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Pullout tests of geogrid embedded in cement-mixed gravel

Watanabe, K. & Tateyama, M.
Railway Technical Research Institute, Kokubunji-shi, Tokyo, Japan

Uchimura, T.
Univ. of Tokyo, Bunkyo-ku, Tokyo, Japan

Yonezawa, T. & Aoki, H.
Japan Railway construction Transport and Technology Agency, Japan

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ABSTRACT: Cement-mixed well-graded gravel has recently been one of the popular ground improvement to construct a backfill of bridge abutments, which allows only a limited deformations. Since the backfill is reinforced by Polymer geogrid and connected to the abutment, the backfill is much stable against seismic load and does not apply external force. For this reason, the abutment can be slenderer than conventional RC bridge abutment. The role of the geogrid arranged in backfill is to prevent the development of crack and ensure the connection between the abutment and backfill. However, the behavior of geogrid embedded in comparatively harder cement-mixed gravel have not been understood in detail yet. In this study, therefore, pullout tests of geogrid were performed. The experiment revealed that bonding strength between cement-mixed gravel and geogrid was sufficiently high and pullout displacement was not largely affected by the confining pressure or quality of cement-mixed gravel. The active length of tension was found to increase by applying cyclic loading or creep loading, but it didn't exceed about 300 mm from the end of the geogrid.

1 INTRODUCTION

Cement-mixed gravel is often used as the backfill material for important permanent structures, such as bridge abutments for railway, requiring a sufficiently high stability while allowing a limited deformation. Figure 1 is a schematic diagram of the first bridge abutment of this type for a bullet train railway constructed in Kyushu (Aoki et al. 2005). For this type of bridge abutment, the cement-mixed gravel backfill is much stable against seismic load and does not apply external force such as seismic earth pressure to the abutment. Further, since the abutment is connected to the backfill by reinforcement (Polymer geogrid), the backfill could laterally support the bridge abutment during earthquake. For this reason, the abutment can be substantially slenderer than conventional RC bridge abutment.

In order to validate the seismic performance, a lateral load was applied to the abutment shown in Figure 1 (Aoki et al. 2005). This field test revealed that the lateral displacement of the abutment against large intensity of loading was remarkably small.

The role of the geogrid arranged in backfill is to prevent the development of cracks in the backfill and to ensure the connection between the abutment and backfill. However, the behavior and interaction of geogrid embedded in comparatively harder cement-mixed gravel have not been understood in detail yet. With these points taken into consideration, pullout tests of the geogrid embedded in the cement-mixed gravel were performed in this study.

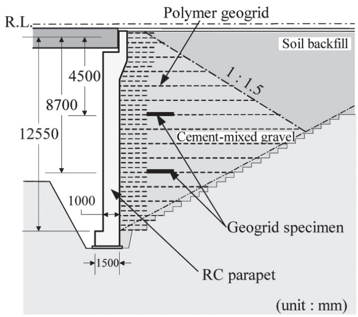


Figure 1. Typical bridge abutment with geogrid-reinforced backfill of cement-mixed gravel.

2 TESTING APPARATUS AND SAMPLE PREPARATION

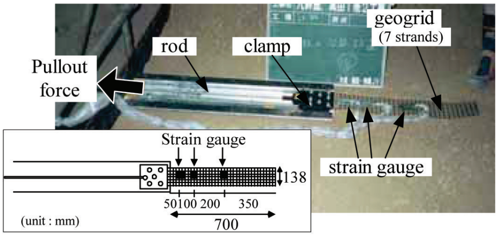
Pullout tests were performed for geogrid embedded in the backfill soil of the abutment constructed in Kyushu (Figure 1) and for geogrid embedded in the test embankment experimentally constructed at the Railway Technical Research Institute, Japan. Cement-mixed gravel (with cement/gravel = 4% by weight) was used for both the backfill of abutment and the test embankment. Cement-mixed gravel was compacted sufficiently controlling the water content close to the optimum water content for the specified compaction energy. The strength and deformation characteristic of the cement-mixed gravel is precisely reported by Watanabe et al. (2003) and Lohani et al. (2004). The pullout tests were carried out approximately one month after the construction.

Two types of geogrid made of vinylon with tensile strength 30 kN/m and 60 kN/m were employed for the tests in the abutment, whereas only one type of geogrid with tensile strength 30 kN/m was employed in the test embankment. These materials are typical geogrid reinforcement products used in soil reinforcement application. Specimens used in all tests are 138 mm in width (7 strands; 51 strands per meter) and 700 mm in length (Picture 1).

The pullout tests in the abutment were performed four times by using two types of specimens which was embedded at two different depths (8.7 m and 4.5 m, Fig. 1). On the other hand, the pullout tests in the test embankment were performed three times at same depth, 45 cm. (explained later)

As shown in Picture 1, the edge of each specimen was held by clamp using two iron plates, and the rod was leaded outside to apply pullout force. Strain gauges were attached onto the centre strand at the locations 50 mm, 150 mm and 350 mm from the clamp. Since it was difficult to directly attach the strain gauges onto the strands, polyvinyl chloride films were attached to both sides of the strand and the strain gauges were attached onto the film surfaces. For a protective purpose, aluminium seals were also attached onto the strain gauges.

A series of short-term in-isolation tensile tests of this geogrid was previously performed (Fig. 2). Preliminary tests showed large difference between the strain measured by relative displacement of clamps and measured by the strain gauge. Based on these test results, the maximum load for the pullout tests was determined (Figure 3). Cyclic loading and creep loading were applied on each load levels. For the pullout tests in the test embankment, the maximum load was set to 50 kN/m, and creep loading was applied on each load levels, while it was failed before it reached the planned maximum load.



Picture 1 Geogrid specimen used in the pullout tests.

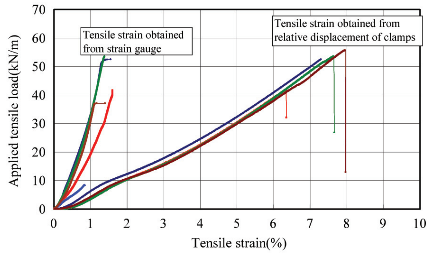


Figure 2. Tensile strain of geogrid obtained from in-isolation tensile tests.

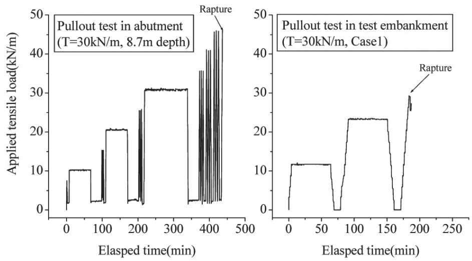


Figure 3 Time history of applied tensile load for pullout tests.

Pullout test in the abutment Pullout test in the test embankment

Picture 2. Geogrid specimens at rapture.

3 TEST RESULTS AND DISCUSSION

3.1 *Pullout tests in the abutment*

Picture 2 shows the specimen at rapture. Five outer strands were failed in the vicinity of clamped portions while the central two strands were failed at deeper positions. This may be caused by the nonuniform distribution of pullout force on each strand. Pullout force may be distributed mainly to the outer five strands due to the lower friction between the central two strands and the cement-mixed gravel, which was caused by aluminium seals on the strain gauges. For this reason the measured tensile load at rapture was close to the tensile strength at rapture of five strands presumed from the in-isolation tensile tests (Figure

2). Since the failure occurred in the vicinity of clamped portions of the geogrid, it seems that the bonding strength between the cement-mixed gravel and the geogrid is sufficiently high.

Figure 4 shows the relationship between applied tension load and pullout displacement. It can be seen that the pullout displacement of the 60 kN/m type geogrid with high rigidity is smaller than that of the 30 kN/m type geogrid. Although the confining pressure is approximately double between the depths of 4.5 m and 8.7 m, the effect of confining pressure on pullout displacement seems to be limited.

It can also be seen that the pullout displacement was increased during creep loading and decreased during reloading and consecutive creep loading on low tension load. Since the cement-mixed gravel does not exhibit such an elastic behaviour, this behaviour may be exhibited by geogrid itself rather that the cement-mixed gravel.

Figure 5 shows the relationship between the active tension length of the geogrid and the applied tension load. The active length of tension indicates a free length of the geogrid which was back calculated from the tensile strain obtained from the in-isolation tensile tests with the completely same loading patterns. The free length was obtained on the assumption that the tensile strain was distributed uniformly on the geogrid. It can be seen that the active tension length increased by

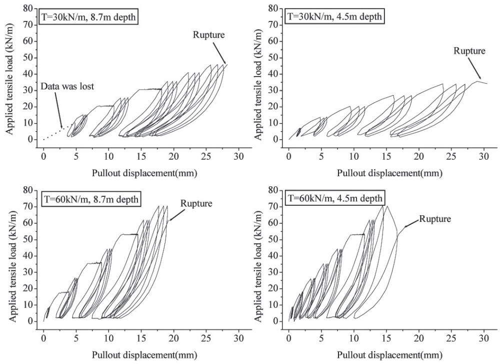


Figure 4. Relationship between tensile load and pullout displacement in the abutment.

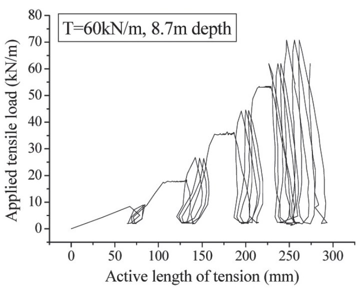


Figure 5. Relationship between applied tensile load and active length of tension.

increasing the tensile load or applying creep loading and cyclic loading, but the tensile load was transferred no more than 300 mm from the end of the specimen. These results agree with the output of strain gauge which was located 350 mm from the end of the specimen.

3.2 *Pullout tests in the test embankment*

After construction of the abutment shown in Fig. 1, undisturbed cores of cement-mixed gravel were recovered from the backfill and subjected to large triaxial test (Watanabe et al. 2005). Although all specimens satisfied the required strength, variability of peak strength was observed. The main reason of this variability may be attributed to the insufficient mixture of cement slurry into the gravel, which generated the local weak area in the specimens.

Although the local weak area was generated in the cement-mixed gravel, this could not become critical problem due to the reinforce effect of geogrid which was arranged on each height. In view of above, additional pullout tests were performed in the test embankment in order to evaluate the effect of quality of the cement-mixed gravel on the pullout characteristic of the geogrid.

The test embankment was divided into three sections and the gravel was mixed with cement-slurry in three different methods as follows;

Case 1: Constructed exactly the same as the construction method used for the actual backfill of abutment ($W_{cement}/W_{gravel} = 4\%$)
Case 2: Constructed by mixing cement with gravel quite sufficiently ($W_{cement}/W_{gravel} = 4\%$)
Case 3: Constructed the same way as Case 1, but total amount of cement was doubled ($W_{cement}/W_{gravel} = 8\%$)

The aim of Case 2 was to improve the quality of the cement-mixed gravel by mixing the cement and gravel sufficiently with the same amount of cement, whereas the aim of Case 3 was to improve the quality by increasing the cement.

Figure 6 shows the deformation modulus of the cement-mixed gravel obtained by FWD (Falling Weight Deflectometer). The deformation modulus was measured at 10 points for each section by keeping

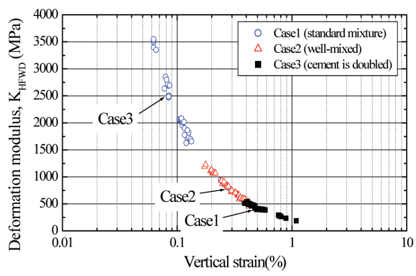


Figure 6. Deformation modulus of cement-mixed gravel obtained by FWD.

the energy constant (Weight : 150 N, Falling height : 45 cm, Diameter of loading plate : 9 cm). It can be seen that the average and variability of deformation modulus can be improved by mixing the cement sufficiently (Case 2). In addition, the deformation modulus was greatly increased by increasing the amount of cement (Case 3).

Figure 7 shows the relationship between applied tension load and pullout displacement. In all tests, when the pullout force reached the range from 24 kN/m to 30 kN/m, the geogrid was failed, which was lower than those obtained from in-isolation tensile tests (Fig. 2) and the pullout tests at the abutment (Fig. 4). This may be due to the non-uniform distribution of the pullout force to the seven strands. However, since the failure occurred at the clamped portions of the geogrid such as observed at the pullout test in the abutment (Picture 2), the bonding strength between the cement-mixed gravel and the geogrid is supposed to be sufficiently high.

Although tensile strength at rapture of Case 2 was lower than other tests, no great difference was observed between three tests. Figue 8 shows the relationship between the active tension length and pullout force of each geogrid. The active length of tension in Case 2 is larger than that in other cases, but it is about 250 mm at the maximum, which generally agrees with the result of the pullout tests in the abutment (Figure 5). It can also be seen from this figure that the active length of tension increased during reloading. This behaviour was not observed in the abutment and it may be due to the deformation of cement-mixed gravel around the geogrid with lower confining pressure compared with pullout tests in the abutment.

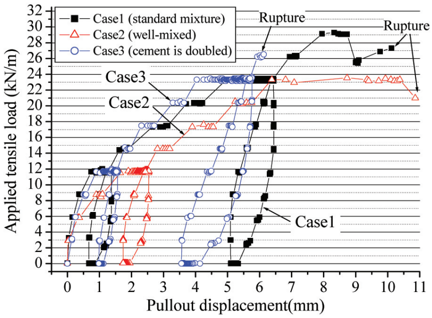


Figure 7. Relationship between tensile load and pullout displacement in the test embankment.

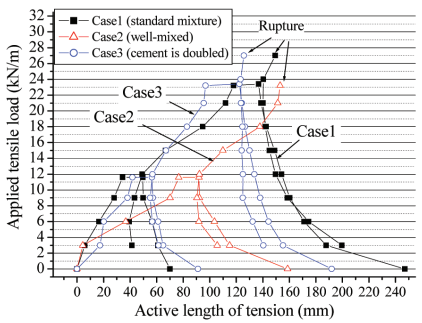


Figure 8. Relationship between applied tensile load and active length of tension in test embankment.

4 CONCLUSION

A series of pullout tests of the geogrid embedded in the cement-mixed gravel were performed and following conclusions were drawn.

1. Since the failure occurred in the vicinity of clamped portions of the geogrid, the bonding strength between the cement-mixed gravel and the geogrid is confirmed to be sufficiently high.
2. The pullout displacement was smaller for the geogrid with higher rigidity. On the other hand, the effect of confining pressure and the quality of cement-mixed gravel on pullout displacement was limited.
3. The active length of tension was back calculated from the tensile strain obtained from the in-isolation tensile. It was found that the active length increased by increasing the tensile load or applying creep loading and cyclic loading. It was also confirmed that the active length was no more than 300 mm from the clamp that agree with the output of strain gauge attached on the geogrid.

Unlike the in-isolation tests, it is difficult to distribute the tensile load uniformly to all strands for pullout tests. In this study, therefore, deformation characteristic of geogrid embedded in cement-mixed gravel was evaluated only qualitatively. Additional research, such as triaxial tests and bending tests, is required to investigate the reinforce effect of geogrid applied to cement-mixed gravel more quantitatively.

REFERENCES

Aoki, H., Yonezawa, T., Tateyama, M., Shinoda, M. and Watanabe, K. (2005). "Development of aseismic abutment with geogrid-reinforced cement-treated backfills", *Proc. 16th ICSMGE*, IS-Osaka, pp. 659-662

Lohani, T.N., Kongsukprasert, L., Watanabe, K. and Tatsuoka, F. (2004). "Strength and Deformation Properties of Compacted Cement-Mixed Gravel Evaluated by Triaxial Compression Tests", *Soils and Foundations*, Vol. 44, No. 5, pp. 95-108.

Watanabe, K., Tateyama, M., Jiang, G., Tatsuoka, F. and Lohani, T.N. (2003). "Strenght characteristics of cement-mixed gravel evaluated by large triaxial compression tests", *Proc. 3rd Int. Symp. On Deformation Characteristics of Geomaterials*, IS Lyon 03, pp. 683-693.

Watanabe, K., Tateyama, M., Yonezawa, T. and Aoki, H. (2005). "Strength Characteristic and Construction Management of Cement-mixed Gravel", *Proc. 16th ICSMGE*, IS-Osaka, pp. 619-622.