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CONFINEMENT OF MASONRY COLUMNS WITH FIBER REINFORCED POLYMERS, EXPERIMENTAL RESEARCH WORK: A STATE OF THE ART

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ABSTRACT

The purpose of this paper is to provide the state of the art and the critical issues and observations on confinement of masonry columns using fiber reinforced polymers (FRP). The use of FRP material for strengthening of reinforced concrete members is well established. As compared to concrete less work has been done on masonry although masonry structures have been strengthened using FRP for walls, columns and arches. This paper provides the detailed review and background on the confinement of masonry columns using FRP. Experimental work on columns carried out by many researchers has been presented considering various parameters studied; such as type of masonry units, types of mortars, types of FRP used for strengthening, amount of FRP reinforcement and strengthening techniques; followed by detailed discussion on results obtained. The paper concludes with the recommendations for work in the strengthening of masonry columns using FRP.

Key words: Masonry Column, Confinement, FRP, Experimental Research Work, Analytical Research Work.

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1. INTRODUCTION

Masonry is one of the oldest materials used for construction. Stone masonry, 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. The widely utilized material for construction in India is brick masonry, due to its advantages like ease of construction, high sound and thermal insulation properties etc. (Vincent Sam Jebadurai S and Dr. Tensing D)[1]. These structures need strengthening due to many reasons such as lack of strength, stiffness, ductility and durability. Generally the old structures are not designed for earthquake loads, and hence many such important structures have suffered during the past earthquakes all over the world.

Most of the old monuments are masonry structures. Historical buildings play an important role in identification of any Nation. They need to be preserved because of their artistic and cultural importance. The Archaeological Survey of India has reported that there are at present more than 3650 ancient monuments and archaeological sites in nation. Retrofitting or strengthening of historic structure is a very critical task as the main objective of such work is to preserve the structure without affecting its aesthetic value.

FRP consists of high resistance fiber impregnated with resins. There are various methods for strengthening of Masonry Structures among which the use of FRP is getting increased attention due to the advantages of FRP such as low 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.

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) (ACI 440.2R-02) [2,3,4]. T. P. Meikandaan and Dr. A. Ramachandra Murthy have stated that, to increase the load carrying capacity of the structural beam as well as to increase the service life of the beam retrofitting with FRP sheets especially GFRP sheets found most suitable and economical.[5] As compared to concrete less work has been done on masonry. Schwegler (1994) and Saadatmanesh (1994) [6] analyzed the use of FRP for strengthening of masonry structures (Daniel et al., 2010) [7]. For masonry structures FRP has been used as strengthening material for walls, arches and columns. The research on walls, major work has been done on FRP retrofitted URM walls under out-of-plane loads and it has been observed that the out-of-plane resistance of URM walls increases duo to strengthening with FRP. (Gilstrap and Dolan 1998, Hamoush et. al. 2001, Albert et. al. 2001, Siva et. al. 2001, Ghobarah and Galal 2004, Tan and Patoary 2004, Galal and Sasanian 2010) [8,9,10,11,12,13].

While the research on the shear strength of FRP retrofitted URM walls has been limited. (Ehsani et al. 1997; Tumialan et al. 2001; Valluzzi et al. 2002; Stratford et al. 2004; ElGawady et al. 2007; Y.Zhuge 2010)[14,15,16,17,18,19]. The literature review reveals that application of externally bonded FRP reinforcement at extrados or at Intrados of the Masonry Arches, always causes an increase in the collapse load. (Valluzzi et. al. 2002, Foraboschi 2004, Briccoli Bati et. al. 2007,De Lorenzis et. al. 2007, Deepa A. Joshi and R. K. Jain (2012)[16, 20,21,22,23]. Masonry column is one of the load-bearing members in masonry structures and hence needs special attention for strengthening. Confinement of column increases axial load carrying capacity of the column. This paper highlights the research done on strengthening of masonry columns as Experimental and Analytical work. The work done has been divided in two categories as ‘Experimental Research Work’ and ‘Analytical Research Work’. The information has been complied in a tabular format when possible so as to get clear and complete understanding. This study aims at providing detailed review of experimental and analytical work on application of FRP material on masonry columns; being carried out all over the world. Finally the guidelines provided in this context as in CNR-DT-200 [24] have been discussed along with the conclusions.

2. EXPERIMENTAL RESEARCH WORK

In the experimental work basic theme is to test un-strengthened masonry columns and compare its results with strengthened masonry columns with FRP application. The testing program starts with various tests such as compressive strength, tensile strength, modulus of elasticity to characterize the basic materials like masonry unit, mortar and FRP. Experimentation has been carried out for developing stress strain curves for unreinforced masonry (Kaushik et al., 2007)[25]. The various parameters studied in experimental work are type of masonry units, types of mortars, types of FRP used for strengthening, amount of FRP reinforcement and strengthening techniques.

The experimental results of solid clay brick masonry columns strengthened with FRP shows that there is substantial enhancement in load carrying capacity of columns.

Abrams et al. (2007) [26], have studied flexural behaviour of slender piers subjected to repeated and reversed in-plane defections and varied axial compression. Whereas Krevaikas and Triantafillou (2005), Aiello et al. (2009), Alecci et al. (2009), Ludovico et al. (2010) , Borri et al. (2011), Bieker et al.. [27, 28, 29, 30, 31, 32] have carried out confinement studies. The effectiveness of four different strengthening techniques for improving seismic resistance was examined experimentally by Abrams et al. (2007) [26].The strengthening schemes adopted were; 1) Adhered FRP polymer strips. 2) Reinforced shotcrete overlay 3) Ferrocement surface coating and 4) grouted reinforcing bars with drilled cores. The parameters studied were lateral strength and ductility.

The detailed discussion of behaviour of each specimen strengthened with different methods has been provided. At the end the conclusions are drawn for each strengthening scheme. The FRP rehabilitated specimen showed high strength but overall seismic capacity was lowest of all specimens due to low ductility. The comparisons of experimental results with the results obtained using FEMA 356 [34] showed that FEMA 356 [34] accurately estimates the strength for non rehabilitated piers overestimates the strength for the rehabilitated piers and overestimates the stiffness for all piers.

The different types of fibers for confinement studies on clay masonry columns were used by various researchers. Krevaikas and Triantafillou (2005)[27] used GFRP and CFRP, Aiello et al. (2009)[28] used GFRP, Alecci et al. (2009)[36] used CFRP, Ludovico et al. (2010)[30] applied CFRP, GFRP and BFRP (Basalt Fiber) whereas Borri et al. (2011) [31] have tested Steel fibers.

Krevaikas and Triantafillou (2005) [27] carried out an experimental investigation on the behaviour of axially loaded short masonry columns confined with FRP jackets, followed by development of an analytical model for the prediction of confined strength and ultimate strain. Total 42 clay bricks masonry column specimens of three different dimensions as 115 x 115, 172.5 x 115 and 230 x 115 mm were tested. Corners of all specimens were rounded at radius of 10mm or 20mm. Strengthening was done by using different number of layers (1 , 2 and 3) of unidirectional CFRP sheets or GFRP sheets. There were total 17 categories with permutation and combination of column dimension, corner radius, no of layers of FRP and type of FRP such as CFRP or GFRP.

In 2009, Aiello et al. [28] have studied experimental behaviour of rectangular masonry columns and compared with analytical results obtained from Italian National Research Council guidelines (CNR DT200-2004) [24]. Total 33 specimens of rectangular columns were tested. The parameters included different strengthening schemes, curvature radius of the corners, amount of FRP reinforcement, cross-section aspect ratio and material of masonry blocks. The strengthening scheme included internal and external application of FRP. Internal application was in the form of FRP bars inserted in the masonry column. In this category variation was made in grade of reinforcement. Externally one or two FRP sheets/strips were wrapped. Corner radiuses were 10mm and 20mm. The masonry units used for columns were limestone and clay. Properties of materials are provided in Table No. 1 and 2. Overall 18 full core columns and 12 hollow core columns of limestone and 3 full core columns of clay were tested with strengthening by GFRP.

Significant increase in peak load and ultimate axial deformation was reported for all the types of specimens. In these tests, 16% increase in strength was obtained for the limestone specimen wrapped with two sheets of GFRP as compared to one sheet of GFRP. 25% increase in load carrying capacity was recorded for the specimen with corner radius 20mm as compared with 10mm corner radius. This research shows that combination of internal FRP bars and external FRP sheets is effective for confinement of masonry columns.

Uniaxial and triaxial tests on brick masonry columns with and without CFRP wrapping have been conducted by Alecci et al. (2009)[29]. Cylindrical masonry column specimens of ¼ scaled dimensions were tested in triaxial compression device (Hoek cell). The failure was characterised by the rupture of the composite wrap in the central zone of the specimen height and by the cohesive debonding of the reinforcement in the bulk masonry for the length of a half perimeter.

For each CFRP wrapped specimen comparison between maximum loads obtained by various methods such as experimentally, analytically using CNR-DT200(2004)[24], by using coefficients proposed by other researchers and upper and lower bounds has been presented. Research demonstrated the upper and lower bound values determined in hypothesis that masonry is still undamaged or completely disintegrated when wrap breaks; are not useful. Another conclusion 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) [30] have carried out the experimental program to access potential of confinement of masonry columns (dimensions in Table no. 3) made up of tuff masonry and clay brick masonry. Column specimens were wrapped using one ply of different types of fibers (CFRP, GFRP, BFRP) and tested for axial compression. The test results and their comparison helped to derive some conclusion in relation with performance of different FRPs. BFRP wrapping was more effective in terms of ultimate axial strain gain. 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.

The application of steel fiber reinforced polymer (SRP) for masonry columns has been investigated by Borri et al., (2011) [31]. Total 23 masonry columns were tested out of which 10 were of square cross section of side 245 mm and 13 had octagonal shape with side of 100mm. 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. Two types of steel cords were used for strengthening the columns. All the fibers were made up of high-strength steel filaments covered with a layer of brass to prevent oxidation of the metallic cords. Type 1 cord was formed by winding four single high strength metallic filaments together and Type 2 was made by twisting five individual filaments together. Type 1 was used only for reinforcing square columns whereas Type 2 was used for both; square and octagonal columns. The edges of the columns were rounded with radius of 30mm. Both the continuous and discontinuous SRP sheets were applied.

Bieker et al.[32] present experimental evaluation of masonry columns strengthened with CFRP and GFRP. Solid bricks of dimensions 7.1 x 11.5 x 24 cm and vertical coring bricks of sizes 11.3 x 11.5 x 24 cm were used for casting the masonry columns with calcium and calcium cement mortar. Uniaxial compression testing was carried out for all specimens and results were recorded. Vertical coring brick, strengthened columns were found to take 30% to 60% higher load as compared to unstrengthned specimens whereas for solid brick, strengthened columns the compressive strength was improved up to 250% to 300%.

Besides clay bricks, the masonry units used for experimentation are calcareous blocks (Aiello et al. (2009, 2008, 2007))[28,36,37], tuff masonry (Ludovico et al. (2008))[35], concrete blocks (Galal et al. (2012))[38]

Aiello et al. (2007)[37] studied mechanical behaviour of circular masonry columns built with calcareous blocks with two different stacking schemes used for casting of columns. Three strengthening techniques were performed, namely continuous wrapping, discontinuous wrapping of CFRP and internal GFRP bars drilled inside the cross section of column. Eighteen columns of diameter 200mm and height 600mm were tested and peak load and strains were recorded. From the experimental results few conclusions are derived such as continuous FRP wrapping was much more effective than discontinuous wraps. Columns confined with three 100mm wide sheets showed higher mechanical properties with respect to the two 150mm wide strips. The analytical results obtained by CNR DT 200 and a model developed by researcher are compared with experimental results.

Experimental evaluation of three different confinement schemes for tuff masonry columns was carried out in 2008 by Ludovico et al.[35] and comparison of the results w.r.t. mechanical behaviour, stress-axial strain relationships and ultimate strain are presented and discussed in the paper. 12 square tuff masonry (external tuff blocks and inner core filled with tuff chips and mortar) columns of dimensions 220 x 220 x 500 mm made up of scaled yellow Neapolitan tuff bricks 50 x 50 x 100 mm and pozzolana based mortar were tested for uniaxial compression. The strengthening schemes adopted were as follows: 1) Uniaxial glass FRP laminates 2) Uniaxial carbon FRP laminates 3) Alkali-resistant fiber glass grid bonded with cement based mortar.

The third scheme of strengthening was achieved by installation of one ply of primed alkali-resistant fibreglass grid between two layers of (about 4mm) cement based mortar reinforced with short glass fibers.

It was observed that GFRP and CFRP wrapping led to similar gain both in terms of compressive strength and ductility to tuff masonry columns under axial loads. It has been concluded by the researcher that the innovative confinement system based on the use of GFRP grids and cement based mortars allowed significant strength gains but reduced the global ductility.

Most of the experimental studies are focused on determination of enhancement in stiffness and ductility of masonry columns on strengthening with FRP. It is important to mention here that a very few work has been done on bond behaviour of FRP bonded to masonry. As FRP is externally bonded to surface of masonry, bond behaviour plays important role in imparting additional stiffness and ductility to member. Bond behaviour also depends on orientation of FRP (Petersen et al. (2009))[39].

Petersen et al. (2009)[39] have carried out the work in which the focus is on bond behaviour of FRP strips bonded to clay masonry. Tests were conducted on clay brick masonry prisms strengthened with near surface mounted (NSM) carbon fiber reinforced polymer (CFRP) strips. The parameter studied were bond strength, critical bond length. FRP strips perpendicular to bed joints (vertically aligned) and FRP strips parallel to bed joints (horizontally aligned) were tested. The main failure mode of the specimen was by debonding of the FRP from masonry prisms. It has been concluded that there is significant difference between the bond behaviour for NSM FRP strips aligned vertically and horizontally.

Experimental investigation of masonry columns with CFRP wrapping has been carried out by Shrive (2001)[40]; he tested 18 columns of three different cross sectional sizes and two different types of masonry units. Strengthening was achieved by wrapping the square section columns directly with CFRP sheets or by wrapping columns after casting a circular concrete jacket around the column. Each column was initially loaded axially until cracking was observed in the masonry. The columns were then wrapped with CFRP sheets over their height and retested under axial compression until failure occurred. The columns were of three different sizes ; 290 x 290, 390 x 390 and 490 x 490 mm and made up of two different shapes of masonry units, one of the types of bricks were regular with sharp corners and the other were of rounded corners termed ass bullnose units. All columns were of same overall height of 1.2m. The cavity formed at the centre of the column in each case was filled with grout.

The % increase in load carrying capacity for individual square columns ranged between 14 and 73 % for the two types, whereas that for the modified circular columns was found to be 200% and 156% for small and intermediate size respectively.

Basic materials along with their properties used by various researchers are presented in Table No. 1, to understand the type of masonry columns tested till today.

Table 1 Properties of Masonry Units and Mortar used for column specimens.

Sr. No.	Research Work	Masonry Units			Mortar		
		Type	**Size (mm)**	**Compressive Strength (MPa)**	**Type**	**Proportion**	**Compressive Strength (MPa)**
1	Borri et al. (2011)[31]	Clay Brick	245 x 120 x 55	20.99	Cement-Lime	10% cement 10% Lime and 80% sand	10.75
2	Ludovico et al. (2010)[30]	Tuff Masonry and Clay Brick	Tuff : 50 x 50 x 100 And Clay Brick : 55 x 115 x 255	Tuff : 2.55 and clay brick : 22.71	Pozzolan (local volcanic ash) based mortar	-	6.9
3	Aiello et al. (2009)[28]	Clay Brick and Limestone	180 x 6o x 30	23.29	Cement-Lime	1:1:5 (w:c:l)	7.8
4	Petersen et al. (2009)[39]	Clay Brick	230 x 110 x 76	-	Cement-Lime	1:1:6 (c:l:s)	-
5	Alecci et al. (2009)[29]	Pressed Brick	65 x 30 x 14	15.71	Cement-Lime	1:1:8 (c:l:s)	2.07
6	Ludovico et al. (2008)[35]	Tuff Masonry	50 x 50 x 100	2.55	-	-	6.9
7	Aiello et al. (2007)[37]	Calcareous stone Block	-	11.85	'M3' according to Italian national code for masonry buildings		7.8
8	Krevaikas and Triantafillou (2005)[27]	Clay Brick	115 x 55 x 40	23.5	Cement-Lime	0.9:1:3:7.5 (w:c:l:s)	2.85, 2.15, 1.93,1.98
9	Bieker et al.[32]	Solid Bricks and Vertical core bricks	71 x 115 x 240 and 113 x 115 x 240	20 for solid and 12 for vertical core bricks	Calcium mortar and calcium cement mortar	-	1 for calcium and 5.1 for calcium cement mortar

Confinement of masonry columns has been achieved by using FRP material hence it is important to consider type and properties of FRP materials. Table No. 2 gives the type and properties of FRP material used by various researchers.

Table 2 Properties of FRP material used for Strengthening

Sr. No.	Research Work	Type of FRP	FRP Properties	
			Tensile Strength (MPa)	Modulus of Elasticity (GPa)
1	Borri et al. (2011)[31]	Steel Cord FRP : Type 1	3311	214.56
		Steel Cord FRP : Type 2	2511	187.356
2	Ludovico et al. (2010)[30]	GFRP	1371	69
		CFRP	3377	228
		BFRP (Basalt FRP)	1814	91
3	Aiello et al. (2009)[28]	GFRP Sheets	1605	74.143
		GFRP Bars	803	40.170
4	Petersen et al. (2009)[39]	CFRP	-	-
5	Alecci et al. (2009)[29]	CFRP	3430	230
6	Ludovico et al. (2008)[35]	CFRP	3380	228
		GFRP	1315	68
7	Abrams et al. (2007)[26]	GFRP	-	-
8	Aiello et al. (2007)[37]	CFRP	1800	200
		GFRP	879	38.604
9	Krevaikas and Triantafillou (2005)[27]	CFRP	3500	230
		GFRP	2000	70
10	Shrive et al. (2001)[40]	CFRP	-	-
11	Bieker et al.[32]	CFRP	3500	230
		GFRP	2250	70

The FRP of various types has been used in different forms such as sheets, rods. The strengthening techniques adopted by various researchers have been presented in Table No. 3.

Table 3 Masonry Columns Sizes and Strengthening Technique

Sr. No.	Research Work	Masonry Column Specimens		FRP Strengthening	
		Masonry Type	Specimen Size (mm)	FRP Type	Strengthening Technique
1	Borri et al. (2011)[31]	Clay Brick	Square 245 x x245 x 500 and Octagonal of side 100mm & height 500mm	Steel Cord FRP (type 1 and type 2)	Continuous Wrap Discontinuous Wrap
2	Ludovico et al. (2010)[30]	Tuff Masonry and Clay Brick	Square (Tuff) – 220 x 220 x 500 Square (clay brick) 255 x 255 x 560	GFRP, CFRP and BFRP (Basalt)	Continuous Wrap by each type of FRP on each type of Masonry.
3	Aiello et al. (2009)[28]	Clay Brick and Limestone	Square 250 x 250 x 500	GFRP	One layer of GFRP wrapping One layer of GFRP wrapping Internal GFRP bars (spacing 160mm) Internal GFRP bars (spacing 160mm) Combination of wrap and bars : i)technique 1 and 3 ii) Technique 1 and 4.
4	Alecci et al. (2009)[29]	Pressed Brick	Cylindrical 5.4cm dia and 8.5cm height	CFRP	External wrapping of sheets with three different concentration of carbon fibers i) 25 % ii) 16.7% iii) 12%
5	Ludovico et al.	Tuff Masonry	Square 220 x 220	CFRP & GFRP	External Wrapping by CFRP

	(2008)[35]		x 500		External Wrapping by GFRP
6	Aiello et al. (2007)[37]	Calcareous stone Block	Cylindrical 200mm dia and 600mm height	CFRP & GFRP	Continuous Wrap CFRP Discontinuous Wrap CFRP Internal GFRP rebars
7	Krevaikas and Triantafillou (2005)[27]	Clay Brick	i)Square 115 x 115 x 340 ii) Rectangular 172.5 x 115 x 340 iii) Rectangular 230 x 115 x 340	CFRP & GFRP	External Wrapping by 1 layer CFRP 2 layers CFRP 3 layers CFRP 5 layers GFRP
8	Bieker et al.[32]	Solid Bricks and Vertical core bricks	Square 240 x 240 x 500	CFRP & GFRP	External Wrapping by 1 layer CFRP 2 layers CFRP 2 layers GFRP 3 layers GFRP

The experimental research on confinement of masonry columns using FRP has shown that the FRP strengthening always causes an increase in the load carrying capacity of the columns. Depending on the type of masonry, type of FRP and various strengthening techniques the increment in capacity varies. Table No. 4 gives the minimum and maximum percentage increase in strength of columns obtained by various researchers experimentally. The parameters for minimum and maximum increment cases may be different.

Sr.No.	**Research Work**	**% Increase in Strength**	
		Minimum	**Maximum**
1	Borri et al. (2011)[31]	67	124
2	Ludovico et al. (2010)[30]	17.4	298.3
3	Aiello et al. (2009)[28]	6.93	19.65
4	Ludovico et al. (2008)[35]	17.43	63.48
5	Aiello et al. (2008)[36]	0.46	183
6	Aiello et al. (2007)[37]	7	124
7	Abrams et al. (2007)[26]	283.75	
8	Shrive et al. (2001)[40]	14	73
9	Biekar et al. [32]	30	300

3. DISCUSSIONS

The experimental work carried out on FRP strengthened Masonry Columns has many parameters such as types of masonry units, types of mortars, column specimen geometry, types of FRP, Strengthening schemes, Strengthening for different actions. The following parameters have been included in the work.

- **Masonry Units** : Solid Clay Bricks (Aiello et al. (2009), Petersen et al. (2009), Alecci et al. (2009), Abrams et al. (2007), Krevaikas and Triantafillou (2005), Bieker et al., Borri et al. (2011), Ludovico et al. (2010))[28, 39,26,27,32,31] , Hollow Bricks (Bieker et al.)[32], Concrete Blocks (Galal et al. (2012))[38], Tuff Masonry (Ludovico et al. (2008) , Ludovico et al. (2010)[37,30]) Calcareous Blocks (Aiello et al. (2009), Aiello et al. (2008), Aiello et al. (2007))[28,36,37]

- **Mortar Types** : Cement Mortar (Galal et al. (2012))[38], Cement-Lime Mortar (Aiello et al. (2009), Petersen et al. (2009), Alecci et al. (2009), Aiello et al. (2008), Krevaikas and Triantafillou (2005), Borri et al. (2011))[28,39,29,36,27,31] Calcium Mortar (Bieker et al.)[32], Calcium-Cement Mortar(Bieker et al.)[32], Pozzolana Mortar (Ludovico et al. (2008))[30].

- **Column Specimen Shapes** : Square (Aiello et al. (2009), Ludovico et al. (2008), Aiello et al. (2008), Krevaikas and Triantafillou (2005), Bieker et al., Borri et al. (2011), Galal et al. (2012))[28,35,36,27,32,31], Rectangular (Petersen et al. (2009), Krevaikas and Triantafillou

(2005), Shrive et al. (2001)),[39,27,40] Hollow (Aiello et al. (2009), Aiello et al. (2008)), Octagonal (Borri et al. (2011))[28,36,31,], Cylindrical (Alecci et al. (2009), Aiello et al. (2007))[28,37], Modified Circular (Shrive et al. (2001))[40].

- **FRP used** : GFRP (Aiello et al. (2009), Ludovico et al. (2008), Aiello et al. (2008), Abrams et al. (2007), Krevaikas and Triantafillou (2005), Bieker et al., Ludovico et al. (2010)), [28,35,36,26,27,32,30] CFRP (Petersen et al. (2009), Alecci et al. (2009), Ludovico et al. (2008), Krevaikas and Triantafillou (2005), Bieker et al., Galal et al. (2012), Shirve et al. (2001), Aiello et al. (2007), Ludovico et al. (2010)), [39,29,35,27,32,38,40,37,30] Alkali Resistant FRP (Ludovico et al. (2010))[30], Steel FRP (Borri et al. (2011))[31], Basalt FRP (Ludovico et al. (2010))[30].
- **Strengthening Scheme** : Continuous FRP wrapping (Aiello et al. (2009), Alecci et al. (2009), Aiello et al. (2008), Krevaikas and Triantafillou (2005), Bieker et al. , Galal et al. (2012), Shirve et al. (2001), Ludovico et al. (2010))[28,29,36,27,32,38,40,30], Discontinuous FRP wrapping (Galal et al. (2012), Aiello et al. (2007)), FRP bars (Aiello et al. (2007)), FRP Strips (Petersen et al. (2009), Abrams et al. (2007)) [38,37,39,26] , Combination of Strips and bars (Aiello et al. (2009))[28].
- **Behaviour Studied** : Compressive (Aiello et al. (2009), Alecci et al. (2009), Ludovico et al. (2008), Aiello et al. (2008), Krevaikas and Triantafillou (2005), Bieker et al., Borri et al. (2011), Shirve et al. (2001), Aiello et al. (2007), Ludovico et al. (2010))[28,29,35,36,27,32,31,40,37,30] Flexural and Bond Behaviour (Petersen et al. (2009))[39], Seismic(Galal et al. (2012))[38] , Triaxial Compression (Alecci et al. (2009))[36].

4. CONCLUSIONS

- Major work has been carried out on solid clay brick masonry; however, other types of masonry units need to be accessed.
- Cement-Lime mortar has been used in major experimental work but most of the historic structures have been constructed with only lime mortar. Hence experimental studies on masonry constructed with lime mortar must be carried out in order to have better mapping with existing old masonry structures.
- CFRP and GFRP fibers are used for strengthening purpose by most of the researchers. However, optimization studies for amount of fibers to be used are required and need further work.
- Strengthening scheme adopted in most of the experimental studies is continuous wrapping of FRP sheets around the column specimens. As experimental results shows that there is large increase in load carrying capacity of column specimens; it is necessary to access whether such a large amount of enhancement is really required. Hence it is felt that large number of experimental studied are required to be carried out for discontinuous wrapping by FRP strips.

A large amount of experimental studies on confinement of Masonry Columns with FRP should be undertaken derive the analytical models, applicable in all cases.

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