HORIZONTAL SHEAR PERFORMANCE OF FULL-SIZE UN-REINFORCED BRICK WALLS RETROFITTED WITH EXPANSIVE EPOXY

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ABSTRACT

This paper presents the results of tests of un-reinforced brick walls retrofitted and repaired with expansive epoxy. The walls were subjected to horizontal, in-plane shear force and their response was monitored under a wide range of cyclic loading. A new type of epoxy formulation was tested to determine its potential for structural retrofitting and strengthening of existing brick masonry buildings. Full-size, un-reinforced brick walls of 10 ft by 10 ft were fabricated using aged brick and masonry mortar to simulate the conditions existing in old brick buildings. One wall was loaded directly as plain, unreinforced brick wall and was used as control. Another wall, identical to the first one was first injected with the expansive epoxy, allowed to cure for seven days and then tested under identical support and loading conditions. After the first (plain) wall was loaded beyond its full cracked state, it was then repaired with the expansive epoxy and re-tested. The results of the tests demonstrate the strengthening and repairing effects of the expansive epoxy. The hysterisis behavior of the plain and repaired walls show a similar degradation pattern although some increase in ductility is noted in the repaired walls. Also the epoxy brought the cracked walls to an almost monolith condition even in the areas that were initially cracked.

Key words: Expansive, Epoxy, Un-Reinforced, Brick Walls, Retrofit, In-Plane.

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INTRODUCTION

A considerable number of un-reinforced brick masonry buildings were built throughout the world in the past and now they constitute an irreplaceable historical asset for civilization. These structures were built following construction techniques different from the current ones and were built to minimal or no construction codes. In the west coast of the United States a good number of these types of buildings were built during the XVIII and XIX centuries following the techniques of the time. Coincidentally, the great majority of these structures are on, or near zones of high seismic activity. That many have survived the numerous earthquakes since their construction is a proof of the quality of workmanship with which they were built. However, so many of these historical buildings are of incalculable aesthetic and historical value and it is not appropriate to leave their preservation dependant to their good luck. Various strengthening and retrofitting techniques have been used through the years, including more recently the used of high strength fiber composite materials (Hamid et al. 1993, Bhende and Ovadia 1994, Keheo 1996, Ehsani and Saadatmsnesh 1996, Velazquez-Dimas et al. 1999) . Also, epoxy injection and consolidation started to be used in the 1960's in Poland Domaslowsy and Strzelczyk 1986) and 1970's in the United States (Gauri and Madiraju 1978). Although the main focus of epoxy repair or conservation has been geared towards the sealing of the porosity or cracks in stone, brick, and mortar materials, to protect them against the weather effects, there has always been a desired to provide also structural enhancing with the epoxy.

In this paper, the strengthening and retrofitting effects of an expansive epoxy applied in brick walls are reported. The Freonless epoxy material fills the cracks and pores of the brick-mortar surface and imparts some continuity and monolithic characteristics. Full-scale brick walls were tested under horizontal shear.

EXPERIMENTAL PROCEDURE

Two, un-reinforced brick walls of 3.0 m (10 ft) by 3.0 m (10 ft) were built in the testing bay of the structures laboratory at California State University, Fresno. The walls were tested under horizontal, in-plane shear force applied at the top of the walls. The following tests were conducted: as built (control), as built and retrofitting, and after being cracked and then repaired.

The walls consisted of two wythes each approximately 100 mm (4 in.) thick, with a 50 mm (2 in.) empty cavity in between. The walls were built on top of a reinforced concrete beam of approximately 780 mm (31 in.) wide, 250 mm (10 in.) tall, and 3.10 m (10-1/3 ft) long which was firmly anchored with six 30 mm (1-1/4 in.) threaded rods to the strong floor of the test bay. The walls were fixed at the base and free to move in all directions at the top so they were tested as cantilever shear walls. The force was applied at one end of the cap beam with a computer controlled hydraulic actuator which was attached to the reaction wall through a hinge mechanism. The force, thus, was applied horizontally and parallel to the wall.

The expansive epoxy used in the retrofitting and repair procedures consisted of a proprietary formulation of a resin and a hardener mixed immediately prior to the application. The resin is preheated to approximately 25 ^{o}C to 28^{o}C and then mixed with the hardener at a volume ratio of about 10 to 1. The mix is then injected into the treated spaces and immediately starts expanding undergoing an increase in volume that depends on the confining condition of the surrounding. The mix adheres to the surrounding brick and mortar filling the gaps and cracks and providing continuity.

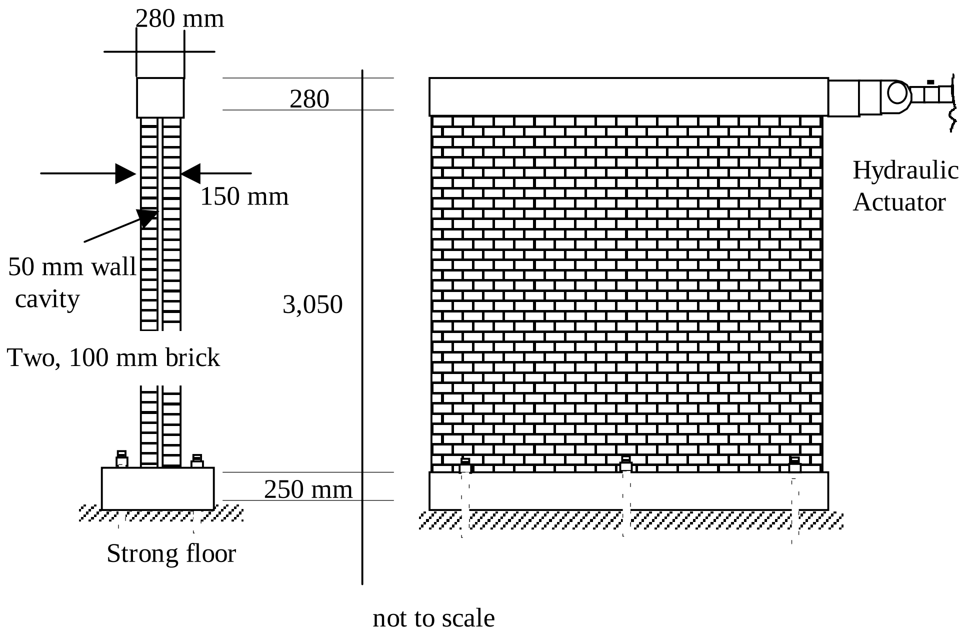

Figure. 1 Schematic of test set up and dimensions of wall

The various wall configurations were tested applying cyclic load under controlled displacement conditions and with gradually increasing amplitude. The hydraulic actuator was attached through a hinge to the reaction wall at one end, and attached to the a cap, reinforced concrete beam at the other end. Thus the actuator was in part supported by the tested wall. The list of the test conducted with in-plane shear force is shown in Table 1.

TEST RESULTS

The test results in terms of maximum load for each wall and test condition are summarized in Table 2. In test 1 the intend was to just crack the wall to then repair it and test it again to simulate the conditions of a repaired wall that has already cracked. In this test, the plain wall failed in tension at the horizontal mortar joints near the base.

After the cracks formed the portion of the wall above the cracks started to uplift and rock in a rigid body motion. The ultimate load was 17,200 N (3860 lb) and there was no indication of diagonal shear failure.

Table 1. List of tests conducted in two identical un-reinforced brick walls

Test No.	Test Conditions
1	AS BUILT (CONTROL)
2	wall tested first, repaired with epoxy then tested
3	wall tested first, repaired with epoxy, reinforced with fiberglass/epoxy mat at the base, then tested
4	wall tested first, repaired with epoxy, reinforced with fiberglass/epoxy mat at the base, subjected to additional axial load, then tested
5	wall injected with the expansive epoxy prior to test, reinforced with fiberglass/epoxy mat at the base, subjected to additional axial load, and tied vertically with steel chain

In test No 2 , the wall tested previously as described above was then repaired by injecting the expansive epoxy. After the epoxy set, the wall was tested under monotonic increasing load and then under cyclic loading.

In the first part, under the monotonic load, the wall was pulled to a horizontal displacement at the top of 6.4 mm (0.25 in.) developing a load capacity of 25,600 N (5750 lb). Under the cyclic loading and after having been already loaded to 25,600 N, the wall exhibited a capacity of 20,000 N (4500 lb) at an asymptotic displacement from 10 mm (0.4 in.) to 20 mm (0.8 in.). It was observed that the cracks that formed during the first test remained together as a result of the epoxy. In addition the epoxy maintained the integrity of the wall proving load transfer across the cracked mortar material. The epoxy is ductile and allows large deformation before it fails. This allows more energy absorption and dissipation in seismic events. After the wall finally failed in tension by cracking at the horizontal mortar joints near the base, the wall above the cracked sections started to rock in a rigid body motion and there were no signs of diagonal shear failure.

In test No 3, the wall tested as indicated before was then repaired by applying a fiberglass/epoxy mat at the base of the wall and firmly attached to the floor. The cracks formed in the previous test were then sealed with the fiberglass and epoxy. The wall tested under cyclic loading developed new horizontal cracks just above the limit of the fiberglass mat and was able to carry a maximum load of 31,100 N (7000 lb). This considerable increased in load capacity is attributed to the fact that the fiberglass reinforced the base of the wall where the epoxy injection may not have filled the spaces properly, forcing new cracks to occur above the level of the limit of the fiberglass where the epoxy filled the spaces better.

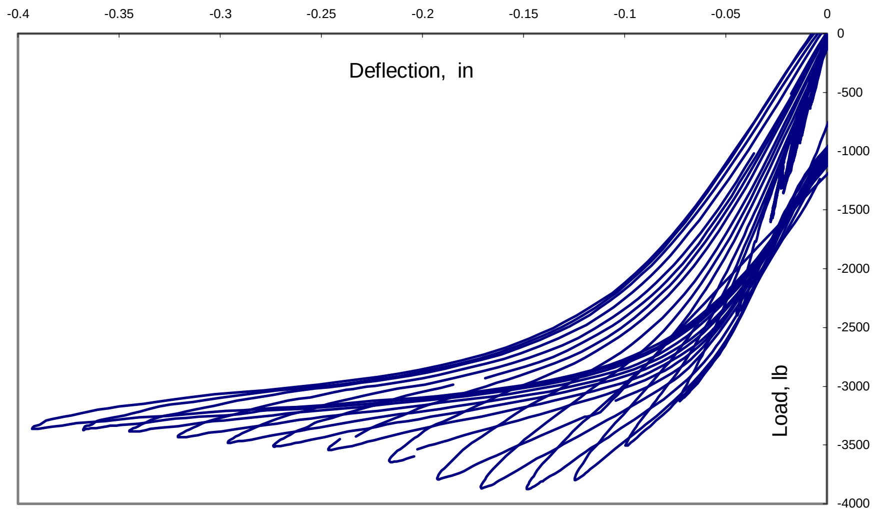

Figure 2. Load-deflection diagram of test No. 1 (control)

Table 2. Summary of test results for each wall and test configuration

Test No. Wall	Maximum Load N (lb)	Displacement at Maximum Load mm (in.)
1	17,200 (3860)	3.8 (0.15)
2	20,000 (4500)	asymptotic from 10 (0.4) 20 (0.8)
3	31,100 (7000)	13 (0.51)
4	44,500 (10000)	7 (0.31)
5	177,900 (40000)	58 (2.28)

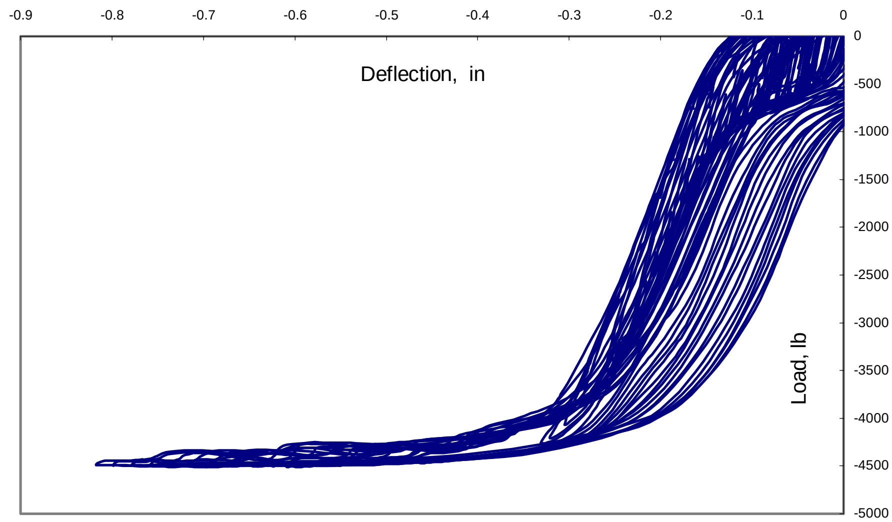

Figure 3. Load-deflection diagram of test No. 2

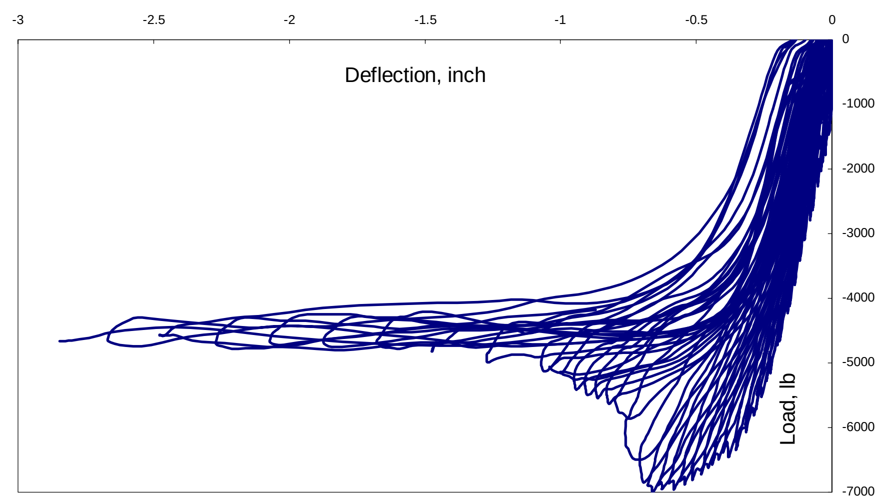

Figure 4. Load-deflection diagram of test No. 3

In test No 4, a new plain wall was retrofitted with the expansive epoxy and also was subjected to a heavier axial load. Two concrete blocks with a total weight of 48,900 N (11000 lb) added an extra vertical axial stress of 79 kPa (11.5 psi). The wall was then tested under cyclic loading and developed a maximum capacity of 44,500 N (10000 lb) at a horizontal displacement of 7 mm (0.31) when horizontal cracks developed. To continue the test, the wall was then reinforced with vertical external reinforcement by attaching two steel chains at both ends of the wall.

The wall was then tested (Test No 5) under cyclic loading again. The extra reinforcement would simulate the effect of heavy axial loading resulting from dead load of supported floors. The chains did not prevent the formation of the horizontal cracks since they were not prestressed and they deformed appreciably before applying the axial load. As the magnitude of the cyclic load increased the wall uplifted at the cracked sections until the restrain of the chains against uplift was such that the wall slipped approximately 50 mm (2 in.) from the foundation beam. The wall showed no signs of diagonal shear although the maximum load increased considerably.

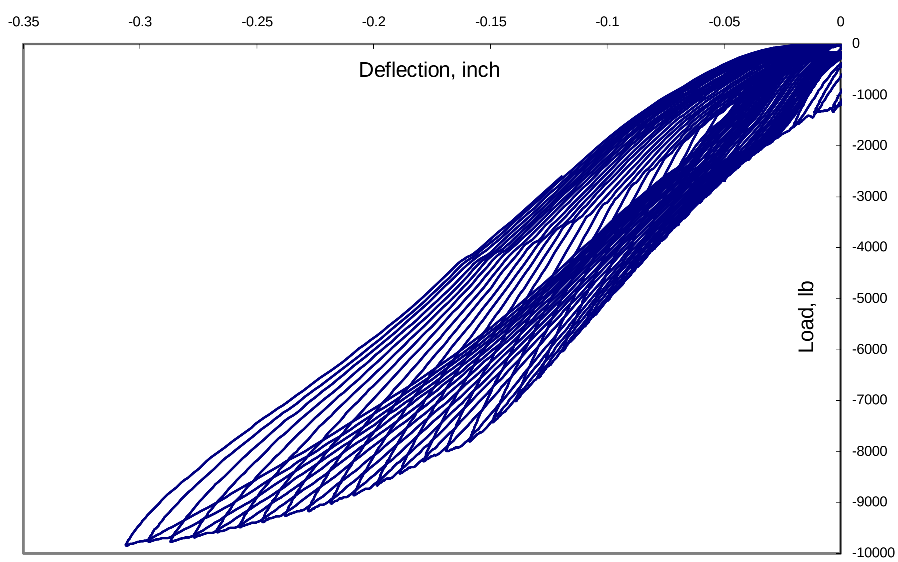

Figure 5. Load-deflection diagram of test No. 4

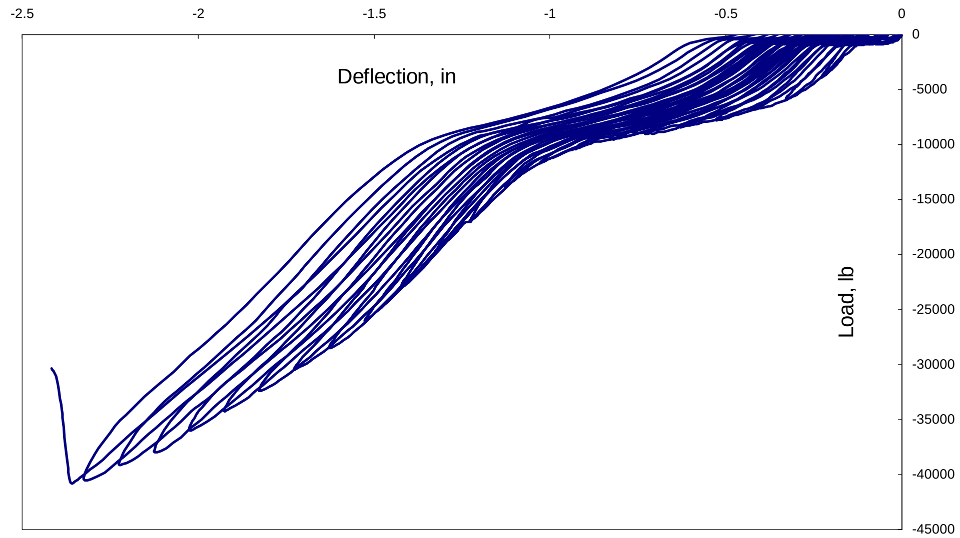

Figure 6. Load-deflection diagram of test No. 5

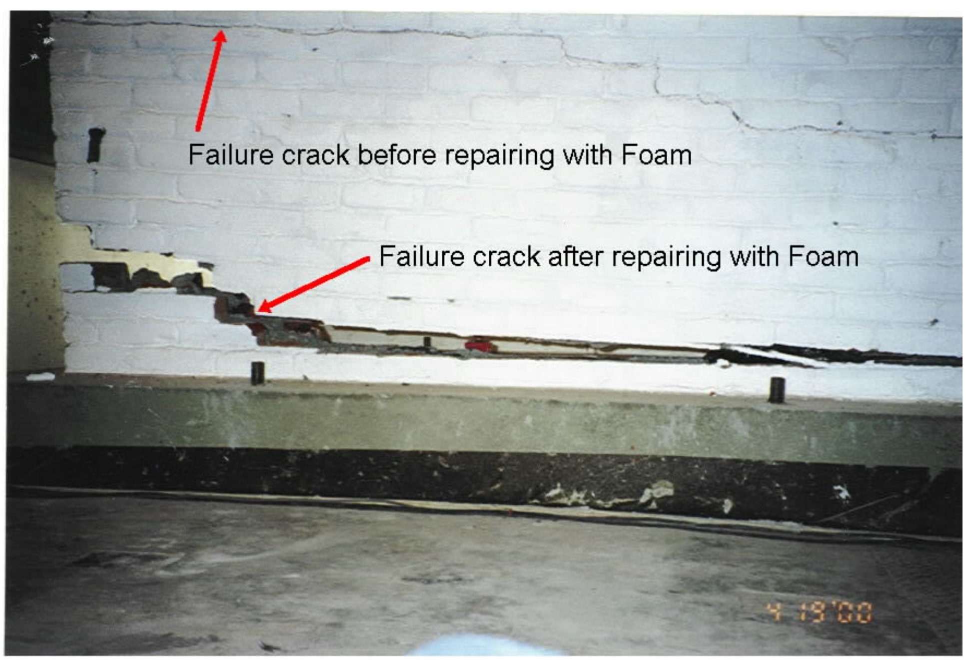

Figure 7. Failure Cracks of the In-Plane Wall Before and After Repairing with Foam

CONCLUSIONS

The injection of expansive epoxy appears to be effective in the repair and retrofit of unreinforced brick walls that are used as structural components in old buildings. In such brick walls, the mortar has deteriorated to such an extent that it can be easily removed by a pocketknife. The foam substitutes the deteriorated mortar joints. It makes the loose brick wall monolithic and increases its integrity. In addition, the ductile foam substitutes the function of the brittle mortar making the wall able to produce much more ductile response in case of seismic ground motions. If the mortar joints are not deteriorated, then they will break at very small deflections due to its brittle nature and inability to carry large tension loads. The foam herein works as the second line of defense that will pick up the lost function of the mortar but in a much more ductile fashion allowing a better distribution and transfer of stresses in the wall. Without the foam, a complete catastrophic failure is expected at relatively small deflections.

The foam also has another important function. It provides a passive control of the vibration of the wall by adding additional damping to the system. The increased damping is resulting from the foam material itself in addition to the energy dissipated in the friction between adjacent blocks of brick. The foam allows more ductile response where various blocks of brick will have large relative motion between them and as a result dissipating much more energy.

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