13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 457

STUDY ON SEISMIC PERFORMANCE OF ABUTMENT ON HIGH EMBANKMENT

Shogo MATSUNAGA[1], Tatsuo IRIE[2], Yoshito MAEDA[3] and Allan D. SUMAYA[4]

SUMMARY

The object of this study is to investigate the seismic performance of abutment with cast-in-place concrete pile foundation on an embankment that has a height of more than 20 meters. In this study, the authors investigated its dynamic behavior using numerical analysis and model experiment. Time history response analysis by finite element method is applied considering the non-linear properties of pile and ground. The conventional Takeda Model is used in pile model while Hardin-Drenevich Model is soil model. Also, online experiment, which directly considers the variation of dynamic properties of soil material collected from ground site, is conducted. Based on the results of investigation, the authors propose a practical design formula, which could easily check the seismic performance of the abutment and pile during large-scale earthquakes. The formula applies the concept of static slide stability analysis, where the seismic horizontal coefficient that is equivalent to dynamic response is derived using two correction factors proposed by the authors based on results of on-line experiment. Moreover, this study revealed that single-row pile foundation show sufficient seismic performance, thus, eliminates conventional two-row pile foundation and suggests reduction of construction cost.

INTRODUCTION

In recent years, abutment on embankment is used to reduce construction cost and spoil by utilizing excavation materials of main line. It is design to be safe for stationary and Level 1 seismic loads based on experimental and analytic results refer to Expressway Technology Center [1, 2]. However, after The Great Hanshin Awaji Earthquake, important routes such as highway bridges must satisfy a particular safety factor with respect to Level 2 seismic loads. In the case of abutment on embankment, seismic design method for this type of abutment and evaluation method of dynamic behavior of embankment during Level 2 earthquake are necessary.

[1] Engineer, CTI Engineering Co. Ltd., Fukuoka Prefecture, Japan. Email: s-matung@ctie.co.jp
[2] Chief Engineer, CTI Engineering Co. Ltd., Fukuoka Prefecture, Japan. Email: irie@ctie.co.jp
[3] Professor, Kyushu Kyoritsu University, Fukuoka Prefecture, Japan. Email: maeda@kyukyo-u.ac.jp
[4] Engineer, CTI Engineering Co. Ltd., Fukuoka Prefecture, Japan. Email: allan@ctie.co.jp

This paper proposed a radical evaluation method of aseismicity of abutments on embankment for Level 2 earthquake based on results of online earthquake response experiment and dynamic analysis by finite element method.

BASIC CONCEPT ON DESIGN OF ABUTMENT ON EMBANKMENT

The abutment on embankment that is referred in this paper is defined in JH Design Code, JH [3], where, in general, the embankment and abutment structure are designed separately. In this paper, the slope of compensation of embankment is 1:1.8 and the high quality soil part, shown in Fig. 1, satisfies JH specifications for substructure subgrade. This omits the stability check of embankment. This implies that the embankments that satisfy the specifications guarantee safety in stationary and Level 1 seismic loads. However, its seismic design for Level 2 earthquake is not indicated in the code manual.

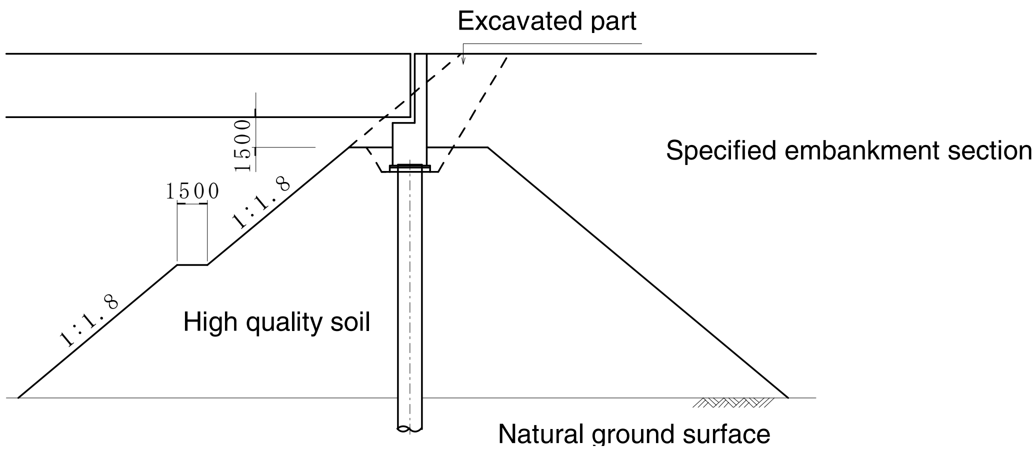

Figure 1 Illustration of abutment on embankment

EVALUATION METHOD OF EMBANKMENT SEISMIC STABILITY

Stability Evaluation method

Concept of stability evaluation

The stability evaluation method for embankment is illustrated in Fig.2. It is convenient to make the checking method for stability of embankment in Level 2 seismic load to be simple, easy and practical. For this purpose, the following policies are considered and examined.

1) The stability of embankment is examined using static stability analysis in consideration of dynamic properties.
2) The static stability analysis applies slip safety factor according to revised Fellinius method.
3) The seismic coefficient considered in static stability analysis as outside force is set as the equivalent seismic coefficient of static force equivalent to earthquake acceleration. This makes the method practical and simple to apply.
4) The influence of pile foundation is considered in stability check of embankment.
5) The soil properties of ground, such as shear strength, during earthquake are studied adequately.

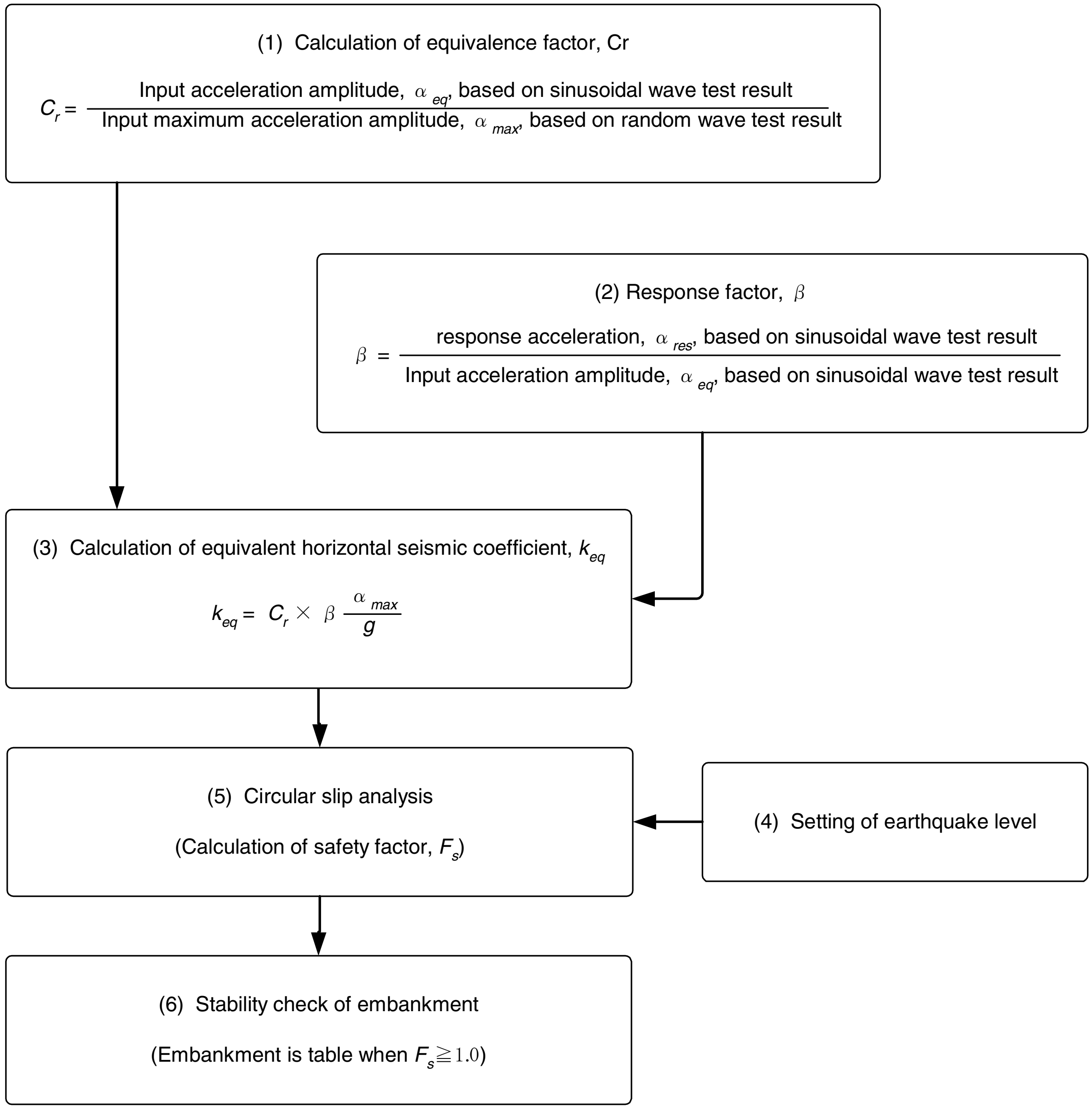

Figure 2 Flowchart of stability evaluation of embankment

Equivalence factor, Cr

Earthquake ground motions irregularly vary in a particular direction and in a short period of time. Moreover, the dynamic strength of soil is determined by repeated shear force and number of repetition. Therefore, seismic coefficient is overestimated when the maximum acceleration is directly used. It is practical to reduce the magnitude of acceleration by considering the repetition characteristic of acceleration wave. This is explained by the following equation.

$$\frac{\alpha_{eq}}{g} = C_r \frac{\alpha_{\max}}{g} \quad \text{(Equation 1)}$$

In this equation, C_r, called the equivalence factor, herein, represents the correction for irregularity of earthquake acceleration.

The value for equivalence factor is determined using the maximum horizontal displacement and number of repetition revealed in the online earthquake response experiment results. The parameters considered in the experiment are studied using the standard acceleration waves indicated in Highway Specifications Part V, and sinusoidal waves.

Response factor, β

The seismic coefficient considered in slip stability study is treated to be uniform along a single direction. However, as illustrated in Fig. 3, in reality, the acceleration generated from bed rock propagates through the embankment with phase difference in horizontal and vertical directions; thus, maximum accelerations are different. This means that the response acceleration distribution within the embankment should be considered. The following equation explains this matter.

$$\frac{\alpha_{res}}{g} = \beta \frac{\alpha_{eq}}{g} \qquad \text{(Equation 2)}$$

In this equation, β, called the response factor, herein, signifies the correction for acceleration response characteristic.

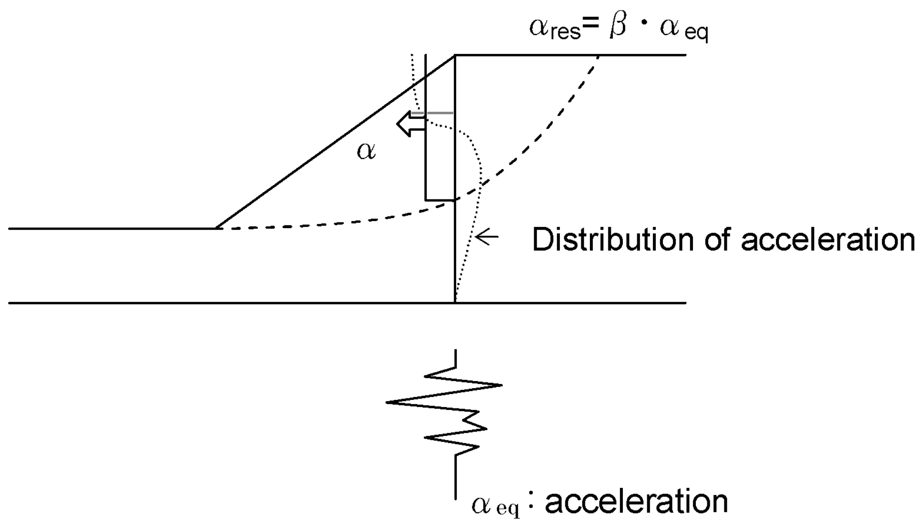

Figure 3 Concept of response factor

As a result, the equivalent seismic coefficient can be expressed by the following equation using the equivalence factor and response factor.

$$k_{eq} = C_r \times \beta \times \frac{\alpha_{max}}{g} \qquad \text{(Equation 3)}$$

Figure 4 illustrates the concept of the corrections due to equivalence factor and response factor.

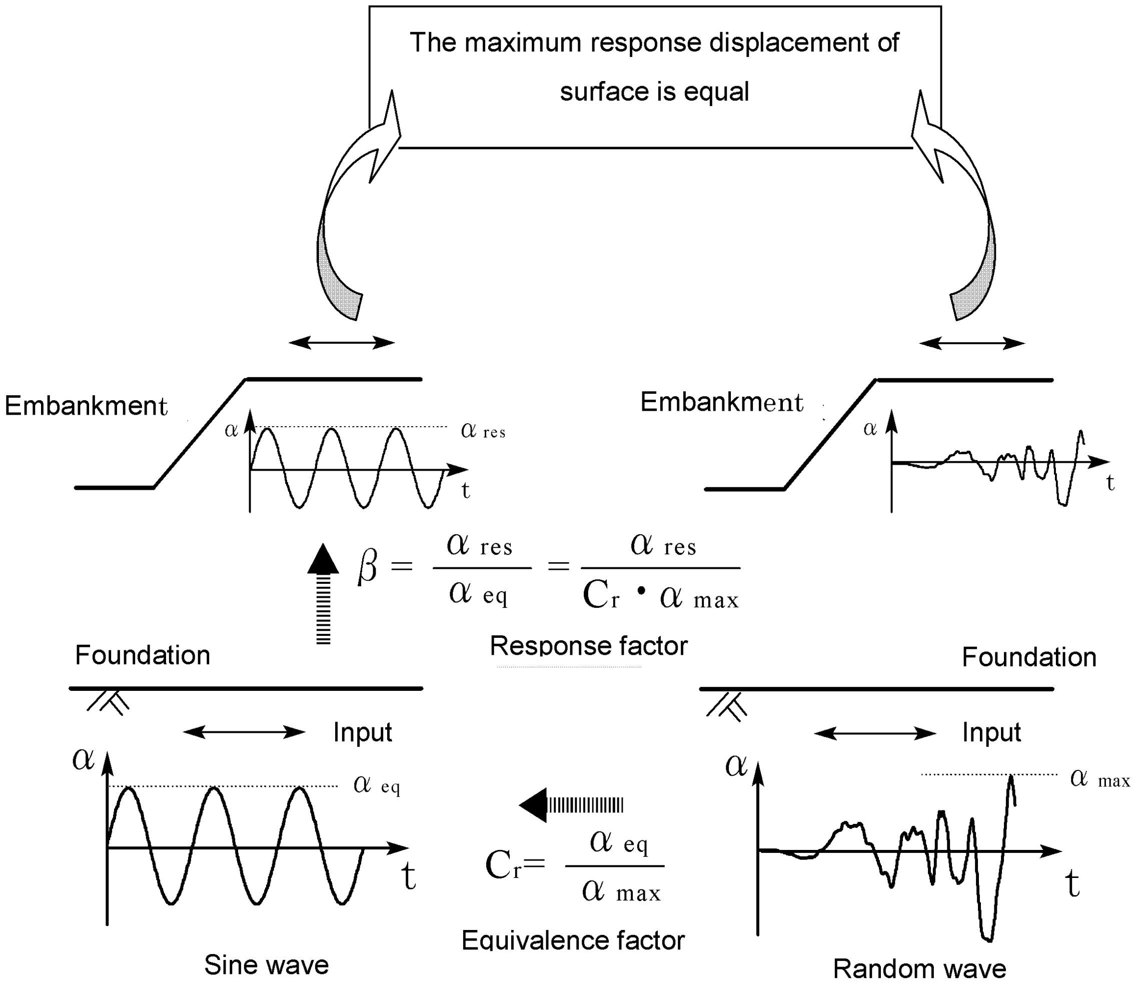

Figure 4 Concept of applying equivalence factor and response factor

SUMMARY RESULTS OF ONLINE EXPERIMENT

The concept of online earthquake response experiment is illustrated in Fig. 5.

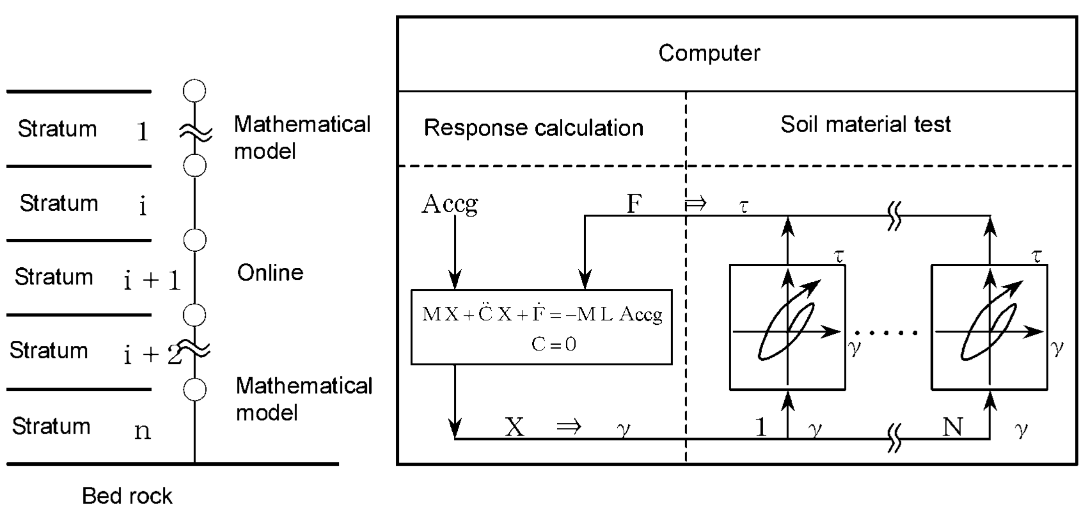

Figure 5 Concept of online earthquake response experiment

In this experiment, the behavior of ground during earthquake is considered directly by connecting the computer that performs the response analysis and the displacement control apparatus containing the soil material. The results obtained from the online experiment are shown as follows.

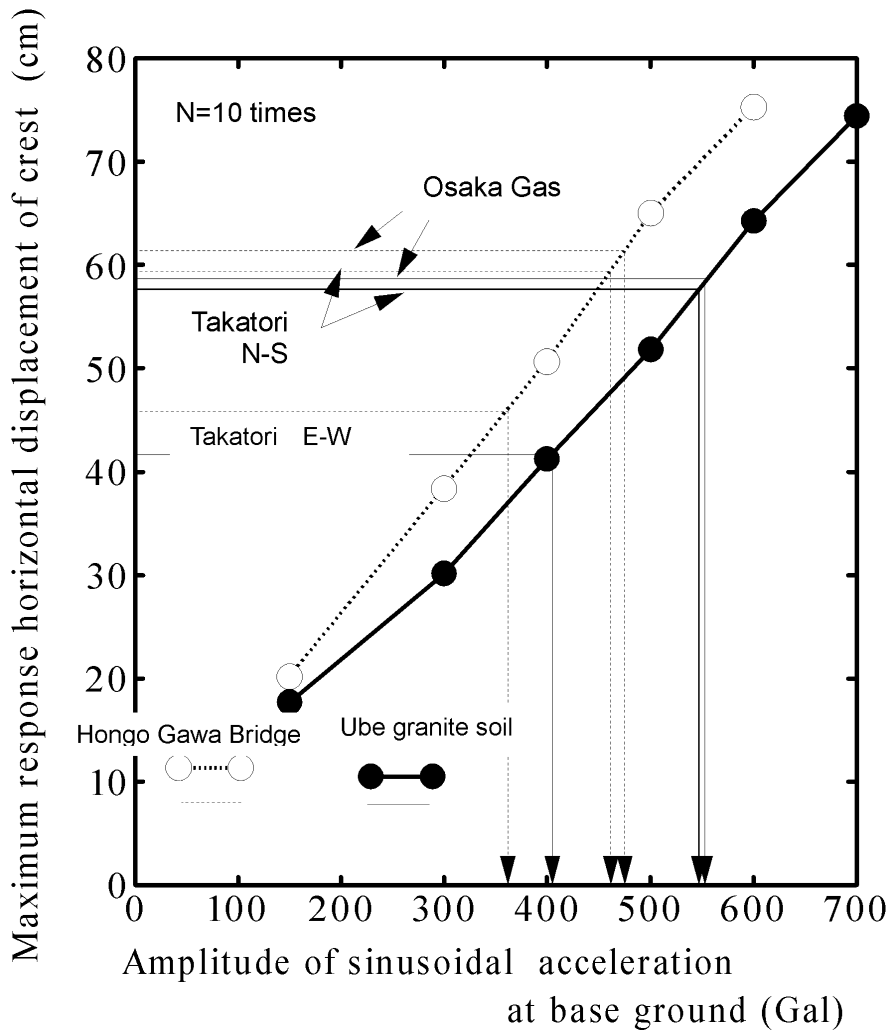

Figure 6 Relationship of input acceleration amplitude and maximum response displacement

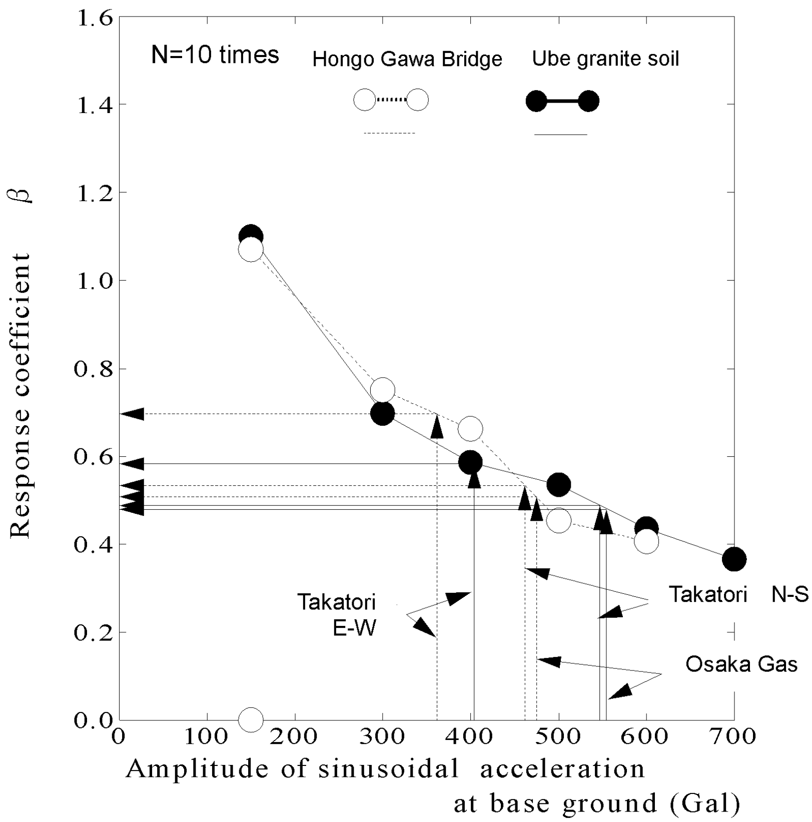

Figure 7 Relationship of sinusoidal acceleration amplitude and response factor

EQUIVALENT HORIZONTAL SEISMIC COEFFICIENT

Calculation of equivalence factor, C_r

Equivalence factor, C_r, is calculated based on online results of random and sinusoidal waves. Computed values of C_r are shown in Table 1.

Table 1 Calculation of equivalence factor, C_r

Ube granite soil	Maximum horizontal displacement	Maximum acceleration (1) α max	Equivalent acceleration (2) α eq	Equivalent factor Cr = (2)÷(1)
Takatori N-S	59.5cm	687 gal	461.65 gal	0.672
Takatori E-W	45.9cm	672 gal	361.83 gal	0.538
Osaka Gas	61.4cm	736 gal	474.65 gal	0.645
			ave.	0.618

Ube granite soil	Maximum horizontal displacement	Maximum acceleration (1) α max	Equivalent acceleration (2) α eq	Equivalent factor Cr = (2)÷(1)
Takatori N-S	57.7cm	687 gal	547.2 gal	0.797
Takatori E-W	41.7cm	672 gal	404.72 gal	0.602
Osaka Gas	58.7cm	736 gal	555.2 gal	0.754
			ave.	0.618
			Total ave.	0.668

This result indicates that C_r of Ube granite soil show almost similar tendency with that of Hongo Gawa Bridge soil, although, the former is approximately 10 percent larger than the latter.

Calculation of response factor, β

The effect of response acceleration distribution of embankment generated by the input acceleration from bed rock is considered using the response factor, β.

Here, response factor is calculated using the results of Hongo Gawa Bridge. It is determined by the average value of response accelerations when the response acceleration at the top of embankment reached its maximum value. Table 2 shows the value of response factor.

Table 2 Calculation of response factor, β

Seismic wave form	Hongo Gawa bridge soil	Ube granite soil
Takatori N-S	0.533	0.488
Takatori E-W	0.696	0.584
Osaka Gas	0.507	0.480
Average	0.578	0.517
Total average	0.548	

This result indicates that β of Ube granite soil show almost similar tendency with that of Hongo Gawa Bridge soil, although, the former is slightly smaller than the latter.

Calculation of equivalent horizontal seismic coefficient, k_{eq}

Table 3 shows the calculated values of equivalent horizontal seismic coefficient, k_{eq}. It shows that the values of Hongo Gawa Bridge soil and Ube granite soil is almost equal. It also revealed that the horizontal seismic coefficient of embankment for Level 2 earthquake is approximately 0.25.

Table 3 Calculation of equivalent horizontal seismic coefficient, k_{eq}

	Seismic wave	k_{max}	Cr	β	k_{eq}
Hongo Gawa Bridge soil	Takatori N-S	0.700	0.672	0.533	0.251
Ube granite soil			0.797	0.488	0.271
Hongo Gawa Bridge soil	Takatori E-W	0.686	0.538	0.696	0.256
Ube granite soil			0.602	0.584	0.241
Hongo Gawa Bridge soil	Fukiai	0.751	0.645	0.507	0.246
Ube granite soil			0.718	0.480	0.258
Average			0.662	0.548	0.254

EXAMPLE OF STABILITY EVALUATION IN EXISTING ABUTMENT ON EMBANKMENT

Table 4 show sample calculations in stability check of abutment on embankment in Level 2 earthquake. The abutments considered herein are those that are already constructed and those that are under construction. It is clear from the results that all existing embankments considered herein are safe, i.e. safety factor is greater that 1.0, in Level 2 earthquake.

Table 4 Sample calculations of embankment stability check

(α max=716gal, kmax=0.74, Cr=2/3)

No.	Embankment height (m)	C (kPa)	ϕ (°)	β	keq	Fs
1	20	15	33	0.53	0.26	1.06
2	38	68	33	0.22	0.11	1.79
3	15	43	31	0.62	0.30	1.42
4	17	15	33	0.58	0.29	1.05
5	17	59	27	0.58	0.29	1.44
6	27	27	32	0.41	0.20	1.23
7	14	20	32	0.63	0.31	1.11
8	15	49	32	0.62	0.30	1.53

CONCLUSIONS

This study presents the following conclusions.

1) In order to replace the random acceleration as static force accurately, the irregularity of earthquake, i.e. represented by equivalence factor, C_r, and the acceleration response characteristic of embankment, i.e. represented by response factor, β, should be considered.
2) It is found that the most appropriate way of determining the equivalent horizontal seismic coefficient is by considering the equivalence factor when the horizontal displacement at top of embankment is maximum value and the response factor when the acceleration at surface is maximum value. This study proposes the following values for equivalence factor and response factor.

    Equivalence factor, $C_r = 2/3$

    Response factor, $\beta = 0.87\text{-}0.017H$, where H is the height of embankment.

REFERENCES

1. Expressway Technology Center of Japan. "Study report on abutment structures on high embankment (in Japanese)," 1989.
2. Expressway Technology Center of Japan. "Study report on abutment structures on high embankment (in Japanese)," 1990.
3. Japan Highway Public Corporation. "Design code Manual Part2 (in Japanese),"1998.