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STUDY OF UNDERGROUND SEISMIC COEFFICIENT

K. SATO1), Y. SAWADA1), H. KUBOTA2), H. YAJIMA1) and J. TOHMA1)

1) Central Research Institute of Electric Power Industry
2) The Tokyo Electric Power Company Incorporated

SUMMARY

The objective of the study is to clear the property of the underground seismic coefficient distribution for assessing seismic stability of ground and slope, on the basis of seismic observation records in several grounds. Underground seismic observation data of 13 points, ranging from hard rock to soft ground and seismic observation data of recent six earthquakes recorded on the surface of rock were collected to analyze underground seismic coefficient. Using those analysis, the property of the underground seismic coefficient normalized by the value at the surface layer was examined.

INTRODUCTION

Static seismic forces loading upon ground are very important for aseismic stability assessment of reactor building foundation ground, surrounding slope and the like. This study was intended to establish the methods for assessing seismic coefficients in ground with dynamic behaviour of ground taken into consideration by examining the destribution of seismic forces in each ground based on the records observed at soft or hard rock ground and slope.

At first, with the use of the respective identified ground models, one-dimensional seismic response analysis was carried out for the observation data and S_2 earthquake input. And the underground seismic coefficient distribution were determined for two definitions. Of two definitions, one is obtained from the maximum acceleration value of the layer (method 1), the other is obtained from the interlayer maximum shear stress difference (method 2). As a result distribution model of underground seismic coefficient was formulated in each ground.

Filed and Analized Seismic Observation Records Underground seismic observation records for hard rocks, soft rocks, soft ground, and fill-up slope were collected and compiled (Table 1). Data of each site were recorded on vertical array observation. Records of recent major earthquakes observed in rock observation point were also collected, and data base was developed for analysis of seismic coefficients in ground. For each set of observed data, the ground conditions of the observation points, list of observed earthquakes, were clarified.
Further, observation data were subjected to spectral analysis to examine the characteristics of propagation through the ground and the characteristics of earthquake input.

Table 1 Site Characteristic of Seismic Observation Point

Classification of ground	Observation Point	Ground profile
Hard rock mass	I W K	sandstone, granite
Soft rock mass	T M K	mudstone, sandstone, diorite
	T T Y	loam, sandstone, mudstone
	S Z J	tuff
	H M Y	clay with gravel, mudstone
Soft ground	T K I	sand, sand and gravel, shale
	S F J	loam, scoria
	H G O	silt, sand, clay
	S I K	clay, sand with silt, sand
	J P D R	sand, sand and gravel, shale
	S D I	clay with sand , alternation of siltstone and sandstone

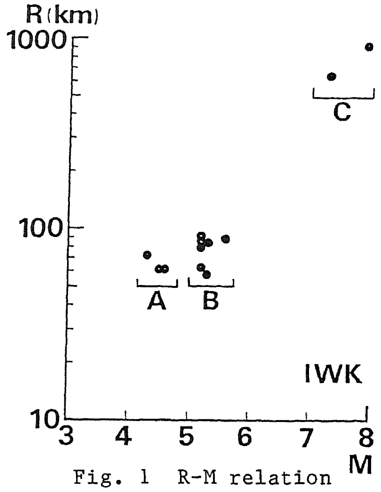


Fig. 1 R-M relation

In addition, earthquake records gained at several stations simultaneously were classified by magnitude of earthquake. 12 earthquakes recorded on three sites, IWK, TMK, TKI were selected and each magnitude classified A, B, and C group is less than 5, from 5 to 6, and more than 6 (Fig. 1). Comparing analized results among three groups, influence of the characteristics of earthquake input to underground seismic coefficient was examined.

Identified Ground Model In each site, identification model of ground was obtained from SPIN (System Parameter Identification by Newton method). At IWK site scattering of identification model was examined for earthquake records. Identified model obtained by averaged transfer function (Table 2, Fig. 2) agreed with average of identified model for each earthquake. At the other array observational sites ground models were also identified. But some of rock ground which recorded the recent major earthquake, were modeled as a half-space ground. Those models were verified to compare the simulated underground motion with recorded value at observational point.

Normalized Underground Seismic Coefficient With the use of above mentioned identified ground models, one-dimensional ground seismic response was analized by multiple reflection theory. After that, the underground seismic coefficient distribution was obtained from two definitions. Two definitions are as follows.

Table 2 Identified Ground Model

depth	Layer	Vs m/sec	Q
0.6m	1	323	16
	2	887	13
21.1 m	3	1329	11
	4	1389	11
70.7 m	5	1444	11
	6	1411	11
200.9 m	7	1516	11
	8	1323	11
	9	1588	11
	10	1497	11
	11	1587	11
	12	2116	11
330.8m	13	2420	21

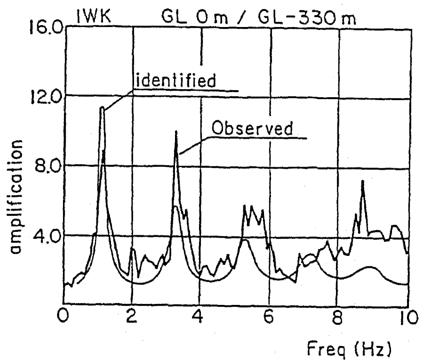


Fig. 2 Transfer function

(Method 1)
Seismic coefficient distribution was obtained from the maximum acceleration value of each layer in ground

$$K_i = A_{imax}/G \qquad (1)$$

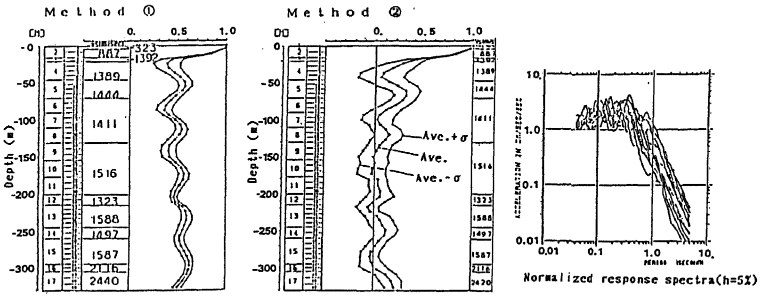
i : Layer number
K_i : Seismic coefficient
A_{imax} : Maximum acceleration
G : Acceleration of gravity

(Method 2)
Seismic coefficient distribution was obtained from the interlayer maximum shear stress difference of the layer in ground.

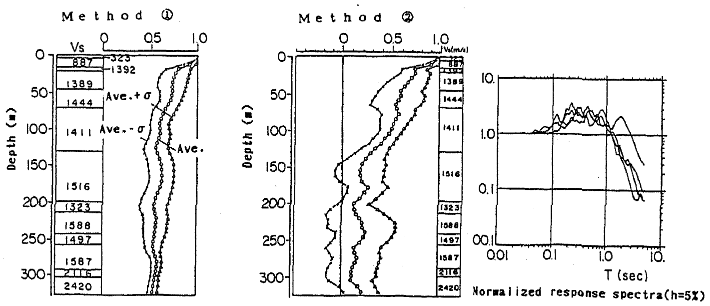
$$K_i = \{|\tau_{imax}| - |\tau_{i-1,max}|\}/\gamma_i \cdot H_i \qquad (2)$$

i : Layer number
τ_{imax} : Maximum shear stress
γ_i : Gravity of unit volume
H_i : Thickness of layer

Of these seismic coefficients, that obtained from the maximum acceleration value of each layer generally has a minimum value at a depth of several tens of meters and sinusoidally varies to converge to a certain value. The seismic coefficient obtained from each interlayer maximum shear stress difference decreases rapidly with the increase in depth. Those underground seismic coefficient distributions normalized by the value at the surface layer were called normalized underground seismic coefficient in this paper. In Fig. 3 average and variation of normalized underground seismic coefficients for B group and C group earthquake observed at IWK were shown with the response spectra of seismic wave input. As a result, it was found that reduction of the underground seismic coefficient distribution was related with the spectrum characteristics of seismic wave input.



(a) B group earthquake in IWK



(b) C group earthquake in IWK
Fig. 3 Normalized underground seismic coefficient

To examine those result, the seismic coefficient distribution for the standard seismic wave (S_2) input were obtained in IWK ground model (Fig. 4), where S_2 waves input were No. 2 (nearby earthquake), No. 7 (distant earthquake), TAFT (EW component) and those max. amplitude was 600 gal. The seismic ground motion was simulated by equivalent linear analysis method. As well as above mentioned result, it was clarified that normalized seismic coefficient distribution was related with the period of response spectra input. Because the reduction of those distributions is more loose with according that the predominant period of response spectra are long in order of No. 2, No. 7 and TAFT.

Formulation of Normalized Seismic Coefficient On the base of above-mentioned considerations, the underground seismic coefficient distribution of the respective grounds for horizontal motion was modelled in such a way that the seismic coefficient at the ground surface was 1.0, and that the coefficient decreased linearly till a certain depth beyond which the coefficient became constant. As a parameter characterized normalized underground seismic coefficient, the depth H_1, H_2 in which the seismic coefficient becomes minimum and the rate of decrease α_1, α_2 which are the average or r.m.s. seismic coefficient in deeper portion than H_1, H_2 were formulated.

The depth H_1, H_2 in hard rock is clearly related with the predominant period of input ground motion. The depth H_1 in rocks (hard and soft rock) was equal to one-forth of wave length ($\lambda/4$) which is given by equivalent Vs in surface layer on baserock and predominant period of earthquake input wave, and H_2 is one and half time larger than H_1. (Fig. 5)

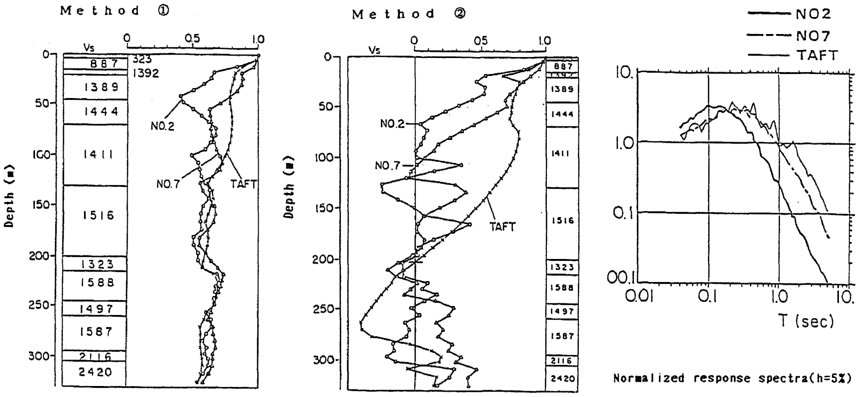
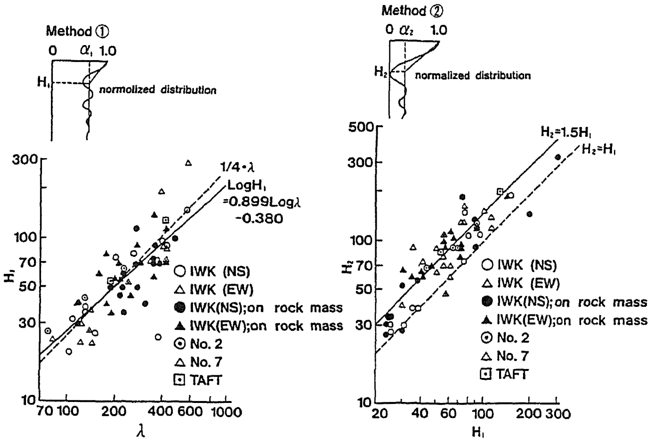


Fig. 4 Normalized underground seismic coefficient for S_2 earthquake

In soft ground normalized seismic coefficient distribution from method 1 is influenced with thickness of surface layer and the natural period of the layer. The depth H_1 in soft ground is $\lambda/4$ when the predominant period of input earthquake T is longer than natural period $T_0(=4H_0/Vs)$ of surface ground, and equals to depth of surface layer H_0 when T is shorter than T_0(Fig. 6).

Then the parameter α_1 is clearly related with the impedance ratio or the shear wave velocity ratio between the baserock and surface layer, and α_2 is constant value. On the case of method 1, the value of α_1, was 0.7 for a homogenous ground, and 0.55 for a ground in which the shear wave velocity ratio between the baserock and the surface layer was 0.5 (Fig. 7). On the otherhand, in the case of method 2, α_2 was 0.3 irrespective of the impedance ratio (Fig. 8).



(a) The relation between the depth H_1 and wave length of input seismic motion

(b) The relation between the depth H_1 and H_2

Fig. 5 The property of H_1 and H_2 in hard rock ground

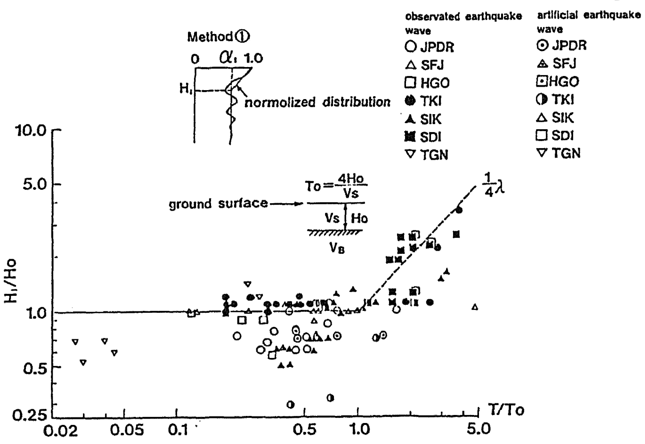
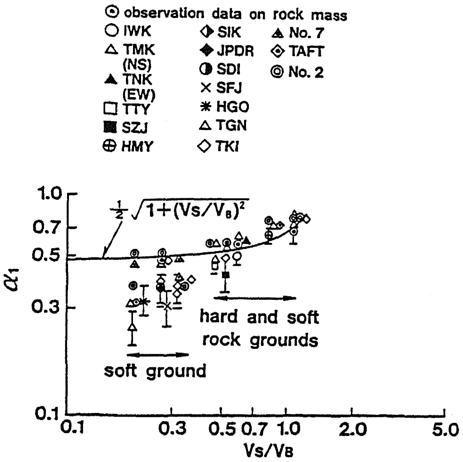
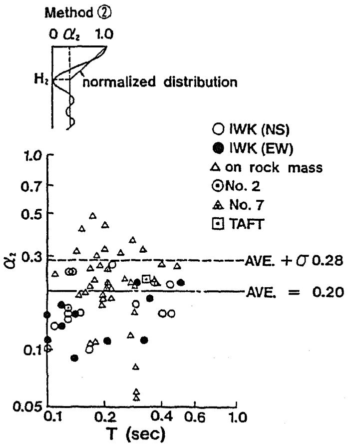


Fig. 6 The relation between the depth H_1 and the predominant period T



g. 7 The property of normalized seismic coefficient in various kinds of grounds



in hard rock ground

Fig. 8 The relation between normalized seismic coefficient α_2 and predominant period T

In comparison of the model with observation data, it was confirmed that these models had sufficient compatibility. In accordance with those results, normalized seismic coefficient distribution model in hard and soft rock grounds was formulated (Table 3).

Table 3 Formulation of the Reduction of Seismic Coefficient in the Ground

Calculation method of normalized seismic coefficient	Parameter	Hard and soft rock grounds	Soft ground
Method①	H_1	$1/4 \cdot Vs \cdot T$	$1/4 \cdot Vs \cdot T$, where $T \geqq 4 \cdot Ho/Vs$ Ho, where $T < 4 \cdot Ho/Vs$
	α_1	$1/2 \cdot \sqrt{1+(Vs/V_B)^2}$	$1/2 \sqrt{1+(Vs/V_B)^2}$
Method②	H_2	hard rock;$1.5H_1$ soft rock;$1.3H_1$	No formulation
	α_2	0.3	No formulation

(Note)

H_1 ; Depth in which normalized seismic coefficient in the ground becomes minimum.

α_1 ; Average value of normalized seismic coefficient at deeper position than H_1.

H_2 ;·Depth in which normalized seismic coefficient in the ground becomes zero or minimum.

α_2 ; Root mean square value of normalized seismic coefficient at deeper position than H_2.

Vs ; Velocity of shear wave of surface layer

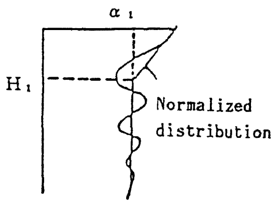
V_B ; Velocity of shear wave of bed rock layer

T ; Predominant period of acceleration response spectra of input seismic motion

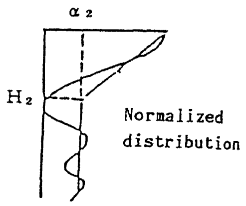
λ ; Wave length

$4 \cdot Ho/Vs$; Natural period of surface layer

(Method ①)



(method ②)



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