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DEPENDENCE OF LONGITUDINAL SUBGRADE REACTION ON DISPLACEMENT VELOCITY AND CYCLES

MIO KOBAYASHI and HIROKAZU ANDO

Fundamental Technology Research Laboratory, Tokyo Gas Co., Ltd.,
1-16-25,Minato-ku, Tokyo, 105, Japan

ABSTRACT

Subgrade reaction is an important factor to analyze behavior of buried pipelines. It has generally been considered that the subgrade reaction is in proportion to the amount of one directional movement. However, strong earthquake occurs with large cyclic deformations. It should, therefore, be considered that effect of displacement velocity and cycles to subgrade reaction are taken into account. Shaking table test was carried out to examine the effect. The main conclusions are as follows.

In case of the plastic coated steel pipes of 150 and 300 mm diameters, there was no considerable dependence of longitudinal subgrade reaction on displacement velocity and cycles. No differences were observed in the result of the subgrade reaction regardless of different shaking conditions or the pipe diameters. The subgrade reaction reached its upper limit in the extent of the minimal displacement even in any shaking condition.

KEY WORDS

Buried pipes; shaking table test; subgrade reaction; dependence on velocity ; cyclic deformation ; Hyogoken-Nambu Earthquake

INTRODUCTION

To understand how buried pipes move during an earthquake, it is necessary to estimate the precise displacement of the buried pipes caused by heterogeneous movements at the ground. In estimation, we can calculate the interaction between the ground and pipes by using the subgrade reaction, that represents the spring-constant between the ground and pipes. When the relative displacement is minimal even in the reciprocal actions of the pipes and the ground, the subgrade reaction and the deformation of the ground in the vicinity of the pipes give a linear relationship. If the reciprocal actions are larger, slippage may occur between the ground and the pipes. In such the case we must consider the non-linearity in the deformation of the ground around the pipes.

We have therefore hypothesized what would happen during a large earthquake and have conducted an experiment using a shaking table to establish an evaluation method of the subgrade reaction. The method is based on the non-linearity of the subgrade reaction in the longitudinal direction caused by relative displacement, relative velocity in cyclic mode. This report discusses results of the experiment.

THE EXPERIMENT

Apparatus

We made the apparatus shown in Figure 1, and equipped measurement system. We conducted the experiment using a steel sand box of 1.2m depth, 1.8m length, and 1.9m width. We then buried steel pipes coated of polyethylene at a depth of 1.2m. Sand was compacted at the rate of higher than 95%. The characteristics of the sand are given in Table 1. Sort of the sand was usually used for backfilling, and we buried the pipe at the standard depth. The compatibility of the sand was slightly excessive; nevertheless, we accepted this compatibility to be on the conservative side.

Steel pipes of two different diameters were used: The first was 300mm (outer diameter Do = 318.5mm, wall thickness t = 6.9mm); the second was 150mm (outer diameter Do = 165.2mm, wall thickness t = 5.0mm).

To keep the confined pressure constant, we increased the rigidity of the sand box to prevent relative displacement of the sand. And we didn't set any apparatus such as place rubber on the inside of the box.

To evaluate precisely the subgrade reaction in the longitudinal direction, the pipes were laid horizontally. For preparatory measurement, we got horizontal displacements many times and set up the experiment so that the pipe was horizontal at an accuracy of 1mm or less. We measured the acceleration in the direction of Z, and also checked the horizontality of the pipes.

In the experiment, we first attached a load cell to either end of each pipe which was fixed to the reaction wall, and then produced relative displacement between the ground and the pipe by shaking the box. We set up the pipe fixing rig and other equipment paying close attention so that there would be no shifting of the rig in its fastened location or no locking of the shaking box in a direction of Y & Z.

As be shown in Figure 1, we placed a velocimeter, displacement meters and accelerometers in the sand box. We glued 24 strain gauges on the external surface of each pipe at every 45 degrees circumferencially, and then coated them with a polyethylene material. We then measured the subgrade reaction by the load cell. All dynamic measurements were recorded at 0.01-second intervals.

Table 1. Properties of the sand

Gs	Gravel(%)	Sand(%)	Silt,Clay(%)
2.72	0	96	4
Uc	Wopt(%)	C(kgf/cm^2)	internal friction angle(deg)
2.1	20.9	0.22	36.66

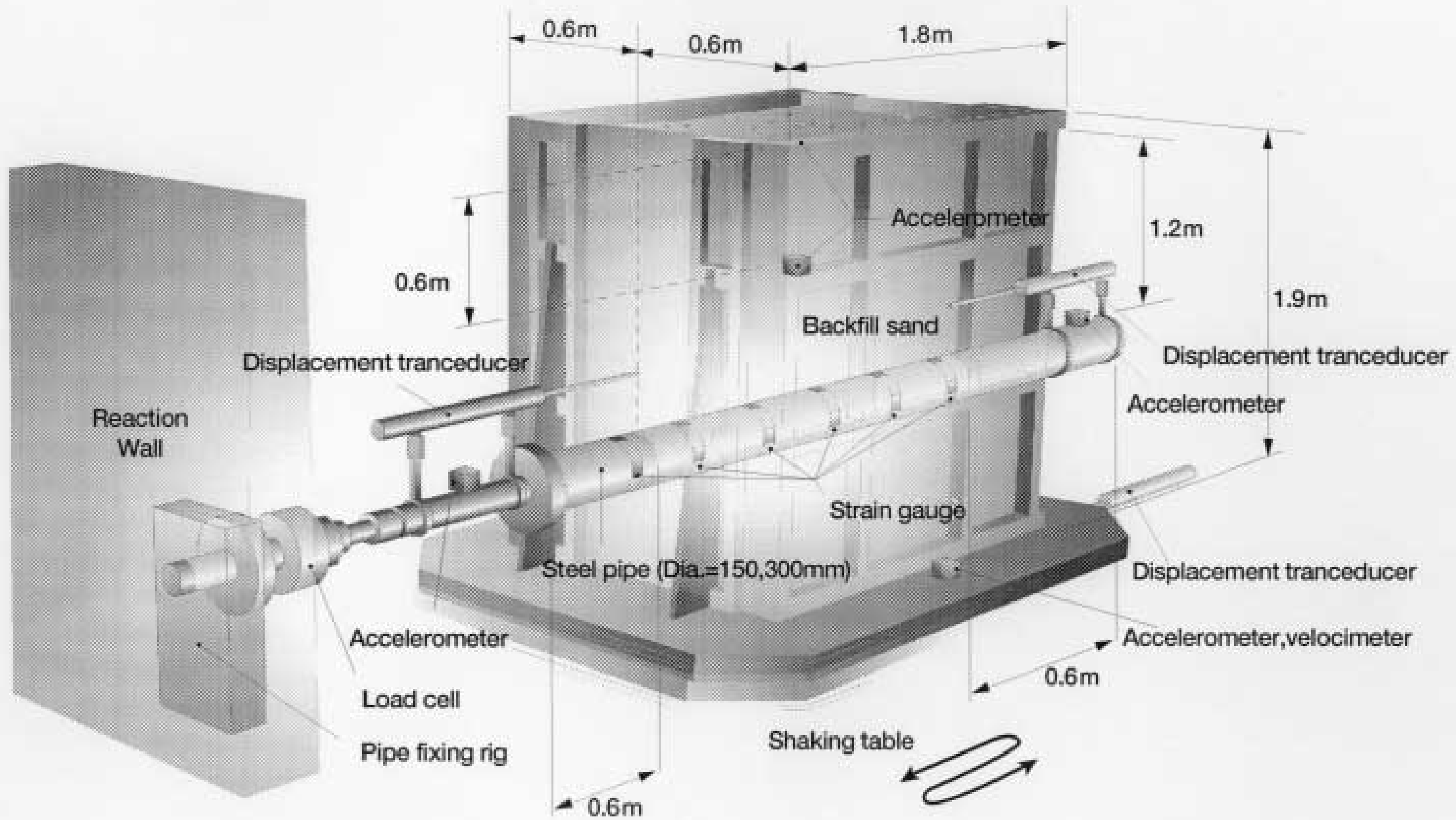


Fig.1. Experimental Devices.

Shaking Conditions

Table 2 shows the shaking conditions. During this investigation, we focused on the effects of the relative velocity (V), and the effects of cyclic ground movement on the subgrade reaction. We determined the influence of the relative velocity by changing the maximum velocity into 3 steps;- 50 kine, 5 kine, and quasi-static 0.5 kine. This change was made by sine waves with a constant displacement amplitude. We examined the effects of a random amplitude during actual earthquakes. According to three different experiments of the limited velocity, a constant amplitude and a variable amplitude, we understood that the characteristics of subgrade reaction appeared cyclically under various conditions.

We set the maximum amplitude of the tapering waves at 10mm and 100mm. As the waves of an actual earthquake, we selected the wave of NS directional components (maximum acceleration Amax = 258gal.) that was observed on the first floor of a building at Tohoku University during the Miyagiken-Oki Earthquake in 1978, and the wave of NS directional component (maximum acceleration Amax = 818gal.) that was observed at the Kobe Kaiyo Meteorological Observatory during the Hyogoken-Nambu Earthquake in 1995.

Both of these earthquakes caused immense damage to buried pipes, including gas pipelines. To reproduce the motions of both earthquakes as precisely as possible, we utilized a reproduction control system in the shaking table. As a result, we achieved wave forms with a maximum velocity of about 36 kine and a maximum displacement of 110mm for the Miyagiken-Oki Earthquake, and 76 kine and 120mm for the Hyogoken-Nambu Earthquake Both the velocity and the displacement of the waves of the actual earthquakes are different from those produced in the experiment. We however, judged, that this was acceptable for determining the subgrade reaction under the critical conditions, and used these conditions unchanged.

We set the confined pressure as a constant. In order to confirm this condition, we set up accelerometers in both the horizontal and vertical directions at the top and bottom of the ground. The conditions seemed to be satisfied because the observed values through this experiment varied little, like the behavior of rigid body was exhibited.

Table 2. Testing condition

Testing condition	Number of cases		Remarks
	300A	150A	
50kine	2	4	1Hz of sine wave ,Maximum100mm. Including the cases which conducted from compression side and after 25days.
5kine	1	2	0.1Hz of sine wave ,Maximum100mm.
0.5kine	1	2	0.01Hz of sine wave ,Maximum100mm.
Tapering wave	2	2	
Miyagiken-Oki Eq.	1	2	
Hyougoken-Nambu Eq.	1	-	

EXPERIMENTAL RESULTS

Dependency of Velocity and Shaking Conditions

It is necessary to compare the subgrade reaction under various shaking conditions while paying attention to its dependency on ground velocity. The subgrade reaction is given as F/ DL, where F is measured by the loadcell.

Figure 2 shows the results obtained at three different the maximum ground velocities (pipe diameter = 300mm). Even when we changed the ground velocity, we found that the value of the subgrade reaction remained nearly the same. We also found that the subgrade reaction reached its upper limit with minimal relative displacement. We confirm the same tendency in the results of diameter 150mm.

The experimental results obtained using the values of the actual seismic waves are given in Figure 3. The subgrade reaction was found to reach critical values with minimal displacement. There were no particular differences in this tendency even in the main displaced area where the greater amplitude of displacement appeared. Moreover, no differences were observed in behavior of the subgrade reaction associated with the two different seismic waves. As previously stated, although the maximum velocity of the seismic waves of the Hyogoken-Nambu Earthquake were about 2 times greater than that of the Miyagiken-Oki Earthquake, there were no differences in the behavior of the subgrade reaction. It is convinced that subgrade reaction is not dependent on the ground velocity.

Cyclic Characteristics

Figure 4 shows the relationship between the critical subgrade reaction and the number of cycle under shaking conditions. Because there were little difference between the pipes of the two diameter, we can discuss only the results of the 300mm-diameter pipe. The critical subgrade reaction have been normalized to the same maximum value found in the experiments of the various cycles.

It was found that the subgrade reaction had the maximum during the initial cycling in the experiment where a large amplitude was applied. It decreased to about 30% at the fifth cycle.

In the experiment where the tapering and earthquake waves were applied, subgrade reaction reached its maximum value after a number of cycles of minimal subgrade reaction. In this case, it as well fell to about 30% after about 10th cycle. Further investigation is required to understand why reduction of the subgrade reaction at tapering and earthquake waves slackened off relative to its behavior at constant amplitudes.

After completing the experiments in each case discussed so far, we again shook the pipes in the boxes, this time for a maximum of half a day, to confirm the recover of the subgrade reaction. The results from these experiments confirmed that the original subgrade reaction was not recovered and that the values again fell down to 25% as discussed previously.

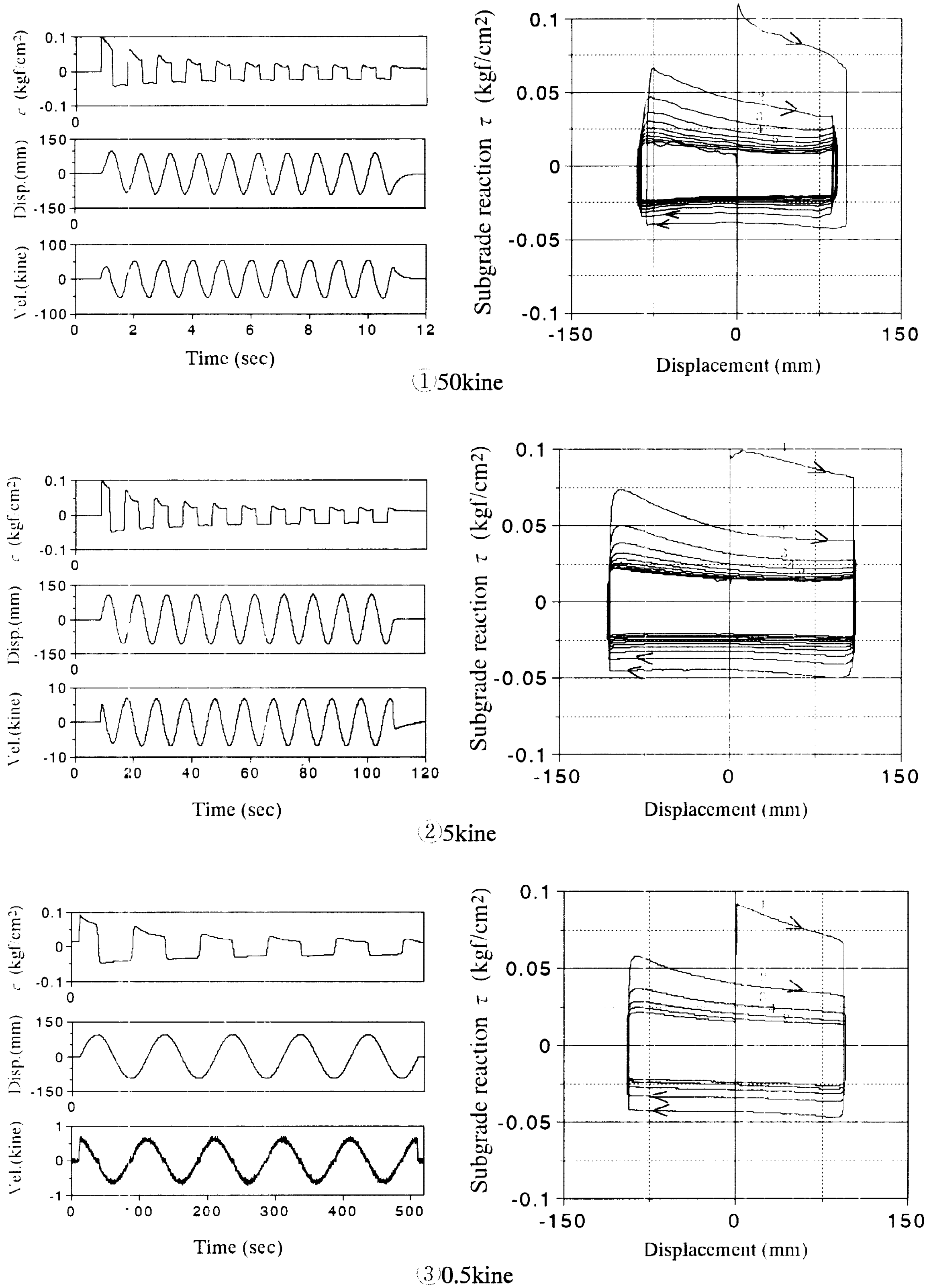
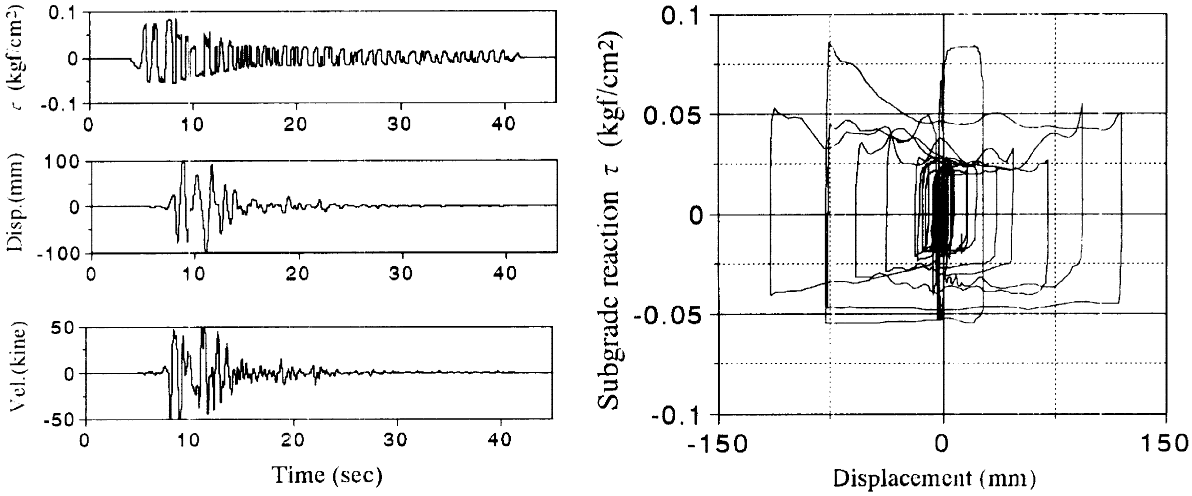
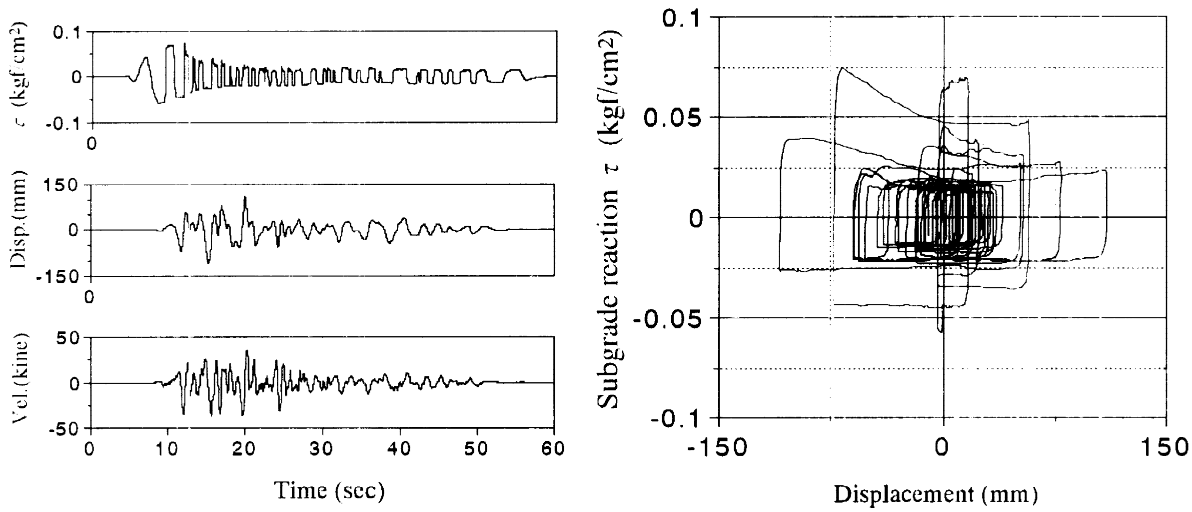


Fig. 2. Influence of relative velocity (pipe diameter = 300mm)



a)Hyougoken-Nambu Eq.



b)Miyagiken-oki Eq.

Fig.3. Experiment by earthquake wave

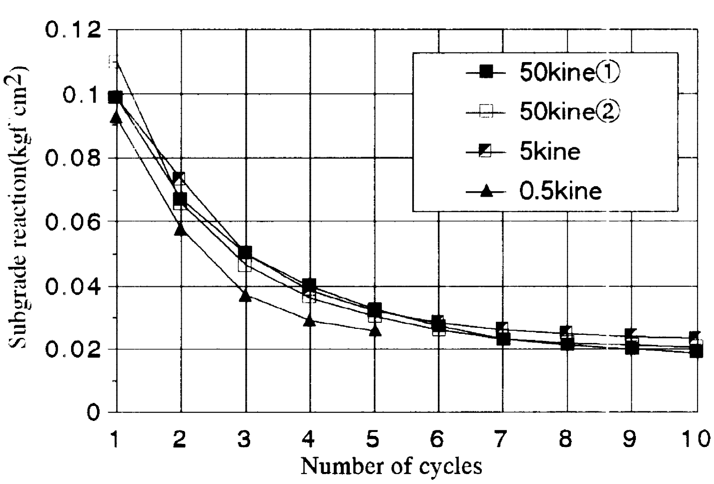


Fig. 4. Effect of velocity on subgrade reaction (pipe diameter = 300mm)

CONCLUSIONS

Regarding the subgrade reaction that acts in the longitudinal direction on buried pipes during an earthquake, we evaluated the characteristics of cycling and dependency on the ground velocity, using a shaking table test on two polyethylene-coated steel pipes of 300mm and 150mm diameters. The following results were clarified by our experiment:

We conducted two types of experiments: one in which we changed the maximum velocity and displacement amplitude with the sine waves, and another in which we applied random relative amplitude by using actual earthquake waves, including those recorded in the Hyogoken-Nambu Earthquake of 1995. In both of these experiments, no differences were observed in the behavior of subgrade reaction due to the shaking conditions or the pipe diameter.

Subgrade reaction was not dependent on the relative velocity of the ground and the pipe, and no differences were observed between the experimental results obtained at the tests of the maximum velocity of 50 kine and in the quasi-static state (0.5 kine). This was also confirmed in the experiments using the seismic waves of the two actual earthquakes where the maximum velocities are different.

Subgrade reaction was not dependent on the shaking conditions and reached its upper limit at an extremely small relative displacement less than 1mm between the ground and the pipe. At greater displacements, there was a tendency for the subgrade reaction to remain constant or to decrease gradually, and the subgrade reaction behaved almost as plastic, even when displacement occurred cyclically. Critical subgrade reaction was small, at approximately 0.1 kgf/cm^2. Using this value, we calculated the dynamic subgrade reaction between the sand and the polyethylene surface to be approximately 25% of the critical shear force of the sand.

Under all the shaking conditions, the subgrade reaction decreases as the cycle of the relative displacement between the ground and the pipe increases. It reduced at about 30% at the 10th cycle from the initial. It was confirmed through the experiment where shaking continued for approximately half a day that the subgrade reaction fell at every cycle and did not recover.

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