Modified conventional estimation method of residual deformation of road embankment caused by earthquake

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ABSTRACT :
In recent years, the damage of road embankments caused by earthquakes occurred frequently in the mountainous area in Japan. The estimation method for residual deformation of the road embankments caused by earthquakes must be required in order to develop the effective aseismic reinforcement technique of the road embankment. In this paper, a modified conventional estimation method, which is composed of the dynamic finite element method and Newmark's method based on seismic coefficient method, is proposed in order to estimate more accurately the residual deformation of road embankments caused by earthquakes. The availability of the proposed method is discussed through its application to a series of dynamic centrifuging model tests for seismic behavior road embankments. Also, the applicability of the proposed method to both toe reinforcement and barrier reinforcement method which has been developed in order to control the slip failure of embankments is discussed.

KEYWORDS:
Earthquake, Residual deformation, Road embankments, Dynamic finite element analysis, Newmark's method

1. INTRODUCTION

In recent years, a lot of near-field earthquakes, for example, the Mid Niigata Prefecture Earthquake in 2004, the Noto Hanto Earthquake in 2007, the Niigataken Chuetsu-oki Earthquake in 2007 and so on, occurred in Japan. A large number of highways, including arterial national highways, suffered remarkably from these earthquakes. The traffic function was lost even if a single damage which intercepts the traffic occurs in highway. The failure of traffic function causes the isolation of disaster areas, so that not only the emergency rescue but also the rehabilitation in these areas was prevented. Especially, in the mountainous area, in which the road network is not entirely established and the only highway is important lifeline, the interception of traffic might be affected more seriously. Consequently, the development of reinforcement technique for the highway structures had to be required.
By the way, a lot of embankments have been used as main highway structures in the mountainous area in Japan. In the case where the strong motion caused by great earthquake would attack the road embankments, it is not economical to keep the perfect soundness of the embankments. Even if the embankments suffered damage caused by earthquakes, it should be required to keep the soundness of runway at the top of embankments. The more accurate and convenient estimation method of residual deformation of road embankments caused by earthquakes could be required in order to develop the reinforcement technique for road embankments based on the concept for allowing the damage of embankments and keeping the soundness of runway.
In this study, a modified conventional method for estimating the residual deformation of road embankments caused by earthquake is proposed. The availability of the proposed method is discussed, through its application to a series of dynamic centrifuging model tests for seismic behavior road embankments. Also, the applicability of the proposed method to both toe reinforcement and barrier reinforcement method which has been developed

in order to control the slip failure of embankments is discussed.

2. MODIFIED CONVENTIONAL ESTIMATION METHOD

The flow chart of the modified conventional estimation method is shown in Figure 1 (Egawa, Y. et al, 2006&2007). In this method, first of all, the dynamic response behavior of road embankments are simulated through the dynamic finite element analysis, in which Ramberg-Osgood model as constitutive relationship for expressing the cyclic stress and strain behavior in order to the distribution of lateral acceleration in the road embankments caused by seismic motion. In general, the uniform lateral acceleration in embankments would be assumed in the conventional Newmark's method, although the lateral acceleration at top of embankments is more than 1.5 times of that at its bottom. Also, the distribution of lateral acceleration affects remarkably the aseismic resistance of embankments and the location of sliding surface. Therefore, the faithful reproduction of the distribution of lateral acceleration in the embankments should be required to estimate more accurately the residual deformation of embankments.
Next, when the sliding failure was occurred is determine by using circular slip method successively. In that, the successive seismic coefficient which is reflected deformation of seismic acceleration in the embankments is applied. At the last, the amount of displacement caused by sliding failure is computed using Newmark's method. In Newmark's method, the response waveform at center of sliding mass is applied to the calculation. This numerical method has some advantages. As previously noted, it can estimate the location of slip surface and displacement accurately. Considering remotely the stress-strain relation ship including strain softening, unlike anamnestic dynamic analysis, this method can represent deformation caused by sliding failure.

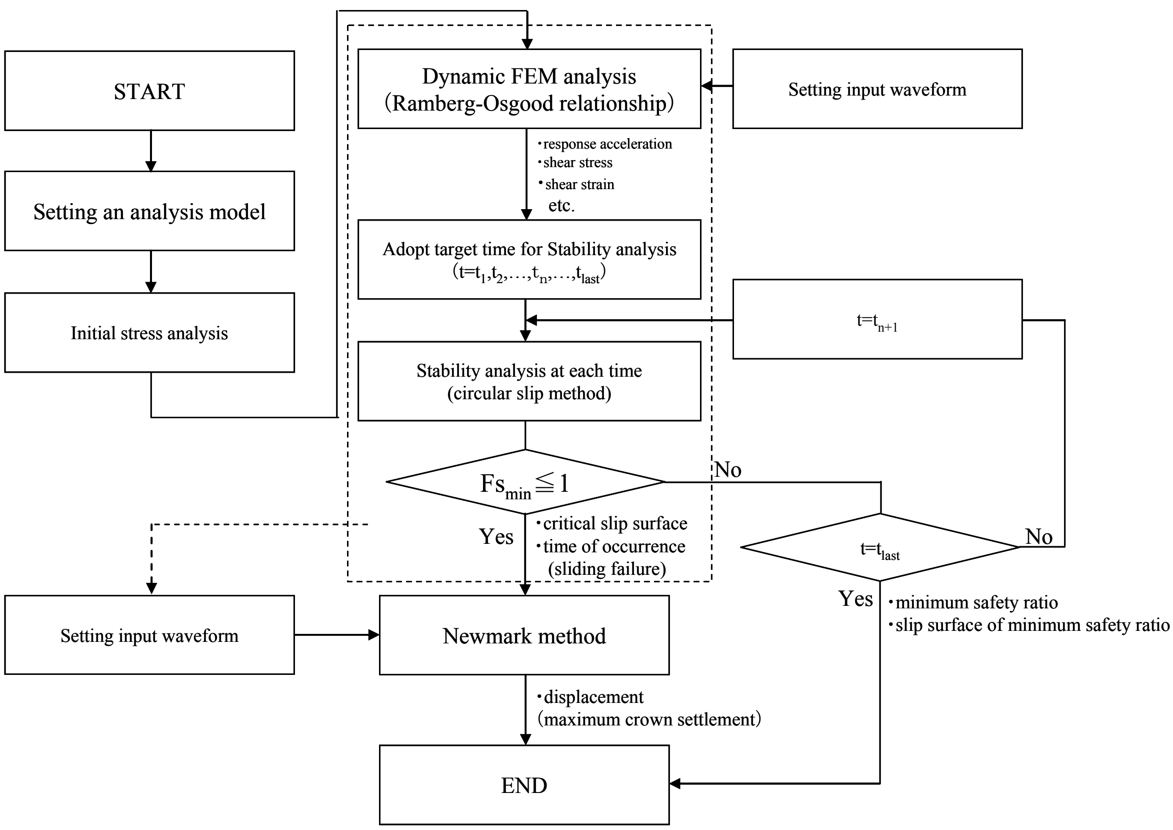


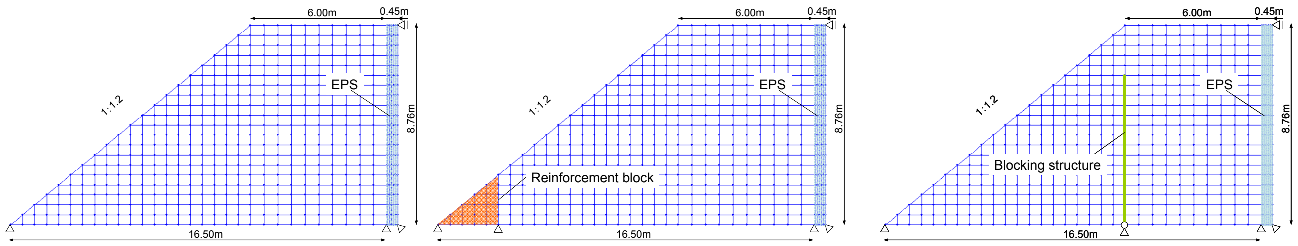
Figure 1 Flow chart of the modified conventional method

3. SIMULATION OF DYNAMIC CENTRIFUGE MODEL TESTS

The applicability of the modified conventional method is examined through the simulations of a series of dynamic centrifuging model tests for seismic behavior road embankments (Tsuma, H. et al, 2007). And its applicability as an evaluation method of the effect on control against sliding failure is reviewed. In addition, the test is simulated also by the conventional Newmark's method. Then the applicability of these two analytical approaches is weighed, and the effect of the two countermeasures: toe reinforcement and blocking structure are examined analytically.
Analytical cases are shown in Table 1, and embankment models in the dynamic analysis are shown in Figure 2. In case 3, after shaking of 300Gal, that of 500 Gal was inputted. In each model, underneath boundary condition is fixed support, and the wall surface of embankments is movable in the vertical and fixed in the horizontal

Table 1 Analytical cases

Analytical case	Coutermeasure	Maximum input acceleration
Case1	Unreinforced	300Gal
Case2		500Gal
Case3	Toe reiforcement	300Gal →500Gal
Case4	Barrier reinforcement	300Gal
Case5		500Gal



(a)Case1 and 2 (b)Case3 (c)Case4 and 5

Figure 2 Analytical model

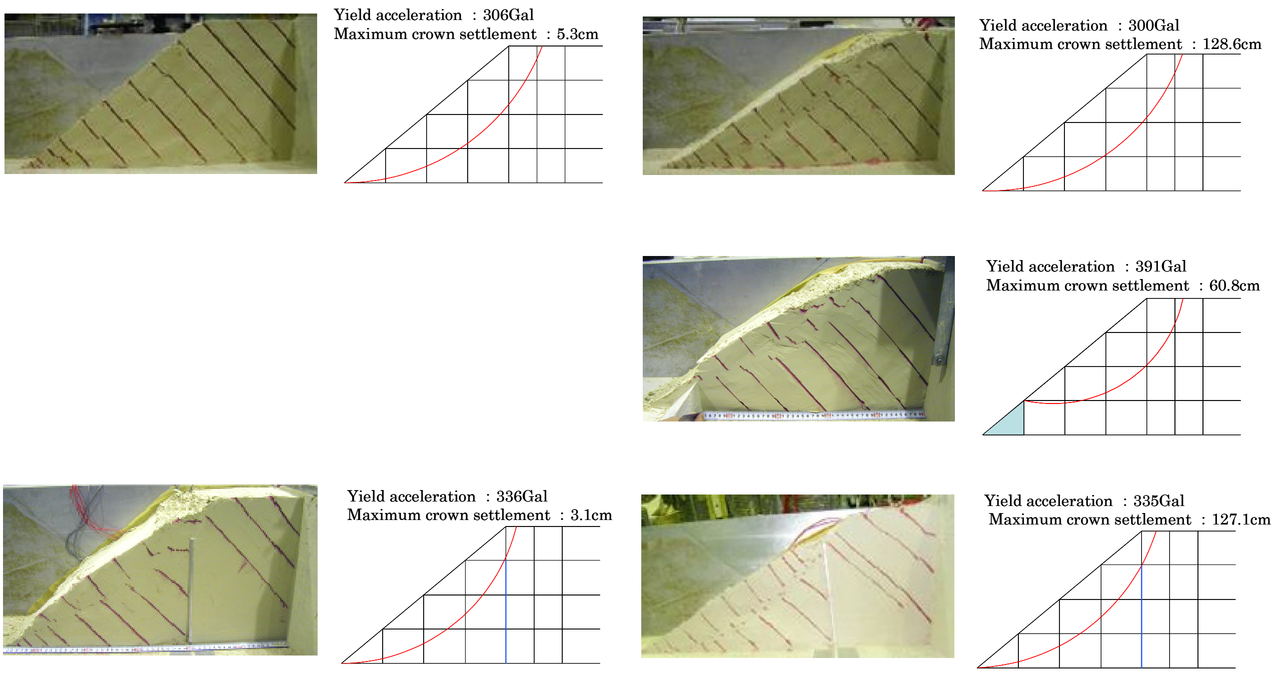
Table 2 Analytical parameters (Soils)

Analytical case	γ_t (kN/m^3)	G_0 (kN/m^2)	σ_m' (kN/m^2)	c (kN/m^2)	ϕ (deg)	ν
Case1	14.81	5.39E+04	43.2			
Case2	15.01	5.24E+04	43.8			
Case3	14.81	4.62E+04	43.2	8.7	37.6	0.33
Case4	14.71	3.79E+04	42.9			
Case5	14.52	4.48E+04	42.4			

Table 3 Analytical parameters (EPS and reinforcement materials)

Material	γ_t (kN/m^3)	E (kN/m^2)	ν
EPS	0.12	2.50E+03	
Toe reinforcement	22.00	1.96E+06	0.33
Barrier reinforcement	26.50	7.00E+07	

respectively. In the case setting blocking structure, the blocking structure is modeled beam element, so it is supported by the pin at the bottom. Analytical parameters of soils are shown in Table 2. Strength parameters were determined based on the results of the triaxial compression test as the location of the slip surface confirm to the test's results. Initial stiffness was determined by the Vs (shear wave velocity) which were measured in the test. The mechanical parameters of the EPS (it placed at the parietal of embankment), and those of the materials which used as countermeasures in the test are shown in Table 3. In the circular slip method and Newmark's method, the slip surface is presumed not to slip through these structures. The input wave form is applied the acceleration waveform which was measured at the base of the earth tank.
Figure 3 shows the residual deformation in the dynamic centrifuge model test and the critical slip surfaces, yield accelerations and the maximum crown settlements calculated by the modified conventional method in each case. According to this figure, comparing the locations of the slip surfaces, though the analysis results are slightly deeper than the test results, the locations of the slip surfaces at the crown are almost same. So, the modified conventional method can estimate the locations of the slip surfaces appropriately. In the test results, the locations of the slip surfaces in Case 4 and 5 are moved to the shoulder compared with the Case 1 and 2, the tendency is confirmed in the analysis results. Therefore, the modified conventional method can evaluate the control effects of the proposal countermeasures for the location of the slip surface.
About the maximum crown settlement, the relationship between test results and analysis results calculated by the each numerical method is shown in Figure 4. The test results in this figure are set from the vertical displacement measured in points on crown. According to Figure 4, the modified conventional method can estimate the maximum crown settlements almost appropriately. Meanwhile, the conventional Newmark's method underestimates it. In addition, the maximum settlement in Case3 is about half of Case2 in the test results, the tendency is confirmed in the analysis results of the modified conventional method. Therefore, the modified conventional method can evaluate the control effect of the proposal countermeasures for the crown settlement



caused by the seismic sliding failure.

4. SUMMERY

In this study, a modified conventional method for estimating the residual deformation of road embankments

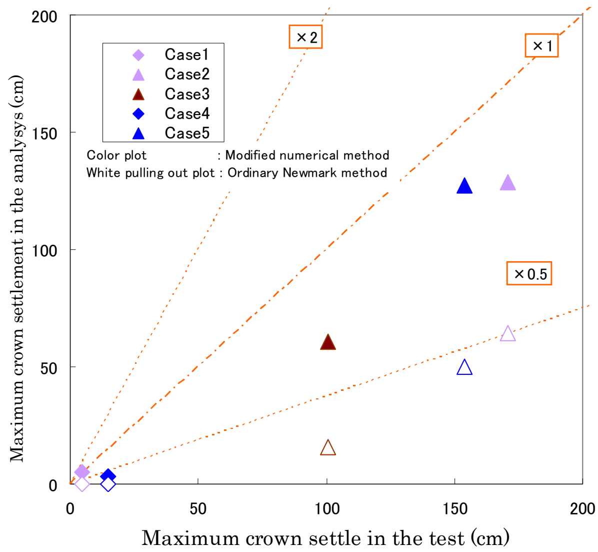


Figure 4 Results of the test and analysis about residual deformation

caused by earthquake is proposed. The availability of the proposed method is discussed, through its application to a series of centrifuge model test for earthquake resistance of the road embankment. Main conclusions are summarized as follows:

1. The modified conventional method proposed can estimate appropriately the locations of slip surface not only in the embankments without reinforcement but also in the embankments with both toe reinforcement and barrier reinforcement.
2. The conventional Newmark's method underestimates the maximum crown settlements of embankments in a series of the centrifuge model tests.
3. The modified conventional method proposed can estimate appropriately the maximum crown settlements of embankments not only without reinforcement but also with both toe reinforcement and barrier reinforcement.

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