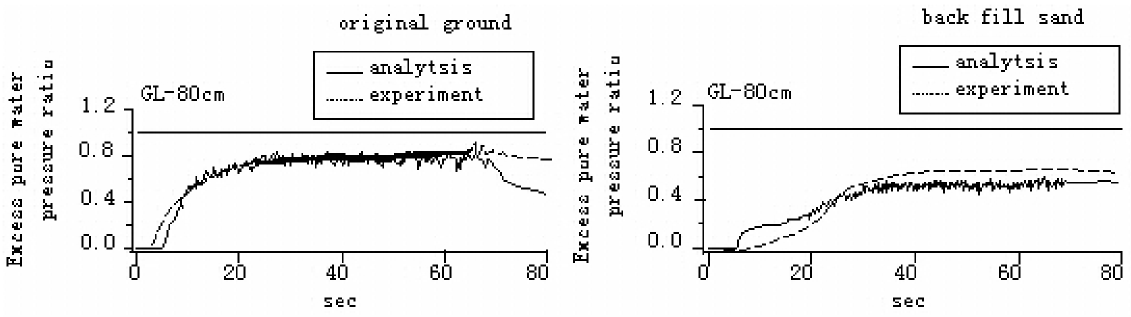

Figure 8 Time histories of excess pore water pressure ratio wave in Exp.3

CONCLUSIONS

The floatation of gas steel pipes due liquefaction was investigated by real scale shaking table experiment and simulation analysis. The conclusions are as follows.

1. When the test ground surface was paved by base course gravel and asphalt, and the backfill sand was compacted according to the manual, the floatation of the pipe was less than 6 cm, with the application of the seismic wave recorded at Hachinohe or one minute sine curve shaking motion at a frequency of 5 Hz and with an acceleration of over 500 gals. Under the same conditions, except that the test ground surface was not paved, the floatation of the pipe was less than 7 cm.
2. When the test ground surface was paved, but the backfill sand was not compacted, the floatation of the pipe was about 20 cm with the application of the same curve motion as that in (1).
3. There were no cracks or damage to the asphalt surface in any experiments in which the ground surface was paved.
4. The fact that the compacted backfill sand did not liquefy completely was considered to be the main reason of the small amount of floatation.
5. It has been shown that the analytical method accurately simulated the depth where liquefaction occurred, and that the increasing pore water pressure was simulated to some extent.

ACKNOWLEDGMENT

After the 1995 Hyogoken Nanbu Earthquake, the Agency of Natural Resources and Energy, Ministry of International Trade and Industry entrusted the investigation of gas pipe behavior due to liquefaction to the Japan

Gas Association. This investigation started in 1996 and will take five years to complete. It is supervised by the committee for investigation of the effect of liquefaction on gas pipelines, chaired by Dr. Tsuneo Katayama, the head of the National Research Institute for Earth Science and Disaster Prevention of the Science and Technology Agency. The authors express their gratitude to all persons concerned at MITI for their permission to publish this paper, and the committee members for their valuable suggestions.

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