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FIELD TESTS ON PARTIAL EMBEDMENT EFFECTS (EMBEDMENT EFFECT TESTS ON SOIL-STRUCTURE INTERACTION)

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ABSTRACT

A series of Model Tests of Embedment Effect on Reactor Buildings has been carried out by the Nuclear Power Engineering Corporation(NUPEC), under the sponsorship of the Ministry of International Trade and Industry(MITI) of Japan.

The nuclear reactor buildings are partially embedded due to conditions for the construction or building arrangement in Japan. It is necessary to verify the pa tial embedment effects by experiments and analytical studies in order to incorporate the effects in the seismic design. Forced vibration tests, therefore, were performed using a model with several types of embedment. Correlated simulation analyses were also performed and the characteristics of partial embedment effects on soil-structure interaction were evaluated.

1. INTRODUCTION

Several embedment types are employed for nuclear reactor buildings depending on individual site conditions. For example, some reactor buildings are constructed directly on the rock ground and others are backfilled with the suitable materials such as the compact sand or breaking rocks. The embedment of structure brings about advantages in seismic design such as the radiation damping and absorption of the vibration energy. However, they have not been considered adequately due to insufficient experimental data and earthquake observations. Therefore, forced vibration tests using a large scale model were performed in order to study the effects of partial embedments on soil-structure interaction. Furthermore, analytical studies were also conducted, which can take the partial embedment into account and its validity was confirmed by making comparisons with the test results.

2. FORCED VIBRATION TEST

A model made of RC was constructed on an actual rock ground, and the model was designed so that its vibration characteristics simulate those of PWR type reactor building. The model has a box type basemat of 8 meter square and 5 meter height. The superstructure is a 2-story frame type. The total weight of the model is 920 tons and its height is 10 meters. The shear wave velocity of the layered supporting ground ranges from 320 m/sec. to 1600 m/sec. Although each actual reactor building employs a complicated and different embedment structure, four types of embedment were defined so as to easily express the effects of partial embedment as shown in Fig. 1; Case 1 is no embedment, Case 2 is one sided embedment, Case 3 is two sided embedment and Case 4 is full embedment. Forced vibrations were applied to the structure in NS and EW directions respectively by the exciter installed on the structure. The displacements of the structure model, earth pressures and accelerations in the ground were measured over all oscillating frequencies. The exciting force was determined so that the linearity of soil responses was maintained.

3. EFFECTS OF PARTIAL EMBEDMENT

Table 1 shows the resonance frequencies, modal damping factors and ratios of displacement components at the top of the structure. The primary resonance frequency of the soil-structure system moved to a higher frequency with increasing embedment for excitations in both NS and EW direction. The modal damping increased with embedment while the damping factors in EW excitation of Case 2 and Case 3 were smaller than that in Case 1, for which the elastic deformation of the superstructure was larger than the swaying and rocking displacements of the basemat.

Fig. 2 shows the resonance curves at the center of basemat bottom. When compared with Case 1, the resonance amplitudes in Case 2 and Case 3 in NS excitation decreased two third and one half, respectively. Case 4 exhibited a slightly lower amplitude than Case 3. In EW excitation, the resonance amplitude in Case 4 decreased significantly, while the differences among Case 1, Case 2 and Case 3 were small. It is supposed that the backfill soil resists the push and pull force more effectively than the shearing force.

The earth pressures showed similar patterns regardless of the embedment types while the amplitude in Case 4 was relatively small as shown in Fig. 3.

The impedance functions derived from the relationship between the response displacements of the structure model and the exciting force are shown in Fig. 4. The horizontal and rotational components of these impedance functions indicate the following tendency with increasing embedment. The real part of the impedance functions in low frequency region which corresponded to the stiffness of the soil spring became large, and the imaginary part which represented the radiation damping toward the half space ground also increased.

4. SIMULATION ANALYSIS

It is important to examine how to evaluate the impedance function for partially embedded foundation including side soil effects in analytical studies. The authors adopted two kinds of analysis methods. One is a simplified procedure combining bottom and side soil springs based on the elastic wave propagating theory, and the soil springs are estimated independently each other. The side soil spring is evaluated considering the partial embedment effect, which is based on the one dimensional wave propagating theory (Ref. 2). The other is a hybrid method coupling a three dimensional thin layer element method and a three dimensional finite element method which can evaluate partial embedment directly.

In the simplified procedure, a sway-rocking model is used, in which the basemat of test model is assumed to be a rigid body and the superstructure is replaced by the bending-shear beam model with lumped mass as shown in Fig. 5. The resonance and phase lag curves at the bottom of basemat obtained from the analyses are shown in Fig. 6. The primary resonance frequency of the soil-structure system for each of the four embedment types coincided with test results as shown in Fig. 2. The analysis for Case 1 reveals a slightly large resonance amplitude, the other cases yield rather small values. These results would be attributable to the side soil spring whose damping has been overestimated because a plane strain problem was assumed in the formulation. The impedance functions calculated by the simplified procedure are shown in Fig. 7. The imaginary part of the horizontal component and both the real and imaginary parts of the rotational component agreed well with test results while the real parts of rotational component are underestimated.

In the hybrid method, a lumped mass model is used for the superstructure, and a three dimensional finite element model is employed for the basemat and marginal ground while a three dimensional thin layer element model for the surrounding ground is used as shown in Fig. 8. The highest frequency in the analysis is closed up to 10Hz because of the limited calculation accuracy and available cpu time. Fig.

9 shows the resonance and phase lag curves at the bottom of the basemat. It is found that the resonance frequency increases and the resonance amplitude reduces with the increase of embedment. The peak values of amplitude in the analyses coincided well with those of test results, and this indicates the appropriateness of the three dimensional model. The impedance functions are shown in Fig. 10. Both horizontal and rotational components derived from the analyses represent similar frequency dependence with those of test results. However, the real parts of the impedance function calculated by the hybrid method are small comparing with those of test results since the finite element mesh size is not fine enough.

5. CONCLUSIONS

The effects of partial embedment have been taken into account in the experimental and analytical studies. The changes in resonance frequencies, modal damping factors and dynamic impedance functions caused by the embedment configuration could be evaluated. It is found that the backfill soil resisting against the push and pull force is more effective than that resisting against the shearing force in the case of partial embedment. The characteristics of the soil-structure system with partial embedment could be adequately evaluated by analytical methods and it would be useful in advanced seismic design.

ACKNOWLEDGEMENTS

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Table 1 Dynamic Characteristics at Resonance Frequency

Excitation		NS Direction				EW Direction			
Embedment Case		Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4
Primary Resonance Frequency (Hz)		5.9	6.9	7.5	7.7	5.5	5.9	6.2	7.1
Modal Damping Factor (%)		5.1	4.8	6.5	7.9	4.2	3.3	3.9	5.9
Contribution Ratio (%)	Swaying	17	15	15	18	11	10	10	9
	Rocking	74	68	63	54	54	47	47	35
	Elastic Deformation	9	17	22	28	35	43	43	56

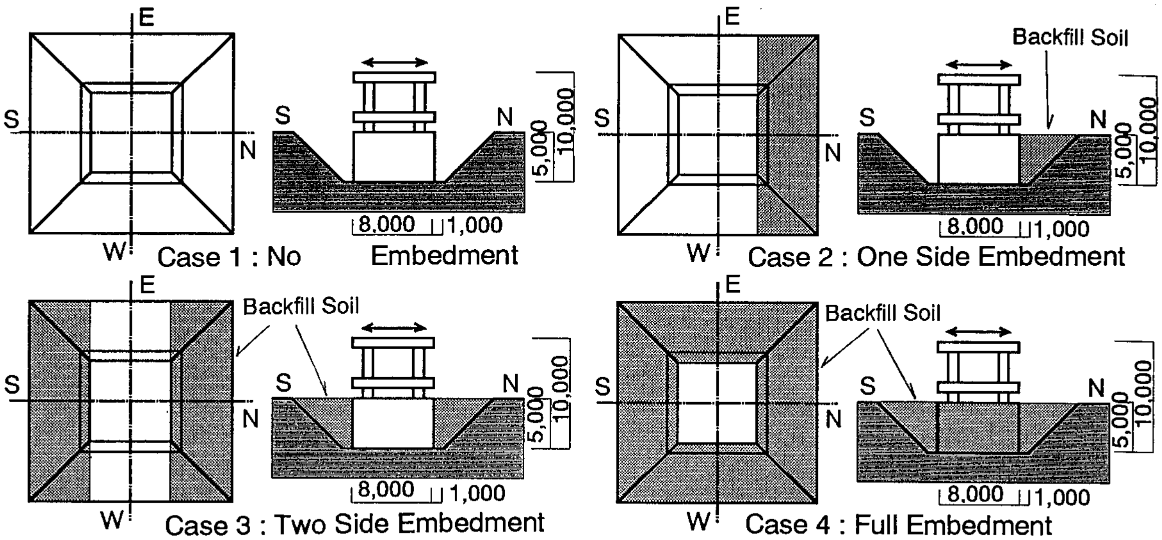

Fig. 1 Embedment Configuration

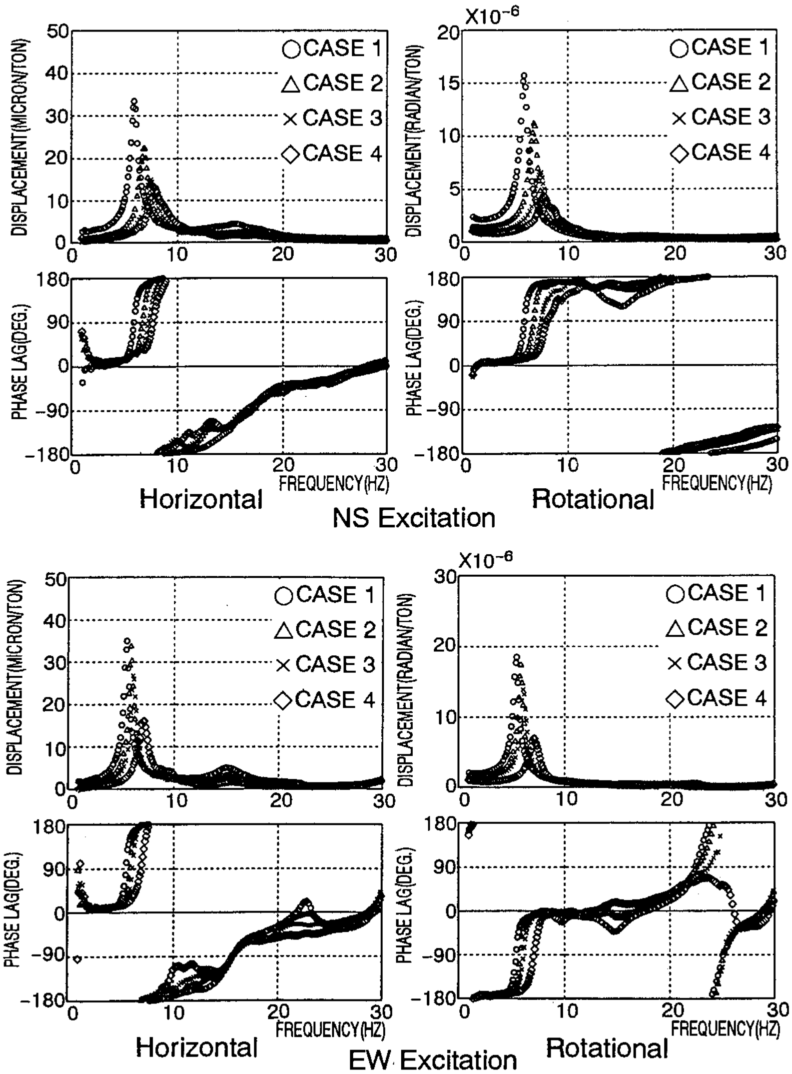

Fig. 2 Resonance Curve Obtained from Forced Vibration Test

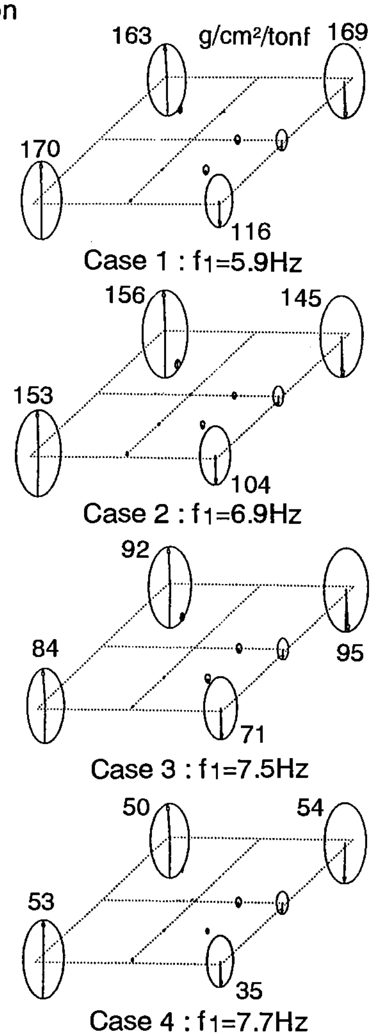

Fig. 3 Earth Pressure Pattern at Resonance Frequency : NS Excitation

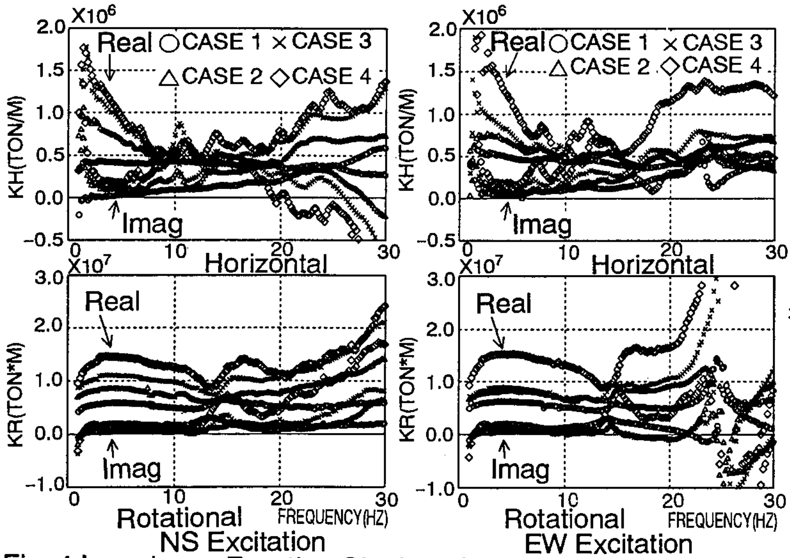

Fig. 4 Impedance Function Obtained from Forced Vibration Test

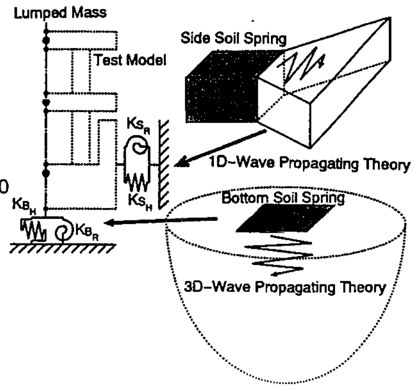

Fig. 5 Sway-Rocking Model

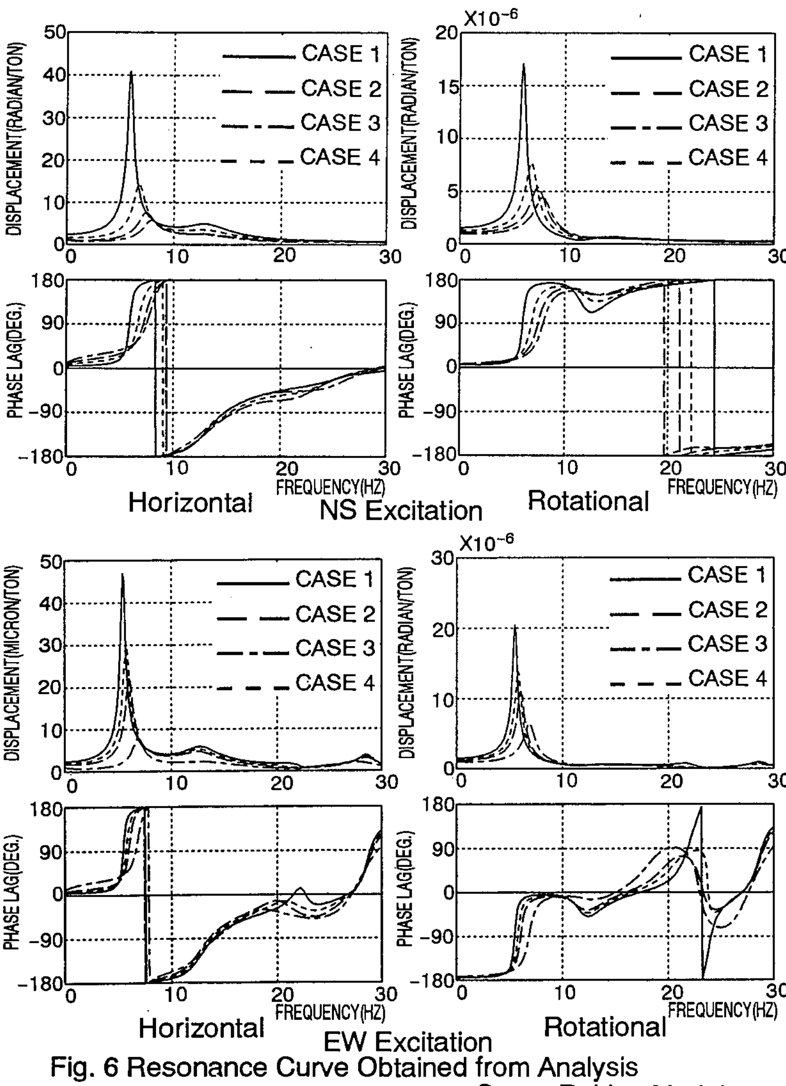

Fig. 6 Resonance Curve Obtained from Analysis
: Sway-Roking Model

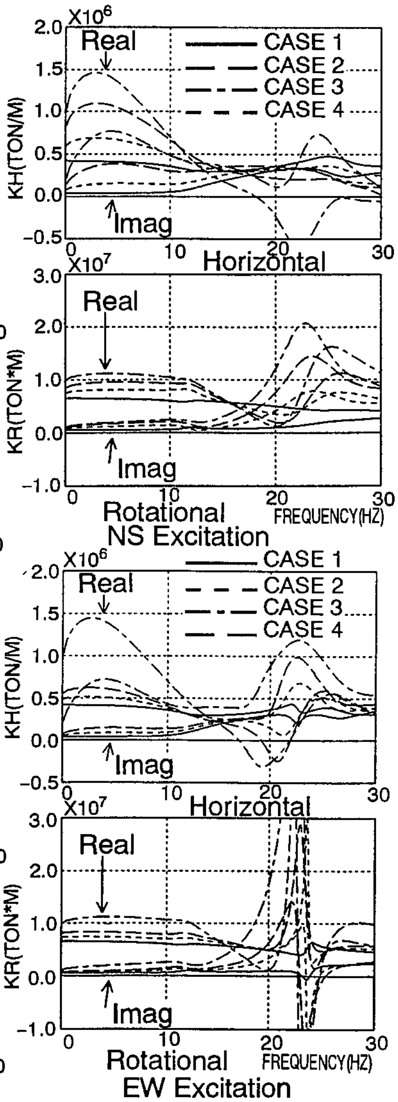

Fig. 7 Impedance Function
Obtained from Analysis
: Sway-Roking Model

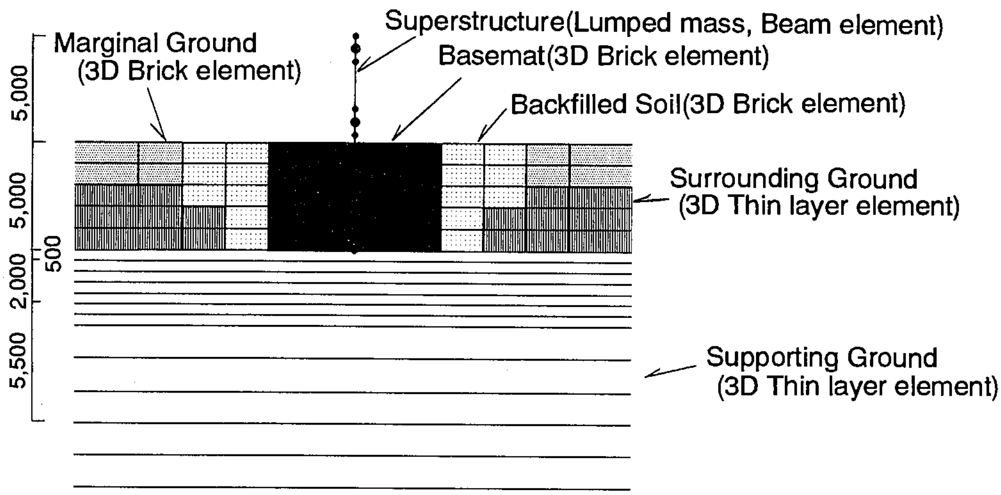

Fig. 8 Hybrid Model

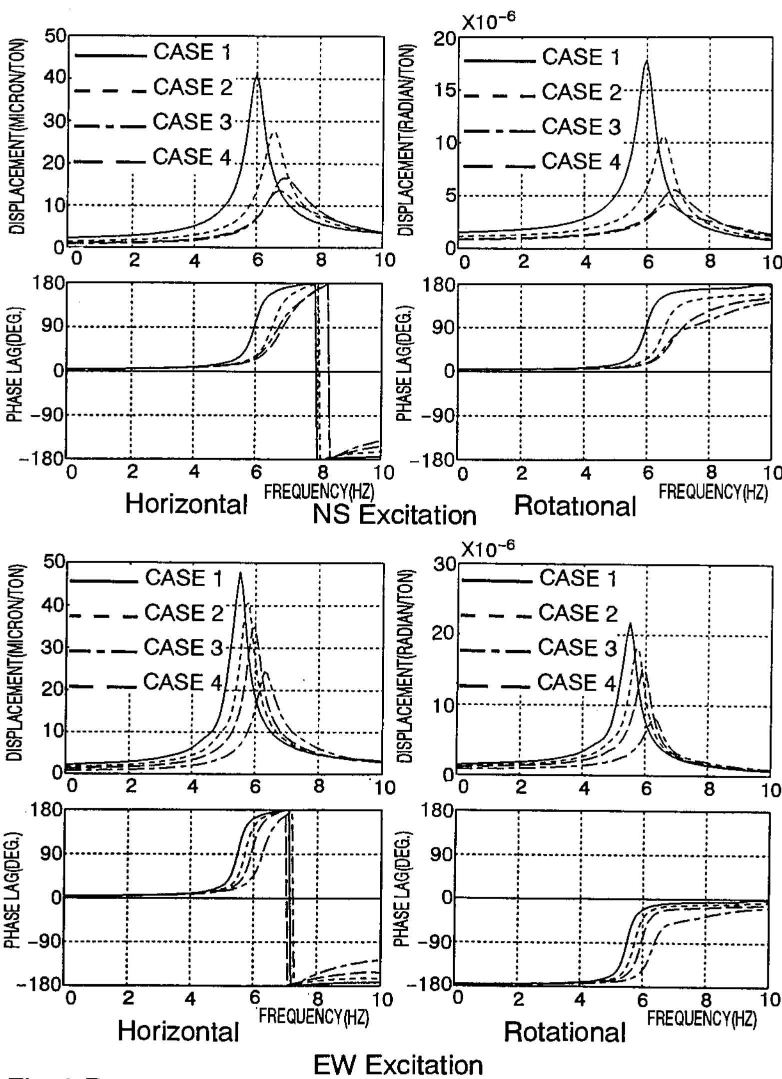

Fig. 9 Resonance Curve Obtained from Analysis : Hybrid Model

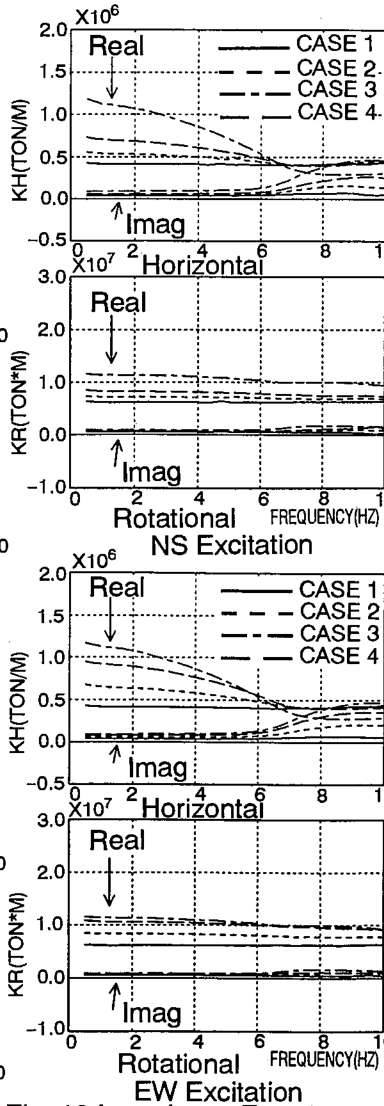

Fig. 10 Impedance Function Obtained from Analysis : Hybrid Model