Dynamic Response of a High-Rise SRC Building Model

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Abstract

A 68 story (224m high) S.R.C. high-rise building will be constructed in Guangzhou City, China. The building has two towers that are connected with over bridges at the 15th floor and the 50th floor. On the top, there is a ball shaped house (30 meter's diameter) for sightseeing (fig.1).

Shaped steel and reinforced concrete columns (S.R.C. columns) will be used in the building structure(fig.2). Shear nail, steel brackets welded on the shaped steel are designed in the columns. These measures are taken to improve the seismic behavior of the building, also to reduce the section area of columns for increasing usable space.

General structural analysis can not reveal the relative movement between the two towers when using the hypothesis of rigid floor. The deformations of the thin neck bellow the ball shaped dining hall may be more serious than the predicted results with normal dynamic models.
In order to verify the dynamic characteristics, to improve the seismic behavior and the reliability of both S.R.C. members and the connection part between the two towers and the neck, a 1/40 scale steel-concrete model was designed and constructed for shaking table test in the Laboratory of South China Construction University. White noise random wave and some recorded earthquake wave were inputted to the 6-DOF shaking table. Accelerations were recorded during each test.

The testing results and the analysis for the dynamic response of the high-rise S.R.C.model are introduced in this paper.

General Introduction

Considering the location and the requirements in the anti-seismic design code[1] and structural design and construction code for high-rise building[2], the designed anti-seismic intensity of the prototype is 7 degree in Chinese scale. The anti-seismic detail's grade is the first grade[2]. The ratio of length to width of the first plain is 1.9, while the value of slenderness achieves to 4.49. The corresponding values of the core tubes are respectively 1.3 and 12.5. The structure of the neck is '[]' shape S.R.C. shear walls, where the corner shaped steels stretched out from the four columns of the two towers. The floor beams of the dining hall are in S.R.C too, which are welded with shaped steels in the corner columns of the shear walls.

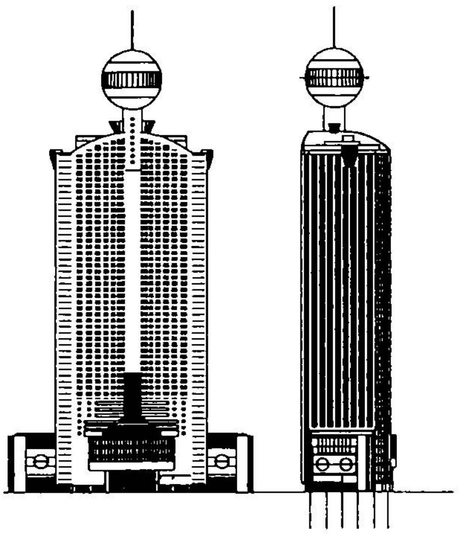


fig.1 Sketch map of the prototype

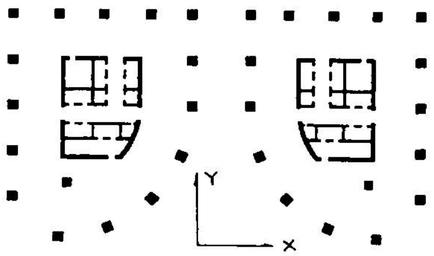


fig.2 S.R.C.colums and R.C. core tubes

The main objectives of the test research were:
1. To mearure structural frequencies and compare with calculation results.
2. To investigate the dynamic response of the entire structure, including the relative movement between the two towers.
3. To study the reliability of the overbridge and the neck under the ball house.
4. To observe the anti-seismic behavior of the S.R.C. model using the specific details.

Only a small part of the research results is reported here because of the page limitation.

The design and construction of the model

1. The scales of the model

Skirt building was included in the design of the model, because It would affect the seismic response of the main structure. The scale parameters of the model are listed in table 1, according to the similarity theory[3]. The value Ce was determined by considering both the model concrete and model steels, ensuring the equivalence of stiffness contribution to the entire structure.

2. The materials of the model

Concrete was modeled with micro-concrete, because the stress-strain relationship would be similar to concrete. Strength grades of concrete varied from C30 to C60, and the strength of micro-concrete from 6.5MPa to 13.0MPa according to the tests. Model steels were made by fine steel bars. The shaped steels were modeled with thin steel plates(thickness from 0.6mm to 1.0 mm). The mean value of steel module was 196000MPa.

3. The design of S.R.C. column model

If such kind of steel elements were equivalently replaced with model steel rod in elastic model, the post-crack characters and torsion stiffness would be far similar from the original elements in the prototype. From this point, the model shaped steels were made with thin steel plates that were formed and welded as "[]" shape or "I" shape sections. The longitudinal steel bars in beams went through the holes pounced in shaped steels (see figure 3, model S.R.C. columns).

Table 1: Scale Parameter of the Model

ITEM	PARAMETER	SCALE	NOTE
Length	Cl	40	
Area	Ca	1600	
Volume	Cvo	64000	
Elastic modular	Ce	2.60	Considering effective stiffness of S.R.C. element
Stress	Cσ	2.60	
Strain	Cε	1.00	
Density	Cρ	0.40	Considering table weight capacity
Velocity	Cv	2.56	
Accelerate	Ca	0.163	Considering the equivalence of inertia force
Gravity	Cg	1.00	
Frequency	Cf	0.064	
Time	Ct	15.69	
Mass	Cm	25600	
Force	Cforce	4160	
Energy	Cen	166400	

4. The design of model beams

Obviously, the thickness of concrete plate could not be scaled down to model plate (2-4mm) by using micro-concrete, because that it was generally 100-150mm. Ensuring the stiffness contribution of floors to the entire structure similar to the prototype, concrete plate and small beams were modeled with model plates. In this case the bending stiffness could be thought suitable but the shear stiffness might be not.

5. The construction of the model

Some surveying tools were used in the construction of the model for accurate dimensions. Concrete blocks for material testing were ready when the concrete was pouring. Forms were made in bubble plasticity, which could be moved out easily when the model had been finished.

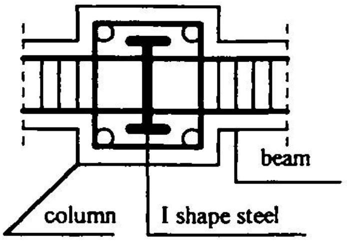


fig.3 Model Columns

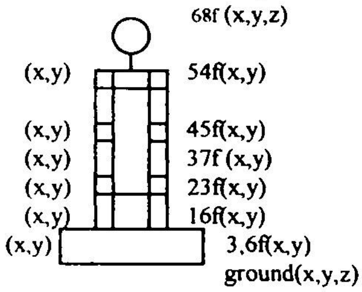


fig.4 Accelerators arrangement

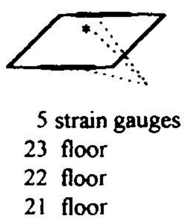


fig.5 Strain meters

Testing plan

1. The mounting of weights

In order to meeting the requirements of weight similarity and active loads, 4.98 ton weights were needed according to the calculation. The mounting of these weights matched the mass distribution of the prototype.

2. The measuring plan

Figure 4 shows the arrangement of accelerators on some floors. Strain meters were stacked in the place of some connection area (see figure 5). MTS data acquisition system was used for signal recording.

3. The earthquake waves

The Guangzhou wave, Taft wave and El-centro wave were chosen for the test. The lasting time and the amplitude were scaled to fit the needs of the tests. The maximum peak acceleration of each wave was increased from 0.036g, 0.104g, to 0.225g (multiply by C_a)respectively.

4. The testing sequences

Tests began with white noise in each term of intensity. Some tests were arranged in single axis in small and basic intensity, but in the rare intensity test, 2-dimensional earthquake waves were inputted to the earthquake table.

Dynamic behavior of structure

1. Vibration Frequency

Figure 6 gives Taft wave achieved on the seismic table.

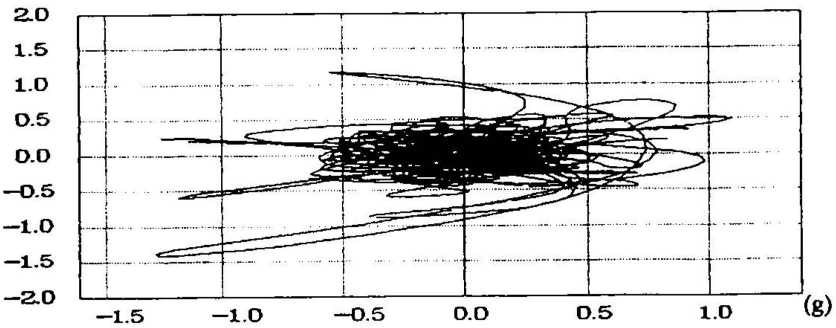


fig.6 Taft wave achieved on the table(x and y direction)

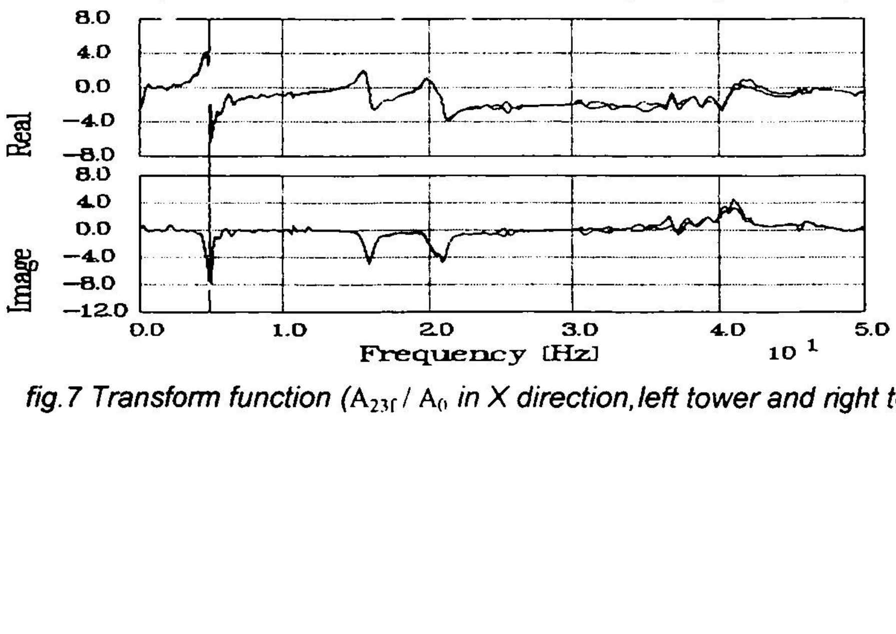


fig.7 Transform function (A_{23r} / A_0 in X direction,left tower and right tower)

The fundamental frequency of vibration was 4.88 Hz in x-direction, and 5.07 Hz in y-direction. Figure 7 shows the transform function of acceleration on some floors (A_{if}) to the acceleration input on the table (A_0), by which the frequency points are obvious. Figure 8 gives the vibration mode shapes from data analysis. Table 2 shows the comparison results between the tested frequencies and the calculated results by the program TBSA(mode analysis method, MDF shear model), where the differences come mainly from the rigid floor assumption and the concrete module without considering steel ratio. Table 3 gives corresponding values in the stage of rare intensity, from which frequency decline could be noticed.

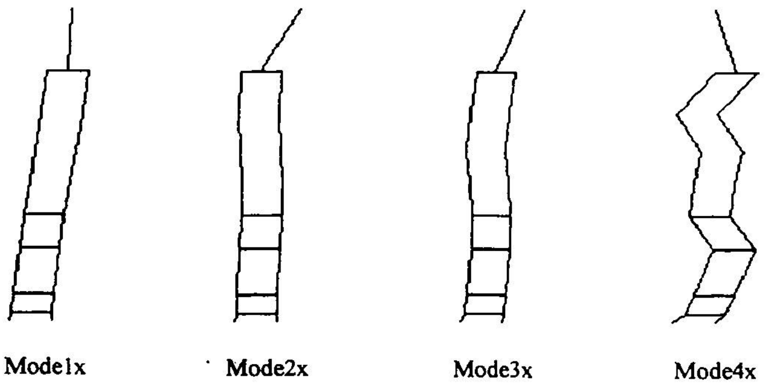


fig.8 Vibration mode shapes tested(X-Direction)

2. Peak acceleration and displacement distribution

Fig.9 and fig.10 give the lateral acceleration and displacement distribution along the height of the model. Considerable relative movement between the two towers took place from the figures. This phenomenon could also be seen by both El-centro wave and Taft wave test, see fig.11. The lateral acceleration at the 37rd floor was larger than the 54th floor (A_{max}=0.225g* C_a).

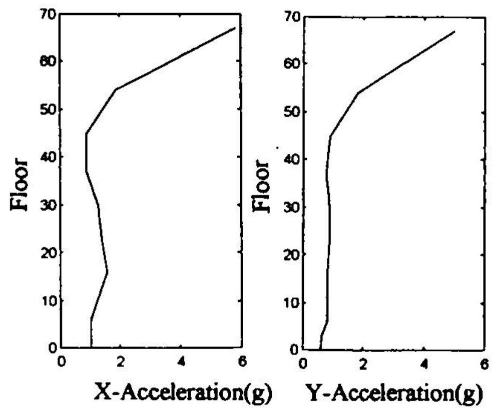


fig.9 Max.acceleration distribution

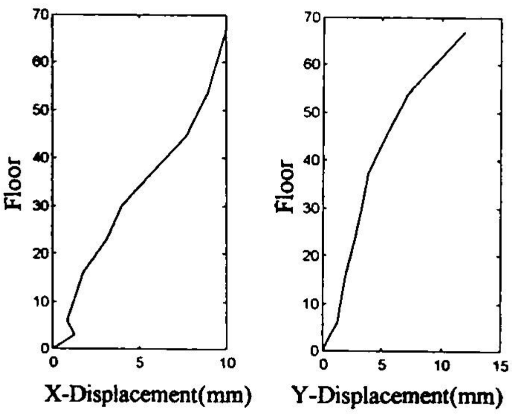


fig.10 Max. displacement distribution

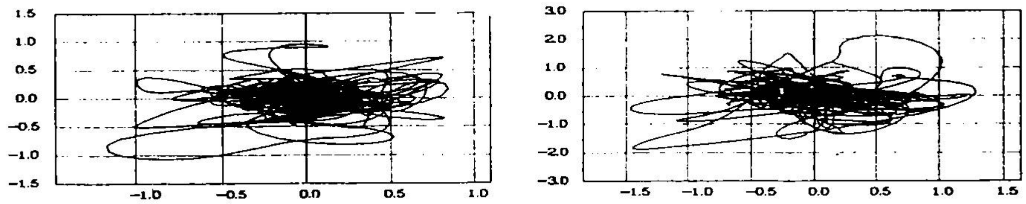
table 2 Comparison on frequency results (Hz) (elastic stage)

Mode	Fe1x	Fe1y	Fe2x	Fe2y	Fe3x
Tested	**4.88**	**5.07**	**15.80**	**15.20**	**20.66**
Calculated*	**3.71**	**4.00**	**11.12**	**10.06**	**16.81**

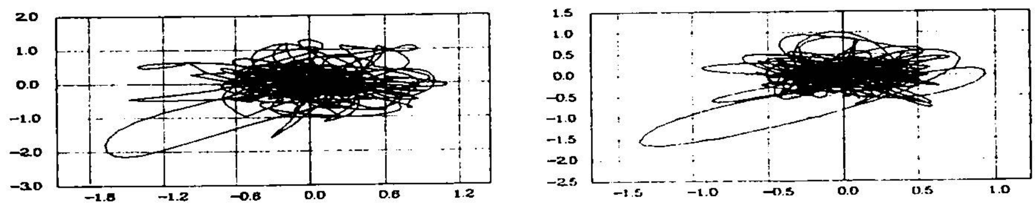
*note: calculation results converted from the prototype into the model.

Table 3 Frequency results(Hz) (elastoplastic stage)

Mode	Fp1x	Fp1y	Fp2x	Fp2y	Fp3x
Tested	3.76	4.32	14.09	12.02	18.03
Fpi/Fei	77%	85%	89%	79%	87%



(a) At the 6th floor (c) At the 45th floor



(b) At the 37rd floor (d) At the 54th floor

fig.11 acceleration track at different elevations (A_{max}=0.225g C_a)*

Conclusion

1. Tested structural frequencies, vibration mode shapes and other dynamic response characters of the S.R.C. model were presented in this paper.
2. Structural frequencies declined obviously when the model experienced different intensity of earthquakes.
3. The two towers connected by the overbridge had considerable relative movement, the lateral displacement and acceleration at middle part were enlarged during vibration.
4. The calculated frequencies approached to the test result. The differences came mainly from the rigid floor assumption and the concrete module without considering steel ratio.
5. MDF shear model is not suitable for the analysis of the complex building. Shape steel ratio should be considered in the stiffness calculation of S.R.C. members.
6. The S.R.C. column details have reliable working behavior. However, very severe cracks appeared on the bottom of the neck when the input acceleration reached to 0.225g. So the connection part should be more safely designed.

Keywords

S.R.C Structure, Dynamic Test, Modeling Techniques, Earthquake Resistant Design

References

[1]. Design Code for Earthquake Resistant Building, GBJ11-89, April,1990, China.
[2]. Structural Design and Construction Standard for High-rise Buildings in Reinforced Concrete, JGJ 3-91, 1991, China.
[3]. G.M.Sabnis,H.G.Harris,R.N.White,M.S.Mirza,Structural Modeling and Experimental Techniques, Prentice-Hall, 1983.