INVESTIGATION OF SEISMIC BEHAVIOR OF SHEAR WALL STRUCTURAL SYSTEM FOR LOW COST HOUSING

Xu Peifu (I)
Wu Lianzong (I)
Hao Ruikun (I)
Presenting Author: Xu Peifu

SUMMARY

In this paper, seismic behavior of a 5 - 6 story building for low cost housing with interior cast-in-situ reinforced concrete walls and exterior brick masonry walls has been investigated. Test results of strength and ductility of 33 reinforced concrete shear walls are presented. Collapsing mechanism in longitudinal direction of the building structure and interaction of exterior brick masonry walls with interior reinforced concrete shear walls have been investigated through model tests and earthquake damage analysis.

SYSTEM INTRODUCTION

This type of apartment building has been widely used in China. It is generally 5 to 6 storied with a floor to floor height of 290 cm. The 16 cm thick interior walls are reinforced concrete shear walls cast-in-situ by wall forms. The 37cm thick exterior walls are made of brick masonry. Prestressed reinforced concrete slabs are used as floor slabs. Between the interior walls and exterior walls, as well as between floor slabs and walls, structural columns and ring girders are used to connect each other. Fig.1 shows a typical floor plan of the building. Among the advantages of such housing system are as follows: (1) Exterior brick masonry walls possess better properties in insulation, waterproofing and finishing at a lower cost. (2) Due to the use of reinforced concrete walls cast-in-situ by wall forms and precast floor slabs, the time for construction is much shortened usually one story can be constructed within four days, and (3)The Seismic behavior of the structure is better than that of masonry structures.

TEST RESULTS OF SHEAR STRENGTH AND DUCTILITY OF SHEAR WALLS

33 reinforced concrete shear walls were tested including 5 shear walls with openings and 28 shear walls without opening.

Shear Strength

According to the shear failure test of 22 shear walls without opening subjected to reversed cyclic lateral static loading, formulas for calculating the shear strength of the wall were proposed:

$$\text{for} \quad m \leqslant 1.5 \quad Q_{kh} = 0.05 R_a b h_o + 0.2 N + R_g \frac{A_k}{S} h_o \qquad (1)$$

(I) structural Research Engineer, Institute of Building Structures, China Academy of Building Research, Beijing, China.

$$\text{for}\quad m > 1.5 \quad Q_{kh} = \frac{1}{m-0.5}\,(0.05\,R_a b h_o + 0.2\,N) + R_g \frac{A_k}{S} h_o$$

$$\geq 0.03\,R_a b\,h_o + R_g \frac{A_k}{S} h_o \qquad (2)$$

Where Q_{kh} = shear strength of shear wall,

N = axial pressure,

R_a = axial compressive strength of concrete,

b = thickness of wall,

h_o = effective depth of the section,

R_g = yield strength of steel,

A_k = area of horizontal wall reinforcement,

S = spacing of horizontal wall reinforcement,

m = shear - span ratio, $m = M/Q\,h_o$

M, Q = moment and shear force of the section

Fig 2 shows the comparison between measured values and calculated ones obtained from formula (1) or (2). It could be seen from Fig.2 that the ratios of measured values to calculated ones (Q^s_{kh} / Q_{kh}) are greater than 1.0. The mean ratio is 1.4. This ratio reduces slightly as axial compressive strength of concrete increases.

Ductility

Test results show the ductility ratio of flexure failural shear walls are greater than 3. Measured ductility ratios are 3.22, 3.29, 3.30, 3.54, 4.08 respectively for 5 flexural failure shear walls without opening. Another 5 shear walls with openings were also tested. Measured ducitility ratios are given in table 1.

SEISMIC BEHAVIOR IN LONGITUDINAL DIRECTION OF THE BUILDING STRUCTURE

Because there are many reinforced concrete shear walls in the transversal direction of the building, the seismic behavior in this direction is the same as that of ordinary shear wall structures. In the longitudinal direction, there are only one interior reinforced concrete wall and two exterior brick masonry walls. Seismic behavior in this direction will be presented as follows including damage mechanism and interaction of exterior brick masonry walls with interior reinforced concrete walls.

Damage Mechanism in longitudinal Direction of the Building

Investigation of the damage of 3 - 4 story brick masonry building in the July 28, 1976 Tangshan earthquake indicated that a lot of such buildings collapsed, because fewer and thinner longitudinal brick masonry walls were provided. Table 2 presents three pairs of examples. For buildings No.1, 3 and 5, shear failure occured in weak longitudinal walls at first, then out of plane collapse of the transversal walls followed with the final falling down of the precast floor slabs. In contrast, for buildings No.2, 4 and 6 located in adjacent site, though serious cracks occured in longitudinal walls but failure did not occured, and the buildings did not collapse during the earthquake. Test of the 6 and 8 story shear wall structural model (1/20 scale) on shaking table indicated similar damage mechanism (Ref.1). Shear failure occured in the longitudinal wall while horizontal cracks occured in the transversal walls. Finally the 2 gable walls in ground floor collapsed outward and floor slabs of the second floor falled down immediately.

The Spatial Behhavior of the Interior and Exterior Walls

The structural model with cast-in-situ interior shear walls and exterior brick masonry walls was tested under longitudinal reversed cyclic lateral static loading. The model is 3 storied (1/3 scale) (Ref.2). Test results indicated that the spatial effect of wall structures with mutually perpendicular longitudinal walls and transversal walls is quite evident and that exterior brick masonry walls and interior reinforced concrete walls do interact with each other. The calculated elastic stresses at the bottom of interior longitudinal wall with consideration of the spatial behavior agree satisfactorily with measured values (fig.3). The ratio of lateral loading carried by interior longitudinal wall and exterior brick masonry walls P_{in}/P_{ex} was found to vary from 1.6 to 2.5, the calculated ratio of which being 2.2. Fig.4 shows the relationship between the ratio P_{in}/P_{ex} and the top displacement. Fig.5 (a), (b) shows load-displacement relationship respectively for interior longitudinal reinforced concrete wall and exterior brick masonry wall. From Fig.5, it can be seen that there is greater degradation of stiffness and evident pinching effect in exterior brick masonry walls. The hysteretic behavior of the interior longitudinal reinforced concrete wall is better than that of exterior brick masonry walls. The energy dissipated by interior longitudinal wall was more than 75%.

CONCLUSION

1. Comparison between calculated and measured value of shear strength for shear walls indicated that the formulas (1) and (2) for calculating shear strength are on the safe side.

2. Ductility ratio of flexural failure shear wall is greater than 3. Ductility for shear walls with openings is better than those without openings.

3. Investigation of the damage of brick masonry structures in Tangshan earthquake as well as the test results of the spatial model showed that care must be taken to prevent longitudinal failure of the building structures.

4. Longitudinal brick masonry walls and reinforced concrtet walls of the building can interact with each other. The provision of longitudinal and transversal reinforced concrete walls improves significantly the seismic behavior of the building in the longitudinal direction.

REFERENCES

1. Research Group on Shear Wall Structures of Tall Buildings, Dynamic Experiments and Analysis of Shear Wall Structural Model, Journal of Building

Structures Vol.1 No.3 1980

2. Research Group on Multistory Apartment Building Structures, Investigation of Seismic Behavior for Mulistory Apartment Building Structures with Cast - in -situ Shear Walls by Wall Form, Journal of Building Structures Vol.1 No.1 1980

Table 1. Measured ductility ratios for shear walls with openings

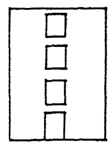
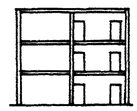
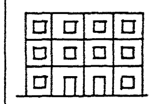
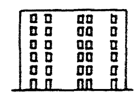
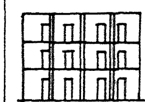
No. of specimen	SW-20	SW-23	SW-24	SW-25	SW-27
Shape					
Measured ductility ratios	6.6	3.6	9.7	7.55	9.55

Table 2. Comparision of earthquake damage examples for brick masonry building in Tangshan earthquake

No.	Collapsed in longitudinal direction				Not Collapsed			
	Name	b_1	b_2	b_3	Name	b_1	b_2	b_3
1	No.1 4-story (4 in total)	24	12 discontinuous wall	37 discontinuous walls	No.2 4-story (one only)	24	37 2 continuous walls	37 continuous walls
2	No.3 3-story (10 in total)	24	18 fewer walls	37	No.4 3-story (2 in total)	24	24 more walls	37
3	No.5 3-story (10 in total)	24	12 fewer walls	37 discontinuous walls	No.6 4-story (3 in total)	24	12 more walls	37 continuous walls

* b_1 — Thickness of interior transversal walls (cm)

b_2 — Thickness of interior longitudinal walls (cm)

b_3 — Thickness of exterior longitudinal walls (cm)

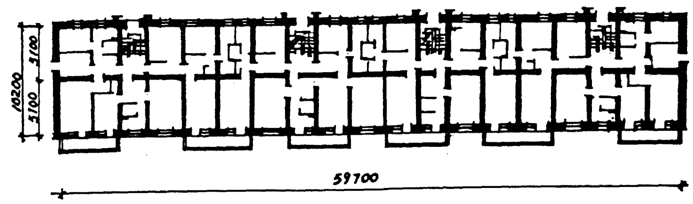


Fig.1 Typical floor plan of the building.

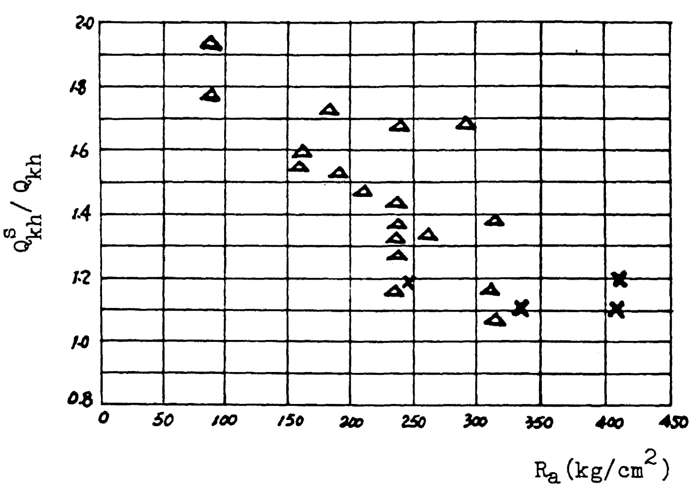


Fig.2 Relationship between ratio Q^s_{kh}/Q_{kh} and R_a for shear walls.

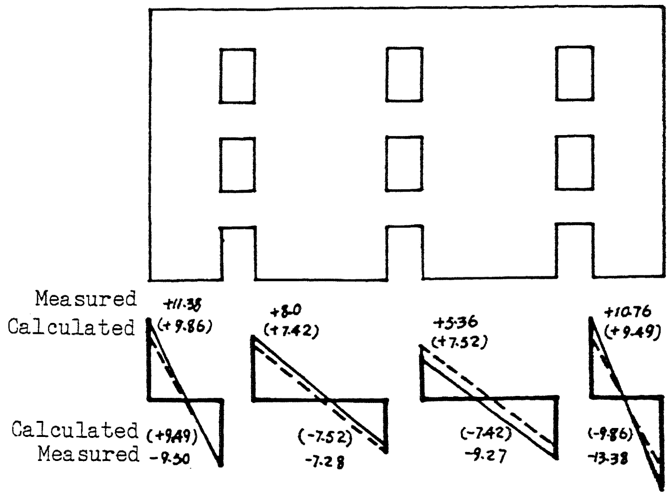


Fig.3 Comparison between measured and calculated stresses in the bottom section of interior longitudinal wall.

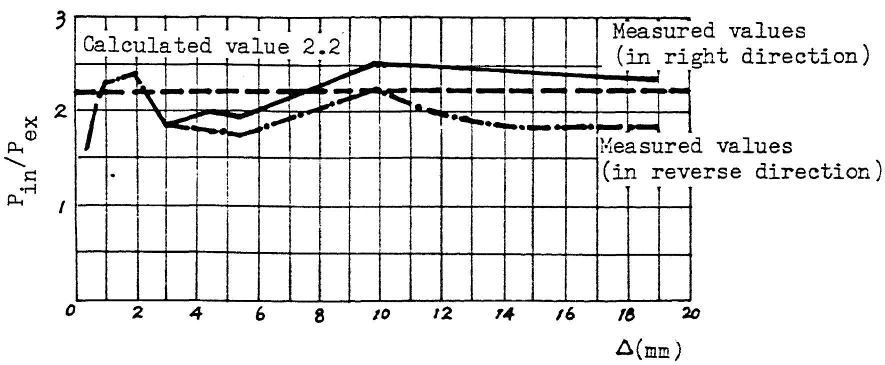
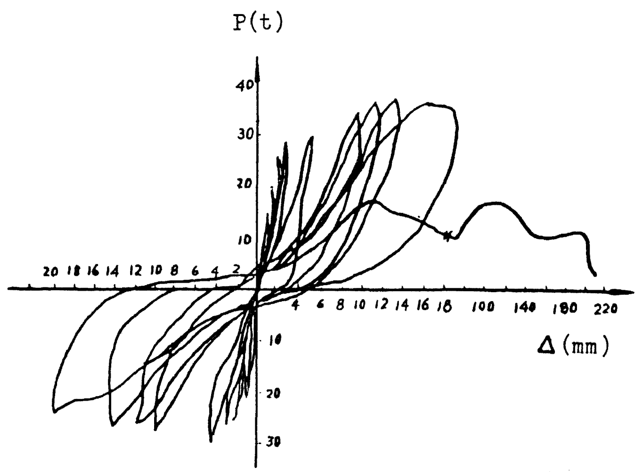
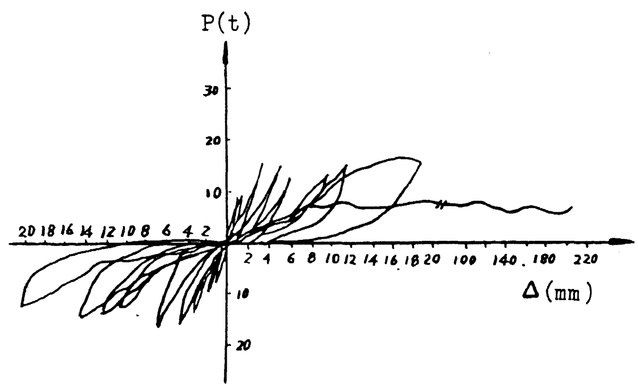


Fig.4 Relationship between the ratio P_{in}/P_{ex} and top displacement Δ.



(a) Interior longitudinal wall



(b) Exterior brick masonry wall

Fig.5 Load-displacement relationship for interior longitudinal wall and exterior brick masonry wall.