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Seismic Evaluation of Masonry Buildings Strengthened with Reinforced Concrete Beams and Columns

An Dong*, Qu Tiejun

School of Civil Engineering, North China University of Technology, Beijing

*hadesloveln@163.com

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Abstract. The pseudo-dynamic seismic tests and lateral cyclic load tests for tie-columns and ring-beams confined masonry structure according to the seismic requirements and masonry structure strengthened with reinforced concrete beams and columns have been carried out. Cracks propagation pattern, hysteretic curves, skeleton curves and stiffness degradation curves were compared and analyzed. The results from tests show that the brick masonry building with tie-columns and ring-beams has good ductility. The brick masonry building strengthened by RC beam-column can keep bearing capacity after serious cracking of masonry wall. The brick building strengthened by RC beam-column can satisfy the requirements of the seismic fortification criterion. The RC beam and column can be used as reinforcement measure to improve the seismic performance of brick buildings.

Introduction

Brick masonry structure is widely common in China. This type of structure is simple and easy constructed, applied in most of rural residential and public buildings. In previous earthquakes, a large number of masonry structures suffered various damage. In Wenchuan earthquake (2008.5.12)， most of collapsed brick buildings without tie-columns or ring-beams had weaker seismic system, and the precast slabs had no tied [1]. In Lushan earthquake (2013.4.20), the seismic damage patterns of masonry residential building without standard seismic design are complicated [2]. The masonry buildings are used in urban construction, and seismic design is an important item on the development of masonry structure. Confined masonry with tie-columns and ring-beams apply in post-earthquake reconstruction. Reinforcement has been added to improve the resistance of masonry. To improve the seismic performance of masonry structure is still concerned in recent research.

Two masonry buildings are designed and fabricated in this paper. One is brick masonry building with tie-columns and ring-beams, simultaneously; the other is strengthened with concrete columns and beams. Pseudo-dynamic and lateral cyclic load tests on two models were carried out in order to contrast failure mechanism and seismic performance of buildings, as well as evaluate the effect of strengthening with concrete columns and beams.

Building Design and Fabrication

The single-bay, single-depth and two-floor building with precast concrete slab was designed and constructed in this test [3-5]. This building is full-scale structure. It was intended to represent some structural characteristics of a typical existing building in China. The dimensions of the building were 3600mm by 2400mm in plan with story height of 2200mm. Fired common clay bricks with 240mm×115mm×53mm were applied in the buildings. The wall was designed with 240mm in thickness. The masonry structure was constructed on the concrete foundation slab.

CM is brick masonry building with tie-columns and ring-beams according to code or design of masonry structures [4]. The size of the cross-section of the structural column which set at four comers of the buildings is 240mm×240mm. The vertical steel reinforcements inside the column is 4Φ12, while the hooping thereof, Φ6 is adopted for common position with a spacing of 200mm. Concrete ring beams are placed at the floor. The size of the section of the ring beam is 150mm×240mm, while its longitudinal steel reinforcements is 4Φ12. Φ6 is used with a spacing of

200mm for hooping of beam. The intersection between the brick masonry and the structural column is laid into a shape of horse tooth joint with restrained steel reinforcements placed every 500mm along the wall height. RM is brick masonry building strengthened with concrete columns and beams. According to the code for strengthening 10, the size of the cross-section of the structural column which set at exterior comers of the buildings is 600mm×600mm. The vertical steel reinforcements inside the column is 12Φ12, while the hooping thereof, Φ6 is adopted for common position with a spacing of 200mm. Concrete ring beams are the same as CM. The rod of 2Φ12 placed every 500mm along the wall height between the masonry wall and the exterior concrete column, anchoring through the concrete pins. The concrete strength grade of columns and beams is C25. The floor and roof adopt two precast reinforced concrete slabs. Door and window frames were constructed of timber sections. Views of the test buildings CM and RM are shown in Fig.1.

(a) **CM** (b) **RM**

Fig.1 Experimental models

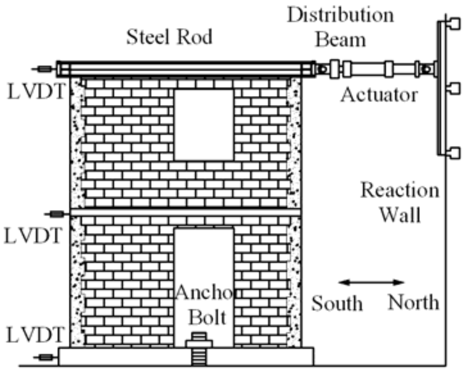


Fig.2 Test loading system

Test System

The test setup consisted of one 500kN and ±250mm actuators located at the roof level, as shown in Fig.2. The steel-rod-beam was used to connect the actuators to the masonry walls at the connection points. 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.

Ground Acceleration Selection

N-S component of San Gabriel of Northridge earthquake (Ms=6.7) of April 17. 1994, has been used to simulate the earthquake ground motion. The duration of the record is 46s (strong phase is 15s long), with peak ground acceleration 135gal. According to code [3], the acceleration record has been scaled to 180% assuming that models will be tested (Fig.3). The peak ground acceleration of model earthquake is 220gal. Consequently, the duration has been reduced to 30 s, whereas the accelerations remained unchanged. As can be seen in Fig.4, the response spectrum of the model earthquake for 5% of critical damping is contrast with the elastic spectrum [3].

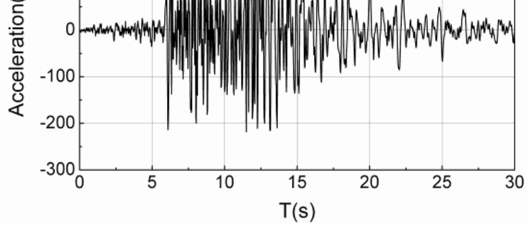


Fig. 3 Acceleration time-history of earthquake

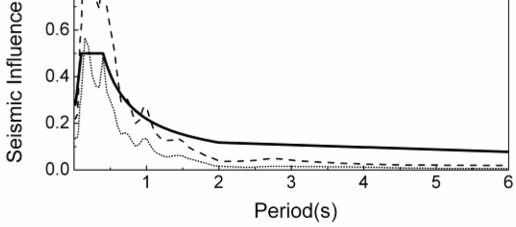


Fig. 4 Spectrum of scaled ground motions

Earthquake Response

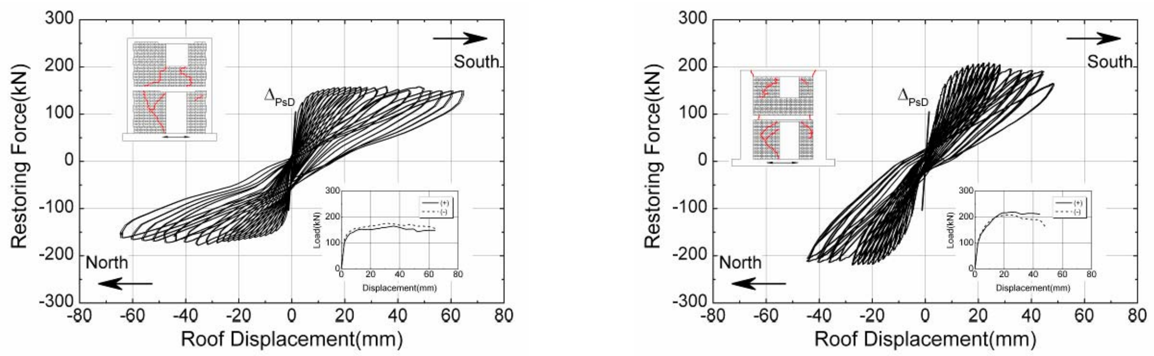
The maximum value of seismic response can be seen in Table 2.The peak displacement of CM and RM is 1.48mm and 1.42mm respectively. The maximum resistance of CM and RM is 81.5kN and 104.7kN. The peak acceleration of CM and RM is 546.7cm/s2 and 553.5 cm/s2。The acceleration amplification coefficient of the two models is respectively 2.49 and 2.52.

Table 2 Seismic response of building during pseudo-dynamic tests

	Acceleration[cm/s2]	Displacement[mm]	Force[kN]
CM	546.7	1.48	81.5
	-526.9	-1.11	-85.0
RM	553.5	1.42	104.7
	-553.9	-1.18	-103.3

Force-Displacement Hysteretic Behavior

Complete hysteresis loops between lateral resistant force versus roof displacement are shown in Fig.10. In the curves shown in Fig.8, maximum displacement values (ΔPsD) and envelopes are also presented. In the lateral cyclic load test, maximum displacement values of CM and RM are 63.95mm and 47.88mm, as shown in Fig.5. 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. After masonry wall cracking, lateral stiffness of CM decreases rapidly. The ultimate lateral load of model RM is greater than model CM.



(a) (b)

Fig.5 Hysteretic curves during low cyclic tests: (a) CM; (b) RM

Conclusions

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

The confined system of tie-column and ring-beam is effective to improve the poor seismic performance of the common brick masonry, by enhancing the lateral load bearing capacity. Reinforced concrete column and beam play an important role for improving the structural integrity.

The masonry building strengthened by reinforced concrete beams and columns can satisfy the seismic fortification criterion at present in the seismic intensity 7 or more zone in China.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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