eJSE International
Electronic Journal of Structural Engineering 14 - 2014

Retrofit of Unreinforced Masonry Walls Using Geotextile and CFRP

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ABSTRACT: A preliminary investigation into the suitability of using geotextile as an inexpensive seismic retrofit material was conducted. Ten specimens of unreinforced masonry (URM) walls were constructed with masonry without bars or other transverse reinforcement. One set of two was left unreinforced. The remaining four sets of two specimens were reinforced with either CFRP (laminate) or geotextile. Two widths of reinforcement were created for each reinforcing material. All specimens were tested with cyclical shear loading. The number of cycles before collapse was recorded. Results are compared for geotextile versus laminate. Both materials reduced drift and increased the number of loading cycles before collapse. Even though the laminate increased the number of cycles the most, the geotextile is a more economical solution to retrofitting URM walls therefore warrants further investigation.

Keywords: Geotextile, FRP strengthening, Unreinforced masonry walls, Seismic loading

1 INTRODUCTION

Unreinforced Masonry (URM) is a common building material in much of the world. ACI 530 allows use of URM walls for seismic load only in seismic design categories A and B, although in many countries and in older structures in the United States, URM walls were used for carrying lateral or shear load regardless of the seismic category. (Masonry Standards Joint Committee 2013)

Reinforcement with non-traditional building materials qualifies as specially reinforced shear walls under ACI 530. They generally have a good response modification factor (R) and have no restrictions about which seismic design categories they may be used in.

Carbon fiber reinforced polymer (CFRP) has been extensively studied for seismic retrofit and has become a commercially available process in several countries. (Teng et. al. 2003) A common application of the material is to enhance confinement of columns by wrapping around them. This is useful for seismic loads. (Seible et. al. 1997) Other applications are to bond plates to beams to increase strength, (Rahimi and Hutchinson 2001) and wrap beam-column joints. (Parvin and Blythe 2012) Unfortunately, the behaviour of the retrofit is often brittle. (Nguyen et. al. 2001) Therefore, they are designed according to elastic force limits.

URM walls subject to seismic loading may fail due to in-plane shear loading, or out-of-plane bending. Out-of-plane failure has been the primary cause of loss of life in earthquakes. (Tobriner 1984) Out-of-plane, resistance has been improved by placing vertical straps of CRFP on the URM walls. (Ehsani et. al. 1999) The straps are effective at carrying the tensile forces in vertical bending.

Although, out-of-plane displacement is the direct cause of fatalities, those large displacements represent a failure of the lateral force resisting system to limit the displacement. Therefore, it is sensible to focus on how to improve drift response in URM walls in shear. A drift limit of 2.5% was proposed for URM walls for life safety level performance based seismic design. (Bebamzadeh et. al. 2012)

For in-plane loading, using CFRP sheets on a URM wall which acts within a frame has the effect of controlling cracking and can increase lateral resistance 300%. (Saatcioglu et. al. 2005) In-plane loading causes diagonal tension cracks in URM. Therefore, the CFRP are placed diagonally. Design forces are found through the strut model.

Bonding of the retrofit materials can be near-surface or exterior-bonded. Exterior-bonded methods simply rely upon adhering the CFRP to the surface of the existing structure. Near-surface bonding involves cutting slots for the fiber bars. This results in superior bonding of the retrofit, but much higher costs. (Hassan and Rizkalla 2003) Exterior-bonded was used in the data collection below because of its ease of application.

Alternatives to CFRP have been investigated previously. Among them is elastomeric polymer coatings on walls to improve blast protection. (Raman et. al. 2011) However, there is limited knowledge with these new materials in structural applications.

Geotextiles (GTs) have recently been investigated for enhancing structures. The most common application is for blast protection. (Malvar et. al. 2007) However, application of geotextiles for seismic retrofit has never been documented.

Geotextile came under consideration as an alternative to CFRP for URM walls because like CFRP it is an engineered product that can be easily formed. The primary requirement is that it be a reliable tension material that can be bonded to URM walls. Geotextile suits this because its primary application is in providing tension strength required for equilibrium of soil structures. Creep is not an issue with seismic loading.

CFRP and geotextile are both commonly made with polymer backing. In the case of CFRP, it is a matrix, and in the case of geotextile is often woven into a fabric. However, the CFRP has carbon filaments that provide for additional strength and stiffness. The effort required to make the composite material means that it is more expensive by volume.

Commercially available CFRP is about twenty times more expensive than geotextile by volume. Given the thicknesses used in the tests below that option was only about five times more expensive. It is available from manufacturers in only a few countries. However, geotextile is widely manufactured across the world. The ease of making it allows several suppliers to produce it, and at a lower cost.

Both CFRP and geotextile retrofits require comparable amounts of labour to install. In a high labour cost country, when CFRP is used the cost of the materials and labour are in the same magnitude. However, in a low labour cost country, the cost of the CFRP dominates the expense. Therefore, lowering material costs can have a dramatic impact on whether a design retrofit is practical. If geotextile were to have superior properties than CFRP, then it might be suitable in countries with high labour cost too.

2 MATERIALS AND METHODS

2.1 *Materials*

The three primary materials in the tests were the masonry, CFRP and geotextile. Hollow concrete blocks of dimensions are 290 by 140 by 110 mm and final cylinder compressive strength is equal 9 to 10 Mpa. Grout was 12 mm thick and had an average prismatic strength of 10 MPa.

CFRP reinforcement with unidirectional fibers (Sika Carbodur S-512) and a geotextile were used in this investigation. Their dimensions and main mechanical characteristics, according to the fabricator, are shown in Table 1. The reinforcement was bonded to the URM with Epoxy: Kimitech EP-TX, ST5-607, ASTM D695-2a compressive strength of 56 Mpa and flexural of 18 Mpa. Epoxy was applied along the length of the reinforcing strip.

Table 1. Nominal Dimensions and Mechanical Properties of Reinforcement

Type of Fiber	CFRP	Geotextile
Thickness (mm)	0.9	4.0
Characteristic tensile strength	250	170
Tensile modulus of elasticity	165	150
Ultimate tensile strain	0.017	0.03

2.2 *Methods*

Test Specimens were constructed and tested in as shown in Fig. 1. Five groupings of tests were done: Unreinforced Masonry (URM), CFRP with 100 and 200 mm widths (CFRP-100, CFRP-200), and Geotextiles with the same widths. (GT-100, GT-200) Both the CFRP and the GT were placed in a crossing pattern from corner to corner on the wall.

The choice of the width and thickness of the strips was determined by practical concerns. A design could have been performed to determine the desired material dimensions. Prota evaluates methods of design that could be used. (Prota et. al. 2008) However, limited types and thickness of CFRP and GT were available at the test site, so they were used. Also, the widths of materials were determined by practical concerns that it needed to be adhered to the wall as close as possible to the corners.

Tests were conducted with hydraulic ram vibrator assemblies. The force and displacement data were obtained by a data logger (TDS-300). A hydraulic ram was place at the top to put the wall into shear as shown Fig. 1. In addition see, Fig. 2. The load of 180 kN was alternated in opposite directions at a rate of 1 cycle per second. Loading was applied post-cracking as long as the walls had residual strength.

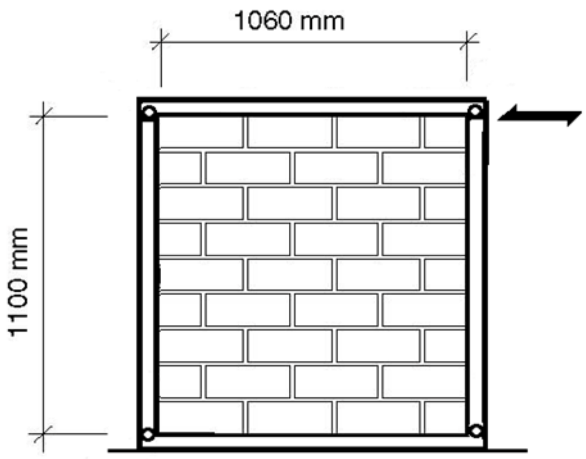

Figure 1. Idealized test arrangement.

Figure 2. Test apparatus with CFRP applied to wall.

3 RESULTS

The overview of the results is shown in Table 2. Figures 3 to 7 show the failure modes for sample specimens. Figures 8 to 12 show drift versus time. All retrofits increased the amount of time before failure. The URM specimens (URM-1 & URM-2) failed with splitting cracks from the diagonal tension. The retrofit specimens mostly failed from delamination of the bonded material and compression bursting of the concrete at the corners where the ram applied the load. Confirming the work of Nguyen, the failures remained brittle even when reinforced. (Nguyen et. al. 2001)

The ratio of time to failure in the CFRP compared to URM was 1.83 and 2.42 for 100 and 200 mm, respectively. The ratios for the geotextile were 1.42 and 1.73 for 100 and 200 mm, respectively. This shows that the CFRP incrementally extended the life of the URM wall twice as much as the geotextile did. The 200 mm wide bands of reinforcement nearly doubled the incremental increase in time before wall failure for both CFRP and GT retrofits.

Table 2. Experimental test results and failure mode

Specimen ID	(Ts) Maximum Time (s)	Band width (mm)	Failure Mode
URM-1	63	0	Splitting crack
URM-2	67	0	Horizontal mortar & Splitting crack
URM Average	65		
CFRP-100-1	117	100	Corner failure
CFRP-100-2	121	100	Corner failure & delamination
CFRP-100 Average	119		
GT-100-1	86	100	Corner failure & delamination
GT-100-2	99	100	Corner failure & delamination
GT-100 Average	92.5		
CFRP-200-1	132	200	Corner failure
CFRP-200-2	182	200	Splitting crack & delamination
CFRP-200 Average	157		
GT-200-1	111	200	Corner Failure and delamination
GT-200-2	114	200	Corner Failure and delamination
GT-200 Average	112.5		

The tests were carried out as long as the wall sections had residual strength. However, an alternative definition of failure is the point where the walls stopped being responsive to the cyclical load. For example in Figure 8, the URM wall stopped following the driving oscillations at 40 seconds. Beyond that there was little residual strength. Using this definition, the failure time ratios for CFRP were 2.75 and 4.1 for 100 and 200 mm, respectively, and the

GT was 2.3 and 2.65, for 100 and 200 mm, respectively.

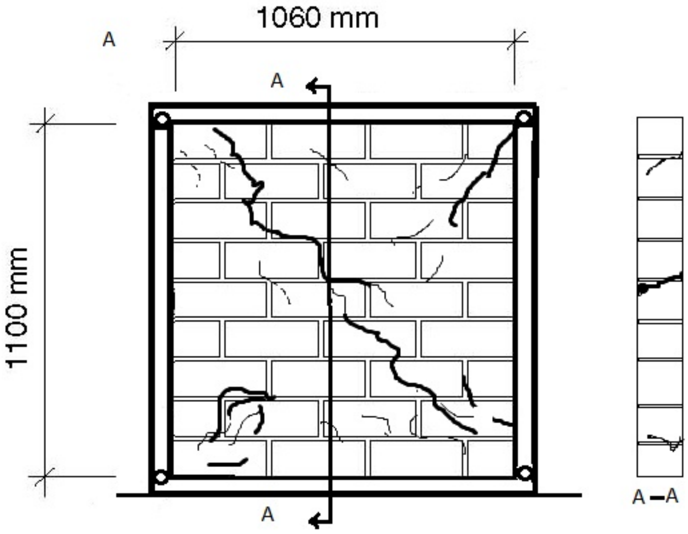

Figure 3. Splitting Crack (URM-1).

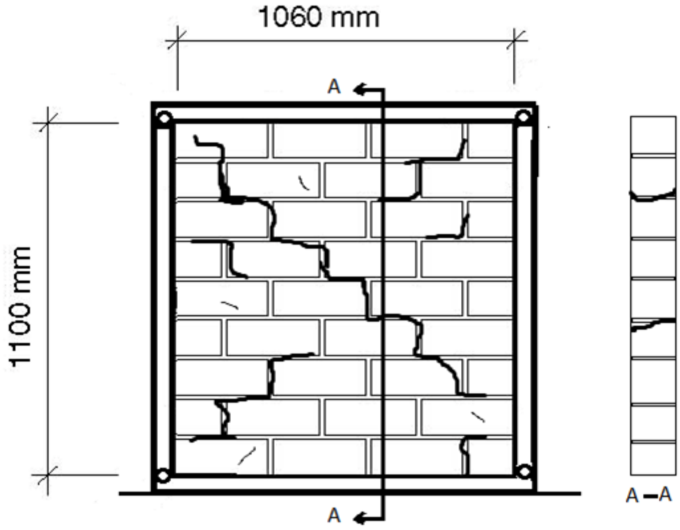

Figure 4. Horizontal Mortar and Splitting Crack (URM-2).

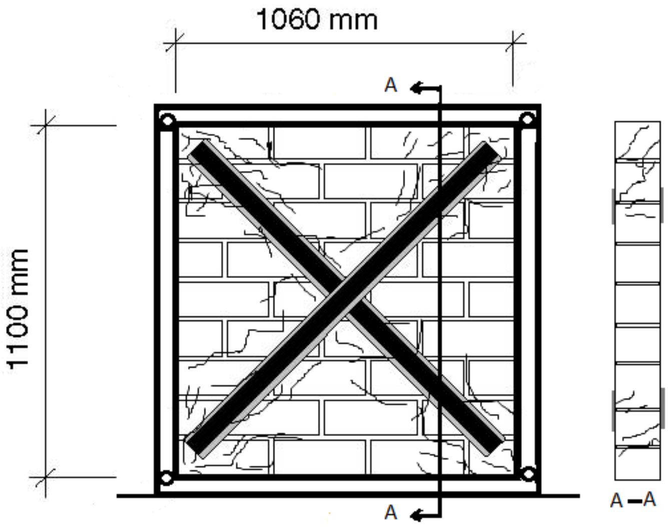

Figure 5. Corner Failure (CFRP-200-1).

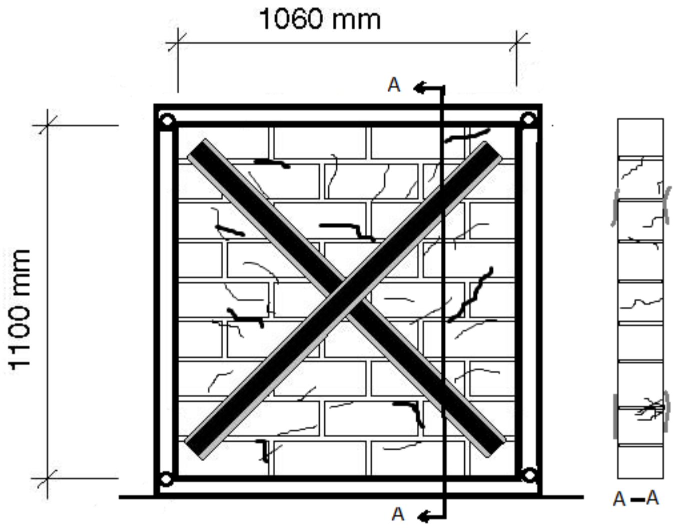

Figure 6. Splitting Crack and Delamination (CFRP-200-2).

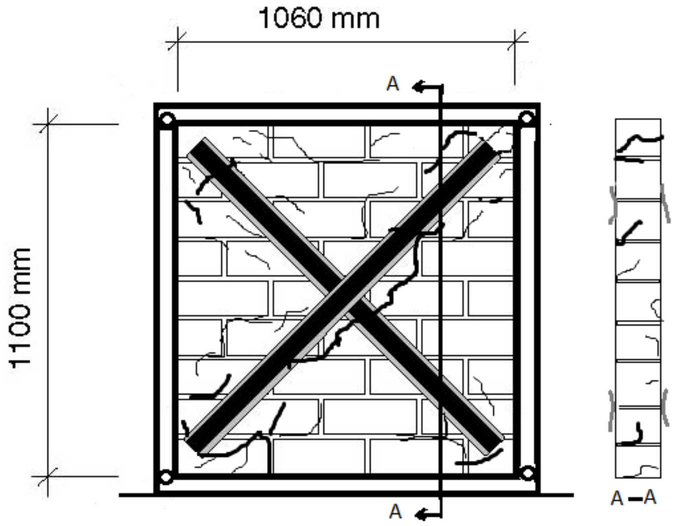

Figure 7. Corner Failure and Delamination (GT-200-2).

Drift was controlled best with the CFRP specimens compared to GT. See Figures 8 through 12. After 10 seconds, the drift was about 45, 20, 20 mm for the URM, CFRP-200, and GT-200 tests, respectively. Five seconds before the wall became unresponsive to the load, the drift was about 65, 30, 20 mm for the same tests, respectively. Adding the reinforcement cut the drift in half. That creates less potential for overturning of out-of-plane walls. Both materials limited drift to below the 2.5% drift limit cited in the introduction, but reaching that goal in other structures is dependent on design to achieve this.

The unreinforced walls failed mostly from splitting cracks which is typical of shear failure. Adding laminates changed failure mechanisms to mostly corner compression burst. This type of failure indicates that force transfer from the load apparatus to the wall is controlling the failure mode. Simultaneously the laminates connected near the corner would usually delaminate.

In these tests, the loads were applied at the top of the wall near the corner. The application of rams fits the strut model but doesn't match reality. In-plane load is transferred through unit shear along the top of the wall and in buildings with column through wedging at the top of the column. The load goes to the strut through arching. When loads are concentrated at one point as in these tests, then bursting occurs. The implication of this is that repeating the tests with full-frame arrangement in the manner of Saatcioglu may produce much higher loading times for the CFRP and GT reinforced walls before failure. (Saatcioglu et. al. 2005)

The strongest ground motion in major seismic events typically lasts for under 40 seconds. (Bolt 1973) All of the retrofit options shown would defer damage to beyond one minute. As long as the shaking can be damped then the retrofit may avert a collapse.

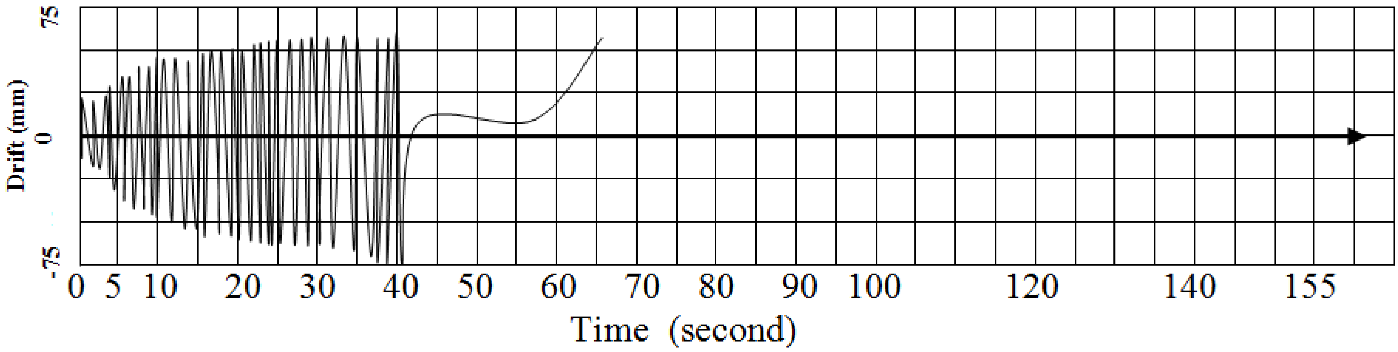

Figure 8. Drift with Respect to Time Under Cyclic Loading of URM Panel.

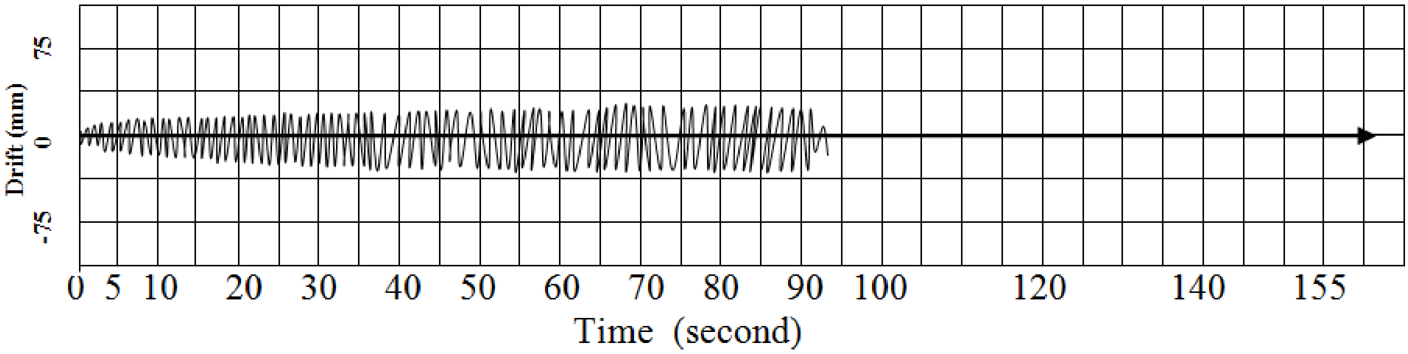

Figure 9. Drift with Respect to Time Under Cyclic Loading of GT-100 Panel.

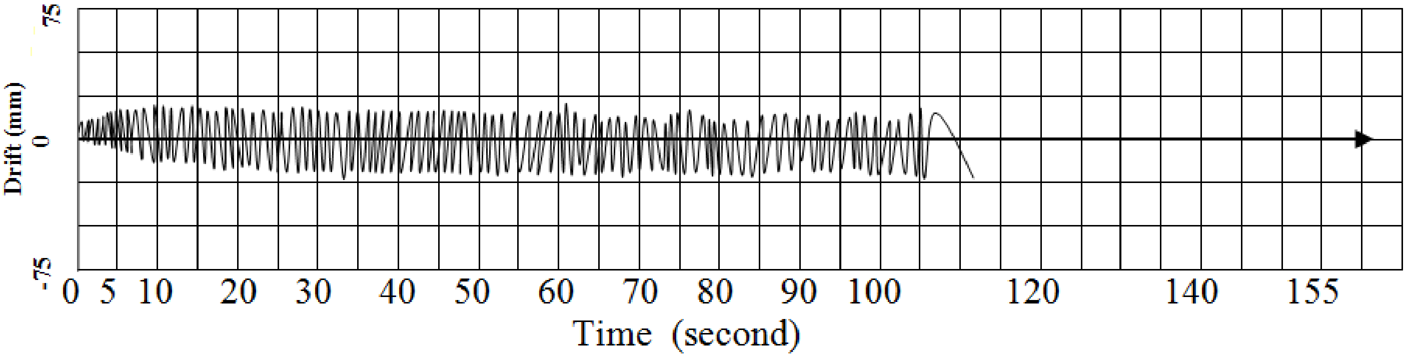

Figure 10. Drift with Respect to Time Under Cyclic Loading of GT-200 Panel.

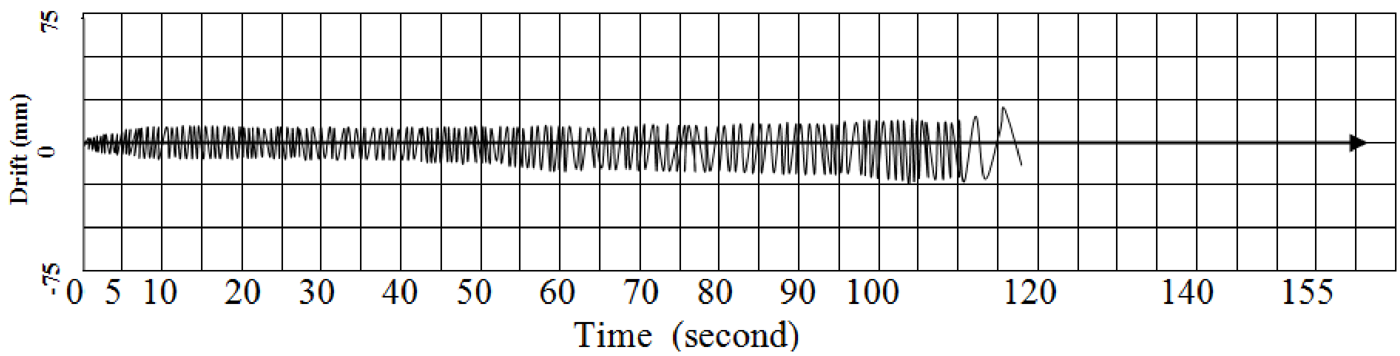

Figure 11. Drift with Respect to Time Under Cyclic Loading of CFRP-100 Panel.

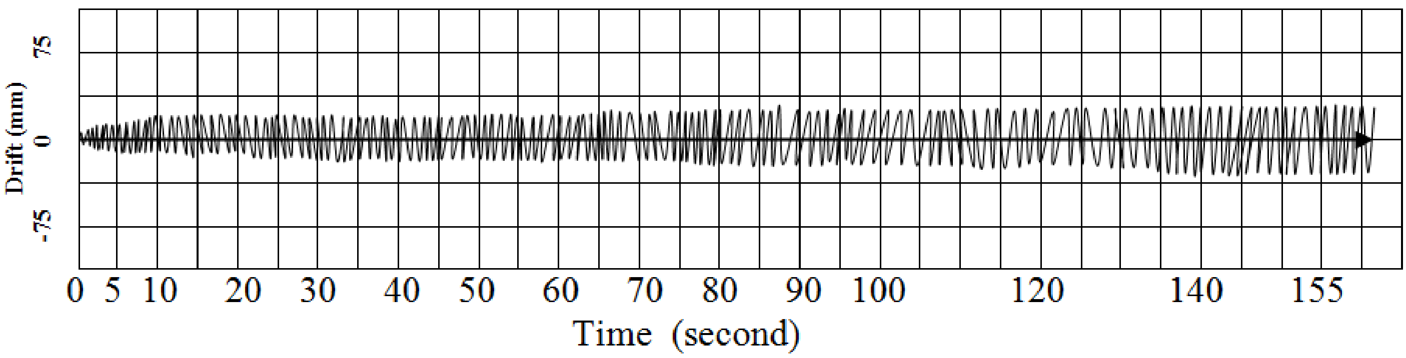

Figure 12. Drift with Respect to Time Under Cyclic Loading of CFRP-200 Panel.

4 CONCLUSIONS

This study dealt with retrofitting unreinforced masonry walls subject to in-plane loading from seismic forces. Out-of-plane displacement is a direct cause of death in seismic loading. However, that displacement is a symptom of inadequate stiffness in the lateral load resisting system. Enhancing the in-plane capacity prevents premature failure and excessive building drift. This indirectly could mitigate deaths in seismic events.

It was found that crossing strips of geotextile are a suitable alternative to CFRP. Both materials reduce drift, and extend the time to failure subject to cyclical load. Therefore, each will damp vibrations.

In Iran, costs of labour are about one tenth that of in the US. This means that is Iran, the material cost of a retrofit with CFRP is roughly three quarters of the total cost. However, using geotextile cuts the cost by more than half and results in materials cost being about one third of the total cost. This makes seismic retrofit much more economical there. This is true for much of the world. The process would likely produce savings in the US, but the total cost is much more a function of the labour cost.

Several issues could be investigated in follow up studies. First, would be to see if different test arrangements produced higher capacities in retrofits. The retrofitted walls failed more commonly due to a compression burst at the corner. This could be due to the use of hydraulic rams placed there. The tests done here could be repeated with equipment that applies load more dispersed along the wall. Second, the geotextile used was woven and not isotropic, so results could be sensitive to installation alignment processes. A study could evaluate whether orientation of the fibers has significant impact on results. Third, CFRP design methods should adjusted for implementing geotextile. This might require a better understanding of how the composite construction reduces drift and improves damping so that a generalized method can be made. Fourth, tests and analysis could determine if for exterior walls it is better to have the strip on one side so that it is exposed to less of the environment and therefore may be more durable, or to have strips on both surfaces for symmetry. Fifth, further tests could be done on why the geotextile had larger drift than the CFRP. Both materials have similar elasticity, but thicker GT was used than CFRP, so simplistic analysis would expect a lower drift from the GT. One hypothesis is that the anisotropic GT was less able deal with real lab conditions such as the load being semi-biaxial and that may have caused micro-tearing.

5 ACKNOWLEDGEMENTS

The laboratories of the Banian Pey & Mahar Shalodeh companies were used for the tests. The research is partly financed by Khuzestan Water & Power Authority (KWPA), also grant 4072218219 from Banian Pey.

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