Seismic Design of Geogrid Reinforced Soil Embankment

- Standard Design of New Shinkansen Railway –

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ABSTRACT: In construction of the New Shinkansen railway, the ballast track is superseded by slab track in order to achieve the running stability during big earthquakes as well as to reduce the maintenance costs of the railway. However, the allowable deformation of the slab track-type embankment at usual as well as earthquake stages is severely limited. Accordingly, it is an important subject to find a reasonable as well as economic design of geogrid reinforced embankment against the predicted big earthquakes. In this paper, the required length of the geogrid reinforcement including its arrangement are examined together with other important design factors such as height and slope of embankment, filled materials, performance in compaction and subsoil conditions etc.

1 INTRODUCTION

Fig.1 shows the slab track-type embankment to be applied in the New Shinkansen Project in place of the existing ballasted track, which will reduce the maintenance costs (RTRI 1999b). In construction of the slab track on the embankment, more careful consideration on the seismically-induced permanent deformation is required compared to construction of the conventional type of ballasted track to achieve its higher requirement for the safety of the high speed trains against big earthquakes. To raise the seismic performance of the slab track on the embankment against the big earthquakes, a method of geogrid reinforcement is introduced here based on the below-stated study. The study aims to present the standard seismic design of Geogrid Reinforced Soil (GRS) embankment. Through the study, various factors affecting on the seismic performance, such as arrangement of geogrid reinforcement, height of embankment, slope gradient, subsoil conditions etc. are examined. According to the Japan railway seismic design standard, the seismic performance should be examined for the seismically-induced permanent deformation of embankment for big earthquake. After the Hyogoken-Nambu Earthquake in 1995, the level two earthquake, which represents big earthquake in Japan, was introduced into the seismic design for important infrastructures.

This paper describes the analysis method and results for the said affecting factors and presents the rational geogrid reinforcement arrangement pattern on the design standards of GRS embankment.

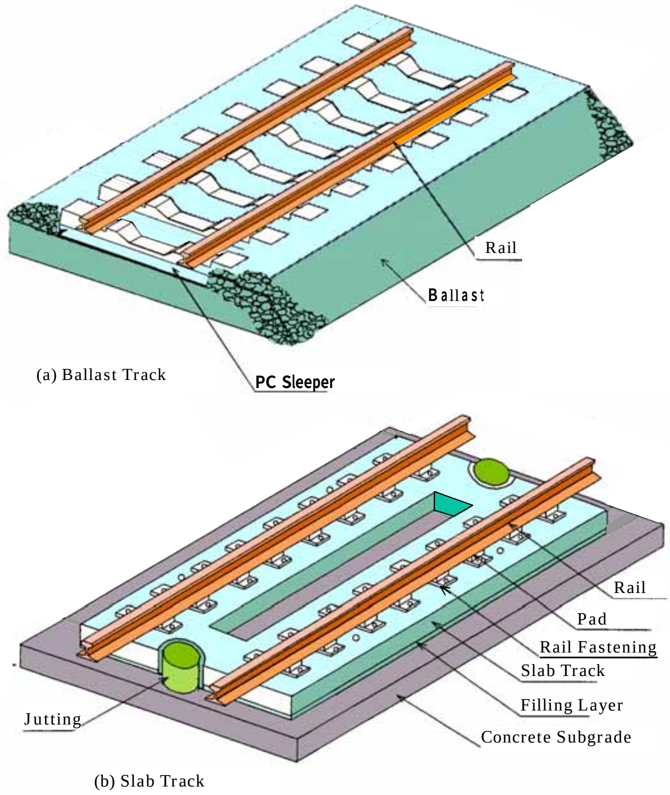

Fig. 1. Section of railway track.

2 SEISMIC DESIGN METHOD

This design method intends to standardize the seismic design of GRS embankment with slab track. Seismically-induced permanent deformation of embankment is mainly caused by 1) sliding displacement along the slip circle of the embankment, 2) shearing deformation due to shaking of embankment, and 3) subsidence due to shaking of subsoil (see Fig.2), and each of which is calculated as follows.

1) Sliding displacement along the slip circle (see Fig.3) : This is calculated by Newmark method (Newmark 1965), applying its theory to the slip circle of the embankment (Horii et al. 1997a).
2) Shear deformation of the embankment : This is calculated based on the accumulated damage concepts (Horii et al. 1997b).
3) Subsidence of subsoil : This is calculated based on the dynamic response analysis for subsoil during earthquake.

Details of these method are referred to RTRI 1999a and 1999b.

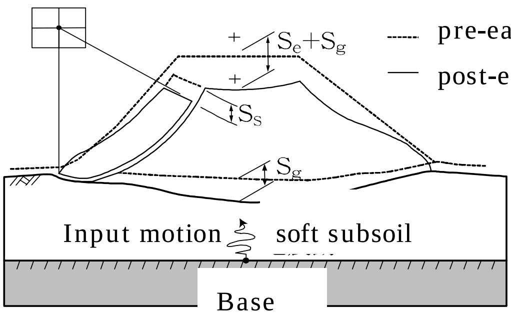

Fig. 2. Schematic drawing of seismic deformation.
(Ss : sliding displacement, Se : Settlement of embankment, Sg : Subsidence of subsoil)

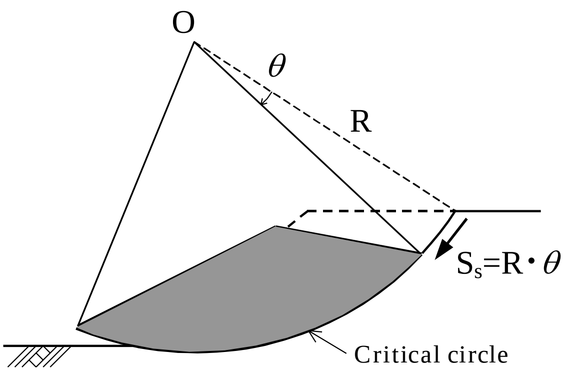

Fig. 3. Sliding displacement along slip circle.
(R : Radius of slip circle, θ : Angle of rotation)

3 ANALYSIS CONDITIONS AND SUPPLEMENTAL EXPLANATION

1) Width of embankment: 11.7 m.
2) Orbital load: 15 kN/m^2
3) Inclination of slope: 1(V) to 1.5(H) and 1(V) to 1.8(H)
4) Height of embankment: 3.0 m, 6.0 m and 9.0 m.
5) Input motion of big earthquake is specified by subsoil classification. The subsoil is classified by the fundamental period given in Table 1. Waveforms of big earthquakes are given in Fig.4. These waveforms are applied to earth structures in Japan railway (Tateyama et al. 1999, Murono et al. 2000).

Table 1. Subsoil Type (RTRI 1999a).

Subsoil Type	Fundamental period (sec)	Soil Condition
G0	—	Rock
G1	—	Base
G2	～0.25	Diluvium
G3	0.25～0.5	Medium

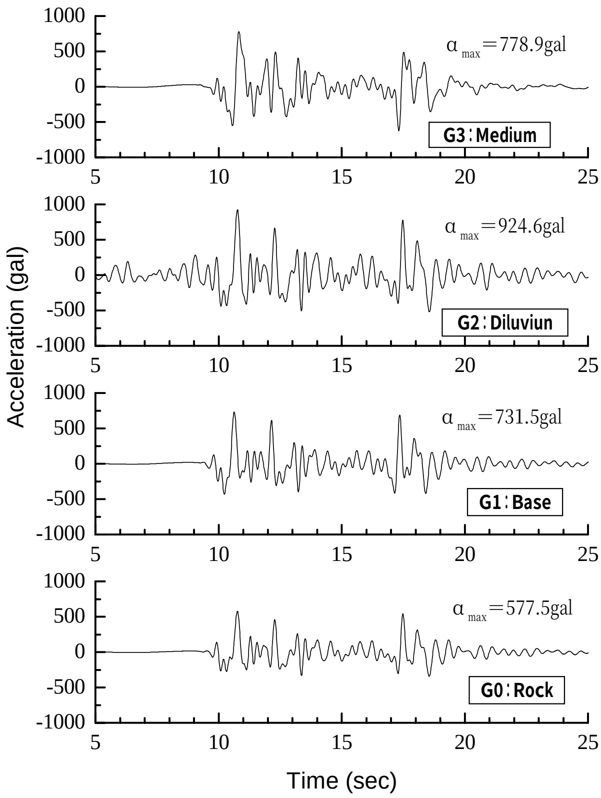

Fig. 4. Input earthquake motion for embankment.

6) Soil material properties of embankment specified in the Design Standard are applied, whose details are given in Table 2 (RTRI 1999a). The relative compaction of the soil type 1 is 95% and more.
7) Different tensile strengths of the geogrid reinforcement of T = 30, 40, 50, 60 and 80 kN/m are applied. And the standard depth interval between the GRSs is taken at 1.5 m. Also, the short reinforcement (geonet) with 2m in length is

installed vertically with 0.3m pitch near the surface of slope to ensure quality of construction. Tensile strength of this short reinforcement is taken at T= 2 kN/m.

8) Fig. 5 shows five patterns of geogrid arrangement in embankment tried.
9) Allowable displacement is governed by two factors, i.e., easiness of recovering, and ensuring the stability and cursorialbility of slab track after earthquake. Once excessive displacement occurred at the orbit, it is not easy to restore its original state. Lessons learnt from the damages of the elevated bridges caused by Hyogoken-Nambu Earthquake (RTRI 1996), allowable displacement of orbit is set nearly at 10 cm.
10) Displacement of shearing deformation is analyzed taking the results of the existing studies into consideration (Yonezawa et al. 2000). Settlement of the subsoil is excluded from the total displacement on the assumption that the supporting ground is high ranked subsoil.

Table 2. Soil Properties of embankment.

Soil Type	Soil Materials	Layer	Unit Weight	Slope Portion (2m Width)	Central Portion
1	Well Graded Sand, Gravel, Rock Debris	Upper layer	18 kN/m^3	$\phi = 45°$ $c = 3\ kN/m^2$	$\phi = 50°$ $c = 6\ kN/m^2$
		Lower layer	18 kN/m^3	$\phi = 40°$ $c = 3\ kN/m^2$	$\phi = 45°$ $c = 6\ kN/m^2$
2	Moderate Sand, Gravel	Upper layer	17 kN/m^3	$\phi = 40°$ $c = 3\ kN/m^2$	$\phi = 45°$ $c = 6\ kN/m^2$
		Lower layer	17 kN/m^3	$\phi = 35°$ $c = 3\ kN/m^2$	$\phi = 40°$ $c = 6\ kN/m^2$

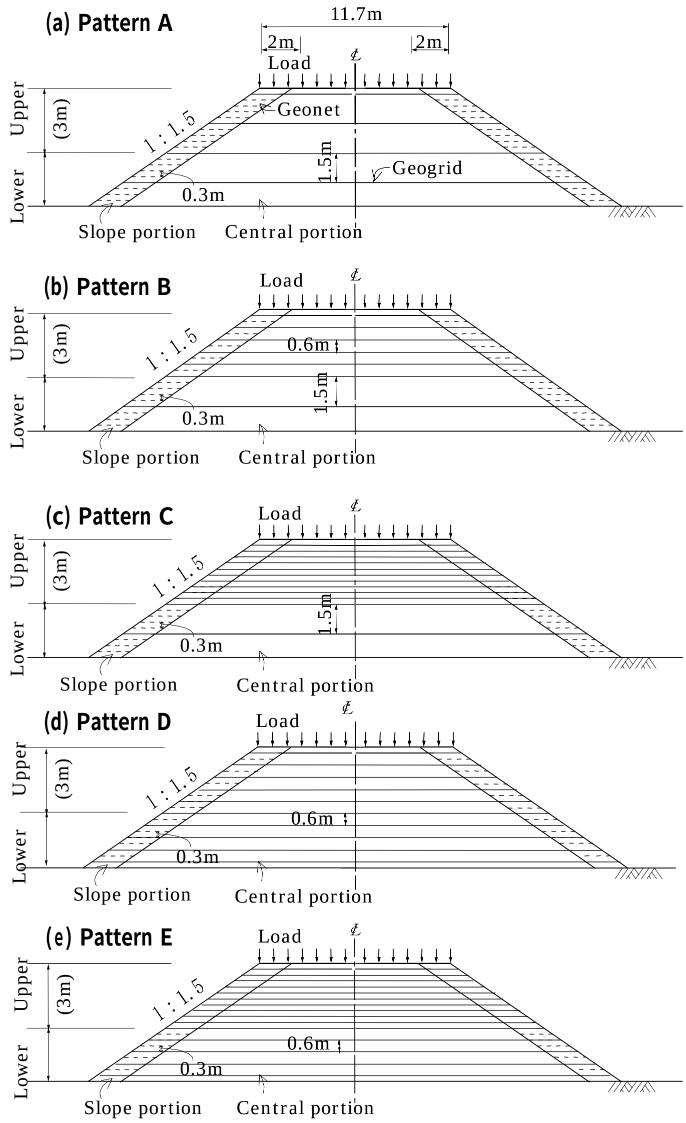

Fig. 5. Arrangemant of geosynthetic reinforcement.

Fig.6 shows the relationship between total displacement and height of embankment , consisted of soil type 2 with the tensile strength of 30 kN/m and subsoil 2, depending on the different reinforcement patterns. From Fig.6, we can see the tendency that the higher the density of reinforcement, the smaller displacement. The reason for this may be attributed to the resisting moment due to the geogrid reinforcement dominated by the intersecting angle between the directions of reinforcement and slip line.

4 SUMMARY OF RESULTS

We conducted the analysis varying the parameters for different conditions of the geogrid reinforced soil embankment. The qualitative tendency over each condition was clarified. Details of analysis are referred to Yonezawa et al. 2000. Analytical results are summarized as follows.

1) When the arrangement of interval of geogrid reinforcement is the same, if strength of reinforcement increases, yield acceleration coefficient becomes bigger, and the location of critical slip circle is deepened. Consequently, the displacement of sliding is also reduced. This suggests that the strength of reinforcement can adjust the amount of displacement.

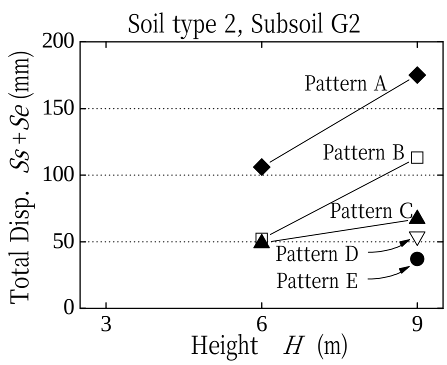

Fig. 6. Relationship between total displacement and height of embankment.

2) Soil type 1 can reduce the amount of displacement compared to soil type 2.
3) Increase in density of embankment by compaction reduces the amount of displacement.
4) The amount of displacement becomes bigger in proportion to the height of embankment.
5) If the inclination of slope becomes gentle, the amount of displacement will decrease. Furthermore, the rate of this reduction effect becomes large, so that embankment height becomes higher.
6) The amount of displacement with berm is less compared to that of without berm.
7) As for the difference in subsoil classification, the amount of displacement becomes bigger at G0, G1, G3, and G2 in order. This suggests that we must make careful judgement on the classification of subsoil.
8) When the reinforcement is arranged densely, the amount of displacement decreases, if the strength of reinforcement is the same.
9) As for reduction effect of the amount of displacement, upper reinforcement is more effective than the lower one.

5 PROPOSAL FOR RATIONAL GEOGRID REINFORCEMENT ARRANGEMENT PATTERN

Fig.7 shows the worked-out relationship between the displacement and the height of embankment to keep the displacement within the allowable limit. Here, we propose to adopt the pattern A (soil type 2, inclination of slope of 1(V) to 1.5(H), subsoil G2m, this case shows biggest displacement among other cases) with the condition of providing upper reinforcement which has high tensile strength, in view of saving the construction cost and safety.

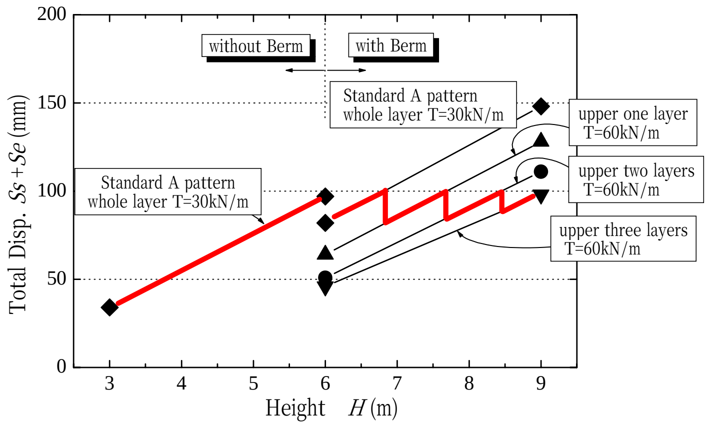

Figure 7. Relationship between total displacement and height of embankment (Soil type 2, Subsoil G2, Slope 1(V) to 1.5(H)).

6 CONCLUSION

The displacement caused by strong earthquake is affected by many factors, such as arrangement of the geogrid reinforcement, embankment material, inclination of slope etc. These factors are clarified. In view of rational and economical design, we propose that the embankment with slab track should be adopted for New Shinkansen railway project.
In the seismic design for strong earthquake, the calculation method of sliding displacement of reinforced soil embankment by modified Newmark method is practically effective, and it is also useful for the evaluation of countermeasure effects.

REFERENCES

RTRI (1999a). “Design Standard of Railroad Structure - Seismic Design”, 467pp.

RTRI (1999b). “Design Standard of Railroad Structure – Earth Structure for Laborsaving Orbit”, 252pp.

RTRI (1996). “Report on Disaster of Railroad in Hyogoken-Nambu Earthquake”, RTRI Report, Sp.Vol.4, pp.39-40.

N. M. Newmark (1965). “Effects of Earthquakes on Dams and Embankments”, Geotechnique, Vol.15, No.2, pp.139-159.

Horii, K., Tateyama, M., Uchida, Y., Koseki, J. and Tatsuoka, F. (1997a). : “Evaluation of Seismically Induced Permanent Displacement of Railway Embankment by Newmark Method”, the 32nd Annual Meeting of Japan Geotechnical Conference, pp.1895-1896.

Horii,K., Tateyama, M., Kojima,K. and Koseki, J. (1997b). “Evaluation of Seismically Induced Permanent Settlement of Sandy Soil Embankment”, the 52nd Annual Meeting of Japan Society of Civil Engineers, pp.148-149.

Tateyama, M., Murono Y., Horii, K., Yonezawa, T., Koseki, J. and Tatsuoka, F. (1999). “Effects of Seismic Waveforms on Permanent Deformation of Geogrid Reinforced Soil Wall”, the 54th Annual Meeting of Japan Society of Civil Engineers, pp.620-621.

Yonezawa, T., Aoki, H., Tateyama, M., Kojima, K., Horii, K. and Tokita, Y. (2000). “Study on Antiseismic Measure using Geogrid for The New Shinkansen Embankment”, Japan Geosynthetics Engineering Journal, Vol.15, pp.215-224.

Murono, T., Tateyama, M., Aoki, H., Horii, K. and Tokita, Y. (2000). “Effects of Seismic Waveforms on Permanent Deformation of Geogrid Reinforced Soil Embankment”, Seismic Design of Earth Structures for Level 2 Earthquake Symposium, Japan Geotechnical Society, pp.347-354.

(Note)
* RTRI : Railway Technical Research Institute.
** in Japanese except Newmark (1965).