Shaking table model test of a super high-rise building with setbacks in elevation

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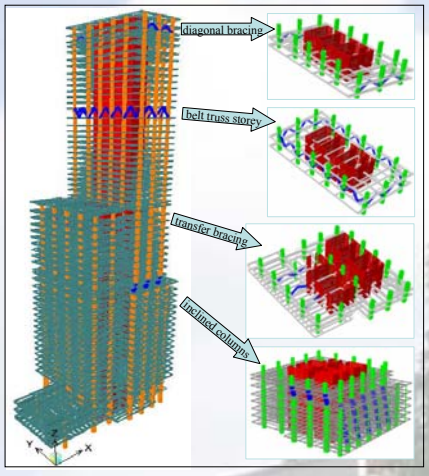
Introduction

Storey: 58 above the ground
and a 4-storey basement
Height: 244.8m (top of roof)
260.0m (top of steel frame)
Function: office building and hotel
Structural system: SRC frame and RC core
Characteristics: setbacks
inclined columns
belt truss storey
transfer bracing
Seismic design intensity: 7 (0.1g)
Code: Chinese code for seismic design of buildings (GB 50011-2001)
Technical specification for concrete structures of tall building (JGJ 3-2002)

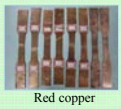


Model design and construction

Model materials

Fine aggregate concrete

Galvanized iron wire



Red copper

Similitude relationship

Parameters	Relationships	Model/prototype
Length	S_l	1/35
Elastic modulus	S_E	0.30
Stress	S_σ	0.30
Strain	S_ε/S_E	1.00
Density	S_ρ	3.50
Force	S_F	2.45E-04
Frequency	S_f	10.25
Acceleration	S_a	3.00

Model construction

Base

Typical floor

Inclined columns

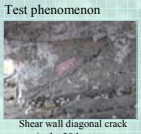
Belt truss storey

Test program

Test case	Case name	Earthquake Occurence Frequency	Input Signal	Peak value of input acceleration (g)						Note
				Direction X		Direction Y		Direction Z		
				Design	Achieved	Design	Achieved	Design	Achieved	
1	W1	White noise 1		0.05		0.05		0.05		3D
2	F7EXY	Frequent 7	El Centro	0.11	0.128	0.09	0.097			2D
3	F7EYX			0.09	0.101	0.11	0.152			
4	F7PXY		Pasadena	0.11	0.129	0.09	0.073			2D
5	F7PYX			0.09	0.126	0.11	0.163			
6	F7SHX		SHW1	0.11	0.123					1D
7	F7SHY					0.11	0.155			
8	W2	White noise 2		0.05		0.05		0.05		3D
9	B7EXY	Moderate 7	El Centro	0.30	0.342	0.26	0.276			2D
10	B7EYX			0.26	0.261	0.30	0.264			
11	B7PXY		Pasadena	0.30	0.349	0.26	0.281			2D
12	B7PYX			0.26	0.299	0.30	0.348			
13	B7SHX		SHW1	0.30	0.436					1D
14	B7SHY					0.30	0.304			
15	W3	White noise 3		0.05		0.05		0.05		3D
16	R7EXY	Rare 7	El Centro	0.60	0.713	0.51	0.418			2D
17	R7EYX			0.51	0.526	0.60	0.508			
18	R7PXY		Pasadena	0.60	0.741	0.51	0.573			2D
19	R7PYX			0.51	0.552	0.60	0.593			
20	R7SHX		SHW1	0.60	0.803					1D
21	R7SHY					0.60	0.471			
22	W4	White noise 4		0.05		0.05		0.05		3D
23	R8EXY	Rare 8	El Centro	1.08	1.407	0.92	0.803	0.70	0.716	3D
24	R8EYX			0.92	1.227	1.08	1.33	0.70	0.654	
25	R8PXY		Pasadena	1.08	1.716	0.92	1.119	0.70	1.012	
26	W5	White noise 5		0.05		0.05		0.05		3D

Test results

Test phenomenon



Shear wall diagonal crack in the 30th storey

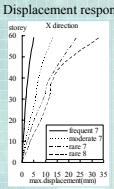
Column diagonal crack in the 31st storey

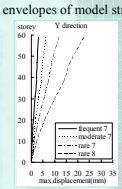
Column crossing crack in the 32nd storey

The first three frequencies and modal shapes

Structure		Model structure			Prototype structure		
No.		1	2	3	1	2	3
White noise 1	Frequency	3.418Hz	3.418Hz	6.347Hz	0.333Hz	0.333Hz	0.619Hz
	Modal shape	X	Y	T	X	Y	T
White noise 2	Frequency	3.418Hz	3.418Hz	6.347Hz	0.333Hz	0.333Hz	0.619Hz
	Modal shape	X	Y	T	X	Y	T
White noise 3	Frequency	2.930Hz	2.930Hz	—	0.286Hz	0.286Hz	—
	Modal shape	X	Y	T	X	Y	T
White noise 4	Frequency	2.930Hz	2.930Hz	5.371Hz	0.286Hz	0.286Hz	0.524Hz
	Modal shape	X	Y	T	X	Y	T
White noise 5	Frequency	2.441Hz	2.441Hz	—	0.238Hz	0.238Hz	—
	Modal shape	X	Y	T	X	Y	T

Displacement response envelopes of model structure



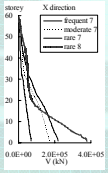


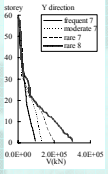
Dynamic response of prototype structure

Inter-storey drift angle of prototype structure

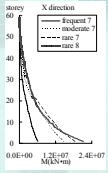
Test phase	Frequent 7		Moderate 7		Rare 7		Rare 8	
Direction	X	Y	X	Y	X	Y	X	Y
Max. inter-storey drift angle	1/838	1/1611	1/352	1/801	1/207	1/308	1/138	1/218
Coded value	1/500	1/500			1/100	1/100		

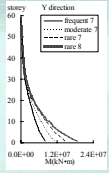
Envelops of shear force





Envelops of overturning moment





Conclusions and suggestions

- Under frequent occurrence of seismic design intensity 7, no visible damage can be observed. The natural frequency remained unchanged. Under moderate occurrence of seismic design intensity 7, the natural frequency decreased very slightly, which indicates that the prototype structure can behave elastically when attacked by those levels of earthquakes. Under rare occurrence of seismic design intensity 7 and 8, the structure damaged locally but still could survive and keep stable, which indicates that the target high-rise building could meet the design criteria of no damage under frequent earthquake and no collapse under rare earthquake;
- The maximum inter-storey drift angles under frequent earthquake 7 and rare earthquake 7 satisfy the limitations of Chinese code;
- Under rare earthquake 8, the setback storey damaged severely which may leads to the weak point of the structure. It is suggested that appropriate improvement on ductility should be made to the stories adjacent the setbacks;
- The angle of inclined columns to the vertical direction should be decreased to improve the seismic performance of the structure.

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