Experimental Study to Strengthen Two-story Brick Buildings with Precast Floor Slabs

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***Abstract*—Quasi-static tests on six two-story masonry buildings were carried out to study the seismic performance of masonry buildings. The paper presents the results of masonry building strengthened with RC beam-column to compare and study. The failure modes, load bearing capacity, deformability, ductility and stiffness degradation of the six models were investigated. The results show masonry buildings without tie-column and ring-beam need to be strengthened. After strengthening, the reinforced concrete column and brick wall have good interaction, as well as the RC beam and column can effectively enhance the deformability and ductility of brick masonry. Compared to tie-columns and ring-beams confined masonry structure according to the seismic requirements, the masonry building strengthened by RC beam-column can satisfy the requirements of the seismic fortification criterion.**

Keywords-Masonry building, quasi-static test, skeleton curve, ductility.

I. INTRODUCTION

In China, there are massive brick masonry houses constructed in last sixty or seventy's, these houses are mostly no seismic design. In 2008.5.12 Wenchuan earthquake, the earthquake damage of brick masonry buildings is very serious, 43% of brick masonry buildings constructed before 1978 need to immediately remove [1]. While in Beijing and Tianjin, brick masonry buildings similar to the building in Wenchuan have been used for many years, most of which is difficult to reconstruct. The masonry house built before 1980, does not meet the requirements for seismic resistance in Beijing, has been implied to seismic reinforcement.

In recent years, the research on seismic strengthening of brick masonry buildings has gradually increased. The reinforcement effects on masonry structure strengthened with external prefabricated reinforced concrete wall has been investigated [2]. The shaking table tests of 1/4 scale models are carried out to study the seismic performance of different models [3]. The results show that the base shear force of masonry structure may be greatly reduced when it is reinforced by the external prefabricated reinforced concrete wall. Two retrofit schemes use of fiber-reinforced polymers (FRPs) and precast concrete panels integrated on the HCT infill were employed [4]. The results indicated that the reinforcement method can significantly improve the earthquake resistance of building. The pseudo dynamic test of the brick wall with FRP [5] was carried out. In this paper, the method of seismic strengthening of masonry structures with external prestressing is employed, and the comparison test of [6] is carried out. The paper makes a comprehensive review of the seismic strengthening methods of the multi story masonry buildings [7].

Brick masonry buildings employed external strengthening reinforced concrete beams and columns, the structure form change from brick masonry to concrete confined masonry. At present, most of the research is seismic reinforcement of brick masonry buildings. In this paper, three different houses were designed and compared tested, respectively for the brick masonry without column and ring beam, brick masonry set structure column and ring beam and seismic strengthening of reinforced concrete beams and columns of brick masonry building. To the above three kinds of brick masonry buildings, the static loading test is carried out to compare the seismic performance of masonry structure.

II. BUILDING DESIGN AND FABRICATION

A. *Building Design*

This single-bay, single-depth and two-floor masonry building resulted in 3600mm×2400mm, which had 2200mm each floor. The masonry structure was constructed with precast concrete floor slabs. The dimension of common fired brick is 240mm×115mm×53mm. The plan and elevation of buildings is shown in Fig. 1.

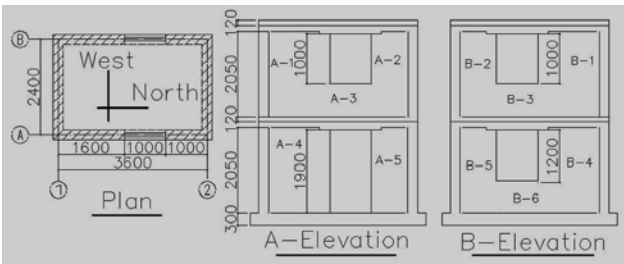

Figure 1. Plan view and elevation of building (dimensions in mm)

BM represents common brick masonry building without column and beam. CM represents confined masonry with tie-column and ring-beam. RM represents common brick masonry building reinforced with concrete column and beam. Six buildings were built while two for

BM/CM/RM. In CM, tie-column was arranged four corners of exterior wall. Cross-section of tie-column adopts 240mm×240mm, the longitudinal bars adopt 4Φ12, the spacing of stirrups is 200mm. The cross-sectional height of ring-beam is 150mm. the longitudinal bars adopt 4Φ12; the spacing of stirrups is 200mm. Fig. 2 shows the joint of tie-column and brick wall. In RM, Cross-section of L column adopts 600mm×200mm, the longitudinal bars adopt 12Φ12, the spacing of stirrups is 200mm. Fig. 3 and Fig. 4 show the joint of tie-column and brick wall.

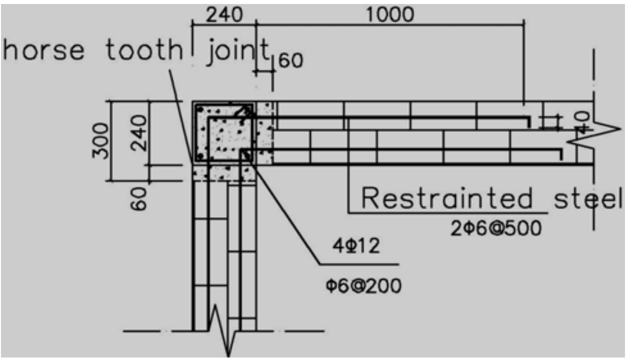

Figure 2. Joints: wall-to-tie-columns

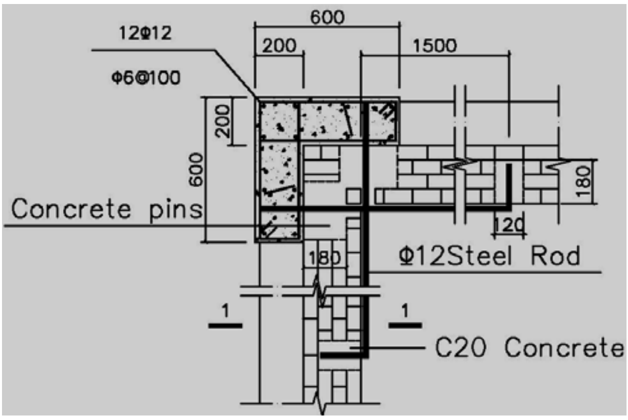

Figure 3. Joints: wall-to-concrete-columns

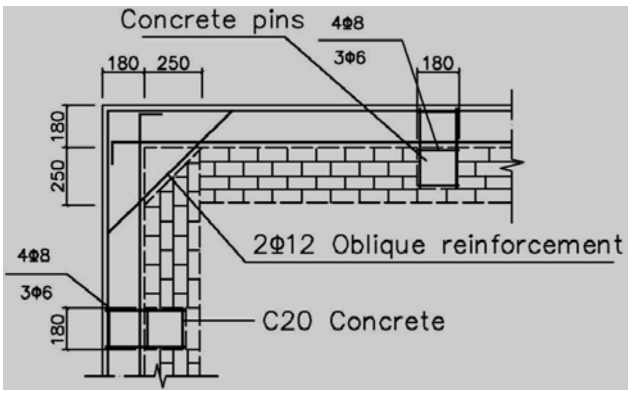

Figure 4. Joints: (wall-to-concrete-beams

The concrete strength grade of tie-column and ring-beam is C25. The floor and roof adopt precast reinforced concrete slabs (1200mm×3600mm). Door and window frames were constructed of timber sections. A view of the test buildings BM/CM/RM are shown in Fig. 5.

B. *Material Properties*

Bricks and mortar cubes were tested for compression. Similarly, concrete cubes were tested for compression. And masonry prisms were tested to evaluate masonry's strength in shear and compression. Bars tensile testing was applied. Average values of the material strength are presented in Table 1.

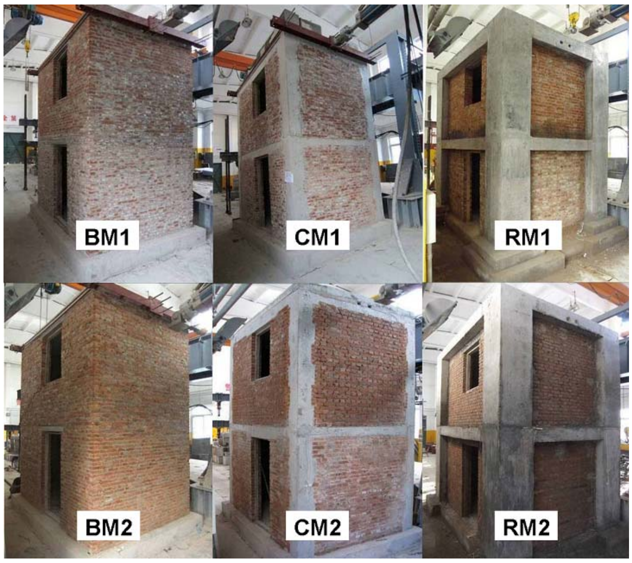

Figure 5. Six experimental models

TABLE I. Average material properties of specimen

Strength (Mpa)	BM1	BM2	CM1	CM2	RM1	RM2
Yield strength of reinforcement	-	-	335.43	370.83	366.45	354.94
Concrete compressive	-	-	27.62	26.25	28.40	25.56
Brick compressive	9.87	10.03	9.96	10.04	9.47	9.47
Mortar compressive	1.10	1.15	0.87	1.09	1.17	1.10
Masonry compressive	2.53	2.58	2.66	3.07	2.40	2.53
Masonry shear strength	0.12	0.11	0.10	0.11	0.10	0.10

C. *Test System*

The test setup consisted of one 500kN and ±250mm actuators located at the roof level, the steel-rod-beam was used to connect the actuators to the masonry walls at the connection points， as shown in Fig.6 and Fig.7. The structure was constructed on the concrete foundation slab which was fixed on the ground through two high-strength bolts. The test was conducted in displacement control, with a displacement profile based on the first vibration mode. The structure was loaded with increasing roof displacements and included one complete displacement cycles at each drift level. The displacements of the building under loading were measured by means of a set of LVDTs.

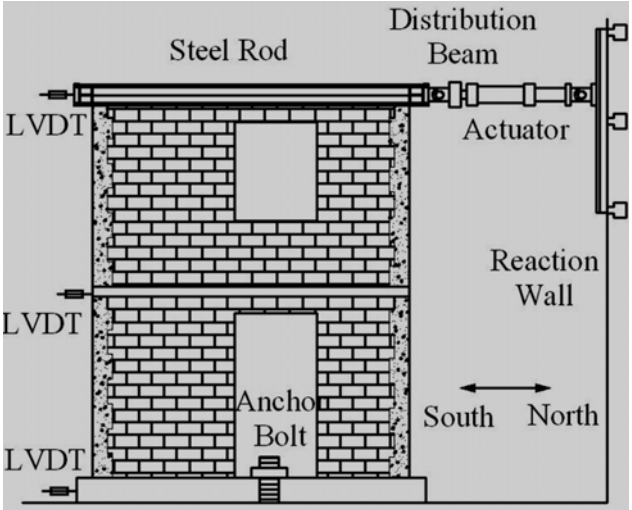

Figure 6.. Elevation view of Test loading system

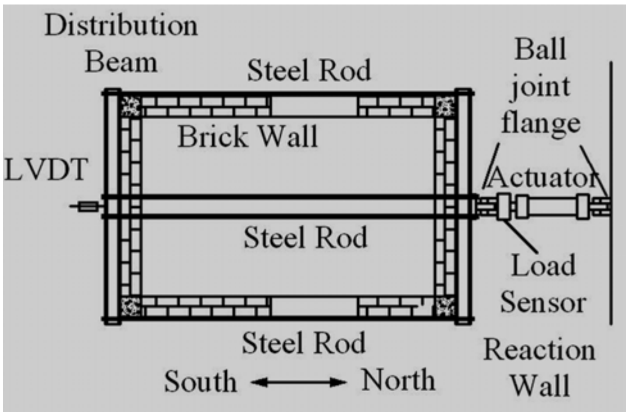

Figure 7. Plan view of Test loading system.

III. EXPERIMENT RESULTS

A. Hysteretic Behavior

Complete hysteresis loops between lateral resistant force versus roof displacement are shown in Fig. 8.

The initial crack and ultimate load of each model building was pointed in the Fig. (8). Hysteretic curve cycles mostly linearly at the first stage of the test. It is evident from the figure that with displacement increases, stiffness (slope of the curve) decreases, and the area under the hysteresis loops increases. The shape of hysteresis loops transfer from spindle -shape to the anti- S. The area of CM is bigger than BM. After masonry wall cracking, lateral stiffness of CM decreases rapidly. The ultimate lateral load of model RM is greater than model CM.

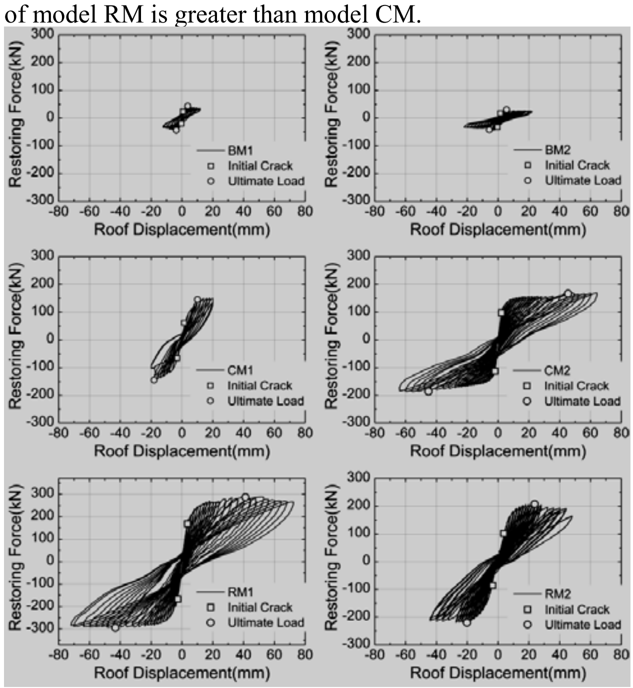

Figure.8. Hysteretic curves during low cyclic tests.

B. Skeleton Curve

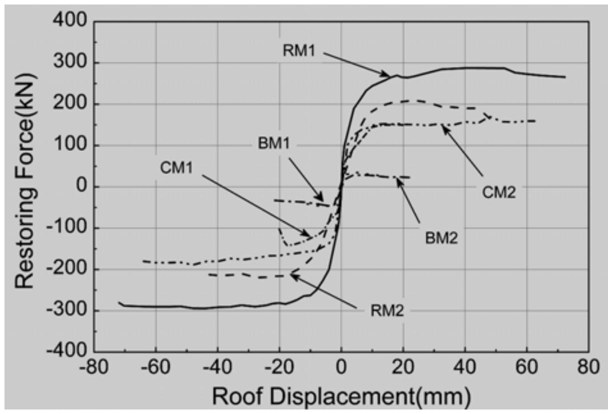

Figure9. Skeleton curves obtained from experiment

Envelop curves obtained from the hysteresis loops of the test models are shown in Fig. 9. Envelop curves obtained from the hysteresis loops of the test models are shown in Fig.9. It can be seen that, the ultimate lateral load and ultimate displacement of CM is greater than BM. The ultimate load of model RM with reinforced column and beam is as long as the CM. The load of CM and RM was not decreased when achieved the ultimate load. Meanwhile, the brick wall is cracked not to load. It can be realized that the lateral load was undertaken by the reinforced concrete

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column and beam. The key point of building-not-collapse is the column and beam.

Experimentally obtained resistance envelope can be idealized with a trilinear relationship [8, 9], representing the relationship between the lateral load and displacement during the lateral cyclic load test of the structure. Three characteristic points are defined on the experimental curve, determined by three pairs of parameters shown in Table 2. At the formation of the first significant crack in the wall, which changes the initial stiffness, elastic limit is determined by lateral load (P_{cr}) and displacement (d_{cr}). Maximum resistance is determined by lateral load (P_{max}) and displacement (d_{pmax}) Ultimate state is determined by lateral resistance (P_{dmax}) at maximum attained displacement (d_{max}).

It can be seen from Table 2 no matter concrete column like CM or reinforced column like RM, concrete column and beam play an important role in improving the bearing capacity of brick masonry buildings. Ensuring the reliable connection of the brick wall and concrete part, concrete column and beam can improve the bearing capacity of the building.

TABLE 2 Parameters of hysteretic envelops (average value)

Building	P_{cr} (kN)	d_{cr} (mm)	P_{max} (kN)	d_{pmax} (mm)	P_{dmax} (kN)	d_{max} (mm)	μ
BM1	25.46	0.46	40.50	8.12	34.29	11.98	4.40
BM2	21.87	0.69	37.21	11.57	27.55	21.90	4.46
CM1	93.30	1.35	134.96	10.01	102.19	19.04	7.41
CM2	108.06	2.01	179.42	37.91	153.28	63.95	11.09
RM1	189.29	4.00	294.84	32.58	265.85	72.29	8.15
RM2	145.27	4.15	214.38	23.95	165.44	47.88	7.15

Ductility factors (u) are also shown in Table 2. Ductility factor is defined by ratio of ultimate displacement (Δ_u) and yield displacement (Δ_y). Ultimate displacement (Δ_u) is determined by lateral load decrease to 85% P_{max}, or $P_{\Delta u}=0.85P_{max}$. Yield displacement (Δ_y) is determined by method of equivalent energy [10]. The average ductility factor of structure not set column and beam masonry building BM was 4.43 and structure CM with tie-columns and ring-beams was 9.25, meanwhile, average factor of building RM with reinforced concrete beams and columns is 7.65. The reinforced concrete column and beam play an important role in evaluating the deformation behavior of brick masonry buildings. CM and RM model are 108.8% and 72.7% grater, respectively, compared with the BM model, which shows that the CM and RM models have good ductility, and the ductility factor of CM model is larger than that of RM model 20.9%.

C. Stiffness Degradation

Strength and stiffness degradation took place when the masonry walls were subjected to repeated lateral cyclic load. Stiffness degradation is an important parameter within the scope of the cycle response of the buildings, as well as of the evaluation of their seismic performance. Secant stiffness at loading cycle was calculated in the test. According to Fig.(10), it is observed that the secant stiffness decreases rapidly as the lateral displacement increases. The initial stiffness of RM is about 22% more than that of CM. After cracking, the stiffness degradation of the model brick wall is obvious. The stiffness degradation of the CM model is slightly faster than the RM model. But with the increase of deformation, the stiffness degradation of BM is very fas. The stiffness degradation of RM is much slower than that of BM and CM. Finally, the stiffness of the model is reduced to 2% of the initial stiffness.

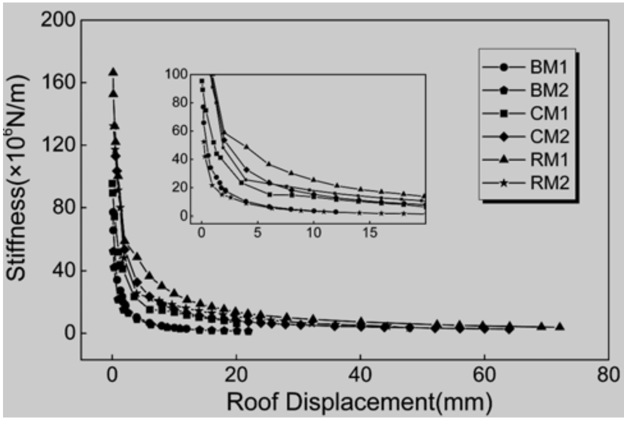

Figure10. Stiffness degradation curve of models.

IV. CONCLUSIONS

Six masonry buildings have been tested by subjecting them to pseudo-static tests. Seismic performance of buildings, as well as the effect of strengthening with concrete columns and beams has been contrasted and evaluated.

Reinforced concrete column and beam can greatly improve the bearing capacity of brick masonry buildings. No matter that the concrete column and beam is strengthened or confined, concrete part play an important role in improving the ultimate load of buildings. Under the premise of ensuring the reliable connection of the brick wall and concrete column and beam, the two part will be work together and resist exterior force like earthquake.

After strengthened by concrete column and bean, the brick masonry buildings without column and beam become combined structure which is brick and concrete structure. When reaching the ultimate load,, a large number of brick wall cracked, meanwhile, the bearing capacity of buildings mainly undertaken by the reinforced concrete column and beam, the integrity of the building strengthened by concrete part is good.

ACKNOWLEDGEMENTS

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