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 analyse 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 seismic 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 distribution 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 S2 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

<table>
<thead>
<tr>
<th>Classification of ground</th>
<th>Observation point</th>
<th>Ground profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard rock mass</td>
<td>I W K</td>
<td>sandstone, granite</td>
</tr>
<tr>
<td></td>
<td>T M K</td>
<td>mudstone, sandstone, diorite</td>
</tr>
<tr>
<td></td>
<td>T T Y</td>
<td>loam, sandstone, mudstone</td>
</tr>
<tr>
<td></td>
<td>S J</td>
<td>tuff</td>
</tr>
<tr>
<td>Soft rock mass</td>
<td>K Y</td>
<td>clay with gravel, mudstone</td>
</tr>
<tr>
<td></td>
<td>T K I</td>
<td>sand, sand and gravel, shale</td>
</tr>
<tr>
<td></td>
<td>S F J</td>
<td>loess, siofla</td>
</tr>
<tr>
<td></td>
<td>M G O</td>
<td>silt, sand, clay</td>
</tr>
<tr>
<td>Soft ground</td>
<td>S I K</td>
<td>clay, sand with silt, sand</td>
</tr>
<tr>
<td></td>
<td>J P D R</td>
<td>sand, sand and gravel, shale</td>
</tr>
<tr>
<td></td>
<td>S D I</td>
<td>clay with sand, alternation of siltstone and sandstone</td>
</tr>
</tbody>
</table>

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

$$K_i = A_{i} \cdot \frac{\text{imax}}{G}$$  \hspace{1cm} (1)

$i$ : Layer number  
$K_i$ : Seismic coefficient  
$A_{i \text{max}}$ : 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.

$$K_i = \left( |\tau_{i \text{max}}| - |\tau_{i-1 \text{max}}| \right) / \gamma_i \cdot H_i$$  \hspace{1cm} (2)

$i$ : Layer number  
$\tau_{i \text{max}}$ : Maximum shear stress  
$\gamma_i$ : 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 these results, the seismic coefficient distribution for the standard seismic wave (S2) input were obtained in 1WK ground model (Fig. 4), where S2 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 H1, H2 in which the seismic coefficient becomes minimum and the rate of decrease α1, α2 which are the average or r.m.s. seismic coefficient in deeper portion than H1, H2 were formulated.

The depth H1, H2 in hard rock is clearly related with the predominant period of input ground motion. The depth H1 in rocks (hard and soft rock) was equal to one-fourth of wave length (λ/4) which is given by equivalent Vs in surface layer on baserock and predominant period of earthquake input wave, and H2 is one and half time larger than H1. (Fig. 5)

![Fig. 4 Normalized underground seismic coefficient for S2 earthquake](image)

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 H1 in soft ground is λ/4 when the predominant period of input earthquake T is longer than natural period T0 (=4H3/Vs) of surface ground, and equals to depth of surface layer H2 when T is shorter than T0(Fig. 6).

Then the parameter α1 is clearly related with the impedance ratio or the shear wave velocity ratio between the baserock and surface layer, and α2 is constant value. On the case of method 1, the value of α1 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 other hand, in the case of method 2, α2 was 0.3 irrespective of the impedance ratio (Fig. 8).
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 $T$

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

Fig. 8 The relation between normalized seismic coefficient $Q_s$ 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

<table>
<thead>
<tr>
<th>Calculation method of normalized seismic coefficient</th>
<th>Parameter</th>
<th>Hard and soft rock grounds</th>
<th>Soft ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method (1)</td>
<td>H&lt;sub&gt;1&lt;/sub&gt;, 1/4 · Vs · T; where T ≥ 4 · Ho/Vs Ho, where T &lt; 4 · Ho/Vs</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>α&lt;sub&gt;1&lt;/sub&gt;</td>
<td>1/2 · √(1 - (Vs/Vp)&lt;sup&gt;2&lt;/sup&gt;)</td>
<td>1/2 · √(1 - (Vs/Vp)&lt;sup&gt;2&lt;/sup&gt;)</td>
</tr>
<tr>
<td>Method (2)</td>
<td>hard rock: 1.5H&lt;sub&gt;1&lt;/sub&gt;, soft rock: 1.3H&lt;sub&gt;1&lt;/sub&gt;</td>
<td>No formulation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>α&lt;sub&gt;2&lt;/sub&gt;</td>
<td>0.3</td>
<td>No formulation</td>
</tr>
</tbody>
</table>

(Note)
H<sub>1</sub>; Depth in which normalized seismic coefficient in the ground becomes minimum.
α<sub>1</sub>; Average value of normalized seismic coefficient at deeper position than H<sub>1</sub>.
H<sub>2</sub>; Depth in which normalized seismic coefficient in the ground becomes zero or minimum.
α<sub>2</sub>; Root mean square value of normalized seismic coefficient at deeper position than H<sub>2</sub>.
Vs; Velocity of shear wave of surface layer
V<sub>p</sub>; Velocity of shear wave of bed rock layer
T; Predominant period of acceleration response spectra of input seismic motion
λ; Wave length
4 · Ho/Vs; Natural period of surface layer

ACKNOWLEDGMENTS

The results were examined at the subcommittee of ground of Japan Society of Civil Engineers as a Electric Utilities Common Research from 1984 till 1987. The data of rock and soft rock were obtained in Electric Utilities Common Research. The authors express their sincere thanks and appreciation to members of these committee.

REFERENCES