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Seismic performance of masonry wall retrofitted by truss system under In-plane cyclic loading

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ABSTRACT

Masonry walls consist of bricks and mortar, making them vulnerable to seismic forces. Seismic reinforcement technology using external prestressed reinforcement trusses can simply be used on existing masonry walls. This study evaluated the seismic performance of masonry walls with this applied technology. The masonry walls reinforced by this new reinforcement technique showed stable behavior and greater shear strength than the control specimen.

1. INTRODUCTION

Since the 1970s, masonry walls have mainly been used for low-rise buildings, and are still in use. However, the masonry walls which are unreinforced are expected to suffer significant damage such as a sudden collapse in an earthquake. Experimental research on the earthquake resistance performance of masonry walls has been actively carried out. Yang (2012) confirmed that shear strength and stiffness are improved when lateral forces are applied to the masonry walls reinforced with post-tensioning wire ropes. Gattesco (2014) used a glass fiber reinforced polymer (GFRP) mesh to study the diagonal compression stress of reinforced masonry walls.

The seismic reinforcement techniques proposed in this study were developed by referring to the method introduced by Yang (2020). This technology utilizes a prestressed rebar truss. The two vertical rebars introduced with prestressed rebar truss is applied to a compressed load in the masonry wall in order to strengthen the seismic resistance of the masonry wall.

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2. EXPERIMENTAL PROGRAM

2.1 Test specimens

In this study, one control specimen (unreinforced masonry wall, URM) and three comparison specimens were determined in order to analyze the reinforcement effect of the external prestressed steel-bar truss unit. The variable was the prestressing force acting on the two vertical steel bars, which was 10%, 20%, and 30% of a yield stress on the vertical steel bar. The upper concrete of all experiments was subjected to compressive force by converting the load of the upper layer.

The height and length of each masonry wall were 2400 mm and 2800 mm, respectively. All the masonry walls were covered with a 20 mm thick mortar. Concrete T-shaped beams were manufactured and installed on the top of the masonry wall.

The other three specimens had the same details as the URM, and the proposed four truss units were installed on both sides of the masonry wall. The height and length of the truss units were 2500 mm and 980 mm, respectively, with horizontal and diagonal bars of SD400 and vertical bars of SD600.

2.2 Materials

To measure material properties, masonry prism tests were performed in accordance with ASTM C1314 (2018) and ASTM E519/E519M (2015). The compressive and diagonal tension strengths of the masonry prism were calculated as the average values of the three specimens. The average compression strength of three masonry prisms with 20 mm thick plaster was 15.5 MPa, 1.47 times greater than that of the masonry prism without plaster (10.5 MPa). In addition, the diagonal tensile strength of the masonry prism with 20 mm thick plaster was 2.07 MPa, 1.8 times greater than that of the masonry prism without plaster (1.13 MPa).

2.3 Test setup and measurement plan

All of the specimens were subjected to both constant axial loads and gradually increased repeated lateral loads. The specimens were subjected to a displacement controlled lateral load, and the lateral displacement gradually increased by 0.125%. The vertical steel bars of the external prestressed steel-bar truss units were subjected to lateral loading with prestressed force applied.

3. EXPERIMENTAL RESULTS

3.1 Failure modes

In the case of C-URM, rocking cracks occurred between the wall and the foundation at a drift ratio of 0.125%. At the drift ratio of 0.25%, sliding failure occurred at the left bottom of the masonry wall. Finally, the test was terminated by destruction at the bottom of the left intersecting wall at 1.0%. For URM-PT1, a vertical crack occurred on the bottom of the intersecting wall with a drift ratio of 0.75%. The crack became wider according to an increasing drift ratio, and the test was terminated at a drift ratio of 1.33%, at which point the maximum shear strength was at 80%. For URM-PT2, horizontal cracks occurred at the back of the anchorage jig in the upper lintel beam. After that, vertical cracks occurred at the bottom of both intersection walls with a drift ratio of 0.625%. A vertical crack at the bottom of the intersecting walls of URM-PT3 occurred at a drift ratio of 0.5%. The test was terminated at a drift ratio of 0.63% because the conchoids of the vertical steel-bar were destroyed.

3.2 Shear capacity

The main experimental results of all the specimens are shown in Table 1. Compared with C-URM and Sample-C without plasters (Yang et al., 2020), the ultimate shear strength of C-URM was 1.2 times greater than that of Sample-C. The 20 mm plaster of the masonry wall helped increase shear strength and energy dissipation. The average initial shear strength ($V_{R,avg}$) and peak shear strength ($V_{p,avg}$) of URM-PT1 were 3.68 and 1.65 times higher than the average initial shear strength (77 kN) and peak shear strength (223 kN) of C-URM, respectively. After reaching the peak shear strength of URM-PT1, the post behavior was different from that of C-URM. This indicated that external prestressed steel-bar truss units can help to improve post behavior. The average peak shear strength ($V_{p,avg}$) of URM-PT2 was significantly lower than the average peak shear strength ($V_{p,avg}$) of URM-PT1 due to the failure of the top concrete beam. The hysteresis behavior of URM-PT3 was similar to that of URM-PT1, until the fracture of the vertical steel-bar conchoids.

Table 1 Summary of test results (Unit: kN)

Specimen	Failure mode	V_R^+	V_R^-	$V_{R,avg}$	V_p^+	V_p^-	$V_{p,avg}$
C-URM	Rocking and vertical cracks	101	52	77	212	233	223
URM-PT1	Rocking and vertical cracks	266	302	284	343	394	369
URM-PT2	Rocking, vertical cracks, and lintel beam failure	171	94	133	295	205	250
URM-PT3	Rocking, vertical cracks, and fracture of steel bar	298	329	314	313	351	332

4. CONCLUSIONS

In this study, we investigated the effect of external prestressed steel-bar truss units on the seismic performance of masonry walls. The external prestressed steel-bar truss unit system effectively increased the initial stiffness, peak shear force, and ductility of the masonry wall. In addition, the vertical and diagonal bars of the truss unit improved the behavior of the masonry wall after the peak shear force.

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