Retrofit of Un-Reinforced Infill Masonry Walls with FRP

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ABSTRACT: This paper describes an experimental program that deals with retrofitting of infill un-reinforced masonry walls (URM) with Fiber Reinforced Polymer (FRP). The primary objective of this research is to develop a retrofit strategy that while economical will minimize the influence of the retrofit on the overall performance of structural frames in predominant seismic regions. Allowing some damage to develop in the infill walls but guaranteeing that no out-of-plane collapse occurs under a moderate to strong seismic event will accomplish this objective. In parallel, analytical studies will aim at establishing design and strengthening guidelines for masonry structures.

The experimental work completed up to date includes the testing of three URM walls retrofitted with vertical rods and horizontal rods, commonly referred to as structural repointing (Tumialan, et. al., 2001). The slenderness ratio of these walls was approximately 22 and the aspect ratio was one.

1 INTRODUCTION

Structural frames infill with un-reinforced masonry walls are a common construction practice widely used all over the world. Although these infill walls are not assumed to contribute to the overall axial and lateral load resisting mechanism of the structure, it has been shown that the performance of structural frames is significantly affected by the presence of the infill walls. Seismic events around the world have shown that the presence of these infill walls greatly affects the load distribution path of the seismic forces. Infill URM walls are prone to significant demands under in-plane seismic loading, which tends to weaken the resistance of infill URM walls in the out-of-plane direction. This is a source of great concern because observed out-of-plane failures of infill URM walls during seismic events has lead many times to life and financial losses.

During the last few years, new techniques have been developed using FRP composites for repair and strengthening of URM walls. Three un-reinforced masonry walls without retrofit or retrofitted with FRP rods were tested to ultimate conditions under in-plane horizontal loading at the University of Missouri-Rolla. This paper describes some experimental results of in-plane loading of infill URM walls.

2 RESEARCH OBJECTIVE

After a comprehensive review of the literature (Dhanasekar et al., 1986, Stafford et. al., 1992, Leuchars et. al, 1976, Zarnic et. al., 1994, and Stuart et. al., 1993), integrated experimental and analytical studies were planned to investigate the capacity of infill URM walls under monotonically in-plane loading. The study reported herein is concerned only with the results obtained in the first series of tests, which include the following test units; (1) a controlled URM wall that is essential to obtain the mechanical behavior of concrete masonry units, (2) a wall retrofitted with vertical FRP rods, and (3) a wall retrofitted with horizontal FRP rods. These walls were tested to ultimate conditions.

These retrofit techniques were implemented to: (1) develop analytical models to predict the response of infill URM walls under in-plane loading, (2) minimize the stiffening effect of infill URM walls retrofitted with FRP materials by allowing some level of damage to occur in the walls, (3) no out-of-plane col-
Lapse occurs under a moderate to strong seismic event.

Analytical studies will enhance the experimental program by developing guidelines to predict the in-plane performance of infill URM walls. The design guidelines will complement existing documents developed by the American Concrete Institute (i.e., ACI-440H, ACI-440F, and ACI-530).

3 TEST SETUP

The test setup is shown in figure 1. The test frame consists of three main parts: a reaction frame, a sliding frame and a chair frame. The load was applied to the sliding frame by a hydraulic jack that was attached to the reaction frame by means of a wide flange section steel beam (WF). The concrete masonry units (CMU) were built on a reinforced concrete (RC) support block, which was tied down to the laboratory strong floor. On the top of the walls a reinforced concrete beam was installed, which was used to provide load transfer from the sliding frame to the walls. Two steel beams that were connected to the sliding frame accomplished the load transfers to the top RC beam.

During testing the sliding frame was restrained from rotation by a chair frame that was tied-down to the laboratory strong floor. This condition will simulate the double bending that URM walls experience within structural frames.

In order to prevent sliding of the walls at the interface between the bottom and top reinforced concrete beams, steel angles were attached to the RC beams at four locations. This was a necessary condition to simulate the boundary condition of infill URM walls under in-plane loading and restrained by adjacent columns.

The concrete masonry units were two-core hollow block that have the nominal sizes 4in.×8in.×12in. (10.2cm×20.3cm×30.5cm). The net area of the blocks was 27.75in.2 (179.0cm2) and the net area compressive strength was 1500psi (0.01MPa) based on the average of 4 unit tests. The nominal size of the walls was 88in. (223.5cm) high by 48in. (121.9cm) long by 4in. (10.0cm) wide. The slenderness ratio of these walls was approximately 22 (that is height versus thickness, h/t) and the aspect ratio was one (that is height versus width, h/w). The walls were built by a group of experienced masons using construction techniques representative of good workmanship.

The specimens were built in two continuous days; half of the wall panel was built during the first day and the other half was built the following day. Then the specimen was cured in natural condition for at least thirty days before testing.
Recorded forces and displacements included those measured by the load cell, linear voltage displacement transducers (LVDTs), displacement potentiometers and strain gages. The load cell was positioned between the hydraulic jack and the sliding frame, as depicted in figure 1. The LVDTs were installed on the top and mid-height of the walls to obtain the lateral displacements of the wall at the top and mid-height, respectively. At bed and head joints, displacement potentiometers were installed to obtain the flexure and shear components of deformation. Finally, strain gages were installed in the middle and at the ends of the FRP rods to measure the increased stains in the rods.

4 TEST MATRIX

The first part of this test program was developed to evaluate the in-plane performance of URM walls with different types of retrofit schemes.

As shown in table 1, the test units were as follows; (1) a controlled URM wall that will be used to obtain the mechanical behavior of concrete masonry units and establish efficiency of the different retrofit schemes, (2) a wall retrofitted with 4 - #3 (D9.53) vertical FRP rods, (3) a wall retrofitted with 10 - #2 (D6.35) horizontal FRP rods, and (4) a wall retrofitted with 4 – 2.5in. (63.5 mm) carbon FRP sheets.

Testing of the first three test units have been completed and testing of the fourth test unit is scheduled for completion in the near future. Table 1 presents the test matrix for this part of the research program.

5 EXPERIMENTAL RESULTS

Design codes around the world impose inter-story drift limitation to reduce among many other factors damage to non-structural components and personal comfort. In the United States the uniform building code (ICBO-UBC 1997) limits the inter-story drift to 2% for structures having a fundamental period greater than 0.7 sec., and 2.5% for those structures with a fundamental period less than 0.7 sec. Thus, one of the main objectives of the experimental part of this research program is to evaluate/assess the damage level of the tested walls within this two design drift levels.
Figure 2 presents the test results of the three test units completed up to date and the position of the 2% and 2.5% drift level for the tested walls. Test results indicate that before debonding of the vertical rods occurred, no significant difference was registered between test units 1B and 1C. However, after this damage level the response of test unit 1B was significantly different in relation to the response of test unit 1C.

The load capacity of test units 1B and 1C were approximately three and six times higher than of test Unit 1A, respectively. Preliminary investigation indicates that this condition may be due to the fact that with horizontal FRP rods, slipping of a column of blocks cannot develop and so the wall serves as a whole unit until the horizontal rods begin to pull-out. This leads to a preliminary conclusion that retrofitting of URM walls with horizontal FRP rods may lead to higher horizontal load capacities.

5.1 Test Unit 1A

Referring to figure 2, it is clear that test unit 1A never reached the allowable design drift levels for structural frames. This indicates that infill URM walls in structural frames designed within allowable drift levels are susceptible to significant damage levels. This observation is consistent with damage levels recorded during moderate to strong seismic events around the world.

Testing of this test unit was stopped at the lateral displacement of 1.0 inch (2.54cm) due to safety concerns. At this displacement level a significant crushing at the compression toe in the bottom of the wall as presented in figure 3 was observed. The maximum load for Test Unit 1A at approximately Δ=1.0 in. (2.54cm) was N=3.1kips (13.8kN).

5.2 Test Unit 1B

Test Unit 1B reached the maximum allowable drift level for standard frames; however for safety concerns the test was stopped at the displacement level of 2.38 in. (6.05cm). This test unit reached the maximum load of 7.5kips (33.36kN) at $\Delta=2.38$ in. (6.05cm). At the maximum displacement of $\Delta=2.38$in. (6.05cm) a significant wide-open crack at the top and bottom of the wall was observed, as depicted in figure 4. Strain penetration of the vertical FRP rods into the top and bottom RC beams was also observed indicating that the rods were efficient in transferring loads from the walls to the beams without pull-out of the FRP rods.

5.3 Test Unit 1C

Test Unit 1C reached the maximum allowable drift level for standard frames and went far beyond the requirement for standard frames. This test unit reached the maximum load of 19.1kips (84.96kN) at $\Delta=2.23$ in. (5.66cm). An overall diagonal crack formed when the load reached 12.81kips (56.96kN) at a deflection of 2.73in. (6.92cm) (see figure 5).

6 CONCLUSIONS

Three concrete masonry walls were tested to ultimate conditions under in-plane horizontal loading. The observed failure mode for the un-retrofitted wall (Test Unit 1A) was sliding failure of the wall along the second bed joint, and crushing of the masonry units’ compression toe at the bottom of the wall.

For test unit 1B the observed failure mode was sliding of the blocks in a single vertical column, crushing of the masonry units compression toe at the bottom of the wall, and pull-out of the vertical rods from the top and bottom reinforced concrete beams.

Finally, for test unit 1C, the observed failure mode was pull-out of the horizontal rods from the bed joints in the out-of-plane direction followed by rapid decrease in the horizontal load capacity. Thus, one of the essential steps of this research program is the identification of potential failure modes or limit states of repaired URM walls and its influence on the load capacity of URM walls.

As part of this research program, retrofit strategies will be developed to provide efficient and economical techniques that can be used to either rehabilitate...
or retrofit un-reinforced infill masonry walls with FRP materials.

Test results indicate that the retrofitted test units showed a significant increase in the horizontal load capacity and stiffness of the walls. These two conditions must be addressed in the seismic response evaluation of structural frames with infill masonry walls. One of the aspects related to the retrofit of infill masonry walls is the stiffening effect of these walls and its impact on the overall progression of the plastic mechanism of structural frames in low to high-rise buildings.

Regions selected to be primary energy dissipation locations, in case of a seismic event, may remain within the elastic range. This response will most likely lead to a significant increase in the displacement ductility demand at other locations. This condition may lead also to other significant catastrophic failures if a proper seismic evaluation of a building is not performed. This is an area of research that is of extreme importance and that will be addressed in the future as part of this research program.

7 REFERENCES


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