FORCED VIBRATION TEST OF BWR TYPE NUCLEAR REACTOR BUILDINGS CONSIDERING THROUGH SOIL COUPLING BETWEEN ADJACENT BUILDINGS

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SUMMARY

Forced vibration test of two adjacent BWR type reactor buildings at HAMAOKA Nuclear Power Station of The Chubu Electric Power Co., Inc. was performed on a rare large scale in 1977. No.1 reactor building--the results of the experiment which was conducted in 1973 and 1974 were already presented in SMIRT3 and 4--was generating electric power since 1975 and No.2 reactor building (RC; 5F + B2F; generated output:840 MW) was under construction adjacently to No.1 reactor building. The purpose of this paper is to introduce the management and method of the experiment in 1977 which was carried out under two different environmental restrictions, that is, power generation and construction in No.1 and No.2 reactor buildings respectively, and the results of the experiment for checking the aseismatic design.

1) Outline of Experiment: Three large vibrational exciters (maximum exciting force: 150 tons per unit) were set up on the 5th floor of No.2 reactor building and excited vibration ranging from 1 Hz to 20Hz in north-south, east-west and vertical directions. For obtaining responses from the buildings, 24 and 33 pickups were placed on the floor of No.1 and No.2 reactor buildings respectively, and 17 dynamic earth pressure cells buried under the foundation of No.2 reactor building were included in the measurement plan. A matter of primary concern in the experiment was finding whether excited vibration would unfavorably affect the machine, piping and other in No.1 reactor building and construction in No.2 reactor building. To check this up, a commitee consisting of mechanical, electrical, construction and radiation control engineer performed a trial test immediately before the experiment.
2) Experiment and Measurement: A method had to be devised to transmit reliably minute electric signals (on the order of mV to tens of mV) of pickups from the radiation controlled area in No.1 reactor building to the measurement center. This matter was solved by application of the wired FM-telemeter which had a remote-gain control system. This meter made easy to protect against electric noise and radiation pollution.
3) Results of Experiment: Resonance curves in which figures were complex and had many peaks were analyzed in respect of natural frequency, the viscous damping ratio and the natural mode by the regression analysis of many degrees of freedom. The results of the experiment give the indication of vibrational behaviors of two reactor buildings coupled through soil.

1. Introduction

A reactor building, different from general structures, is a building with short periods, and the fact that great dissipation of vibration energy to the soil can be expected from the vibrational characteristic in earthquake of such a building is considered advantageous in the aseismatic design of the building. It is, therefore, very important to verify by experiments these vibration damping effects which have already been evaluated in aseismatic analysis.

The Chubu Electric Power Co.,Inc. conducted forced vibration experiments on the No.1 reactor building in the past (in 1973 and 1974) with the main objective of evaluating the dissipation of vibrational energy to the soil and reported on its engineering adequacy in SMIRT 3 and 4. In 1977 when the No.2 building, which was constructed adjacent to the No.1 building, was nearly completed, the electric company planned to carry out another forced vibration experiment as a series to the previous ones. In this forced vibration experiment, it was aimed at evaluating the vibration damping effects with the dissipation of vibration energy to the soil and measuring the vibration interaction between the adjoining two buildings Nos.1 and 2; and in expecting great response displacement of buildings, three large vibrational exciter having a maximum horizontal exciting force of 150 tons at 13 Hz were used. Measurement points, 57 displacement pick-ups in total, were set up at all the stories of the No.1 building in operation and the No.2 building in near completion, and 17 earth pressure cells were buried under the foundation of the No.2 building, thus making this experiment a forced vibration experiment unprecedented in its large scale under the condition of radiation control and the exciting ability employed.

This paper describes i) the design and control, ii) measurement made and iii) results of the aforesaid large-scale forced vibration experiment, and various data obtained by this experiment could be effectively fed back to the procedure of vibration experiment and the aseismatic design of reactor buildings in future.

2. Outline of Experiment

EW section and 5th floor plan of No.1 and 2 reactor buildings at Hamaoka Nuclear Power Plant of the Chubu Electric Power Co., Ltd., where the present experiment was conducted are shown in Figs.1 and 2. The No.1 building has a foundation measuring 64 x 64 m, 5 stories above the ground, 2 basement floors, a height of FL + 47.3 m, a depth of FL - 16.7 m and a gross weight of about 167,000 t; the No.2 building has a foundation measuring 71 x 69 m, 5 stories above the ground, 2 basement floors, a height of FL + 47.6 m, a depth of FL - 18.0 m and a gross weight of about 210,000 t. The foundation of the No.1 building is independent from that of the No.2 building.

The condition of the No.2 building at the time of executing the experiment was as follows: Concreting work of the building and installation of major equipment inside the building were practically completed and fittings such as piping were being installed. PCV and RPV covers were provisionally constructed on the 5th floor, and fuel rods and water in the pool and inside the reactor were still non-existent.

On the exciting floor (5th floor) of the No.2 building, 3 large vibrational exciters having a horizontal maximum exciting force of 150 t were installed, and vibration tests were conducted in the EW, NS and vertical directions. Measuring points by displacement pick-ups were set up at 3 locations, that is, for measuring 2 components in exciting directions and 1 component in the orthogonal direction, on each story of both Nos.1 and 2 buildings; and 4 vertical measuring points were set up on the B2 floor to measure rocking vibration. Further, one measuring point each was installed on the 1st and 3rd floors of the turbine buildings.

Also the 17 vertical earth pressure cells which had been buried under the foundation of the No.2 building, together with the displacement pick-ups, were made into measuring points. The exciting frequency was determined within the range 1 to 20.0 Hz at an interval of 0.1 to 0.2 Hz.

At the time of formulating the experiment execution program, a working committee was established which was formed by the technical staff of the electric company specializing machinery, electricity, construction, power generation and radiation control relative to the No.2 building under construction and the No.1 building in operation, and the following matters were deliberated:

i) Safety of machinery, equipment and piping in the No.1 building and construction scaffolds and provisional lighting, etc. in the No.2 building.

ii) Radiation preventive measures in the No.1 building and working efficiency and maintenance in preparation and execution of the experiment.

iii) The period and time zone for executing the experiment.

iv) Vibration of the exciting floor of the 5th story of the No.2 building.

With the results of the aforesaid examination as guidelines, satisfactory execution of the experiment was ensured by checking with a trial experiment prior to the regular experiment and by performing a mock drill for emergency stop of the vibrational exciter at the time of an unexpected accident. For the time zone of executing the experiment, hours of 18:00 - 24:00 were selected, in order to avoid the vibration noise due to working of the construction.

3. Experiment and Measurement

The large vibrational exciters used were Eccentric Mass Type vibrator developed by Central Research Institute of Electric Power Industry (Japan), and their vibrator portion and performance of exciter are illustrated in Figs.3 and 4 respectively. In the regular experiment, only 2 out of the 3 vibrational exciters were operated at the exciting force in Fig.5.

The characteristic features of the experiment were that i) a considerably large number of measuring points were used, ii) measuring points were covering both Nos.1 and 2 buildings, and iii) the No.1 building was in the environment which restricted experiment execution owing to radiation. To cope with the aforesaid difficulties, the following measures were employed: For all the measurement points in the No.1 building and a part of measurement points in the No.2 building, 36 points in total, a wired FM telemeter (TH Method) equipped with a remote gain control device was employed. This wired FM telemeter operated combinations of sensors and accompanying FM transmitters to transmit 12 sensor signals to the measurement center through one 2-core cable (Fig.6). This FM telemeter had advantages of not only greatly reducing the work load of wiring, but also ensuring highly reliable data transfer and easiness of maintenance throughout the period of the experiment, because signals during the transfer were frequency-modulated and free of external noises.

The signals of some important points were led to the gain phase meter → calculater →

digital plotter and immediately plotted into a resonance curve whereby normal progress of the experiment was controlled (Fig.7). Displacement pick-ups used were of the moving coil type (natural period: 1.0 sec; sensitivity: 2.24 V/kine).

4. Results of Experiment

i) Resonance Curve

Experiment data, after being corrected for sensors, amplifiers, etc., were separated--according to the 2 parallel components and one orthgonal component arranged on each story of the buildings and by assuming that the floor is a rigid body--into parallel components, torsional components and orthogonal components. The resonance curves of EW exciting direction in which exciting force is normalized into 100 tons is shown Fig.10 and the similar resonance curves of NS exciting direction is shown Fig.11. The resonance curve is mainly divided into 3 regions of 1 to 7 Hz, 7 to 14 Hz and more 14 Hz, and the most important lower natural frequency of the reactor building is indicated by several peaks which lie in the frequency about 5 Hz. As peaks common to EW and NS exciting directions, 2 peaks of 4.7 Hz and 5.7 Hz are observed, which are considered to be the interaction effects of Nos.1 and 2 buildings having similar vibrational properties. In the frequency range of 7 to 14 Hz, only the R-story indicates remarkable motion; and in the frequency range more than 14 Hz, phase motions of all stories seem to indicate that they have entered the secondary natural frequency region.

ii) Vibration Patterns

The parallel vibration patterns of 2 peaks at 4.7 Hz and 5.7 Hz of EW and NS exciting directions are shown, with 5F of the No.2 building as a reference, in Figs.8 and 9 respectively. At the peak of 4.7 Hz in EW exciting direction, Nos.1 and 2 buildings are vibrating in the mutually facing directions in a more or less primary vibration mode; whereas at the peak of 5.7 Hz, the two buildings indicate vibration patterns in the same direction. On the other hand, at the peak of 4.7 Hz in NS exciting direction, the vibration patterns in the same phase are shown; whereas at the peak of 5.7 Hz in the NS exciting direction, the patterns are of the inverse phases type. When 4.7-Hz and 5.7-Hz patterns are compared, phases of the two buildings are inverse to each other in all exciting directions.

iii) Evaluation of Vibration Damping Effects

The main objective of the forced vibration experiment is to evaluate vibration damping effects from the resonance and phase lag curves obtained by the experiment. In order to evaluate natural frequency and the damping ratio at high accuracy from the resonance curves having a complicated shape, regression analysis of many degrees of freedom has been employed. The 5 parallel components during EW and NS exciting directions on selected floors of RF, 5F, 3F, 1F, B2F have been given regression analysis of many degrees of freedom within the frequency range of 1 to 9 Hz. The results of analysis made with 12 initial natural frequency settings are shown in Figs.12 and 13. From these figures, it can be easily observed that the curve obtained by regression shows a good fit to the resonance curves obtained by the experiment. Analysis at 1 to 4 Hz indicates 40 to 50% indicating a strong influence of the ground; analysis at 4 to 5.7 Hz indicates 20%, because this is the lower natural frequency where interaction effects of the two buildings are the greatest.

5. Conclusion

Since the data which have been obtained in the present forced vibration experiment are enormous in number and contain vertical vibration experiment data, there are still many points to be analyzed in future. However, in verification of vibration damping effects which is the main objective of the present experiment, it is expected that the primary damping ratio will be 20% that greatly exceeds 10% which was used at the time of designing the No.2 building, and evaluation of the dissipation of vibrational energy to soil in aseismatic designs of rigid structures has been confirmed. It is also found that the wired FM telemeter equipped with a remote gain control device, which was employed for measurement inside the No.1 building where working hours and access to the building were restricted, is a very effective means for achieving labor saving, workability and noise resistance.

6. Acknowledgement

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7. References

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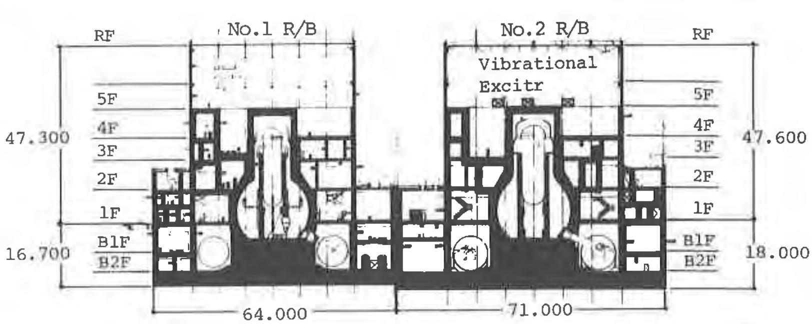

Fig.1 EW Section of No.1 and No.2 Reactor Buildings and Position of Exciter

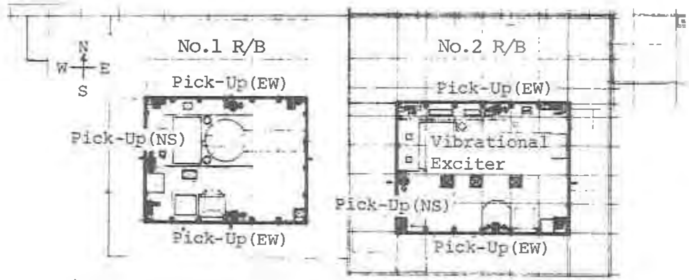

Fig.2 5th Floor Plan of No.1 and No.2 Reactor Buildings and Position of Exciter and Pick-Ups

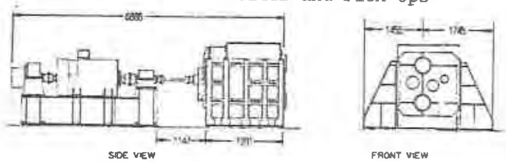

Fig.3 150 tons Vibrational Exciter

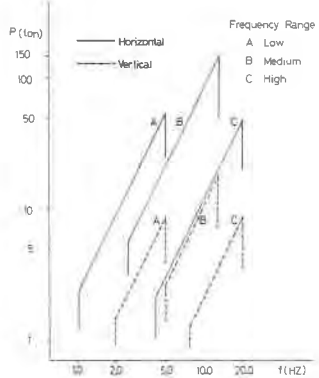

Fig.4 Performance of Exciter

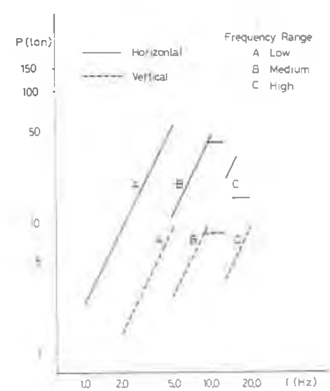

Fig.5 Actual Exciting Force

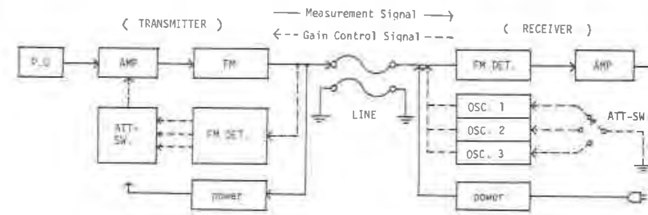

Fig.6 Wired FM Telemeter Equipped with Remote Gain Control Device (TH-Method)

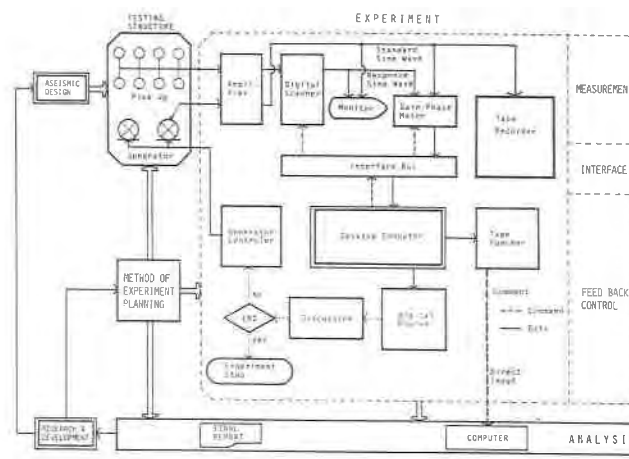

Fig.7 Block Diagram of Forced Vibration Test (FORVITT)

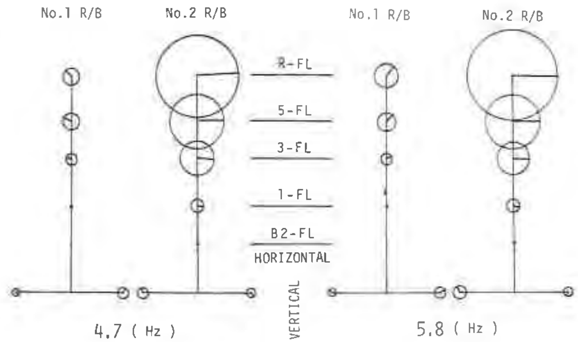

Fig.8 Vibration Pattern (EW Direction)

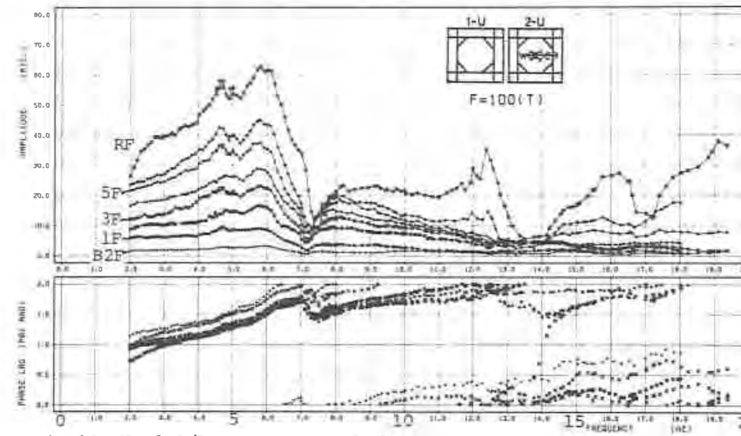

Fig.10 No.2 R/B Resonance and Phase Lag Curves (EW Direction)

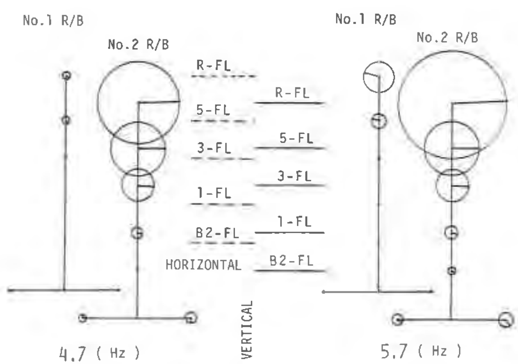

Fig.9 Vibration Pattern (NS Direction)

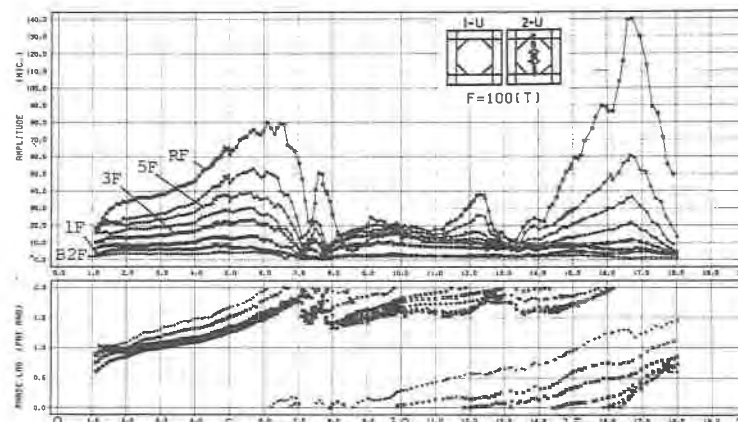

Fig.11 No.2 R/B Resonance and Phase Lag Curves (NS Direction)

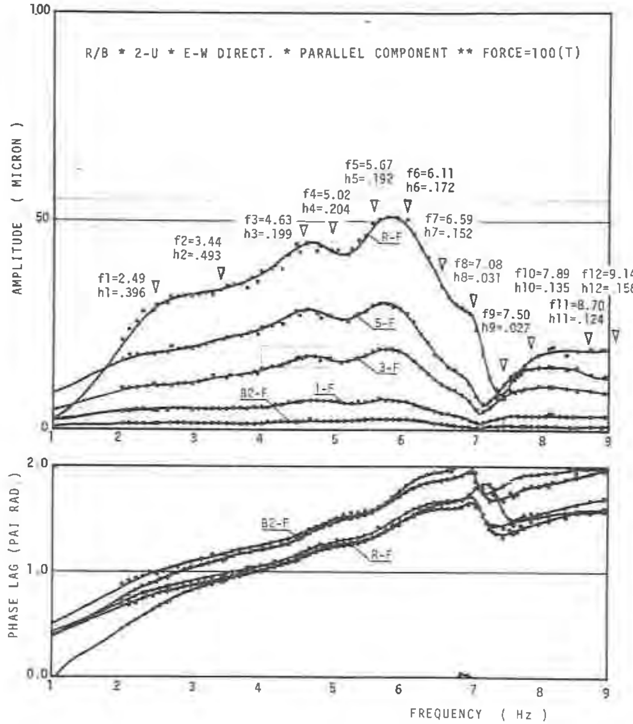

Fig.12 Results of Multi Regression Analysis (EW Direction)

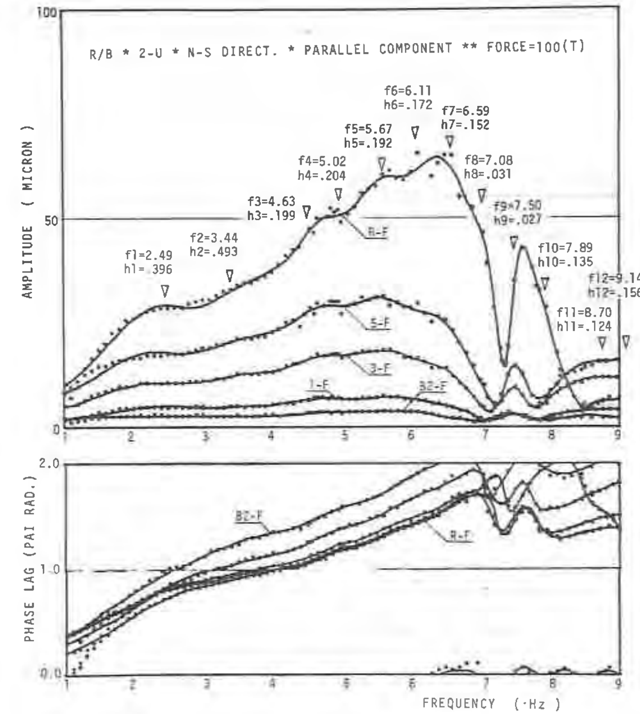

Fig.13 Results of Multi Regression Analysis (NS Direction)