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# EARTHQUAKE RESPONSE OF A LARGE-SCALE STRUCTURE DEEPLY EMBEDDED IN QUARTERNARY GROUND AND ITS SIMULATION ANALYSIS

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## SUMMARY

The SSI correlation analysis for a large-scale structure deeply embedded in the quarternary ground were performed in order to validate the seismic analysis method. Presented in this paper is the results and findings obtained through the analyses using the progressive code and the current codes. Through this study, it is pointed out that the SSI responses are considerably influenced by the surrounding ground responses themselves, and that the reasonable responses can be obtained by the methods when the ground response was provided in good accuracy.

## INTRODUCTION

Several investigations, such as Soil Surveys, Forced Vibration Tests and Earthquake Observations, have been carried out with the experimental fast reactor "JOYO" in order to validate the analysis methods for the motions during earthquakes of a large-scale structure deeply embedded in the quarternary ground. The SSI correlation analysis program may be considered as consisting of three phases as shown in the flow chart of Fig.1. The SSI System is constructed of the design data and the soil data available in the first phase. In the second phase, when the measured responses from the forced vibration test (FVT) become available, the SSI System is evaluated and improved through comparing the calculated responses to FVT with respective measurements. The third phase consists of calculating seismic response and the subsequent comparison and evaluat-

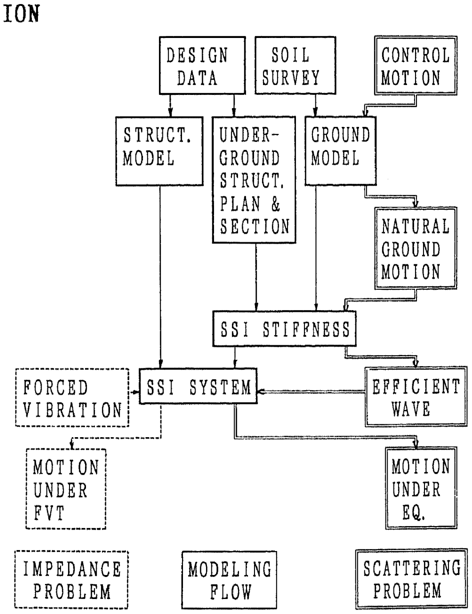



FIG. 1 Modeling and Analysis Flow Chart for SSI Problem

ion. The first two phases have been carried out and described in the paper C12-06 of "9WCEE" by UESHIMA etal, where the SSI stiffness has been identified based on the measured data from FVT. In this paper, it was estimated by the simulation in conformity with the illustrated flow chart using "RESP" and it was found that the peak frequencies and the heights of the calculated transfer functions agree well with those of the identified model, although the SSI stiffness is estimated under the restrictions on the shape of the structure and the characteristics of the ground. Therefore, it has been confirmed that the simulation model is equivalent to the identified model. This paper presents the scattering problem only.

<u>The Numerical Methods and Scope</u> This study uses three kinds of methods on SSI simulation analysis as follows :

(1) RESP : A kind of Hybrid method(Ref.1),which uses the three dimensional point load solution (Ref.2), and joins the solution to the 3D FEM by the four stepped sub-structure method(Ref.3). This code can handle flexible foundation of arbitrary shape embedded in a multi-layered visco-elastic half space.
(2) NOVAK: The lumped mass stick model with the SSI stiffness which is estimated by NOVAK etal(Ref.4). The stiffness is estimated in a layer over half space in the original paper. However,the thickness of the surface layer is replaced by the thickness which we are concerned in this study.
(3) LATT: The two dimensional lumped mass model with plane strain. Mass of the ground part is connected each other with the shear beam vertically and with the normal spring laterally. The SSI stiffness of the model is calculated implicitly except the rocking stiffness which is offered by the other method.

The methodologies of NOVAK and LATT are adopted to the most common and current design, and based on this reason, they were used in order to compare the results with those of "RESP".

## THE STRUCTURE AND THE GROUND

"JOYO", the total weight of which is about 168 ktons is deeply embedded beyond a half of its total height in sand and sandy gravel, and is settled on the

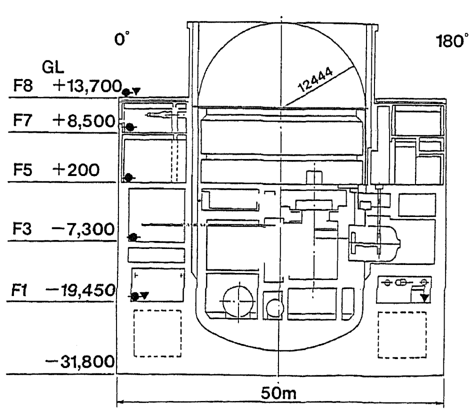



FIG. 2 Profile of Facility

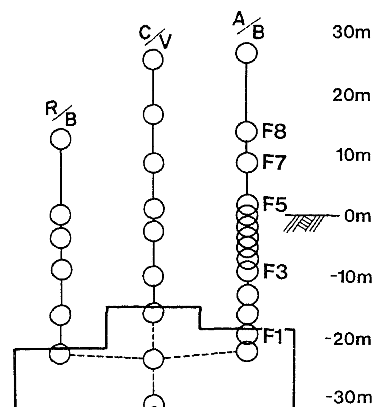



FIG. 3 Numerical Model Structure of Facility

fine sand. Fig.2 shows a cross section of the structure in profile, and the arrangement of earthquake observation points. The "JOYO" structure consists of an accessory building(A/B), a containment vessel(C/V) and a reactor building(R/B). The common foundation mat is a reinforced concrete of 55mX50m in plan. The finite element model as the lumped mass stick model for the "JOYO" structure is shown in Fig.3. Fig. 4 shows the structure of the natural ground of "JOYO" from the elastic velocity survey and the arrangement of all earthquake observation points in the ground. The earthquake observations were continued since 1985 and twenty fairly good records were obtained in '85. Fig.5 shows the observation site and the distribution of epicenters of 20 earthquakes, involving 3 earthquakes beyond magnitude of 6.

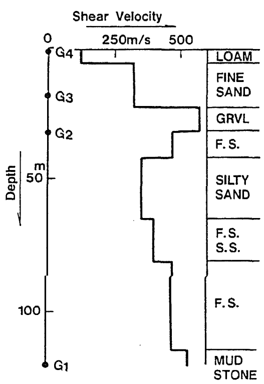



FIG. 4 Structure of Natural Ground

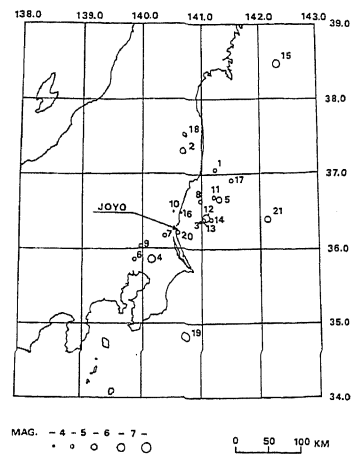
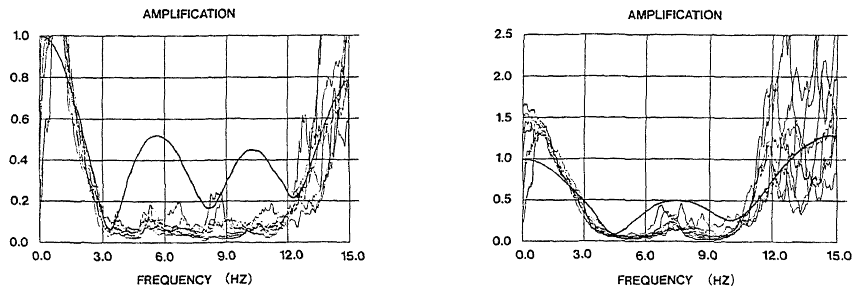



FIG. 5 Distribution of Epicenters and Observation Site

## THE MOTION OF THE GROUND

In order to simulate the responses of the structure, the natural ground motions and the efficient input motion must be estimated according to the flow chart in Fig.1, where the efficient motion acts the end of the SSI stiffness, another end of which is connected to the structure. The SSI stiffness is fixed or available through the impedance problem study in their linear range and the efficient input motion is introduced from SSI stiffness, the ground properties and the shape of the structure. Hence, the efficient input motions are calculated automatically from the motion of natural ground.

Fig.6 shows the example of Fourier amplitude ratios to the ground surface. These natural ground amplification are calculated by seven observed records(EQ. 2,5,4,8,9,11,12 shown in Fig.5). The G3/G4 and G2/G4 curves suggest two predominant peaks at frequencies of 5Hz, 9Hz, three peaks at about 4Hz, 7.5Hz, 11Hz, respectively. The figure shows that each earthquake gives the different curve from others. These curves may be influenced by the coherency of incident wave field such as the type of incident waves and the direction of their approach and by the site conditions such as the geological structure and their properties.




(1) G2/G4 (Structure base level / Surface) (2) G3/G4 (Middle level / Surface)

FIG. 6 Amplification Factor of Natural Ground

Using the SHAKE, the amplification factor of the ground model is calculated and is shown in Fig.6 added to the observed factors where the propeties of the model is confined in their linear range. As shown in the figure, there is large deviation between the model factor and the observed factors. However, use of a soil profile based on shear wave velocities derived from in-situ geophysical investigations provides the good agreement for the impedance problem mensioned above. Hence, it may be pointed out that the deviation is not ascribed to the ground model but to the incident wave field and/or the geological structure. As the many studies have been performed on the source-path-site effect problem, from the present engineering point of view, it is a problem to estimate the amount of error between the observed and the calculated motion using the current analysis.

## SEISMIC ANALYSIS

Seismic analysis are performed for seven earthquakes records at the site using three kinds of code. However, this paper presents typical results for an earthquake only.

Control Motion In order to investigate the differences of the responses with respect to the three kinds of control motions: G2(-32m), G3(-18m) and G4(-1m), the frequency response analyses were performed using "RESP". By use of the transfer functions, the time histories of the response to an earthquake were calculated through the FFT algorithm. Fig.7 shows the distribution of maximum accelerations of A/B with respect to the three kinds of control motions: G2, G3 and G4. The 5% damping acceleration response spectra for the calculated motions and the observed motions at the selected points (F5, F1 and F8) are shown in Fig.8 to 10. The spectra for control motion G3 is eliminated in Fig.9(F1) and Fig.10 (F8) in order to avoid the complication.

As shown in the figures, use of a G2 record as control motion gives the good agreement between observed and simulation results for the scattering problem for this earthquake. While, the calculated responses using G3 and G4 are generally over-estimated and under-estimated respectively for both the spectra and maximum acceleration. One of the authors has described in another investigation (Ref.5) with respect to the deeply embedded structure which is slightly smaller than "JOYO", that the calculated responses using the ground surface motion agree better with the observed ones than the responses using the motion which is observed at the level of the structure base, because the embedded structure is significantly influenced from the surrounding ground motion and the surface ground motion represents the dynamic characteristics of the ground. It must be corrected through this study. Although the G2 records did not always give the best responses for all earthquakes, the calculated responses using observed records as control motion are distributed within (0.5-2) times observed responses for both the spectra and maximum acceleration in this study.

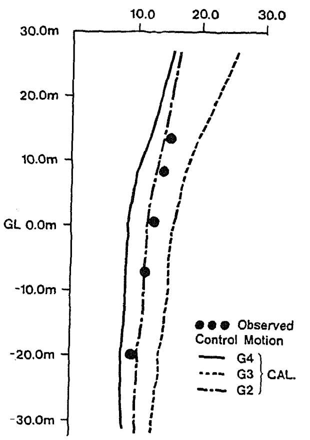



Fig. 7 Distribution of Maximum Acceleration (G2,G3,G4)

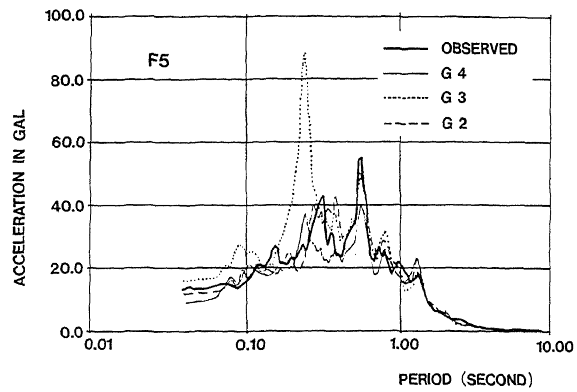



Fig. 8 Response Spectra at Ground Level Floor of the Structure (G2,G3,G4)

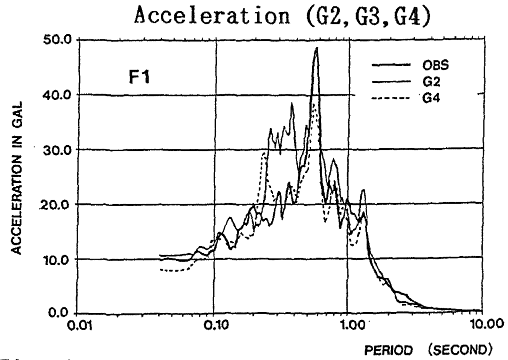



Fig. 9 Response Spectra at Base Mat Surface Floor of the Structure (G2,G3,G4)

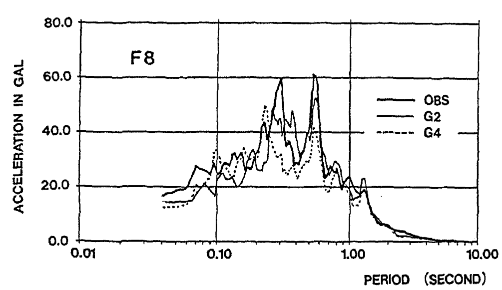



Fig. 10 Response Spectra at Roof Floor of A/B (G2,G3,G4)

ANALYSIS METHODS In order to investigate the difference of the response with respect to the three kinds of calculation methods, the response analysis were performed based on G2 motion as control motion. Fig.11 shows the calculated distribution of maximum acceleration compared with the observed responses. The 5% damping acceleration response spectra for the calculated motions and the observed motions at the F5 are shown in Fig.12. As seen in the figures, the calculated responses agree with the corresponding observed responses. Especially, LATT which is based on the plane strain model and is difficult to accomodate the impedance problem, gives good responses on the impedance problem. These results show that the motions of the embedded structure during earthquakes are sensitive to the ground motion rather than to SSI stiffness.

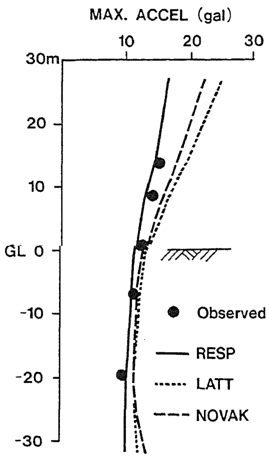



Fig.11 Distribution of Maximum Acceleration (Code)

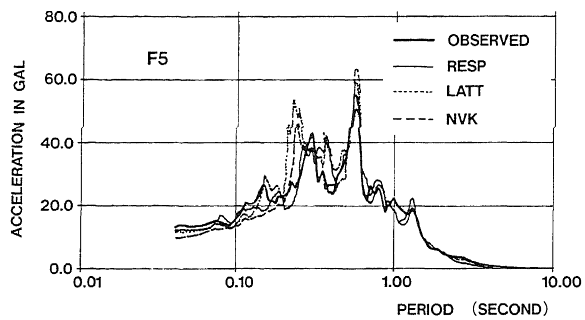



Fig.12 Response Spectra at Ground Level Floor of the Structure (Code)

## CONCLUSION

The correlations of analytical results obtained by three kinds of computer program are carried out based on the observed records. The following conclusions can be drawn through the study:

(1) The motion of embedded structure during earthquakes is significantly influenced from the surrounding ground motion.
(2) The calculated responses based on the 7 observed records as control motion are distributed within (0.5-2) times observed responses for both the spectra and maximum acceleration, using a kind of code.
(3) The motions of the embedded structure during earthquakes are sensitive to the ground motion rather than to SSI stiffness.
(4) The current design methods as well as the progressive method give the good agreement between observed and simulation results.

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