Performance Evaluation and Retrofit of Existing Masonry Structures

Hongnan Wang¹,ᵃ, Fang Wang²,ᵇ and Huabo Liu ³,ᶜ

¹ College of Civil Engineering, Shanghai Normal University, Shanghai, 201418, China
² Yantai Vocational College, Yantai, 264670, China
³ Shanghai Key Laboratory of Engineering Structure Safety, SRIBS, Shanghai, 200032, China

ᵃ hongnanw@163.com, ⁱ b wf cc98@126.com, c huaboliu@163.com

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Abstract. Due to low construction cost, without requiring much technicality, good durability and fire resistance, masonry structure is widely used for buildings in China, especially in rural areas. Existing masonry buildings designed according to standards at the time of construction have not performed well in earthquakes. Obviously it is a potential safety hazard. Evaluation of past performance of masonry structures during earthquakes has led to more stringent design and construction requirements in the current building codes. Therefore, to improve seismic performance of masonry buildings, more and more existing buildings are in need of seismic retrofit to reduce their seismic vulnerability. Various retrofitting techniques are used to lessen the effects of earthquake. In this paper, a 6-story masonry building is used as a case study. The strengthening methods of adding tie columns and coating the walls with reinforced concrete layers are put forward. Some useful conclusions are obtained for references in the design of the similar projects.

Introduction

Masonry structure is widely used for buildings in China, especially in villages and towns, in which income levels are significantly lower than in cities. A large number of masonry structures are houses and schools, which, when struck by earthquakes, have resulted in severe damage. This phenomena has raised concerns about the performance of existing masonry buildings in future earthquakes.

Past earthquakes have shown that masonry structures are more susceptible to failure than other types of construction. For example, a great many masonry school buildings and houses collapsed, a lot of people were killed and even more people lost their homes during the 2008 Wenchuan earthquake. In the days following the devastating earthquake, a detailed survey of damaged buildings was performed. The reasons why so many masonry buildings failed to withstand the earthquake were showed. First of all, the common deficiencies of the buildings were caused by improper seismic design. A large number of masonry buildings, used for many years, was designed without considering the effect of possible earthquakes in accordance with the code requirements at the time of their construction. Next, The poor quality of the construction and construction materials increased the damage. In addition, A majority of the residential buildings in rural areas lacked sound design, even constructed independently by the owners without following any engineering rules.

Based on field survey and study of damaged buildings, in order to improve the seismic performance of buildings, a revision of Seismic Design Code (GB50011-2010) has been carried out. In 2016, a new revision of Seismic Design Code (GB50011-2016) was performed again. A primary goal of seismic design and code provisions is the protection of public safety in future earthquakes, implying that structures should have a relatively low likelihood of earthquake-induced collapse. In china, there has a large inventory of masonry structures, including many historical buildings, many of which have been repurposed and are still in use today. With the improvement of standards, more and more existing buildings can not satisfy the latest codes are in need of seismic retrofit to reduce their seismic vulnerability.

As an example we show a lately retrofitted dormitory building in Shanghai where adding tie columns and coating the walls with reinforced concrete layers were implemented. Many practical principles for strengthening of existing masonry buildings are obtained.
Description of the Building

A 6-story dormitory building is located in Shanghai, China, and was designed and constructed in 1984 per the applicable building codes at the time of construction. As illustrated in Fig. 1, the building is roughly rectangular in plan with middle corridor and represents the state of design and construction practice of the 1980s. It measures 15.65m wide (in NS direction) by 25.8m long (in EW direction). The overall height of the structure is 20.4m above ground. The material of load-bearing wall in this masonry structure is fired common brick of Class 10 (MU10) and the cement-lime mortar is grade M10. The thickness of load-bearing walls is 240mm.

Fig. 1 Reinforcement plan of a dormitory building

Standard of Seismic Evaluation

After the 2008 Wenchuan earthquake, seismic fortification class for educational buildings has been enhanced in the seismic category. According to Standard for Classification of Seismic Protection of Building Constructions (GB50223-2008), educational buildings have been given a higher seismic class. For educational buildings assigned to major fortification category, seismic requirements could be taken as one grade higher intensity than local fortification intensity. Therefore, seismic evaluation for this building should be taken as fortification intensity 8 because local fortification intensity in Shanghai is 7.

Structural Shortcomings

The design of the prototype building is in accordance with the provisions of Code of Design of Masonry Structure (GBJ3-73) and Seismic Design Code of Industrial and Civil Building (TJ11-78), which were much lower than current minimum design requirements. It was constructed based on the two old codes, without any structural seismic design.

The main deficiencies of the seismic constructional measures for earthquake resistance are:

- The total height (20.4m), which is larger than the 18m upper limit of code.
- Lower compressive strength of mortar compared with original design.
- Inadequate anchorage of slab reinforcement into the existing walls to transfer shear.
- The lack of tie columns.
- Inadequate capacity of some load-bearing walls: These exterior walls can’t meet height-to-length ratio in order to make room for windows.
- Inadequate integrality of the staircase due to the lack of tie columns and slabs.
The bad connection of the longitudinal walls with the transverse walls of the structure.

Less longitudinal reinforcement of the ring beams.

**Structural Analyses and Retrofit Methodology**

A finite-element model (FEM) of the structure was developed using the data of measurement survey. The mechanical properties of masonry were assessed on site by resiliometer. Fired common bricks used in these walls have compressive strength of 12.1 MPa and cement-lime mortar has compressive strength of 1.8MPa. Obviously, the compressive strength of mortar can’t satisfy the requirement of original design. The results show that the seismic capacity of many longitudinal exterior walls are inadequate. The rest of load-bearing walls can basically meet the requirements.

Based on the field measuring and computational analysis, to mitigate the above-mentioned seismic deficiencies, a comprehensive retrofit methodology was proposed. Retrofit approach in this case is mainly based on the idea of improving the structural stiffness by adding or strengthening some members of the structure. The components of the seismic retrofit are briefly discussed here.

- Tie columns were added to the four corners of staircase and exterior walls, as well as the junction of longitudinal walls and transversal walls. The columns were expected to significantly enhance the shearing resistance of the structure.
- A ring beam was installed at the perimeter of the top floor level to ensure the integrity of the strengthened system.
- The transversal beams were added to the middle corridor to improve the structural integrity in the north-south direction.
- Part of longitudinal walls between windows were strengthened by reinforced plaster. This technique involves coating the masonry walls with reinforced concrete layers. This method improves the out-of-plane resistance of masonry buildings because it increases the height-to-thickness ratio of the walls.

**Retrofit Design**

**Adding Reinforced Concrete Tie Columns.** For retrofitting of the structure, reinforced concrete (RC) tie columns were added at all corners and intersections. These tie columns should be connected with tie beams along the walls at floor levels for efficient confinement. At the same time, the reinforcing bars should be effectively bonded to the foundation, walls and all other beams above and below in each floor. The longitudinal reinforcements in the columns were ϕ14 bars. Fig.2 (a, b, c) presents a schematic illustration of the methodology.

**Coating the Walls with RC layers.** Reinforced plaster involves coating the walls with RC layers. This process starts with placing a mesh of reinforcing bars on the faces of the wall and covering the reinforced faces with a concrete layer. The shear transfer between the existing and new layers of concrete is ensured with concrete keys. This layer may be placed on one or both sides of the wall. The reinforcing bars should be anchored to the wall to ensure that the wall and RC layers work together(Fig. 2 d, e ).

**Conclusions**

Masonry structures have shown the severe vulnerability against seismic loads during earthquakes. This indicates the urgent need of strengthening these structures. To improve the seismic behavior of masonry structures, different strengthening methods have been studied.

The choice of retrofit methodology is based on failure mechanism of the structures and the lacks of load-carrying capacity and construction. Actually for retrofitting of any structures the detailed nonlinear analysis should be performed and then retrofitting technique is suggested based on results. Furthermore, the basic conceptual design is very important. Seismic retrofit should be considered both building-level and component-level requirements.
Fig. 2 Schematic representation of retrofit: (a) new tie column; (b) new tie column of exterior walls; (c) new tie column of interior walls; (d) reinforced plaster of walls at floor level; (e) reinforced plaster of walls at the bottom of roof boarding.

References


