IMPROVEMENT TECHNIQUE OF EARTHQUAKE RESISTANCE OF ROAD EMBANKMENT THROUGH NUMERICAL ANALYSES

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ABSTRACT :
The 2004 Mid Niigata Prefecture Earthquake which was one of the typical near-field earthquakes caused the serious damage to many kinds of road infrastructures in the mountainous areas. Especially, a large number of road embankments, which have been used popularly as road structures in the mountainous areas, suffered remarkable damage. Therefore, the aseismic countermeasures for improving the resistance of road embankment against earthquake are required to effectively preserve the road network even at an extreme earthquake.
In this paper, two types of aseismic reinforcement techniques of road embankments are investigated in order to develop efficient and economical techniques for improving the resistance of road embankments against earthquake. Firstly, the numerical analytical, in which an elasto-plastic finite element analysis is applied, is proposed to calculate the resistance of road embankment against earthquake. In the analyses, the centrifuge model tests which were carried out to demonstrate experimentally the improvement of resistance of road embankments against earthquake is chosen as an analytical model. In the numerical analyses, the reinforcement area is chosen as a variable parameter. Finally, the availability of aseismic reinforcement techniques to the improving resistance against earthquake is discussed. Furthermore, the deformation characteristics of embankments, especially, location of sliding surface in the embankments are discussed, too.

KEYWORDS:
Road embankment, Reinforcement, Earthquake, Numerical analysis, Improvement

1. INTRODUCTION

The 2004 Mid Niigata Prefecture Earthquake which was one of the typical near-field earthquakes caused the serious damage to many kinds of infrastructures in the central area of Niigata Prefecture. Especially, a large number of road embankments, which have been used popularly as road structures in this area, suffered remarkable damage. The damage of road caused the disruption of the road network in this area, so that it was difficult to deal with an emergency rescue and rehabilitation. About 70% of Japanese country is mountainous area. There are a large number of cities, towns and villages in mountainous areas in Japan. Therefore, the aseismic countermeasures for improving the resistance of road embankments against earthquake are required to effectively preserve the road network even at an extreme earthquake.
In this paper, two types of aseismic reinforcement techniques of road embankments, reinforcing toe of embankments and reinforcing the upper surface of embankments, are investigated analytically in order to develop efficient and economical techniques for improving the resistance of road embankments against earthquake. Firstly, the numerical analytical, in which an elasto-plastic finite element analysis is applied, is proposed to calculate the resistance of road embankment against earthquake. Secondly, a series of numerical analyses, in which the height of reinforcement lump at toe of embankments is a variable parameter, is carried out. Thirdly, another series of numerical analyses, in which the length of reinforced area at the upper surface of embankments is a variable parameter, is carried out. Finally, the improvement of resistance against earthquake

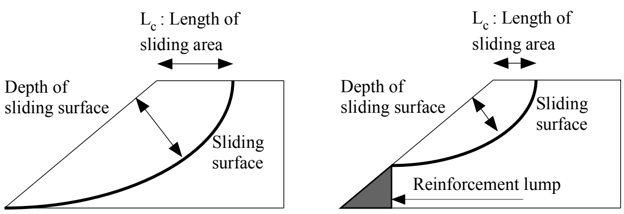
is discussed. Furthermore, the effect of sliding failure is discussed based on the residual deformation at the upper surface of embankments.

2. NUMERICAL ANALYSIS

The numerical analysis, in which an elasto-plastic finite element method was applied, was carried out on the basis of the idea of the seismic coefficient method (Oda et al, 2006A, 2006B). In this analysis, Drucker-Prager criteria is applied as both yield function and plastic potential. In the elasto-plastic calculation, the plastic strain increment is calculated with a return mapping algorithm (Oritz & Simo, 1986) based on non-associated flow role. Also, the spherical arc length procedure proposed by Crisfied (1991), one of the representative displacement control technique, is applied, so that the stable numerical calculation can be carried out.
In the analysis, firstly, self-weight analysis was carried out to determine the initial stress condition. In this analytical stage, the only vertical body force estimated from unit-weight, is applied in each finite element. Secondly, the horizontal body force increases gradually, so that the resistance of embankments to the horizontal body force is mobilized perfectly. The ultimate seismic coefficient can be calculated from the horizontal body force at the mobilized perfectly. Also, the residual deformation in the embankments can be computed in this analysis.

3. TOE REINFORCEMENT

Figure 1 shows schematic diagrams of embankment both without reinforcement and with reinforcement at its toe. The deformation of embankment will be restricted with reinforcing the toe of embankment, so that its seismic resistance will be improved. The advantages of reinforcing the toe of embankments are as follows;
1) The construction of reinforcements can be carried out without suspending the traffic.
2) The sliding zone can decrease, because the substantial height of embankments for sliding failure decreases.



(a) Non-Reinforce (b) Reinforce

Figure 1 Schematic diagrams of both Non-reinforce and Reinforce embankment.

3.1. Analytical Model, Parameters and cases

Figure 2 shows the analytical model used in the numerical analysis. This analytical model was based on the prototype in a series of centrifuge model test for seismic behavior of embankment (Yoshino et al, 2006). The height of embankment is 9m, the width of upper surface and bottom surface of embankment is 6m and 19.5m, respectively. The displacements at the bottom boundary of analytical model are completely restricted. The displacement in the horizontal direction is restricted at the side boundary of the analytical model.

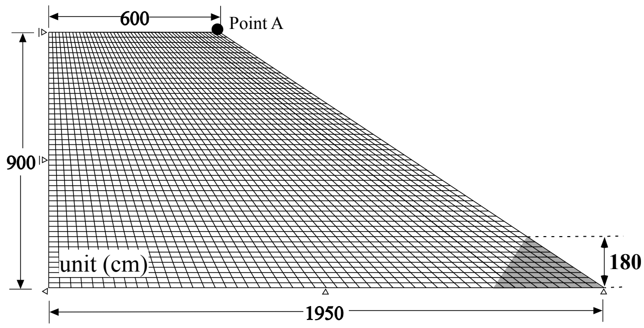


Figure 2 Analytical model (toe reinforcement)

The horizontal body force acting on each element, f_H, is calculated in the following equation.

$$f_H = \alpha_H \rho V_e \tag{3.1}$$

where ρ, density, V_e, volume of each element and α_H, horizontal acceleration. In these analyses, α_H increases linearly with height of embankments. α_H at the upper surface of model embankment is two times of that at the bottom of model embankment.

Table 1 Analytical parameters

a) Embankment body

Elastic modulus	2.45×10^4kN/m^2
Poisson's ratio	0.3333
Cohesion	7.3kN/m^2
Internal friction angle	36.3°

b) Reinforcement

Elastic modulus	2.45×10^6kN/m^2
Poisson's ratio	0.3333

Table 2 Analytical cases

H-0	x: 0.0cm (No reinoforcement)
H-54	x: 54.0cm
H-90	x: 90.0cm
H-144	x: 144.0cm
H-198	x: 198.0cm

The embankment body and reinforcement lump were modeled as perfect elasto-plastic and elastic materials, respectively. Table 1 shows the analytical parameters used in the analysis.
Table 2 shows the analytical cases. The height of reinforcement lump at the toe of embankment was chosen as variable parameters in the numerical analysis.

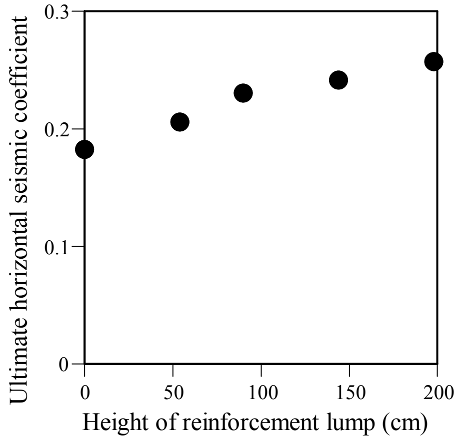


Figure 3 Relationship between ultimate horizontal seismic coefficient and height of reinforcement lump

3.2. Analytical Results

Figure 3 shows the relationship between the ultimate horizontal seismic coefficient, k_{Hmax}, and height of reinforcement lump at the toe of embankment. k_{Hmax} is calculated in the following equation.

$$k_{H\max} = \frac{\alpha_H}{g} \tag{3.2}$$

where g is gravity. The larger the height of reinforcement lump is, the larger k_{Hmax} is. That is, the improvement of resistance against horizontal body force is achieved through reinforcement at toe of embankments.

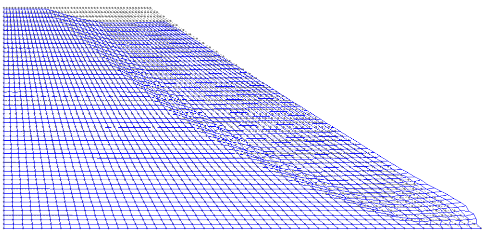


Figure 4 Residual deformation of model embankment in H-0

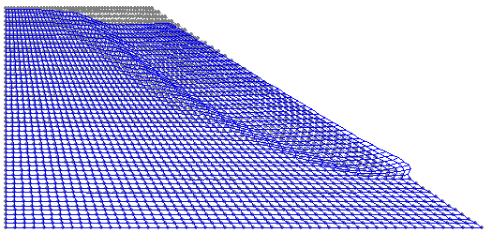


Figure 5 Residual deformation of model embankment in H-198

Figures 4 and 5 show the residual deformation of model embankment in H-0 and H-198, respectively. The numerical analyses can represent the sliding failure of embankment very well. The sliding surface reaches from the toe of embankment to the middle of upper surface of embankment in H-0. Also, it reaches from the top of reinforcement lump to the middle of upper surface of embankment in H-198. The new parameter, L_c, which is length of sliding area, is defined as shown in Figure 1, in order to estimate quantitatively the effect of sliding failure on the soundness of runway on upper surface of embankment. That is, the soundness of runway, which is usually located at the middle part of crest of embankment, will be kept, if the sliding surface reaches near the edge of upper surface of embankment. Figure 6 shows the relationship between L_c and height of reinforcement lump. As far as the height of reinforcement lump is about one-fifth of the height of model embankment, it hardly affects

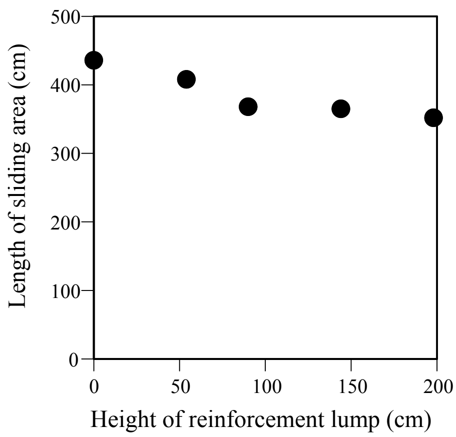


Figure 6 Relationship between L_c and height of reinforcement lump

L_c. Consequently, the position of sliding surface in the embankment hardly can be controlled through reinforcement at the toe of embankments.

4. CREST REINFORCEMENT

The soundness of runway at the upper surface of embankments should be kept, although the embankments suffered some damage caused by earthquakes. The traffic will not be suspended, if the soundness of runway can be satisfied. In the idea of reinforcement at the upper surface of embankment, the embankment directly underneath the runway at the upper surface of embankment is reinforced, in order to prevent the occurrence of sliding failure and keep the flatness of runway.

4.1. Analytical Model, Parameters and cases

Figure 7 shows the analytical model used in this series of analyses. This analytical model was based on the prototype in a series of centrifuge model test (Yoshino et al, 2006), too. The brown part in the model embankment is reinforced area in Figure 7. "L" and "T" are length and thickness of reinforced area, respectively. Also, the embankment body and reinforcement were modeled as perfect elasto-plastic and elastic materials, respectively. The analytical parameters used in the analyses are shown in Table 1.

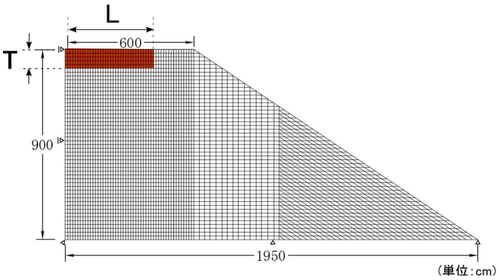


Figure 7 Analytical model

Table 3 Analytical cases

L-0	L: 0.0cm (No reinoforcement)
L-240	L: 240.0cm
L-360	L: 360.0cm
L-480	L: 480.0cm
L-600	L: 600.0cm

Table 3 shows the analytical cases. The only length of reinforcement area at the upper surface of embankment was chosen as variable parameters. The thickness of reinforcement area is 72cm in all analytical cases.

4.2. Analytical Results

Figure 8 shows the relationship between the ultimate horizontal seismic coefficient, k_{Hmax}, and length of reinforcement are at the crest of embankment. k_{Hmax} slightly increases with increasing length of reinforcement area. Especially, k_{Hmax} in L-600 is not much greater than that in L-0, although the all over upper surface of embankment is reinforced. Consequently, the resistance against horizontal body force will be just a little improved with reinforcement at the upper surface of embankments.

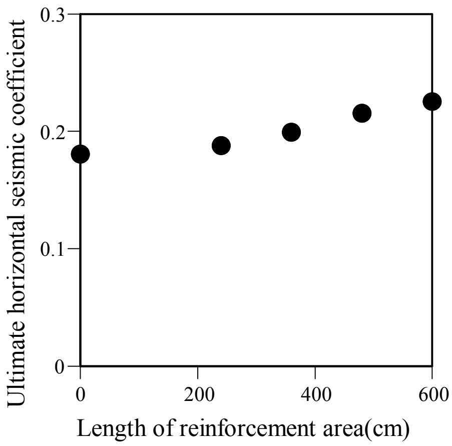


Figure 8 Relationship between ultimate horizontal seismic coefficient and length of reinforcement area

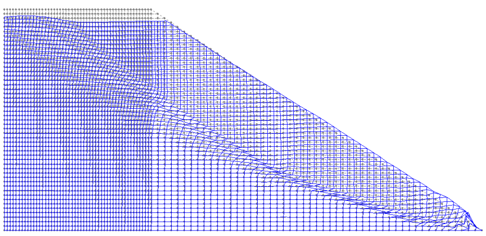


Figure 9 Residual deformation of model embankment in L-0

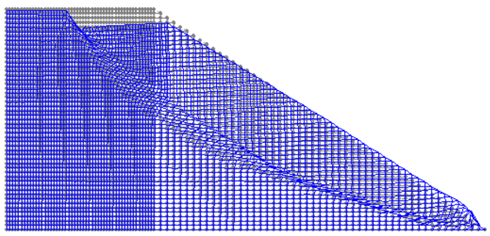


Figure 10 Residual deformation of model embankment in L-240

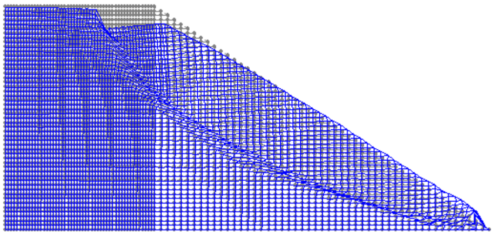


Figure 11 Residual deformation of model embankment in L-360

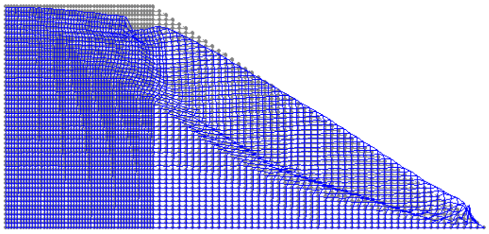


Figure 12 Residual deformation of model embankment in L-480

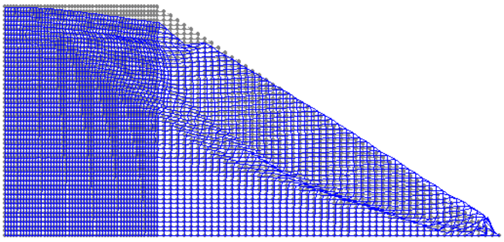


Figure 13 Residual deformation of model embankment in L-600

Figures 9, 10, 11, 12 and 13 show the residual deformation of model embankment in L-0, L-240, L-360, L-480 and L-600, respectively. It is clearly found that a single sliding surface is developed in L-0, L-240 and L-360. Especially, the sliding surface reaches from the toe of embankment to off right edge of reinforced area at upper surface of embankments in L-240 and L-360. The sharp drop occurs between reinforced area and non-reinforced area in these cases. Also, the reinforced area is hardly deformed, so that the upper surface in the reinforced area is almost flat. That is, the upper surface in the reinforced area is hardly affected by the sliding failure of embankment. On the other hand, the sliding surface in the embankment underneath the reinforced area is not clearly developed in L-480 and L-600. The drop between reinforced area and non-reinforced area is not remarkable in these cases. Also, the upper surface in the reinforced area is flat but even. The reinforced area can prevent the development of sliding failure to the upper surface of embankment. Consequently, the availability of reinforcement at the upper surface of embankment on keeping its evenness could be suggested through these numerical analyses.

5. CONCUSIONS

In this paper, two types of aseismic reinforcement techniques of road embankments, reinforcing toe of embankments and reinforcing the upper surface of embankments, are investigated analytically in order to develop efficient and economical techniques for improving the resistance of road embankments against earthquake. Main conclusions are summarized as follows:

1. The numerical analyses can represent the sliding failure and residual deformation of embankment very well.
2. The resistance of embankment against earthquake is improved efficiently through reinforcement at toe of embankments.
3. The position of sliding surface in the embankment hardly can be controlled through reinforcement at the toe of embankments.
4. The resistance of embankment against earthquake will be just a little improved with reinforcement at the upper surface of embankments.
5. The reinforced area can prevent the development of sliding failure to the upper surface of embankment, so that its evenness can be kept.

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