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Experimental study on seismic performance of fire-exposed perforated brick masonry wall

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HIGHLIGHTS

- Seismic performance of fire-exposed perforated brick masonry wall is evaluated.
- Temperature distributions at different positions and depths of the wall are investigated.
- Two pieces of fire-exposed walls are reinforced with carbon fiber cloth and steel mesh cement mortar.
- Load capacity, energy dissipation, and stiffness degradation were quantified.

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ABSTRACT

The seismic performance of perforated brick masonry wall was investigated by subjecting six fire-exposed pieces and one unexposed piece to low reversed cyclic loading. Two of the exposed pieces were reinforced with carbon fiber cloth and steel mesh cement mortar. The effect of the fire duration, fire boundary, cooling regime, and reinforcement method on the failure characteristics of the specimens was investigated. The experimental results revealed that (i) for the same position, the temperature of the mortar was higher than that of the brick and (ii) the cracking load and ultimate load of the walls decreased progressively with increasing fire duration. Moreover, the ultimate bearing capacity of the wall reinforced by carbon fiber cloth and steel mesh cement mortar was higher than that of the wall subjected to the same fire duration. This capacity was also higher than that of the unexposed wall.

1. Introduction

Masonry structure has always played an important role in Chinese and global architecture. This structure is low cost and can be fabricated from various materials and through a simple construction process. Hence, this structure is used in various civil and public buildings. In China, reuse and reinforcement of the existing masonry buildings is important for the construction of cities. These buildings are, however, susceptible to fire damage. Nevertheless, a mature theory and method for properly assessing the safety and seismic performance of fire-exposed masonry structures is lacking. Therefore, (i) an evaluation of the mechanical properties and seismic performance as well as (ii) the development of a reinforcement method for fire-exposed perforated brick masonry structure are significant from both theoretical and engineering perspectives.

To date, research on the seismic behavior of fire-exposed masonry walls remains unreported. Studies have focused mainly on the thermal performance of masonry and the effect of elevated temperatures on the mechanical properties of single brick specimens [1,2]. The strength of clay brick masonry and mortar block masonry increases slightly at a temperature of 300 °C, but the strength of clay brick decreases with temperature. However, the reduction in the compressive strength of clay brick masonry is lower than that of clay bricks and mortar [1]. Moreover, the elastic modulus of clay brick increases slowly with temperatures of up to 600 °C, increases sharply (to 1.6 times the normal value) from 600 °C to 800 °C, and then begins to plummet [2].

Some researchers have conducted experiments and finite element studies on the mechanical properties of fire-exposed masonry walls [3,4]. The temperature, overall deformation, and degradation of local mechanical properties of clay brick wall with different thickness, node fixation, and vertical load have been evaluated. Results showed that the breaking and peeling of bricks is an important indicator of the fire performance of the fire-exposed loaded wall. After the experiment, the porous sintered clay bricks were analyzed via the finite element method. Furthermore, a three-dimensional numerical simulation was established for

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predicting the mechanical properties as well as fire and peeling phenomena of the wall [3]. The bearing capacity of masonry wall exposed to elevated temperatures has been investigated with the finite element software MasSET. That study revealed the influence of the slenderness ratio, load eccentricity, and the boundary conditions on the mechanical performance of the wall [4].

The effect of reinforcement on masonry walls exposed to room temperature has recently been investigated [5–13]. Reinforcement of the masonry structure with fiber materials yields significant improvement in the cracking load and ultimate bearing capacity; the seismic performance is also enhanced [5–7]. Reinforcement of an I-shaped cross-section brick masonry wall with carbon fiber cloth can yield considerable improvement in the shear bearing capacity of the wall [8]. The ultimate bearing capacity of a wall reinforced by CFRP sheet is 32 times the weight of the wall, and the deformation ability of the specimens was significantly improved [9]. The shear bearing capacity and stiffness of a masonry structure with holes can be restored to the pre-destruction level by reinforcing the mortar with single-sided steel mesh [10]. For concrete masonry wall reinforced with steel mesh cement mortar, the shear bearing capacity of the wall is basically the sum of the bearing capacities of the original wall and the surface layer associated with the low-strength mortar. In the case of high-strength mortar, the bearing capacity of the wall changes abruptly, owing to the brittle failure of the mortar. The addition of a steel mesh to the surface layer can, however, alleviate this mutation [11]. After the frame of a broken wall is reinforced by steel mesh cement mortar, the shear bearing capacity of the wall becomes higher than that of the wall prior to breaking. Moreover, the crack formed is smaller than that occurring in the unreinforced wall [12]. The shear bearing capacity of a wall reinforced with concrete mortar is significantly higher than that of the unreinforced wall. During the loading process, the vertical bar in the steel mesh contributes only modestly to the shear bearing capacity of the wall. In fact, the strength of the cement mortar on the steel mesh is correlated with the force of the original wall [13].

The seismic behavior of fire-exposed concrete structures has been considered in some studies [14,15]. In one case, the concrete columns were reinforced by carbon fiber cloth and glass fiber cloth, which can both improve the strength and ductility of fire-exposed concrete columns [14]. In another case, subjecting a shear wall to an external load had little impact on the shear bearing capacity and stiffness of the wall [15].

A literature review has shown that mature theories and methods for evaluating the safety and seismic performance of fire-exposed masonry walls are lacking. For restored use of the fire-exposed masonry structure, the extent of damage should be assessed, and the reinforcement scheme should be determined relatively quickly. The seismic performance of the structure must be calculated to determine whether the fire-exposed masonry structure can be reused after reinforcement. However, determining whether the fire-exposed masonry structure meets the seismic requirements is impossible via current standards. Therefore, in this work, the perforated brick masonry wall was subjected to fire tests and subsequent low cycle tests to determine the effect of different reinforcement methods on the seismic performance of the fire-exposed wall.

2. Fire test of perforated brick masonry wall

2.1. Experimental overview

2.1.1. Test specimens

This study was based on a fire-exposed masonry structure in Shanghai. Some of the walls of the masonry structure were exposed to fire on one side, but many walls were exposed to fire on two sides. Therefore, in our study, five specimens were exposed to fire on two sides and one specimen was exposed to fire on one side. Six perforated brick masonry walls, without loading, were subjected to the fire test. KP1-type perforated brick (strength: MU10, size: 240 mm × 115 mm × 90 mm) was selected in accordance with Chinese codes GB13544-2011 [16]. The arrangement of holes and dimensions of the brick (strength of brick: MU10, mean compressive strength: 10 MPa, strength standard value: 6.5 MPa) are shown in Fig. 1. The grade of the mortar (strength of mortar: M2.5) was designed using different proportions of cement, lime putty, and sand (1:1.14:9.4). The concrete strength of the top beam and the bottom beam was C25. The fire tests were all performed in the large-scale horizontal test furnace housed in the Southeast University Key Laboratory for Concrete and Prestressed Concrete Structure of the Education Ministry of China. Perforated brick masonry walls with sizes of 1500 mm (length)× 240 mm (width)×1865 mm (height) were heated in a 4000 mm (length)×3000 mm (width)×2000 mm (height) furnace; see Table 1 and Fig. 2 for the specimen description and dimensions, respectively.

2.1.2. Material properties

All specimens will be constructed in accordance with Chinese codes GB 50203-2011 [17]. The actual strength of the mortar was determined from three groups (six in each group) of mortar specimens (70.7 mm × 70.7 mm × 70.7 mm). The actual compressive strength of randomly selected masonry brick was measured during the compression test. After 28 days of curing, the average compressive strength of the cement mortar and the average compressive strength of the brick were 2.52 MPa and 12.91 MPa, respectively.

2.1.3. Test procedure

The fire test was based on the ISO 834 standard fire temperature curve, which was recommended by the International Organization for Standardization. Twelve thermocouples were placed in the same location of each specimen. Measurement points T1–T3 at embedded depths of 40 mm, 80 mm, and 120 mm, respectively, were designated for the same brick in the middle of the wall. Measurement points T4–T6 with embedded depths of 40 mm, 80 mm, and 120 mm, respectively, in the mortar joint were located at respective positions corresponding to T1–T3. These six measurement points allowed a comparison of the temperature at the same depth in the brick block and the mortar joint. The temperature distribution, i.e., the temperature recorded by each of the thermocouples placed at the aforementioned depths in the brick block and mortar joint, was determined. Measurement points T7–T12 corresponding to the positions of points T1–T6, respectively, were located at the bottom left of the wall. The array of 12 thermocouples is shown in Fig. 3.

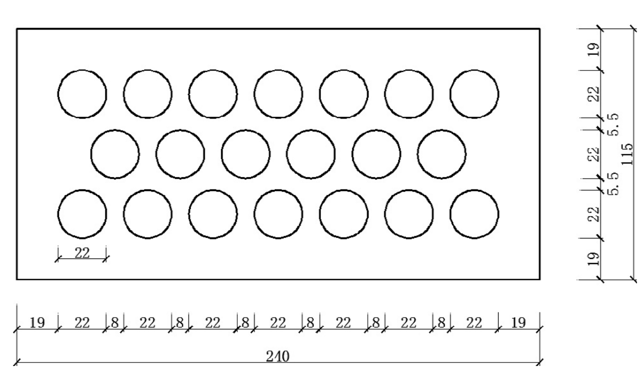

Fig. 1. Dimensions (mm) and hole arrangement of Type KP1 clay brick.