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SHAKING TABLE TESTS OF THE SHEAR WALL STRUCTURES WITH LARGE SPACE IN THE FIRST STORY

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SUMMARY

Two shaking table tests of scaled model of shear wall structure with large space in the first story have been taken for checking the design criteria and comparing the vulnerable point of different configuration. Due to the property of input excitation and the configuration, failure modes of two models are different. More attention should be paid to the shear and torsion resistance in seismic design of such kind of structures. Plastic control approach are effective for protecting the first story columns from damage.

INTRODUCTION

For setting up some commercial stores in the multi-story shear wall apartment buildings, a large space in the first story is often needed. It used to design column supported walls in such kind of buildings. Unfortunately, when earthquake occured, catastrophic hazards were found in most of them like the famous main building of Olive-View Medical Center, which constructed by shear walls supported with two-story columns was seriously damaged in San Fernando earthquake in 1972.

In order to avoid collapse and improve the seismic behavior under strong ground motion, it is suggested that only part of the shear walls be designed to have columns supported, the others be constructed from top all way down to the ground as shown in Fig.1.

Design criteria of such kind of shear wall structures are recommended as following:

1. In order to avoid stiffness changing remarkably between first and second floors, the number of shear walls, which go down to the ground, should not be too few, and they have to be thickened and/or to use higher strength concrete in the first story.

2. The first story of the shear walls (those go all way down to the ground, the same term used below) should neither be damaged by shear, nor yield. The plastic hinge should be controlled to develop at the second floor under strong motion. This has many advantages for protecting the supporting columns of the first story from large lateral deformation.

3. Attention should be paid to the configuration of the buildings. It is better to form some tubes from top to bottom symmetrically. Thus the torsion resistant capacity can be improved.

Two shaking table tests of small scaled models and other investigations, such as the tests of isolated shear walls with or without strengthened at the first story under cyclic loadings have been taken at'RISE (Research Institute of Structure Engineering) of Tsinghua University. The objectives of these investigations are:

1. To explore the failure mode and the vulnerable positions of the shear wall structures with large space at the first story.

2. To demonstrate the reliability of the criteria mentioned above.

3. To compare the behavior of two structures which have some differences in configuration.

Fig.1 illustrates the layout of two models. Both have two end tubes in the first floor. However the upper layout of these two are different as shown in figure. For model 1, the two end tubes and a small lenth of longitudinal wall at each end of the transverse wall go up to the top. While only a fish bone like wall arrangment is designed for the upper part of model 2.

Both models scaled 1/24 are with 5 bays, but with different stories.

SHAKING TABLE TEST OF MODEL 1

General Introduction Model 1 is 9 stories. The shear walls, which go down to the ground are strengthened in thickness and in reinforcement at first story. Moment resistant capacity coefficient (defined as the ratio between ultimate moment resistant capacity and the design flexural moment) of the first story is larger than that of the second story. See Table 1.

Model 1 was tested on a 15 KN electronic magnetic shaking table. During the first stage of test, input excitations in 4 runs were El-Centro 1940 EW earthquake record condenced by 1/8. During the second stage of test, the sine wave was used in 2 runs. All the excitations run in longitudinal direction of the structure.

Results During the first stage of excitation, only some fine diagonal cracks have been seen at the corner of doors.

However, under resonance, which was caused by the sine wave vibration during the second stage, the frequencies of model decreased rapidly. It was noted that, when the basic frequency decreased near to the value of torsion frequency of about 31 Hz, a rather long horizontal cracking suddenly appeared at the bottom of the second story. It started from one end wall and spread over in the longitudinal direction. After the second run of sine wave excitation, the cracks in the second story were developed, mortar began to crush. In addition, another long horizontal crack occured at the bottom of the third story. As shown in Fig.3, cracks distribute unsymmetrically. Severe cracking can be seen on one end wall, while no visible cracks on the other end wall.

It is considered that the structure was damaged by the overturning moment, which was mainly affected by the first mode in longitudinal direction and also the first mode in torsion. The acceleration response envelops in different runs are shown in Fig.4. Table 1 indicates the corresponding overturning moments and the moment resistant capacity of the first and second stories of the model 1. It is shown that, because of the larger capacity of the first story, yielding and damage were occured at the second story. Thus, the first floor, especially the columns were survived.

SHAKING TABLE TEST OF MODEL 2

General Introduction Model 2 has 11 stories. Test was taken on a large multi-degree electro-hydraulic earthquake simulator (see Fig.5). According to the law of similitude, the appended weight of 2.27 KN per story was added and arranged eccentrically for simulating the real situation in buildings.

Test runs are listed in Table 2. It was mainly El-Centro 1940 EW condenced by 1/5 in first stage and white noise wave in second stage. Most of them were excited in 2 horizontal directions simultaneously. The system of coordinate and the number of acceleration transduceres are shown in Fig.6.

Results 12 frequencies, modes amplitudes and damping ratios were obtained after data processing. The coupled phenomenon can be seen in most modes.

The fine cracks were found in end walls and the door corners in first floor during the 8th and 10th run respectively.

The critical damage was appeared after 15th run. The failure mode, which was characteristic of diagonal cracks and mortar spall in first floor walls and in 6-9th floor connecting beams, can be seen from Fig.7.

The frequencies decrease gradually after each run and the descending percentage of the first four frequencies are indicated in Fig.8. It is noted that, the fourth frequency (belong to the second mode) decreased faster than the first three. The causes of such kind of failure and frequency descending may be explained as following:

(1) There was a very strong input frequency component of 22.4 Hz from the shaking table itself, which changed the motion spectrum a lot. Therefore, the second mode amplitude has rather significant effect on the response, especially when the 4th frequency went to close the value of 22.4 Hz. The effect can be seen in Fig.9 from the envelop of inertia calculated by the measured accelerations.

(2) In this model, only one piece of shear wall in longitudinal direction exists. Torsion resistance mainly depends upon the transverse walls and it is vulnerable. In addition. shear resistant capacity of the walls and connecting beams have not designed strong enough comparing with their flexural capacity (only connecting beam of 2-4th floor have been strengthened).

Analysis indicated that if the end tubes of Model 2 were up to the top, the torsion effect would have mitigated to about 1/3.

TESTS OF ISOLATED SHEAR WALLS

8 specimens scaled 1/10 of 7-story shear wall with first story strengthened were tested and investigated under cyclic loading. Some results regard to the objective of this paper will brief here.

Due to large shear being transfered to the first floor level of shear walls, shear forces subjected by the first story walls must be much higher than that of the upper part.

2 specimens among the eight were similar to this situation, thus their shear-to-span ratio of the first story reduced to 1.38. Shear failure was found in both two specimens as shown in Fig.10.

When the plastic hinge developed at second story, the lateral deformation in first story was small. Fig.11 shows one example of the lateral deformation profile.

Only when the flexural moment resistant capacity coefficient of the first story is larger than that of the second story, the plastic hinge can be controlled to develop at second story rather than at first story.

CONCLUSIONS AND RECOMMENDATIONS

Shear wall structures with large space in the first story consist of two types of shear wall, column supported shear wall, and the shear wall constructed all way down to the ground. Safty of such kind of structures mainly relies on the later. According to the tests, the following conclusions and recommendations can be obtained:

1. Design criteria for such kind of buildings, mentioned at the beginning of this paper, are necessary and proper.

2. The plastic hinge control concept is efficiency in this kind of structures. In order to obtain a larger flexural moment resistant capacity in the first story, a design flexural moment for first story wall is recommended as following:

$$M_1^{des} = 1.25 \frac{M_2^{ult}}{M_2^{ana}} M_1^{ana}$$

where 1,2 represent the 1st and 2cd story respectively. "des", "ult" and "ana" mean design value, ultimate moment capacity and analyzed value respectively.

3. For the shear resistance of the first story shear wall, not only the design shear should be determined by the flexural resistant capacity of itself.

but also should be checked the shear-to-span ratio of the first story. If the ratio is less than 1.5, the detailing of the first story shear wall need to be designed as a squat wall.

4. The failure mode of a structure is affected by the property of the ground motion and structure itself. The influence of high modes need to be considered, especially when the resonance of high mode will possibly develop in some regions.

5. Torsion and torsion resistance have to be considered carefully, even if in a symmetric layout structure. The torsion will develop after the cracks occured.

6. Only one shear wall in the longitudinal direction above the first story is not good for torsion resistance. It is suitable to have tubes through the height of the structure. And it also would be better to have all the transverse walls flanged.

REFERENCE

1. H.L.Zhu, E.H.Fang, "Shaking Table Test of A Shear Wall Structure Model With Large Space in the First Story" The Proceeding of 9th National Conference on Tall Buildings, Chengdu, China, (May, 1986).
2. P.J.Fu, E.H.Fang etc., "Shaking Table Test and Analysis of A Shear Wall Structure Model with Large Space in the First Story" The Proceeding of 10th National Conference on Tall Buildings, QingDao, China, (June, 1988).
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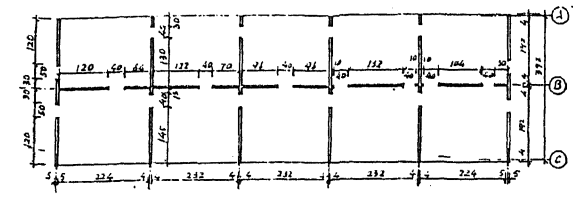
Table 1 Overturning moment and moment resistant capacity of model 1

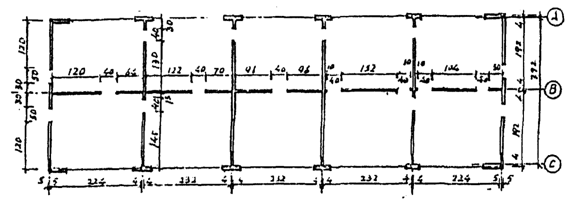
Story	Moment Resistant (KN-m)	Overturning Moment (KN-m)		
		earthquake p. acc. 1.674g	sine wave p. acc. 2.128g	sine wave p. acc. 2.258g
Second	16.5	7.313	13.45	19.62
First	33.7	7.464	13.66	20.12

Table 2 Input and response peak acc. of model 2

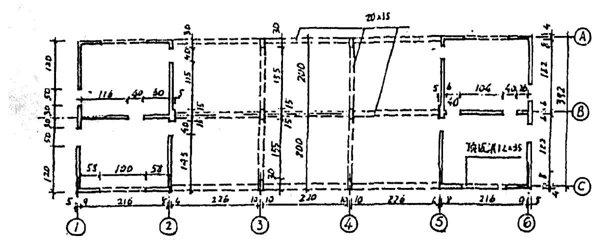
Sequence	Excitation	Direction	Duration	Input peak acc. (g)		Top response peak acc. (g)		
				X_{20}	Y_7	X_{14}	Y_1	Y_{13}
1	White Noise	X	4'30"	0.0628		0.086	0.041	0.045
2	"	Y	4'		0.035	0.018	0.045	0.047
3	El-Centro	X		0.0337		0.070	0.030	0.033
4	"	Y			0.051	0.029	0.077	0.084
5	"	Y			0.066	0.030	0.099	0.104
6	"	X,Y(1:1.04)		0.0578	0.060	0.134	0.109	0.103
7	"	X,Y(1:0.50)		0.224	0.111	0.252	0.158	0.171
8	White Noise	Y	3'20"		0.108	0.017	0.131	0.131
9	El-Centro	X,Y(1:0.22)		0.240	0.052	0.414	0.201	0.218
10	"	X,Y(1:0.52)		0.359	0.185	0.578	0.332	0.330
11	"	X,Y(1:0.52)		0.658	0.340	0.879	0.506	0.544
12	"	X,Y(1:0.62)		0.800	0.496	1.200	0.668	0.774
13	White Noise	X,Y(1:0.43)	3'30"	0.219	0.095	0.245	0.170	0.173
14	"	X,Y(1:0.70)	3'30"	0.455	0.317	0.550	0.592	0.504
15	"	X,Y(1:0.84)	3'30"	0.562	0.473	1.105	0.835	0.738
16	"	X,Y(1:1.21)	3'30"	0.742	0.894	2.880	1.863	1.045
17	El-Centro	X,Y(1:0.88)		0.805	0.708	1.520	0.750	0.718
18	"	X,Y(1:0.63)	2'	1.100	0.698	2.660	2.107	1.931



a) 2-11 floor plan of model 2

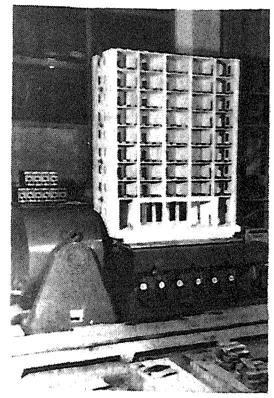


b) 2-9 floor plan of model 1

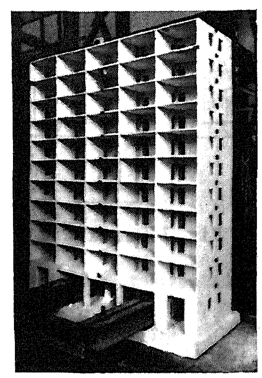


c) 1st floor plan of two models

Fig.1 Layout of models



a) Model 1



b) Model 2

Fig.2 Photo of models

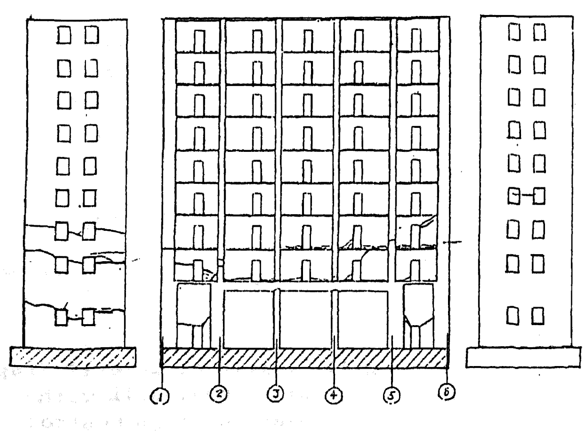


Fig.3 Crack distribution of model 1

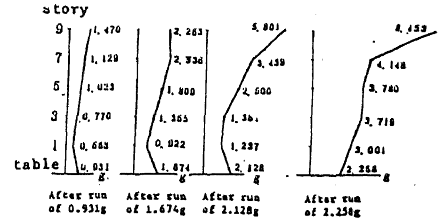


Fig.4 Envelops of max. acc. response of model 1

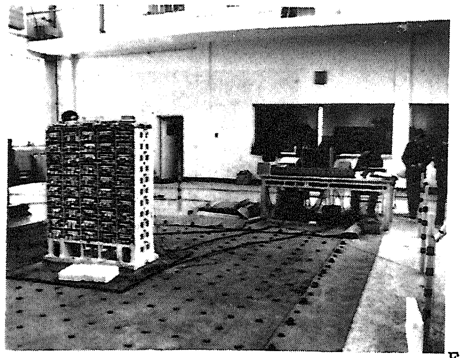


Fig.5 Model 2 on shaking table

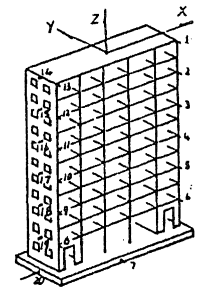


Fig.6 Measure points

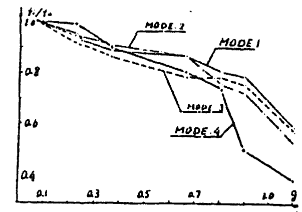


Fig.8 Frequency descending of model 2

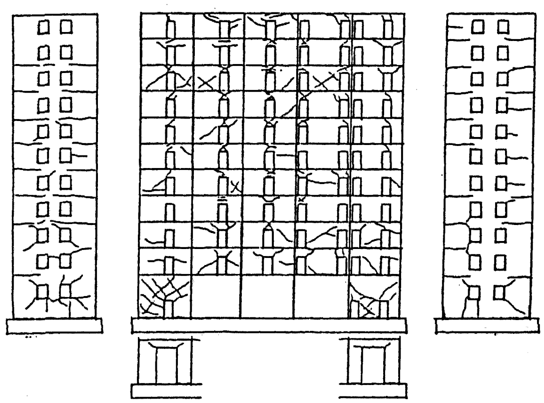


Fig.7 Crack distribution of model 2

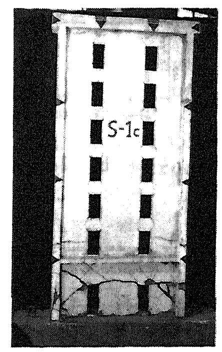
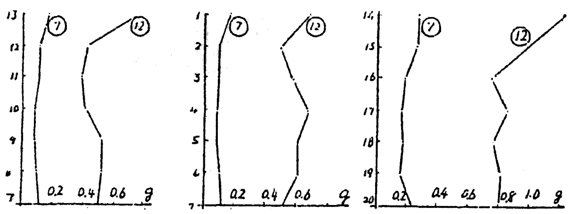
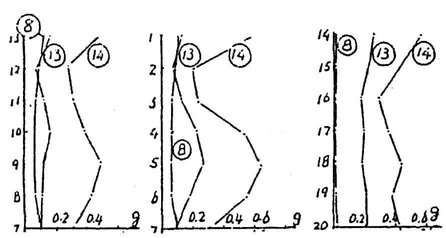


Fig.10 Shear failure of a shear wall specimen



a) under earthquake excitation



b) under white noise wave excitation

Fig.9 Envelops of max. acc. response of model 2

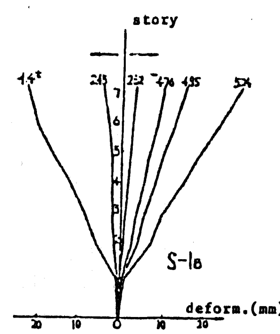


Fig.11 Profile of lateral disp. of a shear wall with plastic hinge control