RESEARCH ON MODELING OF NUCLEAR POWER PLANTS FOR DYNAMIC RESPONSE ANALYSIS

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SUMMARY

This paper presents the modeling of nuclear power plants for dynamic response analysis due to the horizontal component of earthquake ground motions. Three types of three-stick model are introduced to establish the economical and simplified model which is able to simulate the dynamic characteristics by the finite element model of nuclear power plants considering the dynamic soil-structure interaction effects.

The three-stick model is proposed as the economical and simplified model, in which the dynamic soil-structure interaction effects are represented by the statical spring and the equivalent damping coefficient.

INTRODUCTION

The dynamic response analysis has been utilized to evaluate the safety margin of nuclear power plants against major earthquakes. When the aseismic design of nuclear power plants is performed in practice, the dynamic response analyses are repeatedly used under the various conditions. Therefore, it is necessary to establish the economical and simplified model, and a large number of papers on the modeling of nuclear power plants for the dynamic response analysis have been presented so far.

Authors revealed that the dynamic soil-structure interaction effects and the flexibility of the mat foundation to the vertical component of earthquake ground motions had the significant influence on the floor response spectra which were required for the aseismic design of equipments and pipings, and proposed the economical and simplified model for the dynamic response analysis.[1]

The purpose of this paper is to establish the economical and simplified model to the horizontal component of earthquake ground motions. The analysis for modeling is performed in following three stages. First, the finite element models are employed as the exact models of nuclear power plants, in which the dynamic soil-structure interaction effects are evaluated with the elastic half-space. The influence on the frequency-response by evaluating of the flexibility of the mat foundation is investigated. Second, the sophisticated three-stick models are used to estimate the possibility of the simulation of the dynamic characteristics by the finite element models. Third, additional two types of three-stick model are introduced to establish the economical and simplified model, in which the dynamic soil-structure interaction effects are simplified.

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FINITE ELEMENT MODEL

Two cases of the response analysis due to horizontal harmonic excitation were performed in order to examine the influence on the dynamic response analysis by evaluating the flexibility of the mat foundation, in which the mat foundation was treated as the rigid and elastic body. The structure employed in this research was B.W.R. MARK II modified as shown in Fig.1 and was modeled under the assumption that the plan was symmetric with respect to two orthogonal axes. In the case of elastic body, the stiffness of the mat foundation was evaluated with 4 node shell elements as shown in Fig.2. In the case of rigid body, the degree of freedom of the mat foundation was reduced to 2 degrees of freedom, i.e., the horizontal displacement toward excited direction and the rotational angle around antisymmetric axis in the plane of the motion. As shown in Fig.3, the structure consisted of the shield wall, inner wall, outer wall, cross wall, floor slabs and roof slab, and the stiffness was evaluated by the same procedure applied to the mat foundation in the elastic body. The damping matrix of the structure was evaluated as complex stiffness of hysteresis damping with 5 % for reinforced concrete members and 2 % for steel ones. As the soil conditions, the following values were employed, i.e., shear velocity 1000 m/sec, Poisson ratio 0.4 and density of weight 2.0 t/m^3.

The dynamic soil-structure interaction effects were evaluated based on the condition that the mat foundation was rested on the surface of the elastic half-space. The load-displacement relationship at the contact area between soil and mat foundation was expressed by the integral equation using the Green Function. The contact area was subdivided into circular disks having the equivalent area of rectangular elements shown in Fig.2 and each nodal point was assumed to be located at the center of the circular disk. Green Function matrix consisted of displacements excited by unit harmonic loads on circular disk. The diagonal coefficients of Green Function matrix were obtained by assuming that uniform loads were distributed over the element and the off-diagonal coefficients were computed by a concentrated point load at the center of each element. The compliance stiffness matrix which represented the dynamic soil-structure interaction effects was computed as the inverse matrix of Green Function matrix. In the elastic body, the compliance matrix was superposed on the stiffness matrix of the mat foundation in the finite element model. In the rigid body, the degree of freedom of the mat foundation was reduced to 2 degrees of freedom.

The comparisons between the elastic and rigid model were presented in Fig. 4 and 5 in the form of frequency-response curves of acceleration at the mat foundation and the top of the shield wall, respectively. The frequency-response curves at the mat foundation in the elastic body showed the similar behaviors to the rigid body on the horizontal translation in low frequencies, but different in high frequencies and on the rotation in whole frequencies. The horizontal and rotational frequency-response curves of the elastic and rigid body at the top of the shield wall were quite similar with each other.

From these results, it was revealed that the influence on the frequency-response in the finite element models by evaluating the flexibility of the mat foundation could be negligible.

SOPHISTICATED MASS-SPRING-DASHPOT MODEL

The sophisticated mass-spring-dashpot models were introduced to estimate the possibility of simulation of the dynamic characteristics by the finite element model, in which the mat foundation was treated as the rigid body on the results of frequency-response of the finite element model. The dynamic soil-structure interaction effects were evaluated by the same procedure applied to the rigid mat foundation in the finite element model.

The comparisons of frequency-response at the shield and inner wall on the same floor level shown in Fig.6 indicated that in modeling of the structure, the influence on the dynamic response analysis by the deformation of floor slabs had to be investigated. Then, as sophisticated mass-spring-dashpot models, three-stick models shown in Fig.7 were employed herein, in which the nodal points were located at the slab levels and had 2 degrees of freedom for the horizontal and rotational component. The simulation of the dynamic characteristics of the finite element model were carried out on two cases, i.e., the floor slabs were assumed to be infinity rigid(rigid floor) and the deformation of floor slabs were considered(elastic floor). Based on the results of the statical analysis(0 Hz) in the finite element model, the mass and moment of inertia were lumped at the nodal point as shown in Fig.7. The stiffness of each wall was evaluated as spring constant, i.e., the range of cross section that the rotation was presumed to be nearly equal was effective for bending deformation, the cross section of web for shear deformation. In the elastic floor, slabs spaced between walls were assumed to be effective for shear deformation as shown in Fig.8. The damping matrix of the structure was evaluated with complex stiffness by the same procedure in the finite element model.

The comparisons of frequency-response curves of acceleration for the horizontal and rotational component between the finite element model and sophisticated mass-spring-dashpot models were shown in Fig.9 and 10, respectively. For the horizontal component, both of the sophisticated models with rigid and elastic floor could simulate the fundamental frequency and the peak values of the finite element model except high frequency range. For the rotational component, the sophisticated model with elastic floor could simulate the dynamic characteristics of the finite element model more than that with rigid floor in whole frequency range.

From these results, it was revealed that the sophisticated mass-spring-dashpot model considering the deformation of floor slabs could simulate the dynamic characteristics of the finite element model.

SIMPLIFIED MASS-SPRING-DASHPOT MODEL

In addition to the sophisticated model with elastic floor, two types of mass-spring-dashpot model were introduced, in which the dynamic soil-structure interaction effects were simplified, and the response analyses due to harmonic excitations and simulated earthquake ground motions were performed in order to establish the economical and simplified model. In this paper, Model 2 and 3 were termed the simplified models.

Model 1 was the sophisticated model with elastic floor. The mat foundation and structure in Model 2 and 3 were identical to Model 1. The complex stiffness which represented the dynamic soil-structure interation effects was simplified as shown in Fig.11. The real part of the complex stiffness in Model 2 and 3 was assumed to be statical stiffness. In Model 2, the imaginary part of the complex stiffness which represented the energy dissipation was obtained as the constant equivalent damping coefficient to the frequency and defined at the fundamental frequency of the soil-structure interation system. The imaginary part in Model 3 was defined as the constant equivalent damping ratio.

The results of horizontal and rotational component by the harmonic excitation were shown in Fig.12 and 13, respectively. Model 2 could simulate well the frequency-response curves of Model 1 only except high frequency range of rotational component at the mat foundation. Model 3 could simulate both the frequency-response curves of Model 1 for horizontal and rotational component within the low frequency range up to 5 Hz, but not in high frequency range. From these results, it was found that Model 2 could simulate the dynamic characteristics of Model 1.

The response analyses due to the horizontal component of earthquake ground motions were performed. 10 simulated earthquake ground motions of S1 (maximum possible) were employed as input excitations.[2] They were generated in computer to fit the response spectrum of magnitude 7 and epicentral distance 20 Km with 5 % damping.[3] Fitting status to the target spectrum was shown in Fig.14. The average of the maximum response values for the horizontal component and vertical component caused by rotation were shown in Fig.15 (a) and (b), respectively. The maximum response values of horizontal and vertical component of Model 2 were similar to those of Model 1. The maximum difference of Model 3 to Model 1 were 14 % for horizontal component and 19 % for the vertical component at the outer wall.

The average of floor response spectra with 1 % damping for horizontal and vertical component at the shield wall were shown in Fig.16 and 17, respectively. In short period range that it was important for the aseismic design of equipments and pipings, the difference of Model 2 to Model 1 was within small range at the mat foundation and the top of the shield wall, while the difference of Model 3 to Model 1 was within small range at the top of the shield wall, but not at the mat foundation.

From these results, it was revealed that Model 2 could simulate the dynamic characteristics of Model 1 with allowable difference.

CONCLUSION

In order to establish the economical and simplified model of nuclear power plants due to the horizontal component of earthquake ground motions, some types of model were introduced and the dynamic response analyses were carried out.

The finite element model indicated that the influence on the frequency-response by evaluating the flexibility of the mat foundation could be neglected.

The sophisticated mass-spring-dashpot model(three-stick model) with elastic floor could simulate the dynamic characteristics of the finite element model.

The three-stick model could be proposed as the economical and simplified model, in which the dynamic soil-structure interaction effects were represented by the statical spring and the equivalent damping coefficient.

REFERENCE

[1] Toritani, T., Chiba, O., Fukuzawa, R. and Watabe, M., "Research on Modeling of nuclear Power Plants for Dynamic Response Analysis" K2/1 7th SMiRT, Chicago, 1983

[2] Watabe, M., Chiba, O., and Tohod, M., "Generation of Simulated Three-Dimensional Earthquake Ground Motions" K1/2 5th SMiRT, West Berlin, 1979

[3] Hisada, T., Ohsaki, Y., Watabe, M. and Ohta, T., "Design Spectra for Stiff Structure on Rock" Proc. 2nd Intern. Conf. on Microzonation for Safer Construction, Res. and App., vol. III, 1978

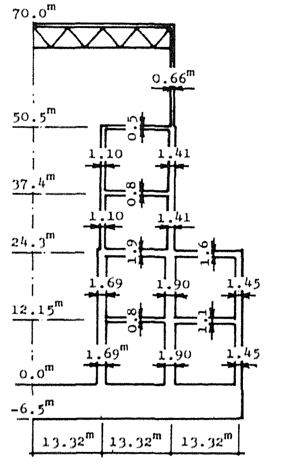


Fig.1 Modified B.W.R. MARK II

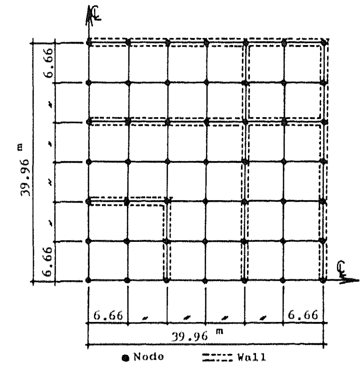


Fig.2 Finite Element Model of the Mat Foundation

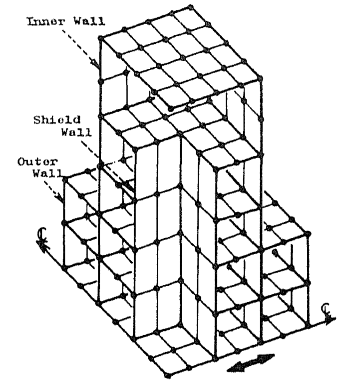
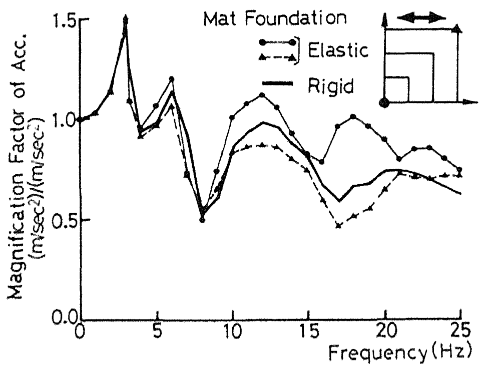
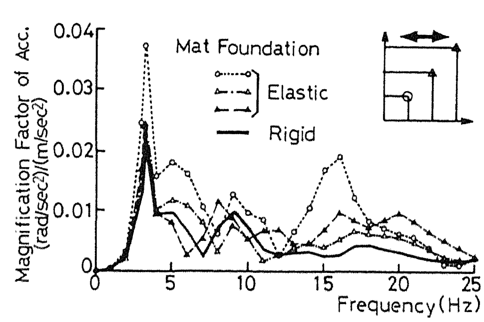


Fig.3 Finite Element Model of the Structure

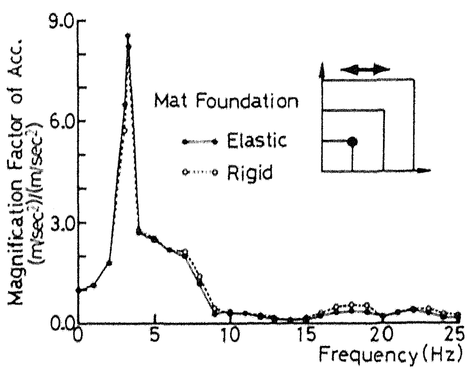


(a) Horizontal Component

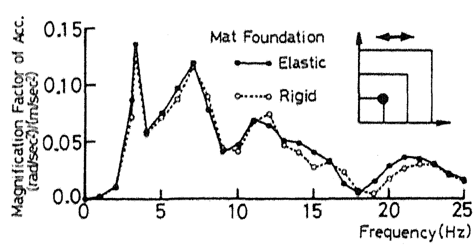


(b) Rotational Component

Fig.4 Frequency-Response at the Mat Foundation

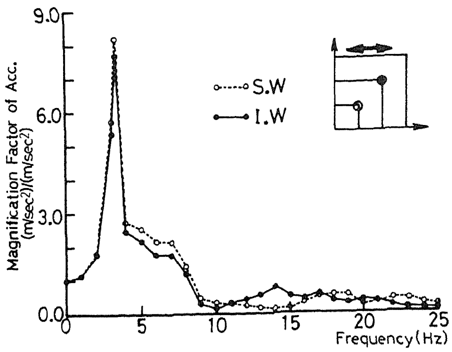


(a) Horizontal Component

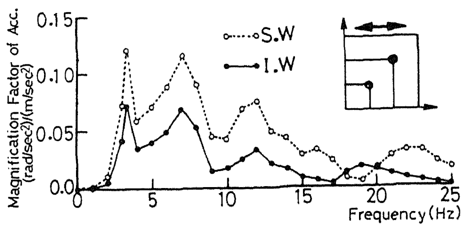


(b) Rotational Component

Fig.5 Frequency-Response at the Top of the Shield Wall



(a) Horizontal Component



(b) Rotational Component

Fig.6 Frequency-Response of the Finite Element Model in Rigid Body

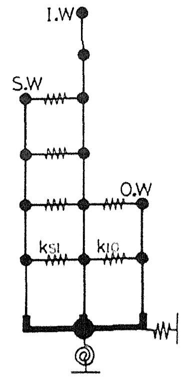


Fig.7 Mass-Spring-Dashpot Model

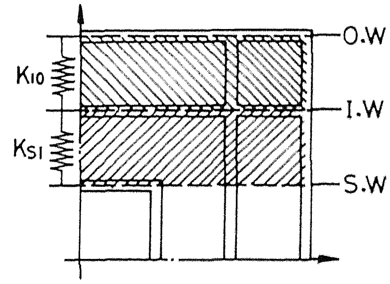
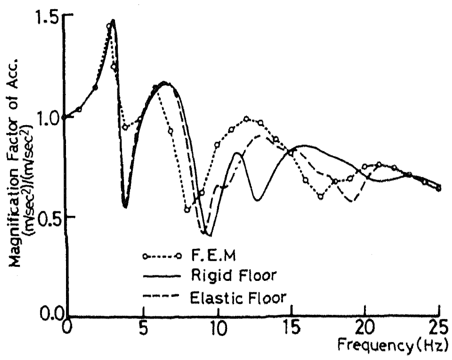
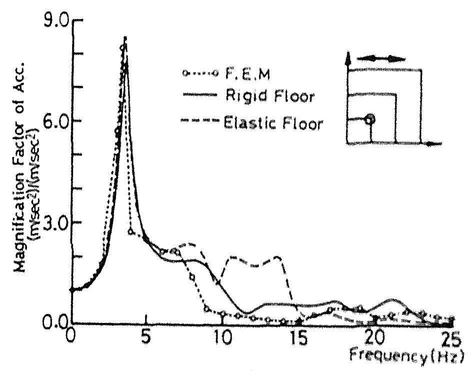


Fig.8 Slabs Spaced between Walls

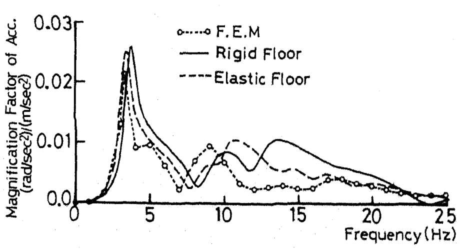


(a) At the Mat Foundation

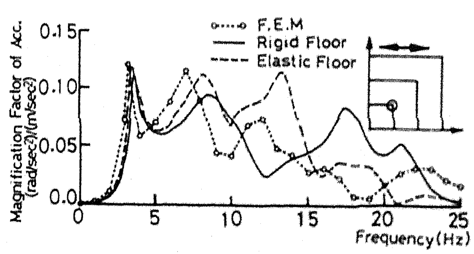


(b) At the Top of the Shield Wall

Fig.9 Frequency-Response for Horizontal Component of the Sophisticated Models

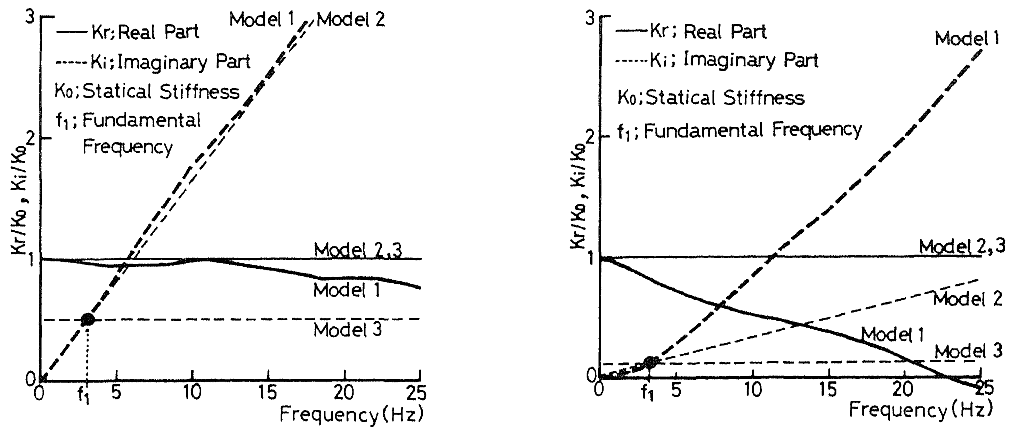


(a) At the Mat Foundation



(b) At the Top of the Shield Wall

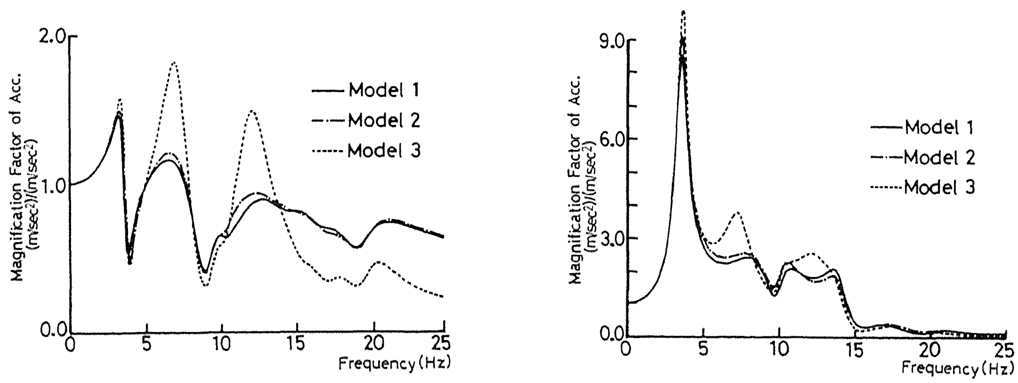
Fig.10 Frequency-Response for Rotational Component of the Sophisticated Models



(a) Horizontal Component

(b) Rotational Component

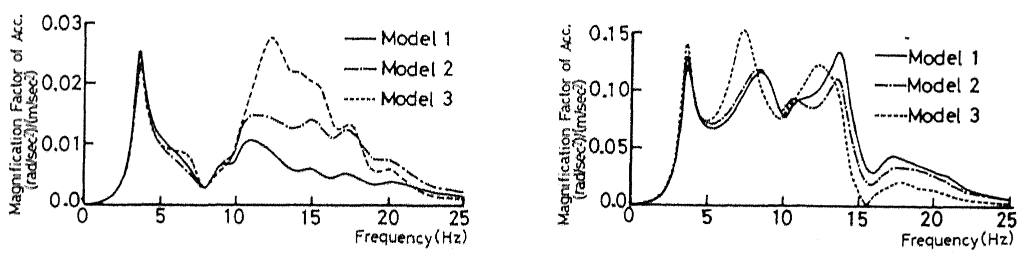
Fig.11 Complex Stiffness of Soil



(a) At the Mat Foundation

(b) At the Top of the Shield Wall

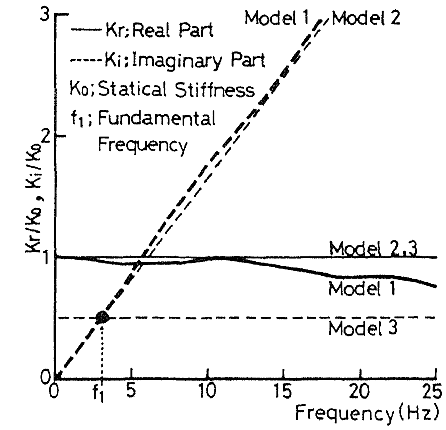
Fig.12 Frequency-Response for Horizontal Component of the Simplified Models



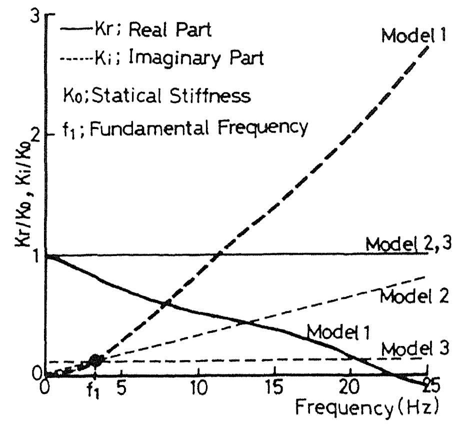
(a) At the Mat Foundation

(b) At the Top of the Shield Wall

Fig.13 Frequency-Response for Rotational Component of the Simplified Models

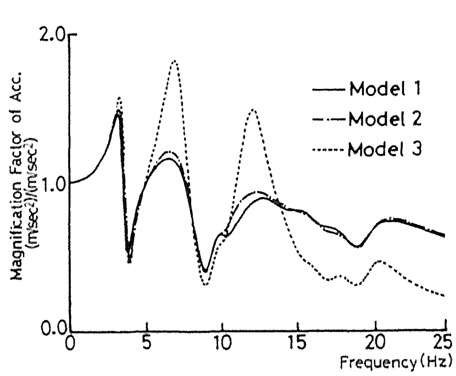


(a) Horizontal Component

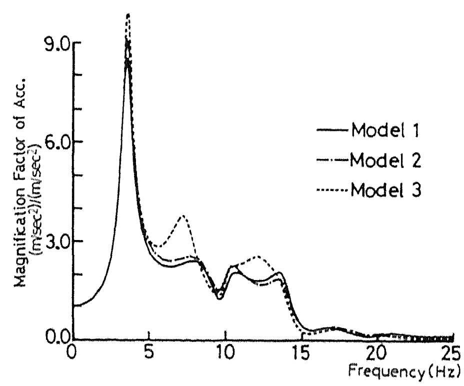


(b) Rotational Component

Fig.11 Complex Stiffness of Soil

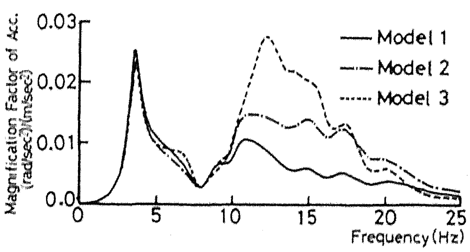


(a) At the Mat Foundation

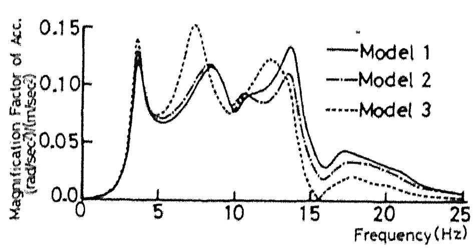


(b) At the Top of the Shield Wall

Fig.12 Frequency-Response for Horizontal Component of the Simplified Models



(a) At the Mat Foundation



(b) At the Top of the Shield Wall

Fig.13 Frequency-Response for Rotational Component of the Simplified Models

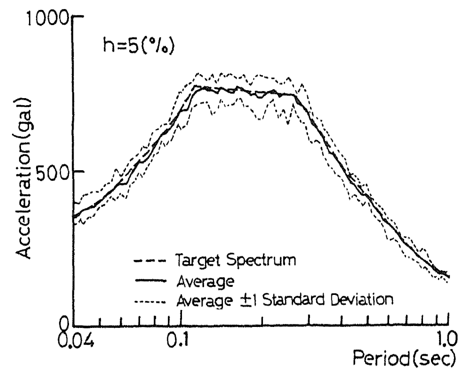
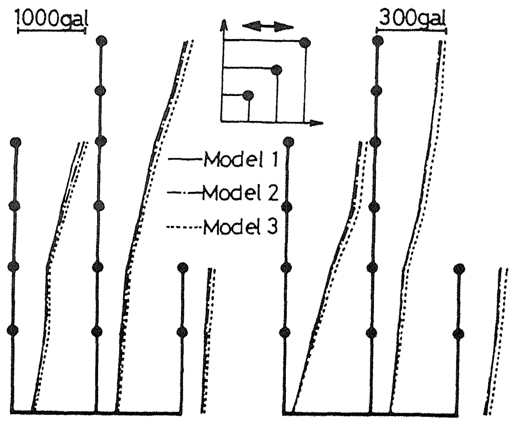


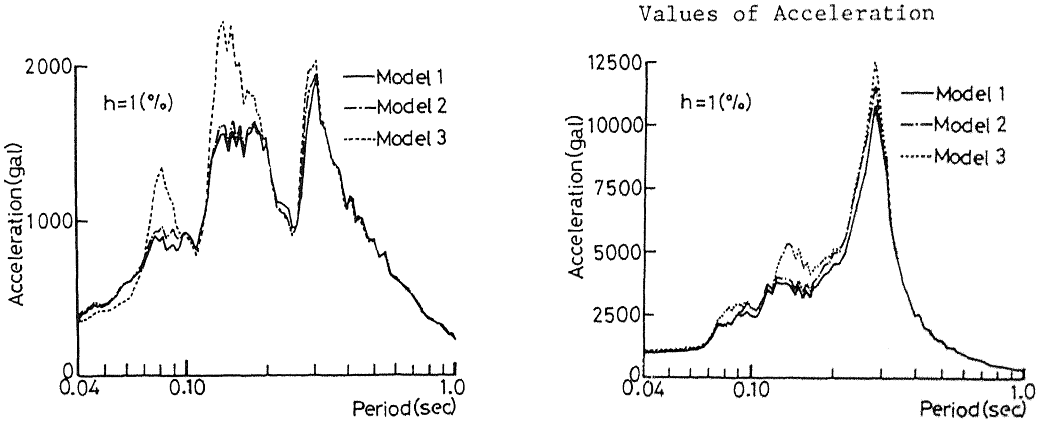
Fig.14 Fitting Status to Target Spectrum



(a) Horizontal Component

(b) Vertical Component

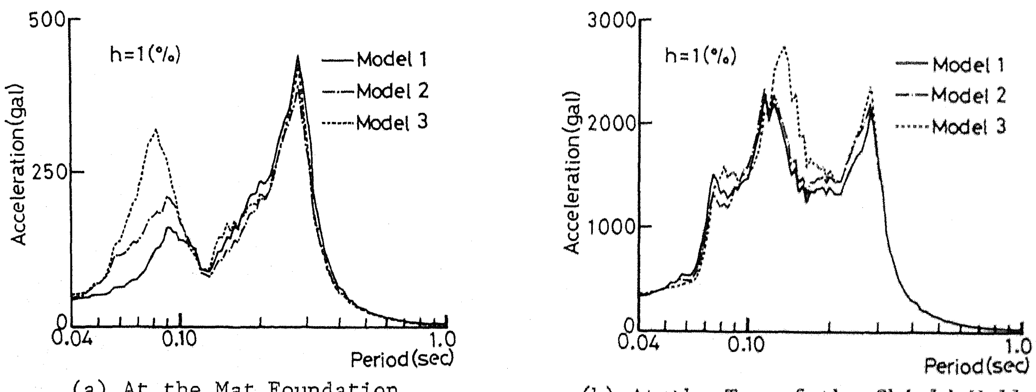
Fig.15 Average of the Maximum Response Values of Acceleration



(a) At the Mat Foundation

(b) At the Top of the Shield Wall

Fig.16 Average of the Floor Response Spectra for Horizontal Component



(a) At the Mat Foundation

(b) At the Top of the Shield Wall

Fig.17 Average of the Floor Response Spectra for Vertical Component