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Research Results

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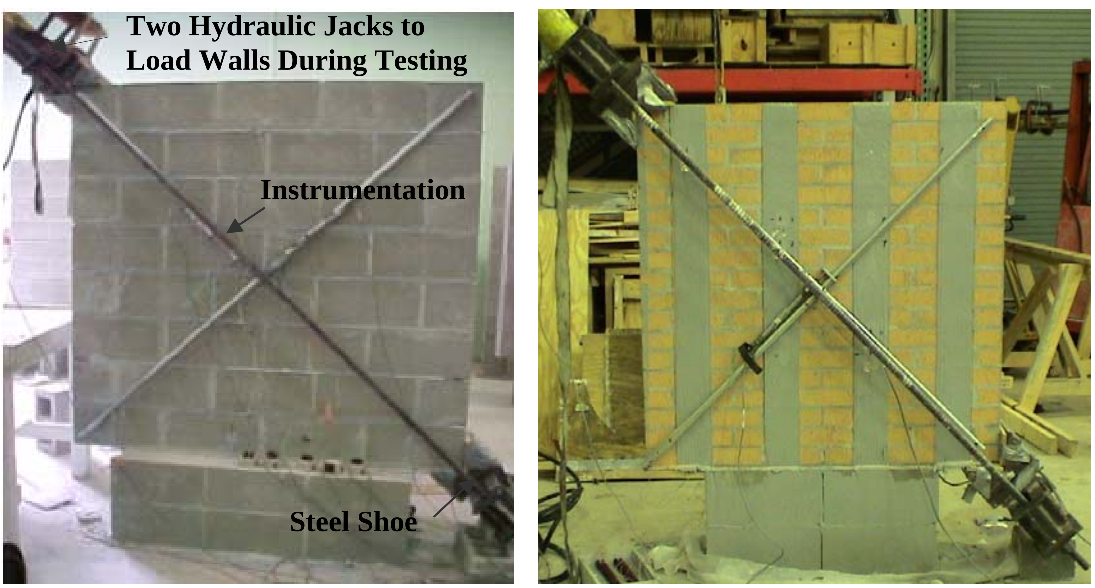
RB2C repair of buildings & bridges with composites

STRENGTHENING OF INFILL MASONRY WALLS USING BONDO GRIDS WITH POLYUREA

SUMMARY

Glass fiber reinforced polymer (GFRP) grids reinforced polyurea was used to strengthen unreinforced concrete masonry and clay brick (URM) walls. The URM walls were loaded to ultimate condition under an in-plane diagonal compressive force (see Figure 1). Different variables including amounts and directions of the polyurea were investigated. It was observed that the failure modes of the URM walls changed due to the strengthening schemes. Test results indicate that application of GFRP grid reinforced polyurea is an effective retrofit scheme for the walls, because the in-plane capacity of the strengthened walls increased significantly. A failure theory was modified to predict the shear capacity of the tested URM walls and the numerical results matched with the experimental results within a reasonable degree of accuracy.



a. Concrete Block Walls **b.** Clay Brick Walls

Figure 1. Test Setup

BACKGROUND

It is well documented that unreinforced masonry walls have demonstrated poor performance during earthquakes, and effective retrofitting schemes are needed to upgrade existing masonry structures. Traditional strengthening methods include: (a) filling of cracks and voids with injected grout; (b) stitching of cracks with metallic or other materials; (c) external jacketing; (d) external or internal post-tensioning with tendons; (e) externally bonding of fiber reinforced polymer (FRP) sheets; and (f) installation of glass FRP (GFRP) bars.

Seismic loads induce severe in-plane and out-of-plane force demands on infill masonry walls. For masonry infill frames, different failure modes can occur based on the interaction mechanism as well as the relative stiffness relationship between the infill walls and the surrounding frame.

These failure modes include shear friction, diagonal tension, shear sliding failure, and compression failure. When subjected to an in-plane load, the infill walls and the surrounding structural frame act in a composite action. The two components separate under loading except in the vicinity of the corners. As a result, compression forces are transmitted through one diagonal compression strut of the infill walls. This condition was simulated in the testing of the walls for the experimental program.

In recent years the application of fiber reinforced polymer (FRP) to strengthen masonry walls has been investigated. Increase of out-of-plane and in-plane capacity of the strengthened unreinforced masonry (URM) walls has been reported.

Strengthening of unreinforced masonry (URM) walls with polyurea was studied in this program. Polyurea is a unique class of polymer defined as the reaction of an isocyanate prepolymer and a blend of primary and secondary amine terminated polols.

A polyurea coating combines extreme application properties, such as rapid cure and insensitivity to humidity, with great physical properties, including high hardness and flexibility. The polyurea spray coating technique has been applied in various areas, including corrosion protection and containment. However, due to the relatively low stiffness and tensile strength, the polyurea is potentially limited in retrofit applications that require increases in strength. Therefore, in this program polyurea was reinforced with GFRP grids to strengthen the URM walls.

OBJECTIVE

To evaluate the effectiveness of in-plane strengthening of URM walls by using polyurea spray system, and to study the behavior of the URM walls subjected to an in-plane diagonal compression load. In addition, one of the primary objectives of this research program was to develop analytical models that are effective in predicting the shear capcapoty of walls retroffited with GFRP girds reinforced polyurea.

SPECIMENS

Five unreinforced concrete block walls and five clay brick walls were tested under a diagonal compressive load test setup. With the exception of one concrete and one clay wall without strengthening, the other four concrete masonry walls and four clay brick walls were strengthened with GFRP grid reinforced polyurea.

The investigated variables include amounts and directions of the reinforced polyurea, as well as the numbers of surfaces of the walls being strengthened. It was found that the shear capacity of the strengthened walls increased significantly. A failure theory was modified to predict the shear capacity of the strengthened walls in this program. Analysis indicated that this modified theory predicted the shear capacity of the tested walls within a reasonable degree of accuracy.

The five concrete block walls were built following a running bond pattern, and had the nominal dimensions of 64 x 64 x 6 in. With the exception of the control (wall A), four walls were strengthened with the grid reinforced polyurea system. Each grid strip was 4 in. wide and 64 in. long. These walls were labeled M-A to M-E, as indicated in Table 1.

The five clay brick walls were built following a running bond pattern, and had a nominal dimensions of 48 x 48 x 3 ½ in. The walls were fully grouted. As before, to the exception of the concrete brick wall the remaining walls were strengthened with the grid reinforced polyurea system. Each grid strip was 4 in. wide and 48 in. long. These walls were labeled B-A to B-E, as also indicated in Table 1.

Before application of the polyurea, epoxy paste was used to level the rough surface of the walls, where the polyurea was to be sprayed. Next, the surrounding areas of the walls were covered by thick plastic sheets. In all strengthened walls, the polyurea was first sprayed to the assigned places, followed by attaching one ply glass grid to the polyurea immediately. Next additional polyurea was sprayed to the grid until it was completely covered. The surrounding areas of the walls were covered by thick plastic sheets before spraying, as shown in Figure 2 and 3. This process was identical for the concrete masonry and the clay brick walls.

Figure 2. Before spraying

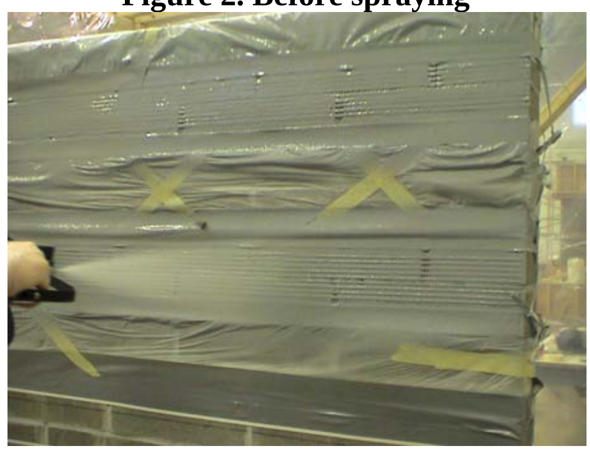


Figure 3. During spraying

The polyurea cured within minutes after application. After the application was finished, each grid reinforced polyurea strip was approximately ¼ in. thick and 5 in. wide.

Two walls (B and C) were strengthened with a horizontal polyurea system, and the other two walls (D and E) with a vertical system. The strengthening schemes for the concrete masonry and clay brick walls were exactly the same and are summarized in Table 1.

Table 1. Strengthening Scheme

Wall	Strengthening scheme	Numbers of polyurea strips	Single/ double sides
M-A	None	--	--
M-B	Horizontal strips	4	Single
M-C	Horizontal strips	8	Double
M-D	Vertical strips	4	Single
M-E	Vertical strips	8	Double
B-A	None	--	--
B-B	Horizontal strips	4	Single
B-C	Horizontal strips	8	Double
B-D	Vertical strips	4	Single
B-E	Vertical strips	8	Double

MATERIAL PROPERTIES

The glass grid was made with longitudinal cords, which were connected to each other by transverse cords of a much smaller size. The tested tensile strength was 85.2 ksi, with an elastic modulus of 5306 ksi. The polyurea demonstrated elastic behavior up to approximately 70% of its ultimate strength, with an elastic modulus of 26 ksi and a tensile strength of 1.0 ksi. In the test, the volume percentage of the glass grid in the entire cross-section of the grid reinforced polyurea is approximately 5%. For this content, the reinforced polyurea was elastic to failure. The material properties of the polyurea system are shown in Table 2.

Table 2. Material Properties

	Tensile strength (ksi)	Elastic modulus (ksi)	Ultimate strain (%)
Grid	85.2	5306	1.8
Polyurea	1.0	26	43.7
Grid reinforced polyurea	5.6	272	2.3

Mortar

The mortar used to build the walls was available in bags in a dry premixed composition of cement and sand. It was classified as Type N according to ASTM standard. The average compressive strength was 823 psi, with a standard deviation of 177 psi.

Concrete Masonry

The concrete blocks had a nominal dimension of 16 x 8 x 6 in. The average compressive strength of the blocks was 2,400psi.

Clay Bricks

The clay bricks had the nominal dimensions of 2 ¼ x 3 5/8 x 7 ¾ in. The average compressive strength of the bricks was 2,330psi.

TEST SETUP

The specimens were tested in a closed loop fashion. Two hydraulic jacks, with a capacity of 67.4 kips each, were connected in parallel and positioned at one end to apply the desired load (see Figure 1). The diagonal forces were applied by one steel shoe placed at the top corner and transmitted to another identical shoe at the bottom corner of the walls through two high strength steel rods positioned on both sides.

INSTRUMENTATION

The diagonal load was recorded through two load cells positioned at the corner of the walls.

RESULTS AND DISCUSSIONS

Concrete Masonry

Wall M-A failed with a shear-friction mode along the diagonal in the direction of external load, with an ultimate load of 31.2kips.

For wall M-B, diagonal shear-frictional crack caused the overall failure. Local cracks were also observed on the blocks along the diagonal. The failure load was 53.4kips.

For wall M-C, although stepped shear friction cracks were observed, the wall failed due to shear slide at the bed joints, with an ultimate load of 43.0kips.

For wall M-D, the typical shear–friction failure was observed on both sides of the wall, with an ultimate load of 34.8kips.

For wall M-E two major diagonal cracks were observed before the wall reached the ultimate condition. The ultimate load was 50.6kips. The test results are compared in Table 3.

Table 3. Test Results – Concrete Masonry

Wall	Failure mode	Load F (kips)
M-A	Shear friction	31.2
M-B	Shear friction	53.4
M-C	Shear slide	43.0
M-D	Shear friction	34.8
M-E	Shear friction	50.6

Clay Bricks

Wall B-A failed due to a shear-friction crack along the diagonal in the direction of external load, with an ultimate load of 18.2 kips.

For wall B-B, the horizontal strengthening constrained the development of the stepped crack, and failure was confined between the top two polyurea strips on the strengthened side. On the other side the diagonal crack was observed at the upper part of the wall. The wall failed due to a shear friction crack with an ultimate load of 29.8 kips.

For wall B-C, horizontal cracks at the bed joints between the grid reinforced polyurea and the mortars were observed. The failure was strictly confined within the top two horizontal strips, where slight local failure of the bricks was observed. The wall failed with a combination of shear slide and shear friction at 33.3 kips.

For wall B-D, on the strengthened side, scattered diagonal cracks were observed outside of the vertical grid reinforced polyurea. On the other side, diagonal cracks passed along the bricks for the entire height of the wall. No significant cracks along the bed or head joints were observed. The ultimate load was 36.4 kips.

For wall B-E, no clear cracks were observed at the bed or head joints, and the failure was caused by a local compression failure of the bricks at the upper portion of the wall. The tension cracks of the bricks were observed as well. The results of the in-plane diagonal load F are shown in Table 4.

Table 4. Test Results – Clay Bricks

Wall	Failure mode	Load F (kips)
A	Shear friction	18.2
B	Shear friction	29.8
C	Combination of shear slide and friction failure	33.3
D	Diagonal tension	36.4
E	Combination of diagonal tension and local failure	33.5

ANALYTICAL MODELS

Mann and Müller developed one failure theory to explain the behavior of masonry walls subjected to shear and compressive stresses based on the Coulomb equation and other equilibrium conditions. It was assumed that compressive stress in the direction of the bed joints was negligible, and no shear stress was transferred through the head joints. Based on a more realistic distribution of normal stress on the bed joints, Crisafulli et al. modified this principle. According to this modified theory the horizontal shear stress τ_m acting on the masonry units along the bed joint creates a torque and needs to be balanced by a vertical couple. These two models were used in predicting the shear capacity of the walls. Further details are presented in the report.

CONCLUSIONS

The following conclusions can be drawn from the current research:

- Strengthening of URM walls with grid reinforced polyurea is an effective scheme. After strengthening, the in-plane capacity was increased significantly.
- The failure mode of the strengthened walls changed after strengthening, and depends on the strengthening schemes..
- Desired failure modes may be achieved by implementing appropriate strengthening schemes.
- The theoretical model gave a reasonable prediction of the capacity of the URM walls subjected to in-plane diagonal loads.

WANT MORE INFORMATION?

Details on this test program and additional data can be found in the final report.

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