SHAKING TABLE TEST OF R. C. BRACED FRAME STRUCTURE WITH SPECIAL-SHAPED COLUMNS

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SUMMARY

15-story braced frame structure model with T-shaped, L-shaped, and +-shaped column section is designed and tested on shaking table. Also two kinds of bracing member with K and inverted V pattern is included. Based on the preliminary test results, the seismic behavior, including fundamental time period, deformation ability, damping ratio etc, as well as the rigidity and mechanism of destruction is studied and forecasted.

INTRODUCTION

In the ordinary reinforced concrete frame structures, the columns are often in rectangular or circle shape. This type of columns in residential buildings may decrease the effective area. If the column's shape is changed into T-shaped, L-shaped, and +-shaped, etc. in the reinforced concrete frame structure, then the structure is named as the special-shaped columns frame structure. Because no column edge can be seen in the room and the architectural design is more feasible, so this type of structure is required for functional or architectural reason by both owners and architects.

On the other hand, when the height of the building is beyond the specified value, the lateral displacement of the frame structure with pure irregular shaped columns may not satisfied the displacement requirement. In many cases, the shear wall is added to increase the lateral rigidity of the whole structure. As we all know, the deformation capacity of shear wall is low and the dissipation capacity is weak, also, the gravity is high. Many references [4] recommended the bracing proposal just as widely used in steel frame structures. The main conclusion of these research is that: (1) The lateral rigidity of braced frame structure is somewhat 8 to 12 times of pure frame structures, the horizontal capacity is 4-6 times of pure frame structures, the coefficient of ductility is about 6. (2) The sequence of plastic hinge is brace-beam-column. (3) The strength and rigidity of the bracing is available to justify, it can be seen to act as the protector of the structure.

The seismic response of reinforced concrete braced frames has been studied in past twenty years. However no reference has been involved to investigate the seismic response of reinforced concrete braced frame with special-shaped concrete columns. Based on the shaking test in this paper, some significant conclusion of the seismic behavior of this kind of structure is given.

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OUTLINE OF TEST

According to the general similitude law, a 15-story braced frame structure model with 1322-mm width, 1671-mm length and 6250-mm height is designed from the prototype. The main scaling parameters are shown in Table 1. Three kinds of irregular shape columns with T-shaped, L-shaped, and +-shaped section are included. Furthermore, two kinds of bracing with K and inverted V pattern are studied. Figure 1 and Figure 2 show the plan drawing and the elevation drawing of the model respectively.

The 15-story model is tested on the shaking table in the Shaking Table Test Division of State Key Laboratory for Disaster Reduction in civil Engineering, Tongji University. The major behavior apparatus of the shaking table is described as below:

Table size: 4000-mm x 4000-mm x 800-mm
Vibration waveform: cyclical, random, earthquake
Max. Specimen weight: 150 KN
Operation frequency range: 0.1 to 50 Hz
Controlled degree of freedom: 6
Data acquisition system: 96 channels

Table 1 Similitude factors between the prototype and the test mode

Similitude parameters	Scaling parameters	Similitude parameters	Scaling
Length S_l	1/7	Velocity S_v	0.56
Modulus S_E	1	Acceleration S_a	2.23
Time of period S_t	0.253	Displacement S_r	1/7
Frequency S_ω	3.95	Stress S_σ	1
Mass density $S_{\bar{\rho}}$	3.14	Concrete strength S_{cu}	1

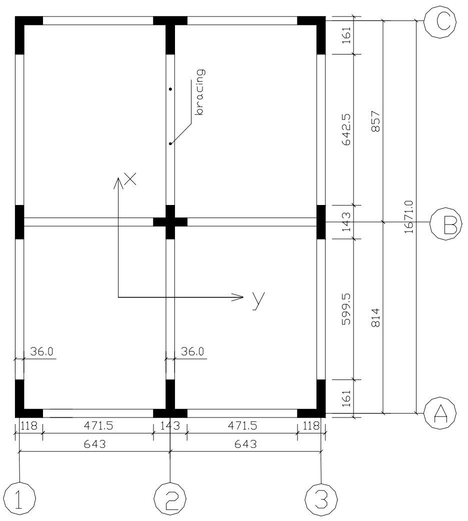

Figure 1 The plan drawing

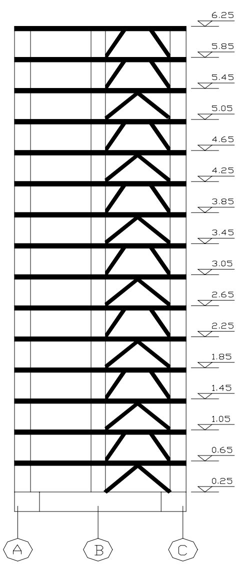

Figure 2 The elevation drawing

Two kinds of earthquake record are chosen as the input wave in this very shaking table test. They are the El-Centro record (N-S) and the Shanghai artificial response wave based on the Shanghai Seismic Design Code (Shw2), as shown in Figure 3 and 4 respectively. Acceleration of x-direction for each story, displacement of x-direction for the 10th and 15th floor, and the concrete strain of bracing for 1 to 4 story are inspected and measured mainly.

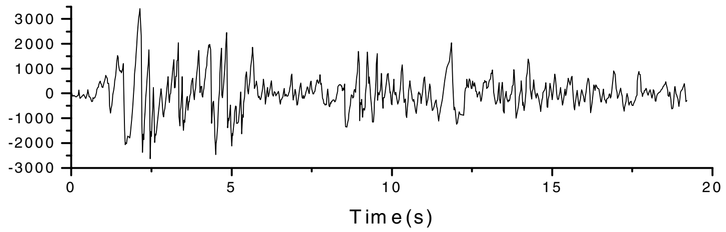

Figure 3 El-Centro record (N-S)

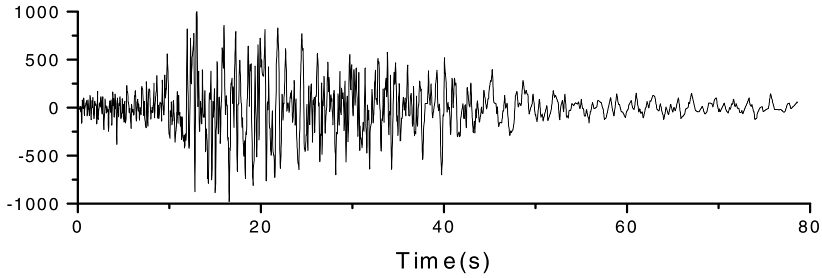

Figure 4 Artificial Shanghai wave (Shw2)

TEST PROCEDURE

The main vibration direction of the shaking table test is x-direction. The standard test program is described in Table 2.

Table 2 Test program

No.	Motion	Peak value of earthquake wave (gal.)		
		X-direction	Y-direction	Z-direction
1	White noise	61	54	40
2	EL-Centro	69	0	0
3	Shw2	78	0	0
4	EL-Centro	210		
5	Shw2	233	0	0
6	EL-Centro	419	0	0
7	Shw2	401	0	0
8	White noise	66		

TEST RESULTS

Experimental Phenomena

In the whole test procedure, four observers stand in front of the four sides of the model to record the vibration phenomena and investigate the cracks appearing after each motion. There is no crack until Motion 6. And the strain of the reinforced bar in the controlling region is less than 600 $\mu\varepsilon$. Based on the above facts, the conclusion can be made that the model is still in the elastic scope. After the motion 7 ended, some slight cracks are founded in the bracing on the second and third floor. The first order frequency is decreased from 3.447 Hz to 3.064 Hz. The peak value acceleration of Motion 6 and 7 is beyond 8-degree intensity of earthquake according to *the Chinese Seismic Design Code for Buildings* [1]. The important and interesting phoneme is the crack occurring firstly in the bracing.

Acceleration Response of the Model

At the condition of the different earthquake wave input, the acceleration response and the amplification of acceleration on each floor of the model structure are given in Table 4, shown in Figure 4 and 5. The maximum acceleration of the model appears at the roof of the structure. The amplification of acceleration decreases when the earthquake amplitude increases, because the damping increases with the structure system approximately entering the nonlinear status. On the other hand, the model has different response in different earthquake, this is because different earthquake waves have different frequency characteristic.

Table 4 Max. Acceleration (X) and amplification of acceleration (k)

	No. 2		No. 3		No. 4		No. 5		No. 6		No. 7	
Story	X(g)	K	X(g)	K	X(g)	K	X(g)	k	X(g)	k	X(g)	k
Base	.06	1.00	.08	1.00	.21	1.00	.23	1.00	.42	1.00	.40	1.00
1	.08	1.23	.09	1.09	.18	.85	.23	1.01	.35	.85	.43	1.06
2	.11	1.65	.12	1.53	.20	.97	.23	.99	.38	.92	.56	1.40
3	.13	1.95	.14	1.81	.27	1.3	.31	1.31	.44	1.06	.66	1.64
4	.14	2.15	.16	2.07	.32	1.54	.37	1.60	.53	1.26	.73	1.81
5	.16	2.35	.18	2.32	.37	1.75	.43	1.85	.61	1.47	.75	1.87
6	.16	2.31	.19	2.46	.38	1.82	.51	2.18	.64	1.52	.82	2.05
7	.15	2.19	.21	2.63	.37	1.75	.57	2.45	.69	1.65	.87	2.18
8	.17	2.49	.21	2.66	.38	1.82	.61	2.61	.73	1.74	.87	2.16
9	.16	2.33	.22	2.83	.43	2.05	.60	2.56	.69	1.65	.83	2.07
10	.17	2.42	.23	2.92	.45	2.13	.55	2.38	.72	1.72	.81	2.01
11	.18	2.56	.24	3.08	.44	2.11	.51	2.18	.76	1.82	.86	2.15
12	.22	3.18	.27	3.47	.43	2.06	.58	2.47	.83	1.97	.97	2.41
13	.25	3.58	.31	3.91	.47	2.26	.64	2.75	.92	2.19	1.03	2.56
14	.27	3.93	.35	4.41	.58	2.76	.74	3.19	1.12	2.67	1.19	2.96
15	.30	4.32	.37	4.68	.66	3.15	.81	3.46	1.31	3.13	1.34	3.34

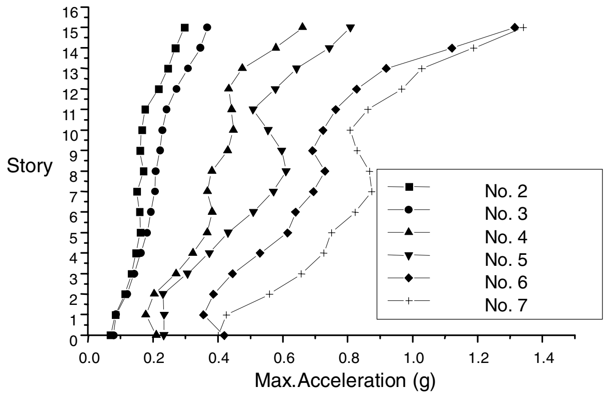

Figure 5 Envelop diagram of X of the model

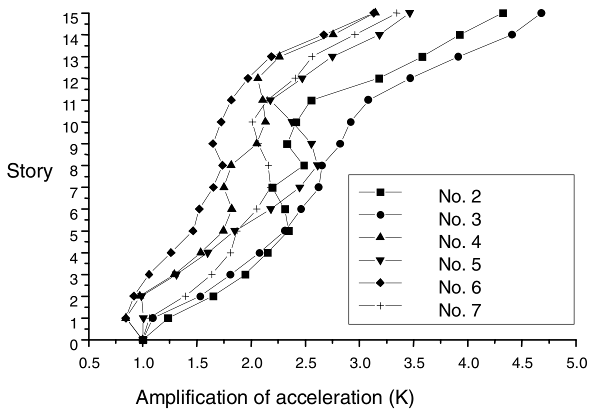

Figure 6 Envelop diagram of K of the model

Displacement Response of the Model

The displacement of the model structure can be calculated by the integral of the acceleration records on each floor. The maximum displacement in x-direction is calculated in Table 5. And the envelop diagram of x-direction displacement is drawn in Figure 6. The absolute displacement on the roof under Motion 6 is 14.78mm, the relative lateral displacement is 1/406. However, the displacement on the roof under Motion 7 is 16.04mm, the relative lateral displacement is 1/374. On the condition of relative lateral displacement greater than 1/500 specified in the Chinese Code [1] under earthquake action, the model is still in the elastic scope even with the relative lateral displacement of 1/406. This tells us that the R. C. braced frame structure with special-shaped columns can resist more deformation within the elastic period.

Table 5 Max. Displacement in x-direction (mm)

Story	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
Base	1.29216	4.95978	3.38814	11.62406	7.21617	22.05576
1	4.48590	4.91566	3.27311	10.67665	6.08861	21.23498
2	1.73178	5.10375	3.44890	11.02652	7.15714	23.28465
3	1.07869	5.14998	4.00077	11.67787	8.24517	24.15599
4	1.87094	4.95891	3.82625	11.21931	9.19775	25.73302
5	1.74308	5.27842	4.37839	11.86630	9.76415	25.75807
6	2.03130	5.29959	4.94620	12.65299	11.45311	27.44710
7	1.88017	5.29389	5.40772	13.17465	12.44157	28.34281
8	3.47246	7.12874	6.00976	13.99907	14.77749	30.67880
9	2.53502	5.86731	6.25510	14.22483	15.63955	28.96494
10	2.89834	5.87152	6.21591	15.31826	16.12280	30.91829
11	3.03929	6.21078	6.69314	15.69822	17.67957	32.50679
12	3.58103	6.64605	7.04599	17.28619	19.01096	34.56741
13	3.64325	6.16389	7.71470	17.74173	20.30038	36.23064
14	3.95801	6.66648	7.70571	18.30036	21.50551	37.18916
15	4.28238	6.77008	7.91916	18.51037	21.99844	38.09163

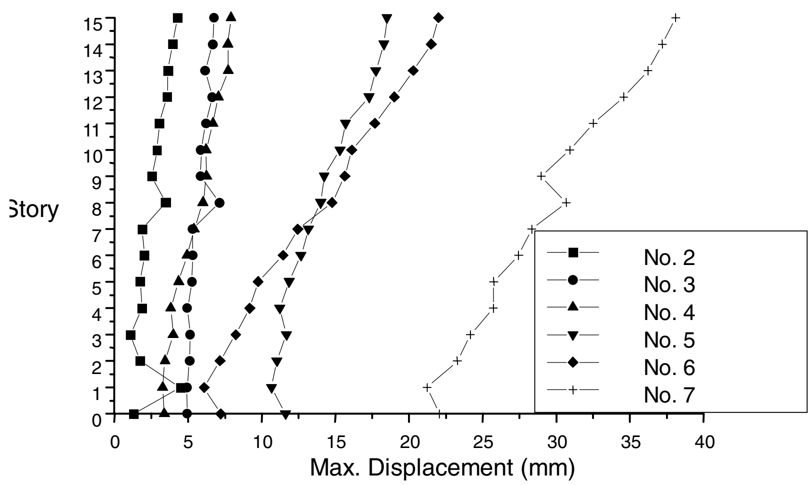

Figure 7 Envelop diagram of x-direction displacement

From the curves shown in the Figure 6, the conclusion of the model's displacement response being very sensitive to the different type of earthquake wave input can be made. For example, Motion 4 has approximately the same peak value as Motion 5; the model's displacement response under exciting of Motion 5 is greater than exciting of Motion 4. The model's displacement response under exciting of Motion 7 is even more greater than exciting of Motion 6, not only because the different type of wave input, but also because the rigidity of the model being decreased by the cracks appearing. What's more, the deformation characteristic of this kind of structure is in flexure-shear type.

CONCLUSIONS

Based on the results of the study and test, the following preliminary conclusions are made:

(1) According to the interesting phoneme of the crack occurring firstly in the bracing, we can forecast that the basic sequence of crack occurring is brace-beam-column.

(2) The model's displacement response is very sensitive to the different type of earthquake wave input.

(3) The R. C. braced frame structure with special-shaped columns has more ability to resist deformation within the elastic scope, and the deformation characteristic of this kind of structure is in flexure-shear type.

(4) The braced frame structure with special-shaped column is an ideal structural system both for resisting earthquake action and for easy architectural arrangement.

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