EXPERIMENTAL STUDY OF CARBON FIBER REINFORCED POLYMER RETROFITTED MASONRY WALLETS

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ABSTRACT: Fiber reinforced polymer (FRP) has become a popular material in the past few decades. It has been ex-pensively used for strengthening and retrofitting of concrete structures. High strength to weight ratio, high initial stiffness, linear elastic behavior and ease in application has made it material of good choice for the seismic retrofitting and strengthening of masonry structure. In this research, an attempt has been made in order to find the optimum quantity and placement of FRP for the strengthening of brick masonry wall system. Required objectives are achieved by performing diagonal compression test on ten masonry wallets. Masonry wallets were carrying different volume and arrangement of FRP strips. Response of masonry wallets with different volume and configuration of FRP strips are recorded using a digital acquisition system. Results of experimentation are carefully analyzed in order to propose an optimum and efficient retrofitting procedure of masonry wallets with FRP. Experimental results shows that correct retrofitting scheme can not only increase the efficiency but can also reduce the retrofitting cost and effort

Key Words: Fiber reinforced polymer, Retrofitting, Diagonal compression test, Optimum volume of FRP

INTRODUCTION

Masonry structures contribute a biggest number in the world inventory of residential structures. Even there are more masonry structures in the world than concrete. Because of its low cost and local availability, masonry has been the structural material of choice for centuries and still one of the most popular construction material in the under developed part of world. Recent earthquake events in the past decade have exposed the seismic vulnerability of masonry structures. This is because of poor lateral load carrying capacity of masonry. During many earthquakes such as in 1989 Newcastle, Australia, 1997 Umbria-Marche, Italy, 2001 Bhuj, India,2003 Bam, Iran, 2005 Kashmir, Pakistan and 2008 Wenchuan, China masonry has contributed a big number in terms of collapse and human causalities especially in those areas where the buildings were poorly designed or only designed for gravity load bearing systems. Most of the houses were constructed using unreinforced solid clay brick walls (URM). Keeping un view the poor seismic resistance of masonry structures, it is of utmost demand to strengthen and retrofit the existing weak masonry structures. According to Meguro et al. retrofitting of low earthquake-resistant masonry structures is the key issue for earthquake disaster mitigation and significant reduction of causalities [Kimiro Meguro and Mayorca, 2005].

Literature review for seismic retrofitting

Seismic vulnerability of masonry structure brought into light the urgent need of seismic retrofitting of masonry structures and attracted the attention of many researchers worldwide. Seismic retrofitting reduces not only the damage to buildings during earthquakes, but also the cost of rescue and first aid activities, rubble removal, temporary shelter preparation and permanent residential reconstruction to re-establish normal daily life [Yoshimura and Meguro, 2004].

In order to deal with the problem of seismic retrofitting of masonry structures many researchers had proposed different retrofitting methods to avoid collapse of masonry structures. Different retrofitting

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procedures has been adopted by different researchers, adding concrete frames, using wire mesh, surface treatments using ferrocement and shotcrete, grout injections and using externally-bonded or near surface mounted fiber reinforced polymer (FRP) laminates, using FRP bars and fabrics over the surface of masonry wallets [Elgawady M, Lestuzzi P, 2004].

FRP retrofitting for masonry

FRP has become very popular in the last few decades. It was originally used for the strengthening of concrete structural members but later on its application is extended to masonry and infilled masonry structures. High strength to weight ratio, linear elastic behavior, corrosion resistance and ease in application are some of inherent advantages of FRP. FRP is composed of high strength fiber of glass, carbon or aramid. These fibers are joined together by a strong bonded matrix epoxy system. Fiber can be of uniaxial type and biaxial type depending upon the direction of placement. These fibers can act like reinforcement by carrying a substantial amount of load in a structural system. There is lot of experimentation carried out in order to evaluate the performance of FRP retrofitted system under in plane and out of plane static and dynamic loading. Most noteworthy work in this regard has been carried out by Triantafillou [Triantafillou, 1998]. He derived some analytical expression to calculate the ultimate response of masonry structures using FRP. Valluzzi [Valluzzi MR, Modena C, 2002] also performed in plane diagonal compression test to determine the in plane behavior of masonry wallet using FRP. Elgawady investigated the behavior of joints strengthened with diagonal laminates of FRP under static and cyclic loading. Similar type of work was also conducted by Santa Maria et al [Santa Maria H, Alcaino P, 2006] and Mahmood et al [Mahmood H, Russel AP, Ingham JM, 2008]. All of these researchers have used FRP for the strengthening of masonry wallets.

RESEARCH OBJECTIVES

In previous researches different type of tests were carried in order to evaluate the increase in strength of masonry wall system and restoration of shear strength in originally damaged walls. But there is few work found in the past which can guide towards the optimum placement and spacing of FRP. Euro code, The Masonry Society (TMS 402), American Concrete institute (ACI 530) and Masonry Standards Joint Committee (MSJC 2008) has given some guidelines based upon some analytical relations to determine the quantity of FRP based upon the amount of seismic base shear for which masonry system has to be strengthened. Triantafillou [Triantafillou,1998] has proposed some analytical relations to determine the contribution of shear force by the FRP. All these relations and design codes determine quantity of FRP which is significantly greater than the actual quantity of FRP required, as there is almost no experimental and analytical study to find out the optimum quantity of FRP to reduce the retrofitting cost. FRP is very expensive and even small reduction in quantity can reduce greatly the retrofitting cost. There is almost no literature in the past related with the optimum spacing of FRP. Main objective of this research is to find out the optimum quantity of FRP by changing the volume of FRP and its spacing. Response of the wallets is measured in terms of strength and ductility. This research can contribute toward the optimization of FRP volume and reducing the cost of retrofitting. The information gathered from this study can provide a reference for the calibration of analytical expressions for the assessment of proposed retrofitting method and will set a basis for exploration of more about the optimum design guidelines of FRP retrofitting methods.

EXPERIMENTAL PLAN

Experimentation is planned in such a way to use minimum available resources and to get maximum details. Experimentation plan consist of carrying out the diagonal compression test on clay burnt brick masonry wallets retrofitted with the different schemes of FRP, to determine their strength and deformation capacity under a dis-placement control system.

Materials

In this experimental study, different type of material including brick, cement lime mortar, Carbon Fiber Reinforced Polymer (CFRP) and a strong epoxy bond is used. Following section explains the properties of material used.

CFRP and epoxy

Biaxial type of CFRP sheets are used with fabric thickness of 0.5mm. E-250 epoxy is used to apply CFRP over the brick surface. Table 1 and 2 show the properties of epoxy and CFRP as provided by the supplier of CFRP and epoxy.

Brick, mortar and masonry

75mm x 50mm x 37.5mm clay solid burnt brick units are used for the construction of masonry wallets. Cement lime mortar with a mixed proportion of cement, lime and sand of 140:1110: 2800 is used. Water cement ratio of the mortar mix was kept 0.14. The selection of brick and mortar is based upon the mechanical properties of mortar and bricks used in the under developing countries. Different types of material tests were performed to determine the properties of masonry. Compression test on brick units are carried according to the mortar compressive strength. Three masonry prism each consisting of five brick with 5 mm mortar thickness are tested according to ASTM C-1314. Shear test and bond test are also carried out to determine the material properties of masonry.

Table 3 shows the properties of masonry and the average values of compressive strength of bricks, mortar and masonry. Mortar cubes and masonry prism were cast using the same conditions. Average compressive strength of brick is 26.1 MPa which is fairly high as compare to ordinary bricks used for the construction. Average compressive strength of masonry prism is found to be 13.42 MPa. Masonry prism for direct shear test consists of three bricks joined together with a mortar thickness of 5mm. Mortar cubes and masonry prisms for compression, shear and bond test were cured for 28 days under same environmental conditions as that of masonry wallets. Bond test is carried out with the help of two steel connected to opposite faces of brick by using strong epoxy. These steel plates are fixed in machines by using two screwing steel rods. Placed samples are than tested using Universal Testing Machine (UTM) at constant rate deformation of 0.05mm/min.

Table 1. Material properties of Epoxy

Material	Specific gravity	Tensile strength (MPa)	Tensile shear bond strength (MPa)	Bending strength (MPa)	Compressive strength (MPa)	Compressive shear bond strength (MPa)	Compressive elasticity modulus (GPa)
Epoxy	1.4	20	9.6	45	50	21	1.5

Table 2. Material properties of CFRP

Material	Specific gravity	Tensile strength (MPa)	Tensile modulus (GPa)	Bending strength (MPa)	Bending modulus (GPa)	Compressive strength (MPa)	Coefficient of thermal expansion ($10^{-6}/C^0$)	Ultimate Elongation (%)
CFRP	1.5	1600	120	130	90	900	0.2	2

Table 3. Material properties of Masonry

Test	Compressive strength of brick	Compressive strength of mortar cube	Compressive strength of masonry prism	Shear strength of mortar	Bond strength of mortar
Specimen	(MPa)	(MPa)	(MPa)	(MPa)	(MPa)
1	25.10	0.57	18.95	0.020	0.0027
2	26.60	0.42	10.70	0.016	0.0041
3	26.70	2.10	10.60	0.032	0.0029
Average	26.10	1.03	13.42	0.023	0.0032

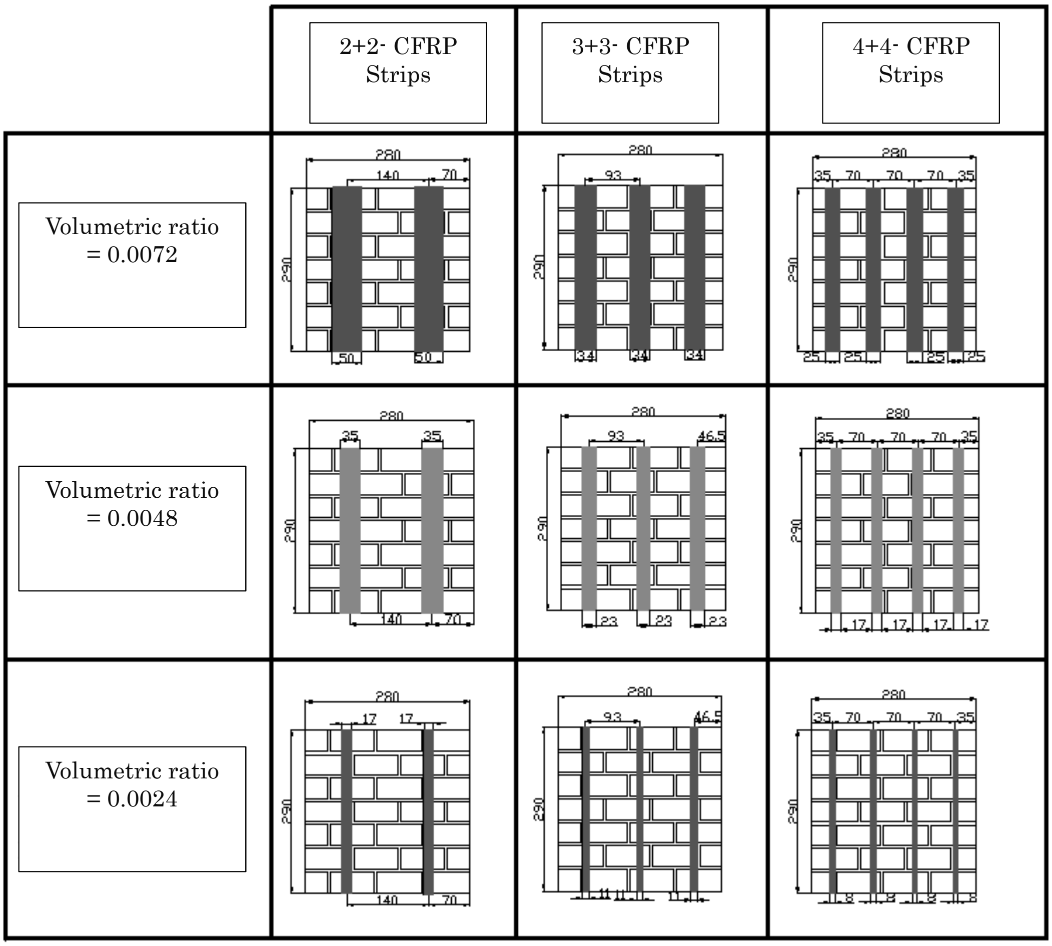


Figure 1. Retrofitting scheme of masonry wallets for volumetric study of CFRP

Masonry wallets testing scheme
Ten masonry wallets are tested under diagonal compression test, nine masonry wallets are CFRP retrofitted as shown in Fig 1 and one wallet is non-retrofitted (URM). Each set of three masonry wallets is retrofitted with same volumetric ratio but with different number of strips to have the different distribution areas over the masonry wallet. There are three volumetric ratios (ratio of volume of FRP to the volume of masonry wall) of 0.0072, 0.0048 and 0.0024 are used for a constant thickness of 0.5mm. These ratios are selected based upon the literature review and FRP volume used in different experiments conducted in the past. Maximum and minimum values of reinforcement ratios are found in the literature for strip type of FRP retrofitting. Each volume of FRP is applied on the masonry wallets with varying number of strips as shown in the Fig 1. Volumetric ratio of 0.0072 is applied in the form of 2 strips, 3 strips and 4 strips on each face. Similar type of arrangement is also used for volumes of 0.0048 and 0.0024. Figure 2 shows the details of masonry wallet retrofitted with a volumetric ratio of 0.0072 with two CFRP strips on each face. Dimension of wallet is 290mm x 280mm x 50mm. All masonry wallets are of same dimensions and constructed using same material under same environmental conditions of curing. In order to have uniformity of application procedure,

all the wall faces were cleaned and attempt is also made to keep the uniform thickness of epoxy in all the CFRP retrofitted wallets. After retrofitting and curing for two days all of the masonry wallets were plastered using mortar with a surface finish thickness of approximately 4mm.

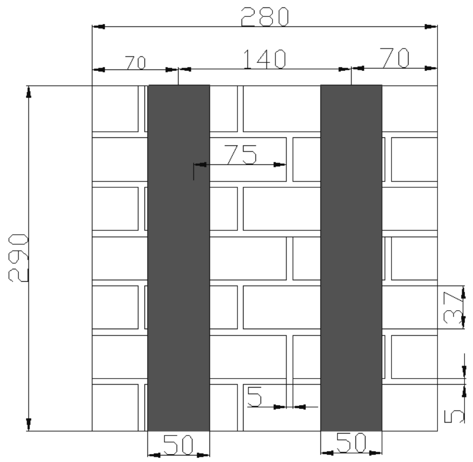


Figure 2. Details of CFRP retrofitted masonry wallet

Test setup
A schematic test setup of diagonal compression test is shown in Fig 3. Diagonal compressive force from platens of machines is applied with specially designed strong wooden wedges placed at the respective corners of wall as shown in the Fig 3. Wallets are tested under displacement control system at a loading rate of 0.25mm/min; same loading rate is used for all of the masonry wallets. In order to record the displacement response, a displacement transducer is directly attached to the masonry wallet to measure the displacements. LDTV displacement transducer with 500×10^{-6} mm sensitivity with a maximum displacement capacity of 25mm is used for measurement of retrofitted wallets displacements.

Figure 3. Test setup of masonry wallet under diagonal compression

RESULTS AND DISCUSSION

Wallets with volumetric ratio of 0.0072

Figure 4 shows the load-displacement curve obtained during diagonal compression test of masonry wallets retrofitted with CFRP volumetric ratio of 0.0072. All the wallets show nearly same initial stiffness but with different ultimate loads. It can be clearly seen from Fig 4 that by increasing number of strips the load carrying capacity of the non-retrofitted masonry wallet (URM) is increased from 2.6kN to minimum of 8.8kN by the use of CFRP. Load carrying capacity is further increased by 42% from 8.8kN to almost 12.5kN by just increasing the number of strips from 2 to 4 on both faces of masonry wallet keeping the same volume of CFRP.

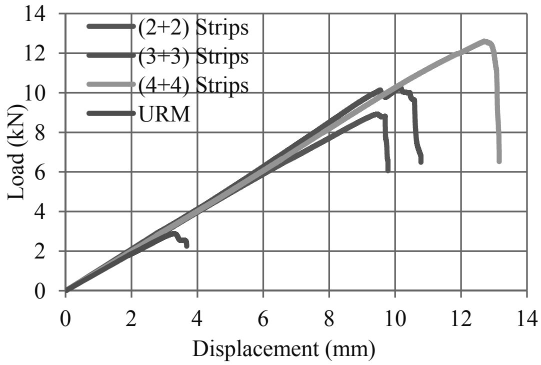


Figure 4. Load-displacement curve with volumetric ratio of 0.0072 of CFRP with varying number of strips

Wallets with volumetric ratio of 0.0048

Load-displacement curves of masonry wallets retrofitted with CFRP volumetric ratio of 0.0048 are shown in Figure 5. Wallets retrofitted with 0.0048 volumetric ratio of CFRP have shown almost similar trend as that of wallets retrofitted with 0.0072 volumetric ratio of CFRP but the increase in load carrying capacity is not proportional to 0.0072 volumetric ratios. A slight increase of almost 14% is witnessed in load carrying capacity of masonry wallets when the numbers of strips are doubled from 2 to 4 keeping the same volume of masonry wallets. Even there was no significant difference in load carrying capacity and failure displacements, when the numbers of strips are varied from 2 to 3. By reducing the volume from 0.0072 to 0.0048 load carrying capacity is also reduced.

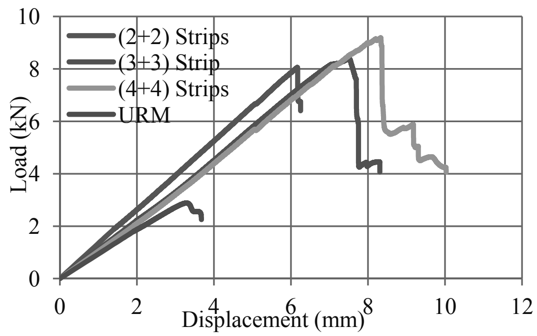


Figure 5 Load-displacement curve with volumetric ratio of 0.0048 of CFRP with varying number of strips

Wallets with volumetric ratio of 0.0024
Figure 6 shows the load-displacement curve obtained during diagonal compression test of masonry wallets retrofitted with CFRP volumetric ratio of 0.0024. In this case, wallets have shown some different trend as that of other masonry wallets retrofitted with 0.0072 and 0.0048 volumetric ratio of CFRP. By increasing the number of strips from 2 to 4 keeping same volumetric ratio of CFRP as 0.0024, load carrying capacity is reduced from 7.4kN to 6.1kN as shown in Fig 6. Ultimate load also remain nearly same in case of increasing the number of strips from 2 to 3 keeping the same CFRP volume of 0.0024 over the masonry wallets. All the wallets have also shown almost same failure displacement.

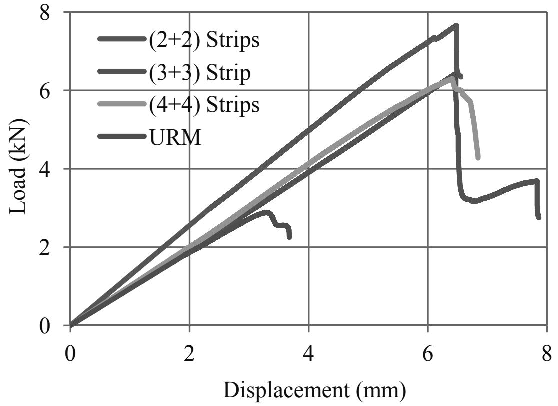


Figure 6. Load-displacement curve with volumetric ratio of 0.0024 of CFRP with varying number of strips

Effect of CFRP volume
Figure 7 shows the three dimensional bar chart view to understand the effect of CFRP volume and number of strips on the ultimate load carrying capacity of masonry wallet. By increasing the volume of CFRP, the strength of masonry wallet is increased but this increase is not proportional to the volume of CFRP. The effect become further complicated when the numbers of strips are also increased, as for two strips on each face with CFRP volume increase from 0.0024 to 0.0072 has increased the wallet strength from 7.7 to 8.9kN. which corresponds to 16% increase in strength for using three times the original volume. But when four strips are used on both faces of the masonry wallet than by increasing the CFRP volume from 0.0024 to 0.0072 the load carrying capacity is further increased from 6.3 to 12.6kN. which is corresponding to 100% increase in wallet strength by increasing the volume almost three times than the 0.0024 volumetric ratio. Using 0.0024 volumetric ratios the strength of wallet is increased from 2.6kN to a minimum of 6.3kN which is almost 140% increase in the strength of non-retrofitted wallet (URM). Whereas 0.0072 volumetric ratio has increased the URM strength from 2.6kN to minimum of 8.8kN which corresponds to 240% increase in ultimate strength of URM by increasing the volume almost three times than the original volume of CFRP .

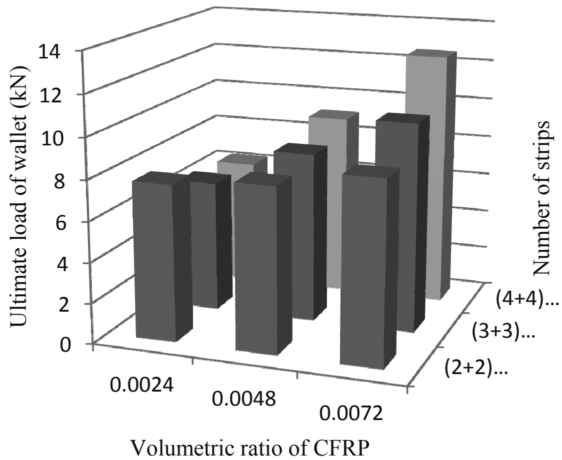
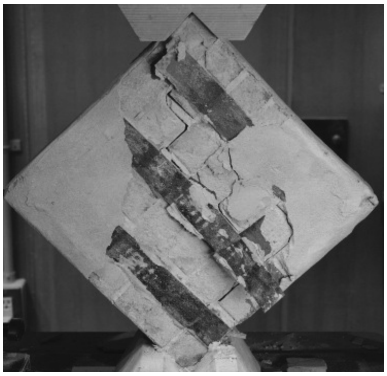


Figure 7. Effect of increase in CFRP volume and number of strips on the load carrying capacity of masonry wallets

FAILURE MECHANISM

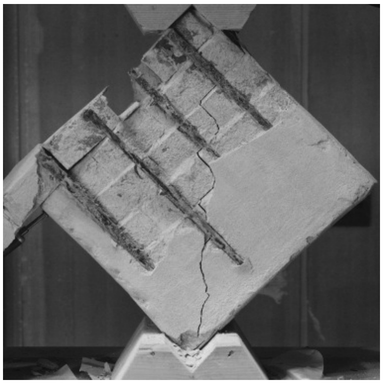
Some typical failure pattern of masonry wallets have been shown in Fig 8. Figure 8 (a) to (c) show the failure pattern of masonry wallet retrofitted with 0.0072 CFRP volumetric ratio with two, three and four number of strips on both faces and Fig 8(d) show the failure pattern of masonry wallet retrofitted with 0.0024 CFRP volumetric ratio with four number of strips on each face . All the masonry wallets have shown a sudden and highly brittle. Always failure was due to debonding of CFRP from brick surface along with some part of brick with FRP showing a good bond between CFRP and brick surface as shown in Fig 8. In case of four numbers of strips the surface plaster has shown the distribution of crack on all over the masonry wallet surface. Wallets with two number of strips has mostly shown one single wide crack over the plaster surface but all the wallets have final failure in diagonal direction.

(a) Failure pattern of masonry wallet retrofitted with 0.0072 CFRP volumetric ratio with two strips on each face



(**b**) Failure pattern of masonry wallet retrofitted with 0.0072 CFRP volumetric ratios with three strips on each face

(**c**) Failure pattern of masonry wallet retrofitted with 0.0072 CFRP volumetric ratio with four strips on each face



(**d**) Failure pattern of masonry wallet retrofitted with 0.0024 CFRP volumetric ratio with four strips on each face

Figure 8. Some typical failure pattern of masonry wallet retrofitted with CFRP.

CONCLUSIONS

This study has given useful information to understand the effect of increase in volume and number of strips over the surface of masonry wallet. For higher volumetric ratio as 0.0072, increasing the number of strips has good effect on the ultimate strength and failure displacement. Below a minimum CFRP volume, reducing the CFRP volume and increasing the number of strips may not be a suitable options as the width of CFRP will be reduced resulting in lower surface area of individual strips. Increment in strength is also not proportional to CFRP volume. There is no significant increase in ultimate load carrying capacity by increasing the CFRP volume by two times or three times than the smaller volumes as 0.0024. Increasing the CFRP volume to get higher strength is not advisable as CFRP is very expensive and increase in CFRP volume highly increases the cost for small increase in strength but will increase retrofitting cost very high proportional to the volume of CFRP. Final selection of FRP volumes is based upon the amount of base shear that has to be transferred to the masonry wall system through the application of CFRP. Analytical expressions requires much more experimental and analytical exploration as bond strength of epoxy and brick surface tensile failure are governing parameter in determining the final strength of masonry wall system.

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