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Title	Development of Out-of-plane Strengthening System by Passive Compression for Masonry Walls

(800 words)

Masonry is one of the oldest structural systems and has been widely used over the world even after engineering materials such as concrete and steel had been introduced in construction. Brick masonry is still the most popular building component in developing countries due to its easy handling and cost-effectiveness. Masonry walls typically have low flexural capacities and possess brittle failure modes when exposed to out-of-plane loads.

The current study focuses on improving the out-of-plane performance of masonry walls. Field investigation was conducted on damaged buildings in a central region of Aceh province by the 2013 Aceh, Indonesia earthquake. Building structural systems in the area are roughly classified into four types: 1) reinforced concrete, 2) confined masonry, 3) timber, and 4) timber with masonry spandrel walls. Reinforced concrete and confined masonry suffered from moderate to heavy damage. On the contrary, damage to timber was none to light. The major cause of damage to confined masonry structures was out-of-plane failure of masonry walls. One of the collapsed buildings was focused to evaluate the minimum seismic resistance of masonry walls in the out-of-plane direction. As a result, it was found that the masonry wall collapsed because it could not withstand the intensity of the earthquake that occurred in the area. It shows a need to upgrade the out-of-plane performance of masonry walls to prevent such kind of collapse.

The new out-of-plane loading system for masonry walls is proposed in this study. Uniformly distributed loads are applied to masonry walls by using a rubber airbag. The test system was developed aiming at obtaining basic mechanical characteristics of simply supported masonry walls in the out-of-plane direction. A test with an aluminum plate specimen was conducted to verify the developed loading system. An easy to handle and lightweight specimen with dimensions of 190 mm x 10 mm for a cross section and a length of 900 mm was used. Consequently, the test results clarified good agreements between the experimental measurements and theoretical estimations.

This study proposes a new out-of-plane strengthening method for masonry walls with passive compression, which is applied to wall cross-section by restraining axial deformation with steel rods. The new strengthening system utilizes geometric deformation characteristics of masonry as well as the mechanism of conventional post-tensioning system. Outer steel rods are provided to apply compression to wall cross-section. Compression is passively induced with geometric axial elongation under out-of-plane loads which is caused by structural characteristics of masonry itself. The strengthening mechanism is implemented to verify its availability. Three brick wall specimens were prepared and tested with/without strengthening with dimensions of 190 mm x 140 mm x 900 mm in width x thickness x length (height). The M8 steel rods which were placed along the wall length and fixed to steel end plates provided on the wall ends are used for strengthening material. As a result, the proposed method significantly improved the structural performance of walls in the out-of-plane direction.

Moreover, a theoretical calculation procedure is presented for the performance evaluation. Verification of the proposed analytical method was conducted through simulating the experimental results of strengthened masonry walls. As a result, good agreements were observed between the experimental and analytical results on the performance evaluation of masonry. Thus, the proposed analytical method can be applied reasonably for estimating the out-of-plane performance of masonry walls strengthened by the proposed method. Moreover, the performance of typical masonry wall in Aceh was evaluated by applying the proposed analytical method. Finally, it was found that the proposed system can effectively improve the out-of-plane performance of masonry walls.