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SIMULATED EARTHQUAKE EXPERIMENT STUDY OF A 1/50-SCALE SHANGHAI RADIO & TV TOWER

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ABSTRACT

Shanghai Radio & TV Tower is 468m high. It is the highest tower in Asia and the third high tower in the world. Seismic effect is one of the main load. In this paper, the Tower is been as the prototype. The model has 1/50 scale, its material and dimensions are designed according to the simulated principle. The vibration modes, earthquake response and failure mode are tested on three dimensional simulated earthquake shaking table. The experimental results show that the Tower is safe in 7-degree earthquake. It will crack in 8-degree and fail in 9-degree.

KEYWORDS

Shaking table experiment; TV tower.

INTRODUCTION

Shanghai Radio & TV Tower, which located at the tip of Lujiazui by the side of Huangpu River, is the highest one in Asia with the total height of 468 metres, and the third in the world. The base of the Tower up to the first large globe is stabilized by a triad of struts which reflect the globular shape of ancient Chinese bronze tripod vessels. The three linked columns forming the Tower's main body continue to a second large globe, and a single concrete column rises to 350m. A steel pylon completes the transmission mast above.The three concrete elements forming the main structure are each 9m diameter hollow tubes rising to a height of 287m, with concrete at 700mm, 500mm and 350mm thicknesses. Seven cross girders link the tubes and 7m diameter tripod support struts come in at 60 degree angles to the level of the first globe at about 90m.The mast above the second major globe is a composite of a single 10.8m diameter concrete tube rising to the 350m height of a final small globe - called spaceship- enclosing a steel mast to the top.

The design seismic intensity of the Tower is 7-degree. Earthquake is one of the main loads.In this paper, a 1/50 scale model, which is made of microconcrete, is tested on three dimensional simulated earthquake shaking table. The experimental method and major results are introduced.

MODEL EXPERIMENTAL METHOD

Model

According to the site of the Tower and the condition of the laboratory, the scale is decided as 1/50. The model is designed as an artificial mass model. The gravity acceleration is neglected. The model is made of microconcrete and steel wire. Lead is used as artificial mass. Prestress is forced with steel bar and springs. The simulated factors are show in Table 1. The model is 9.18m high. Fig.1 is the outline of the model.

Table 1 Simulated Factors

	Simulated factor
Length	0.02
Density	6.975
Elastical modulus	0.50
Mass	5.58×10^{-5}
Time	0.075
Frequency	13.39
Displacement	0.02
Acceleration	3.58
Microconcrete mass	373.94 (kg)
Lead mass	4056.06 (kg)

Measurement

Acceleration, displacement and strain response are measured in this experiment.

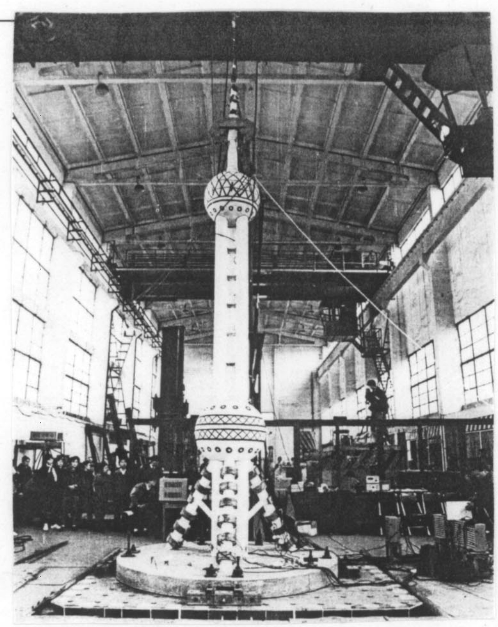

Fig.1. The outline of the model

Input Wave

This experiment is to study the natural frequency, mode of vibration, damping, the response and failure mode of the Tower in different earthquake intensity. Therefore, three kinds of waves are chosen as the input wave of the shaking table experiment. First is the artificial wave. This wave is derived from earthquake hazard research. It is consist of six group. Three group are 5-degree earthquake intensity. Others are 8-degree. Second is earthquake record, including EL-CENTRO record, PASADENA record, SAN-FERNANDO record. Third is artificial wave derived from code response spectrum. Experimental program is shown in Table 2.

Table 2 Experimental program

Earthquake intensity	Step	Wave type	Amplitude-acceleration (g)		
			X	Y	Z
	1	WHITE NOISE	0.05	0.05	0.05
5-degree	2	063-1.S1	0.208		
	3	063-1.S2		0.091	
	4	063-1.S	0.234	0.097	
	5	EL-CENTRO	0.152	0.133	0.034
	6	PASADENA	0.147	0.111	0.086
	7	WHITE NOISE	0.05	0.05	0.05
6-degree	8	S-063.1	0.367	0.196	0.092
	9	S-063.2	0.248	0.208	0.194
	10	EL-CENTRO	0.235	0.209	0.132
	11	PASADENA	0.302	0.223	0.196
	12	003-1.S	0.328	0.188	0.138
7-degree	13	003-2.S	0.512	0.588	0.364
	14	EL-CENTRO	0.530	0.390	0.230
	15	PASADENA	0.770	0.430	0.420
8-degree	16	003-3.S	0.820	0.660	0.549
	17	EL-CENTRO	0.723	0.541	0.390
	18	SAN-FERANADO	0.975	0.470	1.440
	19	WHITE NOISE	0.10	0.10	0.10
9-degree	20	S-003.1	1.430	0.697	0.886
	21	EL-CENTRO	1.380	0.900	0.804
	22	003-3.S	1.630	1.150	0.890

EXPERIMENTAL RESULT

Natural Frequency

Natural frquency and damping, which are measured in white noise wave, are shown in Table 3. Natural mode of vibration see Fig.2. First and second natural frequency are very approximate because of flexible steel master. The Tower has the behavior of mode degradation and whipping effect. The natural frequency in X axis is equal to that in Y axis. So, this tower is a symmetrical structure. Torque may be neglected. The damping is about 3%.

Table 3 Natural frequency and damping

Mode	1	2	3	4	5
Frequency (Hz)	2.604	3.906	8.464	13.02	17.58
Damping	0.030	0.030	0.025	0.018	0.030

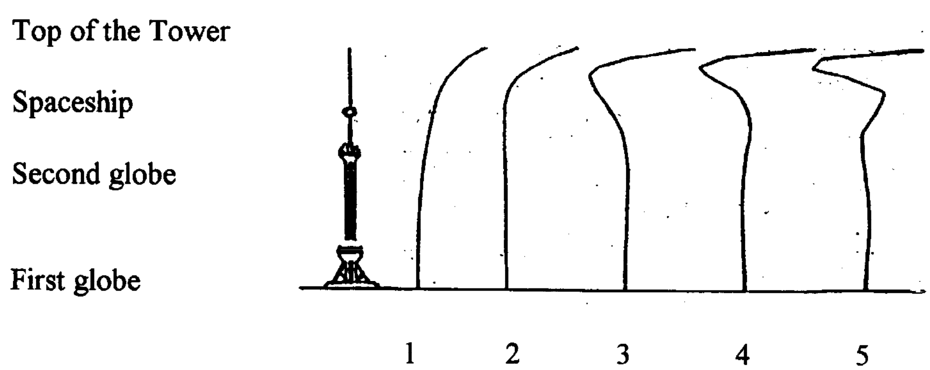

Fig.2. Mode

Earthquake Response

Phenomena. In 5,6,7-degree earthquake intensity, the response of steel mast is strong, but the response of the body is small. The Tower doesn't crack.

In 8-degree earthquake intensity, first crack appears at the concrete mast (see Fig.3). Then the steel mast buckling.

In 9-degree earthquake intensity, the crack widens, and many small cracks appear in concrete mast. The tube and girder crack (see Fig.4). The Tower is failure.

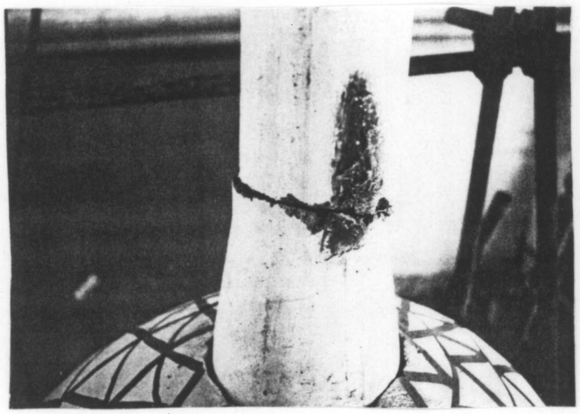

Fig.3. Concrete mast crack

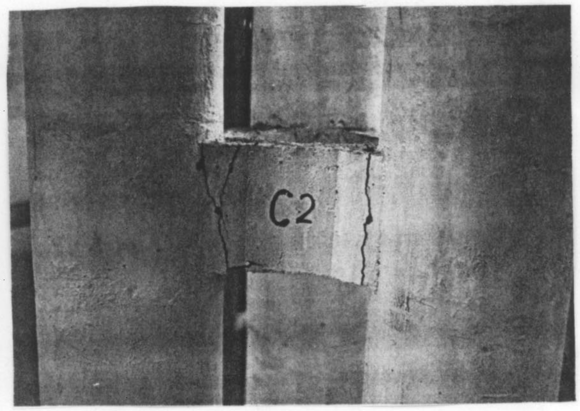

Fig.4. Tube and girder crack

Amplitification Factor. Table 4 shows the amplitification factor of model in different intensity EL-CENTRO wave. The amplitification factor of the steel mast are large, and it will decrease while the earthquake intensity increases.

Table 4 Amplitification factor of model in different intensity EL-CENTRO wave

Intensity	Position	First globe		Second globe		Spaceship			Top of the Tower		
	Axis	X	Y	X	Y	X	Y	Z	X	Y	Z
5-degree	Response acceleration	2.02	1.59	1.12	1.27	4.25	3.13	1.69	39.5	37.3	2.24
	Amplification factor	1.36	1.21	0.75	0.97	2.86	2.39	5.12	26.5	28.6	6.79
6-degree	Response acceleration	2.80	4.43	2.09	2.29	7.15	6.00	7.41	18.8	14.9	9.81
	Amplification factor	1.22	2.17	0.91	1.12	3.11	3.43	5.72	8.17	7.30	7.57
7-degree	Response acceleration	4.27	7.47	3.64	3.31	6.52	9.83	17.2	15.5	15.6	24.6
	Amplification factor	0.82	1.95	0.70	0.86	1.26	2.57	7.57	2.99	4.08	10.8
8-degree	Response acceleration	7.34	11.2	4.87	6.31	10.2	13.3	13.5	6.26	4.44	22.7
	Amplification factor	1.04	2.12	0.69	1.19	1.44	2.51	3.50	0.88	0.84	5.90
9-degree	Response acceleration	9.82	8.61	3.95	7.01	Failure			Failure		
	Amplification factor	1.22	1.16	0.49	0.93						

Table 5 shows the amplitification factor of model in same earthquake intensity. The variance of body's response is small in different waves, which have same earthquake intensity. But the mast has different response.

Table 5 Amplification factoer of model in different wave (8-degree)

Wave type	Second globe	Spaceship	Top of the Tower
S-063.2	1.106	3.465	8.500
EL-CENTRO	1.016	3.267	7.737
PASADENA	1.068	2.854	8.396
003-1.S	1.172	2.569	7.889

Comparion Between Uniaxial and Biaxial Earthquake. In 5-degree earthquake intensity, firstly drive in X axis,then in Y axis,finally in biaxes. Table 6 shows the amplitification factor. The experimental results prove that the response of second globe and spacship in biaxial earthquake are two times of that in uniaxial earthquake. So that biaxial result isn't the simple addition of two uniaxial driving because of the high mode of vibration.

Table 6 Amplification factor of model in uniaxial and biaxial earthquake (artificial wave)

		Second globe	Spaceship	Top of the Tower
Uniaxial earthquake	Response acceleration	0.998	1.666	39.23
	Drive acceleration	0.897	0.987	0.897
	Amplification factor	1.113	1.858	43.74
Biaxial earthquake	Response acceleration	2.024	4.264	42.02
	Drive acceleration	0.952	0.952	0.952
	Amplification factor	2.125	4.478	44.13

Strain. Table 7 shows the model's strain response in 8-degree EL-CENTRO wave.The response of S10 strain gauge, which local at the bottom of concrete mast, is largest. That prove the first crack appears in the concrete mast.

Displacement. The maximum displacement of the model is 4.0cm in 8-degree earthquake intensity.

Table 7 Strain response

Measurment point	Strain gauge	Compression (10^{-6})	Stretching (10^{-6})
Bottom of tube	S1	54.5	32.6
	S2	30.3	34.8
	S3	102.1	97.8
	S4	105.7	168.5
Bottom of strut	S5	105.3	277.6
	S6	104.6	214.5
	S7	225.7	207.1
	S8	163.8	211.2
Bottom of concrete mast	S9	92.2	229.6
	S10	13.5	437.7
Bottom of steel mast	S11	65.1	64.2
	S12	83.3	82.7
3.65m tube	S13	50.0	122.4
3.65m tube	S14	169.5	169.7
3.65m girder	S15	264.1	264.1

CONCLUSION

The first natural frequency of the model is 2.604Hz, and second is 3.906Hz. So, the natural period of the prototype is 5.14s and 3.43s. The stiffness of steel and concrete mast is much smaller than the stiffness of Tower's body.

Different earthquake waves have different spectrum and delay time. Therefore, it induces different response. The effect of different waves should be considered.

The maximum amplitude-acceleration appears at the top of the Tower, then at concrete mast. It seems that the effect of high natural mode of vibration is very strong. The maximum displacement of the model is 4.0cm in 8-degree earthquake, and the displacement of prototype is 2.0m.

The Tower is a space frame structure. There is a triad of struts at the bottom. This structure is better than single tube tower in earthquake resistance.

The Tower is safe in 7-degree earthquake intensity. The steel mast will buckle and the concrete mast will crack in 8-degree earthquake. In 9-degree earthquake intensity, tubes and girders will crack, the Tower will fail. The experimental results prove that the steel mast and concrete mast are the weak elements.

REFERENCES

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