Supported by the National Natural Science Foundation of China (No. **50338040, 50025821),**

Research Report on Shaking Table Laboratory of the State Key Laboratory of Civil Engineering Disaster Prevention, Tongji University **(A20030609-405)**

12 -story reinforced concrete standard frame

Complete data for shaking table model tests

Benchmark Test of a 12-story Reinforced Concrete Frame Model on Shaking Table

Report preparation: Lu Xilin, Li Peizhen, Chen Yueqing

Shaking Table Laboratory ,

State Key Laboratory of Civil Engineering Disaster Prevention, Tongji

University **January 2004**

Table of contents

12 -story reinforced concrete frame structure

Shaking table model test

1 Trial overview

Test Number: S10H Model Ratio:

1/10

Model description: Single span 12 story reinforced concrete frame structure

Excitation waveforms: El Centro wave, Kobe wave, Shanghai artificial wave, Shanghai bedrock wave

Number of working conditions: 62

Test date: 2003.6.16

Test Location: Shaking Table Laboratory, State Key Laboratory of Civil Engineering Disaster Prevention, Tongji University

2 Experimental Design

2.1 Test device

The main performance parameters of earthquake simulation shaking table:

Table size 4.0m×4.0m

Maximum load model weight 25t

Vibration direction X, Y, Z three directions six degrees of freedom

The maximum acceleration of the table top is 1.2g in the X direction; 0.8g in the Y direction; 0.7g in the Z

direction Frequency range 0.1Hzÿ50Hz

2.2 Similar design of the model

Table 1 lists the similarity relationship and similarity coefficient of each physical quantity of the model.

2.3 Model design and production

The model ratio is 1/10, and the dimensions of beams, columns and slabs are converted from the dimensions of the actual high-rise frame structure according to a similar relationship. prototype and The model overview is shown in Table 2, and the model size and reinforcement diagram are shown in Figure 1.

Model materials are micro-concrete and galvanized iron wire. Microconcrete is a model concrete that is The gravel is the coarse aggregate, and the gravel with the smaller particle size is the fine aggregate. Construction method, vibrating method and curing conditions of micro-concrete And the material properties are very similar to ordinary concrete, and have a good similar relationship with the prototype concrete in dynamic characteristics, while And by adjusting the mixing ratio, the requirement of reducing the elastic modulus can be met.

Consider taking into account the weight of the partition wall, floor decoration and 50% live load, and add a mass counterweight to the board. Lay out on standard layer

19.4 kg counterweight for each layer, 19.7 kg counterweight is arranged on the roof layer.

Table **1** Dynamic similarity relationship of experimental models

	physical quantity	relational	1/10 model	Remark
material	strain e	$S_e = 0.1$	1	
fee	stress p	$SS_p =$ AND	1/3.870	
special	elastic modulus *E*	S AND	1/3.870	Model Design Control
sex	Poisson's ratio m	$S_m = 0.1$	1	
	density r	S_r	1	Model Design Control
Several	length *l*	S_l	1/10	Model Design Control
what	Area *S*	$SS_{lS} =$ 2	1/100	
special	Line displacement *X*	$SS_{lX} =$	1/10	
sex	Angular displacement b	$S_b = 0.1$	1	
load	Concentration *P*	SSS *beautiful* 2	1/387	
load	area load *q*	$SS_{Eq} =$	1/3.870	
	Mass *m*	SSS= *m* r *l* 3	1/1000	
verb: move	stiffness *k*	SSS= *lEk*	1/38.7	
force	time *t*	SSS= *kmt* (*l*) 2/1	0.1967	Dynamic Load Control
special	frequency *f*	SS= /1 *f* *t*	5.083	Dynamic Load Control
sex	damping *c*	SSS= *tmc* *l*	0.00508	
	speed *v*	SSS= *tlv* *l*	0.508	
	acceleration *a*	SSS= *come* *l* 2	2.584	Dynamic Load Control

Table **2** Overview of prototypes and models

project	prototype	1/10 model
layers	12	12
H/B	6	6
Floor height	3m	0.3m
Total height	36m	3.6m
Plane size	6m×6m	0.6m×0.6m
beam section	300mm×600mm	30mm×60mm
column section	500mm×600mm	50mm×60mm
Floor thickness	120mm	12mm
Material	C30 Concrete	Particulate Concrete

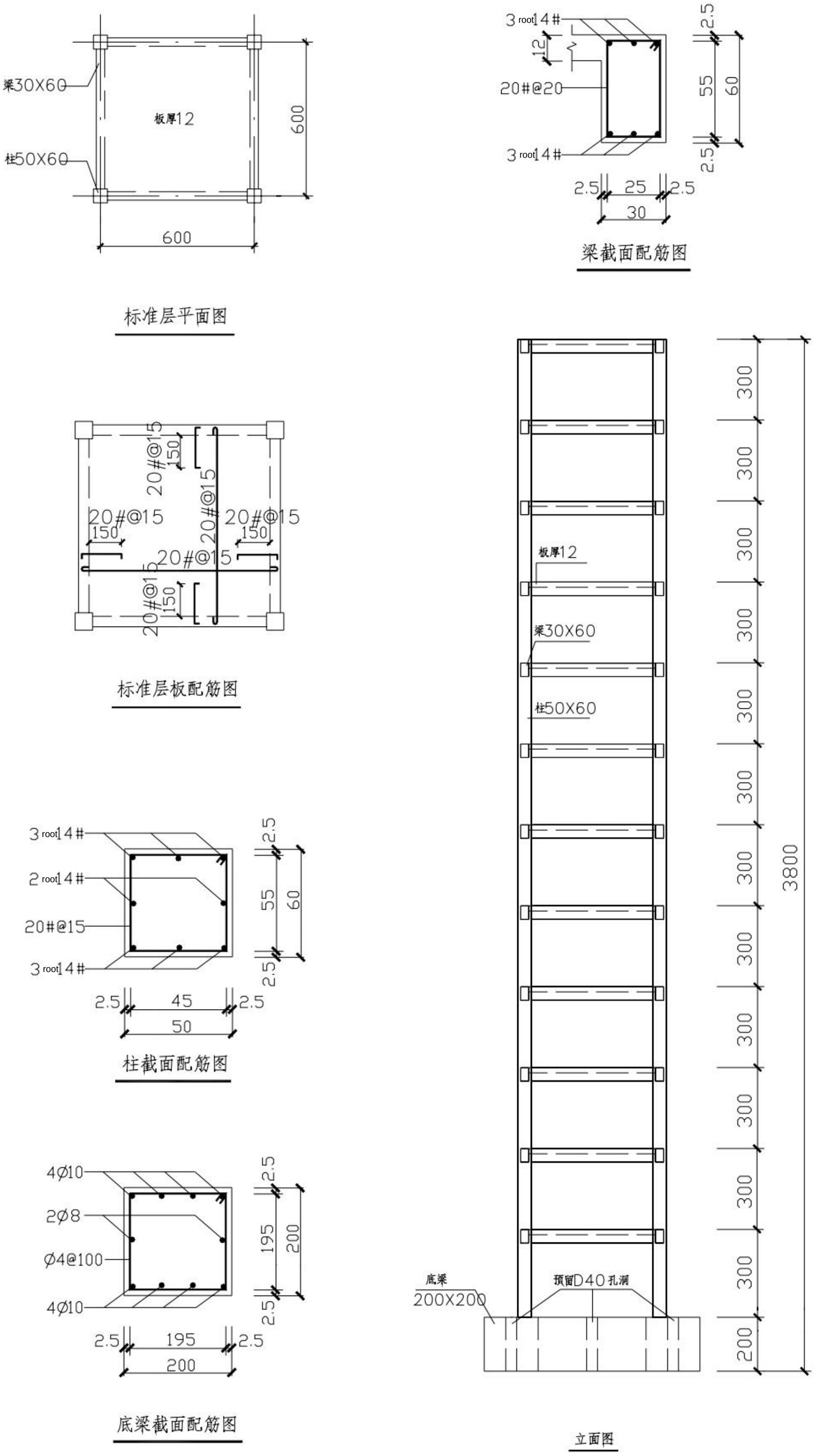


Figure 1 Model size and reinforcement diagram

2.4 Material performance index

Specimens were reserved while pouring the model. The test results of concrete material properties are shown in Table 3, and the test results of steel material properties are shown in Table 4.

Table 3 Concrete material property test results

Category	Specimen Group Number	Pouring Date	Cube Strength (MPa)	Elastic Modulus (MPa)	Average Elastic Modulus (MPa)
micro grain mix Congeal soil	0F	2003.3.26	9.216	10.167×103	
	1F/2F	2003.3.30	7.969	8.490×103	7.751×103
	3F/4F	2003.4.3	5.735	7.062×103	
	5F/6F	2003.4.5	7.402	7.649×103	
	7F/8F	2003.4.10	7.669	7.917×103	
	9F/10F	2003.4.14	7.202	7.322×103	
	11F/12F	2003.4.21	8.202	8.065×103	

Note: (1) The size of the cube compressive strength test piece is 70.7mm×70.7mm×70.7mm;

(2) The size of the elastic modulus specimen is 100 mm × 100 mm × 300 mm;

(3) The sample group number 0F corresponds to the micro-concrete of the base of the pouring model, which is not included in the average value of the elastic modulus;

(4) The date of the concrete material property test is June 2, 2003.

Table 4 Test results of material properties of steel bars

name	model	Diameter (mm)	area (mm2)	Yield Strength ÿMPaÿ	Ultimate strength ÿMPaÿ
iron wire	20ÿ	0.90	0.63	327	397
	18ÿ	1.20	1.13	347	420
	14ÿ	2.11	3.50	391	560

2.5 Measuring point layout

In the test, accelerometers and strain sensors were used to measure the dynamic response of the model structure. The direction of the accelerometer is X, Y,

Z three directions.

The layout of the test points is shown in Figure 2. See Table 5 for the corresponding table of measuring point sensor wiring.

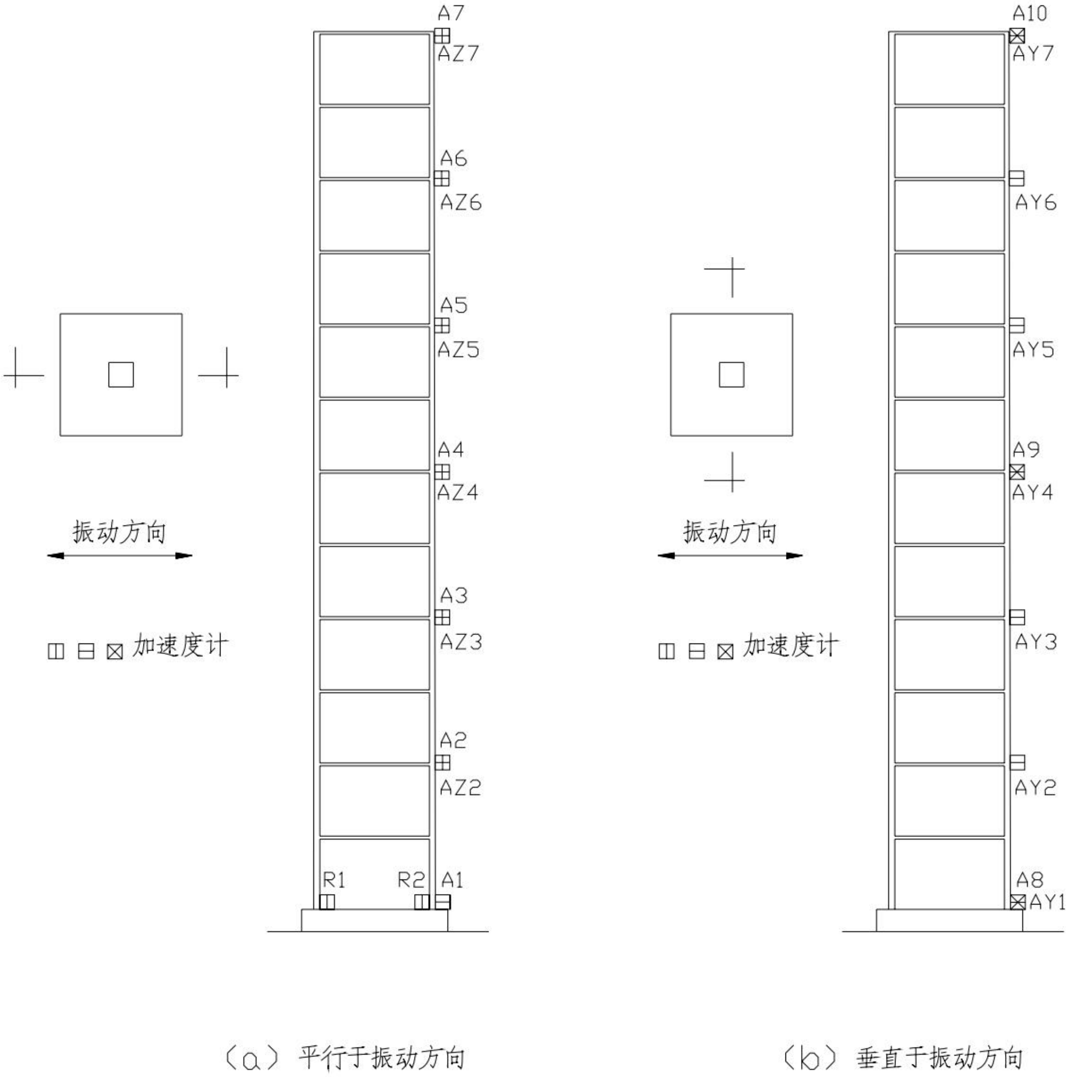


Figure 2 Layout of test points

2.6 Acceleration input wave

The seismic waveforms used in the test include El Centro wave, Kobe wave, Shanghai artificial wave and Shanghai bedrock wave. Input X, Y two-way or X, Y, Z three-way El Centro wave or Kobe wave at the same time. Figures 3 to 6 are El Centro Acceleration time-history curves and Fourier spectra of wave, Kobe wave, Shanghai artificial wave and Shanghai bedrock wave.

The El Centro wave is the acceleration time history recorded at the El Centro station of the IMPERIAL Valley earthquake (M7.1) on May 18, 1940. It is a classical seismic record widely used in structural testing and seismic response analysis. Its main strong earthquake The minute duration is about 26 seconds, the length of all recorded waveforms is 54 seconds, the original recording discrete acceleration time interval is 0.02 seconds, and the acceleration peaks of the NS component, EW component and UD component are 341.7gal, 210.1gal and 206.3gal, respectively.

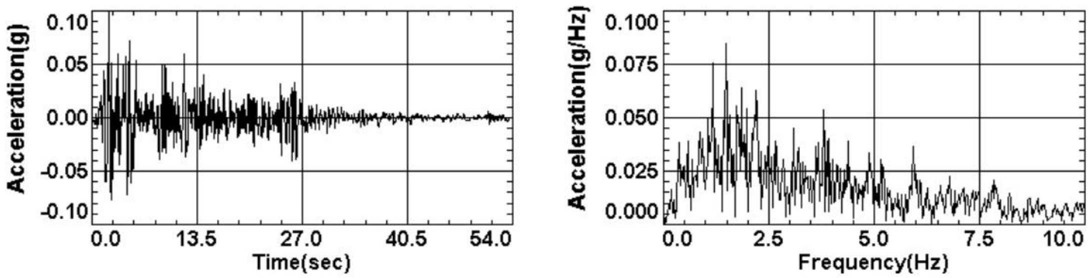
Table **5 S10H** measuring point sensor wiring correspondence table

serial number	Location	direction	Point number	Channel number	Remark
1	base top	X	A1	8	
2	2F	X	A2	7	
3	4F	X	A3	6	
4	6F	X	A4	5	
5	8F	X	A5	4	
6	10F	X	A6	3	
7	12F	X	A7	1	
8	Foundation top surface out of plane	X	A8	27	
9	6F Out of plane	X	A9	26	
10	12F out of plane	X	A10	25	
11	Foundation top surface out of plane	Y	AY1	15	
12	2F out of plane	Y	AY2	14	
13	4F out of plane	Y	AY3	13	
14	6F Out of plane	Y	AY4	12	
15	8F Out of plane	Y	AY5	11	
16	10F Out of Plane	Y	AY6	10	
17	12F out of plane	Y	AY7	9	
18	base top	FROM	R1	24	
19	base top	FROM	R2	23	
20	2F	FROM	AZ2	22	
21	4F	FROM	AZ3	21	
22	6F	FROM	AZ4	19	
23	8F	FROM	AZ5	18	
24	10F	FROM	AZ6	17	
25	12F	FROM	AZ7	16	
26	Column bottom strain		E11	49	Nishigai
27	Column Bottom Strain		E12	50	Nishiuchi
28	Column Bottom Strain		E13	52	East
29	Column Bottom Strain		E14	53	Dongwai
30	Column Bottom Strain		E15	54	Beiwai
31	Column Bottom Strain		E16	55	Kitanai
32	Column Bottom Strain		E17	56	Nannai
33	Column bottom strain		E18	58	NFLS

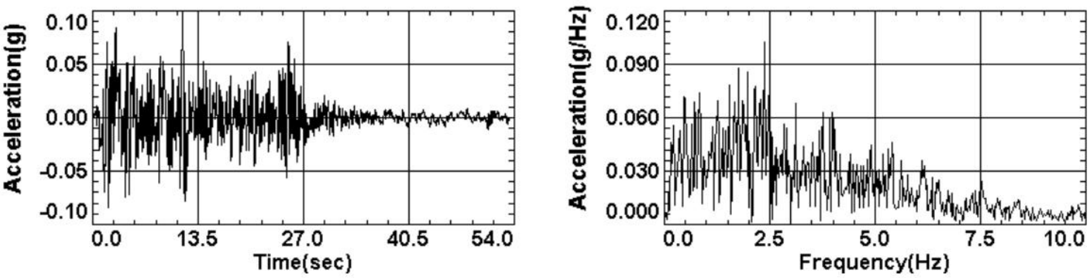
In the test, the NS component is selected as the X-direction input. Its time history curve and Fourier spectrum are shown in Figure 3 (the peak reduction ratio in the figure is 0.1g).

Kobe wave is the Kobe Marine Meteorological Observatory near the epicenter of the Hanshin Earthquake (M7.2) on January 17, 1995. Acceleration time history record. This earthquake is a typical urban direct-type earthquake, and the epicenter distance of the Kobe Marine Meteorological Observatory where the record is located is 0.4km. The duration of the main strong earthquake is about 7 seconds, the length of all recorded waveforms is about 40 seconds, the original recorded discrete acceleration time interval is 0.02 seconds, and the acceleration peaks of the NS component, EW component and UD component are 818.02gal, 617.29gal and 332.24gal, respectively. . In the experiment, the NS component is selected as the X-direction input. Its time-history curve and Fourier spectrum are shown in Figure 4 (the peak reduction ratio in the figure is 0.1g).

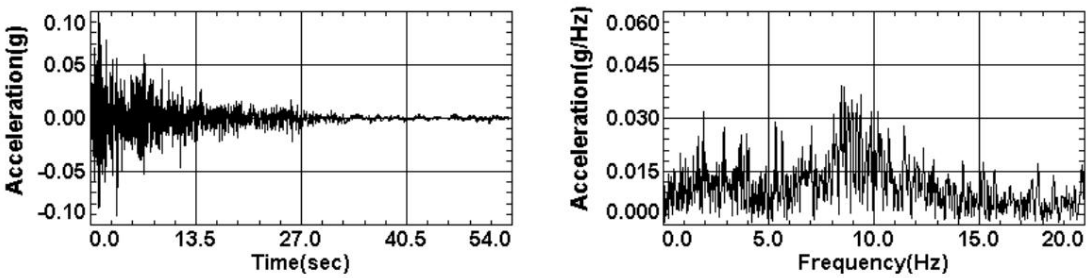
The duration of the main strong earthquake part of the Shanghai artificial wave (Shw2) is about 50 seconds, and the total wave length is 78 seconds. The discrete time interval of the velocity waveform is 0.02 seconds. Its time-history curve and Fourier spectrum are shown in Figure 5 (the peak reduction ratio in the figure is 0.1g). The duration of the main strong earthquake part of the Shanghai bedrock wave (Shj) is about 30 seconds, the whole waveform is 64 seconds long, and the discrete time interval of the acceleration waveform is 0.02 seconds. Its time-history curve and Fourier spectrum are shown in Figure 6 (the peak reduction ratio in the figure is 0.1g).



(a) X direction (NS component)

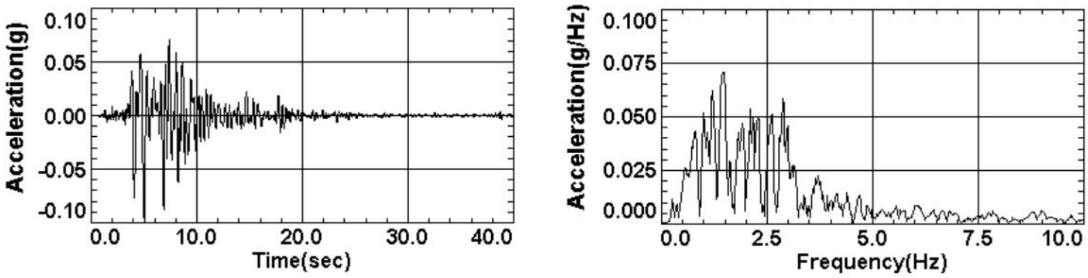


(b) Y direction (EW component)

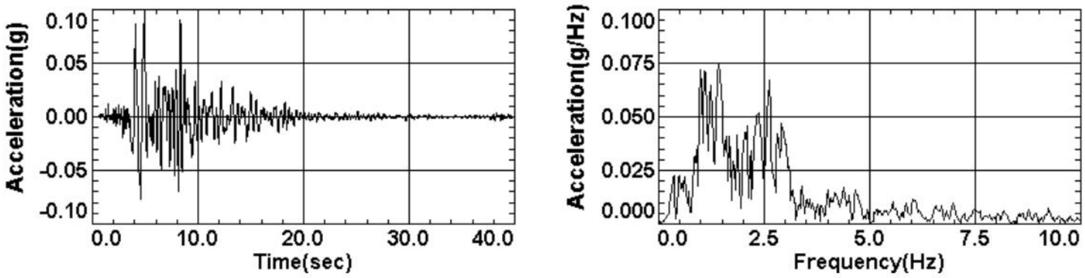


(c) Z direction (UD component)

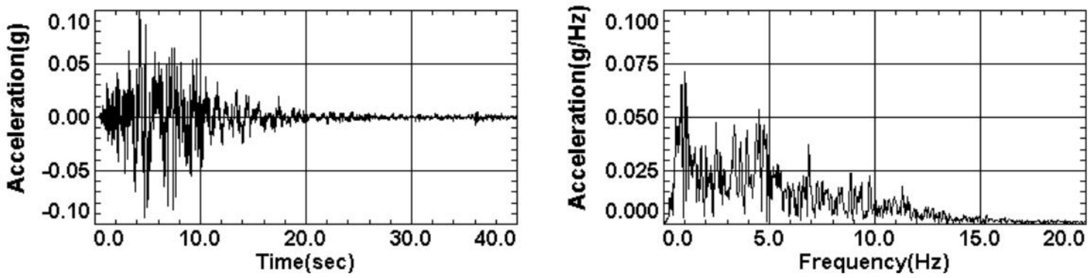
Fig.3 El Centro wave time history and its Fourier spectrum



(a) X direction (NS component)



(b) Y direction (EW component)



(c) Z direction (UD component)

Fig.4 Kobe wave time history and its Fourier spectrum

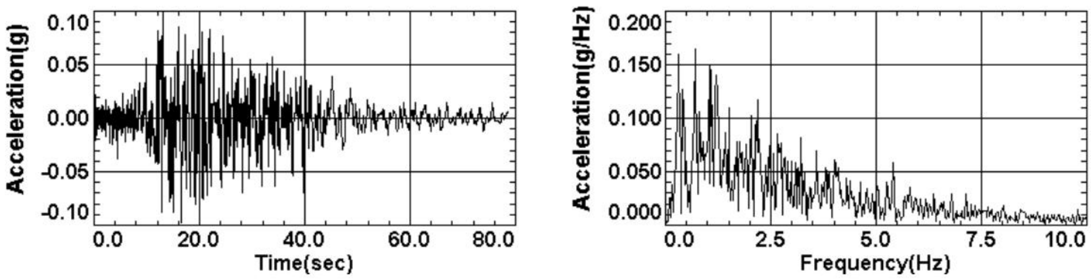


Fig.5 Shanghai artificial wave (Shw2) time history and its Fourier spectrum

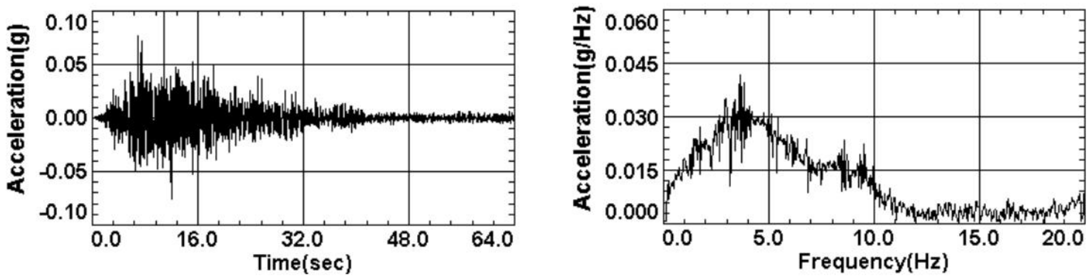


Fig.6 Shanghai bedrock wave (Shj) time history and its Fourier spectrum

2.7 Test loading system In the test, the

input acceleration peak value of the table is gradually increased by a small order, and the acceleration peak value and time period are adjusted according to a similar relationship. interval. The loading system is shown in Table 6. Each time the acceleration input is changed, a small amplitude white noise excitation is input, and the model system is observed. Changes in system dynamics.

3 Test Phenomenon

The model installed on the shaking table during the test is shown in Figure 5.

In the test, under the first 7 working conditions (equivalent to the prototype system withstand the seventh degree of earthquakes), and found no What cracks. After the 9th working condition SH2 (equivalent to the prototype system subjected to a seven-degree earthquake), the frame at the 4th floor parallel to the X vibration direction The beam ends of the beam first appear with subtle top-down and bottom-up The developed vertical crack, the crack width is less than 0.05mm. At the 16th condition Then, the beam ends of the frame beams on the 4th to 6th floors parallel to the X vibration direction There are vertical cracks with a width of about 0.08mm, which are not observed in each column Cracks; also not found in frame beams and columns parallel to Y vibration direction crack. After the 18th working condition SH3, the vertical cracks at the beam ends of the frame beams on the 3rd to 6th floors parallel to the X vibration direction pass through, and the maximum crack width At layer 4, about 0.15mm. After bidirectional EY3 in the 21st working condition, in the frame parallel to the Y vibration direction, on the 4th to 6th floors A vertical crack first appeared at the beam end of the beam, and the crack width was about 0.08mm. After that, as the input excitation increases, the cracks at the beam ends increase, and the cracked beams have The location develops upwards and downwards. After 62 working conditions, on the frame parallel to the X vibration direction on the north and south sides, 1ÿ There are cracks at the beam ends or column ends of the 10th floor, among which the beam ends of the 2nd to 8th floors are penetrated, and the 3rd to 6th floors are the most serious, pulled out or crushed, and the crack width is up to 4mm, forming plastic hinges; On the frame parallel to the Y vibration direction, the beam end or column end of the 1st to 9th floors There are cracks, among which the 3rd to 6th floors are the most serious. The beam-column joint is cracked or even pulled out or crushed. The crack width is up to 3mm, forming a plastic hinge. There are basically no cracks in the uppermost 2-3 layers. By the end of the test, the model had become an unstable maneuvering structure. S10H after the test The crack diagram of the frame structure is shown in Fig.6.

Figure 7 S10H test

Table **6 S10H** test loading regime

serial number	Working condition code	prototype			1/10 model			Remark
		X to	Y to	Z to	X to	Y to	Z to	
1	1WN	ÿ	ÿ	ÿ	0.07	0.07	0.07	
2, 3, 4, 5	EL1, SH1, KB1, SJ1	0.035	ÿ	ÿ	0.090	ÿ	ÿ	
6ÿ7	EY1ÿKY1	0.035	0.030	ÿ	0.090	0.077	-	Seven Degrees of Recurrence
7+	7+WN	ÿ	ÿ	ÿ	0.07	0.07	0.07	
8, 9, 10, 11	EL2, SH2, KB2, SJ2	0.1	-	-	0.258	-	-	Seventh degree
12ÿ13	EY2ÿKY2	0.1	0.085	ÿ	0.258	0.220	-	seventh degree
14ÿ15	EZ2ÿKZ2	0.1	0.085	0.05	0.258	0.220	0.129	seventh degree
16	16WN	ÿ	ÿ	ÿ	0.07	0.07	0.07	
17ÿ18ÿ19ÿ20	EL3ÿSH3ÿKB3ÿSJ3	0.15	ÿ		0.388	ÿ		
21ÿ22	EY3ÿKY3	0.15	0.128	ÿ	0.388	0.329	ÿ	
23ÿ24	EZ3ÿKZ3	0.15	0.128	0.075	0.388	0.329	0.194	
25	25WN	ÿ	ÿ	ÿ	0.07	0.07	0.07	
26, 27, 28, 29	EL4, SH4, KB4, SJ4	0.2	-	-	0.517	-	-	Octave
30ÿ31	EY4ÿKY4	0.2	0.17	ÿ	0.517	0.439	-	octave
32ÿ33	EZ4ÿKZ4	0.2	0.17	0.1	0.517	0.439	0.258	octave
34	34WN	ÿ	ÿ	ÿ	0.07	0.07	0.07	
35ÿ36ÿ37ÿ38	EL5ÿSH5ÿKB5ÿSJ5	0.25	ÿ	ÿ	0.646	ÿ	ÿ	
39ÿ40	EY5ÿKY5	0.25	0.213	ÿ	0.646	0.549	ÿ	
41ÿ42	EZ5ÿKZ5	0.25	0.213	0.125	0.646	0.549	0.323	
43	43WN	ÿ	ÿ	ÿ	0.07	0.07	0.07	
44ÿ45ÿ46ÿ47	EL6ÿSH6ÿKB6ÿSJ6	0.3	ÿ	ÿ	0.775	ÿ	ÿ	
48ÿ49	EY6ÿKY6	0.3	0.255	ÿ	0.775	0.659	ÿ	
50ÿ51	EZ6ÿKZ6	0.3	0.255	0.15	0.775	0.659	0.388	
52	52WN	ÿ	ÿ	ÿ	0.07	0.07	0.07	
53ÿ54ÿ55ÿ56	EL7ÿSH7ÿKB7ÿSJ7	0.35	ÿ		0.904	ÿ		
57ÿ58	EY7ÿKY7	0.35	0.298	ÿ	0.904	0.769	ÿ	
59ÿ60	EZ7ÿKZ7	0.35	0.298	0.175	0.904	0.769	0.452	
61	61WN	ÿ	ÿ	ÿ	0.07	0.07	0.07	

Note: EL - El Centro wave (X unidirectional); EY - El Centro wave (X, Y bidirectional); EZ - El Centro wave (X, Y, Z three directions);

KB - Kobe wave (X one-way); KY - Kobe wave (X, Y bidirectional); KZ - Kobe wave (X, Y, Z three directions);

SH——Shanghai artificial wave (X one-way); SJ——Shanghai bedrock wave (X one-way); XÿYÿZÿ1ÿ0.85ÿ0.5

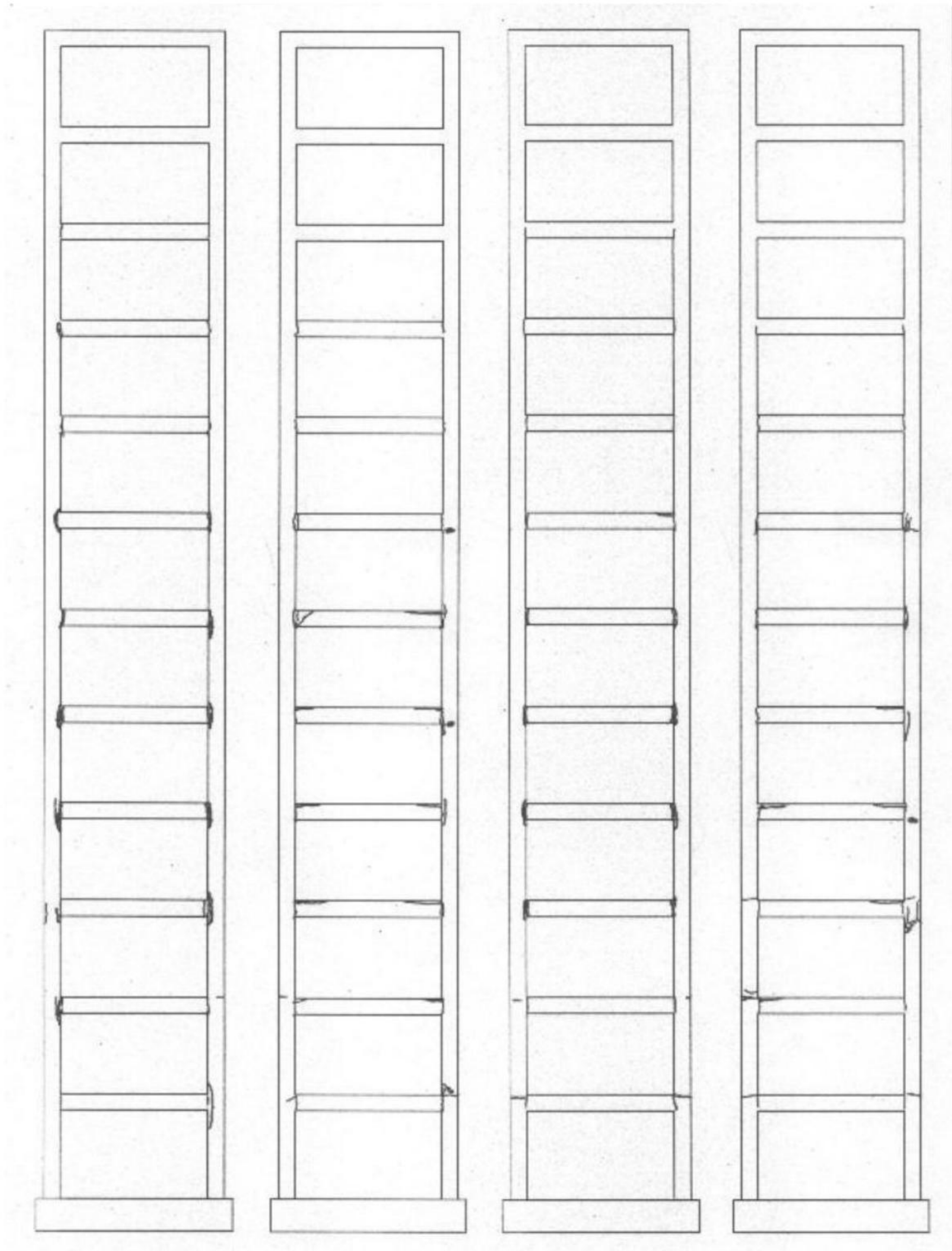


Fig.8 Cracks of frame structure after S10H test

4 Test data files

4.1 AutoCAD files

Model size and reinforcement drawing: S10H_Modal.dwg

Test point layout: S10H_Sensor.dwg

4.2 Input seismic wave data file

Filename: El Centro Wave: elx.txt ely.txt elz.txt

Kobe wave: kbx.txt kby.txt kbz.txt Shanghai artificial

wave: shw2.txt

Shanghai Bedrock Wave: shjibo.txt

Interval: 0.00392 seconds

Note: The input seismic wave peak value is reduced to 0.1g

4.3 Measuring point record data file

File name format: Example:

AY2 e1 s1h.dat

S10H test number

Working condition code, see Table 6

Measuring point number, see Figure 2

Interval: 0.00392 seconds

4.4 Transfer function data file

File name format:

16 trf 8 .txt

Channel number, see Table 5

Transfer Function

Working condition number, see Table 6