

EXPERIMENTAL STUDY ON VIBRATIONAL CHARACTERISTICS OF BOILER BUILDING OF THERMOELECTRIC POWER PLANT

by BOILER BUILDING RESEARCH GROUP*

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SUMMARY

The authors have carried out the vibration tests of the boiler building of a thermoelectric power plant, and the observations of vibrations of the building caused by earthquakes. In the next place, the authors suggested the dynamical model of the structural system and conducted simulation analyses of observed seismic waves. It is proved that the vibrational characteristics of boiler buildings are influenced by the pendulum effects of the boiler, which consists of the outer vessel and the inner panels. Especially, dynamical properties of the outer vessel of the boiler must be considered carefully in a modelling process.

INTRODUCTION

At present, Earthquake-resistant design of the boiler buildings is carried out by seismic intensity method as static design. But, in the near future, the evolution of the earthquake-resistant design will be pointed to the dynamical method. For this reason, the authors carried out vibration tests, earthquake observations and their simulation analyses which are considered to be available as important data for modelling the vibrations of boiler buildings.

VIBRATION EXPERIMENTS OF BOILER BUILDING

The boiler building consists of support-steel-frame and boiler as shown in Figure 1. The boiler is suspended from the top of the frame, and consists of the outer vessel and the inner panels (Figure. 2). In this support system, the outer vessel of this boiler moves as simple pendulum during seismic motion. For this reason, there are the stoppers between the support-steel-frame and the boiler. The function of these stoppers is the transmission of the horizontal force from the boiler to the support-frame during seismic motion. As for these stoppers, the authors supposed the condition of following two cases. (1) The boiler support-frame make contact with the outer vessel of the boiler. (2) The boiler support-frame lose contact with the outer vessel and this both parts are able to slide each other at the stoppers. The authors carried out forced vibration tests at these both condition. From now in the expression of vibration tests, condition (1) is indicated as LINER-ON and condition (2) is indicated as LINER-OFF. At the condition (1),

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the steel liners were used as the method of binding.

The super-structure weight of this boiler building is about 10.000 ton. In other word, the weight of the support-steel-frame is about 6.000 ton and the boiler weight is about 4.000 ton including boiler water. The generation quantity of electric power is 500.000 kw.

Methods of Forced Vibration Experiments

An used vibration generator is BCS-A-200 type*. The location of this shaker is a cross point of G line and 28 line on the roof floor (RF) of the boiler support-frame as shown in Figure 3. The force direction of the vibration generator is NS. In the first place, we drew resonance curve from the experimental data that the excitation frequencies of the shaker were changed step by step. Figure 3 shows measurement points for the experiments of the research of resonance frequencies of the boiler building. In this Figure 3, Mark \longleftrightarrow and Mark \longleftrightarrow are displacement type seismographs whose natural frequencies are 0.5 Hz and 0.2 Hz, respectively. And also, these transducer are moving coil type. Figure 2 shows the measurement points of the inner panels of the boiler. The acceleration meters (1G) of the strain gauge type are used at these observing points. The total of the above-mentioned measuring points are 36 and these points are measured simultaneously. Detection of the resonant conditions were carried out in the both conditions of the LINER-ON and the LINER-OFF. Next, we performed the measurements of the mode of the vibration at the resonance frequencies of the boiler building. This tests were carried out only in the condition of the LINER-ON. The measurements were carried out on the respective floors (RF, 8F, 7F, 6F, 5F, 3F, 1F) of the boiler building.

Methods of the Analysis of the Data

We carried out the A.-D. transformation from magnetic tape of the experiments data. And we made resonance curves, phase curves and vibration modes using the plotter. These phase curves are phase lag towards pulse signal of the vibration generator.

Results of the Tests of Resonance conditions of the Boiler Building

At the beginning, we obtained resonance curves of the boiler building in the all range of excitation frequencies, and calculated the normalization of response curves as the excitation force of 1 ton. For example, Figure 4 shows the response curves in the condition of the LINER-ON and the LINER-OFF. And the measuring location of these response curves are at the point of RF.G-27 on the boiler support-frame. Figure 5 shows the transition of the vibration modes of the successive resonance conditions on the boiler building, in the conditions of the LINER-ON and the LINER-OFF. The 1st, 2nd, 3rd modes of the boiler support-frame are MODE-NO. ①, ⑦, ⑪ in Figure 5. And the main resonance modes of the outer vessel of the boiler are MODE-NO. ④, ⑤, ⑥, ⑧ in the same figure. For example, the MODE-NO. ④ in the condition of the LINER-OFF is shown in Figure 6. This figure shows the vibration mode as a pendulum of the outer vessel of the boiler during the half period of the recorded waveforms which are divided into six equal intervals. So, it indicates the mode shapes at the same instants. Next, Figure 7 shows the transition of

*BCS-A-200; maximum exciting force: 3.0 ton, exciting moment: 2 - 200 kg.m, exciting frequency range: 0.2 Hz - 20 Hz (two simultaneous operation: 0.2 Hz - 8.0 Hz).

the damping factor that correspond to the MODE-NO. of the vibration modes in Figure 5. These damping factor are average values that are obtained by $1/\sqrt{2}$ method. The damping factors of the 1st, 2nd and 3rd of the boiler support-frame are respectively 1.4%, 4.0% and 3.7% in the condition of the LINER-ON and are respectively 2.8%, 3.6% and 2.6% in the condition of the LINER-OFF.

Measurement of the three Diemnsional expression of the modes

Figures 8, 9 and 10 show the example of three dimensional modes of the support-frame of 1st, 2nd and 3rd degrees respectively. These are the modes of the displacement ratios which are measured respect to the standard point RF.G-27, replacing other instruments from floor to floor. The characteristics of these three dimensional modes are as follows. At the 1st vibration mode, the frame of J-row side is oscillated larger than Ea-row by the restriction effect of the turbine building. At the 2nd mode, this restriction is far smaller than that on the 1st mode. At the 3rd mode, the frames of F, G and H rows are oscillated in the same phase. But, the frames of Ea and J rows are oscillated in anti-phase, and the shapes of these modes are similar to the 1st or 2nd modes. These difference of the mode shapes at the 3 frames in the middle part and at the 2 side frames is seems to be caused by the difference of the rigidity of these frames.

OBSERVATIONS OF EARTHQUAKES

System of the Observations of the Earthquakes

The distributions of the observing points of the earthquakes are shown in Figures 11, 12 and 13. This observation system consists of 12 observing points (A-1, A-2,, A-12) and 2 starter points (S-1, S-2). The instrument of S-1 point is a velocity type seismograph (moving coil type) whose natural frequency is 1 Hz. The other transducers (A-1, A-2,, A-12, S-2) are servo-type acceleration meters whose natural frequency is 500 Hz. The component of the observation is vertical at S-2, the other components are NS. This system starts the recording when the acceleration amplitude of the earthquake of S-2 point or the velocity amplitude of S-1 point become bigger than the given value at the respective points.

Observations of the Earthquakes

The seismological items of one earthquake which occurred at off Aki (Aki-nada), at 9:32 a.m. on December 10, 1983 are as follows. The epicenter is at 132° 40' of the east longitude and 33° 54' of the north latitude, the magnitude is 4.9, the focal depth is 50 km, the seismic intensity is III (JMA) at city of Hiroshima, and the epicentral distance to the power plant site is 49 km. For example, the Fourier spectra for the seismograms due to this earthquake at observing points of A-1 and A-6 are shown in Figures 14. Main resonance frequencies of the boiler building which are obtained in the experiemnts by the shaker are written in these figures. It is able to find that the fundamental (1st) resonance mode of the support-steel-frame of the boiler and the vibrational mode of the outer vessel of the boiler as the pendulum motion are predominate in the earthquake response.

ANALYSIS OF THE OBSERVED SEISMIC WAVES BY MEANS OF SIMULATION

Model of the Dynamical Analysis of the boiler Building

The authors proposed the model of the boiler building for the dynamical analysis as shown in Figure 15. This model consists of the series of the shear and bending bars with 46 mass points. And it is assumed that the base of this model is the fixed foundation as shown in the figure. We performed the dynamical analysis of the boiler building by means of this model.

Results of the Simulation Analyses

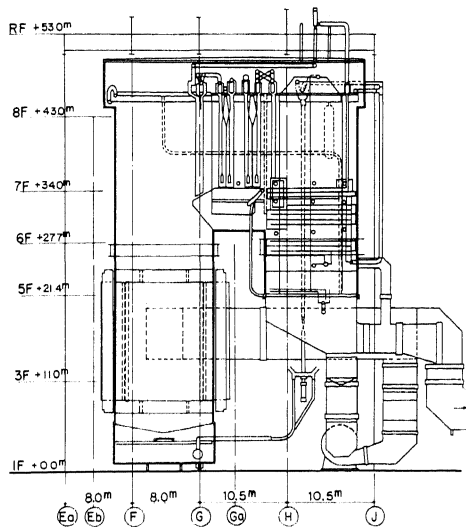
The seismic waves at the above-mentioned earthquake were analyzed using by our analysis method. The input seismic waves which used in the dynamical analysis were observed at the measuring point of A-5 (see Figures 12 and 13). The process of the analysis are as follows. The method of the response analysis are ordinary Modal-method. The linear differential equation of the motion of the building are analyzed numerically by the Fourth Degree of the Runge-Kutta. In this analysis, the damping factors of the respective degrees are obtained by the respective analysis cases to fit the results of the forced vibration tests on the shaker. The natural frequencies and the damping factors of the respective degrees obtained from the analysis of CASE-2 and the vibration tests and the observed seismic data are shown in Table 1. We can find that the natural frequencies of the predominant vibration mode in the earthquake are almost equal to those values which are obtained at the experiment of the vibration generator in the condition of LINER-ON. The response acceleration time history in the case-2 at measuring point A-1 is shown in Figure 16 comparing with the observed seismic waves. The observed vibration modes of the boiler building are shown with the modes that obtained from analysis, in Figure 17. On this figure, it can be seen that the vibration mode as a pendulum of the outer vessel of the boiler predominates. And also, the comparisons of the so called floor response spectra at the measuring point A-1 are shown in Figure 18. According to these analysis, the damping factors of the support-steel-frame of the boiler is 2% in the fundamental vibration mode, and that of the vibration as a pendulum of the outer vessel of the boiler is about 7% in the modal damping.

CONCLUSIONS

According to our experiments of the boiler building by the forced vibration with the vibration generator and the observations of the seismic waves, it must be considered seriously the characteristics of the vibration of the outer vessel of the boiler.

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3. Nakagawa, K. et al., "Experimental Study on Vibrational Characteristics of Boiler Building of Thermoelectric Power Plant (Part 3), - Earthquake Observations and Simulation of Results -, "Report of the Technical Research Institute, OHBAYASHI-GUMI, LTD. vol. 28, 1984, pp. 60 - 64



Type: Combined Circulation Boiler, outdoor
Type
Maximum continuous Steam Generation
Volume: 1.730 ton/h
Main Steam Pressure: 255 kg/cm².g
Main Steam Temperature: 543°C/569°C
Fuel: Crude Petroleum, L.P.G.
Fig. 1 VIEW OF BOILER

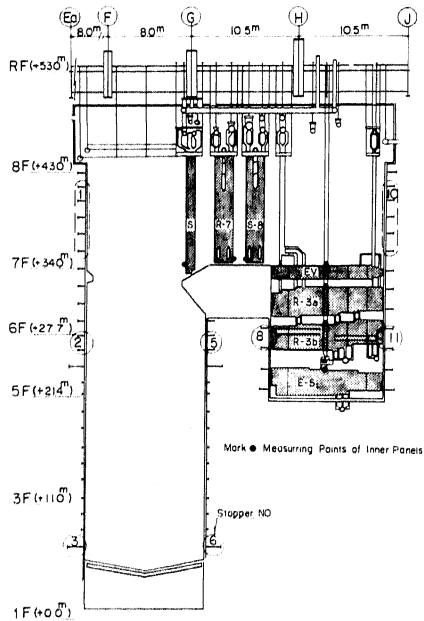


Fig. 2 VIEW OF OUTER VESSEL AND INNER PANELS

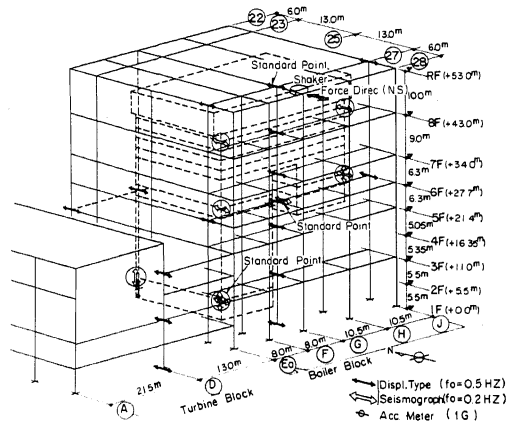


Fig. 3 MEASURING POINTS OF RESONANCE DETECTION TESTS

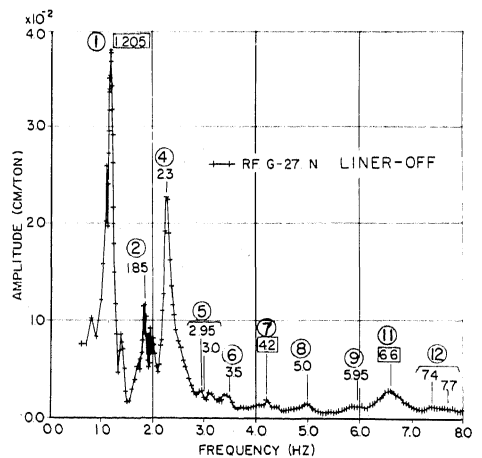
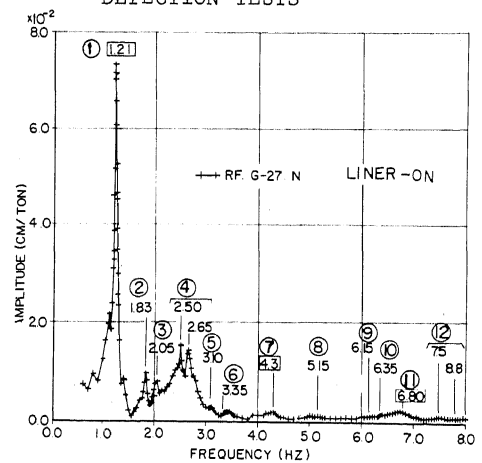


Fig. 4 RESPONSE CURVE

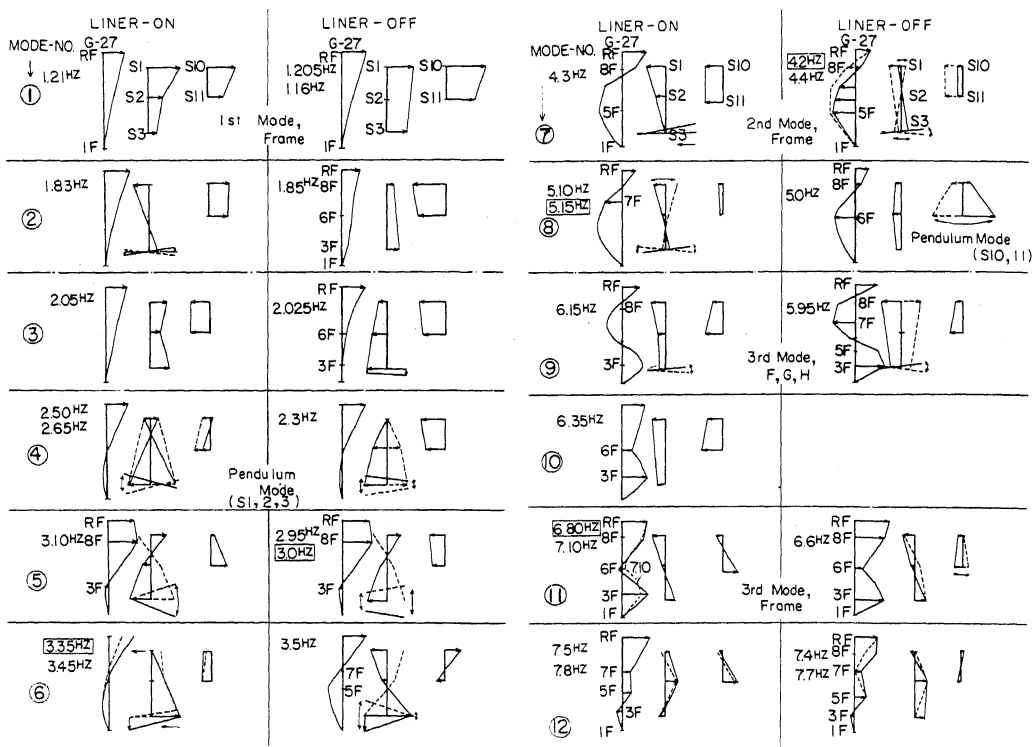


Fig. 5 TRANSITION OF VIBRATION MODES

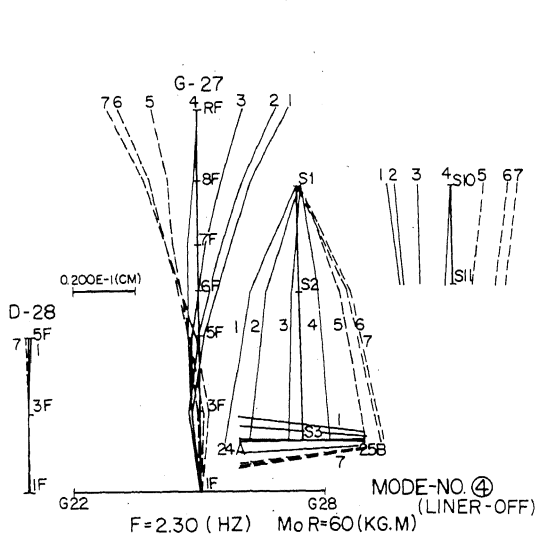


Fig. 6 MODE AS PENDULUM OF OUTER VESSEL (S1, 2, 3)

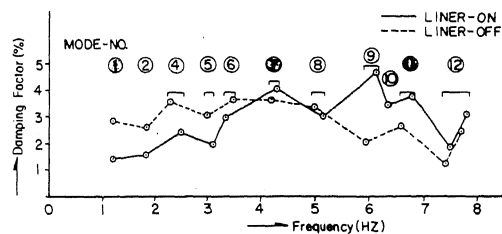


Fig. 7 TRANSITION OF DAMPING FACTOR

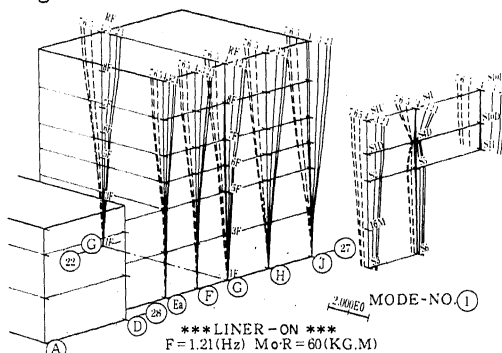


Fig. 8 1ST MODE OF SUPPORT-FRAME

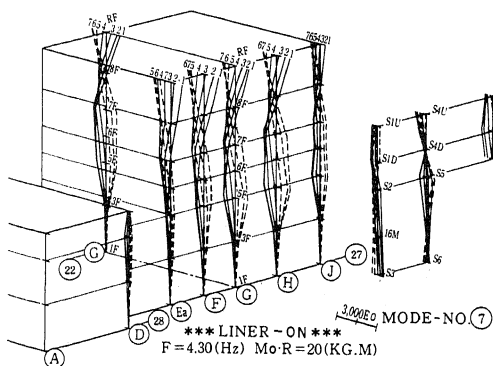


Fig. 9 2ND MODE OF SUPPORT-FRAME

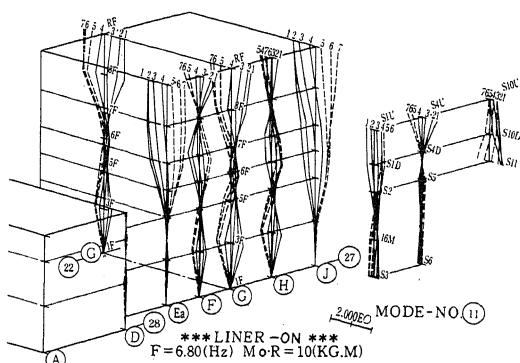


Fig. 10 3RD MODE OF SUPPORT-FRAME

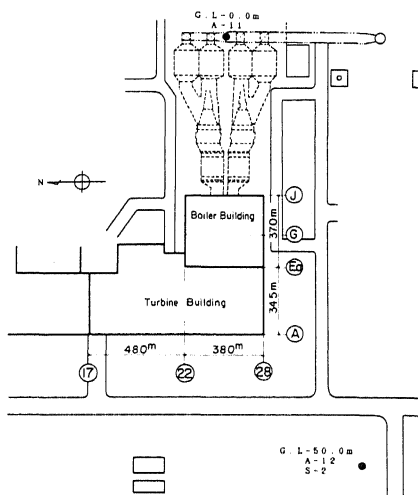


Fig. 11 VIEW OF SITE

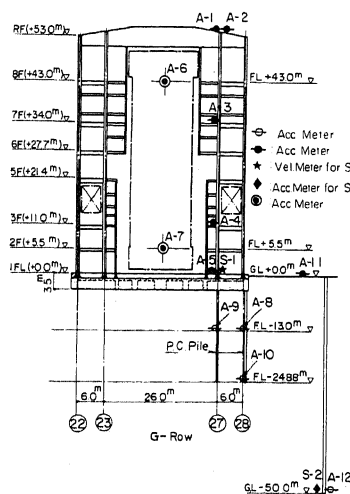


Fig. 12 EARTHQUAKE OBSERVING POINTS

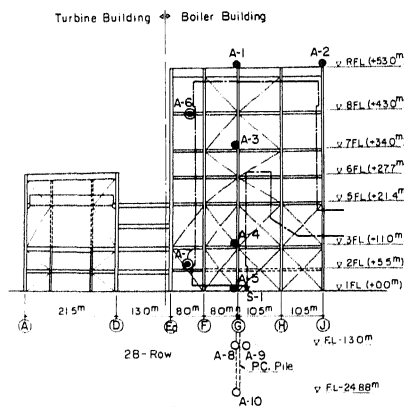


Fig. 13 EARTHQUAKE OBSERVING POINTS

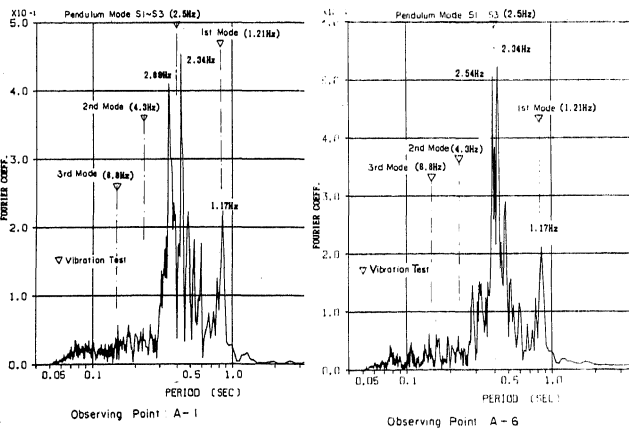


Fig. 14 FOURIER SPECTRA

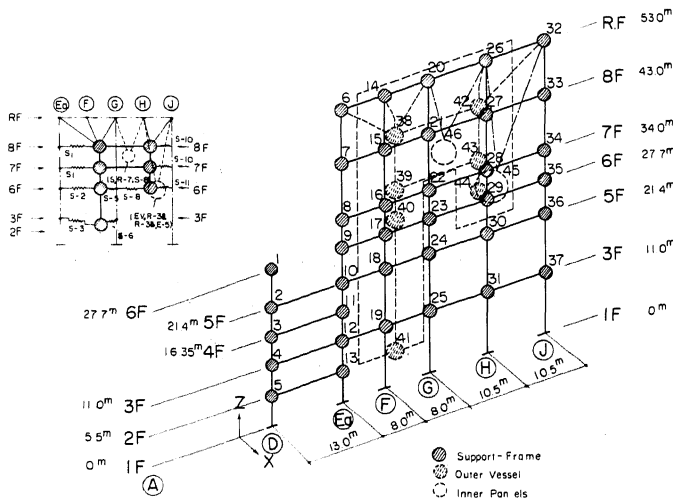


Fig. 15 ANALYTICAL MODEL

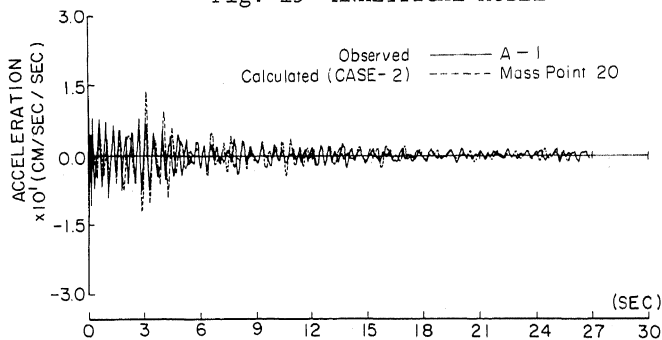


Fig. 16 RESPONSE WAVES AT A-1 POINT

MODE - NO.												
	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫
LINER-OFF												
Natural Frequencies (Hz)	1.16	1.85		2.3	4.2			5.0	6.6			
Damping Factors (Z)	2.82	2.57		2.92	3.62			3.33	2.64			
LINER-ON												
Natural Frequencies (Hz)	1.21	1.83		2.5	4.3			5.15	6.8			
Damping Factors (Z)	1.42	1.57		2.4	4.03			3.74				
Mode Characteristics	B/B	Only Support-Frame, T/B		Pendulum S1 - S3	B/B			Pendulum S10, 11	B/B			
Observed												
EQ. -NO. 1: (Hz)	1.25			2.34	2.77							
Predominant Frequen.				2.44	2.78							
EQ. -NO. 2: (Hz)	1.22			2.34	2.89							
EQ. -NO. 3: (Hz)	1.17											
(This EQ. was used in this report.)												
Calculated												
Degree	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th		
Mode Characteristics	B/B	Only Support-Frame, T/B		Pendulum S1 - S3	B/B	T/B	S1 - S3	B/B	S10, 11	B/B		
CASE-2.	fo(Hz)	1.19	1.92	2.27	2.92	4.60	5.02	5.52	6.43	6.66	7.17	
	hi(Z)	1.5	3.0	7.0	6.0	4.03	3.0	3.0	3.74	3.0	3.0	
Calculated 1st and 2nd modes are natural frequencies of the inner panels of E-5 group (RV, R-3a, R-3b, E-5) and S group (S, R-7, S-8), (see Figure 2).												
These natural frequencies are about 0.33 Hz and 0.5 Hz, respectively.												
B/B : Boiler Building, T/B : Turbine Building, S1 - S3, S10 and S11 : Stepper No.												

Table 1. NATURAL FREQUENCIES AND DAMPING FACTORS

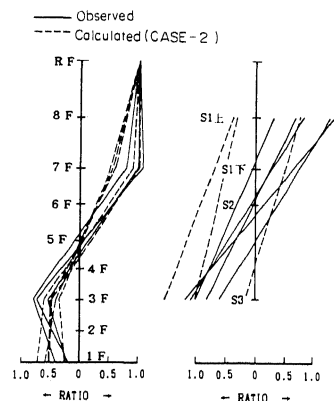


Fig. 17 COMPARISON OF VIBRATION MODE

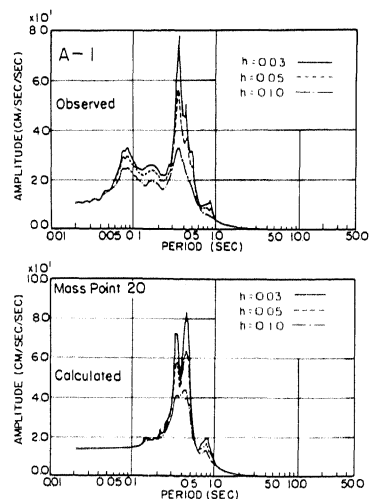


Fig. 18 COMPARISON OF RESPONSE SPECTRA