STUDY ON BEHAVIOR OF BURIED PIPES IN LIQUEFIED GROUND

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SUMMARY

This paper describes the results of the experiment using the actual sized pipes and the on-site investigation after the 1995 Hyogoken Nanbu earthquake concerning about the behavior of buried pipelines in the liquefied ground. This experiment was conducted by using a large-sized laminar shear soil vessel, and it turns out that use of collars in connection parts between structures enables pipelines to follow the ground subsidence, reduce the stress generated on pipe bodies, and can be an effective measure against liquefaction. In addition to that, comparing experiment results with calculation results, it shows that the coefficient of subgrade reaction and the coefficient of friction between pipes and ground are estimated to be 5% of those in the normal ground condition under this test conditions. According to the results of on-site investigation of practical pipelines buried in the areas where liquefaction occurred after the earthquake, it turned out that the ratio of pipeline extension in the axis direction was almost 50 % of the average ground strain caused by the liquefaction.

INTRODUCTION

The 1995 Hyogoken-Nanbu (Kobe) Earthquake caused extensive damage to the water pipelines. Since there was heavy damage to the pipelines especially in the areas where liquefaction occurred, it is obvious that a measure against liquefaction is one of the important subjects to consider about making pipelines be earthquake-proof.

To study the measure against liquefaction for pipelines, it is essential to grasp the behavior of pipelines and the force acting on pipe bodies. Therefore, authors carried out an experiment on actual sized pipes by using a large-sized laminar shear soil vessel. In this paper, we describe the coefficient of subgrade reaction of liquefied ground and the measure against liquefaction for connection parts between structures where maximum attention is required for ensuring the safety of pipe distribution, as well as the relationship between the ground strain and the amount of expansion-contraction of pipeline joints in the liquefied ground based on the investigation results of the practical behavior of pipelines buried in the areas where liquefaction occurred after the earthquake.

DAMAGE TO PIPELINES IN LIQUEFIED GROUND

The incidents of damage to water distribution pipelines reportedly amounted to as many as 4,000 in the overall earthquake stricken area, including about 1,760 in Kobe City(2). As to the types of damage, slip-out of joints occurred on ductile iron pipes, and slip-out of joints and damage to pipe bodies occurred on both cast iron pipes and polyvinyl chloride pipes(2), (3).

Figure 1 shows the relationship between the degree of liquefaction mentioned by Reference [2] and the damage ratio of pipelines calculated by the following equation; numbers of damage to pipeline/pipeline length. The damage ratio in severely liquefied areas (liquefaction ratio 100%) was 1.87 incident/km, which was 3.7 times of that in non-liquefied areas (liquefaction ratio 0%), 0.50

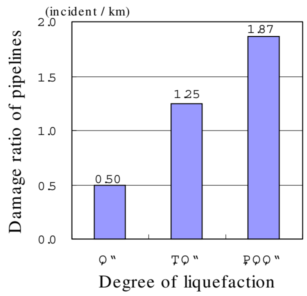

Figure 1 Influence of Liquefaction over Pipeline Damage

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incident/km. This means there were more incidents of damage to pipelines in liquefied areas.

EXPERIMENT RESULTS CONCERNING PIPELINE BEHAVIOR IN LIQUEFIED GROUND

We carried out experiment on actual sized pipes by using a large-sized laminar shear soil vessel, and studied the pipeline behavior and the force acting on pipelines (coefficient of subgrade reaction) when liquefaction occurs. The experiment was carried out on distribution pipes in connection parts between structures. Since a greater relative displacement may occur between structures and the liquefied ground where subsidence of ground results in, the connection parts between structures require maximum attention when pipelines are designed. In fact, the 1995 Hyogoken-Nanbu (Kobe) Earthquake caused numbers of damage to the connection parts between structures. We tested on two types of distribution pipelines, and also studied the measure against liquefaction for the connection parts between structures

Table 1 Values of Physical Properties of Test Sand

Relative Density (%)	39.6
Water Content (%)	21.2
Void Ratio	0.74
Density of Soil Particle (g/cm?)	2.718
D50 (mm)	0.3106
Maximum Dry Density (g/cm?)	1.731
Minimum Dry Density (g/cm?)	1.386
Sand Content (%)	94.6
Silt Content (%)	4.5
Clay Content (%)	0.9

Test Method:

1) Large-Sized Laminar Shear Soil Vessel

We used a large-scale liquefaction reproduction device developed by the National Research Institute for Earth Science and Disaster Prevention of Science and Technology Agency(4). As shown in Figure 2, this device mainly consists of a shaking table and a laminar shear soil vessel (6m in height, 12m in length and 3.5m in width; with a total of 29 laminar shear frames). The ground was made as saturated sand ground by applying the underwater dropping method. Table 1 shows values of physical properties of the test sand.

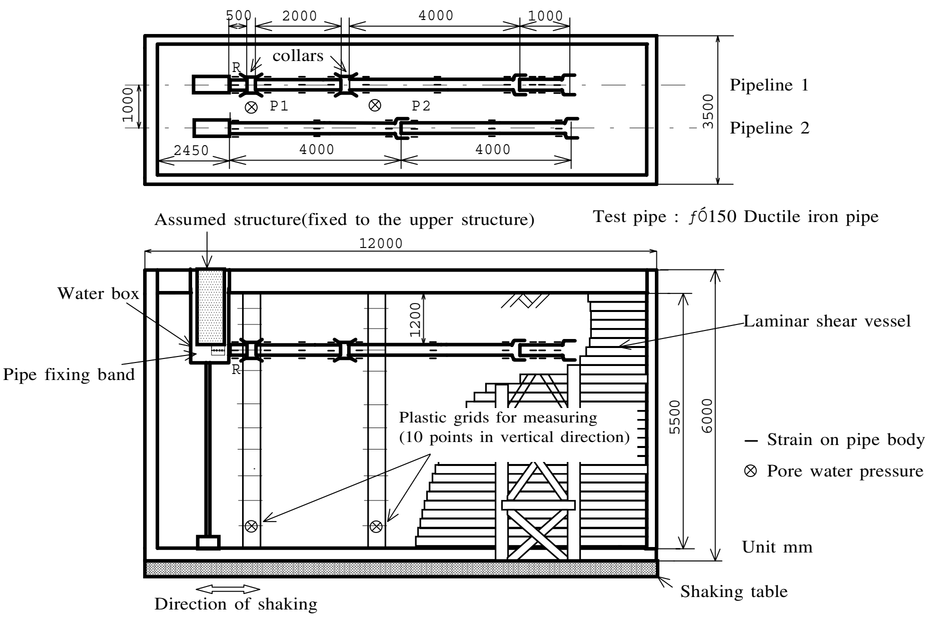


Figure 2 Test Pipeline

2) Test Pipelines and Items to be Measured

We designed two types of pipelines as shown in Figure 2. Both types use ductile iron pipes of 150 mm in nominal diameter with joints. Pipeline 1 was assembled with two collars in its connection part between structures to connect with a straight pipe, while Pipeline 2 consisted of only straight pipes. Joints of both types of pipelines had flexibility, expand-contract and anti-slip-out performance[6]. Some weights were inserted into the pipes so that the specific gravity of the pipes became equal to that in the full water condition (gravity: 2.25). The frame assumed as a structure was fixed to the upper frame above the soil vessel, and extended into the water box in the soil so that it was not influenced by the soil movement, and it could move simultaneously according to the movement of the shaking table.

During the test, the stress generated on pipe bodies, the excess pore water pressure of ground, and others were measured.

3) Shaking Conditions

The specimen was applied with two kinds of shaking observed at 32 m underground at Port Island (Kobe City) in the 1995 Hyougoken-Nanbu Earthquake; 380 gal at maximum with wave forms in the north-south direction. Then, it was applied with shaking of 100 kine at the final stage of the test.

Test Results:

1) Figure 3 shows the distribution of maximum values of excess pore water pressure ratio of the ground measured at the P1 and P2 points (Figure 2). Except at the base of the soil vessel, the excess pore water ratio exceeded 1, which means the occurrence of liquefaction.

2) Figure 4 shows an example of the measured wave forms of the acceleration of shaking table, the excess pore water pressure ratio and the stress generated on pipe bodies at 380 gal. This stress on pipe body was measured at the point 100mm distant from the connecting part to the assumed structure (Point R in Figure2). The stress generated on pipe bodies was maximum when the excess pore water pressure ratio reached to the maximum level

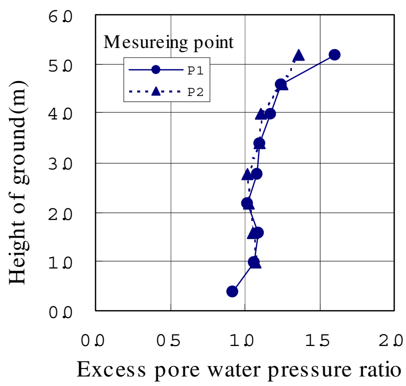


Figure 3 Measurement Results of Excess Pore water pressure

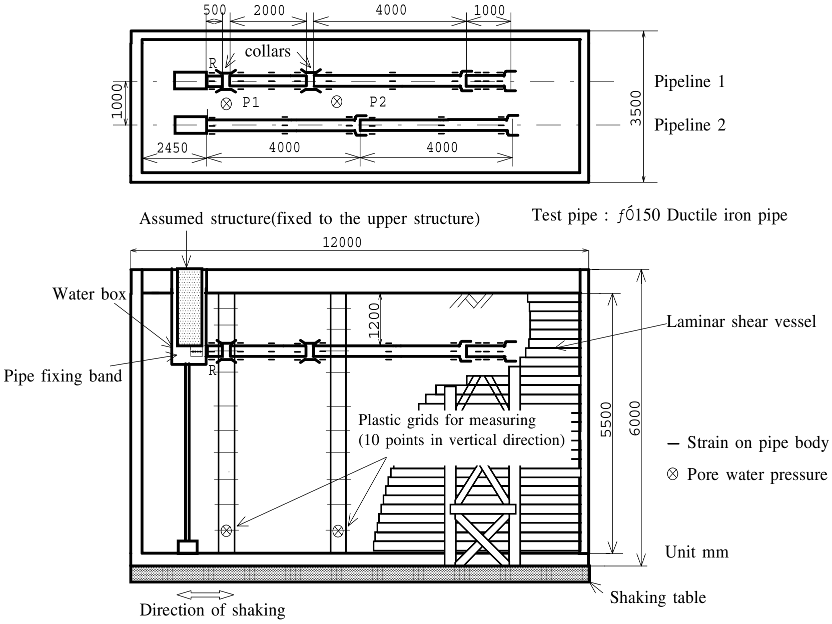


Figure 4 An Example of Measured Wave Form

3) Figure 5 shows the measurement result of the maximum stress generated on pipe bodies when shaking the specimen at 380 gal. Since the values of the tension force occurred in the upper part of pipes and the compression force occurred in the lower part of pipes were almost the same, we consider that bending stress was generated on the pipe bodies by the ground subsidence caused by the liquefaction. The stress generated on overall pipes in Pipeline 1 was as small as 10.8 N/mm2 at maximum. Meanwhile, the stress generated on pipes fixed on the structure in Pipeline 2 was 54.8 N/mm2 , about five times of that in Pipeline 1.

4) Figure 6 shows the condition of pipelines after shaking the specimen at 100 kine by giving the measurement result of the amount of expansion-contraction of joints, the inclined angle of pipe, and the settlement of pipeline ends. Since Pipeline 1 well followed the ground subsidence owing to the bend of collars, the settlement of the end of Pipeline 1 was about 51 cm. Meanwhile, the settlement of the end of Pipeline 2 was about 34 cm, which is less than that of Pipeline 1. This result shows that Pipeline 2 did not follow the movement of ground satisfactorily.

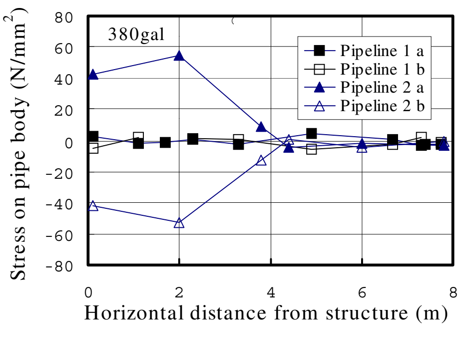
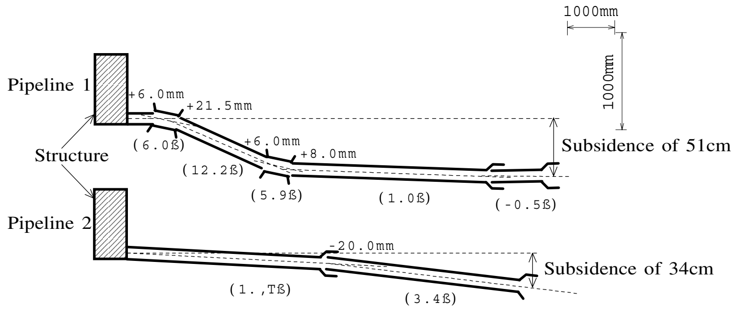


Figure 5 Measurement Results of Stress on Pipe Bodies



Note) 1. Numbers of joints : the average amount of expansion-contraction of joints
+¥¥¥¥expansion
|¥¥¥¥contraction
2. Numbers in ( ) under pipes : the inclined angle of pipes

Figure 6 Measurement Results of Pipeline Behavior

3.3 Design of Pipelines in Connection Parts between Structures:

As a result of the above mentioned test, it turns out that use of collars in the connection parts between structures enables pipelines to follow the ground subsidence, reduce the stress generated on pipe bodies, and could be the effective measure against liquefaction.

ESTIMATION OF COEFFICIENT OF SUBGRADE REACTION

Estimation Method:

The stress generated on pipe bodies of pipeline could be calculated when the pipeline is regarded as a beam on the elastic foundation as shown in Figure 7 and is applied with ground subsidence observed during the test. In this model, we set the coefficient of subgrade reaction and the coefficient of friction between pipes and ground at 50%, 20% and 5% of those in the normal ground condition, and estimated the coefficient of subgrade reaction as well as the coefficient of friction between pipes and liquefied ground by comparing them with the values of stress generated on pipe bodies we obtained from the experiment.

Also in this model, the joint was idealized as a spring element with respect to tension, compression and bending freedoms, and the pipe and the ground were connected with each other by soil springs. Figure 8 shows the spring characteristics of joint used in the experiment for expansion and contraction which was obtained by laboratory test. The spring characteristic of soil in pipe axis direction was modeled to be represented by a bi-linear model shown in Figure 9(1). The inclination of soil spring 'k' is determined by the coefficient of subgrade reaction, and the maximum value of the soil spring τ_0 is equivalent to the coefficient of friction between pipes and ground. On the other hand , the spring characteristics of soil in pipe orthogonal direction was modeled as shown in Figure 9(2), and the slip between pipe and ground was not considered for pipe orthogonal direction

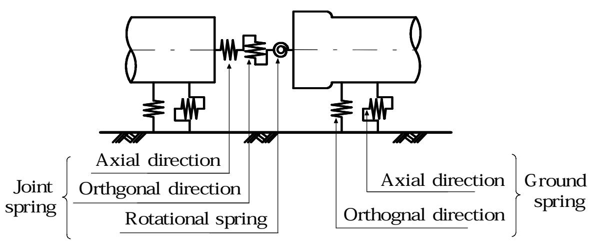


Figure 7 Analysis Model

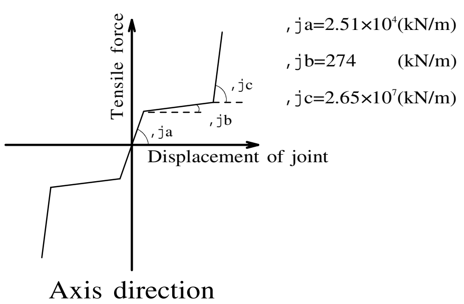
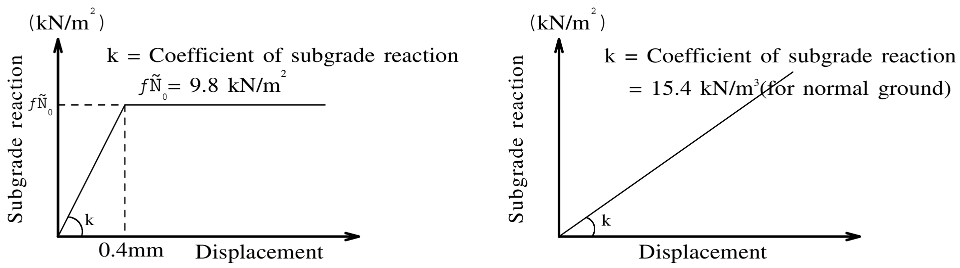


Figure 8 Joint Spring Characteristics



(1) Axis direction (2) Orthogonal direction

Figure 9 Soil Spring Characteristics

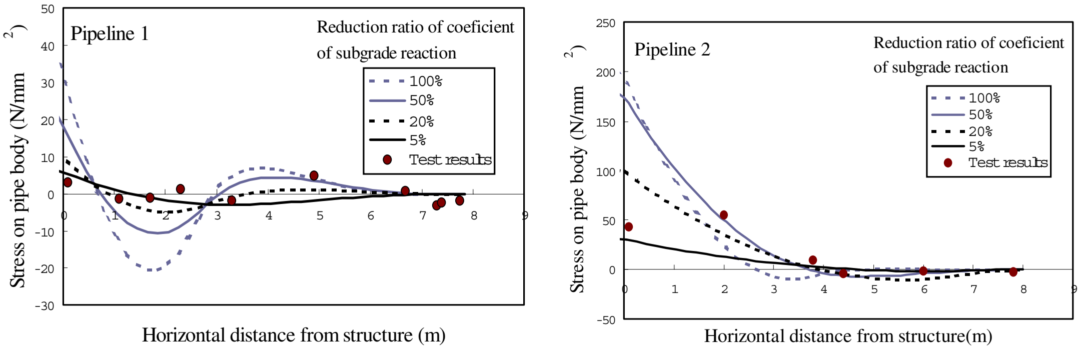


Figure 10 Comparison between Calculation and Test results

Estimation Results:

Figure 10 shows the comparison between calculation and test results. The coefficient of subgrade reaction and the coefficient of friction between pipes and ground nearly match when they are 5% of those in the normal ground condition. As a result, under this test condition, the coefficient of subgrade reaction of liquefied ground and the coefficient of friction between pipes and liquefied ground are estimated to be 5% of those in the normal ground condition.

MEASUREMENT RESULTS OF PIPELINE BEHAVIOR IN LIQUEFIED GROUND

Investigation on Pipeline Behavior:

Kobe Municipal Waterworks Bureau investigated the behavior of the pipelines buried in artificial islands located in Kobe City, Rokko Island and Port Island, where were severely liquefied and great ground deformation such as cracks and lateral displacement of ground occurred in the 1995 Hyogoken-Nanbu (Kobe) Earthquake(1).

Kobe Municipal Waterworks Bureau carried out an investigation using a TV camera inserted into pipelines to watch the behavior of the pipelines, measured the amount of expansion-contraction of each joint, and then determined the value of pipeline extension from the starting point by accumulating the amount of expansion-contraction of each joint. Figure 11 shows an example of the measurement result of the amount of joint expansion-contraction and the value of extension from the starting point in a pipeline of 300 mm in nominal diameter. In this measurement area, a half of all the joints fully expanded by 80mm. The whole pipeline expanded by 435 mm, and the ratio of pipeline extension calculated by Equation [1] was 0.8%.

$$Er = \frac{E_l}{L - E_l} \times 100\% \qquad [1]$$

where

Er: Ratio of Pipeline Extension

E l : Value of Pipeline Extension in Pipe Axis Direction

Average Ground Strain in Pipe Axis Direction:

Professor Hamada and his colleagues measured the amount of lateral displacement of ground by observing the aerial photographs taken before and just after the earthquake(5). For this paper, we determined the value of average ground strain in the pipe axis direction according to their measurement results which show the direction and amount of ground displacement.

We placed traverse lines along the investigated pipelines, determined values of ground displacement in the pipe axis direction by a surrounding lateral displacement vector, plotted the values as shown in Figure 12, and then calculated the average ground strain in the pipe axis direction, 1.7%.

L : Pipeline Length

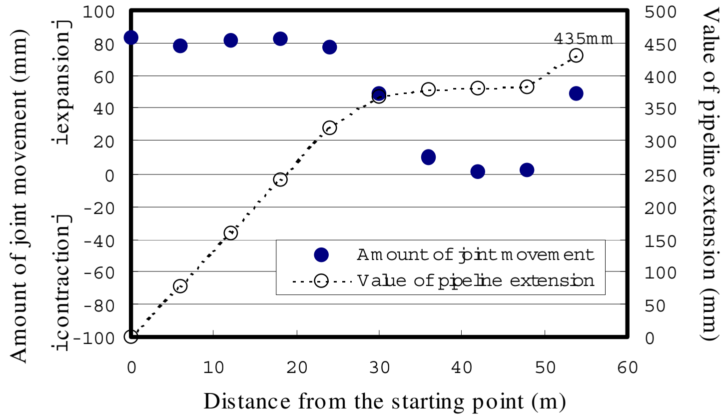


Figure 11 Amount of Joint Expansion –Contraction and Value of Pipeline Extension

Relationship between Pipeline Behavior and Ground Deformation

The investigation on the pipeline behavior was carried out in four areas. We analyzed three areas where data of the lateral displacement had been obtained and found the relationship between the average ground strain in the pipe axis direction and the ratio of pipeline extension in the pipe axis direction. Figure 13 shows the relationship between the average ground strain in the pipe axis direction and the ratio of pipeline extension in the pipe axis direction, which indicates there is a proportional relationship between the two.The ratio of pipeline extension was almost 50 % of the average ground strain. This means that slip occurred between the ground and the pipes. This result shows that the joint displacement equivalent to 50 % of the presumed ground strain should be considered when designing earthquake-proof pipelines in a place where there is some possibility of causing liquefaction.

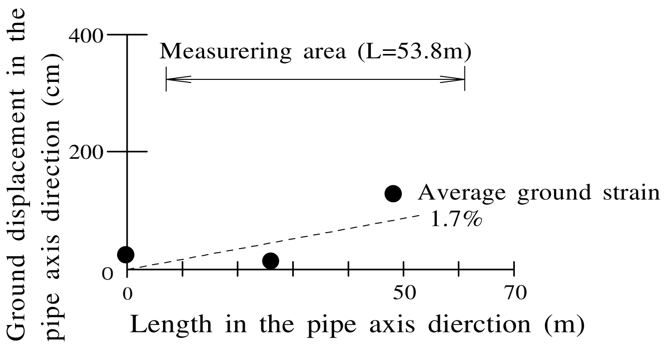


Figure 12 Calculation Method of Average Ground Strain in Pipe Axis Direction

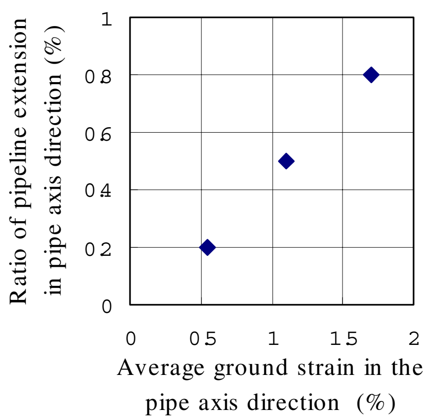


Figure 13 Relationship between Average Ground Strain and Ratio of Pipeline Extension

CONCLUSIONS

By the experiment using the large-sized laminar shear soil vessel and the on-site investigation on the pipeline behavior in the liquefied ground, the following results were obtained:

It turns out that use of collars in connection parts between structures enables pipelines to follow the ground subsidence, reduce the stress generated on pipe bodies, and could be an effective measure against liquefaction.

Under this test condition, the coefficient of subgrade reaction and the coefficient of friction between pipes and ground are estimated to be 5% of those in the normal ground condition.

The ratio of pipeline extension in the axis direction was almost 50 % of the average ground strain caused by the liquefaction. This result shows that the joint displacement equivalent to 50 % of the presumed ground strain should be considered when designing earthquake-proof pipelines in a place where there is some possibility of causing liquefaction.

Finally, we would like to express our deep appreciation to Director Nobuyuki Ogawa and Takahiro Minowa at the National Research Institute for Earth Science and Disaster Prevention of Science and Technology Agency for their guidance in the experiments.

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