IN SITU MEASUREMENT OF DYNAMIC CHARACTERISTICS OF ATOMIC POWER PLANT EQUIPMENT*

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SUMMARY

The seismic response of the equipments is normally based on theoretical evaluation of stiffness of the supporting systems and an estimated value of damping. It is always difficult to assess analytically the contribution of the piping connections to these parameters. For the realistic assessment of stiffness and damping, full scale free vibration tests have been carried out on various pieces of equipment located in plant buildings both during the construction stage and after they are erected. Initial displacement or initial velocity was used to excite the free vibrations. Initial displacement was imparted by means of steel rope pulled with chain pulley block. The sudden release was achieved by means of a clutch system. Acceleration transducer with amplifier and ink writing oscillograph was used for recording the vibrations. Frequency and damping was evaluated from the acceleration records. Observed values for some equipment are given in the following table:

Table 1. Typical values of natural frequency and damping

S. No.	Equipment	Frequency c/s		Damping in Percentage of Critical Damping	
		Long.	Trans.	Long.	Trans.
	TURBINE BUILDING EQUIPMENT				
1.	Gland Steam Condenser	8.62	5.95	6.45	6.45
2.	Turbine Oil Cooler	—	7.29	—	2.28
3.	B.S.R. Drain Tank	38.52	24.84	4.60	3.93
4.	Air Ejector Condenser	8.74	55.57	3.53	—
5.	L.P. Heater	26.74	17.85	—	—
6.	Deaerator & Storage Tank	11.55	7.10	3.75	1.68
7.	Reheater/Separator				
	(a) Reheater	7.58	6.20	6.45	7.40
	(b) Separator	6.01	78.72	3.06	—

For some equipment, it has been possible to obtain the values with and without pipe connections. The frequency of L. P. Heater in longitudinal and transverse directions without pipe connection were 17.86 and 10.04 Hz but with pipe connections the values increased to 26.74 and 17.85 Hz. Similarly there has been increase in the damping values too. Thus both the frequency and damping increases substantially with the addition of pipe connections. Moreover, their values are quite different in the two principal directions, pointing out to the importance of in situ measurements on prototype equipment.

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1. Introduction

An essential requirement for the ultimate safety and safe operation of a nuclear power plant located in moderate or severe seismic zones is that all structural systems and associated components are designed to withstand probable maximum and the probable earthquake effects respectively. The designer must consider all possible combinations of loads in order to avoid all the dangerous situations to the environment due to strong earthquakes. Shibata et.al[6] in their report have dealt with the aseismic design procedures for equipment in atomic power plants in Japan. The components vital to safety of nuclear power plants are classified as class 'A'. These are required to be designed for the probable maximum design basis earthquake which is also termed as safe shutdown Earthquake (SSE). Other components which are important to power generation are designed to remain operational under a probable earthquake called the operating Basis Earthquake (OBE) which is usually smaller than SSE. The following processes are usually applied for dynamic design.

i) Estimating the natural frequency and mode shapes of the system;

ii) Estimating its damping characteristics

iii) Estimating the behaviour of the system during strong earthquakes;

iv) Deciding the design criteria, specially allowable stresses to earthquake loadings

The possibility of making a reliable estimate of earthquake force depends on choosing the correct values for the dynamic characteristics of structures and equipments. An insitu test has been developed in USA by Teledyne Co. for testing dynamic characteristics of nuclear reactors using ambient vibration survey. This system has been used and good engineering data have been obtained for comparing results from experimental and mathematical modelling analysis of reactors.

The equipments' natural frequency and damping are used in finding its response. The use of floor response spectra in the analysis and design of equipments or piping mounted in a massive structure has been emphasised by Biggs (4). This work is mainly related to the nuclear power plant equipments and has become most popular for aseismic design of equipment in view of the fact that, in a nuclear plant there are numerous equipments and to consider them in the mathematical model of the structure as a whole will be very complicated. The modelling is further complicated due to the various piping and other connections attached to the equipment. Moreover since the equipment mass is usually a small fraction of the total floor weights, their considerations as such may actually be unimportant so far the floor responses are concerned.

2. Determination of Dynamic Characteristics of Equipment

The theoretical determination of dynamic characteristics of the equipments has been found to be quite cumbersome due to a number of associated connections and their participation in vibration. In the theoretical calculations, all associated piping and other connections can not be properly accounted and hence frequencies calculated will be far from the realistic values. Further the seismic response calculation of the equipment is normally based on the theoretical evaluation of stiffness of the supporting system and an estimated value of damping. When the equipment is mounted on a floor, the general practice is to consider it as a rigid mounting and hence taking its natural period as zero. But in practice, it is very difficult to get a rigid mounting and also due to its own flexibility, the equipment may not behave as a rigid system. Hence experimental determination of dynamic characteristics becomes a basic requirement.

Realising the importance of dynamic characteristics determination of the equipments for their seismic response analysis a study has been conducted on two nuclear power plants which are under construction in India. In this study, insitu test results of dynamic characteristics of various equipments housed in the Turbine building, Service building and Pumphouse structures are described.

Both the power plant structures are located on good rock foundation. The turbogenerator and service buildings in both plants consist of reinforced concrete structure housing equipments like Glend Steam Condenser, Oil Coolers, Drain Tanks, L.P. and H.P. Heaters, Deairator and storage tanks, Reheater Seperator located at various floors.

In one of the plants the testing has been conducted when the equipments are ready for commissioning, while in the other there is partial erection of equipments and in some of them the piping and other associated connections have not been installed. Thus the two plants present two extreme cases of testing and the results obtained will give an idea of the change in the dynamic characteristics in the extreme situations.

The free vibration tests were carried out using initial displacement or initial velocity approach to excite the free vibrations.

3. Instrumentation Used For Recording Vibrations

The following instruments were used for measuring the natural frequencies.

i) Accelerometer (Miller, CEC make, Type 4-260)

This accelerometer utilizes variable reluctance to measure accelerations, undamped natural frequency 200 Hz. and damped natural frequency 140 Hz, range upto ± 12g. Accelerometer consists of a spring mounted seismic mass which is the common armature of two variable inductors. Deflections of the armature caused by gravity, centrifugal forces, or accelerations produced by vibrations will change the inductances of the normally balanced inductors resulting in an electrical output proportional to deflection.

ii) Universal amplifier (Model RD 5612)

This amplifier has a high gain carrier amplifier and a medium gain d.c. amplifier. The unit could be used with resistive and reactive transducers.

iii) Oscillograph (ink writing, BRUSH Model RD 2321 00)

This is a dual channel instrument with facility to record the vibrations on paper with ink writing. When this instrument is used alongwith Universal amplifier, it provides a flat frequency response of D.C. to 100 cps. It has three paper moving speeds of 5,25 and 125 mm per second.

Alongwith these main instruments several other auxiliary instruments like dial gauge, loading device, clutch release mechanism etc. were used for completing the observations.

4. Free Vibration Characteristics

4.1 Natural Frequency

The load release method was used for vibrating the system freely. Suitable fastening points in the equipments were selected, one end of the ordinary wire rope of 1.5 to 2mm diameter was tied with the equipment and another end of the rope to some fixed point. A clutch release device and a pulling device of 1/2 to 2 tonnes depending on the weight of the equipment were inserted within the rope length between the two ends. A calibrated dial gauge was attached to measure the pull applied in the system. The necessity of measuring the load applied arose so as to control the applied load to these pieces of equipments which were in commissioning stage and it was to be ensured that the testing may not disturb the alignment of the equipment. Secondly, knowing the load and displacements for an equipment, it would be possible to have some idea of its stiffness for use in theoretical analysis.

When the load is applied by the pulling device, it causes the equipment to displace elastically to some initial displacement. Sudden release with the clutch release mechanism causes the equipment to vibrate starting from the initial elastically displaced position. The pull was applied in two orthogonal directions of the equipment seperately so as to measure the longitudinal and transverse frequencies of free vibration. The free vibration was picked up with the help of accelerometer placed on the body of the equipment under test and the records obtained on the oscillograph after amplifying the signal through the universal amplifier. From the free vibration records the natural frequency of the equipments was measured. Figure 1 shows the arrangements for a typical free vibration test setup.

4.2 Damping from Free Vibration Records

The free vibration records have also been used for evaluating the damping factor, measured as a fraction of critical viscous damping, by using the concept of logarithmic decreament as follows:

$$\zeta = \frac{1}{2\pi} \log_e (X_1/X_2)$$

where ζ = Critical viscous damping coefficient

X_1 & X_2 = Two successive amplitudes on the vibration record $X_1 > X_2$.

5. Results and Discussion

The mounting of the equipment on various floors are of two type. Some equipments like pumps are mounted on the raised floor itself and generally considered as rigid mountings. While some other equipments like Reheater/Seperator, Deairator and storage tank, Seperator Drain Tank etc. are mounted on frame work and would be taken as flexible mountings. For the equipments rigidly mounted the frequency varies from 18 Hz to 118 Hz and damping ranges from 2% to 8.5%. The equipments which are on flexible supports the frequency was found to vary from 5Hz to 14 Hz and their damping ranges from 1.75% to 8%. The weight of the equipment under investigation ranges from 3 to 73 t in empty condition where as the flooded weight of an equipment like Deairator and Storage tank could go as high as 380 tonnes. The force applied at the time of measurement was about 0.5 to 2 t and the damping values obtained from the records are for this low magnitude of force. A study by Arya, Chandra and Gupta (3) indicates that the acceleration induced in the floor of the turbogenerator building structure taken on an average for operating basis earthquake will be approximately 0.3 g. Hence for safe shut down earthquake taken twice of OBE, it could be about 0.6 g. Taking these values of accelerations at the floor as effective for the equipment, various equipments will be subjected to earthquake forces of magnitude varying from 1 to 23 t for OBE and this force could become double for SSE Conditions. The damping obtained for various equipments in Table I and II are for a lower level of strain produced in the equipment, hence may be taken to be on the lower side. Comparing the measured values with the recommended values shown in Table III, it therefore appears that the recommended values of damping as shown in Table III, are on the conservative side.

The equipments of MAPP were in the erection stage and in majority of the equipments the associated connections were not completed, whereas at RAPP most of the equipments were ready for commissioning and hence these indicate the two extreme conditions in which the measurements have been taken. There are only minor differences in the capacity, size, shape and mounting conditions for various equipments at these two plants and hence some comparison could be made. For turbine oil cooler when all associated connections are partially completed the frequency is 6.21 Hz and when it is ready for commissioning its frequency is obtained as 7.29 Hz an increase of about 17.5% indicating the effect of piping etc. Taking the case of L.P. Heaters similarly, the change in frequency in longitudinal direction is from 17.86 Hz to 26.74 Hz and in transverse direction from 10.04 Hz to 17.85 Hz, the increase in longitudinal direction being 49.72% and in transverse direction 77.78%. Similarly damping values have also differed under the influence of piping connections. Moreover the frequencies and damping have also been found to vary in two principal directions pointing out the importance of insitu measurements on prototype equipment.

6. Conclusions

Results of insitu measurements for evaluating the dynamic characteristics of equipments demonstrate that the frequency and damping both increases substantially with the addition of piping connections and their values are quite different in the two principal directions. The damping values obtained experimentally even at lower strain are higher than the values usually recommended for design. Therefore there is a need to reconsider the design values. The insitu tests indicated above are simple to conduct and does not disturb the construction schedule of the project. These measurements can be repeated so as to obtain the characteristics of the equipment at every stage of their installations.

7. Acknowledgement

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8. References

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TABLE I

DYNAMIC CHARACTERISTICS OF EQUIPMENTS OF RAJASTHAN ATOMIC POWER PROJECT (RAPP-2)

Sl. No.	Name of Equipment	Natural Frequency in Hz.		Damping in %	
		Long.	Trans.	Long.	Trans.
1	2	3	4	5	6
1.	Main Boiler Feed Pump 4321 BP # 1	56.50	62.50	3.16	3.16
2.	Auxiliary Feed Pump	62.55	51.96	2.12	3.58
3.	Glend Steam Condenser 4115 - GS # 1	8.62	5.95	6.45	6.45
4.	Turbine Oil Cooler 4133 DC # 3	7.29	7.29	2.28	2.28
5.	B.S.R. Drain Tank	38.52	24.84	4.60	3.93
6.	Reheater Drain Tank 4113 RDT # 1	13.46	9.53	1.88	3.48
7.	Auxiliary Boiler Feed Pump 4321 BPP # 3	68.08	52.85	4.66	4.74
8.	Air Ejector Condenser 4212 - AE # 1	8.74	55.57	3.53	*
9.	Pump House Pump 7121 CWP # 4	16.66	13.74	3.33	2.76
10.	Condensate Extraction Pump (Secondry Cycle Pump) 4321 CEP # 1	20.14	21.55	2.61	1.84
11.	Reheater/Seperator (i) Reheater 4113 RH # 2	7.58	6.20	6.45	7.40
	(ii) Seperator 4112 MS	6.01	78.72	3.06	*
12.	Deairator & Storage Tank 4312 DST # 1	11.55	7.10	3.75	1.68
13.	H.P. Heater 4312 HTR # 6	21.06	116.47	*	1.72
14.	L.P. Heater	26.74	17.85	*	*
15.	H.P. Process Water Pump 7133 PWP # 1 (i) Pump	62.16	75.47	2.60	3.42
	(ii) Motor	22.66	40.68	3.76	2.93
16.	Compressor 7510-C # 10	17.86	17.38	8.54	6.45
17.	Chilled Water Pump 7191 # P2 motor	72.93	61.58	4.58	5.80
18.	Chiller 7191 HX # 1 C/F	9.08	18.03	4.40	4.16

* Record not good for damping calculation.

TABLE II

DYNAMIC CHARACTERISTICS OF EQUIPMENTS OF MADRAS ATOMIC POWER PROJECT (MAPP-1)

Sl. No.	Name of Equipment	Natural Frequency in Hz		Damping in %	
		Long.	Trans.	Long.	Trans.
1	2	3	4	5	6
1.	Air Ejector Condenser	24.71	23.81	2.70	2.22
2.	H.P. Process Water Pump				
	(i) Pump	36.85	38.10	3.00	8.20
	(ii) Motor	35.51	22.33	0.055	0.017
3.	Process Water Heat Exchanger				
	(i) Pump	32.89	34.14	3.30	7.80
	(ii) Motor	26.63	28.52	4.00	4.40
4.	L.P. Heater	17.86	10.04	6.70	4.50
5.	Air Receiver	13.13	13.13	5.20	5.20
6.	Turbine Drain Cooler	45.38	57.58	5.30	5.90
7.	Seperator Drain Tank	*	0.878	*	2.40
8.	Main Condensate Extraction Pump	9.67	12.27	3.10	6.20
9.	L.P. Flash Tank	21.72	22.79	3.50	2.80
10.	Auxiliary Feed Pump	102.65	82.27	4.30	4.30
11.	Reheater Drain Pump	21.12	19.93	3.00	4.60
12.	Hydrogen Cooling Pump				
	(i) Pump	41.67	109.28	5.70	4.90
	(ii) Motor	*	53.21	*	2.90
13.	Turbine Oil Cooler	6.21	6.21	3.90	3.90
14.	Diesel Engine Generator				
	(i) Generator	85.95	30.95	3.00	5.00
	(ii) Motor	41.79	37.50	8.20	5.60

* Record not good for analysis

TABLE III

RECOMMENDED DAMPING VALUES FOR NARORA ATOMIC POWER PLANT PROJECT (Percent of Critical damping)

Sl. No.	Structure or Component	Operating Basis Earthquake	Safe Shut down Earthquake
1	2	3	4
1.	Equipment and Large diameter piping system pipe, diameter greater than 300 mm	2	5
2.	Small diameter piping Systems, diameter equal to or less than 300 mm	1	2
3.	Welded Steel Structures	5	7
4.	Riveted/Bolted Steel Structures	7	10

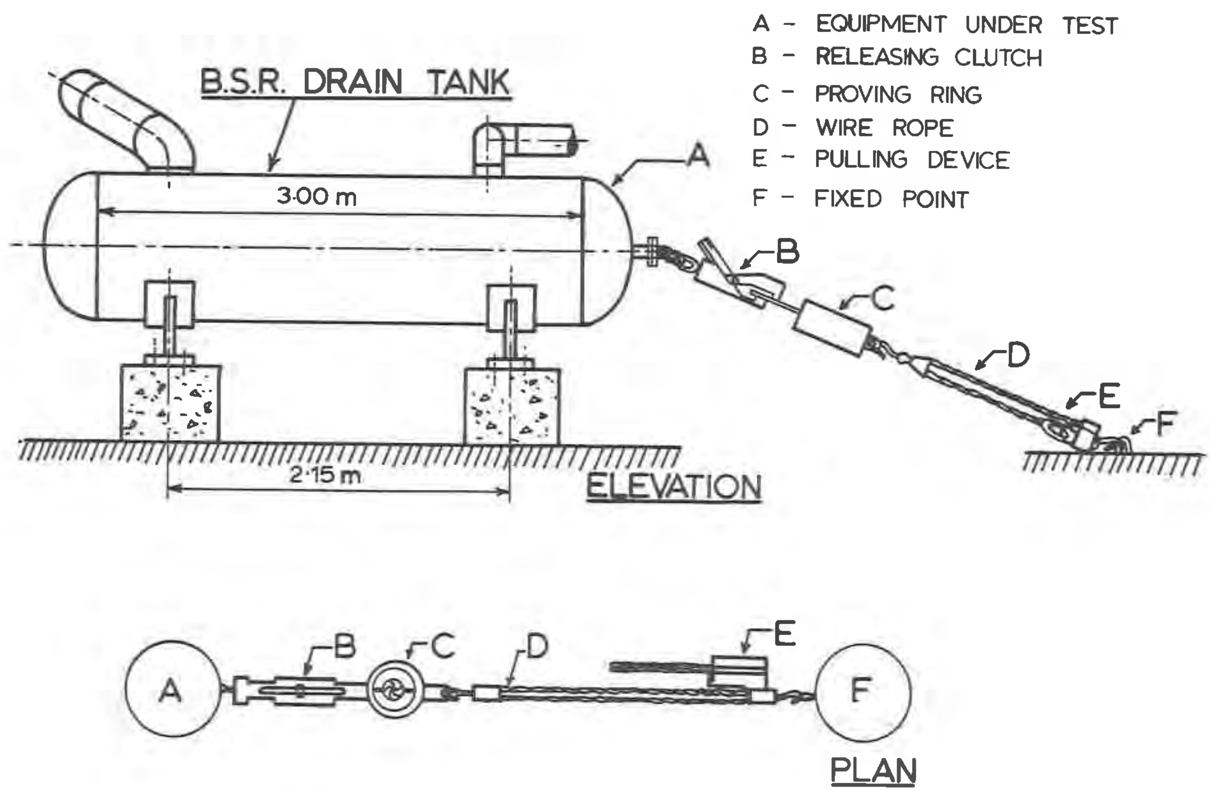

FIG.1. ARRANGEMENT FOR FREE VIBRATION TESTS