Evaluation tests of ballasted track reinforced with geosynthetic bags

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ABSTRACT: In order to reduce deformation of ballasted tracks during large earthquakes, pre-cast concrete blocks are currently employed. However, construction of concrete blocks needs heavy equipments, which prevents early completion of measures. Therefore, a new method to reinforce ballasted tracks with stacked geosynthetic bags that are filled with ballast was developed. This method can be installed only by human power and more economical than the concrete blocks. In this study, based on results of shaking table model tests, it is confirmed that the reinforced ballasted tracks have a sufficient resistance against a seismic load that is larger than the so-called Level 2 earthquake motions. Moreover, it is confirmed that improved versions of the reinforced ballasted tracks have a sufficient seismic resistance under a condition of the wide tracks on which a larger inertia force acts during earthquakes. Construction test on commercial lines revealed that the new method has good workability.

1 INTRODUCTION

Since the beginning of the Tokaido Shinkansen's (or the first bullet train's) operation in 1964 in Japan, the capacity and speed of the line have been raised to match social needs. Presently, more than 300 trains are operated daily at the maximum speed of 270 km/h.

Since the line, carrying more than 130 million passengers annually, plays an important role for Japanese economy, we must prevent its long-term suspension and improve the vehicle running stability. In order to improve seismic stability of the civil engineering structures of the Shinkansen, such as embankment, steel bridge, and viaduct bridge, several measures have been executed. However, the shoulder of conventional ballasted tracks that are also employed for the line may fail due to a large earthquake load, and the track settlement may be greatly increased. Therefore, it is important to study the seismic behavior of ballasted track structure and to develop a procedure to raise its earthquake resistantance. In view of the above, the present study focuses on a new method to reinforce ballasted tracks with geosynthetic bags.

2 GEOSYNTHETIC BAGS METHOD

In order to reduce deformation of ballasted railroads during large earthquakes, pre-cast concrete blocks are currently employed in Japan (Figure 1). Since construction of concrete blocks needs heavy equipments, it prevents early completion of construction and becomes expensive. Figure 2 shows a newly proposed method to reinforce ballasted railroads. It is composed of stacked geosynthetic bags that are filled with ballasts and iron bars that are driven into the roadbed to reinforce the bags. The characteristics of the proposed method may be summarized as follows:

・The bags are layered with further reinforcement using iron bars.

・No special construction equipment is required. The bags can be constructed solely by human labor, and thus they are more economical and efficient for construction than the concrete blocks.

・Recycled ballasts can be used to fill the bags.

・The mesh of the bags has large opening, so the frictional resistances between adjacent bags are well mobilized.

Bags are used to construct a retaining wall to stabilize a potentially collapsible slope. When a bag undergoes external force, a tensile force is mobilized along the bag, which in turn enhances the bearing capacity of the bag by adding an apparent cohesion c (Figure 3).

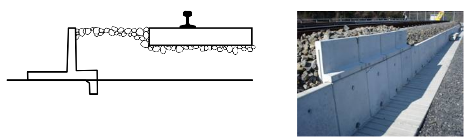

Figure 1.Concrete blocks for reducing deformation of ballasted railroads

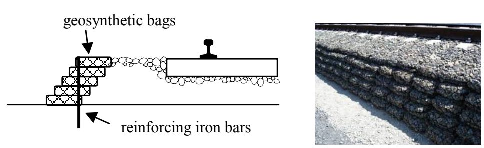

Figure 2.Ballasted railroads reinforced with geosynthetic bags

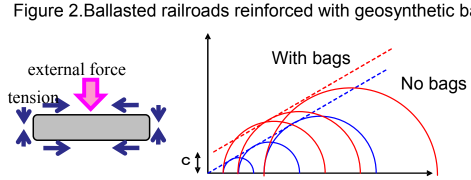

Figure 3.Effects of wrapping bags (after Matsuoka, 2003)

3 SHAKING TABLE MODEL TESTS ON BASIC VERSIONS

In order to elucidate the dynamic response of ballasted railroad reinforced with geosynthetic bags subjected to seismic loads, a first series of shaking table tests was performed. Figure 4 shows a schematic view of the test set-up. Full scale models of a half section of a double track were constructed in a rigid steel box on the shaking table. The steel box was partitioned into two spaces, and thus two models could be excited at the same time. A round reinforcing bar having a diameter of 12 mm with a smooth surface was driven into the roadbed as deep as 200 mm. The bags were made of polyester mesh having an opening of 25 mm, They were filled with 25 kg of ballasts and compacted into a size of 400* 400*100 mm with a plate compacter. The roadbed was prepared by compacting a sandy soil at a wet density γ_t of 17.0kN/m^3. The model track was made of track components that are usually used in Tokaido Shinkansen.

Figure 5 shows input motion for the shaking table tests. It was assigned based on response acceleration at the top of an embankement supporting the track when it was subjected to so-called Level 3 design ground motion. It is larger than the so-called Level 2 earthquake motions employed for the design of railway structures (RTRI, 1999), and it has characteristics that the shaking duration is long, and long period components are dominant. The response acceleration was calculated with FE dynamic analysis method.

Figure 6 shows the result of concrete blocks (Case 1). When the maximum acceleration exceeded 1,000 gal, the horizontal displacement at the top of the block increased remarkably, showing the maximum displacement of about 15 mm.

Figure 7 shows the result of the basic version (Case 2) of the proposed method. When the maximum acceleration exceeded 1,000 gal, the horizontal displacement at the top of the layered bags increased in a similar manner. Thus, it could be confirmed that the reinforced ballasted tracks exhibit a similar seismic resistance to that of the concrete blocks. It should be noted that the horizontal displacement of bottom of the layered bags is much smaller than the value measured at the top of the layered bags, suggesting that the layered bags suffered an overturining mode of displacement, rather than a sliding mode along the base foundation.

Figure 8 shows the result of the basic version under a condition of wider tracks (Case 3). With this case, the reinforced ballasted tracks could not perform sufficiently, due possibly to the effects of a larger inertia force of the enlarged ballast body. Thus, it was attempted to further improve the proposed method.

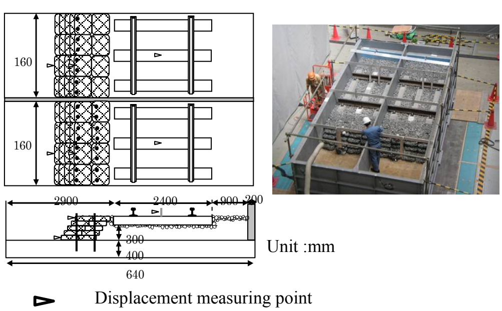

Figure 4 Shaking table model tests of basic versions

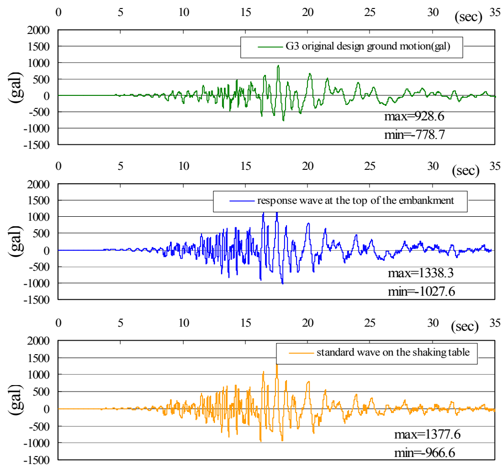

Figure 5 Input motion

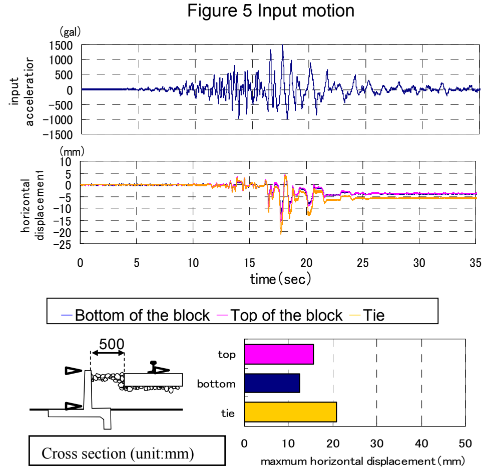

Figure 6 Result of the concrete block

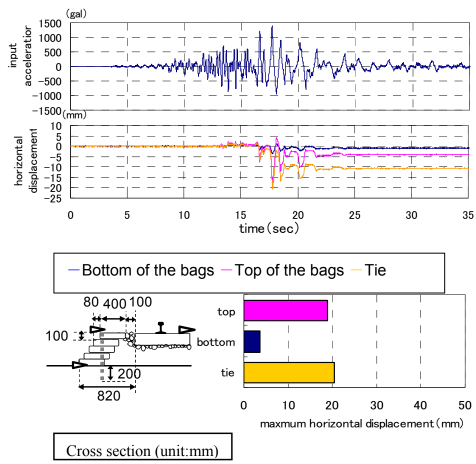

Figure 7 Result of the reinforced bags

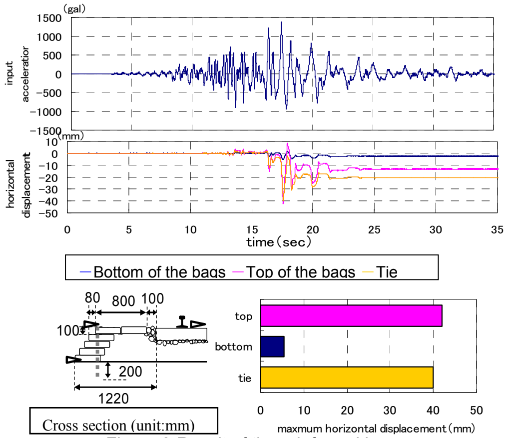

Figure 8 Result of the reinforced bags

4 HORIZONTAL BEARING CAPACITY TESTS

In order to improve the horizontal bearing capacity, it is necessary to modify the structure of the proposed method. So horizontal loading tests on several types of ballasted structures were performed. As schematically shown in Figure 9, the horizontal load was applied through an oil cylinder to the ballast cover. For each type of ballasted structure, three tests were conducted.

Figure 10 shows the relationships between the horizontal load and the horizontal displacement measured at the top of the layered bags or the concrete block. The performance of the basic version (Case (a)) was less than that of the concrete block (Case (b)). By increasing the embedment depth of the reinforcing iron bars by 100 mm (Case (c)), the horizontal bearing capacity could be improved.

Referring to the relevant study reporting that the shear strength of inclined stacked bags is much larger than that of horizontally stacked bags (Matsushima et al., 2008), modification of the proposed method is made by piling up the bags with an inclination of 22.5 degrees measured from the horizontal direction (Case (d)). As a result, the horizontal bearing capacity could be significantly improved.

Moreover, in order to resist against the overturning of the bags in a more effective manner, the reinforcing iron bars were driven with an inclination of 110 degrees (Case (e)). It could achieve further improvement.

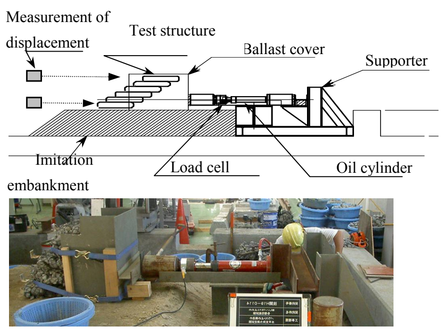

Figure 9 Horizontal bearing capacity test

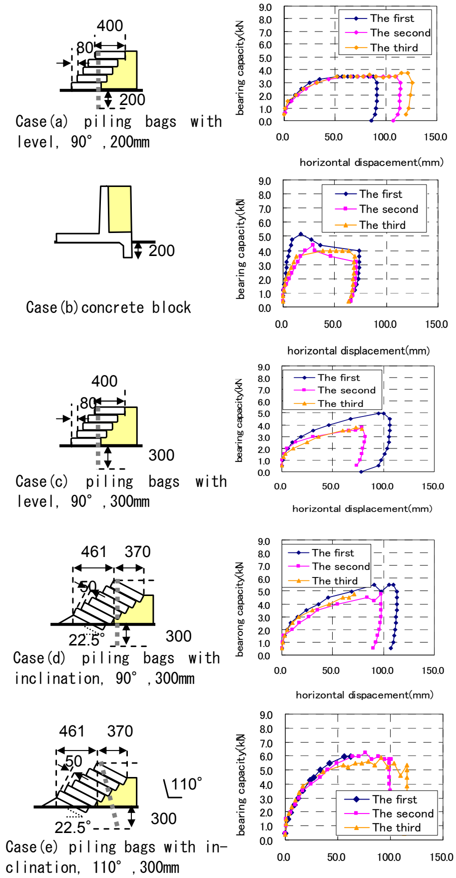

Figure 10 Results of the horizontal bearing capacity test

Figure 11 summarizes the horizontal bearing capacity that was measured when the horizontal displacement at the bottom or top of the layered bags or the concrete block became 10, 20 and 30 mm. Among several types of the layered bags tested herein, only Case (e) could exhibit performance that is equivalent to or even better than Case (b) with the concrete block.

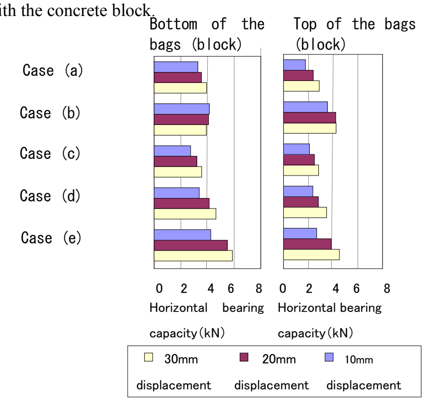

Figure 11 Results of the horizontal bearing capacity test

5 SHAKING TABLE MODEL TESTS ON IMPROVED VERSION

In order to confirm the seismic resistance of the improved version of the proposed method under a condition of wider tracks, a second series of shaking table tests was performed. Figure 12 shows a schematic view of the test set-up. Due to the limitation of the capacity of the shaking table employed for the second series, one model was constructed in a smaller sand box and excited. Reinforcing bars having a nominal diameter of 13 mm with a deformed surface were driven into the roadbed as deep as 300 mm. In order to increase the overall stiffness of the layered bags, adjacent layers were connected to each other by using a U-shaped reinforcing iron bars.

Figure 13 shows the result of shaking table tests on the improved version. The maximum horizontal displacements became smaller than those of the concrete blocks (Fig. 6). Thus, it could be confirmed that the improved version of the reinforced ballasted tracks, employing pilied bags and reinforcing bars with inclination, exhibits a sufficient seismic resistance even under a condition of the wider tracks.

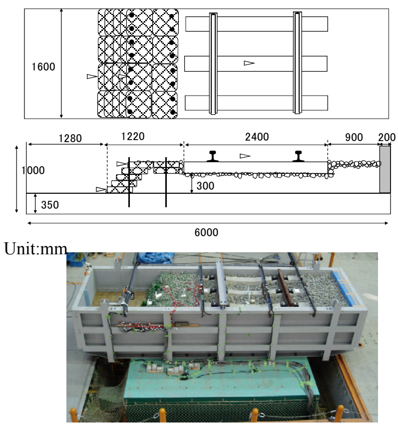

Figure 12 Shaking table model tests of improved versions

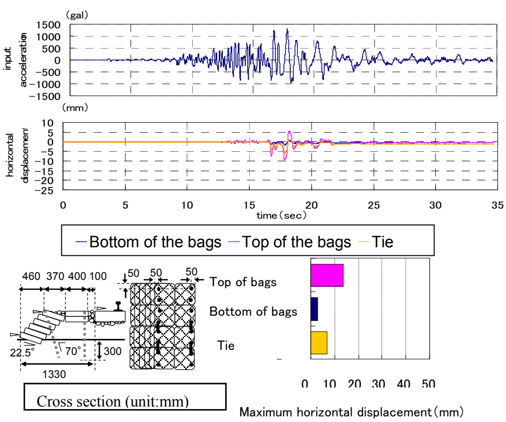

Figure 13 Result of shaking table model test for improved version.

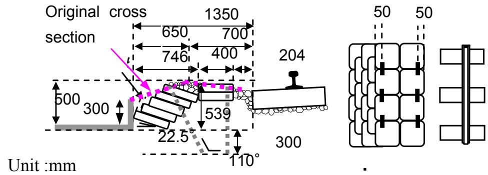

Figure 14 Cross section of construction test

6 CONSTRUCTION TEST

In order to confirm workability of the proposed method, construction test was performed on commercial lines. Figure 14 shows schematic view of the construction test where the workabilities of piling bags with inclination and driving iron bars with inclination are evaluated. As typically shown in Fig. 15, the piling process of bags with inclination was found not to reduce the workability as compared with the level piling process. In addtition, by using an electric breaker with a protractor, the driving process of reinforcing bars with inclination could be achieved without any technical difficulties. Thus, it could be confirmed that the proposed method has good workability.

Figure 15 Construction test

7 CONCLUSIONS

The following conclusions are drawn from the present study.

- Based on results of full-scale shaking table model tests, it is confirmed that the reinforced ballasted tracks with stacked geosynthetic bags have a sufficient resistance against a seismic load that is larger than the so-called Level 2 earthquake motions.
- It is confirmed that the improved version of the reinforced ballasted tracks, employing piled bags and reinforcing bars with inclination, have a horizontal bearing capacity that is comparable to that of concrete blocks.
- It is confirmed that the improved version has a sufficient seismic resistance even under a condition of wider tracks on which a larger inertia force acts during earthquakes.
- Based on results of construction tests on commercial lines, it is confirmed that improved version has good workability.

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