EXPERIMENTAL RESEARCH ON SEISMIC BAHAVIOR OF MULTISTORY FRAME-SUPPORTED AND PARTIALLY FRAME-SUPPORTED SHEAR WALL STRUCTURAL SYSTEM

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SUMMARY

In order to investigate the seismic behavior of multistory shear wall structural system, among which there are a part of the walls supported by frame, seven specimens of frame-supported shear walls had been tested to simulate some actual building structures.

Tests with or without horizontal reactionary forces at the top level of the frames supporting the shear walls, considering the effect of elastoplastic action of the floor slab on frame-supported shear walls, were carried out respectively to simulate the restraining action given by those walls which are not supported by frames.

INTRODUCTION

In the frame-supported shear wall buildings, the structural rigidity is greatly reduced in the first story. Catastrophic failure might occur in the first story during strong earthquake motion, consequently total collapse of the building is unavoidable, this had been proved by the past earthquake lessons.

The behavior of the structure may be much improved, if sufficient amount of shear walls not supported by frames are reasonably arranged in the structural system. The floor slab just above the frame must be rigid enough in its plane to act as a transfer diaphragm through which the base shear of frame-supported wall can be transferred to the adjacent shear walls not supported by frames. Owing to the transfer action of the floor slab, the load exerted on the frame will be reduced. The load transferred by the floor behaves as lateral reactionary force applied on top of the frame. Considering the elastoplastic effect of the floor slab with the increment of in plane deformation, the reactionary force will decrease accordingly.

DESCRIPTION OF SPECIMENS AND OUTLINE OF EXPERIMENT

The first group of specimens (FW-1, FW-2, FW-3) was used to simulate a frame-supported shear wall of a 12-storyed shear wall building (REF.1). The prototype is shown in fig.1. The structure was designed to sustain

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an earthquake loading of intencity 8. Analysis of the structural system, considering the interaction of walls and frames gives the value of reactionary force exerted on top level of the frame to be 17.06 T.

The configuration and thickness of the specimen is 1/5 and 1/3.2 of the prototype respectively. The specimens consist of four lower stories of the proto-structure, as shown in fig.2, for simulation the shear force P_1, vertical force q and bending moment M were applied on top of the specimen. The bending moment M is converted into $P_1 L$, $(L = M/P_1)$

The loadings applied on the specimen are reduced proportionally and the horizontal reactionary force is

$$P_2 = -\frac{17.06}{5 \times 3.2} = -1.07^T$$

Specimen FW-1 simulates the prototype, specimen FW-2 is same as FW-1 except no openings on the wall, and specimen FW-3 is identical with FW-1 but no horizontal reactionary force exerted on the frame during experiment.

The second group of specimens (FW-4, FW-5) was used to simulate frame-supported shear wall of a 14-storeyed shear wall building (REF.2). The prototype is shown in fig.3 . Under the action of earthquake loading, a lateral reactionary force equals to 58.33 T is interacted at the top level of the frame under the shear wall.

Three lower storeys of the proto-structure were taken to form the specimens on the scale of 1/4, as shown in fig.4 . The horizontal reactionary force is:

$$P_2 = -\frac{58.33}{4 \times 4} = -3.65^T$$

Specimen FW-5 is identical with FW-4, except no reactionary force is applied during experiment.

Test of FW-4 was carried out in two stages. In the first stage, reactionary force P_2 is equal to 3.65T, and reduced to 2.72 T in the second stage to simulate the effect of deformation of the floor slab.

The third group of specimens (FW-6, FW-7,FW-7(1), FW-7(2)) was used to simulate two frame-supported shear walls of another 12-storeyed shear wall building (REF.3) . The prototypes are shown in fig.5 . As shown in fig.6, specimen FW-6 and FW-7 correspond with its prototypes on the scale of 1/4, the horizontal reactionary forces are -4.98 T and -4.70 T respectively.

As mentioned before, the tests of FW-6 and FW-7 were also carried out in two stages. Besides, as a third stage, specimen FW-7(2) was tested without reactionary force P_2.

ANALYSIS OF EXPERIMENTAL RESULTS

Load-bearing Capacity

In the course of testing, the hydraulic jacks for loading P_1, P_2 are operated by synchronized-control through the same pressure value, hence it is possible to use one unified value P_1 to judge the bearing capacity of various specimens. The experimental results are listed in table 1 .

It can be seen from table 1 that the difference between P_1 value of different specimens in the stage of cracking is very small. This is because the effect of reactionary force P_2 is not obvious with small displacement of the specimen. With the increase of experimental loading, the difference between bearing capacities of the specimens is enlarged, this explains the significant action of the reactionary force.

It can also be seen, the values of failure load P_1 considering reactionary force are 1.6 to 2.4 times greater than those disregarding reactionary force.

table 1

Group no.	Specimen	Compressive strength of concrete (kg·cm²)	P_2 Theoretic value (T)	P_1 (First stage)		P_1 (Second stage)	P_1 (Third stage)
				cracking (T)	failure (T)	failure (T)	failure (T)
I	FW-1	320	-1.07	5	12		
	FW-2	173	1.07	4	9		
	FW-3	178	——	3	5		
II	FW-4	325	-2.72	6		19	
	FW-5	352	——	5	12		
III	FW-6	351	-3.24	5	7*	18	
	FW-7 (1)	373	-3.05	5		12*	
	FW-7 (2)	373	——	5			9

NOTE: Symbol* illustrates that the structure is not failed at that loading.

Rigidity

The structural rigidity can be described by an equivalent value B.

$$B = \frac{P}{\Delta} \qquad (1)$$

where: P — converted horizontal loading at the top level (see fig. 7),

Δ — displacement at the top level.

The loading applied on the specimen can be converted to a force P exerted at the top level of the specimen. From fig.7 it can be formulated as following:

$$Ph = P_1 h + P_1 L - P_2 d$$

$$P = \frac{P_1}{h}\left(h + L - \frac{P_2}{P_1} d\right) \qquad (2)$$

Knowing the substitute force P and experimental displacement Δ, from eq. (1), the values of equivalent rigidity B corresponding to various loadings can be found, by comparison, values of rigidity degrading factor β are obtained.

Curves representing $\beta \sim \frac{P}{P_U}$ relationship are shown in fig.8, 9 and 10, where P_U is the ultimate loading. From these figures a common characteristic can be seen, specimens with reactionary forces have smaller top displacements and larger equivalent rigidities, in the process of loading the degradation is much slower than those frame-supported shear walls without reactionary forces.

Ductility

From the hysteresis loops measured at the top of specimen, the ratio of lateral displacement Δy relevant to the yielding of the structure and the ultimate displacement Δu corresponding to the failure of structure gives the value of ductility factor $\mu = \Delta u / \Delta y$.

It can be seen from table 2 that frame-supported shear walls with horizontal reactionary force applied at the top of frame possess higher ductility and higher load-bearing capacity.

Table 2

Group no.	Specimen	Compressive strength of concrete (kg cm²)	Direction of loading P_1	Yielding of structure		Failure of structure		$\mu = \frac{\Delta u}{\Delta y}$
				loading (T)	displacement Δy (mm)	loading (T)	displacement Δy (mm)	
I	FW-1	320	+	8	5.6	12	28.9	5.16
	FW-2	173	-	6	8.2	9	35.0	4.26
	FW-3	178	—	3.7	7.5	5	34.0	4.53
II	FW-4	325	—	11	3.6	19	25.9	7.19
	FW-5	352	+	8	3.5	12	15.0	4.28
III	FW-6	351	+	8	2.08	18	14.95	7.19
			-	8	1.68	18	9.18	5.46
	FW-7 (2)	343	+	6	9.40	9	30.27	3.22
				6	6.40	9	22.22	3.47

Specimen FW-7(1) is applied with a reactionary force, before P_1 = 12 T it is still in the elastoplastic stage. As to specimen FW-7(2), failure occurs when P_1=9T, the displacement is about 8 times that of FW-7(1) at the same loading, see fig.11.

Characteristics of cracking and failure

Under horizontal loading, crack appears firstly at the corners of wall and openings on the frame-supported shear walls with lateral reactionary force. The cracks extend at 45 degrees and along the wall-beam interface. Cracks occur on both ends of the external column and the beam-column joints successively. Finally, shear cracks extend through the whole wall-beam interface, the logitudinal reinforcements at both ends of the external columns yield consequently, and the structure collapses immediately.

As to the frame-supported shear walls without lateral reactionary force, lateral displacement increases rapidly, under horizontal cyclic loading plastic hinges are formed at both ends of the columns. The shear resistant capacity of the upper wall is not entirely developed and there are only very few cracks on the wall. Finally under the simultaneous action of horizontal and vertical loadings, owing to P-Δeffect, the columns fail on plastic instability.

The columns of the speicmens of second and third groups are totally detailed with closely spaced hoops, the ductility behaviour is much improved. In general, the failure loading of second and third groups are greater than those of first group, in which the column hoops are closely spaced only at both ends.

CONCLUSION

(a) Tests show that for the same frame-supported shear wall structure with or without lateral reactionary force representing frame-supported and partially frame-supported shear wall structures, the ductility factor and failure load of the latter is about 60% and 50% of the former repectively. Under the same loading the deformation of the latter is about 3 to 5 times that of the former. Hence totally frame-supported shear wall structural system is not recommended for aseismic buildings.

In a partially frame-supported shear wall structure system, lateral reactionary force is the most important factor to assure the load bearing capacity, ductility, rigidity and stability of the structure.

(b) In order to provide necessary lateral reactionary force on the frame-supported shear wall, the structural system must be so arranged that the floor slab just above the frame should have enough rigidity and integrity to act as a transfer diaphragm between two shear wall not supported by frames.

(c) For frame-supported shear wall it is extremely important to take measures assuring necessary ductility of the columns, such as providing closely spaces hoops for the whole height of the columns, preferably spiral hoops, besides, compressive stress in columns should be limited.

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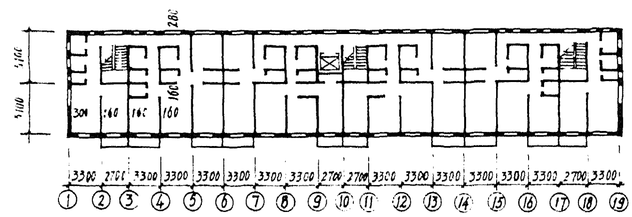
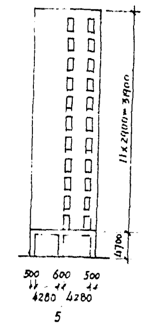
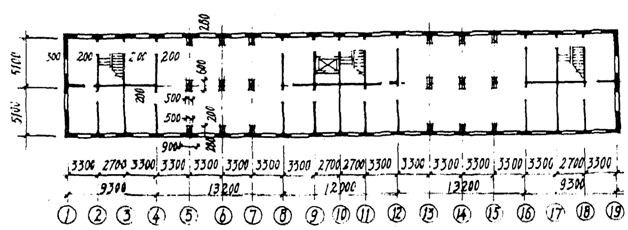


1b. typical floor plan



1c. frame-supported shear wall investigated



1a. ground floor plan
fig.1

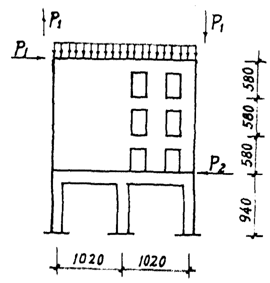
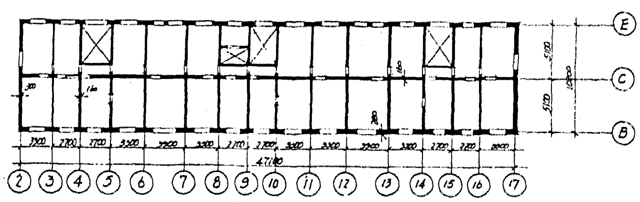
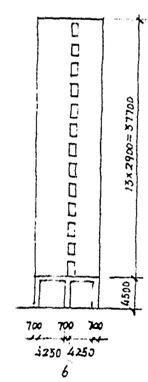


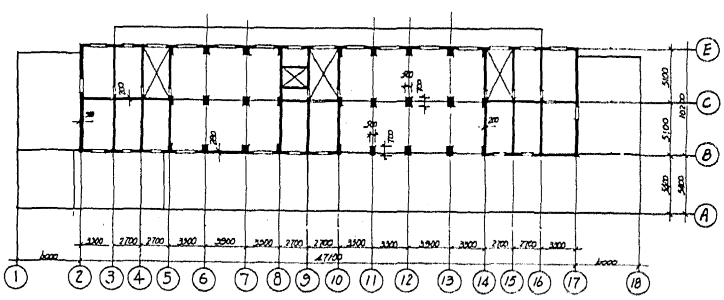
fig.2



3b. typical floor plan



3c. frame-supported shear wall investigated



3a. ground floor plan
fig.3

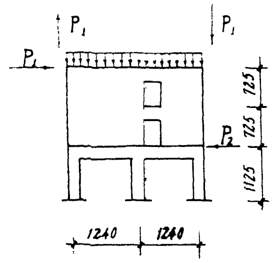


fig.4

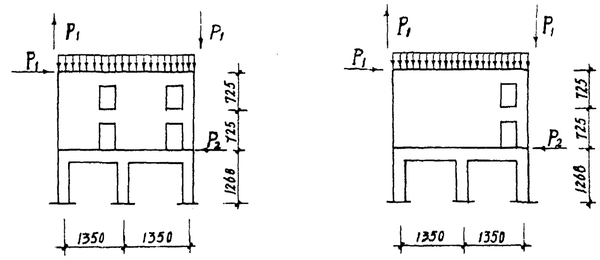
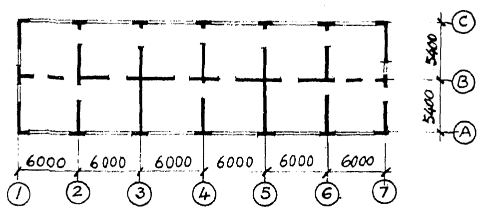
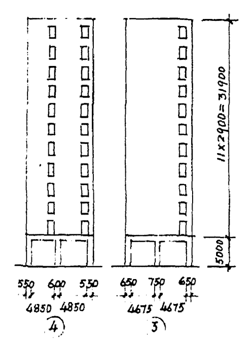
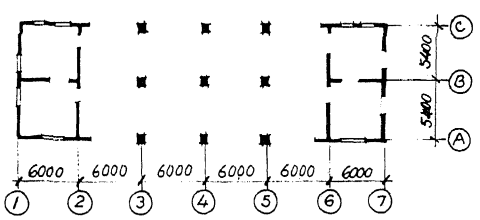


fig.6



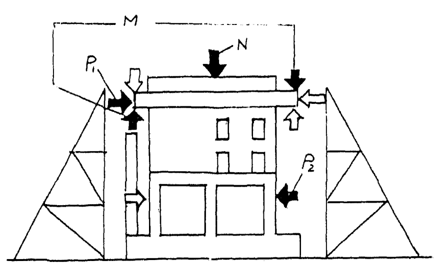
5b. typical floor plan



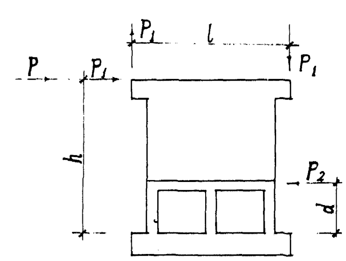


5a. ground floor plan
fig.5

5c. frame-supported
shear walls
investigated



7a. actual loadings applied
on specimen



7b. converted
horizontal loading P

fig.7

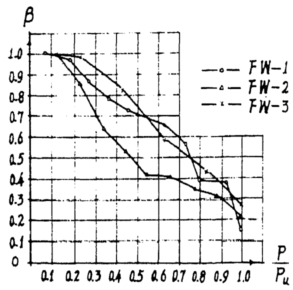


fig.8

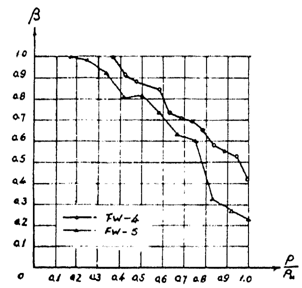


fig.9

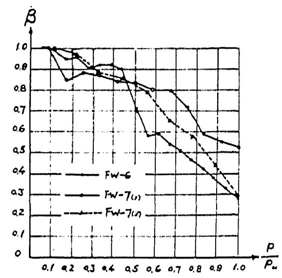


fig.10

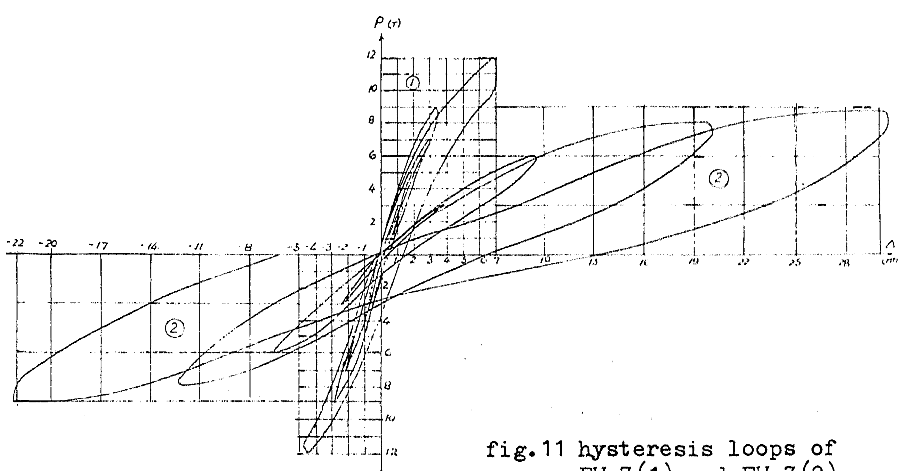


fig.11 hysteresis loops of
FW-7(1) and FW-7(2)