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DYNAMIC BEHAVIOR OF BURIED PIPE BEND WITH LIGHTWEIGHT THRUST RESTRAINT DURING LIQUEFACTION

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Abstract: At a bend in a pressure pipeline, thrust force is generated according to the bending angle and internal pressure. Generally a concrete block is used in such a bend in order to provide a lateral resistance. However, the thrust block is a weak point for an earthquake. Therefore, in our previous study, the lightweight thrust restraint using geogrids was suggested and lateral loading tests were carried out. The model tests confirmed that our proposed method was effective to increase the lateral resistance. However it is unknown whether the new method is stable during an earthquake.

In this study, four shaking table tests were conducted in order to verify the safety of the lightweight thrust restraint in liquefaction. In the tests, four types of model pipelines (200 mm) consisting of four short pipes and a bend (30 degrees) were used. In first test, a concrete block was used and in other tests, geogrids were attached to the bend. These model pipelines were backfilled in a large pit (6 m × 4 m × 1.4 m) with saturated loose sand. In third and fourth tests, gravel was used as a backfill material around the model pipeline. During the shaking table, the model pipelines were subjected to a lateral load (1.4 kN). Acceleration, lateral displacement of models, pore water pressure, earth pressure and tensile strains in geogrids were discussed.

It was revealed that a phase difference between the concrete block and the adjacent pipelines was caused. On the other hand, the difference was not seen in case of the lightweight thrust restraint. In addition, using gravel, the liquefaction wasn't caused and the lateral displacement of pipeline was restrained. It was concluded that the lightweight thrust restraint was sufficiently stable during an earthquake.

Keywords: geogrid, earthquake, seismic behaviour, pipeline, tensile strain, resistance

INTRODUCTION

Unbalanced force, which are called thrust force, act on bends of a pipeline depending on the magnitude of internal pressure and the bending angle. Thrust force acts on the bend outward and tend to move the bend. Generally passive earth pressure acting on the bend resists thrust force. If thrust force is larger than passive force, thrust restraint is required. Currently, a concrete block is usually installed at a bend.

However, it was reported that the concrete block was week point in earthquakes. In the Hokkaido-Nansei-Oki earthquake in Japan in 1993, the concrete block at a bend was largely moved in liquefied ground due to thrust force and adjacent pipe was slipped out as shown in Figure 1 (Mohri *et al*, 1995).

In our previous study, a lightweight thrust restraint using geogrids was suggested (Kawabata *et al*, 2005). In order to verify the effectiveness of the proposed method as thrust restraint, laboratory model tests and large-scale tests (Sawada *et al*, 2008) were carried out. From these results, it was found that the lateral resistance against thrust force increased and the lateral displacement was reduced in the proposed method.

However, it is unknown whether the proposed method is stable in liquefied ground. In this study, shaking table tests for buried bends were conducted at National Institute for Rural Engineering in Japan to verify the safety of the lightweight thrust restraint in liquefied ground.

Figure 1. Damage to buried bend in the 1995 Hokkaido-Nansei-Oki Earthquake

SHAKING TABLE TEST

Test Equipment

The shaking table used for the test has plane dimensions of 6 m × 4 m, with the maximum loading capacity of 50 tf. Its excitation system is a electro-hydraulic servo. The test pit (5.6 m length, 3.6 m width, and 1.4 m) was installed on the shaking table. Displacement transducers, pore water pressure transducers and accelerometers were laid out for observing the behaviour of the pipelines and the surrounding ground as shown in Figure 2. Moreover, strain gauges were attached on both faces of geogrids to measure tensile strain of geogrids.

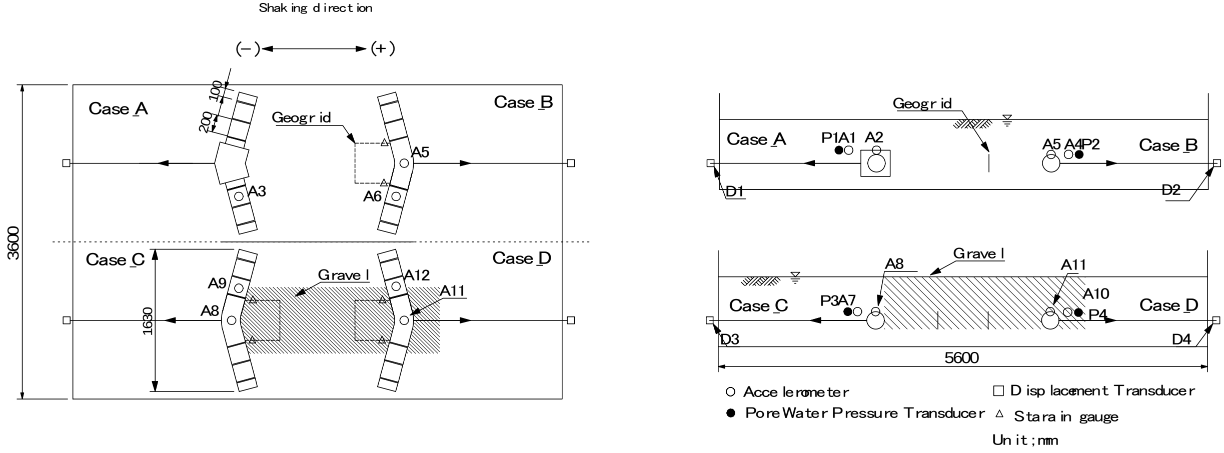


Figure 2. Schematic view for test

Model Ground

Kasumigaura-sand and gravel were used as the backfilled materials. The properties of Kasumigaura-sand are shown in Table 1. The grain size distributions of Kasumigaura-sand and the gravel are indicated in Figure 3. The ground was compacted every 0.1 m and the relative density (*Dr*) of the ground was 45 %.

Table 1. Properties of Kasumigaura-sand

Density of Soil Particle, ρ_s	2.715t/m^3
Maximum Dry Density, ρ_{max}	1.699t/m^3
Minimum Dry Density, ρ_{min}	1.387t/ m^3
Maximum Void Ratio, e_{max}	0.957
Minimum Void Ratio, e_{min}	0.627

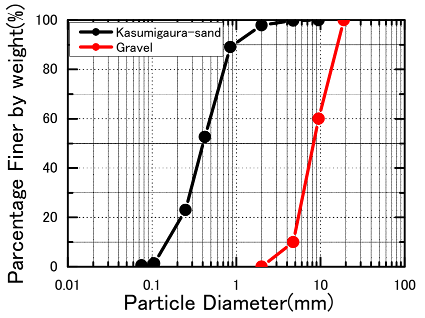


Figure 3. Grain size distributions

Test Conditions

The test conditions are indicated in Figure 2. Four model pipelines (CASE A~D) having a diameter of 200 mm were buried at a depth of 0.4 m. Pipelines consisted of a bend having an angle of 30° and short pipes. In CASE A, a concrete block was installed at the bend. In CASE B, C and D, geogrid was connected with the bend. In CASE C, gravel was used as the backfill material around geogrid. In CASE D, gravel was used around geogrid and the bend. Figure 4 shows the results of the tensile tests of geogrid.

Procedure of Experiments

After the ground was saturated from the bottom of the pit, the bend was laterally loaded at 1.4 kN. First, sine wave of 5 Hz with maximum acceleration of 300 gal was applied in horizontal direction as shown by Figure 2. Figure 5 shows the acceleration response on the shaking table. Next stage, sine wave of 5 Hz with maximum acceleration of 500 gal was applied.

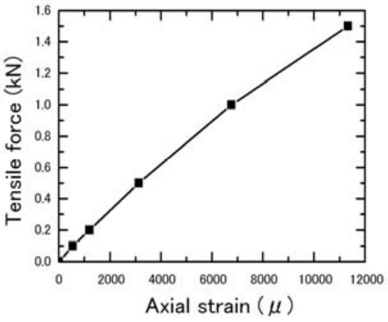


Figure 4. Result of tensile test

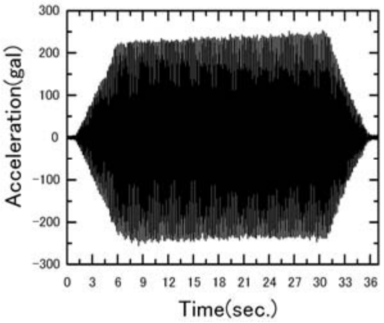
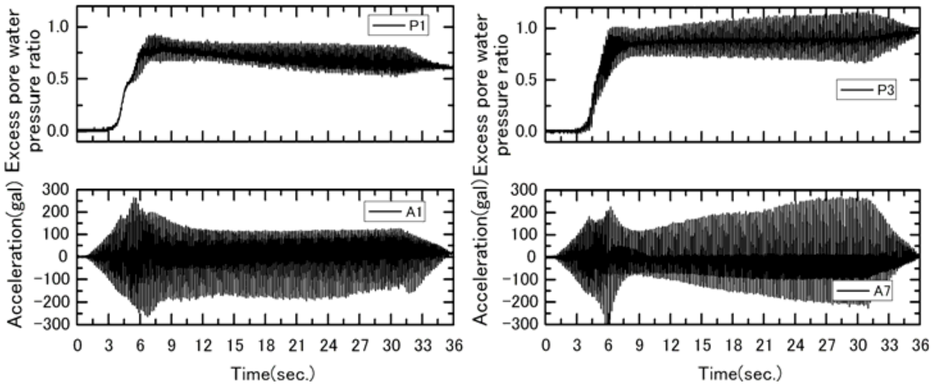


Figure 5. Acceleration of shaking table

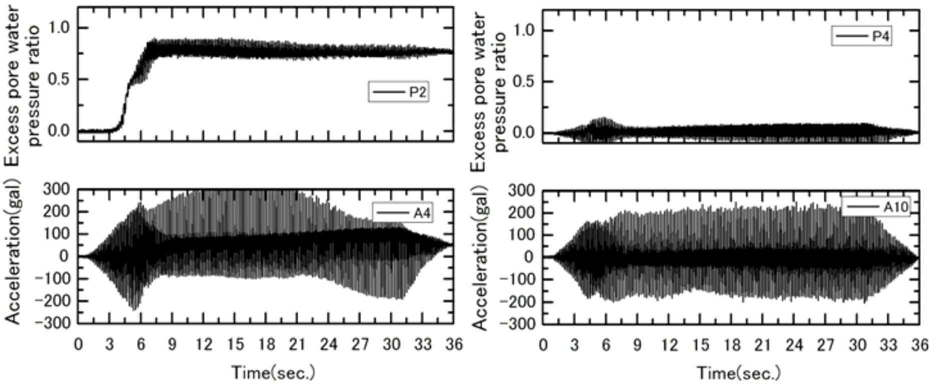
TEST RESULTS

Liquefaction of ground

Figure 6 shows the responses of the excess pore water pressure ratio and the acceleration response of the ground. The responses of the excess pore water pressure ratios of P1, P2 and P3 (See Figure 2.) increased from 4 sec. The amplitudes of the acceleration responses of A1, A4 and A7 increased from the start of the shaking and the amplitudes decreased from 6 sec. It is considered that these tendencies indicate that the ground liquefied. On the other hand, the amplitude of response of the excess pore water pressure ratio of P4 increased slightly from the start and decreased immediately. In addition, the amplitude of the acceleration response of A10 corresponded to the input wave as shown in Figure 5. These results indicate that the gravel did not liquefy.



(a) CASE A (c) CASE C



(b) CASE B (d) CASE D

Figure 6. Responses of excess pore water pressure ratio and acceleration response

Movement of pipe bend

Figure 7 shows the response of the lateral movement of the bend. The lateral movements of the bend in all cases increased from 3 sec. The lateral movements of the bend in CASE A, B and C increased largely from 6sec. when the ground liquefied as discussed in Figure 6. It is considered that this response was cause by the passive resistance reduction due to the liquefaction of the ground.

In comparison of the lateral movement of the bend in CASE A and B, the movement in CASE B was smaller than that in CASE A. The result indicates that the resistance against the lateral force was generated due to the geogrid. Furthermore, compared with the lateral movement of the bend in CASE B, the lateral movement in CASE C was extremely small. It is considered that the resistance against the lateral force increased due to the gravel around the geogrid. In addition, in comparison of the lateral movement of the bend in CASE C and D, the lateral movement in CASE D was smaller than that CASE C. It is found that the passive resistance did not reduced due to the gravel in front of the bend.

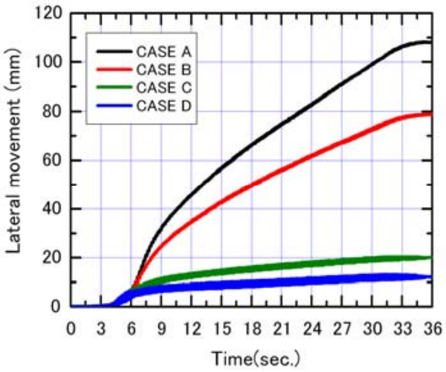


Figure 7. Response of lateral movement

Tensile force of geogrid

In the case of the proposed method, it is considered that the geogrid contribute to the increase of the lateral resistance against lateral force. The lateral resistance is equivalent to the tensile force in the geogrid. The tensile force was calculated from the tensile strain of both side of the geogrid as shown in Figure 2, using Figure 4.

Figure 8 shows the relationships between the lateral movement of the bend and the tensile force of the geogrid. The tensile force increased with the lateral movement of the bend. However, the tensile force in CASE B did not increased after the lateral movement of the bend approached 40 mm. It is considered that the friction between the geogrid and the ground was reduced due to the liquefaction of the ground. In comparison of the tensile force in CASE B, C and D, the tensile force in CASE C and D was larger than that in CASE B. It is considered that the friction in CASE C and D was larger than that in CASE B due to the gravel.

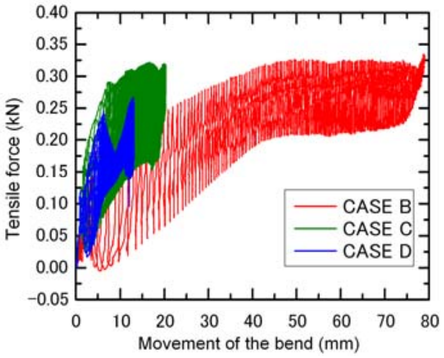


Figure 8. Relationships between lateral movement of bend and tensile force in geogrid

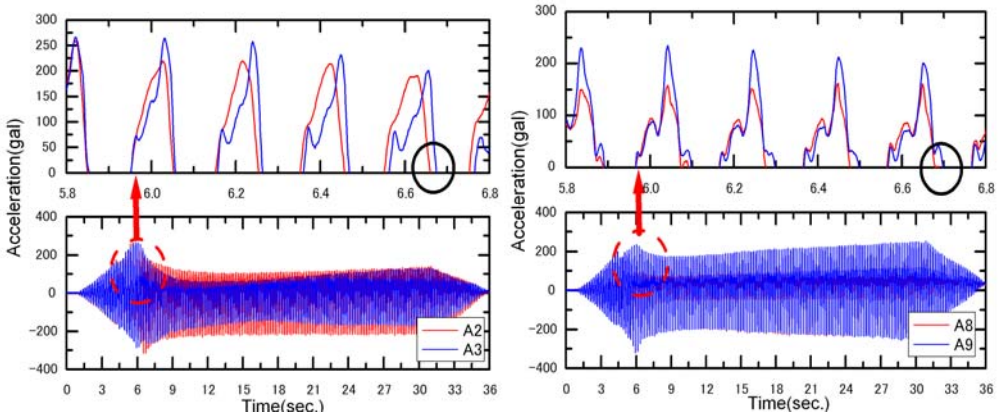
Phase difference between bends and adjacent pipe

Figure 9 shows the acceleration response of the bends and the adjacent pipe. In CASE A, the acceleration response of A2 was similar to the acceleration response of A3 before the ground liquefied as shown in Figure 9(a). The result means that the behaviour of the bend was similar to that of the adjacent pipe. The acceleration responses of A2 and A3 decreased from the about 6sec. due to the liquefaction of the ground.

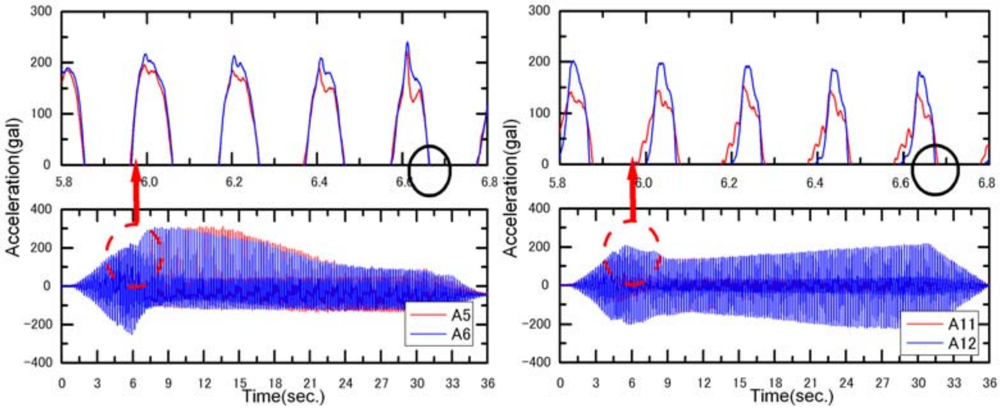
The acceleration response of A2 and A3 showed the phase difference during the liquefaction of the ground. In CASE B, the acceleration response of A5 corresponded to that of A6 as shown in Figure 9(b). The concrete block in CASE A was fifteen times as heavy as the bend in CASE B. Therefore, it is considered that the result was caused due to the difference of the inertia force (Mohri *et al*, 2000).

In CASE C and D, the phase difference occurred between the acceleration responses of the bend and the adjacent pipe during the liquefaction of the ground as shown in Figure 9(c), (d). The result was caused by the difference of the backfill material around the pipeline (See Figure 2).

It is considered that a pipeline could damage or a ground could fail due to the difference of the behaviour of the bend and the adjacent pipe in an earthquake. Judging from the result, it is found that the bend with the proposed restraint was more stable than the bend with the concrete block.



(a) CASE A (c) CASE C

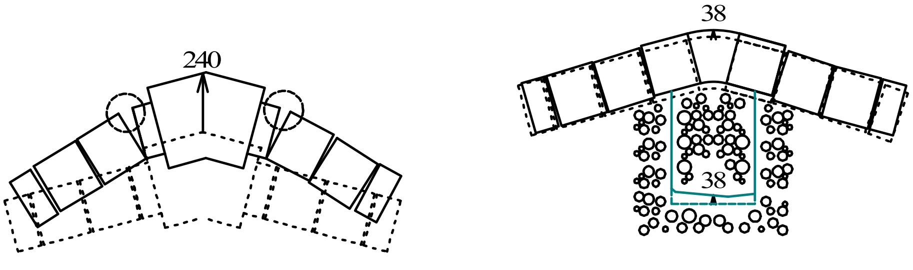


(b) CASE B (d) CASE D

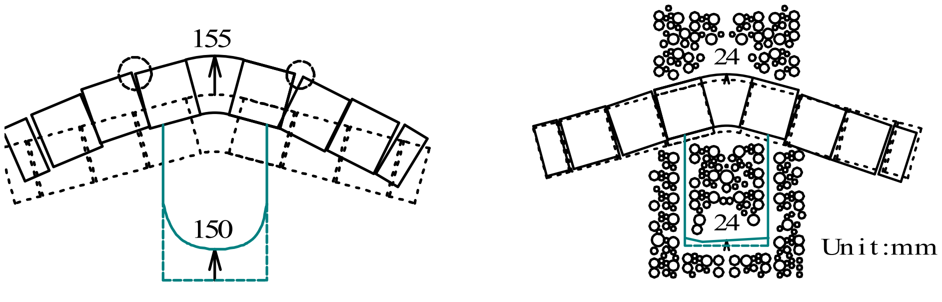
Figure 9. Acceleration responses of bend and adjacent pipe

Movement between bend and adjacent pipes

Figure 10 shows the movement of the pipelines after the shaking that the sine wave was applied with maximum acceleration of 500gal. The shapes of the pipelines before the shaking are illustrated in broken line, and the shapes of the pipelines after the tests are illustrated in solid line. In CASE A, the lateral movement of the concrete block was larger than that of the adjacent pipes. In compared with the difference of the movement between the bend and the adjacent pipes in CASE A, that in CASE B was small. Furthermore, in comparison of the difference of the movement in CASE B, C and D, the differences of the movement in CASE C and D were smaller than that in CASE B.



(a) CASE A (c) CASE C



(b) CASE B (d) CASE D

Figure 10. Movement of pipeline

CONCLUSIONS

A shaking table test was conducted in order to verify the safety of the lightweight thrust restraint in liquefaction. The following points were clarified from the test results:

- In CASE A with the concrete block, the lateral movement of the bend was large. On the other hand, in case of the proposed method using the geogrid and the gravel, it was extremely small.
- The phase difference occurred between the concrete block and the adjacent pipes during the liquefaction of the ground. Furthermore, the lateral movement of the concrete block was larger than the adjacent pipes. These results show that using a concrete block makes a weak point for pipeline.

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