SOFT GROUND IMPROVEMENT METHOD FOR RAILWAY EMBANKMENT USING CEMENT-MIXED GRAVEL AND GEOSYNTHETIC

MÉTHODE D'AMÉLIORATION DU SOL MOU SOUS UN REMBLAI FERROVIAIRE AU MOYEN DE GRAVE TRAITÉE AU CIMENT ET D'UN GÉOSYNTHÉTIQUE

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ABSTRACT - In recent years, cement-mixed gravel, crushed stone with a little volume of cement for mechanical stabilization, are frequently applied to soil structures allowing a limited degree of deformation. In Japanese railway field, such materials are a standardized type applicable to approach blocks of bridge abutments of a new Shinkansen line. Laboratory tests or on-site tests have revealed that such materials have sufficient strength and deformation characteristics equivalent to those of concrete. Cement-mixed gravel with geogrid reinforcement to resist tensile stresses can therefore act as bending member, for example, as a slab on top of ground-improvement piles and be used as a new-type countermeasure method for soft ground. In this study, the applicability of this proposed method was evaluated by model tests and the practical application to railway embankment was introduced.

RÉSUMÉ - Ces dernières années, la grave traitée au ciment, c'est-à-dire des roches broyées avec une petite quantité de ciment pour les stabiliser mécaniquement, est fréquemment utilisée dans les ouvrages en terre qui ne doivent subir que des déformations limitées. Pour les chemins de fer japonais, ces matériaux forment une classe normalisée qui est applicable pour les remblais d'accès aux culées des ponts de la nouvelle ligne de Shinkansen en cours d'études. Les essais de laboratoire et réalisés sur site ont montré que ces matériaux ont une résistance suffisante et des caractéristiques de déformabilité équivalentes à celles du béton. La grave traitée au ciment, renforcée par une géogrille pour résister à la traction peut pour cette raison servir de comme élément résistant à la flexion, par exemple comme radier sur des pieux de renforcement du sol et être utilisée pour la construction sur les sols mous. Dans ce travail, l'applicabilité de cette méthode a été évaluée par des essais sur modèles et son application à un remblai ferroviaire a été ébauchée.

1. Introduction

A research project to use well-compacted cement-mixed gravel as the backfill material for important permanent structures allowing a limited amount of deformation, such as bridge abutments for railway, has started, aiming at reducing the seismic-induced settlement of the backfill while increasing the cost-effectiveness. Figure 1 presents a schematic diagram of the first bridge abutment of this type for a bullet train railway constructed in Kyushu for the period of 2002-2003 (Watanabe et al., 2005).

From laboratory tests or on-site tests, it was revealed that cement-mixed gravel have sufficient strength and deformation characteristics (Watanabe et al., 2003, 2005). Therefore, the cement-mixed gravel backfill of this bridge abutment is much stable against seismic load. 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.

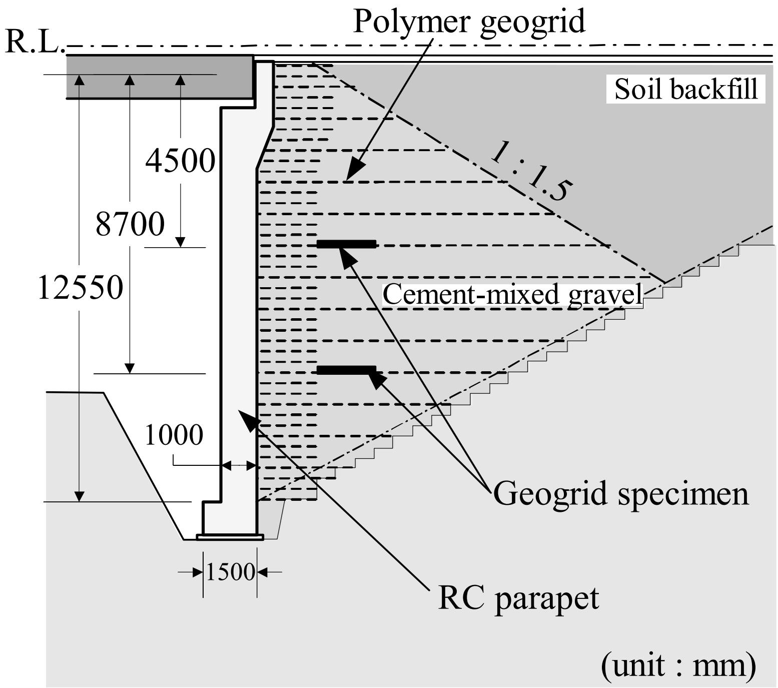

Figure 1. Typical bridge abutment with geogrid-reinforced backfill of cement-mixed gravel

The role of the geogrid placed in the backfill is to prevent the development of cracks in the backfill and to ensure the connection between the abutment and backfill. The behavior and interaction of geogrid embedded in comparatively harder cement-mixed gravel was precisely investigated by pullout tests of the geogrid and these tests revealed that the bonding strength between the geogrid and cement-mixed gravel was sufficiently high. (Watanabe et al., 2006).

From these results, it was suggested to apply this cement-mixed gravel where geogrid is used as tensile material to make a bending resistant slab on top of ground-improvement piles, as a new-type countermeasure method for soft ground as schematically shown in Figure 2. In the current design standard of ground improvement for railway embankment, the total amount of ground-improvement piles which is necessary for the stability of the embankment is determined in order to avoid settlement of embankment between the adjacent piles (punching failure). This indicates that it become possible to reduce the ground improvement by installing a slab between the soil structure and the piles.

The purpose of this study was to evaluate the bending deformation characteristics of a slab made of a composite material consisting of cement-mixed gravel and geogrid. Further, shaking table model tests were performed to evaluate the applicability of proposed method and the practical application to railway embankment was introduced.

2. Estimation of bending deformation characteristics of cement-mixed gravel

In order to investigate the effect of geogrid as a tension member on the bending characteristic of cement-mixed gravel, two rectangular parallelepipedic specimens with or without geogrid were subjected to the bending member tests.

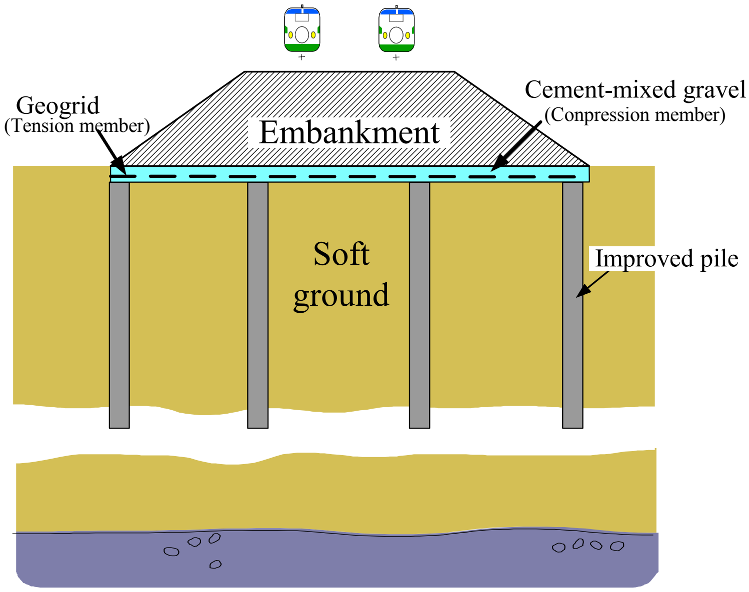

Figure 2. Proposed method to apply the composite material (cement-mixed gravel and geogrid) to the construction of embankment on soft ground

Well-graded quarry gravels, crushed sandstone (called Chiba gravel) was used for the specimen and a fixed cement/gravel ratio in weight equal to 2.5% was used for these tests. The specimens were 200 mm in height, 200 mm in length, and 700 mm in width. For the first case (Specimen 1), the geogrid, which had a strength of 30 kN/m and holes 20mm in both directions, was placed horizontally at 50mm height from the bottom of the specimen (Figure 3), while the geogrid was not arranged for the second case (Specimen 2). Furthermore, local deformation at the bottom surface of the specimen was measured by a few LDTs (Local Deformation Transducer).

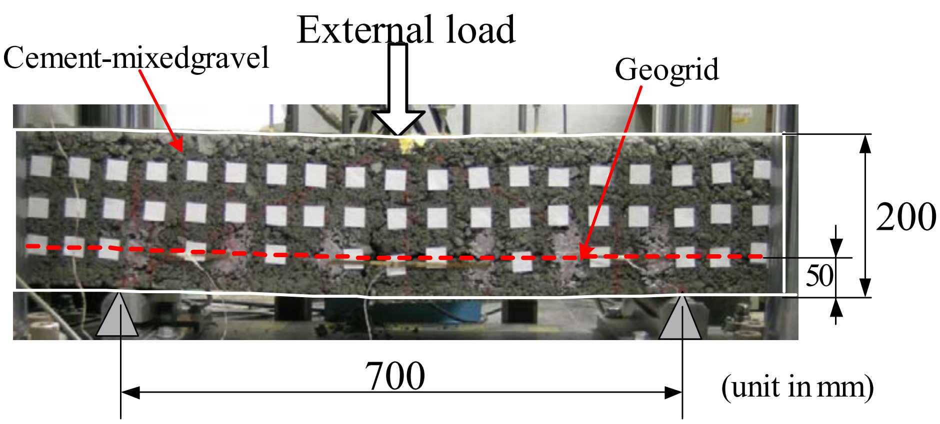

Figure 3. Bending load test of cement-mixed gravel with geogrid (Specimen 1)

Figure 4 shows the external load, strain of geogrid and crack width of each specimen. From these figures, it was apparent that the strength reached its maximum when the crack appeared at the bottom of the specimen. Furthermore, the crack width was about 0.13 mm for both specimens at this time. However, the strength of the Specimen 2 without geogrid decreased rapidly after the peak state, while Specimen 1 reinforced by geogrid exhibited a high ductility after the peak state.

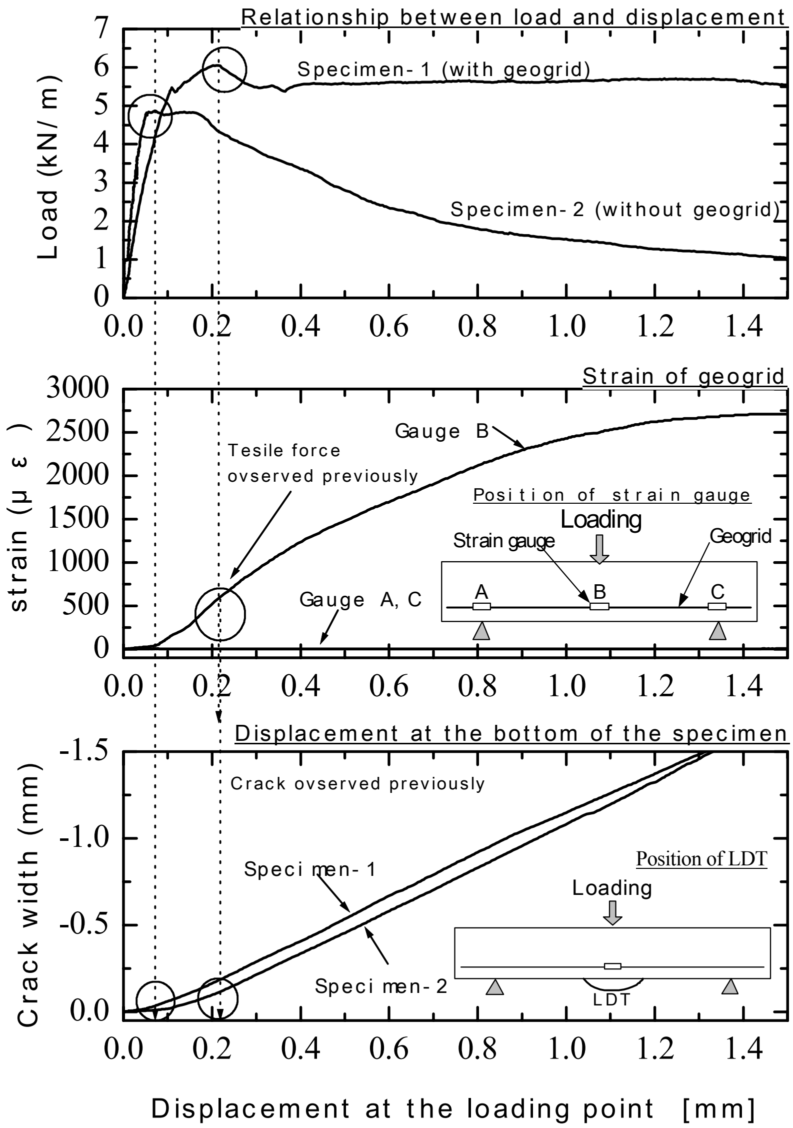

Figure 4. Results of bending load tests

As shown in these figures, the tensile force appeared just before the peak state and maintained after the peak state. This indicated that the ductility of cement-mixed gravel was mobilized by tensile force of reinforcement.

3. Shaking table tests of proposed countermeasure method for soft ground

From the bending loading tests, it was evident that cement-mixed gravel reinforced by geogrid exhibited high bending deformation characteristics. For this reason, cement-mixed gravel would be effective to apply as mass structures typified by bridge abutment (Figure 1) as well as members under bending stress (Figure 2). For example, ground-improvement piles for soft ground should be designed, as the ratio of piles is more than 25 % in order to avoid punching failure of embankment. However, arranging a slab of cement-mixed gravel under the embankment may enable to reduce this ratio because the slab supports dead load of embankment and live load. In order to evaluate the effect of proposed method for the construction of embankment on the soft ground, several shaking table tests were performed.

3.1 Test conditions

Shaking table tests were conducted as schematically shown in Figure 5:
Case 1: Conventional countermeasure method (called Column-net method)
Case 2: Countermeasure method using slab with improved piles (Improvement ratio = 5 %)
Case 3: Countermeasure method using only slab
The shaking table tests without countermeasure had been already conducted and the details of results were reported by Tateyama et al. (2001).

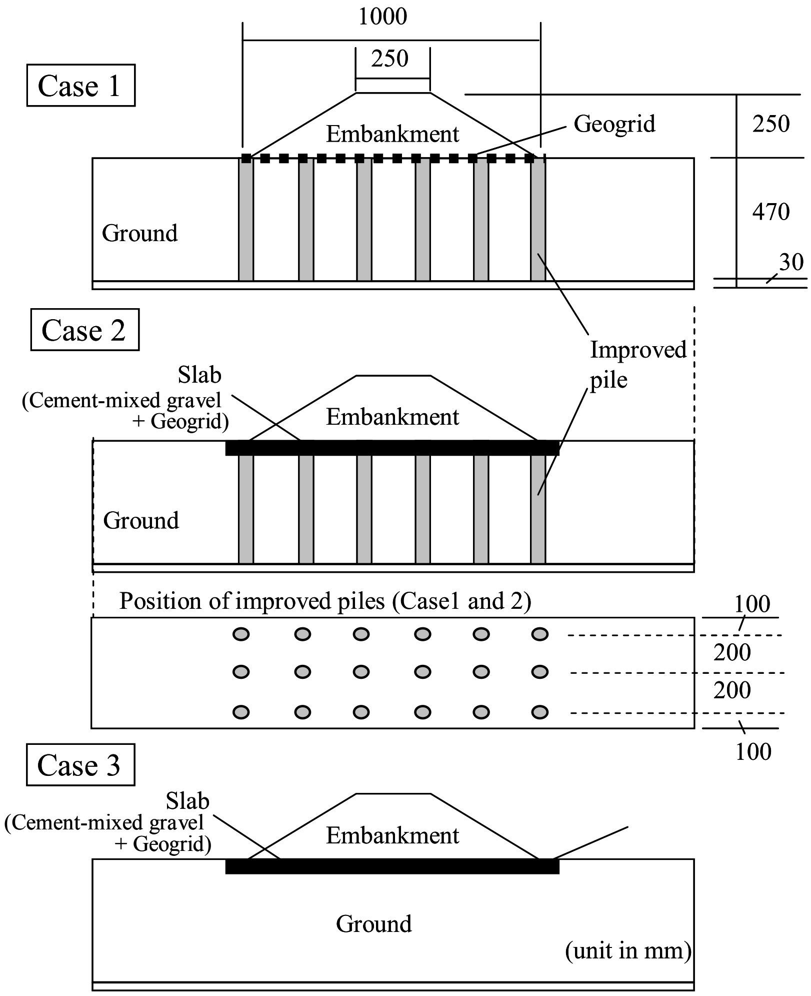

Fig. 5 Cross-section of model for shaking table tests

Due to the difficulty of making the soft ground model which will be gradually consolidated by the dead load of embankment, it was made of loose saturated sand instead, which will easily liquefy by small intensity of shaking. That is, the gradual consolidation was realized by gradual increase of excess pore water pressure which is caused by relatively small continuous excitation.

The slab, which was made of cement-mixed gravel and the model geogrid, was arranged horizontally. The geometric shape of this slab model was set by referring to that of typical ones having a height of about 80 cm, while reducing their size to a scale of almost one-tenth. Considering the similitude of this model, a polyester mesh sheet with a tensile strength almost 10 times smaller than actual reinforcement, was employed for the reinforcement model.

The improved piles used in the Case 1 and 2, the diameter of which was 50mm, were made of cement-mixed loam. The amount of cement was determined, as the unconfined compression strength of specimen was larger than 200 kPa, which is almost 10 times smaller than actual improved pile.

This model was subjected to sinusoidal excitation (3 Hz), with an amplitude of 100 gal for initial 10 waves and 200 gal for next 20 waves in Case 1 and 30 waves in Case 2 and Case 3. By this small continuous excitation, the excess pore water pressure increased gradually.

3.2 Results of shaking table tests

Figure 6 shows the time histories of vertical displacement at the top of embankment, subsidence of subsoil and base acceleration. For all cases, the displacement started when the base acceleration was 200gals. The displacement at the top and the subsidence of subsoil accumulated in a similar manner, which indicates that the deformation of embankment was quite limited.

Figure 7 shows the photographs after the experiments in each case. The embankment and the ground deformed largely around the toe of embankment for Case 1, while it was quite limited for Case 2. The settlement of embankment for case 3 was slightly larger comparing with those in other cases, but large deformations did not occur as in the Case 2. In order to evaluate the effectiveness of the counter-measure, it is important to compare the different cases at the moment when the excess pore water pressures (EPWP) were on the same level. Therefore, comparison was made when the EPWP reached the effective overburden load. According to this definition, the fully liquefied time was 24th wave in the Case 1, 21st wave in the Case 2 and 27th wave in the Case 3. The settlement at the top of embankment at this moment was 10 mm for Case 1, 6 mm for Case 2 and 15 mm for Case 3, while it was 40mm without countermeasure (Tateyama et al., 2001). This indicated that the countermeasure methods employed in all cases were effective.

The settlement of the embankment in Case 1 was larger than that in Case 2. This was due to the subsidence of geogrid between the adjacent piles. The settlement of Case 2 was decreased, which indicates the effective resistance of slab against the weight of the embankment.

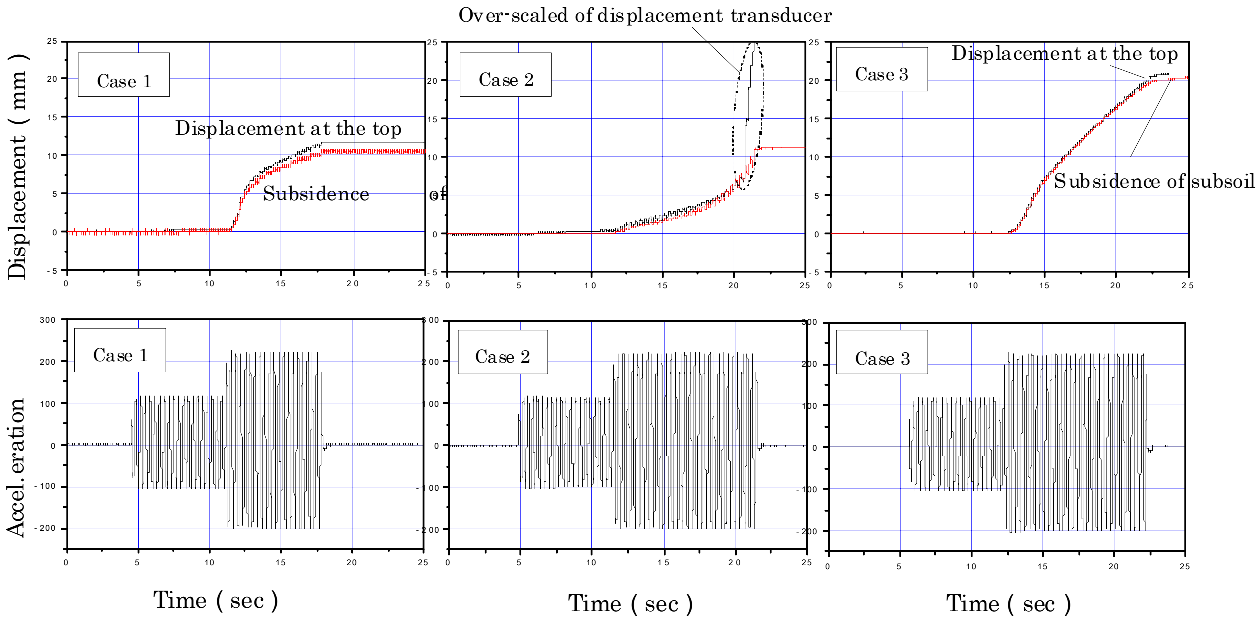

Fig. 6 Time histories of vertical displacement at the top of embankment, subsidence of subsoil and base acceleration

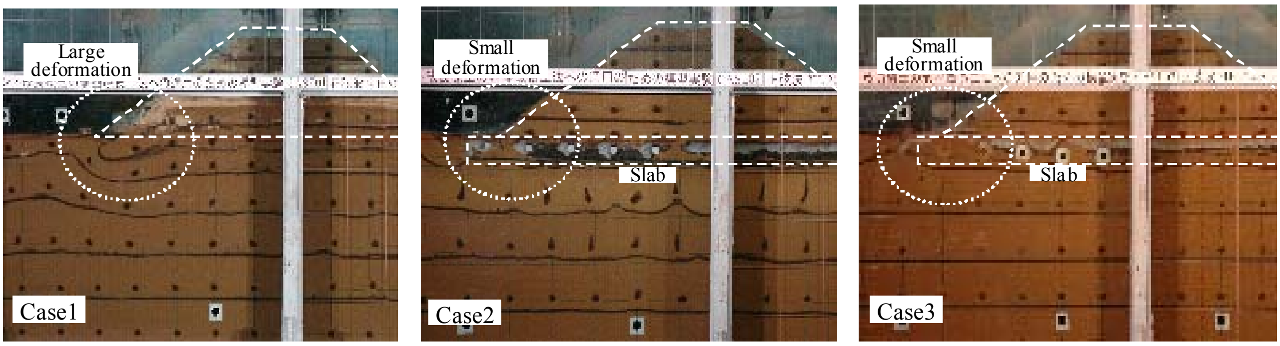

Fig. 7 Displacement of each model after shaking

It is very noteworthy that, although the subsoil was completely liquefied, the residual displacement and deformation of embankment for case 3 without any improved pile was quite limited. This is mainly due to following two reasons:

1) the slab made by cement-mixed gravel and geogrid model had a sufficient strength against bending moment mobilized by the dead load of embankment. The dead load of embankment was transferred widely to the subsoil through the slab, which reduced the subsidence of sub-soil;
2) the response acceleration of embankment was reduced by the liquefaction of subsoil. This result indicates that even if some improved piles suffered from shear deformation as observed at Case 2 (piles at the toe of embankment), the residual displacement and deformation of embankment could not be large due to the existence of slab between the embankment and the soft ground.

4. Practical application to railway embankment was introduced

The proposed method was applied to an actual railway project in Japan. The construction of the railway embankment (maximum height: 3.5 m, length: 110 m) was planned for the elevation of an existing railway. Since cohesive soft ground was distributed widely and deeply in this area, it was necessary to improve the ground drastically. In order to decrease the improvement ratio of the cohesive soft ground, the proposed method was applied.

Figure 8 shows the construction of the slab, which made of a composite material consisting of cement-mixed gravel and geogrid. Since this composite material can be installed much easier and faster than reinforced concrete, large cost reduction could be realized by this proposed method. The ratio of ground improvement was decreased almost by half.

5. Conclusions

(1) The slab which is made of cement-mixed gravel and geogrid exhibited a high ductility against bending load. This high ductility was mainly caused by the tensile force mobilized in geogrid after peak state. This result indicates that it is effective to apply this composite material made of cement-mixed gravel and geogrid as a bending member for the construction of embankment on soft ground.
(2) By arranging the slab between the embankment and the soft ground, it is possible to reduce the total amount of improved pile. Since this composite material can be constructed much easier and faster than reinforced concrete, large cost reduction can be realized by

this proposed method. The proposed method was applied to the construction of railway embankment in Japan.

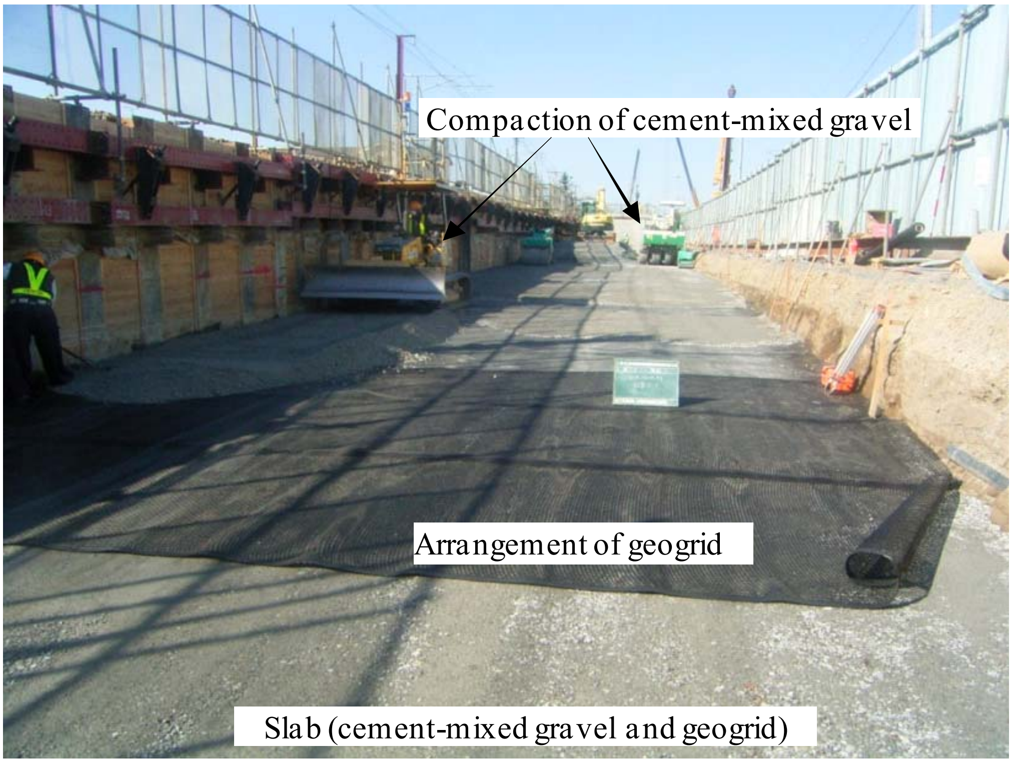

Figure 8. Application of the proposed method to the construction of railway embankment on soft ground

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