Dynamic behaviour of suspended-boiler and the analysis of its earthquake damage

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Summary

This paper describes the study of dyhamic behaviour of the suspended-boilers through dynamic model tests. In the first part, through some parameters of actual structures, the dynamic characteristics of suspended-boiler of usual type, and the way of transmission of its seismic force to the frame structure are investigated. The second part presents an analysis of the earthquake damage on the suspended-boiler structure in the Dou-he power station during the Tang Shan earthquake 1976. Finally a simplified practical analysis procedure and some asismatic engineering measures are proposed.

1. On mathematical model and force transmission of the boiler supporting

(1) simplified mathematic model

Generally the calculation sketch of a suspended boiler can be considered as a suspension structure with horizontal vibration only. The main feature of this structure is the interaction between the boiler and the frame. Therefore it can be analyzed as a system with two degrees of freedom(Fig. 1). For such a system, the main dynamic parameters of seismic response are the mass ratio $m_2/\tilde{m}_1$, and the stiffness ratio $k_2/\tilde{k}_1$ of the suspended boiler and its frame. From which the period ratio T_2/T_1 is determined. Where $\tilde{m}_1$, $\tilde{k}_1$ are the equivalent mass and stiffness respectively as the frame is transformed to a single degree of freedom system. According to the calculating data of five actual suspension boilers of 130~1000 T/H, the mass ratio $m_2/\tilde{m}_1$, of the boiler and the frame is about at 1.06 4.67, the period ratio T_2/T_1 at 1.58~4.32. In the light of these data, the length of hanger rods and the weight of the boiler for various tested models are determined (Table-1).

Being a system of two degrees of freedom, the frequencies f_I, f_{II} of the boiler supporting frame system should satisfy the following relations.

$$f_I^2 \cdot f_{II}^2 = f_1^2 \cdot f_2^2$$
$$f_I^2 + f_{II}^2 = (m_2/\tilde{m}_1 + 1) f_2^2 + f_1^2$$

Where $\tilde{m}_1$, m_2, f_1, f_2 are the masses and natural frequencies of the frame and the suspended boiler individually.

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These parameters in various cases are determined through the model test. The resonance curve and mode shapes are shown in Fig. 2. Experiments indicated the following results:

1. The above mentioned relations could be well satisfied (Table-2), so that the correctness of the mathematical model can be proved.

2. The seismic inertial force of the boiler is totally transmitted to the top of the frame through the hanger rods. It does not exist the problem of non transmitting or only partially transmitted as some informations have mentioned.

(2) response spectrum of seismic acceleration of suspension structure

Usually the response spectrum in the response spectrum in the Code beyond a certain value of period is considered as a constant.

During strong earthquake, the natural period will be much longer possibly approached to the calculated value. Therefore under the seismic wave action with high dominant frequency, the response will be much smaller than that calculated from the response spectrum in the Code. On the base of the above mentioned experiment, a model is selected in correspondence with that commonly used in engineering. Vibration tests simulating the seismic wave have been carried out. The accelerogram record of the Soong-pang earthquake in the Autumu 1976, with a magnitude of 7.2, and dominant vibration period of 0.12 second has selected. The plots of the dynamic amplification factor β of the suspended boiler found in the experiment and the vertical stress σ_z at the base of the frame against to the dominant frequency of the input wave are shown in Fig. 3. Evidently, the values and correspond to the actual dominant frequency of the Soong-pang earthquake are mucu lower than those calculated by the present Code . Therefore for the suspended boiler system the ordinary response spectrum with constant value within the range of long period is not adoptable.

2. Preliminary analysis of earthquake damages of the Dou-he power plant

(1) model test and measurement of the characteristics of natural vibration

Boiler 2# of the Due-he power plant is selected for model test to analyse the earthquake damage of the suspended boiler during the Tang-shan earthquake. The geometric scale of the model is 1:90. Firstly, the characteristics of natural vibration of the structure and the stresses of vibration mode of typical parts are measured through sine wave vibration. Various conditions, such as with or without rear pase connection, with or without shock damper are considered in the tests. The prototype natural frequencies in various cases are listed in table-3.

(2) earthquake response

A model of free suspended boiler is selected for the seismic wave test. A similar accelerogram from II class soil foundation with the dominant vibration frequency of 8-9 Hz during the Soong-pang main earthquake is used in the test. In considering the effect of long period component a accelerogram recorded in Peking Hotel during the Ning-he earthquake(M=6.9) on Nov. 1976 is also used. The acceleration wave shapes at the table, the top part of the frame and the boiler are shown in Fig. 4. According to the actual earthquake damages corresponding measuring points are arranges on the model as shown in Fig. 5. The stresses in the tests are transformed into the bending moments of supports of the prototype, and to compare these with the ultimate bending moments at the sections of corresponding members (Table-4). And the relative differential values are used as criteria for assessing the possible damages. It can be seen from table 4, that the testing results of most measuring points are corresponded to the earthquake damages. Preliminary explanation has shown that the test reflects the actual earthquake damages as a whole.

3. Conclusions and suggestions

(1) The aseismatic design of suspended boiler supporting frame can be analyzed with a simplified calculation model of a two degrees of freedom system in the longitudinal and lateral directions.

(2) In the aseismatic design of the frame the total seismic inertial force of boiler acting on the top of the frame should be included.

(3) To prevent the over swing of boiler and the serious damages at the connections between the boiler and the smoke, air ducts, during strong earthquake, viscous dampers for example can be installed at tje bottom of the boiler on the isolated columns.

(4) The behaviour of suspended boiler during strong earthquake and its dynamic characteristies deserve further investigation.

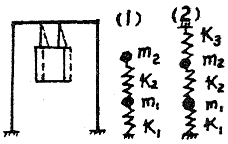

Fig. 1 Sketch of the suspended boiler and frame
(1) Without connection
(2) With connection

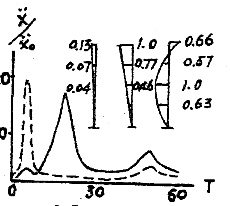

Fig. 2 Resonance curves and mode shape of the system — frame ---- boiler

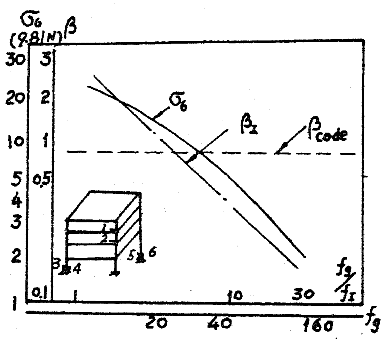

Fig.3 $\sigma_6 \sim f_g$, $\beta \sim f_g$

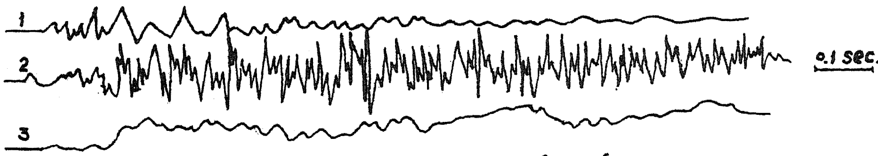

Fig. 4 Acceleration waves of system

1 Top of the frame
2 Surface of the shaking table
3 Boiler

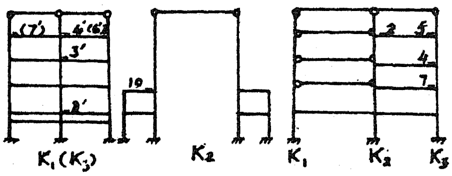

Fig. 5 Measuring points on the model of Dou-he boiler

Table 1 Main parameters of plexiglass model

Groups / Parameters	Length of hanger rods			
	30 cm	20 cm	20 cm	12 cm
	Weight of boiler (N)			
	147	98	21	21
$m_2/\tilde{m}_1$	2.27	1.52	0.33	0.33
$K_2/\tilde{K}_1$	0.095	0.296	0.29	1.28
T_2/T_1	4.9	2.27	1.09	0.5

Table 2 Calculated results by formula of two degrees of freedom

Items	Length of hanger rods			
	20 cm	20 cm	12 cm	30 cm
	Weight of boiler (N)			
	98	21	21	147
$f_I \cdot f_{II}$	90.7	188	367	44
$f_1 \cdot f_2$	91	196	346	46.5
$(1+m_2/\tilde{m}_1)f_2^2+f_1^2$	380	477	807	338
$f_I^2+f_{II}^2$	380	476	908	340

Table 3 Natural frequency of model of Dou-he boiler (HZ)

Mode number	Longitudinal Vibration			Leteral vibrotion	
	Free suspended	With vibration absorb	With tail part	Free suspended	with tail part
I	2.1	2.3	4.7	1.72	4.1
II	8.6	8.9	9.1	6.8	7.5
III	22.5	21.5	20.5	17.2	17.4

Table 4 Comparision of seismic internal forces of prototype of Dou-he system

Measuring points	Soong-pan earthq. (0.6g) I	Design calcul. (0.6g) II	Ultimate bending moment III	(I − III)/III %
4′	102	311	107	-5
3′	130	264	107	21
2′	138	221	129	7
10′	52.5	215	147	-64
7′	126	248	108	16.7
2	116	720	220	-47
5	112	811	206	-45
4	50.8	398	145	-65
7	78	574	177	-56

Brief description of earthquake damage

4′ Upper reinf. in beam 4 Φ32 all broken
Lower reinf. not broken

3′ K_3 Upper reinf. 2 of 4 Φ32 broken
K_1 not broken

2′ and 10′ not broken

7′ K_1, K_3 Upper reinf. 5 Φ32 all broken
Lower reinf. not broken

2 One side: Upper reinf. 4 of 7 Φ32 broken
Lower reinf: not broken.
Other side: Upper reinf. not broken
Lower reinf. 2 Φ32 broken

5 One side: Upper reinf. 7 Φ32 all broken
Lower reinf. not broken
Other side: Upper reinf. 5 of 7 Φ32 broken
Lower reinf. not broken

4 All reinf. not broken. Only on one side 2 Φ32 broken

7 All reinf. not broken