Thessaloniki-GREECE 2007

4th International Conference on
Earthquake Geotechnical Engineering
June 25-28, 2007
Paper No. 1307

A STUDY ON THE APPLIFICABILITY OF THE MODIFIED NEWMARK METHOD

Yoshiya HATA [1], Norihiko YAMASHITA[2], Takashi TSUCHIDA[3] and Seiji KANO[4]

ABSTRACT

A permanent displacement of an embankment due to an earthquake is computed by using Newmark method in the current seismic design of embankments in Japan. However, the seismic response characteristics of embankments are not considered with Newmark method. So, the modified Newmark method proposed by Kremer, Razaghi, and so on considers the seismic response of embankments by modeling the embankment with SDOF model. However, it was limited for the application of the modified Newmark method to the actual embankment failure since the ground motion adjacent to the embankment failure was limited. This paper describes the applicability of the modified Newmark method to the embankment failure located in the Nishinomiya city. The seismic motion was estimated by the procedure proposed by Sato et al since the adjacent ground motion was not observed at Hyogoken-nambu earthquake.

Keywords: Modified Newmark method, FEM, permanent displacement, railway embankment.

INTRODUCTION

Japanese seismic design code has been modified after the catastrophic damage of civil structures by Hyogoken-nanbu earthquake. However it is unrealistic to design earth structures without aby damage subjected to Level 2 seismic motion. Therefore, it is required to develop the design code which considers the occurrence of damage within a permissible displacement. Newmark method (Newmark, 1965) is widely used in prediction of the permanent displacement of embankments due to an earthquake in Japan. However, the seismic response of embankments is not considered with Newmark method. Previous studies show two major effects due to seismic response of embankments. As for the first, according to the experimental results of the dynamic centrifuge model tests, the maximum seismic acceleration at the crest of embankments is amplified by about two or three times as the ground surface (Hayashi, 1998; Sakemi et al., 1998). As for the second, according to the experimental results of shaking table tests, the estimation of the permanent displacement by using the acceleration due to the seismic response in the embankments inside is better than that by using the acceleration at the toe of slope. (Ugai et al., 2001). So, the modified Newmark method that seismic response of embankments were considered by modeling the embankment with SDOF model is proposed (e.g. Kramer et al., 1997). However, it was limited for the application of the modified Newmark method to the actual embankment failure (e.g. Wakai et al., 2004) since the ground motion adjacent to the embankment failure was limited.

[1] Researcher, R&D Center, Nippon Koei Co., Ltd., Japan, Email: hata-ys@n-koei.jp
[2] Associate Professor, Dept. of Civil Engineering, Kobe City College of Technology, Japan.
[3] Professor, Graduate School of Engineering, Hiroshima University, Japan.
[4] Research Associate, Graduate School of Engineering, Hiroshima University, Japan.

This paper describe the applicability of the modified Newmark method to the railway embankment failures in the southern Nishinomiya city with the simulated earthquake motion since the earthquake motion was not measured at Hyogoken-nambu earthquake. And the some actual subsidence data of embankments are compared with the permanent displacement by the modified Newmark method and the vertical displacements by finite elemental method. Moreover, the input ground motions at the in-situ of the collapsed embankments during the Hyogoken-nambu earthquake were estimated.

THE TARGETED RAILWAY EMBANKMENTS

There are three case histories of the embankment failures due to Hyogoken-nambu earthquake that there were owned by Hankyu Corporation. The actual site investigation carried out after the earthquake is shown in Table 1 (JGS, 1996). Its location and the cross sections of these 3 embankments (JGS, 1996) are shown together in Figure 1.

Table 1. The collapsed outline of the targeted railway embankments

(a) Site: A

Location (latitude, longitude) (deg.)		N34.7807, E135.3563
Geotechnical condition	Soil material	Sand with gravel
	Groundwater level	0.5m underground surface
	Inclination degree of base ground	Inclined base ground (almost 10 deg.)
	Mean N-value	Approximately 3
Filling condition	Shape	Half-bank
	The height of embankment (m)	4.0
	The width of crest (m)	10.0
	Soil material	Sand
	Mean N-value	Approximately 3
Permanent displacement (m)		0.2

(b) Site: B

Location (latitude, longitude) (deg.)		N34.7390, E135.3313
Geotechnical condition	Soil material	Sand with silt
	Groundwater level	2.0m underground surface
	Inclination degree of base ground	Horizontal base ground
	Mean N-value	Approximately 15
Filling condition	Shape	Double-bank
	The height of embankment (m)	4.7
	The width of crest (m)	8.3
	Soil material	Sand with gravel
	Mean N-value	Approximately 4
Permanent displacement (m)		0.55

Table 1. The collapsed outline of the targeted railway embankments (continued)

(c) Site: C

Location (latitude, longitude) (deg.)		N34.7455, E135.3773
Geotechnical condition	Soil material	Sand with silt
	Groundwater level	1.5m under ground surface
	Inclination degree of base ground	Horizontal base ground
	Mean N-value	Approximately 15
Filling condition	Shape	Double-bank
	The height of embankment (m)	Fore land side = 5.7, Interior land side = 6.0
	The width of crest (m)	9.5
	Soil material	Sand with silt
	Mean N-value	Approximately 13
Permanent displacement (m)		0.3

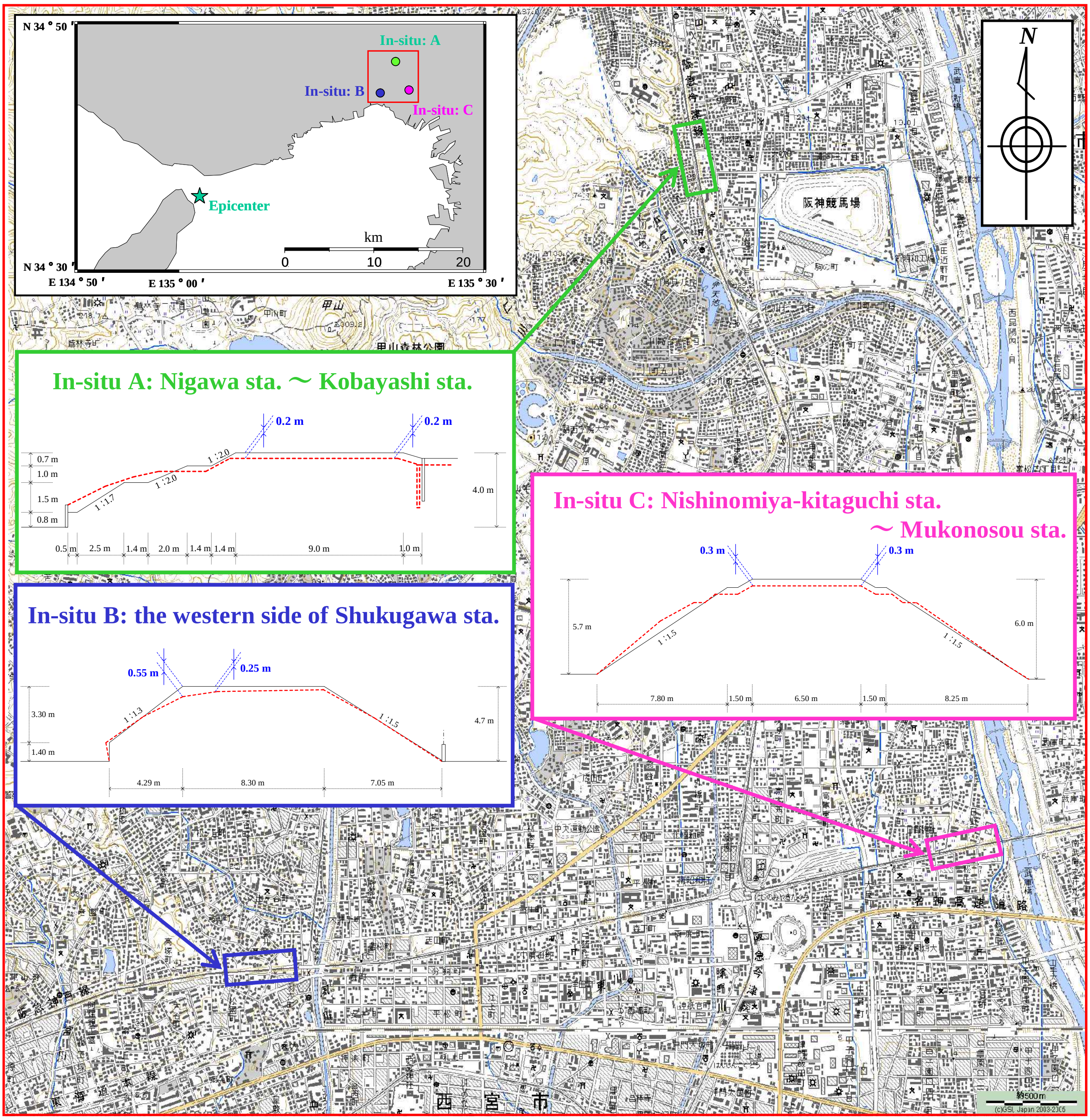


Figure 1. Location and cross section of the collapsed embankments in this study.

INPUT GROUND MOTION

Estimation methodology of Input Ground Motion

We know that the distribution of damaged structures matches to the distribution of seismic intensity well due to the earthquake. We also understand the importance of the ground motion for evaluating the damage of structures. But few records during the Hyogoken-nanbu earthquake were recorded unfortunately since the seismic observation network had not been serviced at the time. Of course the seismic record in the southern part of Nishinomiya city does not exist.
At the start of this study, the estimation of seismic ground motion in the area was conducted. This chapter describes the estimation method of ground motion.

The seismic ground motion was estimated fro each site, with the methodology proposed by Sato et al. (1997). This model considers the specific characteristics of fault rupture at Hyogoken-Nanbu earthquake and predicts bedrock ground motion (Irikura, et al., 1995). The bedrock ground motion was amplified by the multiple reflection theory to the ground surface motion. The acceleration power spectrum of SDOF system (square of response spectrum of acceleration) is calculated for the amplified ground motion (with 10% dumping), and evaluated by using the spectral moment method.

Because this method is the technique developed for the purpose of computing an acceleration response spectrum in the ground surface, an accelerogram in the ground surface can't be looked for directly by the calculation. However, the second author in this paper predicted the seismic wave motion following the above-mentioned method and compared to the actual observation at Fukiai (Osaka Gas Co., Ltd.). He concluded that the predicted wave matched in response spectra well (Kohiyama et al., 2003).

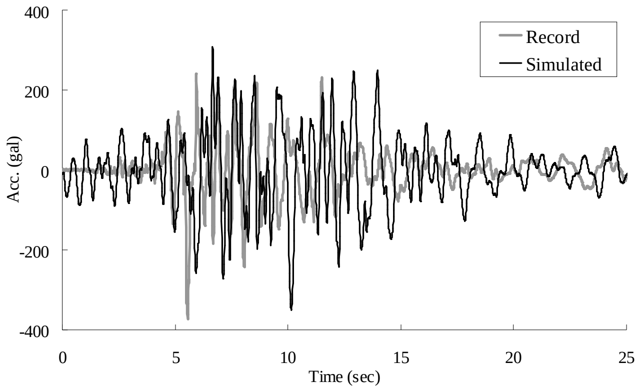
Verification Analysis

There is no ground motion record at 1995 Hyogoken-nambu earthquake in Nishinomiya city. In order to check the simulation method, seismic ground motion at Taketani Elementary School of Amagasaki city was simulated to compare with the actual ground motion record. The Taketani Elementary School is located away from these investigation sites by about 2 km.

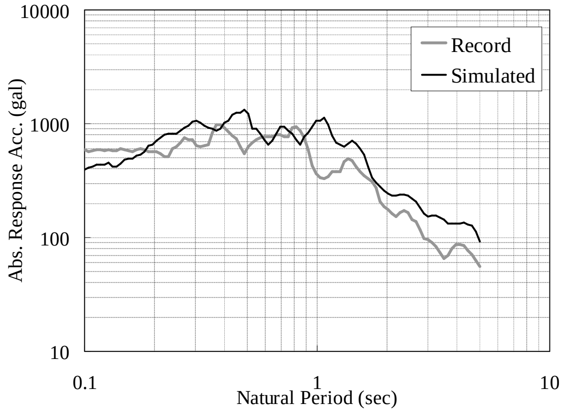
The soil profile at Takatani Elementary School was modeled based on borehole logs and Standard Penetration Tests (SPT) for subsurface soil layers and the digital elevation model for deep sediment layers (Editorial Committee for the Report on the Hanshin-Awaji Earthquake Disaster, 1998). The seismic motion at Takatani site was saturated and predicted by Kagawa et al. (1996) in terms of the waveform of the ground motion. Figure 2(a) shows the comparison of time history of acceleration, and Figure 2(b) shows the comparison of response spectra of acceleration between recorded and simulated results. The simulated time history of acceleration matches to the recorded ground motion history. For example, the peak acceleration of the seismic motion record is 371.9 gal and the simulated accelerogram gives also a similar value of 350.6 gal. The simulated ground motion overestimates the response spectrum at periods ranging from 0.2 to 0.6 second except at the period of 0.4 second which corresponds to the predominant period of observed ground motion. Therefore, this method can be confirmed to be applicable to the prediction of seismic displacement for the practical purpose.

Input Ground Motion at Investigated Sites

Input ground motions at investigated three sites were calculated respectively by using the above-mentioned method. Time histories of acceleration calculated for each site are shown in Figure 3. Estimated peak ground accelerations ranged from 690 gal to 820 gal, which matches to the estimated peak horizontal acceleration at the southern part of Nishinomiya City which covers these sites published by (e.g. Kansai Branch of the JSCE, 1998).

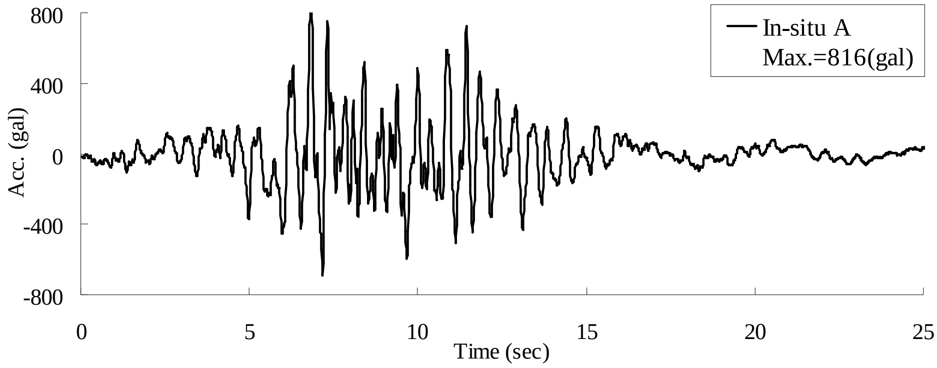


(a) accelerograms

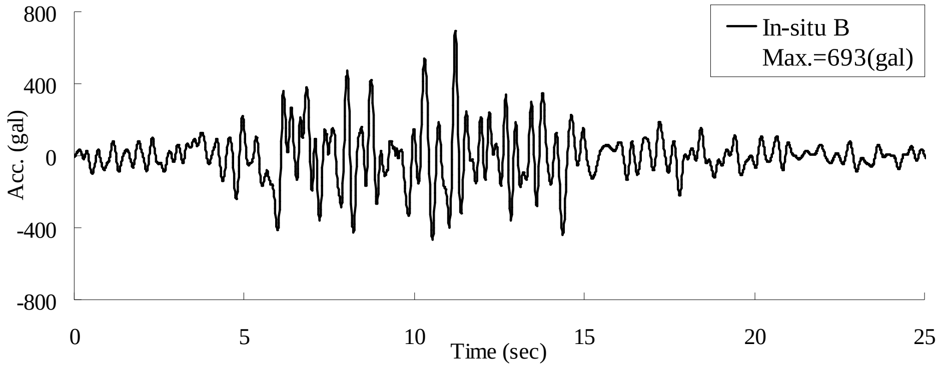


(b) Response Spectra

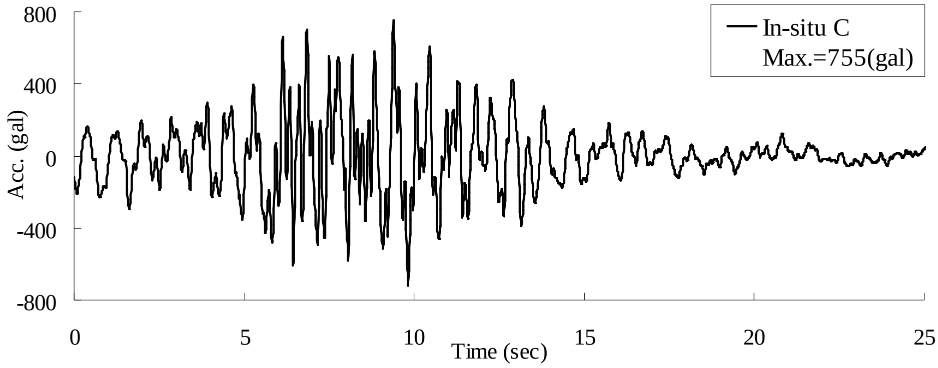
Figure 2. Comparison between the accelerograms and the response spectra from the simulation and corrected strong motion record at Taketani Elementary School of Amagasaki city.



(c) In-situ A



(b) In-situ B



(c) In-situ C

Figure 3. Estimated input ground motions

COMPUTATION OF THE PERMANENT DISPLACEMENT

Modified Newmark Method

Newmark method is used for the computation of the permanent displacement of embankments due to an earthquake in Japan such as the seismic design of railroad structure (e.g. RTRI, 2000).
However, the modified Newmark method was used in this study since it was improved to take the seismic response of embankments into consideration. The schematic figure of the computation of the sliding displacement is shown in Figure 4. The permanent displacement calculation process is shown as follows.

The embankment was modeled by SDOF system to perform the simple seismic response analysis. The time history of response acceleration was computed with estimated input ground motions. The natural frequency of the embankment, which is required as an input parameter, was estimated by the method proposed by Hata et al. (2006) which considers the shape of the embankment in the calculation of the natural period. The computed seismic response accelerations of the embankment were used as an input motion in the calculation of Newmark displacement. The critical slip surface was obtained by pseudo static method applying the maximum ground acceleration, and the yield acceleration was calculated. Finally, the angular velocity $\dot{\theta}$ and the rotation angle θ are computed one after another by doing the numerical integral calculus. And, the sliding displacement δ is computed from the radius of the critical circle R and the rotation angle θ .

Table 2 is the list of input parameters for the modified Newmark method. Not only the input parameter used with usual Newmark method but also a shear wave velocity is required with the modified Newmark method in the estimation of the natural frequency. In this study, unit weight of soil (γ), cohesion (c), internal friction angle (ϕ), and shear wave velocity V_s were estimated referring to site investigation results of in-site density tests and SPT (JGS, 1996) and previous studies (JGS, 1999; Tamada, 2004). However, input parameters of site C were estimated based on the boring data of K-net Nishinomiya (NIED) which is away from site C by about 2 km since SPT was not performed at site C.

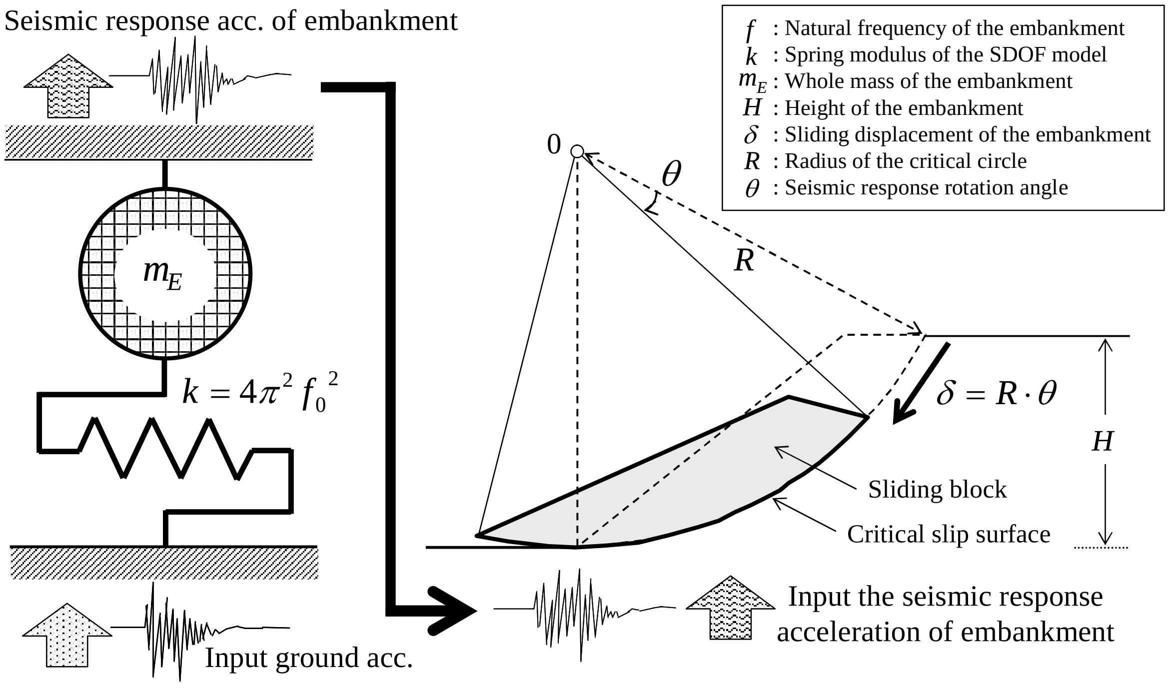


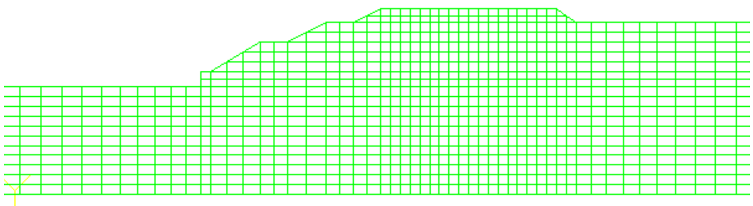
Figure 4. The concept of the computation of the sliding displacement

Table 2. Input parameter of the analytical embankment model

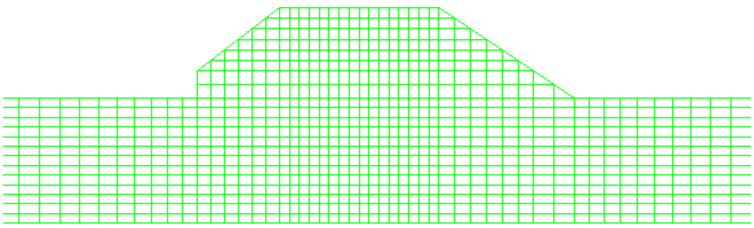
Input Parameter	Site A	Site B	Site C
Breadth of crest, B (m)	9.0	8.3	9.5
Height of embankment, H (m)	4.0	4.7	6.0
Gradient of embankment (-)	1∶2.3 / -	1∶1.3 / 1∶1.5	1∶1.5 / 1∶1.5
Unit of weight, γ_t (kN/m^3)	18	18	17
Cohesion, c (kPa)	5	3	6
Angle of internal friction, ϕ (deg.)	27	30	27
Shear wave velosity, V_s (m/sec)	145	166	172
Natural frequency of embankment, f_0 (Hz)	4.961	6.816	7.392

Finite Elemental Analysis

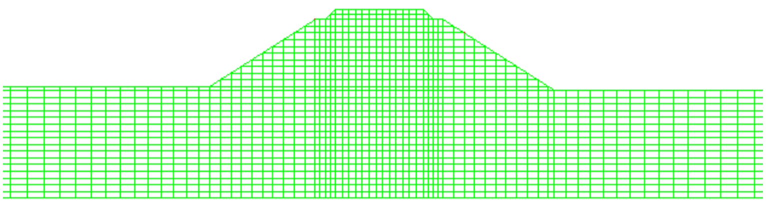
The Non-linear seismic responses of these embankments were calculated by finite element method (FEM) since it is accepted as an accurate numerical method for the calculation of deformation in Japan. Figure 5 shows input geometries of three embankments used for FEM. The input seismic motion is the same as the input in Newmark method shown in the figure 3. But, these input accelerations are pulled to the analytical base equivalent in FEM calculations. Since dynamic deformation tests were not performed for these sites, the experimental equation for dynamic properties proposed by Imazu and Fukutake (1986) was adopted. As for other soil properties, the same value which shown in Table 2 was quoted.



(a) Site A



(b) Site B



(c) Site C

Figure 5. Input mesh for these sites

Analytical Conditions for FEM

Table 3 shows conditions of numerical analyses. The calculation was carried out for all six conditions including the plus and the minus of input acceleration.

Table 3. Analytical conditions of each case

Case No.	Site	Code of Acc.
Case A-O	A	Observe
Case A-R	A	Reverse
Case B-O	B	Observe
Case B-R	B	Reverse
Case C-O	C	Observe
Case C-R	C	Reverse

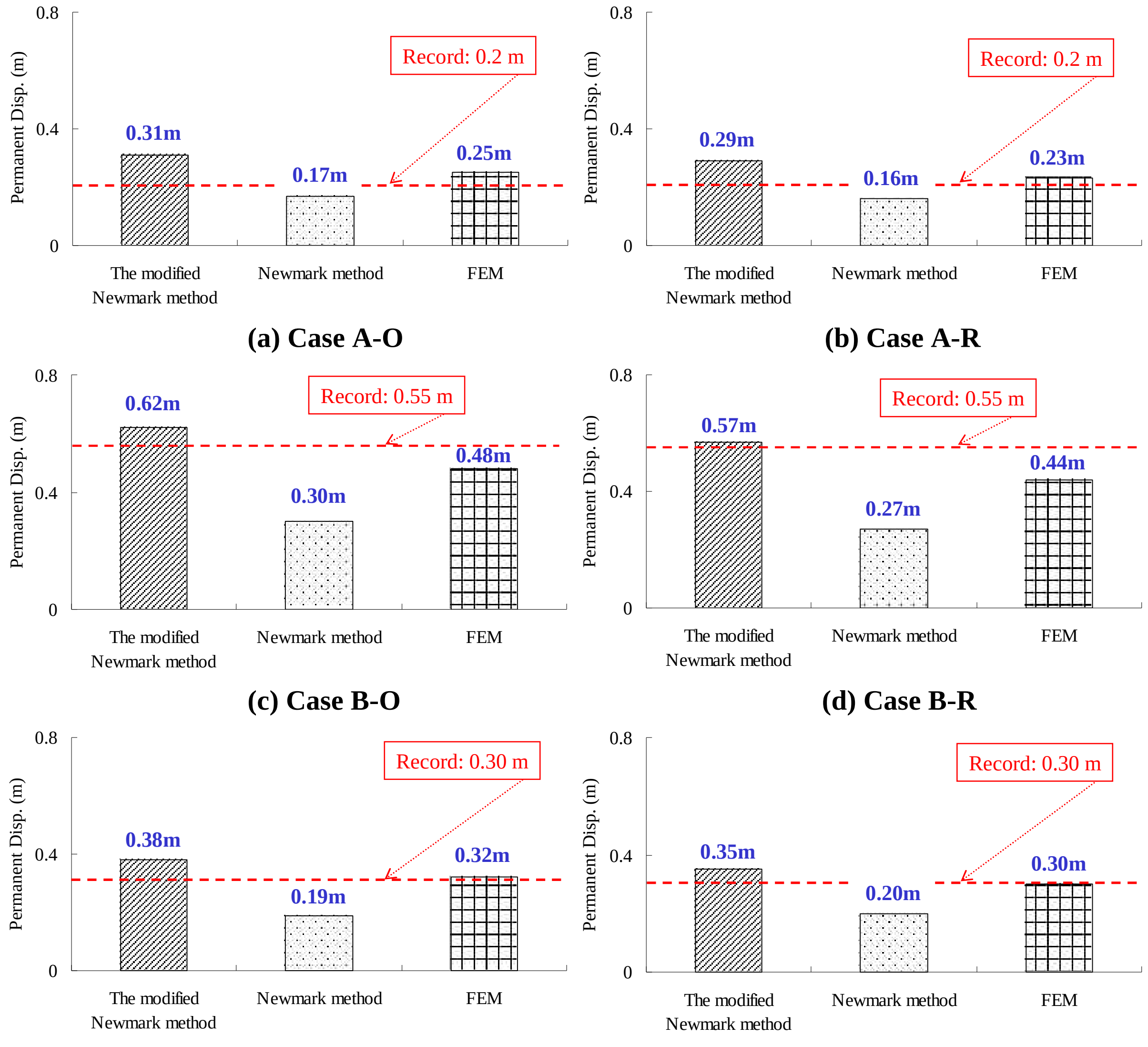
DISCUSSION

Figure 4 shows the comparison of the observed and the predicted permanent displacement due to the earthquake for each analysis conditions. According to the Figure 4 (a) and (b), Newmark method and FEM predicted permanent displacements within 0.05 m of observed displacements though the modified Newmark method predicted larger values by 0.1 m than observed values. Therefore, the usual Newmark method predicted the permanent displacement better than the modified Newmark method.

According to the Figure 4 (c) and (d), the modified Newmark method predicted the permanent displacement within 0.07m of the observed displacement, which was better than the used Newmark method within 0.28m of the observed displacement. FEM underestimated the permanent displacement by 0.1 m. Therefore the modified Newmark method seems to be the best in prediction the permanent displacement at site B.

According to the Figure 4 (e) and (f), the modified Newmark method predicted the permanent displacement within 0.08m of the observed displacement, which was better than the used Newmark method. FEM underestimated the permanent displacement by 0.02 m. Therefore FEM seems to be the best in prediction the permanent displacement at site C.

Based on these results, the modified Newmark Method predicted the permanent displacement better than the usual Newmark method except the site A which has the largest height of the embankment with the shape of half-banked. One of the reasons for the overestimation of the permanent displacement at site A by the modified Newmark method can be due to the assumption of double-banked embankment in estimating the natural period of the embankment. Also, it can be seen that the usual Newmark method underestimation the permanent displacement for each permanent displacement record. This tendency may come from the assumption of the usual Newmark method neglecting the seismic response of the embankment. Based on these results, it is capable to predict the permanent displacement with the combination of the seismic motion estimation and the modified Newmark method. In addition to these results, the FEM predicted displacement and the recorded displacement were observed between the modified Newmark method and the usual Newmark method.



(a) Case A-O **(b) Case A-R**

(c) Case B-O **(d) Case B-R**

(e) Case C-O **(f) Case C-R**

Figure 6. Comparison with the permanent displacement

CONCLUSION

The seismic permanent displacement by the modified Newmark method and the usual Newmark method was compared with the seismic deformation of the actual measurement for the railroad embankment in southern part of Nishinomiya City which suffered in the Hyogoken-nambu earthquake to examine the applicability of the modified Newmark method.

This paper shows that it is possible to predict the permanent displacement of the embankment during an earthquake by combining the modified Newmark method with the estimated seismic motion given the earthquake scenario. And, the need to take the seismic response characteristics of the embankment into consideration was indicated. However, the application of the modified Newmark method was limited depending on the geometry of the embankment.

The detail study will be undertaken with a result of centrifuge tests for the evaluation of numerical methods in predicting the permanent displacement due to an earthquake in future.

AKNOWLEDGEMENTS

For allowance to use earthquake motion data, the Committee of Earthquake Observation and Research on the Kansai Area (CEORKA in Japan), are greatly appreciated.

REFERENCES

Editorial Committee for the Report on the Hanshin-Awaji Earthquake Disaster "Report on the Hanshin-Awaji Earthquake Disaster," General Issues Vol.2, 190p., 1998 (in Japanese).

Hata, Y., Kano, S., Tsuchida, T. and Yamashita, N. "A calculation method on the natural frequency of embankments in the horizontal and vertical directions considering its shape", Proc. of 41st Japan national conference on geotechnical engineering, No.1056, pp.2111-2112, 2006 (in Japanese).

Hayashi, H., Nishikawa, J. and Taniguchi K. "Seismic behavior of road embankments," Centrifuge98, Vol.1, pp.243-248, 1998.

Imazu, M. and Fukutake K. "Dynamic shear modulus and damping of Gravel materials", Proc. of 21st Japan national conference on soil mechanics and foundation engineering, No.1024, pp.509-512, 1986 (in Japanese).

Irikura, K. "Seismic motion characteristics of the 1995 Hyogoken-nambu earthquake", The Kenchiku Gijutsu, 1995 (in Japanese).

Japan Geotechnical Society "Report on the Hanshin-Awaji Earthquake Disaster", Material edition, Vol.2, 1996 (in Japanese).

Kagawa, T., Irikura, K. and Yokoi, I. "Restoring clipped records of near-field strong ground motion during the 1995 Hyogoken-nambu (Kobe) Japan earthquake," Jour. of Natural Disaster Science, Vol.18, No.1, pp.43-57, 1996.

Kansai Branch of Japan Society of Civil Engineering "Learns in the earthquake disaster," editorial committee for the report on the Hanshin-Awaji earthquake disaster, Vol.1, 1998 (in Japanese).

Kohiyama, M., Yamashita N., Sato, T., Hengjian, L., Maki, N., Tanaka, S. and Hayashi, H. "Expansion of the Nishinomiya Built Environment Database," *Natural Hazards*, Vol.29, pp.501-522, 2003.

Kramer, S. L. and Smith, M. W. "Modified Newmark model for seismic displacements of compliant slopes," Jour. of Geotech. Eng., ASCE, Vol.123, No.7, pp. 635-644, 1997.

Newmark, N. M. "Effects of earthquakes on dams and embankments," Fifth Rankin Lecture, *Geotechnique*, Vol.15, No.2, pp. 139-160, 1965.

Railway Technical Research Institute "Design guidelines for railroad structures," earth structure edition, Maruzen Co.,Ltd., 336p., 2000 (in Japanese).

Razaghi, H. R., Yanagisawa, E. and Kazama, M. "An approach to seismic permanent displacement of slopes," Jour. of Geotech. Eng., JSCE, No.659, pp. 1-16, 2000.

Sakemi, T. "Dynamic behavior of embankments on clay foundations against strong earthquake," Centrifuge98, Vol.1, pp.249-254, 1998.

Sato, T., Kita, K. and Maeda, T. "Estimation of acceleration response spectra in the severely damaged area due to the 1995 Hyogoken-nambu earthquake," Jour. of Structural Mechanics and Earthquake Engineering, JSCE, No.563/ I -39, pp.149-159, 1997 (in Japanese).

Tamada, K. "Proposal of simplified estimation method for seismic permanent displacement on fill slope considering seismic motion intensity and period characteristic", master eng. Dissertation, Kobe University, 2004 (in Japanese).

Ugai, K., Wakai, A., and Ohniwa, Y. "A prediction of the seismic permanent displacement of the dryness sand slope based on Newmark method," Proc. of Kanto branch of JSCE Annual Conference, pp.388-389, 2002 (in Japanese).

Wakai, A. and Ugai, K. "A simple constitutive model for the seismic analysis of slopes and its applications," *Soils and Foundations*, Vol.44, No.4, pp.83-97, 2004.