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Full-scale vibration test of Atucha II N.P.P. - Part IV: Numerical simulation of steady-state vibration response by axisymmetric FEM

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ABSTRACT : Essential data which include the characteristics of soil-structure interaction on Quaternary deposits were obtained from forced vibration tests. The uses of these characteristics in analysis are also discussed.

Two analyses have been conducted for GL+18.8m excitation in the X-direction. The first was a preliminary analysis carried out before forced vibration tests using the axisymmetric finite element (FE) model used in the design procedure. The other was a simulation analysis carried out after the test.

This paper describes the characteristics of Atucha II, constructed on Quaternary deposits, by axisymmetric FE analysis.

1. INTRODUCTION

Atucha II is a German type PHWR(Pressurized Heavy Water Reactor) type nuclear reactor building constructed on Quaternary deposits. It has an inner concrete structure(I/C), which is encased by double spherical containment vesseles comprised a steel inner wall(primary containment vessel : PCV) and a reinforced concrete outer wall(reactor building : R/B). R/B is almost independent of the other components and is built on a base mat.

Some forced vibration tests for the PHWR type nuclear power plant have been conducted, but none have been conducted for a nuclear power plant on Quaternary deposits in Japan.

This paper describes two axisymmetric FE analyses, and then discusses the frequency characteristics of the PHWR type nuclear power plant Atucha II, including the soil-structure interaction between the structure and Quaternary deposits.

2. PRELIMINARY ANALYSIS

2.1 *Analytical Model*

The purpose of the preliminary analysis was to predict the dynamic frequency characteristics using the axisymmetric FE model shown in Fig.-1. This model was utilized in design and analyzed by ASHSD2(Ghosh et. al. 1975).

The analytical model consisted of thin shell elements representing PCV, R/B, base mat and shear walls of the I/C located in the circumferencial direction, and solid elements representing I/C and soil. The rigidities of the solid elements of the I/C are evaluated from horizontal components of shear walls located in the radial direction. Thus, these solid elements have only in-plane shear moduli. The location of the loading point is also indicated in Fig.-1 and the soil and structure constants are shown in Tables-1 and 2.

The shear wave velocities of the soil which supports the structure, are between 281m/sec and 482m/sec. Thus, these strata seem to be Quaternary deposits.

In the FE model, the viscous boundary and the energy transmitting boundary are applied (Berger et. al. 1975). In analysis, only the first term of the Fourier series is considered.

2.2 *Analytical Results*

The resonance and phase lag curves obtained from preliminary analysis are shown Fig.-2 up to 10Hz. The first peak appears at about 2.9 Hz, because phase lag curves cross the 90 degree line. The significant resonance peak of PCV is found at 7.6Hz and its amplitude reaches about 9.6μm/ton . This peak at 7.6 Hz only appears in the resonance curve for the PCV, and there are dips in the resonance curves for the other points.

Two resonance modes at 2.9Hz and 7.6Hz occuring at the same time when the maximum amplitude appears, are shown in Fig.-3. It is clear from Fig.-3(a) that the whole structure is vibrating in the same direction. It is also clear that the vibration mode of the I/C is dominated by the rocking mode of the base mat, because the horizontal amplitude of the base mat is small. It is also found from Fig.-3(b) that only the PCV vibrates at 7.6 Hz.

3. COMPARISON BETWEEN TESTS AND ANALYTICAL RESULTS AND MODIFICATION OF ANALYTICAL MODEL

The resonance curves obtained from the forced vibration tests at the tops of the R/B and the PCV are shown in Fig.-4 and the resonance modes at 5.9Hz and 7.3Hz are shown in Fig.-5(a) and (b).

The dominating peak of the PCV appears at 5.9Hz, which is lower than the 7.6Hz value obtained from the preliminary analysis. Its amplitude is also very different from test results, by about four times. At 7.3 Hz, the test results show dominating peaks of R/B and PCV, and these peaks are not found in the analytical results. This seems to be because the force of the exciter can not propagate to the R/B in this model.

It is thus necessary to make some modifications to the analytical model, considering the actual condition of the structure in the test. However, there is limited information such as soil type and structure weight for the test.

I/C is connected with R/B at GL level by a shell element because steel plates were already decided for construction when the forced vibration test was performed. The rigidities of the R/B and the PCV are reduced, because there are large equipment hatches and some open holes in these structures for construction. The damping coefficients are changed to 1.5% for all elements to adjust the amplitude .

4. SIMULATION ANALYSIS

A simulation analysis was conducted after some modifications were made. The analytical results for resonance and phase lag at each point are shown in Fig.-6, together with the test results. A significant peak for the R/B appears at 7.3 Hz, so the steel plate for construction between the I/C and the R/B was effective at small vibrations. The results at the PCV, R/B and I/C are in good agreement with the test results up to 10Hz. However, the results at the other points are a little different. This new model considering actual conditions can almost present the frequency characteristics of this plant.

There is no peak in the resonance curves for the simulation analysis from 12 Hz to 20 Hz, but there are many small peaks, especially at the top of the I/C, in the test results in the same frequency range. These seem to be local vibration phenomena which can not be represented by axisymmetric assumptions.

The dynamic impedance based on the rigid basement assumption is shown in Fig.-7. Damping coefficients evaluated from horizontal and rotational impedances by equation

(1) are shown in Fig.-8 by solid lines. Broken lines indicate damping coefficients based on the Vs=500m/s assumption to compare the those of Atucha Ⅱ .

$$he=\sin\{0.5 \tan^{-1}(K_I/K_R)\} \qquad (1)$$

At 2.9Hz, the damping coefficients are 54% for the sway spring and 30% for the rocking spring. These figures indicate that this plant has a larger damping system than that on a rock site. Thus, the amplitude at the first peak of soil-structure interaction is not so high and sharpe.

The damping coefficients at each peak evaluated from the resonance curves obtained from analysis using the half power method, are about 43%, 2% and 2.5%, respectively. At the first peak 2.9Hz, the whole structure vibrates with soil deformation, so the damping coefficients is strongly influenced by the dynamic impedance. At the second peak 5.9Hz and the third peak 7.3Hz, the soil deformation is small, so the damping coefficients presents mainly the structural damping.

Fig.-9 shows the resonance mode shape at the same time at each frequency. At frequencies up to 4.0 Hz, whole structures vibrate in same phase and only PCV vibrates at 6.0 Hz. From 7.0Hz to 10.0Hz, the I/C vibrates in the opposite phase against the PCV and the R/B. These are special features of PHWR type reactor buildings, because it has three independent structures, R/B, PCV and I/C, and each structure has its respective natural frequency.

The resonance mode of the base mat is not straight. It is found that its rotation is not the same, and is complicated. This is because the thickness of the base mat of this plant is about 2.8m, less than that of a Japanese nuclear power plant.

5. CONCLUSION

Analyses for Atucha Ⅱ , constructed on Quaternary deposits, have been conducted using an axisymmetric FE model. Concluding remarks are as following;

1. The simulation analysis considering the actual condition of the structure through forced vibration tests well presented the frequency characteristics of the structures.
2. The dynamic impedance at this plant built on the Quaternary deposits make a larger damping system at this plant, than for a building on a rock sites.
3. Vibration at the I/C is dominated by the rocking mode rather than the sway mode.
4. The base mat is not so thick, so its vibration mode is wave.

6. ACKNOWLEDGMENT

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Ghosh, S. and Wilson, E 1975. ASHSD2 - Dynamic Stress Analysis of Axisymmetric Structures under Arbitrary Loading, *EERC report 69-10, September 1969, reviced September 1975.*

Berger, E., Lysmer, J and Seed H.B 1975. ALUSH - A Computer Program for Seismic Response Analysis of Axisymmetric Soil-Structures System, *EERC report 75-31,1975.*

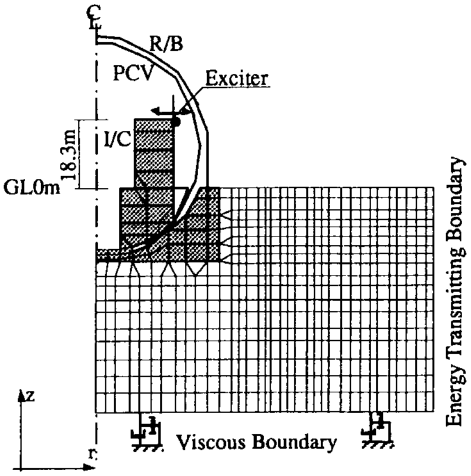


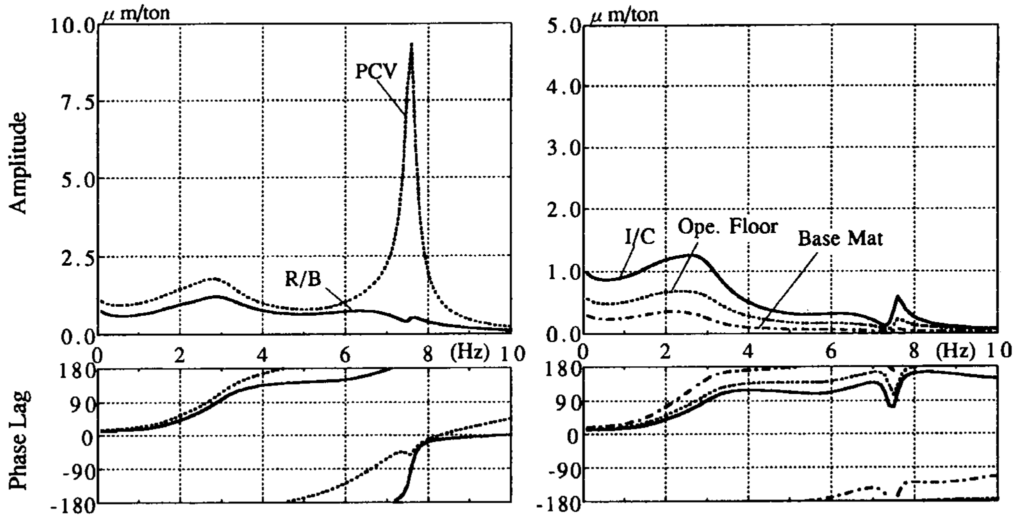
Fig.-1 Axisymmetric F.E.Model

Table-1 Soil Profile

Depth (GL–m)	Thickness (m)	Vs (m/sec)	Poisson's Ratio	Unit Mass (ton s^2/m^4)
0~6	6.0	272.	0.35	0.19
6~13	7.0	229.	0.35	0.19
13~20	7.0	261.	0.35	0.19
20~26	6.0	281.	0.35	0.19
26~33	7.0	308.	0.35	0.19
33~41	8.0	344.	0.35	0.19
41~50	9.0	417.	0.35	0.19
50~60	10.0	482.	0.35	0.19

Table-2 Structure constants

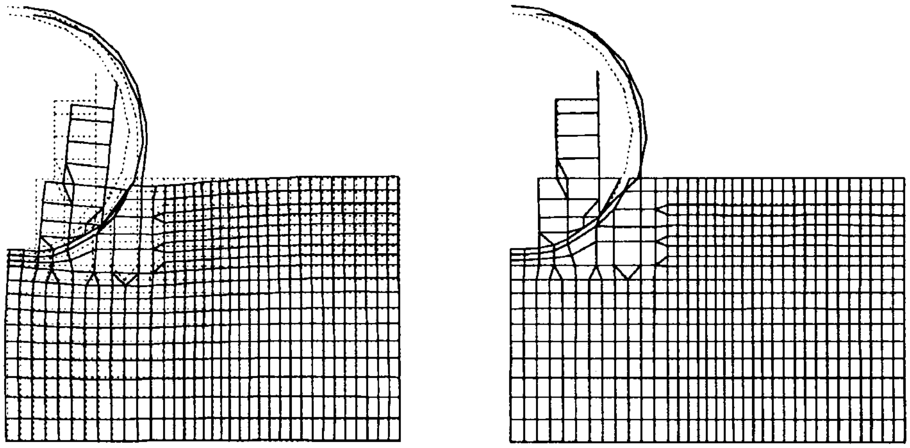
Part	Young's Modulus (t/m^2)	Poisson's Ratio	Unit Mass (ton s^2/m^4)	Thickness (m)
R/B	3.5x 10^6	0.2	0.2447	0.6
PCV	2.1x 10^7	0.3	0.7970	0.3
Base Mat	3.5x 10^6	0.2	0.2447	2.8



(a) R/B and PCV

(b) I/C , Operationg Floor and Base Mat

Fig.-2 Resonance and Phase Lag Curves by Preliminary Analysis



(a) 2.9Hz

(b) 7.6Hz

Fig.-3 Resonance Mode Shape by Preliminary Analysis

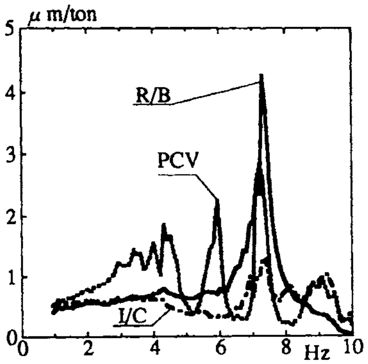
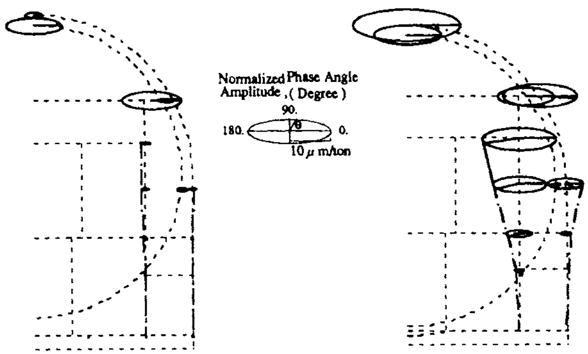


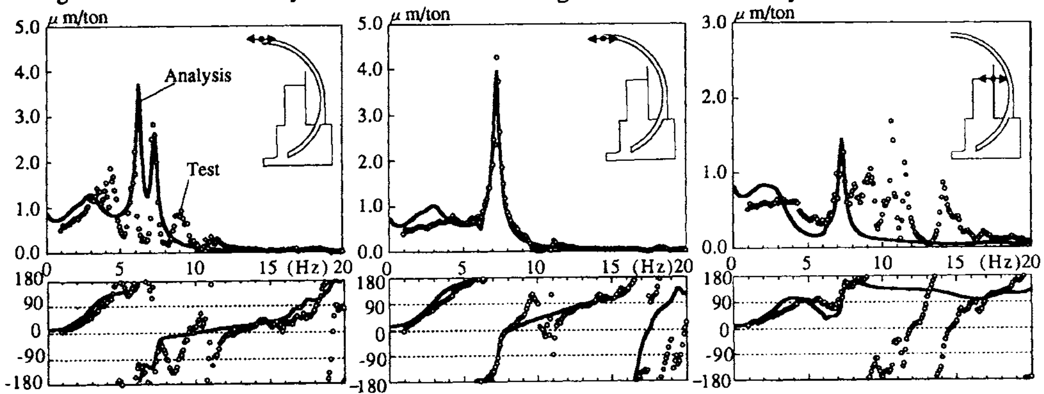
Fig.-4 Resonance Curve by Test



(a) 5.90(Hz)

(b) 7.30 (Hz)

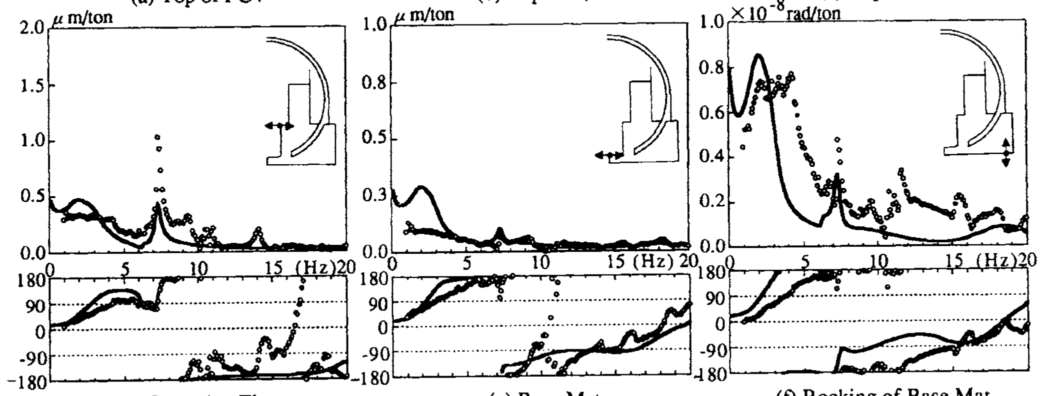
Fig.-5 Resonance Mode by Test



(a) Top of PCV

(b) Top of R/B

(c) Top of I/C

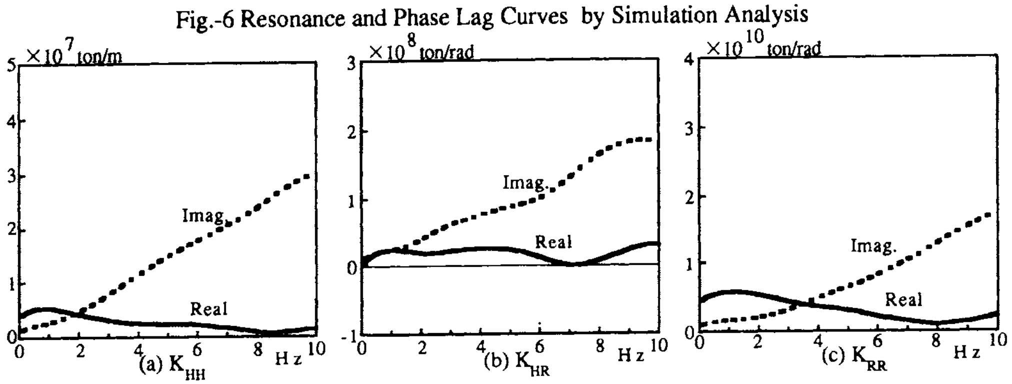


(d) Operating Floor

(e) Base Mat

(f) Rocking of Base Mat

Fig.-6 Resonance and Phase Lag Curves by Simulation Analysis



(a) K_{HH}

(b) K_{HR}

(c) K_{RR}

Fig.-7 Dynamic Impedance with Rigid Basement

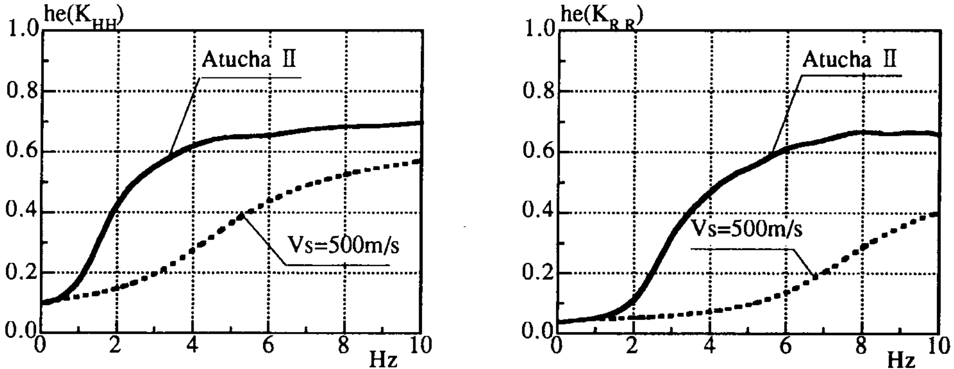
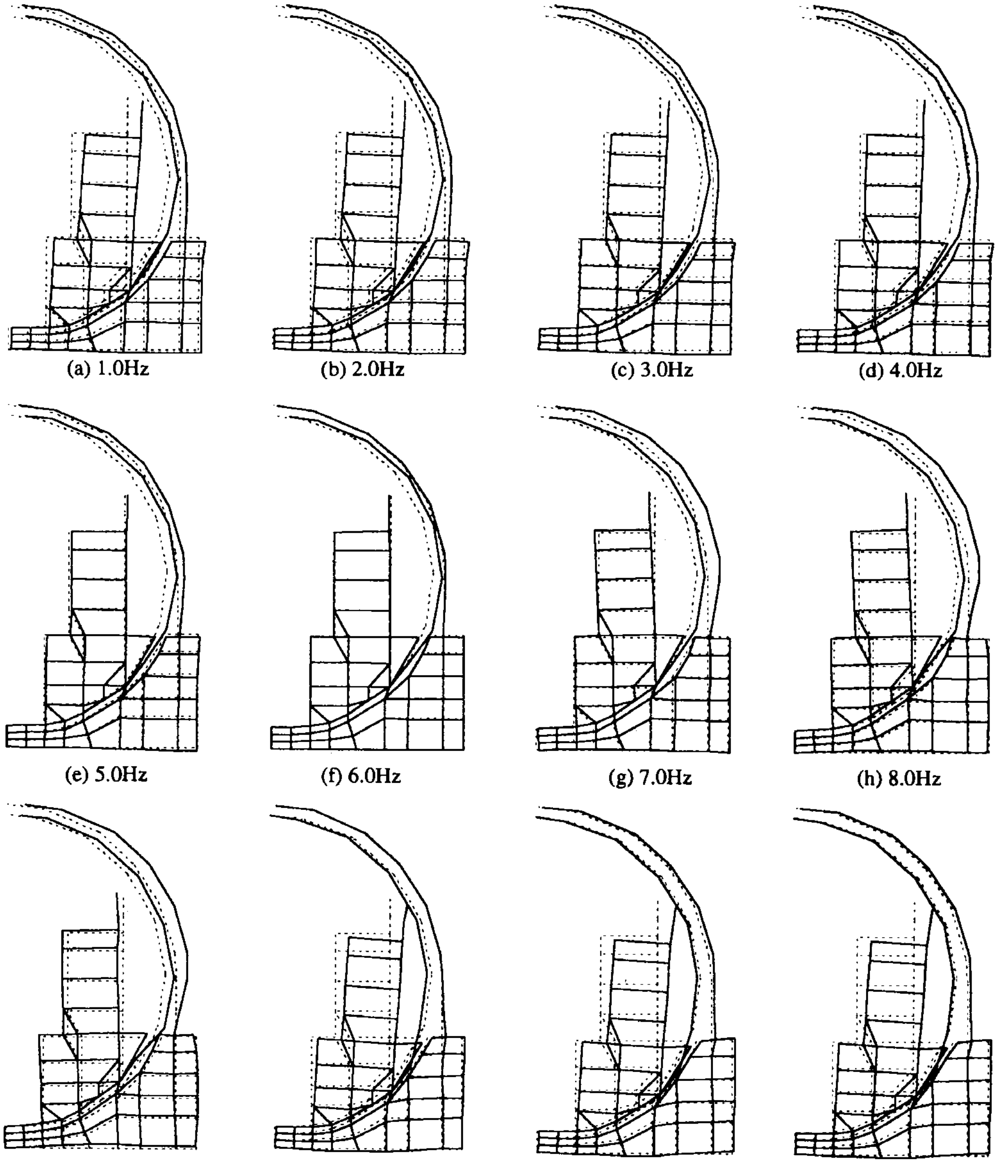


Fig.-8 Damping Coefficient evaluated from Dynamic Impedance


(a) 1.0Hz (b) 2.0Hz (c) 3.0Hz (d) 4.0Hz

(e) 5.0Hz (f) 6.0Hz (g) 7.0Hz (h) 8.0Hz

(i) 9.0Hz (j) 10.0Hz (k) 11.0Hz (l) 12.0Hz

Fig.-9 Resonance Mode at Each Frequemcy by Simulation Analysis