Experimental Investigations on Rectangular Brick Masonry Columns Retrofitted with Fiber Reinforced Polymers

[Deepa A. Joshi, Dr. R. K. Jain, Dr. Gopal Rai]

***Abstract*— This paper presents an experimental study of rectangular clay brick masonry columns retrofitted with Fiber Reinforced Polymers (FRP). The experimental program involves casting of 15 column specimens out of which 3 specimens were tested as control specimens without application of FRP and 12 specimens were wrapped with FRP strips. The control specimens were tested till failure under uniaxial compressive load whereas the other 12 specimens were subjected to pre-compression load of around 80 to 90 % of ultimate failure load till vertical splitting cracks were observed predominantly. The FRP material used for retrofitting was Carbon (CFRP) and Glass (GFRP). The potential of FRP anchors in enhancing the load carrying capacity of columns was also accessed through the experimentation. The arrangement of FRP strips for all specimens were kept identical to have fair comparison for other parameters. From the analysis of experimental results it can be concluded that the FRP strip wrapping is an effective retrofitting technique for brick masonry. The detailed discussion on experimental results and comparisons for various parameters has been presented in this paper. This work will add to reliable experimental data base and can be utilized for further research work.**

Keywords— ***Masonry Columns, Retrofitting, FRP, GFRP, CFRP***

Introduction

Masonry is one of the oldest materials used for construction of various types of structures. Stone and brick masonry structures are present in large number all over the world. New as well as old residential buildings, bridges, churches, temples are the major categories of masonry structures. These structures need strengthening due to many reasons such as lack of strength, stiffness, ductility and durability.

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Generally the old structures are not designed for earthquake loads, or they need retrofitting to meet current code provisions. Most of the old monuments are built with masonry structures. Historical buildings play an important role in identification of any Nation. They need to be preserved because of their artistic and cultural heritage. The Archaeological Survey of India has reported that there are at present more than 3650 ancient monuments and archaeological sites in nation.

There are various methods for strengthening of Masonry Structures among which the use of Fiber Reinforced Polymer (FRP) has received increased attention due to the advantages of FRP, mainly lower specific weight, resistance to corrosion, ease of application and cost effectiveness. One of the important features of FRP that makes it suitable for Masonry is its adaptability to curved and rough surfaces. FRP consists of high resistance fiber impregnated with resins.

The use of FRP material for strengthening of reinforced concrete material is well established. FRP systems were first applied to reinforced concrete columns for providing additional confinement in Japan in the 1980s [Fardis and Khalili 1981; Katsumata et al. 1987] [1]. As compared to concrete less work has been done on masonry. Schwegler (1994) and Saadatmanesh (1994) [2] analysed the use of FRP for strengthening of masonry structures [3].

Masonry column is one of the load bearing member in masonry structures and hence needs special attention for retrofitting. Abrams et al. (2007) have studied flexural behaviour of slender piers subjected to repeated and reversed in-plane defections and varied axial compression. [4]. Whereas Krevaikas and Triantafillou (2005)[5], Aiello et al. (2009) [6] , Alecci et al. (2009) [7], Ludovico et al. (2010) [8] , Borri et al. (2011) [9], have carried out confinement studies. The effectiveness of four different strengthening techniques for improving seismic resistance was examined experimentally by Abrams et al. (2007) [4]. Krevaikas and Triantafillou (2005) carried out an experimental investigation on the behaviour of axially loaded short masonry columns confined with FRP jackets [5]. Strengthening was done by using different number of layers (1 , 2 and 3) of unidirectional Carbon FRP (CFRP) sheets or Glass FRP (GFRP) sheets. In 2009, Aiello et al. have studied experimental behaviour of rectangular masonry columns and compared with analytical results obtained from Italian National Research Council guidelines (CNR DT200-2004)[10]. The strengthening scheme included internal and external application of FRP. Internal application was in the form of FRP bars inserted in the masonry column. Externally one or two FRP sheets/strips were wrapped.

Uniaxial and triaxial tests on brick masonry cylindrical columns with and without CFRP wrapping have been conducted by Alecci et al . (2009) [7]. Along with the conclusions derived on the basis of experimental results, one more conclusion provided by researchers is that the final strength of the compressed masonry member confined with FRP does not depend on the initial strength but on the residual strength of the confined masonry. Ludovico et al. (2010) have carried out the experimental program to access potential of confinement of masonry columns made up of tuff masonry clay brick masonry.[8] Column specimens were wrapped using one ply different types of fibers. Comparison of performance of tuff masonry and clay brick masonry showed that overall efficiency of FRP wrapping is more significant on clay brick masonry than on tuff [8]. The application of steel fiber reinforced polymer (SRP) for masonry columns has been investigated by Borri et al, (2011) [9]. It has been reported by the researchers that octagonal masonry columns are quit common in Italy and the rest of Europe in many historical constructions such as churches, monasteries and porticoes. Besides clay bricks, the masonry units used for experimentation were calcareous blocks [6, 11, 12], tuff masonry [8, 13] concrete blocks [14].

In most of the experimental studies the retrofitting has been done by continuous wrapping of FRP. FRP reinforcement that completely encases the strengthened member may prevent migration of moisture especially in case of brick masonry members. Even the Italian National Research Council guidelines (CNR DT200-2004) states that such FRP systems shall not be applied continuously on extended areas of the wall surface to ensure migration of moisture [10]. Also it has been proved by the researchers that continuous wrapping techniques improves the performance of masonry columns; hence in this experimental work the potential of discontinuous wrapping of FRP has been assessed. The detailed experimental program has been presented in this paper followed by results and conclusions.

I. Experimental Program

Total 15 brick masonry solid column specimens of 210 mm x 210 mm in cross section and 480mm of height were cast. Three column specimens were tested without FRP wrapping to serve as control specimens under uniaxial compression load till failure. Twelve column specimens were retrofitted using FRP and tested for the enhancement in load carrying capacity.

A. *Material Properties*

Mechanical properties of basic materials required for casting specimens were determined experimentally. Characterization of bricks, mortar has been done by conducting various tests on them. On bricks, compressive strength, water absorption tests were conducted as per IS 3495 (Part 1 & Part 2): 1992. The average compressive strength of bricks was found to be 5.3 N/mm^2. Compressive strength of cement mortar (1:8) was determined experimentally by testing mortar cubes of dimensions 70 x 70 x 70 mm as per IS 2250: 1981, in CTM (Compressive Testing Machine) after 28 days. The average compressive strength of mortar was found to be 1.4 N/mm^2

B. *Retrofitting Techniques Adopted*

The retrofitting of cracked column specimens was done by using two composite materials, namely CFRP and GFRP. Wrapping of FRP to the columns were done in strips. The horizontal strips of width 80mm were placed at three locations. As these are masonry columns, vertical strips were also applied for proper confinement. The vertical strips were applied at two locations; at corners and at the location of vertical splitting cracks which are at the middle portion on all faces. Hence for each column, four vertical strips (one at each corner) of width 50mm, four vertical strips (middle of each face) of width 30mm and three horizontal strips of width 80mm were fixed. Retrofitting scheme explained above was used for all twelve columns but the variation was done in composite material and use of anchors. Four categories were made depending on material and anchors as follows

1. GFRP without anchors
2. GFRP with anchors
3. CFRP without anchors
4. CFRP with anchors

In each of the above mentioned categories, three specimens were tested. The specimens were named such that it becomes easy to understand category of it by just reading the name of specimen. The first alphabet used indicates the type of FRP material, the specimens with GFRP starts with ‘G’ and specimen name for CFRP starts with ‘C’. For the specimens tested without anchors, ‘WO’ has been added next to first alphabet whereas for the specimen tested with anchor, only ‘W’ has been added. The last digit indicates the serial number of the specimen in the category. Hence for the first specimen of GFRP wrapped without anchor category, will have ‘GWOA 1’ name or label.

C. *Retrofitting Procedure*

All the columns were first loaded under uniaxial compressive load up to around 80 to 90% of ultimate capacity of control column. Vertical splitting cracks were observed on all four faces as shown in Figure no. 1. These cracks were first filled with ‘Lime Surkhi’. Lime Surkhi was prepared by mixing Lime and brick powder properly with water to form a paste. Instead of cement mortar or grout, Lime Surkhi was used to fill the cracks to avoid contribution of filling material in increase of load carrying capacity of the specimen. The crack filled specimens were kept for 24 hours, after which the specimens were made smooth by using the grinder m
achine. The corners of the column were rounded and made smooth. This is very essential so the FRP material gets properly bonded to surface.

Figure 1 : Vertical Splitting Cracks

FRP Application

- Application of Primer: Primer was prepared by thoroughly mixing Resin Primer Base and Hardener in the proportion 1:0.5 (kg). This solution is applied all over the column surface as base coat. The specimens were kept for 24hours.
- Marking for the locations of FRP strips was done on the columns, can be seen in Figure 2. Mixture of Base, Hardener and aggregate powder was prepared. The proportion for this mix was 1 kg Base: 500gm Hardener: 3.5 kg aggregate powder. This mixture is termed as 'Putty'. The putty was applied at locations of FRP strips, which were marked previously.

Figure 2 : Marking for FRP strips on Primer applied specimen

- On the putty, epoxy was applied. Epoxy solution was prepared by adding Matrix base and hardener in the proportion of 1 Kg : 350 gm.
- The vertical strips at corners and middle portion were carefully placed at the locations and then fixed by pressing with roller. After fixing all vertical strips, horizontal strips were applied at marked locations.
- For the specimens with anchors, holes of 12 mm diameter and around 100 mm length were drilled at the location of anchors. For each specimen three anchors were used. The anchors were inserted at the overlap of each horizontal strip in staggered manner. For GFRP wrapped specimens, GFRP anchors were used and for CFRP wrapped specimens, CFRP anchors were used. Figure 3 shows CFRP specimen with anchor.
- The FRP wrapped specimens were kept for four days and testing under uniaxial compressive load was carried out.

Figure 3 : CFRP with Anchors

Figure 4 : GFRP without Anchors

Figure 4 shows photograph of GFRP wrapped specimens. All specimens were tested under Universal Testing Machine (UTM) of 100 tonnes capacity for uniaxial compression till failure.

II Results & Discussion

The experimental results obtained for all specimens are presented in Table No 1. The control specimens, which are unstrengthened, brick masonry columns, failed at an average load of 46.33 kN. Whereas the minimum load taken by retrofitted columns was 83kN.

The category one specimens retrofitted with GFRP without anchors carried an average load of 83.03 kN whereas GFRP with anchors could take 93 kN load. The average load carried by category three specimens, retrofitted with CFRP without anchors was found to be 170.66 kN and CFRP with anchors could carry 196.33 kN load.

Table No. 1 : Experimental Results for Retrofitted Specimens

Category No.	Name of Specimens	Number of Specimens	Average Load Carried (kN)
0	Control	3	46.33
1	GWOA 1-3	3	83.03
2	GWA 1-3	3	93.13
3	CWOA 1-3	3	170.7
4	CWA 1-3	3	196.33

Minimum % increase in load carrying capacity of retrofitted specimen as compared to controlled specimen obtained is around 80% whereas maximum is around 320%. CFRP wrapped specimens could take double the load as compared to GFRP wrapped specimens in both with and without anchor category. The anchors could increase 12-15 % load carrying capacity of retrofitted columns for both composite materials.

Failure Mode

In case of GFRP retrofitted columns without anchors, failure occurred by delamination of GFRP horizontal strips from brick masonry surface. In some portion the part of GFRP strip got delaminated along with brick masonry material. Vertical GFRP strips showed fracture but horizontal strips predominantly failed due to delamination which can be seen in Figure 5. In case of specimens with GFRP anchors, more confinement was achieved as the anchors delayed the delamination of horizontal strips and specimen could carry some more load but ultimately failure occurred due to delamination.

Figure 5 : Failure of GWOA Specimen

CFRP retrofitted specimen in both cases with anchor and without anchor failed by rupture of FRP. The vertical strips got fractured first and the brick masonry inside was crushed completely to powder form. The load was carried by the specimens till rupture of horizontal strip occurred. Figure 6 shows photograph in which rupture of horizontal strip can be seen. The specimen with anchor showed increased capacity as compared with specimens without anchors.

Figure 6 : Failure of CWOA Specimen

III Conclusion

Experimental investigations of rectangular brick masonry columns, retrofitted with FRP was carried out. The FRP used for retrofitting was Glass and Carbon. The potential of FRP anchors in enhancing the load carrying capacity of columns was also accessed through the experimentation. The retrofitting technique adopted was discontinuous wrap with FRP strips. Following conclusions were drawn from the results of experimental program.

1. Retrofitting using FRP is an effective technique for brick masonry as the load carrying capacity of columns increased from 46.33 kN to minimum 83.03kN and maximum 196.33kN.
   Also the addition of FRP material on masonry did not cause significant increase in self weight of columns.
2. Performance of CFRP retrofitted column specimens was observed to be higher than GFRP retrofitted column specimens.
3. The anchors were found to be effective in delaying the delamination of GFRP strips. Increase in load carrying capacity was obtained for both composite materials due to fixing of anchors.

This experimental work shows that discontinuous wrapping technique is an effective technique and further study on optimization for the amount of FRP can be carried out. The optimized solution for discontinuous wrapping will be better alternative for continuous wrapping technique.

The literature review reveals that very less work on retrofitting of masonry structures using FRP has been done as compared to concrete structures. There is large scope of experimental as well as analytical work on retrofitting of masonry structures using FRP.

Acknowledgment

The writers gratefully acknowledge the support of laboratory staff of Pad Dr DYPIET, Pimpri and technical staff of R & M Internationals. All FRP and material required for FRP application for this experimental program was sponsored by R & M Internationals.

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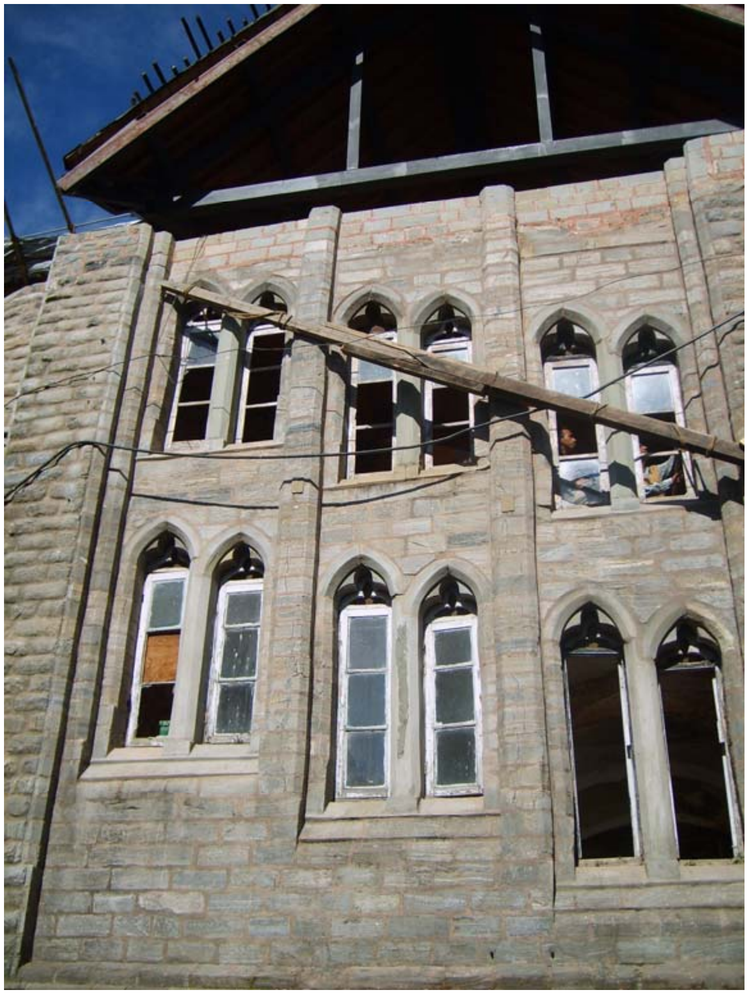
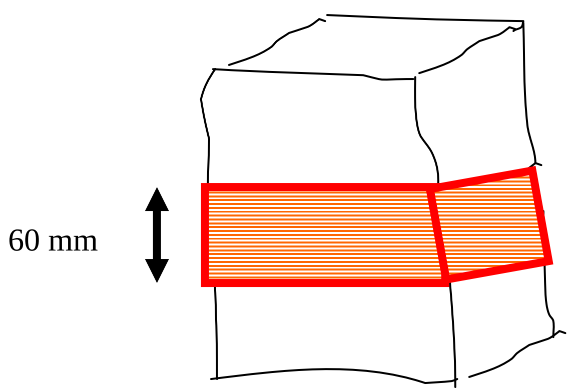
ANNEXURE – III



External View (Gaiety Theater Simla)


Section A-A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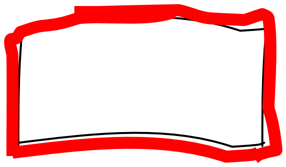

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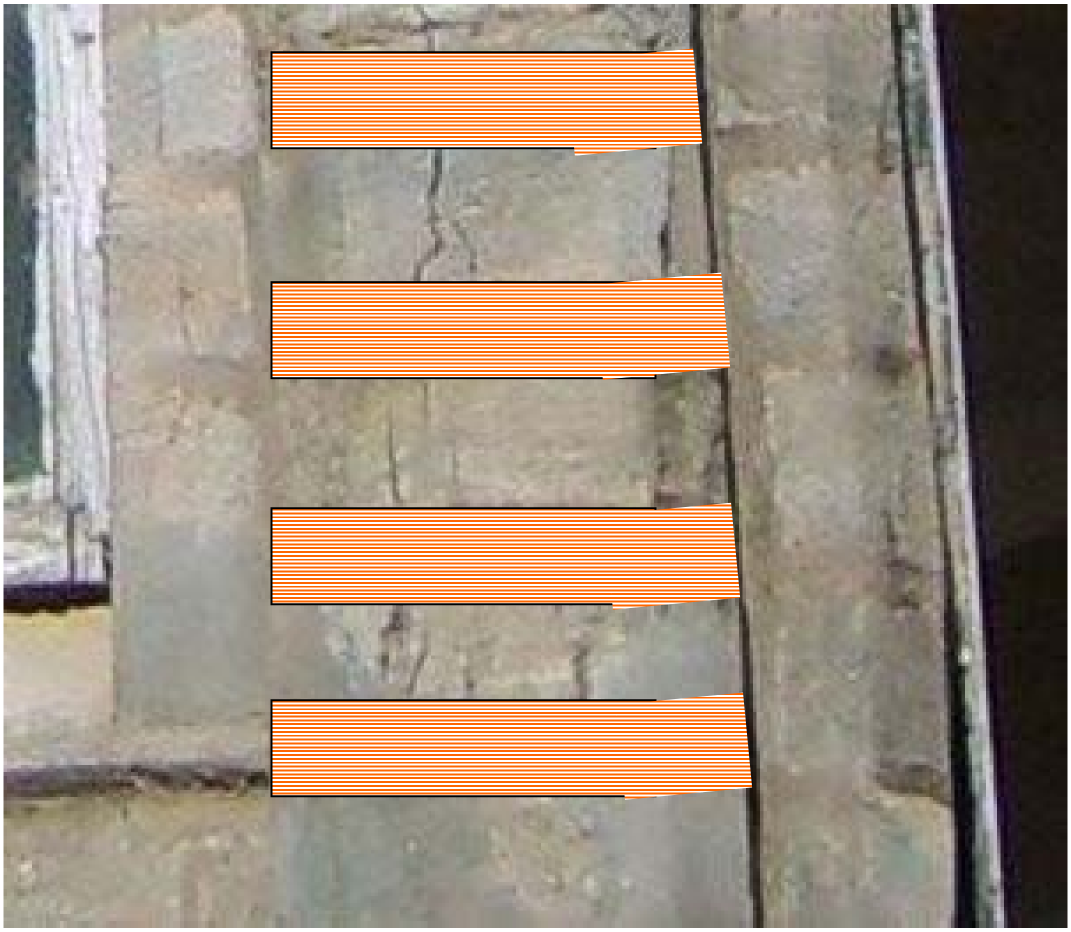

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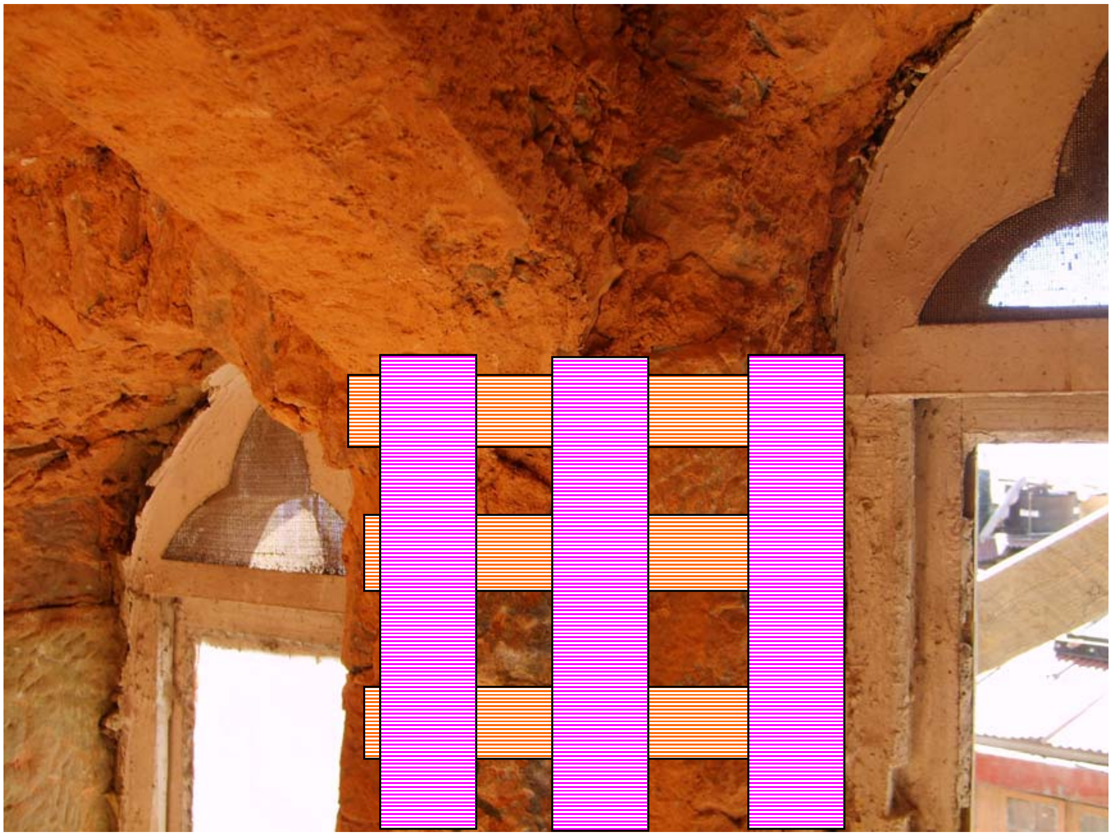

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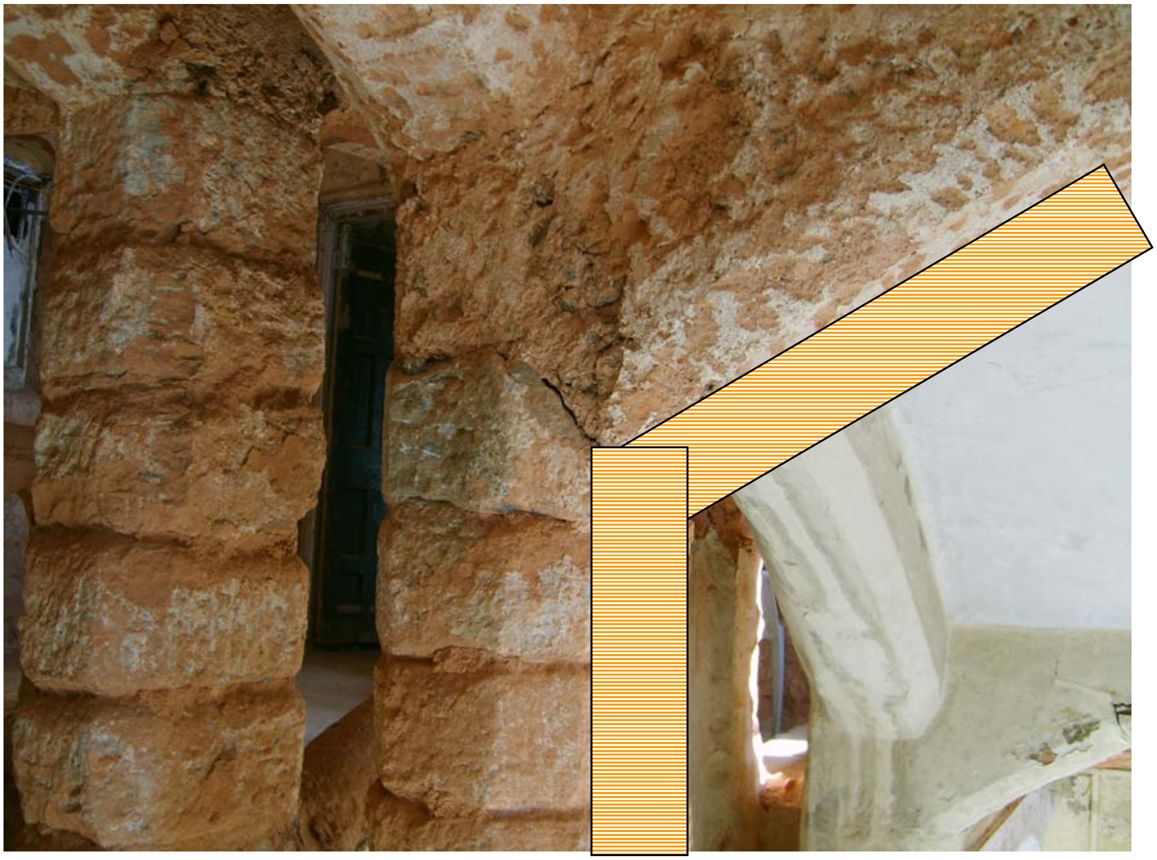

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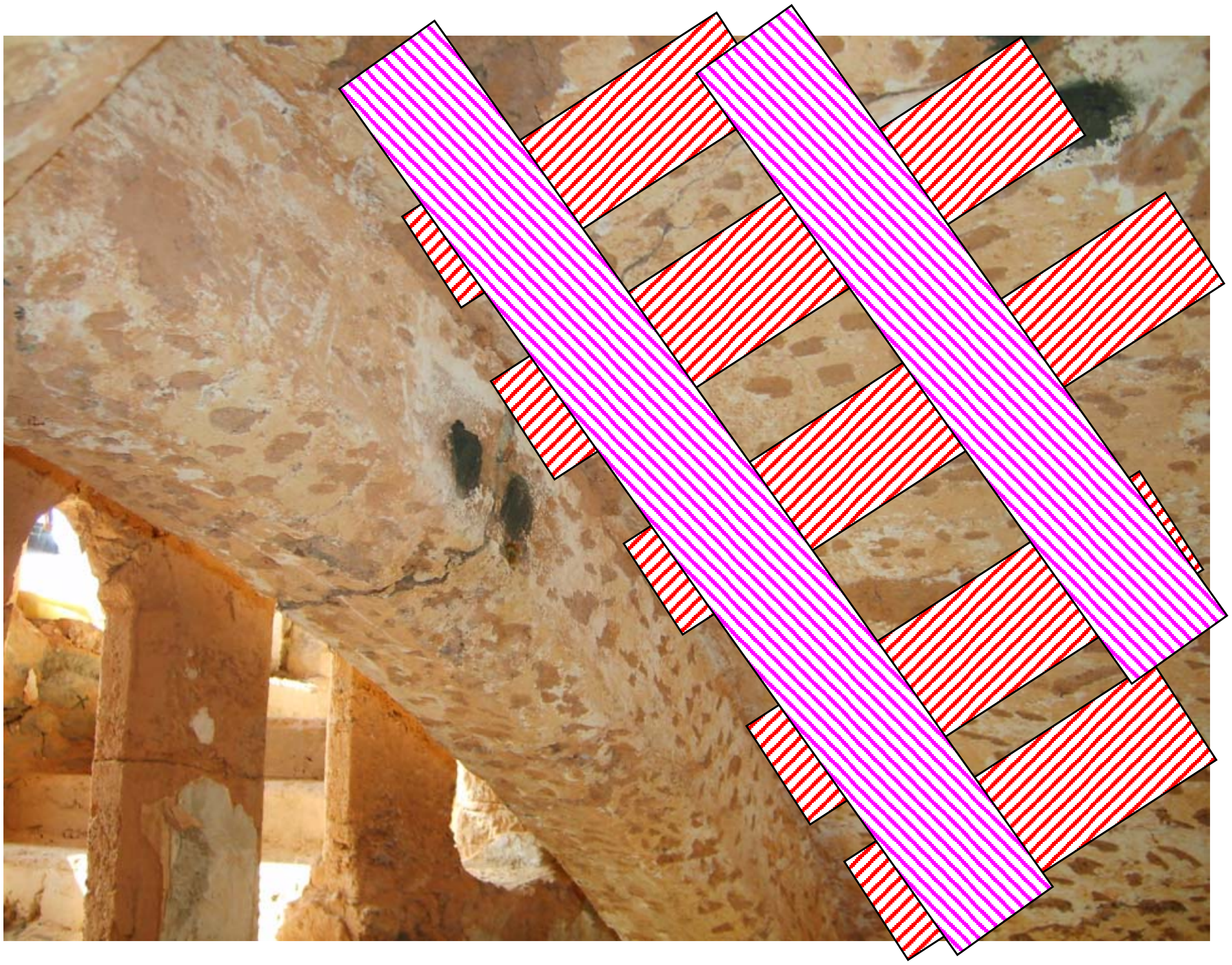

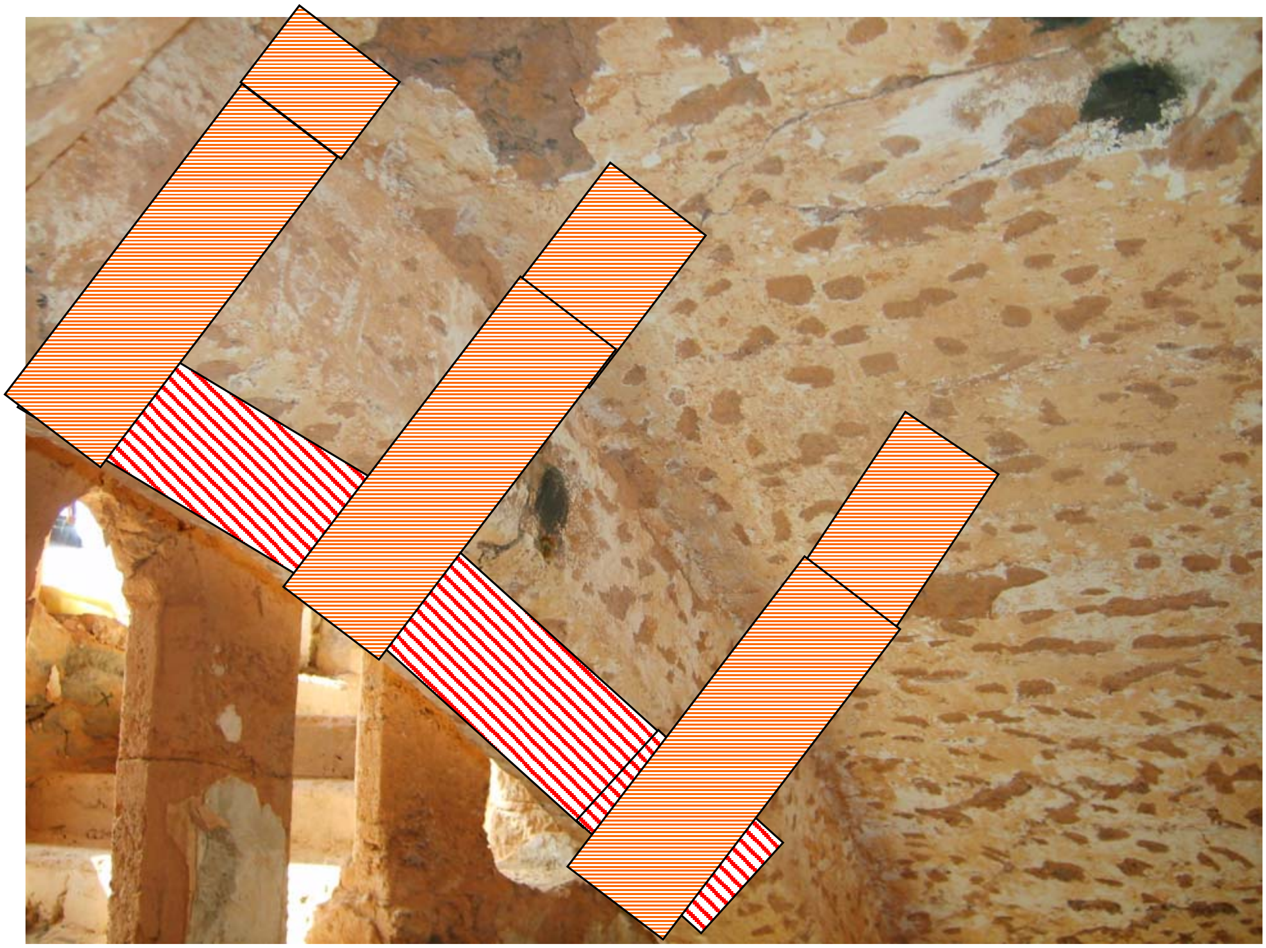

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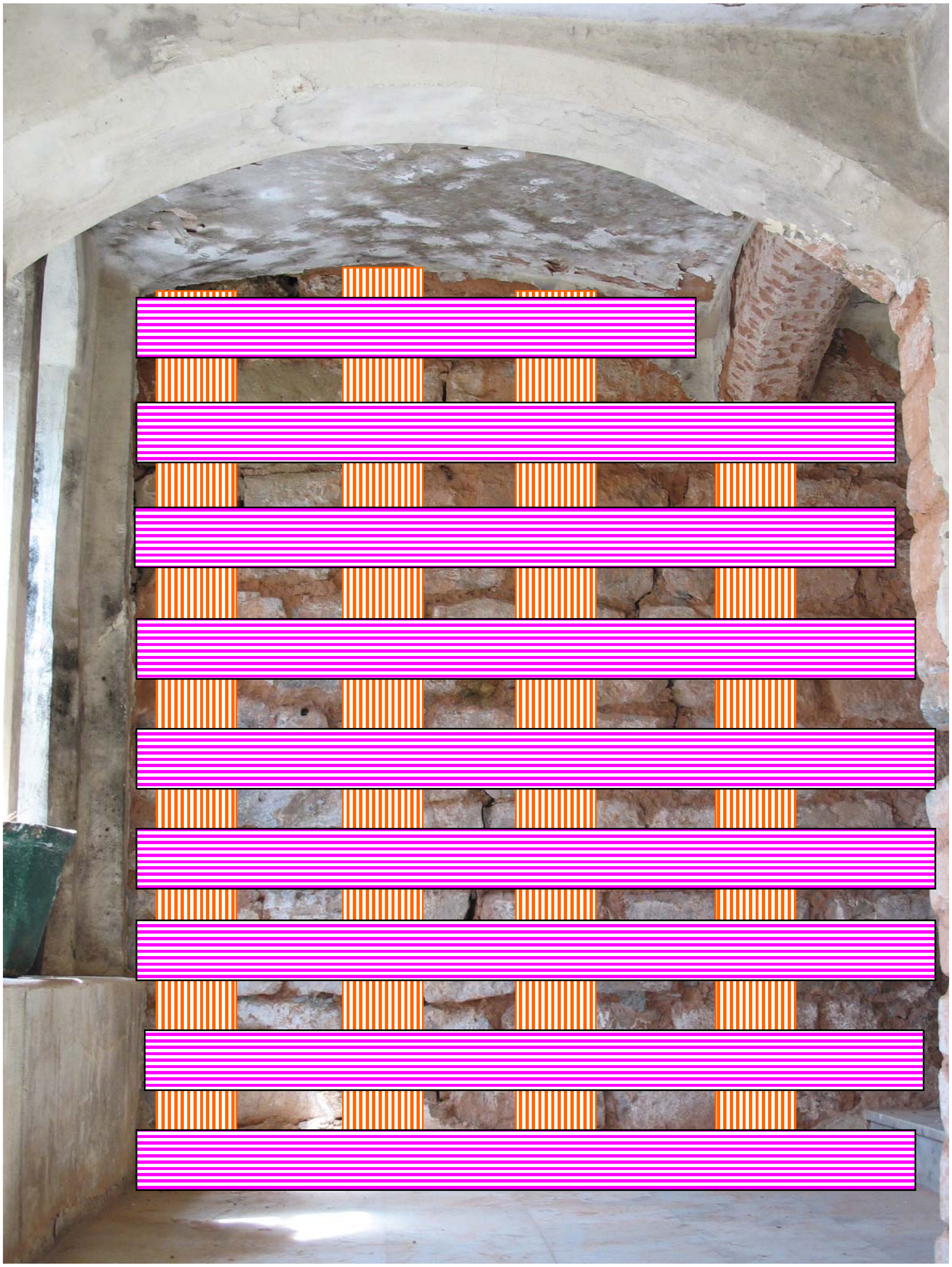

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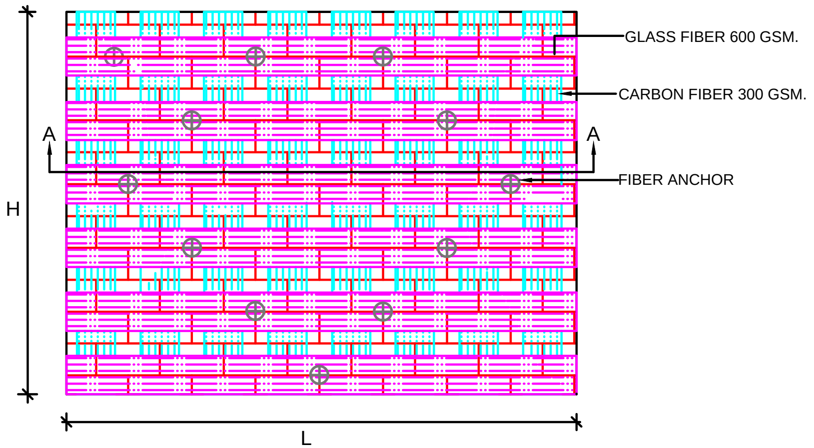
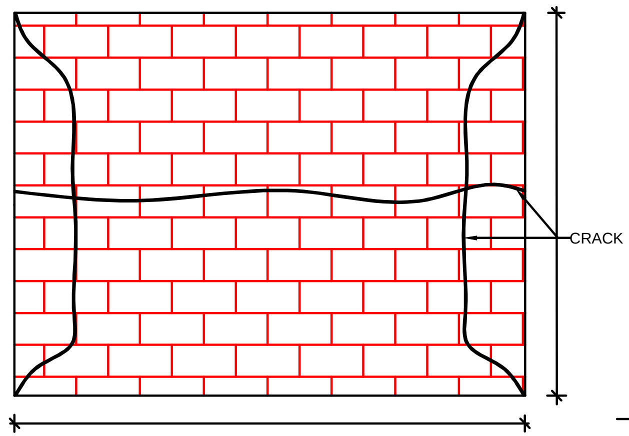
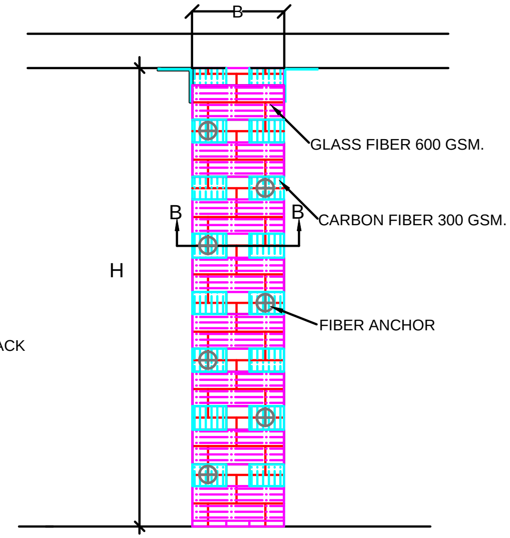
ANNEXURE – IV



ELEVATION VIEW OF WALL
POST STRENGTHENING

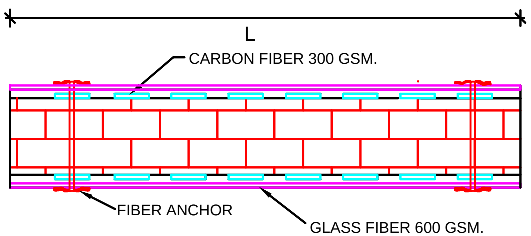


ELEVATION VIEW OF WALL
SHOWING CRACKS



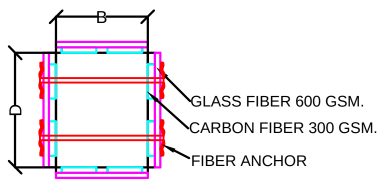
ELEVATION VIEW OF COLUMN

STRENGTHENING OF MASONRY COLUMN
(TYPICAL)



SECTION -A-A

STRENGTHENING OF MASONRY WALL
(TYPICAL)



SECTION -B-B

REV.	DESCRIPTION	BY	APPR.	DATE

CLIENT R&M INTERNATIONAL PVT. LTD.

PROJECT STRENGTHENING OF MODEL TOWN G-3/3

TITLE STRENGTHENING OF MASONRY WALL & COLUMN (TYPICAL) MODEL TOWN, G-3/3

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CHD.: DIVYA	DWG. NO.: RM-324-1-R0-01	ISSUE R0

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