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LATERAL LOADING TESTS FOR A NEW THRUST RESTRAINT TECHNIQUE USING LIQUEFIED STABILIZED SOIL WITH GEOSYNTHETICS

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Abstract: Thrust forces can be generated on the bend of a pipeline due to internal water pressure. Commonly, the thrust force is resisted by passive resistance acting on the bend. A concrete block can be installed at the bend when the thrust force is larger than the passive resistance. However, the heavy concrete block can become a weak point during an earthquake, because the concrete block moves largely due to inertia. Therefore, new methods for thrust restraint are required.

In this paper, new backfill methods for thrust restraint using geogrids are proposed. The new method comprised geogrids, installed in the passive area to improve the strength of the ground. In addition, liquefied stabilized soil blocks were installed within the passive area. In order to verify the effectiveness of the proposed methods, lateral loading tests were carried out using a model pipe with a diameter of 114 mm. The model pipe was backfilled with dry sand. After backfilling, the model pipe was laterally loaded at 0.5 mm/min. using a jack. The lateral resistance and lateral displacement acting on the model pipe were both measured. It was confirmed that the lateral resistance increased when using the proposed methods.

In addition, numerical analyses (Discrete Element Method) were performed to assess the mechanical behaviour of soil particles within the reinforced area. The modelling and analyses has shown that the new methods have helped to stabilise the soils within the passive area.

Keywords: pipeline, laboratory test, geogrid, reinforcing effect, stabilization, resistance

INTRODUCTION

Generally pipelines for irrigation purposes are subjected to internal water pressures. The bend in such pressure pipelines can be subjected to thrust forces depending on the pressure level and bending angle. The thrust force tends to move the bend of underground pipelines outward. Commonly, the thrust force is resisted by the passive resistance acting on the bend. A concrete block is normally installed at the bend when the thrust force is larger than the passive resistance. However, it is expected that such a heavy concrete block becomes a weak point during an earthquake as the concrete block moves largely due to inertia. In addition, the heavy concrete block induces local settlement in areas of soft ground.

For these problems, Kawabata *et al.* (2005) proposed a lightweight thrust restraint using geosynthetics and an anchor plate as shown in Figure 1. In the lightweight thrust restraint, three components of resistances, (1)Passive resistance acting on anchor plate, (2)Pull-out resistance of geogrid, (3)Passive resistance acting on bend can be expected. Sawada *et al.* (2008) conducted large scale tests using a pipeline (ϕ300mm) to investigate the effect of the lightweight thrust restraint for full scale pipes. It was confirmed that the resistance in the case of using the thrust restraint increased the passive resistance by 60 % compared to the case of the non reinforced pipe.

On the other hand, Kawabata *et al.* (2002) conducted a series of lateral loading tests for a rigid pipe (ϕ260) and a square object (260mm) buried in sand. It was revealed that the passive resistance of the pipe was approximately 65 % of that of the square object. In addition it was concluded that sand slipped on the surface of the top and/or bottom of the pipe judging from the lateral earth pressure distribution acting on the model pipe.

In this paper, new backfill methods using geogrid and liquefied stabilized soil for buried pipeline bend were proposed as shown in Figure 2. In the new methods, geogrid and liquefied stabilized soil were installed in the passive area to improve the strength of the ground. In order to verify the effectiveness of the proposed methods, lateral loading tests were carried out. In addition, in order to discuss the resistance mechanism of the new methods, numerical analyses using distinct element method (DEM) were performed.

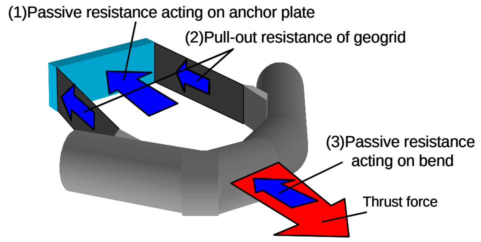


Figure 1. Light weight thrust restraint

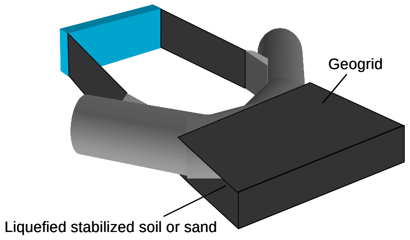


Figure 2. New backfill method

OUTLINE OF TESTS

Test apparatus

Figure 3 shows a schematic view of the test apparatus. For the tests, a medium sized rigid steel pit having a length of 1460 mm, width of 500 mm and depth of 500 mm was used. Greased sheets were used to reduce friction between the edge of the model pipe and the wall. A pipe bend was modelled by straight polyvinyl chloride pipe having a diameter of 114 mm. The geogrid used in the tests was manufactured from polyethylene.

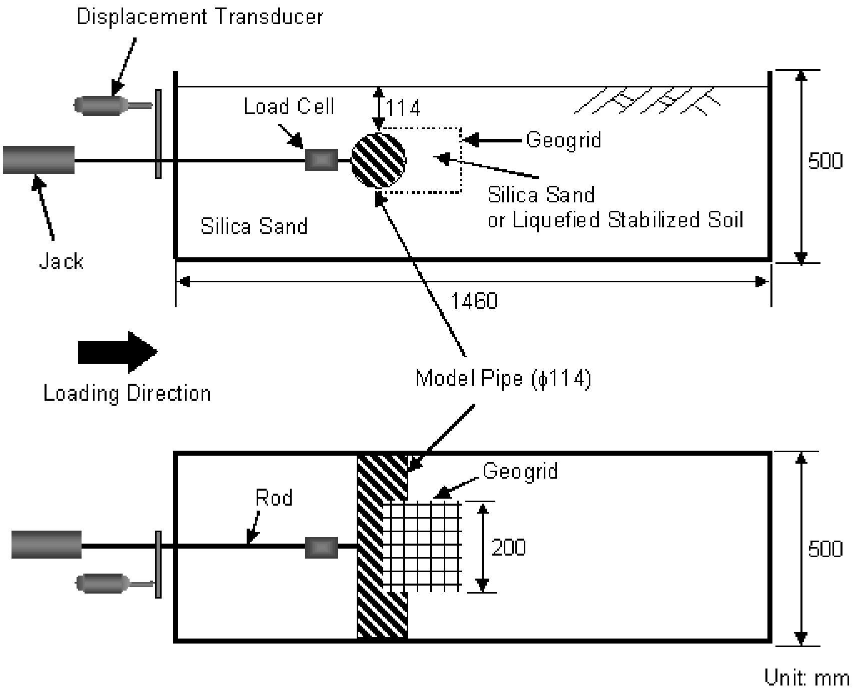


Figure 3. Schematic view of test apparatus

Backfill material

Dry silica sand was used as the backfill material. The properties of the silica sand are shown in Table 1 and the grain size distribution is indicated in Figure 4. In one of the test cases, liquefied stabilized soil block was installed in front of the model pipe. The unconfined compressive strength (q_u) of the liquefied stabilized soil block was 125 kN/m^2.

Table 1. Properties of silica sand

Density of soil particle, ρ_s [g/cm^3]	2.641
Minimum dry density, ρ_{min} [g/cm^3]	1.232
Maximum dry density, ρ_{max} [g/cm^3]	1.575
Maximum void ratio, e_{max}	1.143
Minimum void ratio, e_{min}	0.676
Internal friction angle, ϕ [deg.]	39.8
Cohesion, c [kN/m^2]	0

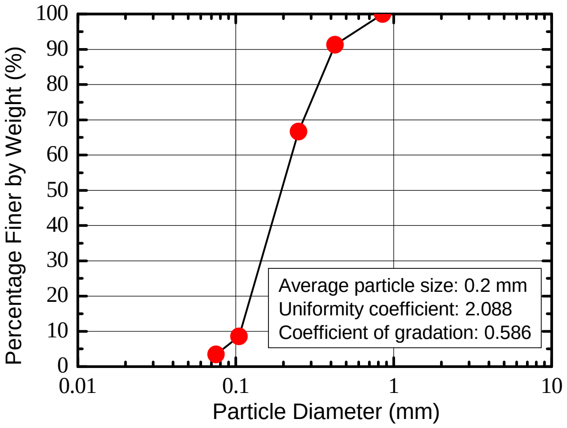


Figure 4. Grain size distribution

Test Procedure

The thickness of the foundation bed was 193 mm. The model pipe was installed in dry sand. The ground was compacted with a hand compactor every 50 mm of thickness. The relative density of the ground was approximately 95 %. After backfilling, the load was applied by a screw jack at 0.5mm/min. The lateral displacement of the pipe and the lateral resistance were measured with a displacement transducer and a load cell as shown in Figure 3.

Test cases

Three test cases were carried out as shown in Figure 5. For Case-A, the passive area in front of the model pipe was not reinforced. For Case-B, the passive area was reinforced by geogrid. For Case-C, liquefied stabilized soil block with geogrid was installed at the passive area.

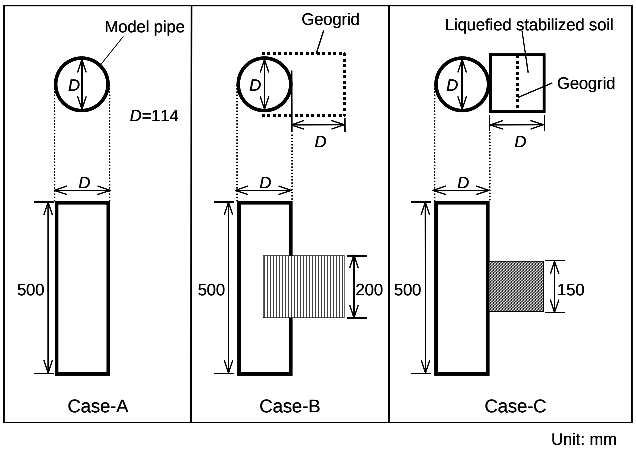


Figure 5. Test cases

OUTLINE OF NUMERICAL ANALYSIS

Analytical model

In order to clarify the resistance mechanism of the proposed methods, numerical analyses by two dimensional DEM were performed. Figure 6 shows the analytical model. To model the backfill material, approximately 20,000 particles were used. The parameters are shown in Table 2. The buried pipe was modelled using a polygonal element suggested by Nakase *et al.* (2001). In addition, a trussing polygon of 20 sides incorporating the polygonal element was applied to the frame of the model pipe. The spring constants were determined on the assumption of the rigid pipe. Geogrid was modelled by tying the soil elements together with springs. In order to determine the parameters for the geogrid model, pull-out experiments were simulated by DEM (Table 3). In the analysis, the pipe was displaced at a speed of 10 mm/sec.

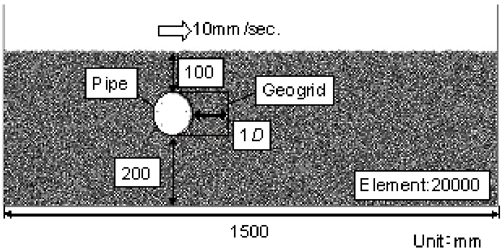


Figure 6. Analytical model

Table 2. DEM parameter for sand

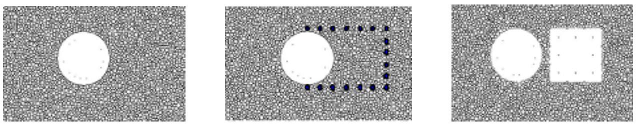
Average diameter	6.0E-03 (m)
Uniformity coefficient	1.52
Element density	2.4E+03 (kg / m^3)
Normal spring coefficient	8.0E+07 (N / m)
Tangential spring coefficient	2.0E+06 (N / m)
Normal damping coefficient	7.3E+02(N·s / m)
Tangential damping coefficient	1.9E-02 (N·s / m)
Friction angle between elements	24.0 (deg.)
Rolling friction angle	24.0 (deg.)
Time increment	1.0E-06（s）

Table 3. DEM parameter for elements of geogrid

Diameter	6.0E-03 (m)
Element density	2.4E+03 (kg / m^3)
Normal spring coefficient	8.0E+06 (N / m)
Tangential spring coefficient	2.0E+05 (N / m)
Normal damping coefficient	1.1E+03(N·s / m)
Tangential damping coefficient	4.2E-02 (N·s / m)

Analysis Cases

Three cases of analysis were carried out within densely compacted ground. These cases are shown in Figure 7.



CASE-1 CASE-2 CASE-3

Figure 7. Analysis cases

RESULTS AND DISCUSSION

Results of tests

Lateral resistance

Figure 8 shows the relationships between the lateral resistance and the lateral displacement for each test case. Figure 8 shows that the lateral resistance increases with the horizontal displacement and peak resistance is generated in each case. By comparing Case-A and Case-B, the lateral resistance of Case-B is larger than that of Case-A. It can be considered that the failure of the ground was suppressed by the geogrid. In addition, the peak resistance of Case-C is larger than that of Case-B although the residual resistance is smaller. From the result, it is found that the liquefied stabilized soil block behaved like a rigid body to 8.5 mm of the lateral displacement.

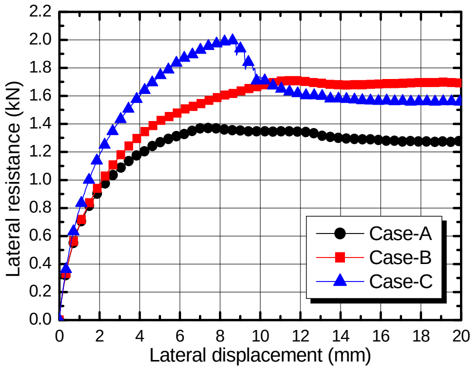
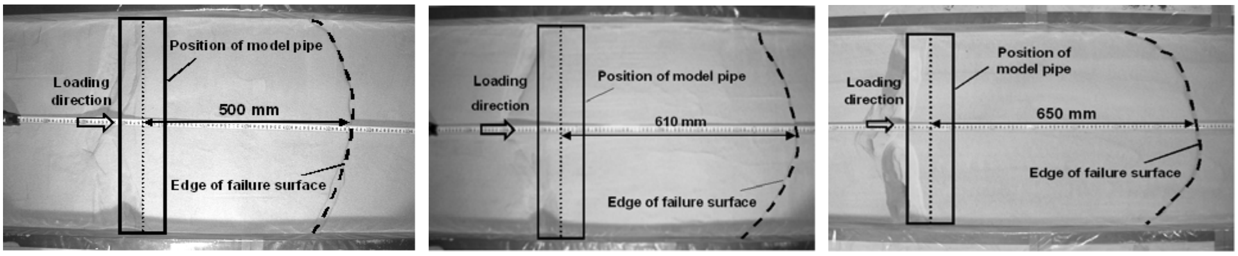


Figure 8. Relationships between lateral resistance and lateral displacement in tests

Observation of ground surface

Figure 9 shows the ground surface at 20mm displacement of the model pipe. The positions of the model pipe, the loading direction and the front edge of the failure surface are illustrated in each case. In Case-A, the front edge of the failure surface was observed 500 mm from the centre of the model pipe. The front edge of the failure surface in Case-B was observed 610 mm from the centre of the model pipe and in Case-C, the value was 650 mm. In addition, the edge of Case-C bulges to a greater extent in comparison to that of Case-A. From the results, it is assumed that the reinforced area in front of the model pipe in Case-B and Case-C acted as a composite body of reinforced soil. Thus, as mentioned above, the lateral resistance of Case-B and Case-C was increased in comparison to that of Case-A.



Case-A Case-B Case-C

Figure 9. Ground surface

Results of analysis

Lateral resistance

Figure 10 shows the relationships between the lateral resistance and the lateral displacement in the DEM analysis. From Figure 10, the peak resistance is generated in each case. In CASE-1, the peak resistance is about 2.9 kN at 5.5 mm. In CASE-2, that is about 4.9 kN at 10.2 mm. Thus, the peak resistance of CASE-2 is approximately 1.7 times that of CASE-1. By comparing CASE-1 and CASE-3, the peak resistance of CASE-3 is approximately 1.93 times that of CASE-1. From the results, it is understood that the liquefied stabilized soil block is an effective material to act against the lateral force.

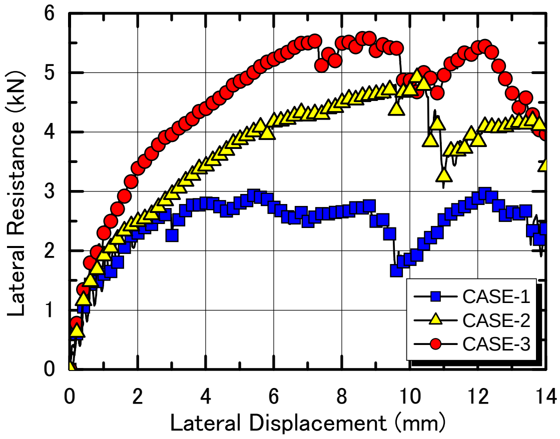


Figure 10. Relationships between lateral resistance and lateral displacement in analysis

Contact forces between particles

Figure 11 shows normal contact forces between particles for an 8mm displacement. In CASE-1, the contact forces progress from the front of the pipe within about 45 degrees from the spring line. On the other hand, in CASE-3, the contact forces progress from the lateral side of the liquefied stabilized soil block. In addition, it is apparent that the contact forces in CASE-2 and CASE-3 are widely distributed in comparison to that in CASE-1. It is shown that the passive area of the ground is improved due to the reinforcement.

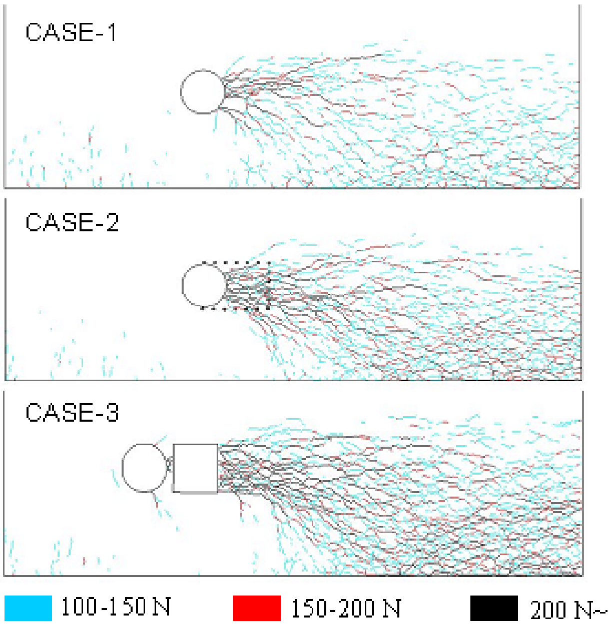


Figure 11. Normal contact force between particles

Shear strain of ground

Figure 12 shows the shear strain of the ground for an 8mm displacement. In CASE-1, the large shear strain is generated from the lateral side of the pipe obliquely upward. It is thought that this large shear strain of the ground is the failure surface. It can be seen that the length between the front edge of the failure surface and the pipe in CASE-2 and CASE-3 is large in comparison to that in CASE-1. In addition, for CASE-2 and CASE-3, the shear strain of the reinforced area is comparatively small.

Judging from the discussion above, it is assumed that the ground of the reinforced area acts as a reinforced composite body. This composite soil body contributed to the increase of lateral resistance.

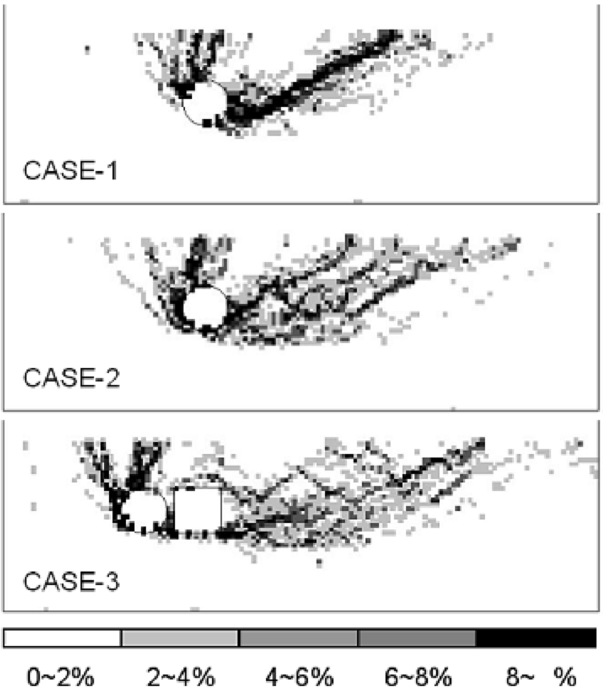


Figure 12. Shear strain of ground

CONCLUSIONS

In this paper, new backfill methods for increasing the passive resistance of a pipe bend were proposed. In order to verify the effect of the proposed methods, lateral loading tests were conducted. In addition, numerical analyses using distinct element methods were performed to further analyse the resistance mechanism. Conclusions are described as follows.

- Lateral loading tests were carried out to clarify the effect of the reinforcement. It was confirmed that by introducing reinforcement the lateral resistance was larger than that of the case of non-reinforcement. From the results, it was verified that the new methods have advantages for the increase of the lateral resistance against thrust force. In particular, the liquefied stabilized soil appeared to be an effective material.
- In order to discuss the resistance mechanism of the proposed methods, numerical analyses were performed. It was concluded that the composite effect of the reinforcement and soil contributed to an increase of the lateral resistance.

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