EARTHQUAKE RESPONSE OF NUCLEAR REACTOR BUILDING DEEPLY EMBEDDED IN SOIL

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SUMMARY

As for the research on earthquake response of nuclear reactor building embedded in soil, experimental and theoretical investigations has been performed on a model of size (height-3.75 meter, bottom cross section-5 × 5 meter, weight-173 ton) made of concrete under the financial support of Japanese government (The Science and Technology Agency). The top of model was excited by an eccentric mass vibration that can generate maximum force of 3 ton. Earthpressures were measured at the bottom and side wall of model, and displacements were also measured at the top of model (6 components) and ground surface (18 components). These tests were conducted at a field site where embedded depth was changed at 5 steps which were 0, 20, 47, 73, 100% (against the height of model). Using these experimental results and soil properties, we studied dynamical characteristics that included resonant frequency, radiation damping, vibrational mode, frequency response and earthpressure distribution around the model at varying embedment by lumped model, cylindrical elastic wave model and FEM models (thin layer elements).

In case of the lumped system, resonant frequency and radiation damping comparatively identified experimental results with theory at each embedded depth, but pressure distribution curves at the bottom of model must be adopted for calculation of lumped system uniform on sway and triangular on rocking motion.

As for cylindrical wave theory, variance of resonant frequency was close to experiment at different levels of embedment but radiation damping was estimated smaller than experimental data in case of a deep embedment over a center of gravity of model. In case of FEM model using thin layer element, displacement on model and ground, variance of resonant frequency, radiation damping at each embedment and earthpressure distribution were identified experimental results respectively.

As a conclusion from these experiments and analyses, we can say that deeply embedded reactor buildings especially over center of gravity have a very great radiation damping and very high eigenfrequency, and when suffering earthquake motion, the building moves together with the soil. And even in case of 100% embedment, the ratio of rocking motion in the response of model is larger than sway motion.

1. INTRODUCTION

Nuclear reactor buildings are very stiffen in comparison with general buildings and are deeply embedded in ground, which center of gravity, in some cases, exist even in underground. However, the radiational damping and inputted energy through the embedded side wall during earthquakes has not been available untill now. This study is one of research series to try to make clear the mechanism of input and output energy by measuring whole earthpressures of embedded concrete block during excitation. However this paper bound to refer to comparison between such experiments and several kinds of analyses, as the concrete block embedded in soil is oscillated at the top for the object of the estimation of output energy.

This experiment have several special features in comparison with existing experiments as mentioned as follows. The first was to install the special device of large scale earth-pressure transducer. The second was that the tested model has probably been largest in the scale as 5m X 5m X 3.75m and total weight as 173 ton in comparison with existing experiments. Finally the object of this research aim to evaluate the input-output mechanism of energy through embedded wall and this kind of research has not been seen untill now in the point of view of this quantitative and accurate research procedure.

2. OUTLINE OF EXPERIMENT

2-1 TEST SPECIMEN

The experimental model is schematically shown in Fig. 1. The specimen is made of concrete and earthpressure transducers are installed at its side walls and bottom base. Dimension of experimental model is 5m X 5m X 3.75m as shown in Fig. 1. This earthpressure transducer can measure dynamical soil pressure of lateral and transverse component on a receive plate . Dimension of receive plates is 2.5m width and 0.5m height for one piece as shown in Fig. 1. The earthpressure was measured as the resultant mean force operating on receive plates. Earthpressure transducers installed on embedded wall for transverse and lataral direction to excitin force are assembled with seven pieces and six pieces respectively. And earthpressure transducers at bottom are assembled with five pieces. This transducer must be stiffer as well as possible, as its flexibility did not affect the dynamic behaviour of concrete block, and then semiconductor strain gages were used for the sake of detecting the small strain.

2-2 SOIL PROPERTY OF SITE

The soil profile and soil constants of the site are shown in Fig. 2. From this figure it is observed that the relative uniform soft soil layer exists on hardy clay bed rock. Poisson's ratio are observed to be very close to 0.5 as the results of the observed compressional (V_p) and shear (V_s) wave velocity. Until the depth of nine meter, the silty component of soil exceeds 50%, and from nine to ten meters, sandy component is 63.5%, which water content ratio are from 63.7% to 134.5% and the unit volume weight are from 1.376 to 1.590 (gr./cm^3).

2-3 LOCATIONS OF MEASUREMENT

Displacements were measured on the ground surface, on the model and under the ground, and earthpressures were measured on side walls and bottom base of the model. Arrangement of displacement transducers are shown in Fig. 3. The arrangement of earthpressure transducers surrounding test model are shown in Fig. 1. This measurement results give the valuable information for evaluating the mechanism of In and Output current energy between soil-structure interaction.

2-4 PROCEDURE OF EXPERIMENT

The experiment was performed for five kinds of back filling depth schetched as shown in Fig. 4. Back filled works were carried out by packing sand in trench holding same water content ratio and density. As a result the shear modulus of back filled sand becomes to be 370 - 460 kg./cm^2.

3. EXPERIMENTAL RESULTS

3-1 FREQUENCY RESPONSE

Fig.5 ; Frequency response of horizontal displacement at top of model.
Fig.6 ; Frequency response of vertical displacement at top of model.
Fig.7 ; Frequency response of normal earthpressure at bottom base.
Fig.8 ; Frequency response of shearing earthpressure at bottom base.
Fig.9 ; Frequency response of horizontal displacement on ground surface of horizontal component to direction of Rayleigh wave propagation.
Fig.10 ; Frequency response of horizontal displacement on ground surface of horizontal component to direction of Love wave propagation.

3-2 DISTRIBUTION OF EARTHPRESSURE ON BOTTOM AND SIDE WALL

Fig.11 ; Distribution of normal force on bottom for each stage of embedment.
Fig.12 ; Distribution of shearing force on bottom for each stage of embedment.
Fig.13 ; Distribution of normal force on side wall for each stage of embedment.

4. ANALYTICAL METHODS

Four kinds of analytical method were adopted to try to evaluate the correlation between experimental results and analytical results such as.

(A) One mass method supported with weightless springs and equivalent dashpots.(Lumped) In this analysis, one mass is assumed to be supported with weightless springs and equivalent dashpots as shown in Fig. 14(c). Weightless springs (K_H,K_R) and equivalent dashpots (C_H,C_R) on the base were evaluated by the theory[1] of vibration on the surface of elastic homogeneous half space assuming uniform pressure. However there was not any analytical method to estimate the weightless spring (K_{HH}) and the equivalent dashpot (C_{HH}) on the wall. Then, some approximation was adopted for estimating these values, that is, these values were assumed to be nearly equal to results by the theory of vibration on the surface of elastic homogeneous half space assuming uniform pressure shown in Fig. 14(b) for the exchange of the one to be obtained by the model shown in Fig. 14(a). The attention had be paid that this assumption contain some daring assumption of the difference of exciting direction except for the difference of " on surface of media " and " in the media " explained as shown in Fig. 14(a) and (b).

(B) Analytical theory of vibration of embedded cylinder.(Cylinder theory)

The analytical theory of vibration of cylinder embedded in elastic infinite layer 'A' was adopted[2] as shown in Fig. 15. However, in this theory, the horizontal boundary was plased at the base of cylinder between 'A' and 'B'. For estimating the flexibility and the radiational damping of the layer 'B', the theory of vibration on the surface of elastic homogeneous half space assuming uniform pressure was adopted. For this assumption, the radiational wave can not propagate to the infinite of the layer 'A' for the small range of frequency and the damping had been assumed to be under estimated.

(C) Two dimensional Finite Element Method (2D-FEM)

Two dimensional FEM is utilized to simulate experimental results having following features (shown in Fig. 16).

C-1; Two dimensional incompatible isoparametric plane strain element used.

C-2; Vertical boundary is restrained in vertical and free to move in horizontal.

C-3; Mode superposition method adopted for evaluating frequency response.

C-4; Damping factor was given as modal damping for each modes.

(D) Three dimensional Axisymmetric FEM(Finite Element Method) with energy transmitting boundary shown in Fig. 17.(3D-FEM)

Three dimensional axisymmetric FEM is tried to simulate experimental results having following features.

D-1; The energy transmitting boundary derived by thin layered element method is used on the vertical boundary.

D-2; The damping was introduced by complex shear modulus.

D-3; Frequency responses obtained to solve simultaneous linear equations.

5. CONCLUSION

(A) Increasing the depth of embedment, the stiffness constraining the model increase and consequentry the resonant frequency increase. This phenomena is shown in Fig. 18 with the experimental results and several analytical results. Through this figure, the results by "Lumped" and "2D-FEM" are observed to be close to the experimental results for small value of embedded ratio (D/H) but to be smaller than the experimental result when the embedded ratio become close to unit. On the other hand, "Cylinder theory " and "3D-FEM" can simulate the experimental result for large value of embedded ratio and especially such phenomena as the experimental result have the maximum at embedment ratio D/H=0.75 ,though they give over-estimated values to the experimental value for the small value of embedment ratio D/H.

(B) Increasing the depth of embedment, the radiational damping increase. This features are shown in Fig. 19 with the experimental result and analytical results. Through this figure, it is observed that the result by "Cylinder theory" can not simulate the experimental result for the reason mentioned in (B) in 4. The result by "2D-FEM" is not suitable for this kind of comparison because the modal damping is given for each mode and is eliminated in this figure. The other two method of "3D-FEM" and "Lumped" show rather good agreement with the experimental result.

6. ACKNOWLEDGEMENT

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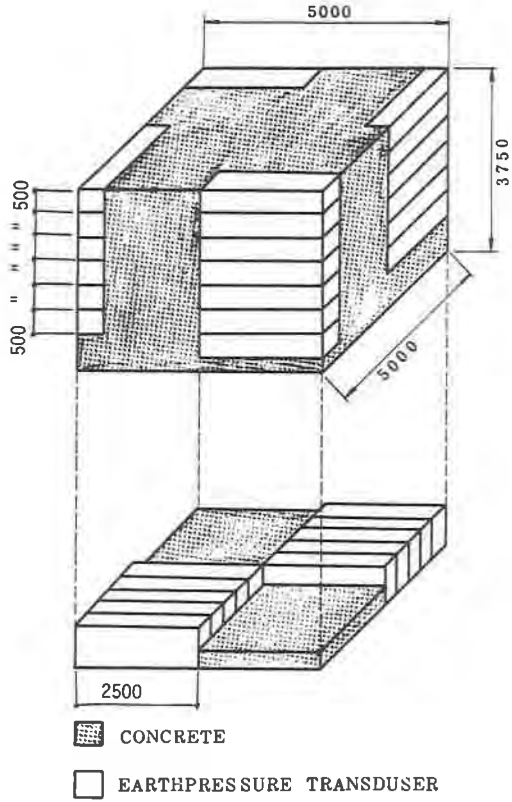

Fig.1 Sketch of Specimen.

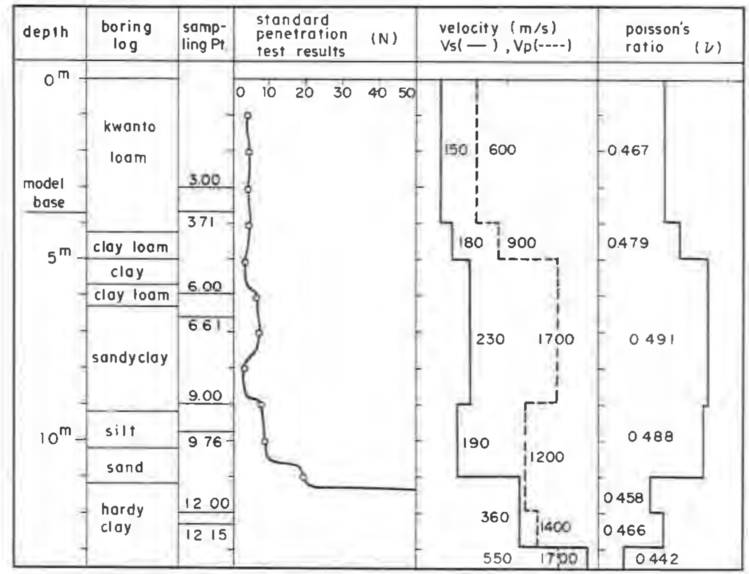

Fig.2 Soil Profile of Site.

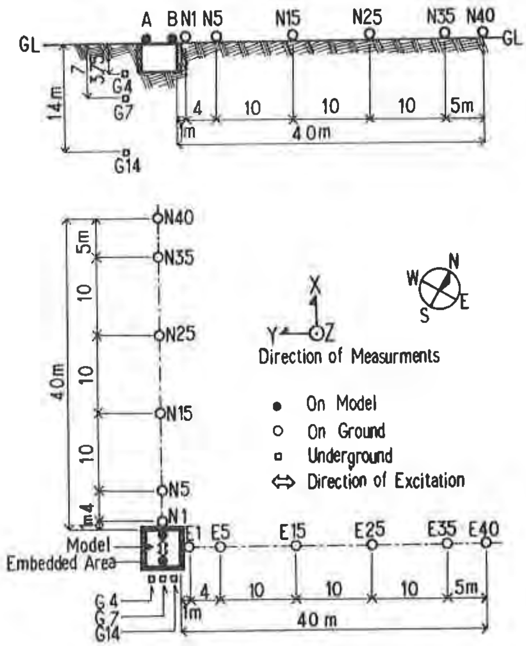

Fig.3
Arrangement of Displacement
Transducer.

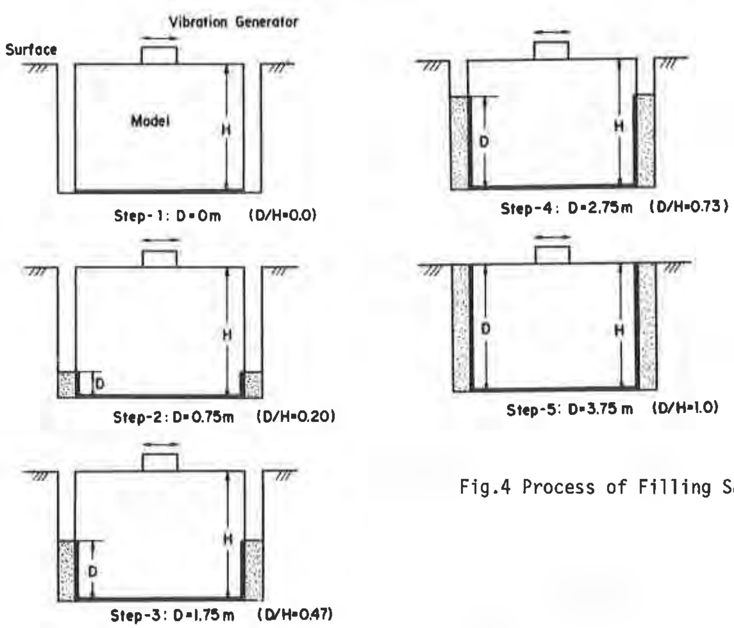

Fig.4 Process of Filling Sand.

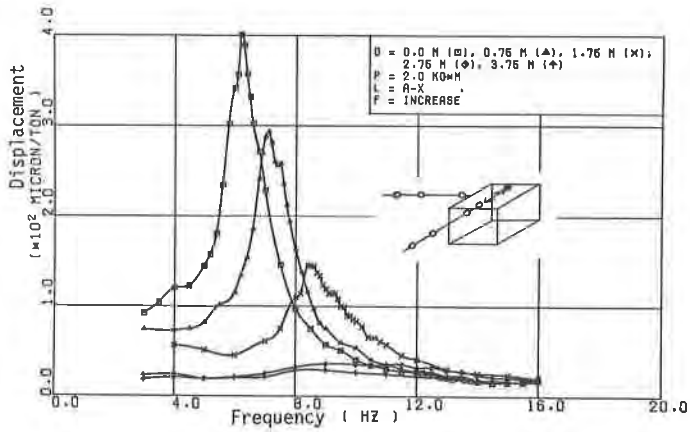

Fig.5
Horizontal Response
of each Embedded Depth
on Model.

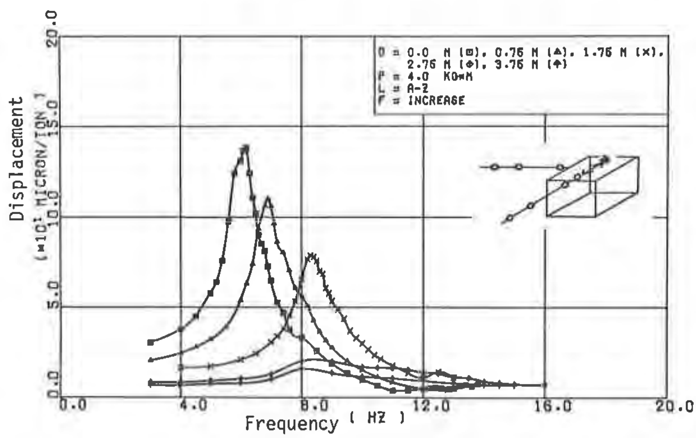

Fig.6
Vertical Response of
each Embedded Depth on
Model.

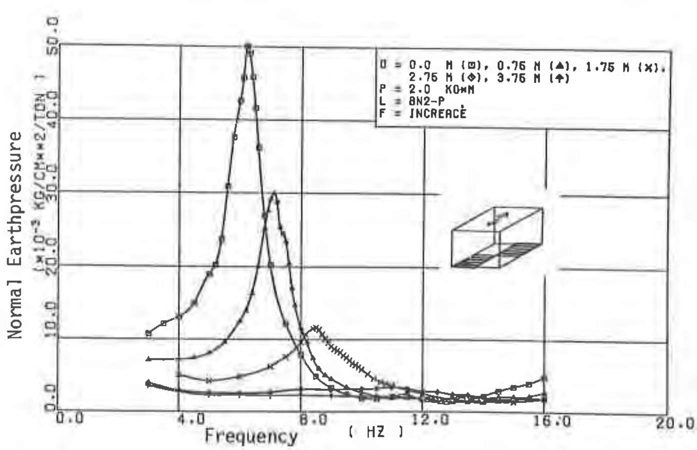

Fig.7
Earthpressure Response
of each Embedded Depth
at Bottom.

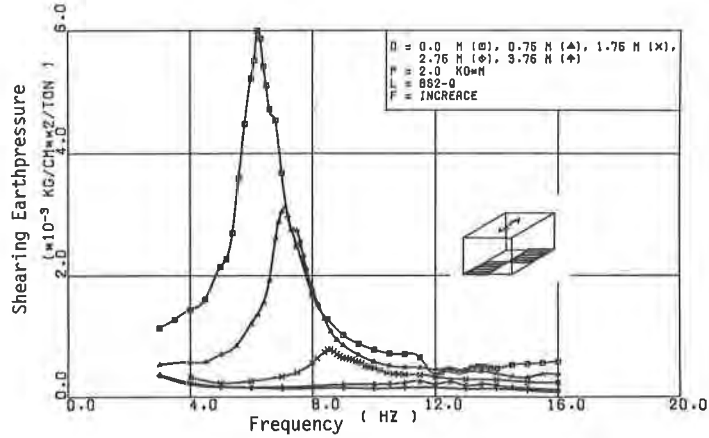

Fig.8
Earthpressure Response
of each Embedded Depth
at Bottom.

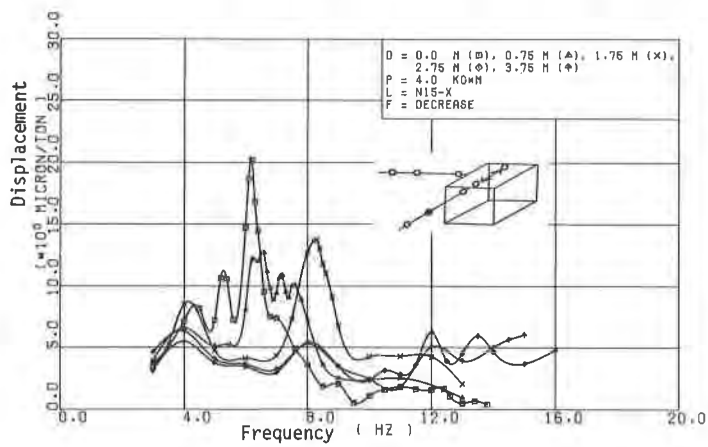

Fig.9
Horizontal Response
of each Embedded Depth
to Rayleigh Wave
Propagation.

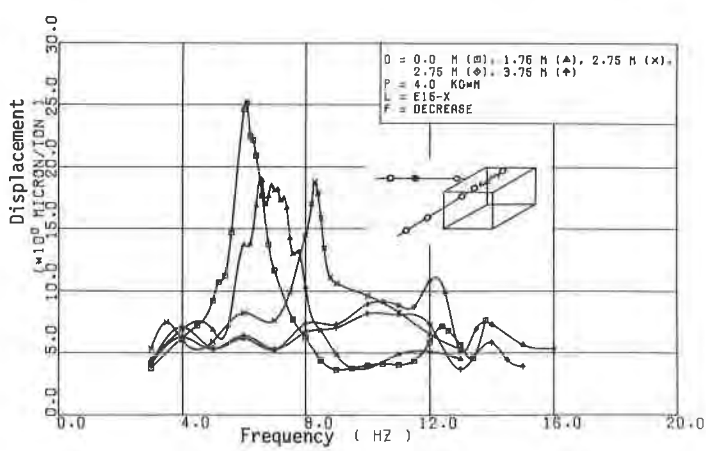

Fig.10
Horizontal Response
of each Embedded Depth
to Love Wave Propaga-
tion.

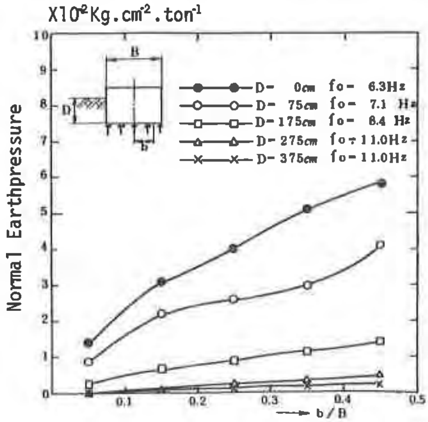

Fig.11 Distribution Curves of Normal Stress at the Bottom by each Embedded Depth.

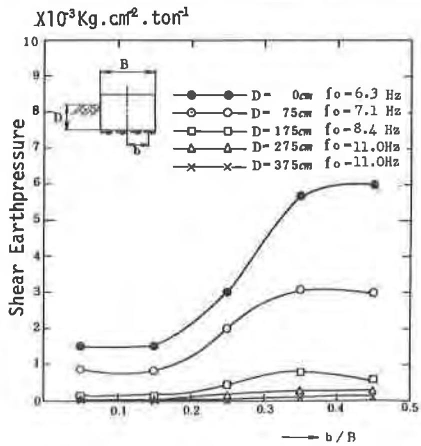

Fig.12 Distribution Curves of Shearing Stress at the Bottom by each Embedded Depth.

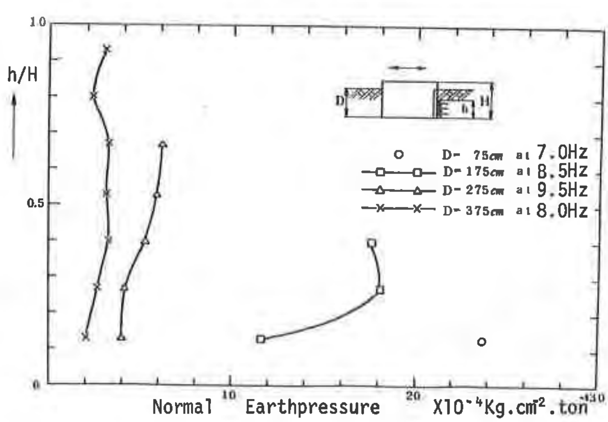

Fig.13
Distribution Curves of Normal Stress at the Side Wall by each Embedded Depth.

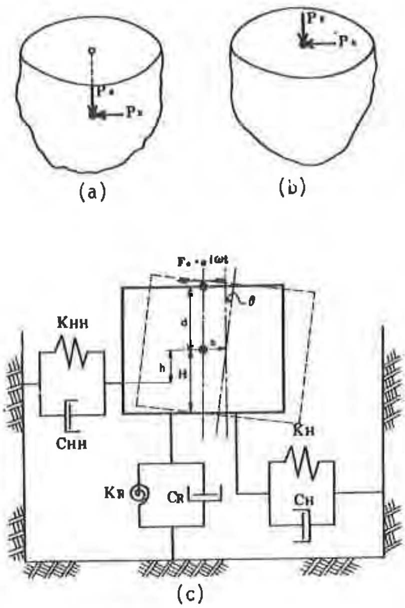

Fig.14 (a);Load within the body.
(b);Load at the surface.
(c);Mathematical Model of Lumped System.

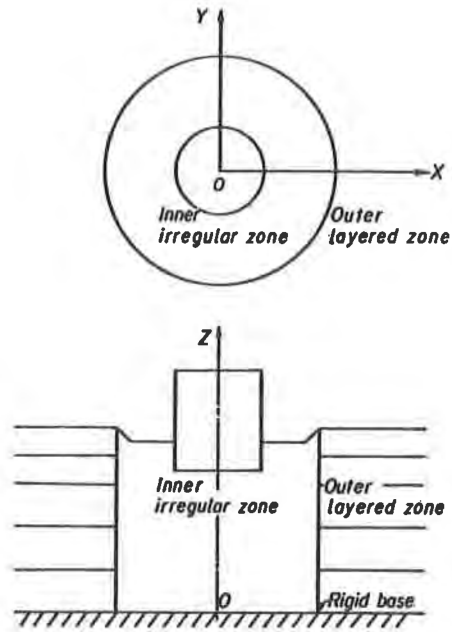

Fig.17 Mathematical Model of FEM using Thin Layered Element .

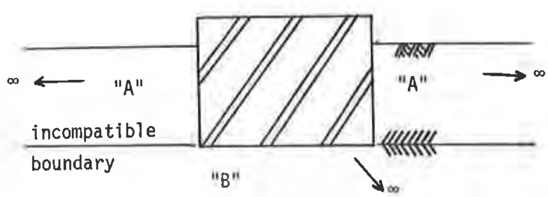

Fig.15 Mathematical Model of Cylindrical Wave Theory.

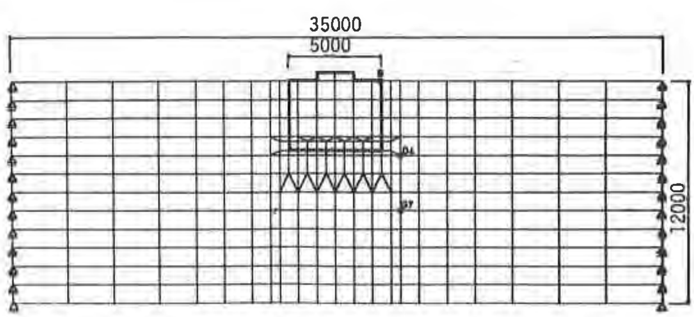

Fig.16 Mathematical Model of Two Dimensional FEM.

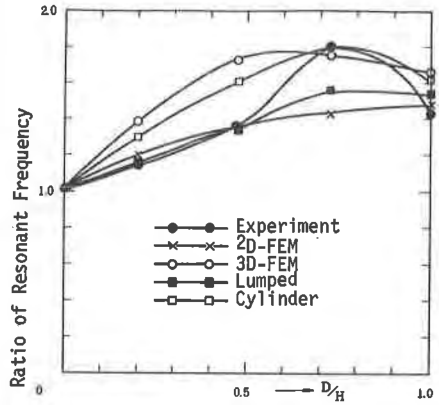

Fig.18 Resonant Frequency Compared with Experiment and several Analyses.

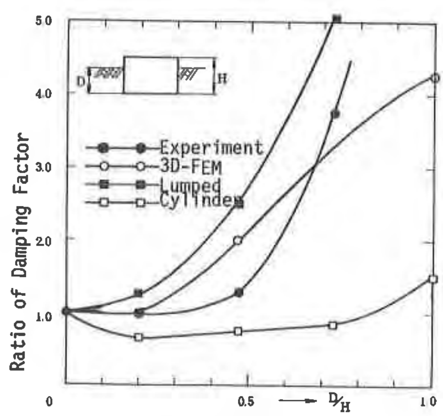

Fig.19 Equivalent Damping Factor Compared with Experiment and several Analyses.