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Development of aseismic abutment with geogrid-reinforced cement-treated backfills

Développement d'un aboutement séismique d'un remblai renforcé avec géogrid et traité avec ciment

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ABSTRACT
This paper describes a new type of bridge abutment with geogrid-reinforced cement treated backfill. The practical design procedure was also described with separately considering the abutment itself and reinforced section by using static nonlinear analysis. To validate the seismic performance of the proposed abutment with geogrid-reinforced cement treated backfill, a lateral load was applied to an actual proposed abutment in the field. Filed test results showed that the lateral movement of the rigid facing was a remarkably small and can be validated the high seismic performance of the proposed bridge abutment.

RÉSUMÉ
Cet article décrit un nouveau type d'aboutement de pont en utilisant le geogrid pour le renforcement et le ciment pour traitement du remblai. Une méthode de conception pratique a été également décrite en considérant l'aboutement et la section renforcé séparément, en utilisant une analyse statique non-linéaire. Pour valider la performance séismique du système proposé, une charge latérale a été appliquée à un modèle réel. Les résultats d'essai in-situ ont approuvé que le mouvement latéral du revêtement rigide était une valeur remarquablement petite et peut valider la performance séismique élevée du système.

1 INTRODUCTION

A number of conventional bridge abutments among railway structures were seriously damaged with a relative settlement between the bridge abutment (Fig. 1) and the backfill and an absolute settlement due to seismic loading, especially in the 1995 Hyogoken-Nambu Earthquake (Watanabe et al. 2002 and Aoki et al. 2003) and 2004 Niigataken-Chuetsu Earthquake. It is important task for railway industries to eliminate such settlements during strong seismic loading for safety train operation.

One of the conventional measures against such problems is to construct "approach block" (Fig. 2) with densely compacted well-graded crushed gravel. This method is also generally used to reduce a settlement during train load in static condition in Japanese railways. In this paper, a new type of approach block abutment with geogrid-reinforced cement-treated backfill is proposed to substantially increase seismic stability (Fig. 3). The procedure of this abutment is that the cement-treated approach block is constructed with horizontally installed geogrid reinforcement. After construction of the backfill, a lightly steel-reinforced concrete facing is cast-in-place directly on the wrapped around wall face while firmly connecting the facing to the main body of the reinforced backfill. Finally, the girder was placed on a parapet of the above facing. The proposed abutment has the following features:

1) An absolute settlement during earthquake can be significantly reduced by means of using cement-treated backfill.

2) The concrete facing is connected with the multi-layered geogrids through the cement-treated backfill. This construction method can make the stability of the concrete facing high and lighten a working load applied to the foundation structures.

3) Before constructing the concrete facing, the approach block and backfills previously construct. Due to the above construction procedure, stress concentration between the facing and the geogrids can be reduced effectively.

4) In spite of a new type of abutment, the construction procedure and its mechanism is easy to understand for constructor.

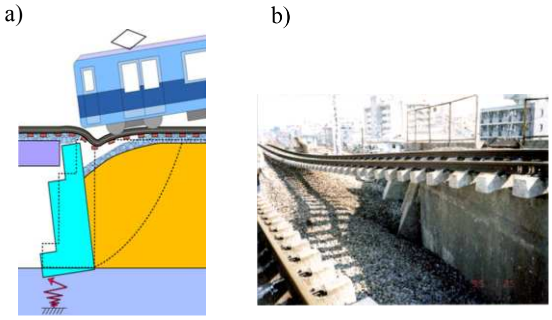


Figure 1. Typical deformation of backfill during earthquake: a) schematic figure of abutment and backfill, b) large settlement of backfill during 1995 Hyogoken-Nambu-Earthquake.

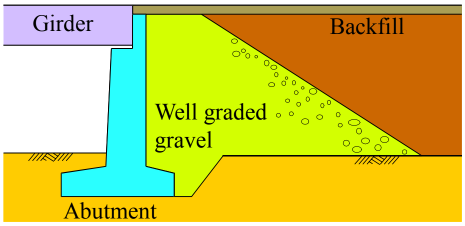


Figure 2. Approach block abutment.

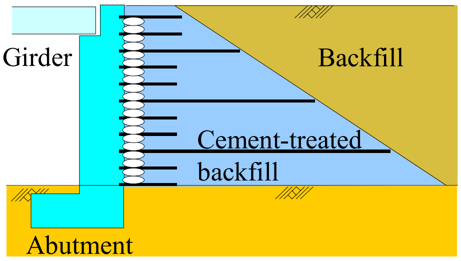


Figure 3. Proposed aseismic abutment

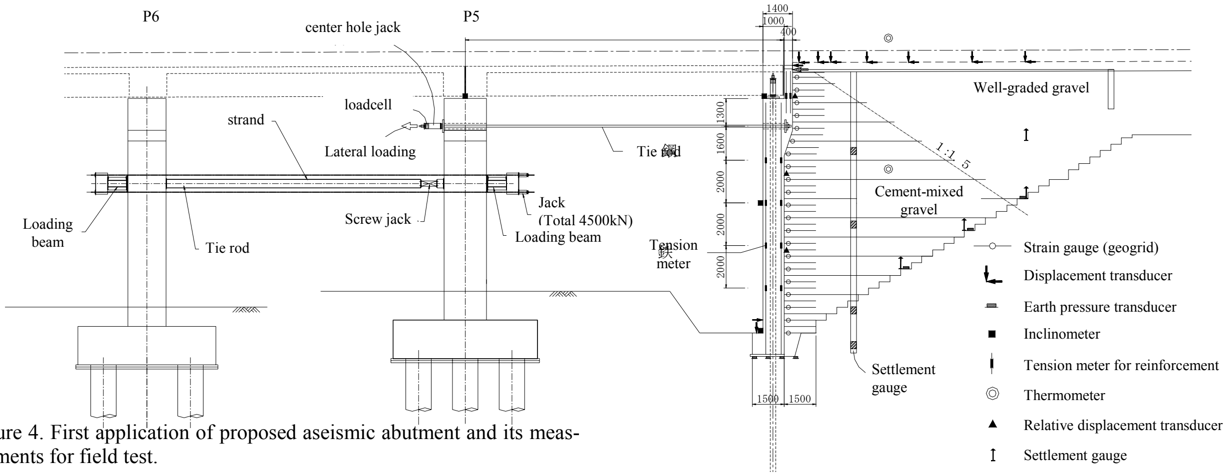


Figure 4. First application of proposed aseismic abutment and its measurements for field test.

Figure 5. Location of recently constructed proposed abutment for the Kyusyu planned shinkansen.

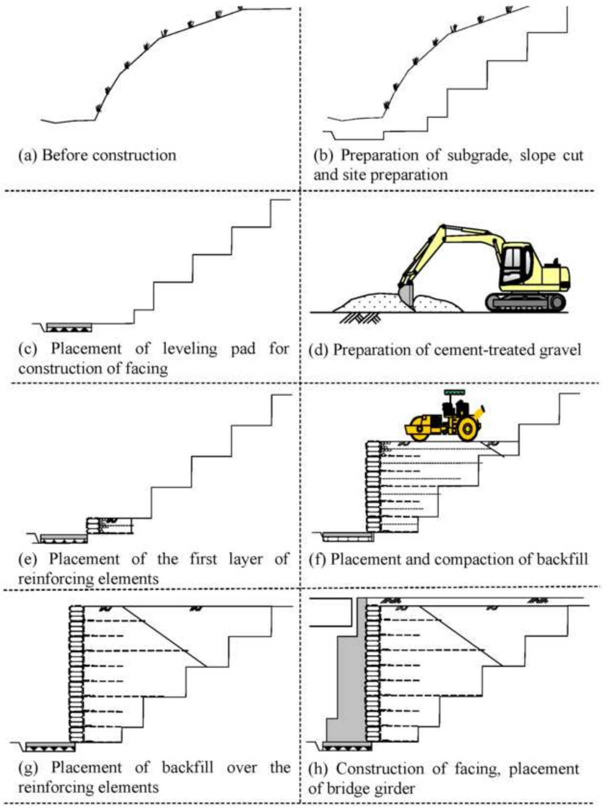

(a) Before construction
(b) Preparation of subgrade, slope cut and site preparation
(c) Placement of leveling pad for construction of facing
(d) Preparation of cement-treated gravel
(e) Placement of the first layer of reinforcing elements
(f) Placement and compaction of backfill
(g) Placement of backfill over the reinforcing elements
(h) Construction of facing, placement of bridge girder

Figure 6. Construction sequence

The first prototype abutment with geogrid-reinforced cement-treated backfills was constructed in Fukuoka City, in Japan (Fig. 4 and 5). The backfill of the abutment is cement-treated densely compacted well-graded crushed gravel, reinforced with geogrid layers with a vertical spacing of 30 cm. To have a better insight into the seismic stability for the abutment with geogrid-reinforced cement-treated backfills and to develop the relevant seismic design methodology, a field test was performed to apply the horizontal force to the above abutment. This paper also reports the field test results and its application to the design methodology.

2 FILED TEST PROCEDURE

2.1 *Construction of proposed abutment*

In the fall of 2002, the first prototype abutment with geogrid-reinforced cement-treated backfills was constructed to support a railway plate girder of planned Kyusyu-Shinkansen in Fukuoka City, Japan (Fig. 4 and 5). The height of the abutment is about 12.6 m from the top of the footing to the top of the girder. The backfill was very well compacted, cement-treated well-graded crushed gravel that was reinforced with geogrid layers with an average vertical spacing of 30 cm. The abutment was constructed as described in Figs. 6a through 6h:

1) Preparation of subgrade: This step involves removal of unsuitable materials from the area to be occupied by the retaining structure. Slope cut and site preparation was conducted, if necessary (Fig. 6a and 6b).
2) Placement of leveling pad for construction of facing: This generally unreinforced concrete pad is often 100 mm thick on the well-compacted gravel with 200 mm thick. The purpose of this pad is to serve as a guide for facing construction and is not intended as a structural foundation support (Fig. 6c).
3) Preparation of cement-treated backfill: Cement-treated backfill is supposed to be prepared before placement. Prescribed amount of cement, water and basically used well-graded crushed gravel for backfill should be used (Fig. 6d).
4) Placement of the first layer of reinforcing elements on the subgrade: The reinforcements are placed and wrapped around to the gabions (Fig. 6e).
5) Placement and compaction of backfill on the placed reinforcement and its compaction: The fill should be compacted to the specified maximum dry density, say 95% (Fig. 6f).
6) Placement of the backfill over the reinforcing elements to the level of the next reinforcing layer and compaction of the backfill: The previously outlined steps are repeated for each successive layer (Fig. 6g).
7) Construction of facing: After placement of the final reinforcement and backfill, a lightly steel-reinforced concrete

facing (i.e., a FHR facing) was cast-in-place directly on the wrapped-around wall face while firmly connecting the facing to the main body of the reinforced backfill (Fig. 6h).

A long-term measurement of the tensile strain of reinforcement, deformation of backfill and concrete facing, was started from the beginning of the construction to September 30th 2003. The tensile strain of reinforcement was gradually increased during construction of the backfill. After construction of the backfill, the tensile strain became stable even when the railway plate girder was placed on the concrete facing. Very importantly, the long term deformation of the concrete facing and the backfill is negligible.

2.2 *Loading and measuring methods*

To validate high seismic performance of the proposed abutment with geogrid-reinforced cement-treated backfill, a field test of the above described abutment was conducted. Fig. 4 shows a large number of gauges, such as strain gauges to measure the tensile strain of reinforcement, earth pressure cells placed on the slope cut and the bottom of the footing, displacement transducers to measure the fluctuation on the backfill surface and facing, thermometers to measure the temperature in air and the backfill.

To apply a vertical load equivalent to the weight of the railway plate girder, three hydraulic jacks were attached to the top ends of each steel bar which was installed into the cement-mixed subgrade through the concrete facing. For the sufficient reaction of the lateral loading, eight steel bars were installed into a pair of piers (P5 and P6) to become one reaction frame as shown in Fig. 4. A prescribed lateral load was applied by using six hydraulic jacks attached to the top ends of each steel bars which were horizontally connected between the wall facing to the pier P6. Fig. 7 shows a time history of lateral load. A maximum lateral load was 4,000 kN assumed a strong seismic force (level 2 earthquake).

3 TEST RESULTS AND DISCUSSIONS

Fig. 8 shows the relationships between the lateral load and lateral displacement of the pier P6 measured at the 1.3 m lower than the top surface. Fig. 9 shows the relationships between the lateral load and the lateral displacement measured at the parapet of the abutment. The actual maximum lateral load is 4,000 kN. Because the applied structures were not only for field test but also for service of Kyusyu planned shinkansen so that the lateral loading should be stopped before large deformation. In Fig. 8 and 9 the lateral displacement of both structures increased with increasing lateral load. Importantly, an absolute lateral displacement of abutment was only 15.5 mm. On the other hand, the absolute lateral displacement of P6 was a relatively large value of 34.2 mm. This indicates that the stability of abutment against lateral loading assumed seismic loading is very higher than P6.

4 DESIGN OF PROPOSED ABUTMENT

4.1 *Model*

Fig. 10 shows a seismic design model in which the abutment is connected with the cement-treated backfill through the geogrids working as a kinematical spring. As explained later, the design procedure of proposed abutment has two steps. One is design for the abutment itself. The second is design for the cement-treated backfills.

4.2 *Design of abutment*

Fig. 11 shows a schematic of seismic working loads. Driving forces are self weights of abutment and railway plate girder, in-

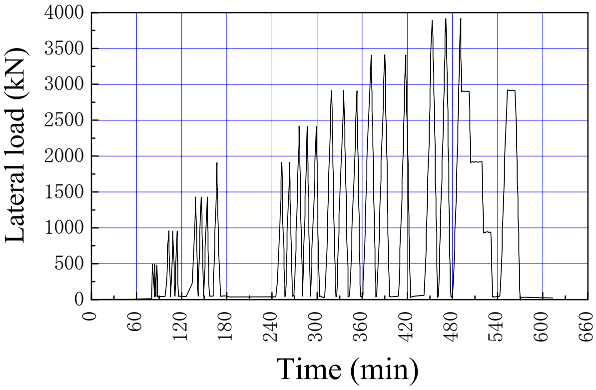


Figure 7. Time history of lateral loading.

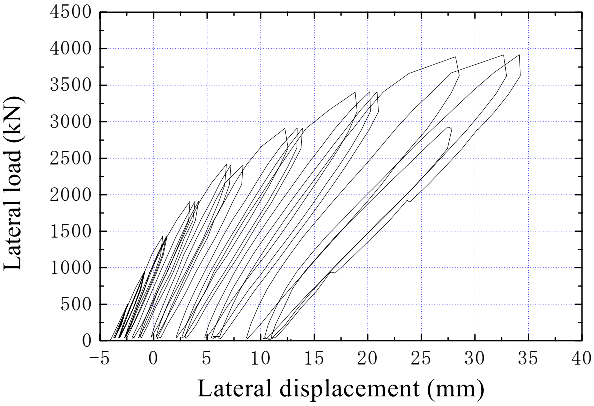


Figure 8. Lateral load and displacement relationships of P6.

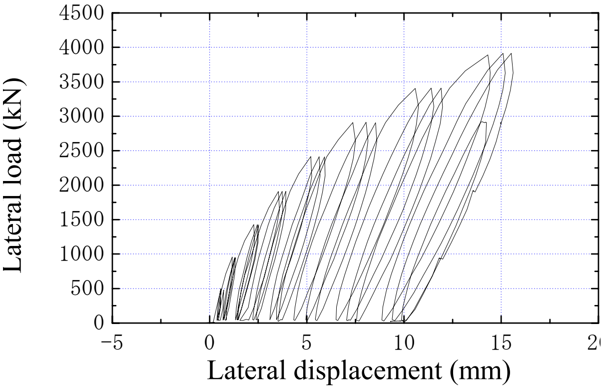


Figure 9. Lateral load and displacement relationships of abutment.

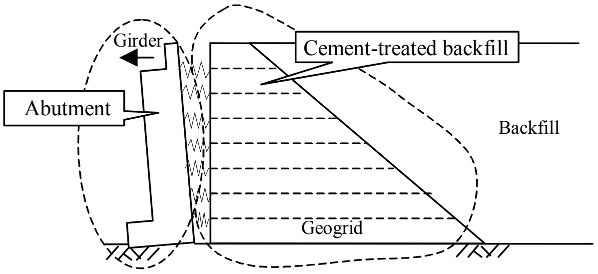


Figure 10. Seismic design model.

ertia force and traffic surcharge. Importantly, an active earth-pressure of backfill does not consider for the design of abutment on the premise that the stability of cement-treated backfill can be evaluated.

Fig. 12 shows a model for design of abutment. The abutment is modeled as a beam element, subgrade is modeled as a rotational spring and horizontal spring and geogrid is modeled as a horizontal spring. A nonlineality of abutment is considered by generally used M-ϕ model. The springs of subgrade and geogrid are bi-linear and tri-linear models. A push-over analysis should be conducted to evaluate a failure mode or ductility factor of foundation structure according to the design code.

4.3 *Design of geogrid-reinforced cement-treated backfills*

Fig. 13 shows a schematic of seismic working loads in the cement-treated backfill for the evaluation of internal and external stability. Driving forces are a reaction force of horizontal spring modeled geogrid obtained from the push-over analysis of abutment, self weight and inertia force of cement-treated backfill and backfill, surcharge and traffic load, active earth pressure of backfill.

The evaluation of stability during construction is that the safety factor can be calculated by reinforced soil structure according to the design manual on the assumption that the cement does not harden. Then the stability evaluation treats the cured cement-treated backfill as a composite homogeneous soil mass. The criteria in the above evaluation for level 1 earthquake is that the working forces are the lesser than the design strength, besides, the stability of backfills is satisfied. For level 2 earthquake, a deformation analysis should be performed by Newmark method by using the peak friction angle before yielding and residual friction angle after yielding. Then the deformation obtained from the above analysis is required to be satisfied with the criteria.

5 CONCLUSIONS

A new type of abutment with geogrid-reinforced cement-treated backfill has been proposed so as to substantially increase the stiffness and decrease the residual deformation against long-term traffic load and seismic load. The first prototype aseismic abutment with geogrid-reinforced cement-treated backfill was constructed for the planned Kyusyu-Shinkansen. To validate the high seismic stability of the abutment, a field test was carefully performed by applying a lateral load. From the filed test results, the seismic stability of the abutment was sufficient high even when applying a strong seismic load.

Aseismic abutment with geogrid-reinforced cement-treated backfill described in this paper can be constructed as permanent important structures having a high stiffness for long-term repeated load, such as traffic load as well as a seismic stability.

REFERENCES

Watanabe, K., Tateyama, M., Yonezawa, T., Aoki, H., Tatsuoka, F. & Koseki, J. 2002. Shaking table tests on a new type bridge abutment with geogrid-reinforced cement treated backfill, *Proc. of the 7th International Conference on Geosynthetics*, Vol.1, pp.119-122, Nice.

Aoki, H., Watanabe, K., Tateyama, M. & Yonezawa, T. 2003. Shaking Table Tests on Earthquake Resistant Bridge Abutment, *Proc. of the 12th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering*, Singapore.

RTRI Design Standard for Railway Earth Structures. 2000. Railway Technical Research Institute (RTRI), Maruzen, (in Japanese).

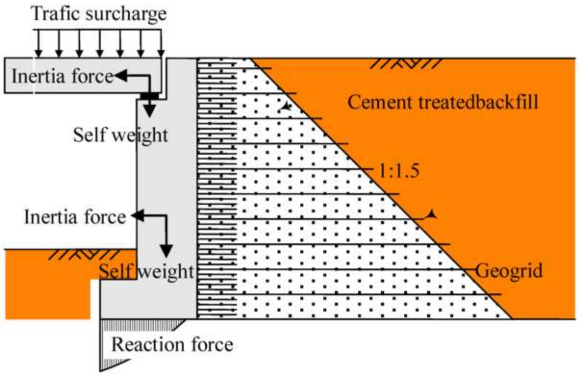


Figure 11. Schematic of seismic working loads.

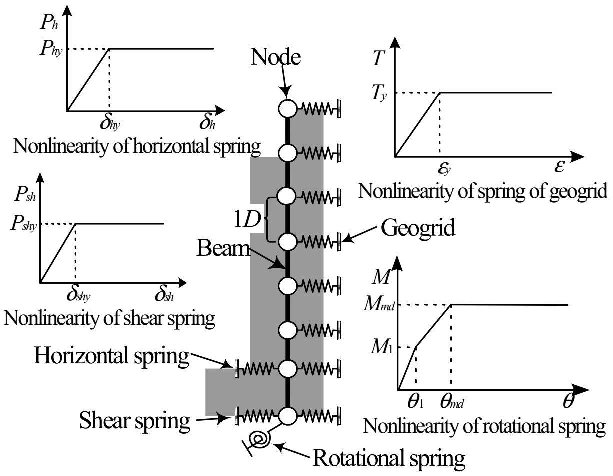
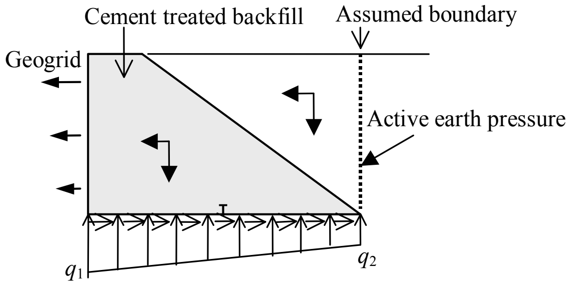


Figure 12. Model for design of abutment.



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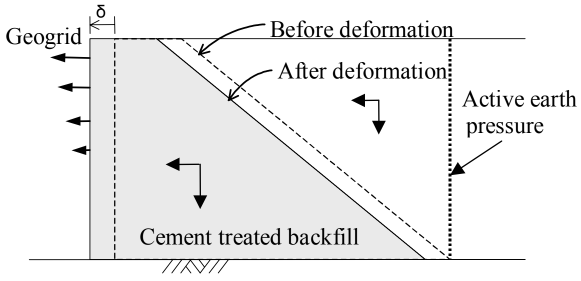

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Figure 13. Schematic of seismic working loads in the cement-treated backfill.