A new cost-effective and fast method to reinforce existing embankment slopes by nailing and geo-cell facing

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ABSTRACT: Recently a number of soil structures, in particular embankments, were seriously damaged by natural disasters, mostly severe earthquakes, heavy rainfalls, floods and their combinations. As railway is a continuous linear system, it cannot function properly even if a soil structure collapses at a single location. For this reason, soil structures, including embankments, are required to exhibit similar stability as other types of railway structure (i.e., bridges, tunnels and viaducts) when subjected to severe natural disasters, although they are much more vulnerable to natural disasters. The paper reports a new cost-effective and fast method developed to reinforce existing embankment slopes against severe earthquakes and heavy rainfalls by nailing the embankment body and covering the slope surface with geocell layers that are firmly connected to the head of nails. The research, the design method and case histories are introduced.

Keywords: earthquake, embankment, geocell, nailing, rainfall, reinforcement

1 INTRODUCTION

As railway systems are required to always function properly, they should be stable enough even when subjected to severe natural disasters. Recently, a number of severe earthquakes occurred in Japan, including the 1995 Hyougo-kenn Nambu, the 2004 Niigata-ken Chuetsu, the 2011 Tohoku-chiho Taiheiyo-oki and the 2016 Kumamoto Earthquakes. Since the 1995 Hyougo-kenn Nambu Earthquake, the seismic design for railway structures to be newly constructed and the reinforcement of existing structures taking into account such strong seismic loads as experienced in this earthquake (called Level 2 seismic load) have been performed first with RC structures and then with soil structures. However, the number of existing soil structures, in particular embankments, to be reinforced is tremendous. Therefore, the development of cost-effective technology that can alleviate this problem has been strongly required. In addition, recently the number of embankments that collapsed by heavy rainfall, of which the intensity has become stronger and the duration of heavy rain at the same place has become longer than before, is increasing. Therefore, the development of a method or methods that can cost-effectively and quickly reinforce existing embankments against both of severe earthquakes and heavy rainfalls has become necessary. In this paper, a new method using geo-cells and nailing developed for this purpose is reported.

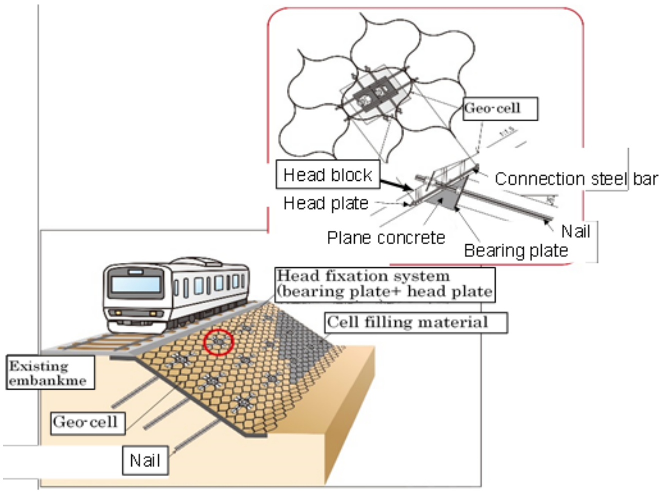

Figure 1. A new method to reinforce embankment slope

2 DEVELOPMENT OF A NEW REINFORCEMENT TECHNOLOGY

As illustrated in Fig. 1, the slope surface of existing embankment is covered with layers of geo-cell made of HDPE (high density polyethylene; Fig. 2). These geocell layers are firmly connected to the head of nails that have been installed in the embankment so that sufficiently large connection forces can develop. Then, the facing of geocell layers can apply sufficient confining pressure to the slope while sufficiently large tensile forces can be developed in the nails. In addition, the geocell layers stabilized by this connection can effectively protect the slope from erosion during heavy rainfalls. In these ways, the embankment reinforced by this method can behave in an integrated way exhibiting a high stability against severe seismic loads and strong seepage forces and surface flow by heavy rainfalls. This method is excellent not only in workability but also in cost-effectiveness and applicability due to the following characteristic features: 1) Geo-cell is light, therefore easy to transport and handle when arranged at the site, while the seismic inertial becomes small. 2) Geocell is not corrosive.3) It is easy to cover the whole slope of embankment. 4) Various materials can be used to fill the cells, such as plane concrete for high stability or soil for vegetation, to be completed as slope facing.

a) Expanded geocell b) Folded geocell

Figure 2. Geo-cell

3 CONNECTION STRENGTHS

The performance of the reinforcement system is controlled by: 1) connection strength between the geocell layer and the nail; and 2) connection strength between adjacent geocell units. These were evaluated experimentally.

3.1 *Geocell - nail connection*

A tensile loading test was performed to evaluate the geocell – nail connection strength as shown in Fig. 3, where the upward direction denotes the embankment side. Tensile load was applied to a vertically arranged nail, which was resisted by the reaction force applied to the back face of the geocell layer. Fig. 4 shows the planned and measured histories of tensile load and the time histories of vertical displacements of the nail and the mortar block in contact with the bearing plate at the head of the nail, together with the horizontal displacement at the right end of the horizontal bar connecting the cells of the geocell layer. At state 1, failure started at the periphery of the connection block, which resulted in a small temporary drop in the load. At state 2, progressive failure started in the head block, which resulted in unstable behavior of the tensile load. At state 3, the maximum load was reached as a result of failure of the head block associated with the failure of connection rod horizontally arranged inside the geocell layer. At state 4, the load started decreasing as a result of total failure of the head block. As the measured maximum load, 48 kN, is much larger than ordinary design limit tensile resistance of nail, equal to about 30 kN, this geocell – nail connection will not become a weak point of the system in ordinary cases.

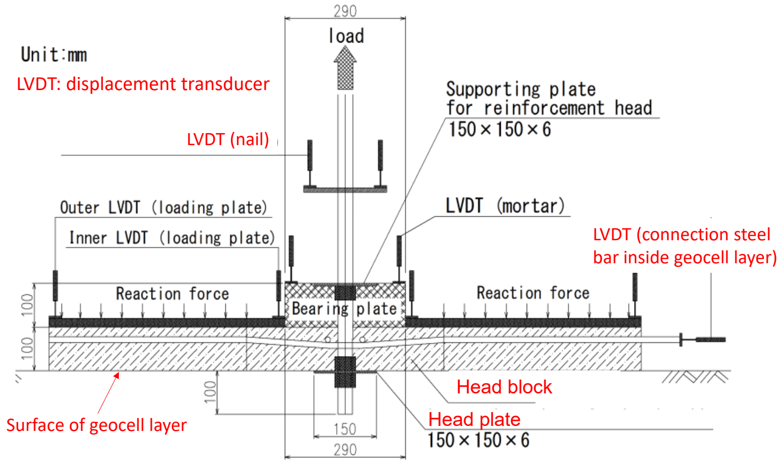

Figure 3. Loading test on geocell- nail connection

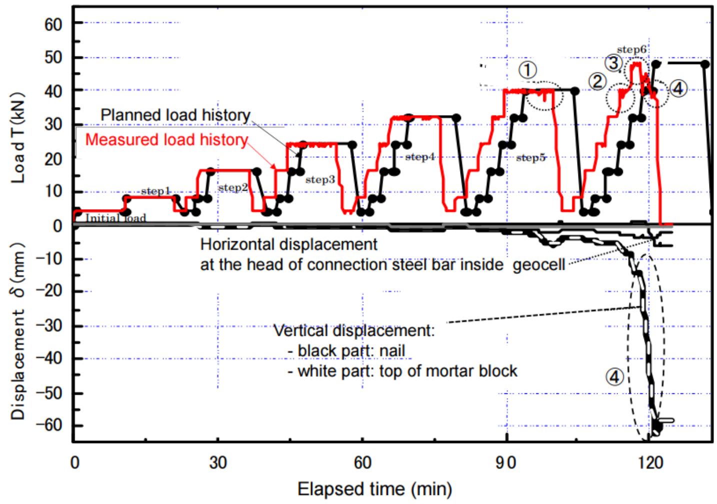

Figure 4. Test result

Figure 5. Connection method

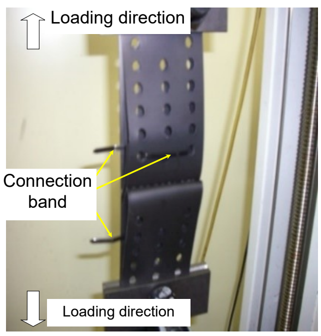

Figure 6. Tensile test on the geocell unit connection

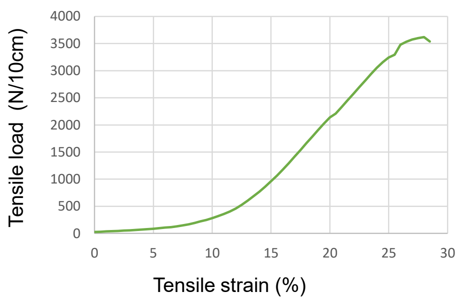

Figure 7. Test result

3.2 *Connection of geo-cell units*

A single geo-cell unit, which is 14.25 m in length, 2.56 m in width, 0.1 m in height, usually cannot cover the whole area of a given slope. Usually several geo-cell units are connected to each other in ordinary projects. In that case, the connection strength should be equal to, or higher than, the strength of geocell unit. Besides, the connection method should be simple and fast enough to connect many units at the site. Although the conventional connection method using a stapler is simple and fact, which is usually used for non-structural geocell systems, the connection strength is not large enough for the system shown in Fig. 1. In view of the above, a new method connecting adjacent units by inserting bands of polypropylene in holes and tighten them by hand (Figures 5 and 6) was developed. To evaluate the connection strength, tensile loading tests were performed following the tensile loading test method of geocell unit specified by the US Corps of Engineers (Figure 6). Figure 7 shows the test result. The tensile strength per 10 cm is about 3500kN, which is much larger than the product assurance strength of geocell unit (1700 kN). Therefore, this connection method is applicable to the reinforcement system (Fig. 1).

4 DESIGN

In the design of the reinforcement system shown in Fig. 1, the stability and residual deformation of reinforced embankment and geo-cell facing when subjected to Level 2 earthquake ground motion is evaluated by following the flow shown in Fig. 8, which is applicable to embankment slopes in general. It is confirmed that the tensile force that develops in the geocell, T_d, is smaller than its allowable strength, T_a by Eq. (1) that was developed based on the cable theory.

$$\gamma i = \frac{[illegible]}{[illegible]} \leq 1.0 \qquad (1)$$

where γg is material index, T_d is evaluated by the equation shown in Fig. 9, where *f* is the limit value of the deflection determined by multiplying the deflection ratio corresponding to the limit value of the tensile strain by the material coefficient, the material correction coefficient and the spacing between adjacent nails.

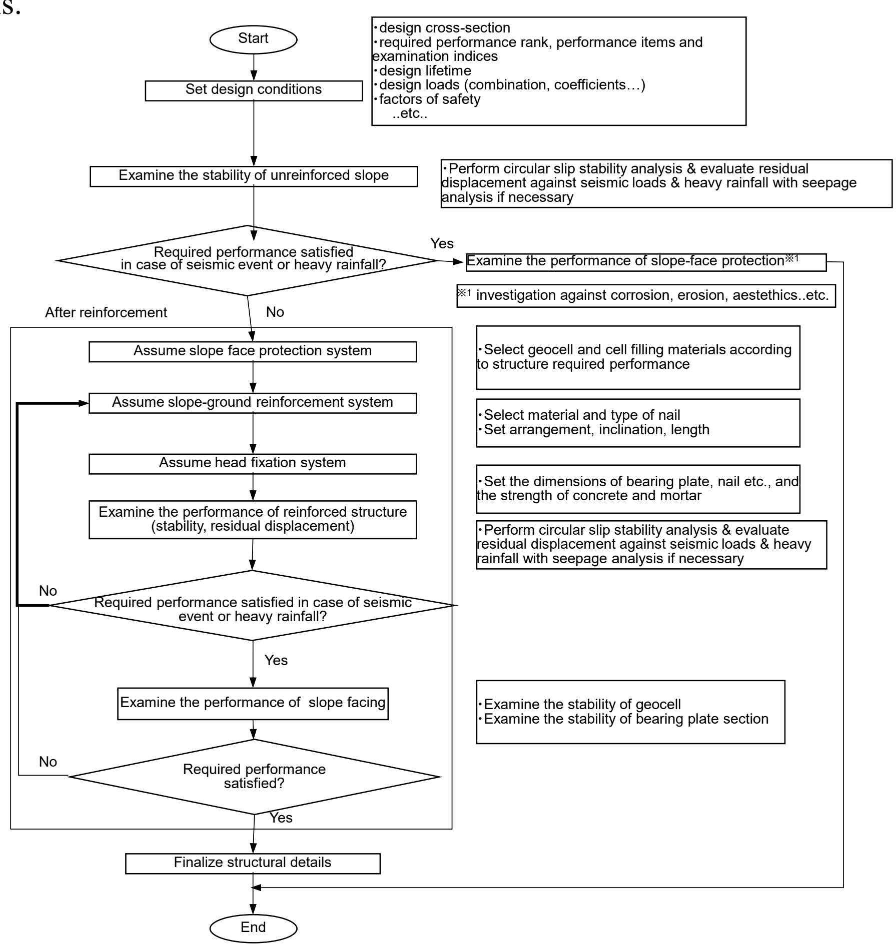

Figure 8. Flow of design

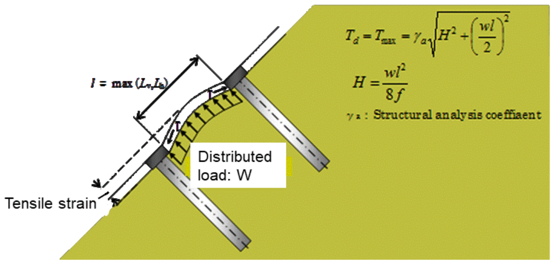

Figure 9. Cable theory to evaluate the ten-sile force Td in geocell.

5 CASE HISTORIES

This method was applied to several railway embankments. Fig. 10a shows embankments of Sanriku Rai-way that were damaged by the 2011 Tohoku-chiho Taiheiyo-oki Earthquake and reinforced as shown in Fig. 11. Although these embankments were damaged, they did not fully collapse with the main body hav-ing survived. Therefore, this method was chosen as the most cost-effective and fast method. Typically in this case, this method could reinforce existing slopes by nailing without reconstruction by excavation and filling while the slope face could be covered with geocell layers without using large construction plants. On the other hand, Figs. 10b and c show an existing embankment for an ordinary railway that was rein-forced by this method to be used for a new high speed railway (i.e., Hokkaido Shinkansen).

6 CONCLUSIONS

(a) Sanriku Railway (b) Hokkaido Shinkansen (c) Hokkaido Shinkansen

Figure10. Projects where the proposed method was used

(a) Nailing (b) Arranging geo-cell layers (c) Shotcrete on geocell lay-ers

Figure11. Construction procedure

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