Input motions for rigid foundations to observed seismic waves

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ABSTRACT: In order to estimate the foundation input motion that is important characteristics on soil-structure interaction, earthquake observations for soil layers have been performed and an approximate method to evaluate the input motion is presented. The input motions for the non-embedded and embedded foundations using observed seismic records are also presented and it is indicated that the embedment effect reduced the horizontal input motion and increase the rotational input motions.

1. INTRODUCTION

The evaluation of the impedance functions and the input motions becomes the key step in computation of the response of structures including the soil-structure interaction effect. The impedance functions represent the relationships between the harmonic external forces and the responses of a massless foundation, and the foundation input motions the response of a massless foundation to earthquake excitations. Most of experimental studies of soil-structure interaction effect have been focused on the evaluation of the impedance functions using foundation models. On the other hand, earthquake observations of the soil-structure models can provide useful information of the input motions. This procedure, however, requires the dense array of seismometers set on the foundation-structure system. This paper presents an approximate but practical method to evaluate the foundation input motions using the free-field ground motions. The characteristics of the foundations input motions are also discussed.

2. EARTHQUAKE OBSERVATIONS

An earthquake observation site is located on the northern part of Tohoku area in Japan. The observations are performed on structure models and in soil layers as shown in Fig. 1. The observations for soil layers consist of "free field" and "excavated and backfilled grounds".

This paper discusses on the characteristics of "excavated and backfilled grounds" motions and the input motions using observed earthquake records. Many seismometers are set in "excavated and backfilled grounds" and rock layers. Three components of acceleration are provided for all observed points of "excavated and backfilled grounds".

Soil layers consist of the backfill soil, loam, soft rock and hard rock layers. The boring examinations and elastic wave tests on the soil non-embedded were performed to confirm the soil properties. The earthquake observation for "excavated ground" was performed from April 1990 through June 1992, and the observation for "backfilled ground" was conducted from July 1992

The key parameters of observed earthquake records selected in this study are shown in Table 1. The earthquake No. 25 was selected for "excavated ground" and No. 55 for "backfilled ground". These seismic waves may have considered to have traveled from east of the observation site and are supposed to be SH waves judging from the epicentral distance and depth. The time histories and Fourier spectra of response accelerations in "excavated and backfilled grounds" are shown in Fig. 2 and Fig. 3, respectively. It may be noticed that the observed results corresponding to the same depth show the almost same peak values and spectral characteristics.

An axisymmetric finite element method (FEM) was used to simulate the dynamic responses of ground. Soil properties obtained by the boring examination are used in the analysis as shown in Table 2. Fig. 4 shows the analytical models for axisymmetric FEM. Fig 5 shows the comparison of the transfer functions derived from observed and analytical results. The observed transfer functions indicate two peaks at 6.5Hz and 15Hz that correspond to the natural frequencies of the soil layers, surrounding ground and backfill soil. The frequency dependency of the calculated transfer functions shows good agreement with that of the observed transfer functions.

3. FORMULATION OF INPUT MOTIONS

The complete formulation of the input motions was presented by Wong et al. (1978) for the non-embedded foundation and Iguchi (1982) for the embedded foundation. Iguchi has also developed an approximate method to evaluate the foundation input motions as shown by equation (1).

\[ \{U^*\} = [H]^{-1} \int_S [A(\vec{X})]^T \{u^f(\vec{X})\} dS - [K]^{-1} \int_S [A(\vec{X})]^T \{\tau^f(\vec{X})\} dS, \vec{X} \in S \]  ...................................... (1)

where \{U^*\} is the foundation input motion vector which is composed of six components, S means the interface area between foundation and soil.

\[ [A(\vec{X})] = \begin{bmatrix} 1 & \ldots & 0 & \ldots & 0 & \ldots & 1 \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ -1 & \ldots & 0 & \ldots & 0 & \ldots & -1 \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ \end{bmatrix} \begin{bmatrix} \rho(X) [A(X)]^T \{u^f(X)\} dS \\ \{\tau^f(X)\} \\ \end{bmatrix}, \vec{X} \in S \]

\{u^f\} is free-field motion and \{\tau^f\} is traction force associated with stress in the soil layer. [K] is impedance matrix, [H] is consistent with the impedance matrix [K], and [A] is rigid-body motion influence matrix.

Equation (1) requires the information of both the displacements and stresses at the interface S in addition to the impedance matrix. Generally, it is quite difficult to measure the stresses in the soil layers during actual earthquakes. The objective here may be obtained an alternative expression of the input motions. The last term in equation (1) can be rewritten in terms of the displacements as in equation (2).

\[ \{U^*\} = [H]^{-1} \int_S [A(\vec{X})]^T \{u^f(\vec{X})\} dS - \omega^2 [K]^{-1} \int_S \rho(X) [A(X)]^T \{u^f(X)\} dV', \vec{X} \in S, \vec{X} \in V' \]  ...................................... (2)

where V' means the region inside the interface S, and \rho means the density of soil.

Equation (2) is based on equivalent relation between the traction forces subjected at the interface S and the inertial forces in the region V'.

In the case of the non-embedded foundations, the last term of equation (1) vanishes and the following approximation is obtained by Tani et al. (1973).

\[ \{U^*\} = [H]^{-1} \int_S [A(\vec{X})]^T \{u^f(\vec{X})\} dS, \vec{X} \in S \]  ......................................................... (3)

Equation (3) indicates that the input motion can be expressed by the averaged value of the displacement on the interface between the soil and the foundation.
4. INPUT MOTIONS OF NON-EMBEDDED AND EMBEDDED FOUNDATIONS

Let consider 8 meter square foundations with no embedment and 5 meter embedment instead of backfill soil as shown in Fig. 6. It is possible to evaluate the input motions for these foundations approximately using equations (2) and (3) provided that the soil displacements and impedance functions are known. Since the forced vibration test was not performed for "excavated and backfilled grounds", the impedance matrix could not be obtained experimentally. The impedance functions obtained from the forced vibration test for the frame type structure (see Model C in Fig. 1.) with 5m embedment is employed (Kurimoto et al. 1993). Fig. 7 shows the impedance functions to estimate input motions for the embedded foundation.

Fig. 8 and Fig. 9 show the input motions normalized by the response of "free field" ground surface. The characteristics of input motions indicate that the horizontal components decrease and rotational components increase in the range below 10Hz. The horizontal input motion for the embedded foundation is more reduced than that for the non-embedded foundation due to the embedment effect. In the high frequency range above 15Hz the accuracy may be degraded lower because the displacement distribution is assumed to be linear for limited observation points. The analytical result coincides with observed one in the range below 10Hz.

5. CONCLUSIONS

Firstly, a lot of valuable earthquake records have been obtained for the systematic observation array. The simulation analysis for "excavated and backfilled grounds" were performed to confirm the amplification and frequency characteristics of soil responses.

Secondary, the input motions are evaluated using the seismic responses of "excavated and backfilled grounds". The characteristics of input motions showed fairly good agreement with analytical results evaluated by the axisymmetric FEM. Therefore, these results could be applicable to practical use for seismic study before construction.

ACKNOWLEDGMENT

This work was carried out by Nuclear Power Engineering Corporation(NUPEC) as the entrusted project sponsored by the Ministry of International Trade and Industry in Japan. This work was supported by "Committee on Verification Test of Quaternary Siting Technology" of NUPEC. The authors wish to express their gratitude for the cooperation and valuable suggestions given by the members of Committee.

REFERENCES

Table 1 Earthquake Records

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<th>Earthquake No.</th>
<th>Magnitude</th>
<th>Epicenter</th>
<th>Epicentral Distance (km)</th>
<th>Depth (km)</th>
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Fig. 1 Location of Seismometers

Fig. 2 Time Histories of Response Acceleration in Soil Layers
Table 2 Soil Properties used in Axisymmetric FEM

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Fig. 4 Axisymmetric FEM Model

Fig. 5 Transfer Functions
Fig. 6 Massless Rigid Square Foundations

Fig. 7 Impedance Functions for Embedded Foundation obtained from Forced Vibration Test

Fig. 8 Foundation Input Motions for Non-embedded Foundation (Earthquake. No. 25)

Fig. 9 Foundation Input Motions for Embedded Foundation (Earthquake. No. 55)