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Field test of a pipeline buried at shallow depth with a geogrid

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ABSTRACT: This paper presents an experimental study of the performance of buried pipeline in which geogrid reinforcement was used with the pipeline at a shallow depth. Regarding the underground structure, they may be uplifted by groundwater buoyancy. To avoid this phenomenon, pipe must be buried with deep cover depth. The material around the shallow embedded pipeline is confined with geogrid wrapping. The effectiveness and unification of geogrid and gravels were confirmed in some laboratory test. In this paper, stability of shallow cover method with geogrid was confirmed at actual 2,800 mm pipeline in one-year measurement. The measured results have clearly confirmed the stability of pipeline installed at shallow depth along with geogrid cover.

1 INTRODUCTION

Underground structures, such as pipelines, are subjected to buoyancy of groundwater and have risk to be uplifted. To avoid its uplifting, countermeasure work must be considered. Most of pipelines were buried with deep cover of depth in order to get sufficient overburden weight. The weight of soil just above pipe can be considered as counter weight against uplifting. The designs are usually carried out by considering force equilibrium between the prism load and buoyancy. However, during earthquake, larger buoyancy would act on the pipe due to lique-faction. Many underground structures had been uplifted due to liquefaction of surroundings foundation in past earthquakes.

We have developed a new construction method named "shallow cover method with geogrid" for pipeline execution with geogrid for countermeasure against uplifting caused by buoyancy of underground water. The method is to wrap the gravel by geogrid unified with soil and pipeline (Fig. 1.1). Fig. 1.2 shows the force mechanism involved in the shallow cover method. The forces which resists the buoyancy are the weight of gravel, W_{1-2} and W_2 (unified by geogrid) and the backfill soil above the geogrid, W_{1-1} and W_3. Fig. 1.3 shows the construction procedure of shallow cover method, while Fig. 1.4 shows the photo taken during installation of pipe and geogrid during actual construction.

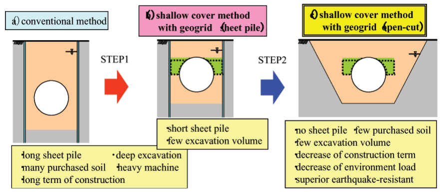

Figure 1.1 Outline of shallow cover method.

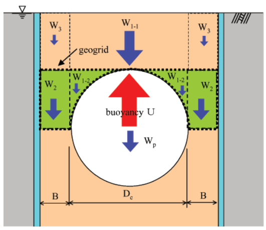

Figure 1.2 Forces involved in shallow cover method.

2 BEHAVIOR DURING LIQUEFACTION

To confirm the effectiveness of shallow cover method with geogrid during earthquake, shaking table test were conducted. The results of the displacement vector for surrounding soil measured during shaking by PIV analyses are shown in Fig. 2.1 and Fig. 2.2 respectively for conventional (TEST1) and shallow cover method (TEST2). PIV (Particle Image Velocimetry) analyses

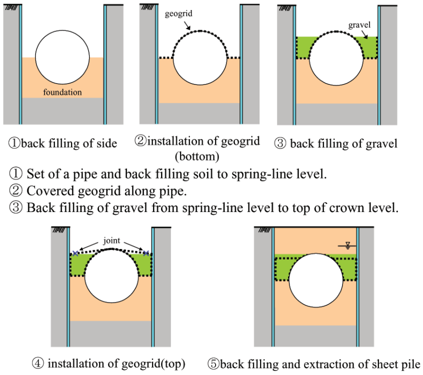

Figure 1.3 Figure showing the construction procedure.

Figure 1.4 Installation of pipe and geogrid during construction.

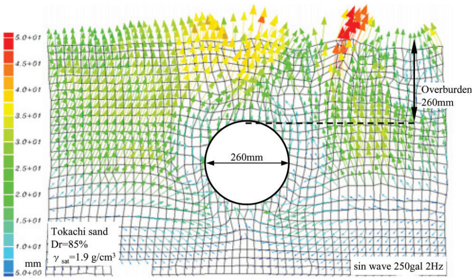

Figure 2.1 TEST1 (Conventional method).

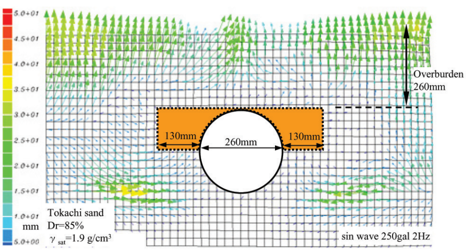

Figure 2.2. TEST2 (Shallow cover method with geogrid).

were performed using GeoPIV which is developed by D.J. White and etc (D.J. White, 2001). In TEST1, large displacement of soil was observed. Just after liquefaction, surrounding soil moved along the pipe surface, from the crown to bottom, which ultimately results in uplifting of the pipe to the ground surface. On the other hand, for TEST2, the uplift displacement of pipe did not occur just after liquefaction. It seems that the weight of gravel wrap with geogrid provided sufficient counter weight and also block the way for the surrounding soil to moves at the bottom of pipe thereby preventing concentration of uplift pressure at the bottom of the pipe. These results depict that in comparison to the conventional method, shallow cover method is a superior earthquake-resistant method for pipeline execution and is more effective in preventing deformation and uplift of pipe and ground deformation during the earthquake.

3 OUTLINE OF FIELD TEST

3.1 *Installation and instrumentation of pipe*

Fiber Reinforced Pipe with Mortal (FRPM), 2,800 mm in diameter, was installed in test field, in FUKUI prefecture, Japan. Fig. 3.1 shows the cross section of the pipes and layout of transducers of the field test. Pipeline was buried with 1.5 m cover of depth. Gravel was used for backfilling around the pipe, whereas excavated soil was used as a backfill material for upper part of the pipe. Table. 3.1 shows material data of gravel, sand and excavated soil.

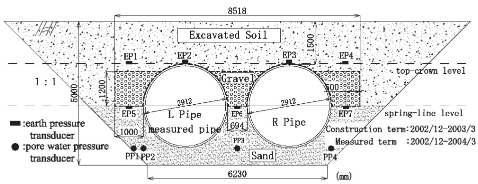

Figure 3.1 Cross section and layout of transducers

Table 3.1 Material data of gravel and sand.

	Maximum dry density	Dry density	Degree of compaction
Gravel	1.991 g/cm^3	1.808 g/cm^3	90.8%
Sand	1.633 g/cm^3	1.501 g/cm^3	91.9%
Excavated soil	2.083 g/cm^3	2.126 g/cm^3	102.1%

3.2 *Characteristic of geogrid*

Figure 3.2 shows the geogrid (manufacture $T_{max} = 36$ kN/m) that was used as a countermeasure against uplifting in the field test, while it's tensile stress-strain curve is shown in Fig. 3.3.

3.3 *Measurement details*

(1) Deformation of pipe (Flexure of pipe)
To evaluate the deformation of pipe (flexure), the vertical and horizontal deformation of pipe were measured during the construction. The measured locations are shown in Fig. 3.4.

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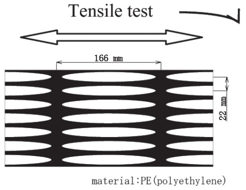

Figure 3.2 Geogrid.

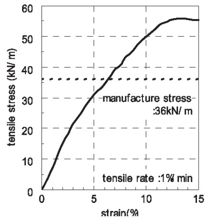

Figure 3.3 Stress-strain curve of geogrid.

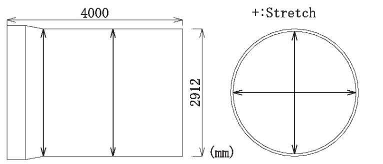

Figure 3.4 Measured position for flexure deformation of pipe.

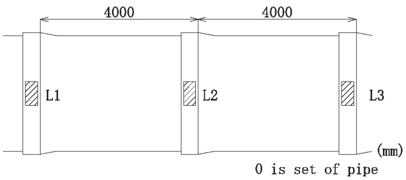

Figure 3.5 Measured position for uplift and settlement of pipe (L Pipe).

(2) Displacement of top crown pipe
Settlement and uplifting of pipe was measured at the top crown of pipe. Fig. 3.5 shows measured position.

(3) Ground water level and Earth pressures
Pore water pressure transducers (PP1-PP4) were installed around the pipe for measuring the ground water level. Also, soil pressure distribution along the top geogrid surface which confined the gravels by geogrid were confirmed by measuring earth pressures that acts on gravel. Fig. 3.1 shows measured position.

(4) Tensile strains of geogrid
Regarding the performance of geogrid, tensile strains were measured on the geogrid. Stresses were estimated from strain measured by strain gauges. Figure 3.6 shows measured position.

And also Table 3.2 shows construction process.

4 RESULT AND DISCUSSIONS

4.1 *Deformation of pipe (Flexure of pipe)*

Figure 4.1 shows deformation of both L and R pipes from installation stage to completion of construction. Both pipes have maximum vertical oblong deformation

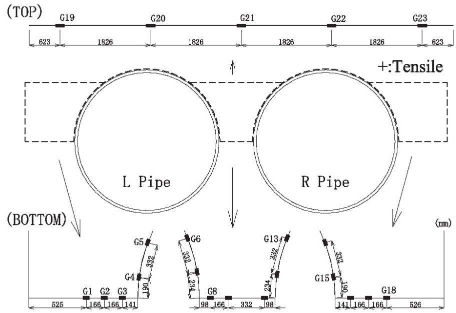

Figure 3.6 Measured position of strain gauges.

Table 3.2 Construction procedure.

Set of a pipe	0 day
Backfilling to spring-line level (Set of geogrid)	4 day
Spring-line level + 1.2 m (Joint of geogrid)	6 day
Backfilling to top-crown level + 0.6 m	12 day
Backfilling to top-crown level + 0.9 m	45 day
Completion of construction	108 day
Measurement long-term	~450 day

due to horizontal earth pressure when backfilling to top-crown level. Further backfilling above the top-crown level results in the horizontal deformation that range from 2-6 mm due to over burden weight. However, the flexure deformation of pipes were within 1% (28 mm) of pipe's diameter. These deformation patterns are in a safe range compared with design standards (3%, 84 mm).

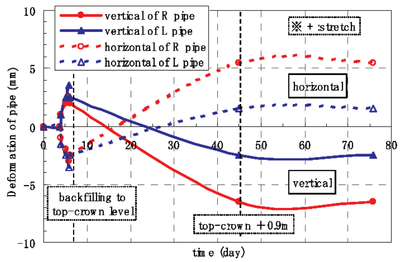

Figure 4.1 Flexure deformation of pipe (Flexure of pipe).

4.2 *Displacement of pipe and ground water level*

Figure 4.2 shows displacement of pipe and variation in ground water level during and after construction. Displacement of pipe during construction, by load of backfilling, was 14-18 mm; where as the overall displacement from start to end of construction was 20-25 mm. These values are smaller than conventional method. This settlement restraint effect was due to decrease of vertical load by shallow cover method with geogrid and unification of backfilling material (gravel) by geogrid. The variation in groundwater level was also small during and after construction.

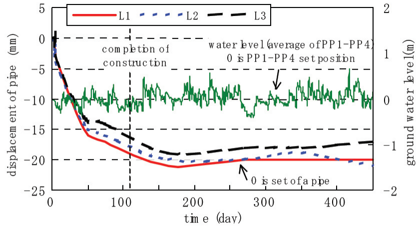

Figure 4.2 Displacement of pipe and ground water level.

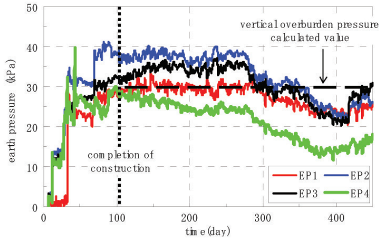

Figure 4.3 Time histories of earth pressure transducers, EP1-EP4.

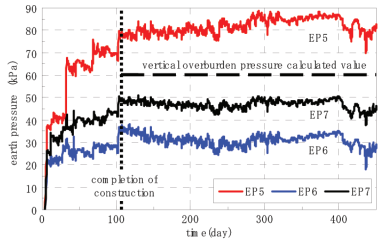

Figure 4.4 Time histories of earth pressure transducers, EP5-EP7.

4.3 *Earth pressures*

Figure 4.3 and Fig. 4.4 show the time histories of earth pressures transducers, EP1-EP7. It may be seen that after completion of construction, earth pressures above the pipe (EP1-EP4) was nearly equal to vertical overburden pressure. These pressure conditions were enough to resist the uplift caused by buoyancy of underground water. Also, at top crown level, the measured earth pressure values (EP1-EP4) were 0.6-1.0 times smaller than the calculated value (30 kPa) in 450 day. On the other hand, at spring level, the measured earth pressure values (EP5-EP7) were 0.6-1.3 times larger than the calculated value (60 kPa) in 450 days with the minimum earth pressure between pipes (EP6). These results indicate that this pipeline is stable enough to withstand the uplifting effect caused by buoyancy of underground water.

4.4 *Tensile strains of geogrid*

Figure 4.5 shows tensile strains of geogrid during different stages of construction. Along the side of the pipes (G5, G6, G13), large strain were developed during installation of geogrid and at the beginning of construction. Especially the strain gauge, G6 showed more than 2,500 $\times 10^{-6}$ strain. It may be due likely to back filling and compaction of gravels at these parts of geogrid. When the backfilling is further continued from the top crown level, the pipe deformed horizontally, due to increasing overburden pressure, as a result the side part of the geogrid tend to relax and strain values drops a little. However, the change was not significant. Large strains were also developed in the top part of the geogrid (G19-G23) during construction stage and tensile stress increases as overburden increases. Moreover, the geogrid strain at top of the pipe was larger than other part of geogrid during construction. After construction, strain of geogrid almost remain constant. Maximum value of strains that were recorded from backfilling stage to the compaction of top-crown were respectively about 3,000 $\times 10^{-6}$ and 6,000 $\times 10^{-6}$ strain in side and top of the pipes. Stresses of geogrid calculated from these values, using stress-strain curve (Fig. 3.3), were about

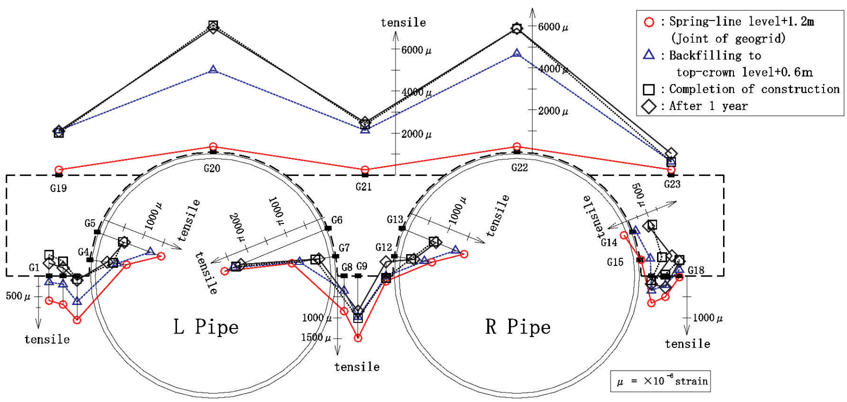

Figure 4.5 Tensile strains of geogrid during different stages of construction.

2-4 kN/m. This value is more-or-less 1/10 times smaller than the rupture strength of geogrid (12%). These results clearly indicate the effectiveness of shallow cover method against uplifting. Geogrid can also be stretched during construction for more safety.

5 CONCLUSION

From the discussion made in this paper, it can be concluded that the pipe line constructed with shallow cover method was safe and stable enough against the possible uplift due to buoyancy of under-ground water both during construction and after construction.

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