Transactions of the **13th International Conference on Structural Mechanics in Reactor Technology** (SMiRT 13), Escola de Engenharia - Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil, August 13-18, 1995

Forced vibration tests and simulation analyses of a nuclear reactor building - Part 1: Outline of the forced vibration tests

Nakagawa, S.[1], Kuno, M.[1], Naito, Y.[2], Nozawa, T.[2], Momma, T.[2], Motohashi, S.[2], Niwa, M.[2]
1) Chubu Electric Power Co., Nagoya, Japan
2) Kajima Corporation, Tokyo, Japan

ABSTRACT: This paper describes forced vibration tests carried out at the Hamaoka (BWR) Unit 4 reactor building in Japan in April and May of 1992. Fundamental dynamic characteristics of the R/B including its interaction with the adjacent T/B and the soil-structure interaction were obtained. Results for preceding R/Bs are compared, and probable causes for fluctuation of the resonance curve around the 1st peak are discussed.

1 INTRODUCTION

This paper describes forced vibration tests carried out at the Hamaoka (BWR) Unit 4 reactor building in Japan in April and May of 1992. Results showed the dynamic characteristics of the nuclear reactor building (R/B) including the soil-structure interaction as well as the interaction with the turbine building (T/B). The main part of the building is reinforced concrete, and it has a flat, steel-frame roof. The 83.5m x 83.5m mat slab of this building is directly founded on rock with an equivalent shear wave velocity (Vs) of approximately 800m/sec. The total weight of this building is 370,000 tons. When the tests were performed, construction of the R/B and the T/B, and installation of the machinery and piping were nearly finished.

2 METHOD OF THE TESTS

2.1 *Object of excitation and measurement*

Two horizontal exciters were set on the operating floor (FL+27.8m and the 4th floor) of the R/B. Harmonic forces were applied in the NS and EW directions, respectively. To confirm the interaction between the R/B and the T/B, the responses of the R/B as well as the adjacent T/B were measured. Sections of the R/B and the T/B are shown in Fig.1. A plan of the operating floor of the R/B, showing the locations of the two exciters, is shown in Fig.2.

2.2 *Instrument for the tests*

(1) *Exciter*

In the tests, two counter-rotating eccentric weight type exciters were synchronized. The maximum force of each exciter was 10 ton-f over 2 Hz. The unbalanced moment of each exciter was fixed to 630 kg-m from 1 to 2 Hz, and the force of each exciter was fixed to 10 ton-f from 2 to 20 Hz.

(2) *Sensor*

The building responses were measured by servo-type velocity sensors and the obtained data were converted to displacement and normalized to responses per ton-f of exciting force. To eliminate noise and to determine the real responses to the exciting force, cross-correlation functions between the rotational signal of the exciter and the observed signals were calculated and utilized (Kajima 1991). In the measurement, 100-cycle records were used to calculate the correlation. The system has 47-channel simultaneous measurement and data acquisition capacity.

3 TEST RESULTS

3.1 *Resonance curve, natural frequency and damping factor*

The resonance curves obtained from the NS test are shown in Fig.3 and Fig.4. The 1st predominant peak is around 4 Hz for the R/B, and around 5 Hz for the T/B. Resonant frequencies and damping factors of the R/B estimated from the 1st peak using solid lines in Fig.5 are shown in Table 1 and Fig.5. Damping factors are relatively large because of the effect of soil-structure interaction.

3.2 *1st mode of vibration*

Fig.6 shows the 1st vibration modes obtained from the amplitudes and phases of the responses at the main measuring locations. The ratios of sway, rocking and elastic deformation for the absolute displacement of the top of the R/B are respectively 14%, 36% and 50% for NS excitation and 14%, 35% and 51% for EW excitation. These ratios indicate the large effect of the soil-structure interaction on the vibration modes.

3.3 *Spring constant of soil calculated from test results*

Force and moment acting on the bottom surface of the base are calculated from the inertia force of each part of the R/B and the force of the exciter. Sway and rocking motion of the base are estimated from the horizontal and vertical responses of the base. Using these forces, moment and responses, spring constants are calculated for each frequency. Fig.7 shows the spring constants (vs. frequencies) of the soil for sway and rocking motion based on the forced vibration test results.

4. DISCUSSION

4.1 *Comparison with preceding (Unit 1~Unit 3) reactor buildings*

Table 2 and Fig.8 compare results of forced vibration tests of this (Unit 4) reactor building with those of the preceding (Unit 1~Unit 3) reactor buildings. The response amplitude of Unit 4 R/B is smaller than that of Unit 1 and Unit 2 R/B and slightly larger than that of Unit 3 R/B. This tendency is consistent with the building weights, base areas, equivalent wave velocities of the ground and the embedment ratios. The responses in Fig.8 are normalized to a 1 ton-f exciting force and therefore tend to be inversely proportional to the building weights and spring constants of the ground. The spring constants depend on the ground rigidities (equivalent Vs) and the base areas. Furthermore, the larger the embedment ratio, the larger the damping ratio and the less the response.

4.2 *Fluctuation of resonance curve around the 1st peak (3.6~5.4Hz)*

One of the most important objectives of forced vibration tests is to evaluate the frequency and damping ratio for the 1st peak. For both NS and EW excitations, the resonance curves have fluctuation around the 1st peak. The resonance curve of the 4th floor of the R/B is shown in Fig.9. If the 1st peak is recognized as being one peak and not multiple peaks with an appearance of one peak, it is desirable that the cause and the mechanism of fluctuation should be identified. The vibration modes shown in Fig.11 indicate that most of the R/B has similar modes through this frequency range (3.6~5.4 Hz), but that some parts have different peaks at frequencies such as 5.4 Hz for the adjacent T/B and 5.3 Hz for vertical movement of the roof of the R/B (vid. Fig.4 and Fig.10). The vibration modes for the R/B roof and the T/B for 3.6~4.1 Hz and 4.7~5.4 Hz are different. For example, the phases for the R/B and the T/B are opposite at 3.6 Hz , at 90 deg. difference at 4.7 Hz, and the same at 5.4 Hz. The response of the T/B is comparatively large at 5.4Hz. The soil-structure interaction between the R/B and the ground is inferred to be one of the causes, although the test results do not confirm this. Therefore, possible reasons for the fluctuation in resonance curve around the 1st peak of the R/B are as follows.

1) vertical vibration of the R/B roof
2) mutual interaction between the R/B and the T/B
3) soil-structure interaction between the R/B and the ground

Conclusions from the simulation will be shown in part 2.

5. CONCLUSION

Fundamental dynamic characteristics of the R/B including its interaction with the adjacent T/B and the soil-structure interaction are obtained from the results of forced vibration tests. Results for preceding R/Bs are compared and probable causes for resonance curve fluctuation around the 1st peak are discussed.

REFERENCE

Kajima Corporation, MIK system vibration measuring van, Katri leaflet 91-6, 1991

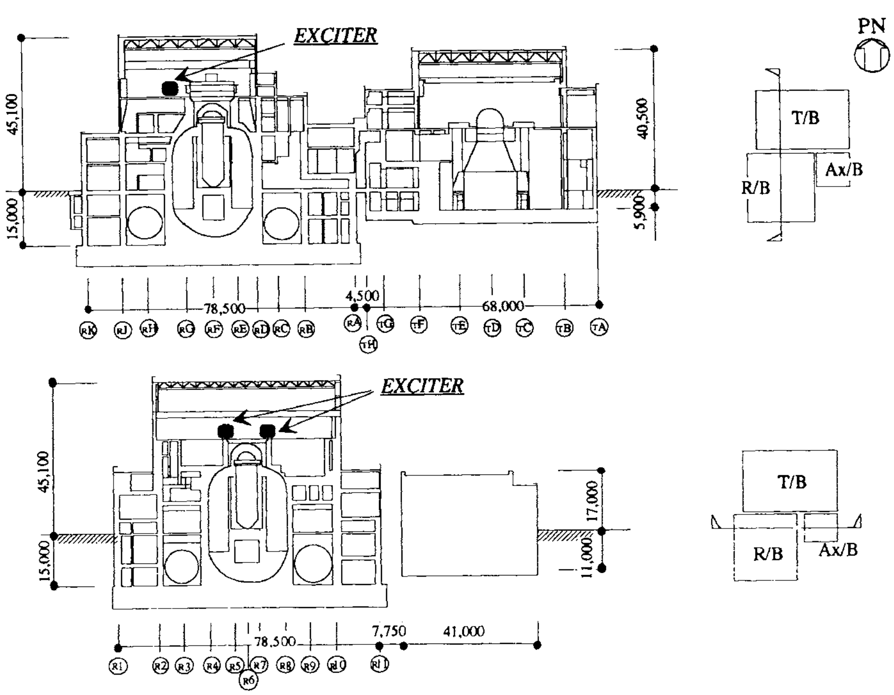


Fig.1 Section through reactor building (R/B) and turbine building (T/B)

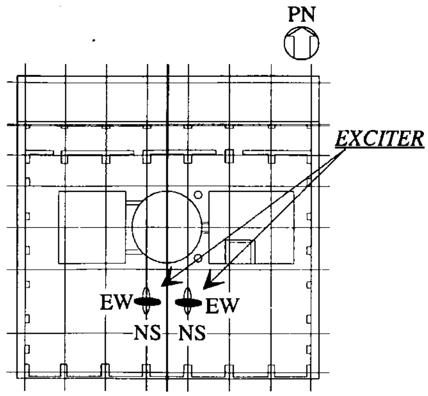


Fig.2 Plan of operating floor with locations of two exciters

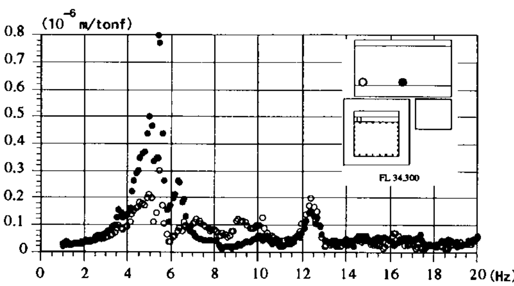


Fig.4 Resonance curves at T/B for NS excitation

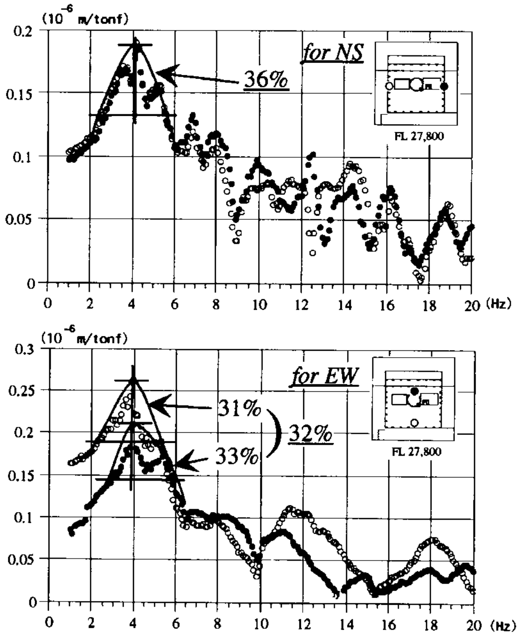


Fig.5 Resonance curves at R/B, FL+27.8m

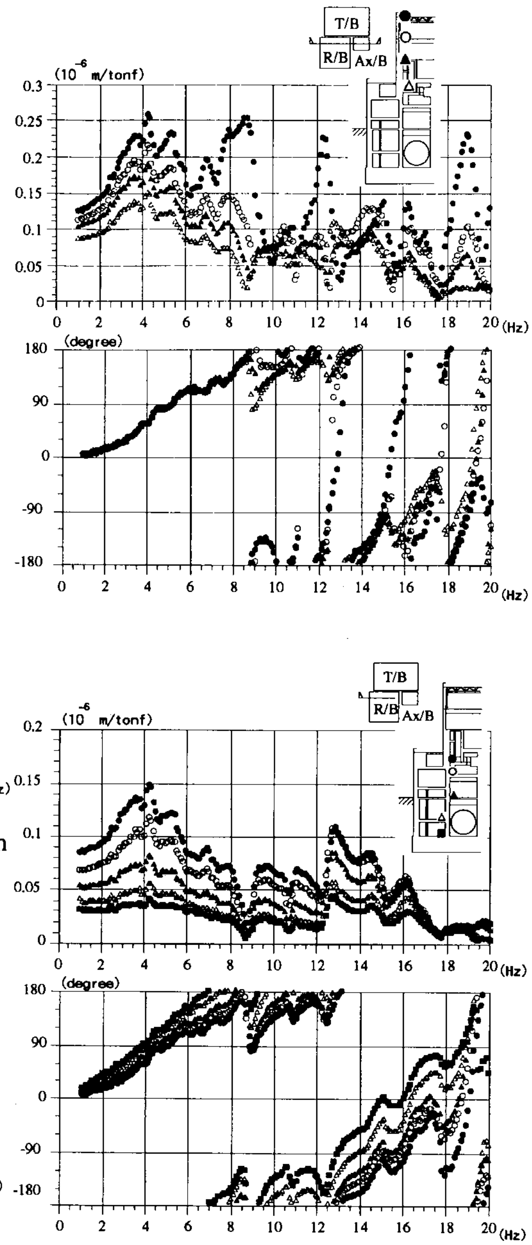


Fig.3 Resonance curves at R/B for NS excitation

Table 1 Resonance frequency and damping factor of the R/B

NS	frequency (Hz)	4.1 Hz
	damping factor (%)	36 %
EW	frequency (Hz)	4.0 Hz
	damping factor (%)	32 %

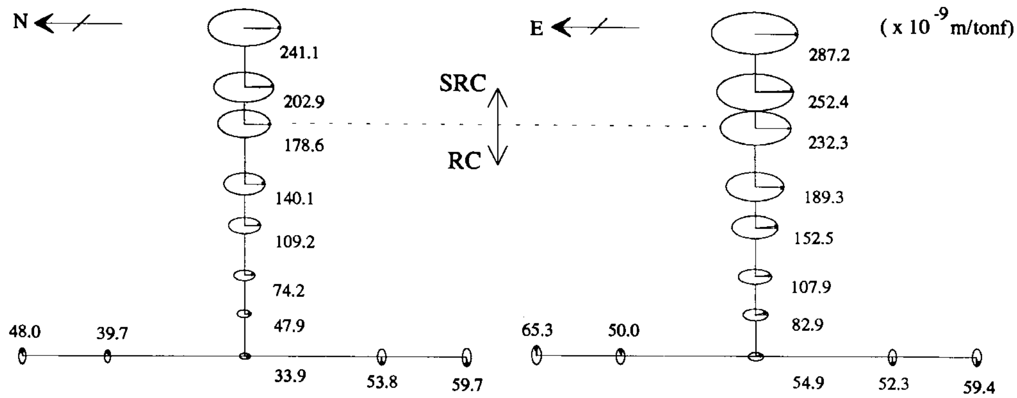


Fig.6 1st vibration modes obtained from amplitudes and phases of responses of the main measuring locations

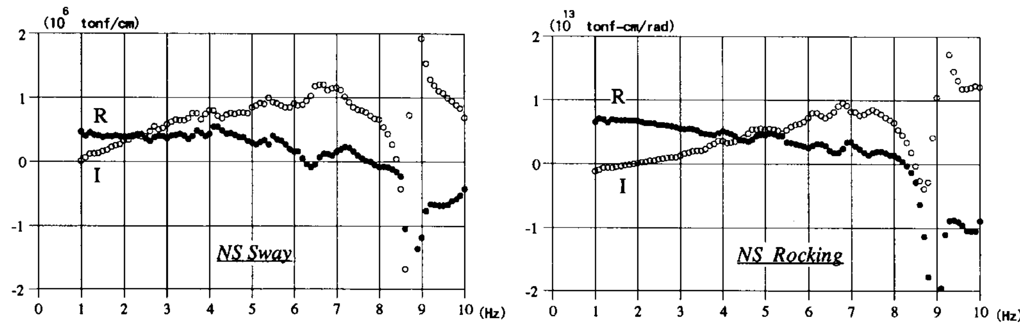


Fig.7 Spring constants of the soil for sway and rocking motion based on forced vibration test

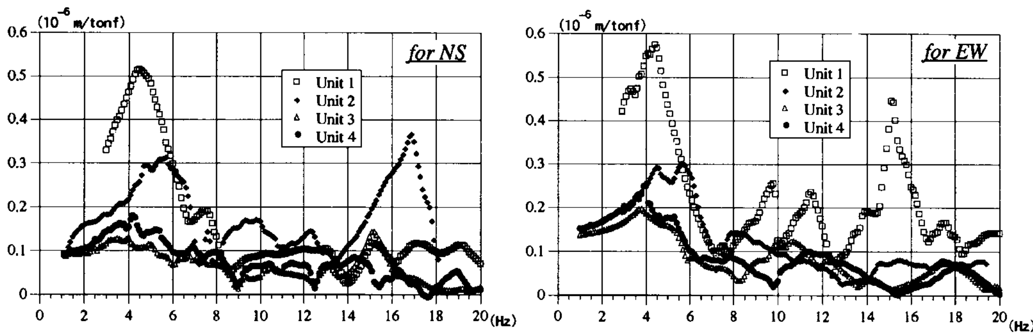
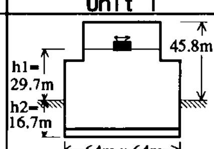
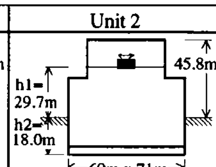
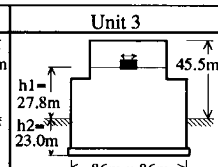
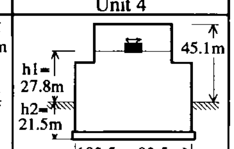


Fig.8 Resonance curve compared with those of 3 preceding R/Bs

Table 2 Comparison of the forced vibration tests of R/B with those of 3 preceding R/Bs

	Unit 1	Unit 2	Unit 3	Unit 4
size				
weight	157,000 t	212,000 t	395,000 t	370,000 t
Vs	786 m/sec	798 m/sec	824m/sec	793m/sec
ratio of embedments h2:(h1+h2)	1 : 2.8	1 : 2.7	1 : 2.2	1 : 2.3
response ratio at the 1st peak	3.9 *	2.3 *	1.0	NS - 1.4 * EW - 1.3 *

* normalized by the response for Unit 3

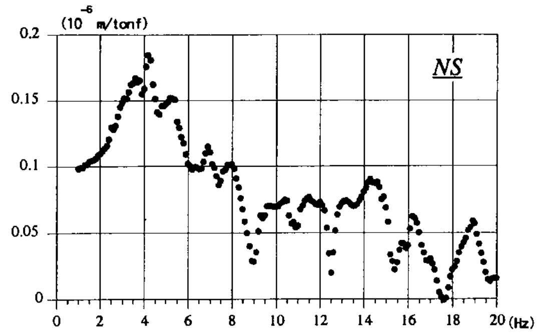


Fig.9 Resonance curve of the 4th floor of the R/B

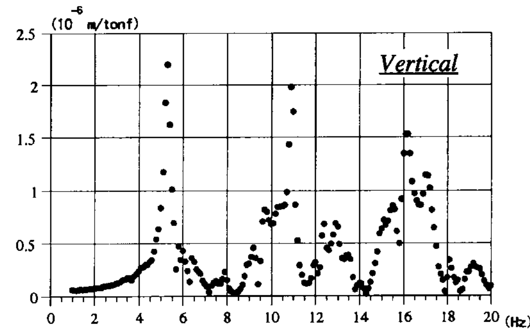
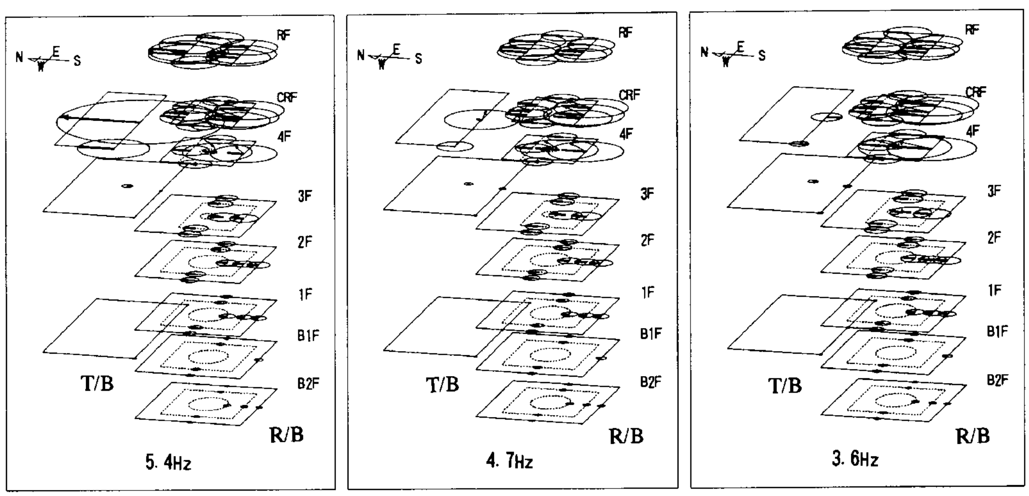
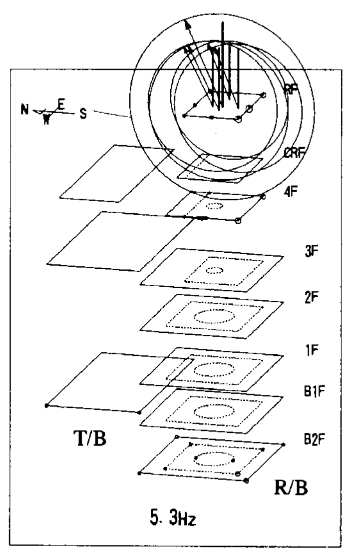


Fig.10 Resonance curve of the roof of the R/B



a. horizontal (NS) motion of R/B and T/B



b. vertical motion of roof and others

Fig.11 R/B vibration modes