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FORCED VIBRATION TESTS ON THE REACTOR BUILDING OF A PWR TYPE NUCLEAR POWER STATION

S. Setogawa[1], T. Kitano[1], S. Asano[1], Y. Yasui[2], N. Konoue[2], M. Nakamura[2], K. Kawasaki[3] and T. Kanayama[3]

[1]The Kansai Electric Power Company Inc., Osaka, [2]Technical Research Institute, Obayashi Corporation, Tokyo, [3]Design Department, Obayashi Corporation, Osaka (Japan)

ABSTRACT

This report describes the forced vibration tests and numerical analysis carried out on the reactor building of Unit No.3 at Ohi Nuclear Power Station (ONPS) of The Kansai Electric Power Company Inc. The primary purpose of the tests was to confirm the vibration characteristics, such as natural frequencies and damping factors of the inner concrete structure (I/C) and the prestressed concrete containment vessel (PCCV) of the reactor building. Further, the vibration tests were numerically simulated. Considering the differences between the moduli of elasticity of the actual structure and these used for design, it is concluded that the vibration characteristics of the PCCV can be described well with the lumped mass model for design. As for the I/C, a FEM model is effective to describe the complex vibration characteristics of the structure. Concerning the transfer functions for ground motion,the lumped mass model and the compound model using FEM for the I/C produce similar results. We confirm that the lumped mass model is a reliable practical tool for earthquake resistant design.

1 INTRODUCTION

Unit No.3 at ONPS has a 4-looped type Pressurized Water Reactor(1180MW) covered with PCCV. In order to investigate the design safety of the I/C and the PCCV against earthquake, the forced vibration tests on the reactor building using the vibration generators were carried out just before the completion of the plant. This paper describes the results of the vibration tests and the numerical simulation.

2 OUTLINE OF THE VIBRATION TESTS

The vibration tests were carried out on the I/C and the PCCV of the reactor building. Both structures were built independently of each other on the same base mat whose thickness was 11.1 meters. Figures 1 and 2 show the plan view and cross section of the building. For the forced vibration test on the I/C, two vibration generators with maximum exciting force capacity of 10tf were symmetrically set on the operating floor(EL+33.6m) and operated synchronously. The operating frequency was varied step by step in the range between 1Hz to 25Hz. During the forced vibration test carried on the PCCV, a generator with maximum exciting force capacity of 3tf was set on the top of the

PCCV(EL+82.7m) and operated in the 1-20Hz frequency range. The exciting directions of both tests were along the N-S and E-W axis, respectively. As an example, some of the measuring points used in the tests are shown in Figure 2. The test on the I/C was carried out in October 1990 and as for the PCCV, in January 1991 after tensioning of the tendons in the PCCV.

3 TEST RESULTS

The resonance curves obtained from the forced vibration tests and the simulation analysis discussed in next section are shown in Figures 7 through 11. The values of natural frequencies and the damping factors are also shown in Tables 1 and 2. According to Table 2, no differences appear when comparing the natural frequencies of the PCCV in the N-S and E-W directions. Moreover,the damping factors of the PCCV and the I/C are similar with these[*1,etc.] obtained from previous experiments shown in Figure 3.

4 SIMULATION ANALYSIS

First, we conducted simulation analysis using the lumped mass model for design. Secondly, a model based on FEM was applied to the I/C.

4.1 Constants corresponding to Test Conditions

The dynamic modulus of elasticity of concrete is estimated through simultaneous elastic wave tests performed on the reactor building and Young's modulus tests performed on small concrete blocks collected from the actual PCCV and I/C. We concluded from these tests that Young's moduli were 4.3×10^5 kgf/cm^2 for the PCCV and 3.7×10^5 kgf/cm^2 for the I/C. These values are about 1.4 times higher than the design values. Next, because the empirical dynamic stiffness values of the base mat evaluated from the I/C exciting test show good agreement with values obtained using wave propagation theory(Fig.4), an uniform stress distribution under the base mat was assumed. Consequently, the dynamic stiffness used in the calculations is estimated by this assumption.

4.2 Simulation of PCCV

Table 3 compares the natural frequencies calculated using the lumped mass model for design shown in Figure 5 and test results. Simulation and test resonance curves are shown in Figure 7. We assumed that the Young's moduli of the concrete are equal to the values given in the previous section. Based on the vibration test results, the damping factors are 2% for the PCCV and 3% for other types of concrete. The simulation results and tests for the first order mode of the PCCV show good agreement. Considering the difference between the moduli of elasticity of the actual structures and these used for design, the vibration characteristics of the PCCV can be described well with the lumped mass model for design.

4.3 Simulation of I/C

We assumed that the correct behaviour of the I/C would not be simulated by the lumped mass model in case of exciting directly a central part of the I/C. Therefore, a FEM simulation model for the I/C was adopted. Because of the symmetry of the I/C along the N-S axis, the FEM model treats only half of the structure. The FEM model is fixed on the base mat. The constants of concrete adopted for the model were the same as in section 4.1. Considering computational efficiency, the elements in the FEM model were reduced in number while preserving the shape of the structure. Calculated and test results are compared in Table 4. The table shows that the first and second calculated natural frequencies are similar to measured frequencies in N-S and E-W direction, respectively. Next, we prepared the compound model which includes the FEM model and the lumped mass model of the PCCV and E/B (Enclosure Building), fixed independently of each other on the same rigid base mat supported by a dynamic spring. The outline of this model is shown in Figure 6. Hereafter,this model is called I/C-FEM model. The calculated resonance curves by the I/C-FEM model compared with the test results are shown in Figures 8 through 11, together with the results of the lumped mass model. We have been able to simulate satisfactorily the test results of the I/C in all frequencies up to 25Hz by using this I/C-FEM model. Accordingly,a model using FEM is effective to describe the complex vibration characteristics of the I/C structures.

4.4 Transfer Function for Ground Motion

For the purpose of evaluating the vibration characteristics of the structures for earthquake, we have studied the transfer functions for ground motion of the lumped mass and the I/C-FEM models. Considering the differences of the strain levels between the vibration tests and actual earthquake, we have estimated the Young's moduli of concrete for earthquake to be smaller than these used in simulation and have adopted 3.9×10^5 kgf/cm^2 for the PCCV and 3.4×10^5kgf/cm^2 for the I/C. The damping factors of the PCCV and other types of concrete are assumed to be 3 and 5%, respectively. The results computed by using the two models are shown in Figures 12 and 13. In the N-S direction, the response of the lumped mass model is partially seen to be larger than the one obtained by the I/C-FEM model. But it means that the results by lumped mass model are more safe in comparison with the I/C-FEM model for earthquake resistant design. In the E-W direction, the results of both analytical methods are similar in all frequencies up to 25Hz. Finally, we confirm that the lumped mass model is a reliable practical tool for earthquake resistant design.

5 CONCLUSIONS

The following conclusions can be made based on the forced vibration tests of the I/C and the PCCV of Unit No.3 at Ohi Nuclear Power Station:
1) The natural frequencies of the I/C and the PCCV are clarified at first and second modes of vibration.
2) Considering the difference between the moduli of elasticity of the actual structures and these used for design, the vibration characteristics of the PCCV can be described satisfactorily using a lumped mass model for design.
3) As for the I/C, a model using FEM is effective to describe the complex vibration characteristics of the structures in case of exciting directly the I/C.
4) By studying the transfer function for ground motion, it is concluded that the lumped mass model is a reliable practical tool for earthquake resistant design.

REFERENCES

1) Kato,M., et al. (1989), Forced Vibration Tests on the Reactor Building of Tsuruga Unit No.2 Nuclear Power Station, Nuclear Engineering and Design 111,pp.327-340

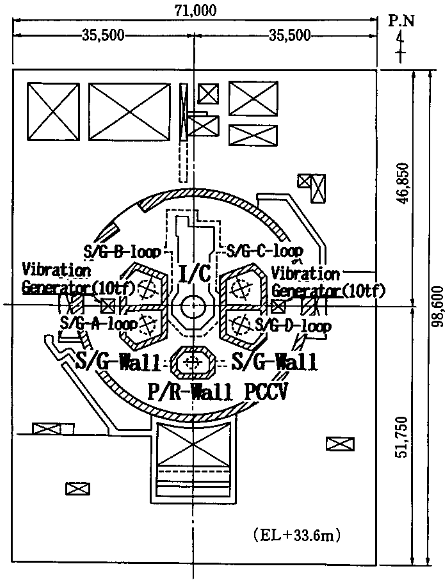

Fig. 1 Plan View of Reactor Building

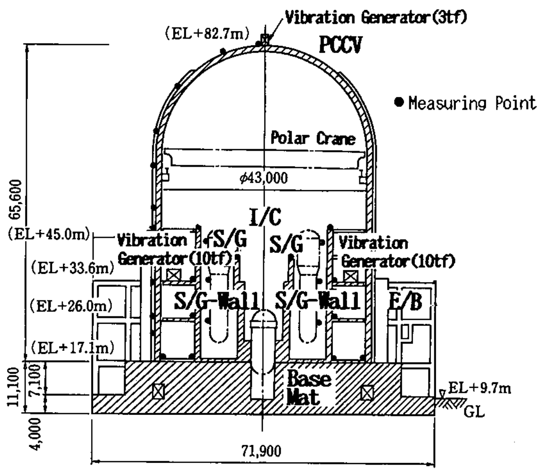

Fig. 2 Cross Section of Reactor Building and Example of Measuring Points

Table 1 Test Results on I/C

Structure	Direction	Mode	Natural Frequency	Damping Factor
I/C	N-S	1st	9. 78Hz	3. 0%
		2nd	11. 88Hz	1. 8%
	E-W	1st	10. 62Hz	2. 0%
		2nd	12. 69Hz	1. 2%

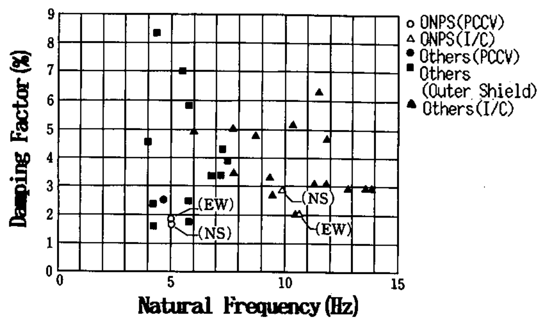

Fig. 3 Damping Factors of This Test and Previous Experiments

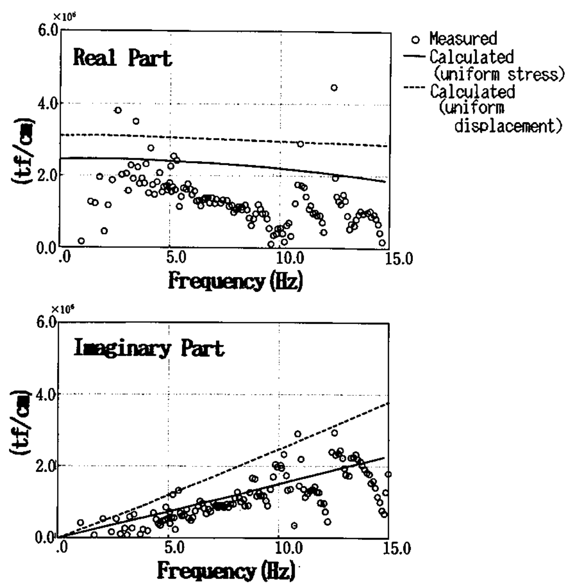

Fig. 4 Dynamic Stiffness of Test and Calculation (Swaying)

Table 2 Test Results on PCCV

Structure	Direction	Mode	Natural Frequency	Damping Factor
PCCV	N-S	1st	5. 01Hz	1. 7%
		2nd	14. 89Hz	1. 1%
	E-W	1st	4. 97Hz	1. 9%
		2nd	14. 88Hz	1. 7%

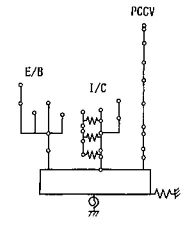

Fig. 5
Lumped Mass Model
for Design

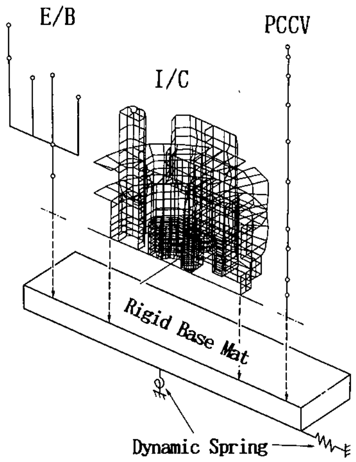

Fig. 6 I/C-FEM model
for Simulation

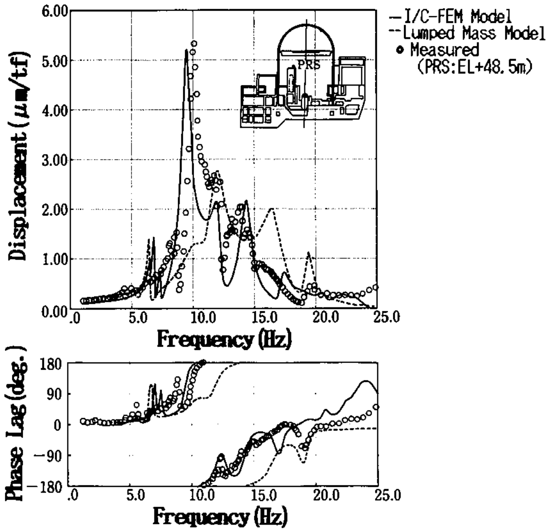

Fig. 8 Resonance Curves of Test
and Calculation in the I/C
N-S Excitation (Top of PR Wall)

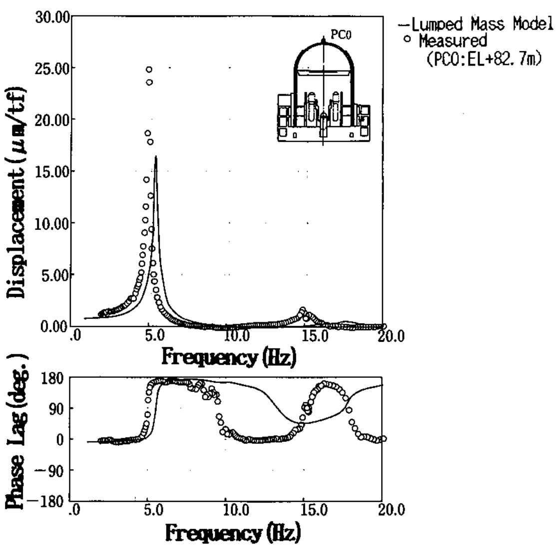

Fig. 7 Resonance Curves of Test
and Calculation in the I/C
N-S Excitation (Top of PCCV)

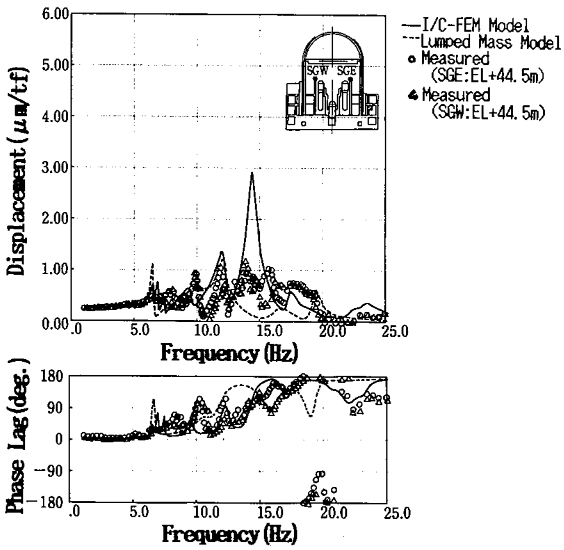

Fig. 9 Resonance Curves of Test
and Calculation in the I/C
N-S Excitation (Top of S/G Wall)

Table 3 Natural Frequency of Test
and Calculation on PCCV

PCCV	1st. Natural Frequency (Hz)	
	N-S direction	E-W direction
Calculated	5.5	5.5
Measured	5.0	5.0

Table 4 Natural Frequency of Test
and Calculation on I/C

I/C	Natural Frequency (Hz)			
	N-S direction		E-W direction	
	1st. Mode	2nd. Mode	1st. Mode	2nd. Mode
Calculated	9.4	12.0	10.5	12.1
Measured	9.8	11.9	10.6	12.7

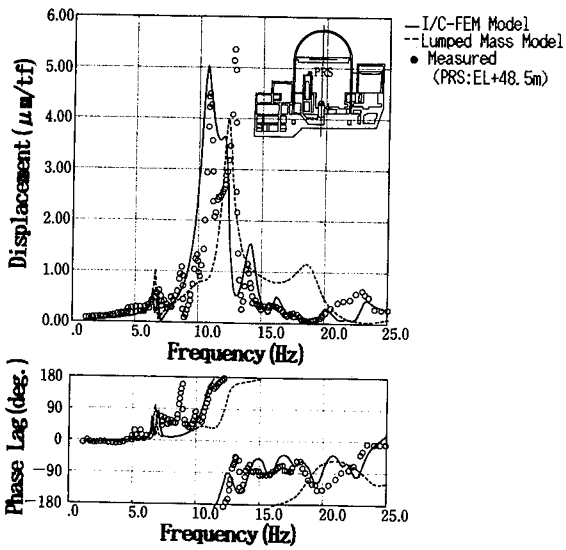

Fig.10 Resonance Curves of Test and Calculation in the I/C E-W Excitation (Top of PR Wall)

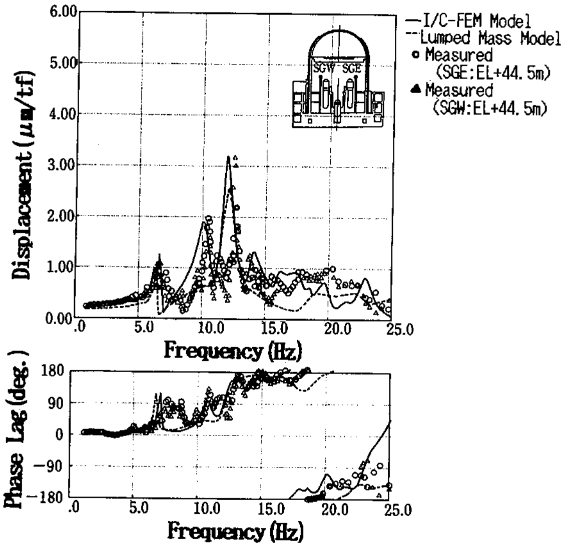

Fig.11 Resonance Curves of Test and Calculation in the I/C E-W Excitation (Top of S/G Wall)

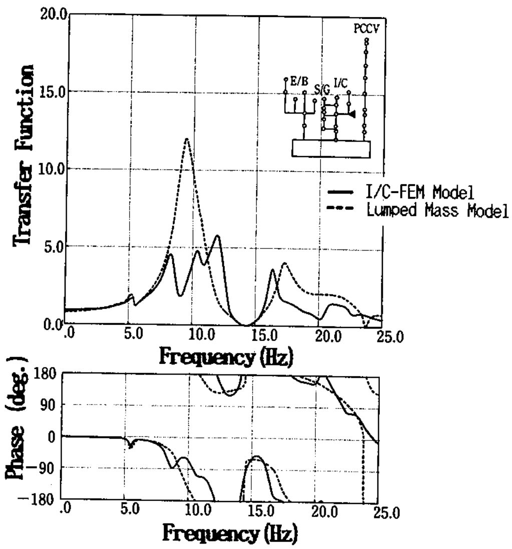

Fig.12 Transfer Functions by I/C-FEM and Lumped Mass Model (Operating Floor in N-S direction)

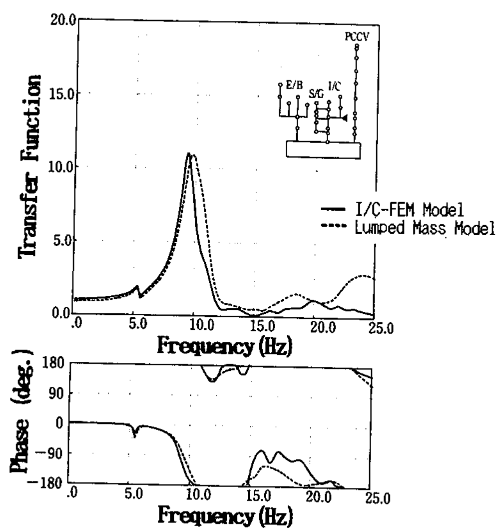

Fig.13 Transfer Functions by I/C-FEM and Lumped Mass Model (Operating Floor in E-W direction)