BEHAVIOR OF ECCENTRICALLY LOADED FRP WRAPPED MASONRY COLUMN

Md. Muminul Islam*[1] and Dr. Ataur Rahman*[2]

[1]*Design Engineer, Delma Structures Builders Limited, Bangladesh, e-mail: muradce100@gmail.com*
[2]*Professor, Khulna University of Engineering & Technology, Bangladesh, e-mail:ataur107@yahoo.com*

***Corresponding Author**

ABSTRACT

The application of fiber reinforced polymer (FRP) as a means of increasing the axial capacity of masonry column through lateral confinement is investigated in this study. This study mainly concentrates on the confinement effects of slender column for the eccentric compression capacity after confining with three types of externally bonded FRPs, they are i) high strength CFRP (Carbon Fiber Reinforced Polymer), ii) environment friendly natural fiber, JFRP (jute fiber) and iii) Cotton-FRP(cotton fiber). This study also examines the possibility of utilizing environmental friendly natural fibers over the use of artificial and costly fibers like CFRP. The test parameters include the width-to-thickness ratio and tensile strength of these fibers. Four specimens are tested for eccentrically applied axial loading. Mechanical tests on the materials are also carried out to know their characteristics. An epoxy resin based adhesive is used for bonding the FRPs with the masonry columns. Static load test is carried out on eccentrically loaded columns to know the ultimate carrying capacity and deflection of these columns wrapped with different FRPs. It is seen that columns wrapped with carbon fiber, jute fiber and cotton fiber can have an eccentric load of 100%, 40% and 20% respectively more than the reference column without any wrapping. The corresponding displacement also increased by 6.3, 3.8and 3.0 times of that of reference column. So, it is evident that a significant increase in load carrying capacity and ductility is possible of masonry column after strengthening by different FRPs. It may conclude that, FRPs wrapping can turn masonry column from brittle to ductile nature and at the same time increase its carrying capacity more than double.

Keywords: *Brick Masonry Column, Fiber Reinforced Polymer (FRP), Natural FRPs, Confinement, Eccentric loading*

1. INTRODUCTION

Masonry like materials have in common property that they can scarcely bear tensile stress and they are, therefore, known as no-tension materials. The failure mechanism produced by uniaxial compression is characterized by cracks that develop along the direction of the compression force and are commonly thought as produced by exceeding the limit value of transverse strain. There are some events responsible for the damage of masonry structures i.e. construction techniques inadequacy and wrong materials selection, settlements of foundation, seismic loads, and environmental changes. Apart from the damages, they often need to be upgraded with the changed usages and mandatory design requirements for seismic loads. The confinement of masonry columns, traditionally obtained through reinforced concrete jacketing or steel jacketing could prevent brittle failure of masonry members subjected to compressive overloads, seismic or static actions. In the last decades, the use of traditional strengthening techniques has been largely investigated to make a safe design of strengthening masonry members. The most interesting technique we got in this area has been the introduction of the fiber-reinforced polymer. Widespread masonry use in the past including world cultural heritages, makes it necessary to find innovative materials to safeguard masonry constructions. However, due to the lower number of applications in existing structures, engineers do not have adequate experimental results to base their design calculations. Only few studies have been conducted on FRP confinement to increase both the deformation capacity and axial strength on masonry columns. Besides, sometimes some techniques are not environment friendly, some are high cost, some are not adequate. So in this present paper, suitability of low cost environment friendly natural jute fiber, cotton fiber and highly strong carbon polymer fiber will be evaluated.

The development of fiber reinforced polymer (FRP) materials in various forms such as nonwoven, that is loose fibers, woven, that is braided fibers, textile or fabric, that is strongly braided along with a backing material such as latex backing or natural rubber backing, etc. and configurations offer an alternative design approach for the strengthening of new and existing structures. FRPs offer a potential solution of a crisis in civil infrastructures, with the combinations of properties, not available from other materials. So it is suitable for structural retrofitting including an attractive alternative to any other retrofitting techniques for repairing as well as strengthening. The advantages of FRP are many such as high strength to-weight ratio, high specific tensile strength, good fatigue resistance, ease of installation and corrosion resistance characteristics, ease of repairing, directional strength and higher ultimate strength and lower density than steel, etc. These properties make FRPs ideal for applications in strengthening.

Carbon fiber is one of the costliest of all the fibers, followed by aramid fibers, and although it comes with an advantage of increasing the structural potential by many folds, it cannot be easily considered as a good outcome based market product.

So, Development of new materials for structural strengthening is essential and these materials have good properties and potential for structural improvement for economic and other related factors. In many developing countries, where natural fibers are abundant in demand, scientists and engineers apply appropriate technology to utilize these natural fibers as effectively and economically for possible structural upgradation and other housing needs.

Development of plant fiber composites has only begun. Large number of various natural fibers, such as jute (Milanese et al., 2011; Gassan and Bledzki, 1999; Summer scales et al., 2010; Joshi et al., 2004; MunikencheGowda and Naidu, 1999) coir, cotton, nylon banana and sisal etc. mainly manufactured in Bangladesh, are among those fiber reinforced composites which are of particular interest as these composites have high impact strength besides having moderate tensile and flexural properties compared to other lignocelluloses fibers.

The evaluation of the effective collaboration of an FRP wrap and the estimate of the ultimate strength of the structure was the subject matter of several experimental researchers on concrete specimens Faella et al. 2006; Campione and Miraglia 2003; Albert, M. L., Elwi, A. E., and Cheng, J. J. R. (2001), Saadatmanesh et al. 1994; Tamuzs et al. 2006a,b,c, brick masonry specimens (Borri and Grazini 2004; Corradi et al. 2007; Krevaikas and Triantafillou 2005; Faella et al. 2004a), and tuff masonry specimens (Faella et al. 2004b). Recent experimental research, carried out on members with circular, square, and square with round corners cross section (Campione and Miraglia 2003), studied problems concerning the efficacy of reinforcement in some critical regions. The effects of pretension of FRP wrap was investigated by Tamuzs et al. (2006a), that tested several concrete specimens wrapped, with different pretension levels, with CFRP yarns.
Other experimental investigations on this topic are reported in Faella et al. (2004) Micelli et al. (2003) Aiello et al. (2005, 2007) and Faella et al. (2007). Also Studies on the use of FRP as a strengthening material for masonry have been numerous. Detailed concepts and analytical results on the applicability and effectiveness of FRP tendons used to apply circumferential pre-stressing to historic masonry

structures were developed first by Triantafillou (1993, 1997!). A study on the use of epoxy-bonded carbon fiber-reinforced polymer (CFRP) strips as seismic strengthening elements of masonry was performed by Schwegler (1994), who demonstrated the effectiveness of this technique through full-scale in-plane and out of-plane cyclic testing of one-story masonry walls and developed an analytical model for the in-plane behavior of CFRP strengthened walls within the framework of stress fields theory.

However the number of results is still not sufficient to define an adequate stress-strain relationship of the FRP strengthened masonry columns and in case of buckling resistance. In order to allow a successful application of this technology in practice, reliable tools for design must be developed, and their validation through experimental results is necessary.

Here, an attempt is made to study the possibilities of using jute and cotton fiber materials as jute and cotton fiber reinforced polymer, in structural strengthening of Masonry column. Though design codes have been drawn up by institutions, engineering community are in hesitation to implement this alternative. In part, lack of standardization and the proprietary nature of the fiber and resin combinations is the reason behind this. So CFRP was being chosen for strengthening of masonry column.

2. MATERIALS & METHODS

2.1 Specimens

All the column specimens had the dimension of 300 mm × 300 mm × 1067 mm as shown in Figure 1. The summary of all specimens are given in Table 1.

Table 1: Sample geometry

Column ID	Specification	Cross Section (mm)	Height (mm)	Slenderness Ratio	Thickness of Wrap (mm)	Wrapping configuration
RC	Control column	300 × 300	1067	12.12	0	No wrapped
JC	Jute wrapped (full)	300 × 300	1067	12.12	1.304	Fully wrapped
CTC	Cotton wrapped(full)	300 × 300	1067	12.12	1.298	Fully wrapped
CC	Carbon wrapped(full)	300 × 300	1067	12.12	0.111	Fully wrapped

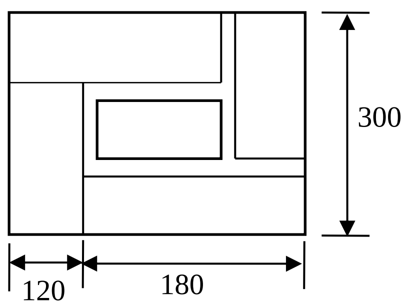

Figure 1: Column specimen cross section (in mm)

In total four types of column specimens were prepared. One of them were control column (RC) and the rest three columns were for strengthening purposes. The thickness of mortar was 10 mm. Before wrapping the FRP sheets, the masonry surface was cleaned with abrasive paper and epoxy putty was used to remove defects as much as possible. Specimens were wrapped with one layer in transverse direction, applied through the use of a two-part epoxy adhesive. One of them were strengthened with CFRP, one with jute fiber and one with cotton fiber.

2.2 Materials

Good quality bricks that have the compressive strength of 18 MPa were used for this experimental study. Sylhet sand was used to produce mortar of 20 MPa. The carbon fiber was collected from manufacturer. The jute and cotton were collected from the local market. Epoxy adhesive was used for attaching jute fiber, cotton fiber and carbon fiber to the surface of the column. The adhesive that consists of Part A epoxy resin, and Part B hardener were also obtained from the local market. Tensile strength test of carbon, jute and cotton fibers was conducted according to ASTM D 638.

2.3 Experimental Setup & Tests

All columns were tested under eccentric loading with an eccentricity of the order of30 mm until failure. Experimental setup for this study is shown in Figure 2 where the schematic diagram is shown in Figure 3. Applied load was through a load dial gauge with 25KN load increment per minute. The mid height buckling of the column was determined using another deflection dial gauge. In eccentrically loaded column as shown in Figure 1, the load was applied until significant amount of failure was observed in the column and the increase of load was in cease.

Figure 2: Experimental setup for the compressive test of column

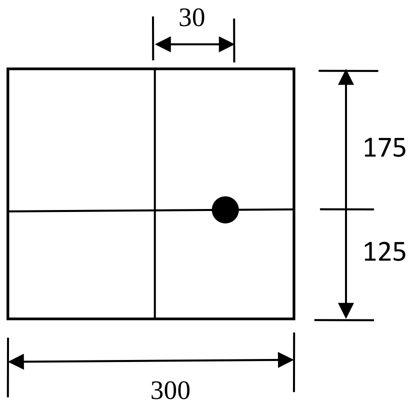

Figure 3: Schematic diagram showing 30mm eccentricity of loading point

After the compressive test of these columns, the failure pattern were observed. It had been noticed that the unwrapped (RC) and cotton fiber wrapped (CTC) columns failed in material disintegration where as for CFRP wrapped (CC) and Jute fiber wrapped (JC) columns, failure was predominantly in the fiber itself as shown in Figure 4. So it can be said that, CFRP and Jute Fiber ensure more lateral confining effect than cotton fiber. The same phenomenon was also supported by the loads at failure i.e. higher the confining force, higher will be the compressive force.

RC CC JC CTC

Figure 4: Failure Pattern of unwrapped Brick Masonry Column (RC), CFRP wrapped column (CC), Jute fiber wrapped column (JC) and Cotton fiber wrapped column (CTC)

3. RESULTS& DISCUSSIONS

3.1 Load - Deflection Relationship

Table 2 shows the ultimate load at failure and maximum deflection for all the four columns.

Table 2: Test result of RC, CC, JC and CTC column

Column ID	Ultimate Load (KN)	Maximum Deflection (mm)
RC	250	1.2
CC	500	7.6
JC	350	5.8
CTC	300	3.7

The load − deflection relationship for Reference Column (RC), CFRP Wrapped Column (CC), Jute Fiber Wrapped Column (JC), and Cotton Fiber Wrapped Column (CTC) are shown in the following Figures 5 to 8.These graphs illustrate the increase in deflection for every 25KN loading interval.

So, it can be seen that, load carrying capacity of eccentrically loaded brick columns has increased quite significantly with the use of different fibers. The load carrying capacities of the FRP wrapped columns have increased with respect to control column (RC) of an amount of 100%, 40%, and 20% for CC, CJ, and CTC respectively. The ultimate deflection for RC, CC, JC, and CTC are found to be 1.2 mm, 7.6 mm, 4.8mm, and 3.4mm respectively. A better comparison between load and deflection of various columns are shown in Figure 9

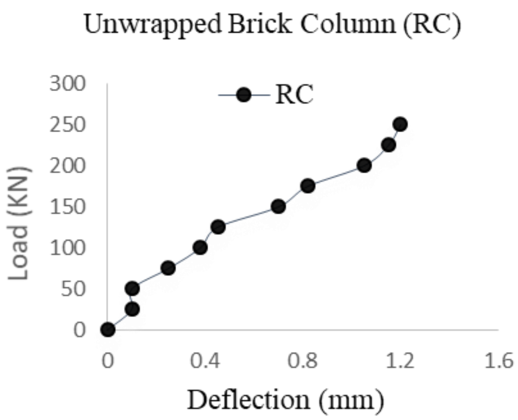

Figure 5: Load-Deflection relationship of reference column (RC)

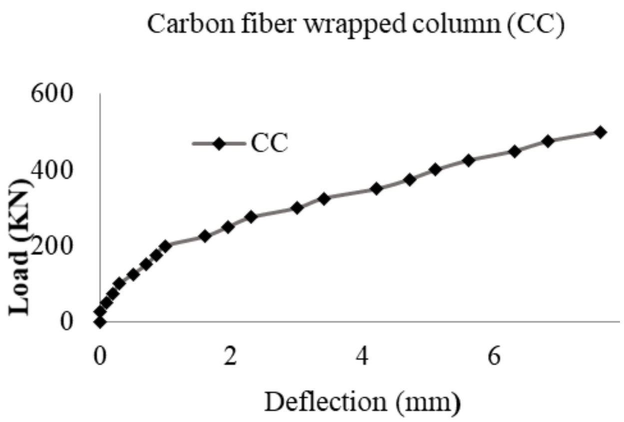

Figure 6: Load-Deflection relationship of CFRP wrapped column (CC)

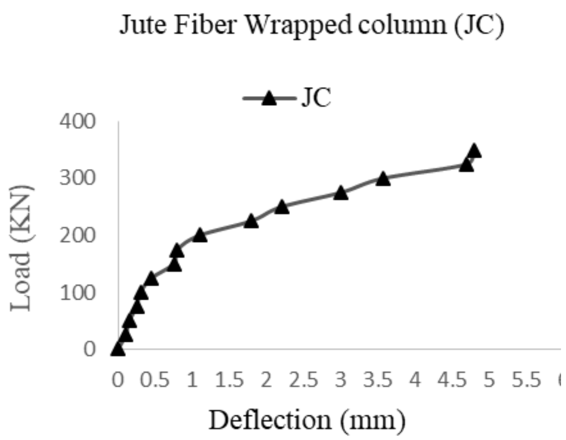

Figure 7: Load-Deflection relationship of Jute wrapped column (JC)

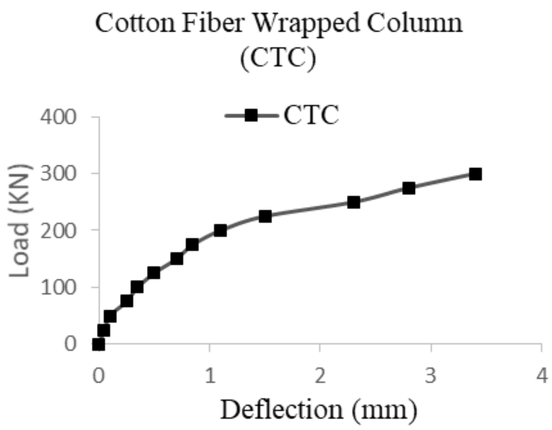

Figure 8: Load-Deflection relationship of Cotton wrapped column (CTC)

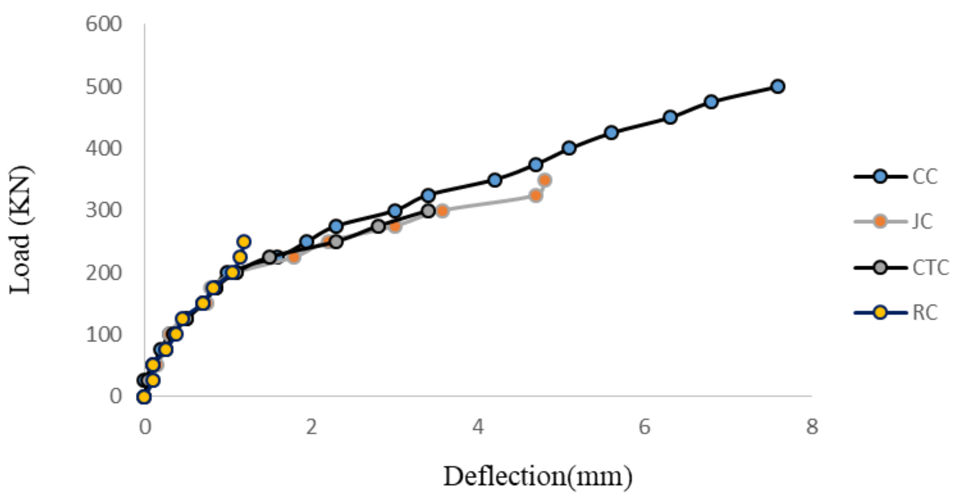

Figure 9: Load-Deflection relationships for all four columns

Among the four wrapping fibers, CFRP increases the load carrying capacity almost twice of that of unwrapped column. So, it can be said that CFRP wrapped column offers more stiffness than the other three. Interestingly it is also observed that CFRP column produces more ductility than rest of the wrapping fibers. Ductility is an important criterion for seismic design of masonry and RC structures. It is also important to note that these natural fibers (cotton and jute) were also performed very well in eccentrically loaded columns. They were not as stiff as CFRP but their stiffness is reasonably higher than the unwrapped column. Moreover, natural fibers are cheaper than the CFRP and are very environmental friendly as they have zero carbon footprints.

3.2Load-Moment Relationship

To determine the resistance against the rotation, a load moment relationship can be shown in Figure 10 for all the four columns. Considering the second-order effect, the mid-height flexural moment can be calculated as,

$$M = P\left(e + \Delta_m\right)$$

Where, e = eccentricity and Δ_m = mid height deflection.

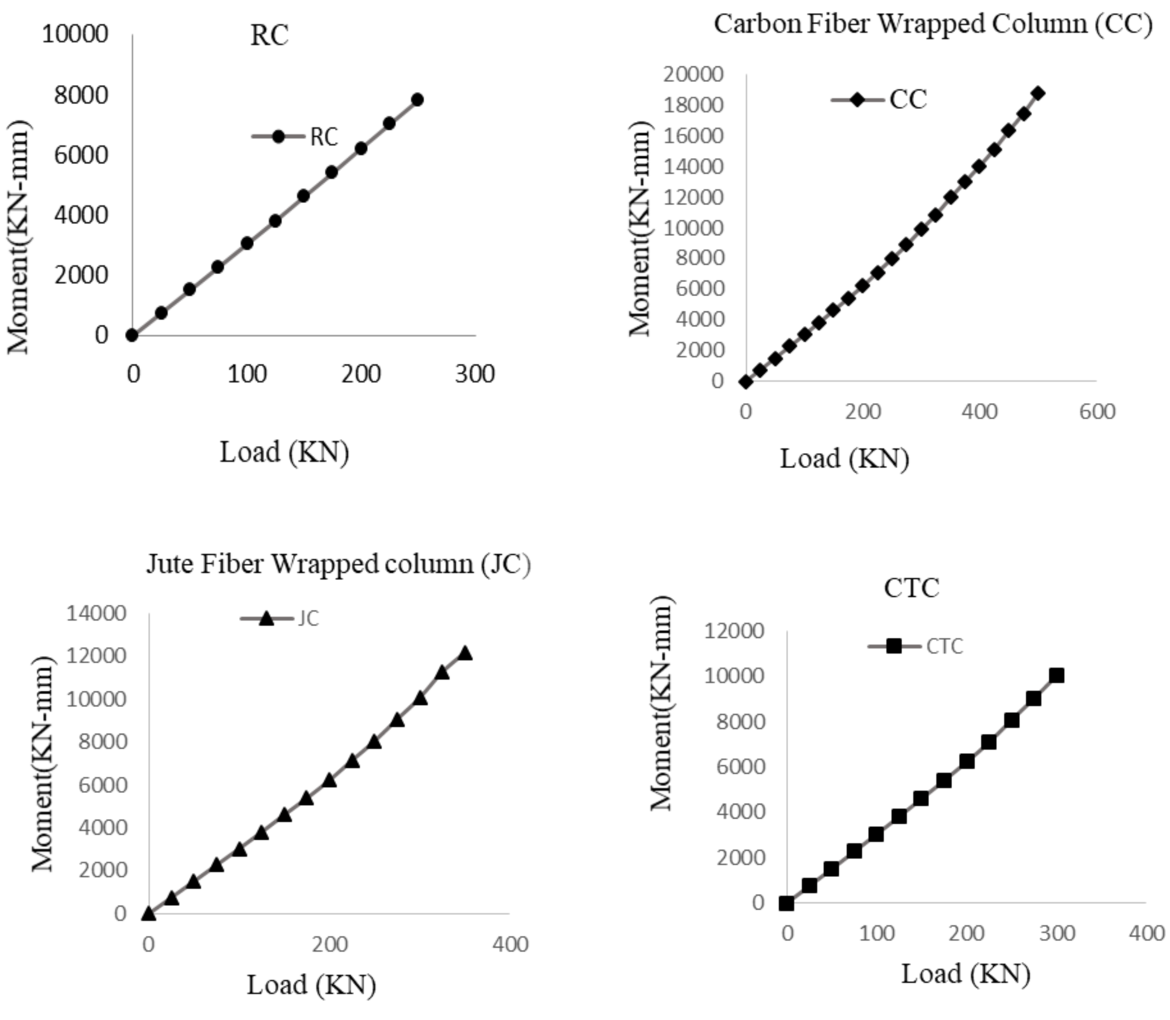

Figure 10: Load-Moment relationship for all four columns

From these graphs, it is seen that moment capacity of eccentrically loaded brick column has increased to an amount of 18800 kN-mm with the use of fibers and CFRP. It is also seen that natural fibers were effective in increasing moment capacity of eccentrically loaded brick column but gave less than CFRP.

4. CONCLUSION

In this study, high strength Carbon Fiber Reinforced Polymer (CFRP) and cost effective environment friendly Jute Fiber (JC) and Cotton Fiber(CTC) was applied on slender masonry column to increase the axial load bearing capacity as well as buckling resistance. To achieve this goal, all the necessary tasks were completed following the standard specifications. On the basis of the results obtained from the tests stated in aforementioned sections, following conclusions can be dawn:

1) The ultimate load carrying capacity of masonry columns increased by 100% for CFRP (CC), by 40% for Jute fiber (JC), and by 20% for Cotton fiber (CTC) with respect to reference column. So it can be said that all the three fibers used as strengthening technique in this study were effective to enhance the stiffness as well as ductility of the masonry columns. .

2) As the jute and cotton fibers are locally available and they have zero Carbon Foot Print, they are environment friendly and as the same time cost effective. So, column strengthening with Jute and Cotton can be an eco-friendly product to substitute costly CFRP that have a Carbon Foot Print of about 900 kg/ton.

3) The modes of failure in the RC, CTC, were found to be material failure. Whereas the failure in JC and CFRP columns were in the fiber itself. So, it can be said that CFRP and Jute offer more lateral confinement effect than Cotton fiber. Structure where there is a demand of heavy axial load, CFRP or Jute can be used. And in the place of relatively low axial load is expected, Cotton fiber can be an economic and effective alternative to Jute and CFRP.

ACKNOWLEDGEMENT

I would like to show my gratitude to my parents. Besides, this study was carried out under the guidance and supervision of *Dr. Ataur Rahman*,Professor**,** Department of Civil Engineering, KUET. Besides, I am showing my gratitude to all the lab assistants who were very helpful and their guidance made this work easy.

REFERENCES

Albert, M. L., Elwi, A. E., and Cheng, J. J. R. (2001) “Strengthening of unreinforced masonry walls using FRPs.” *J. Compos. Constr.*, 5.2, 76–84.

Borri, A., and Grazini, A. (2004) “Masonry column strengthening with FRP materials.” *Proc., 2nd Congress Mechanics of Masonry Structures Strengthened with FRP-Materials: Modeling, Testing, Design, Control, L. Ceriolo and V. Zerbo, eds., Cortina Ed., Padova, Italy*, 13(3), 193–202 in Italian.

Borri, A., Avorio, A., and Bottardi, M. (2000) “Theoretical analysis and a case study of historical masonry vaults strengthened by using advanced FRP.” *Advanced composite materials in bridges and structures III, [6] J. Humar and A. G. Razaqpur, eds., Canadian Society for Civil Engineering, Montréal*, 577–584.

Campione, G., and Miraglia, N. (2003), “Strength and strain capacities of concrete compression members reinforced with FRP.” *Cem. Concr. Compos.*, 25(1), 31–41.

Campione G, Miraglia N. Strength and strain capacities of concrete compression members reinforced with FRP. *Cement Concr. Compos* 2003, 23, 31–41.

CNR. (2004) "Guide for the design and construction of externally bonded FRP system for strengthening existing structures." CNRDT200/2004, CNR, Roma.

Corradi, M., Grazini, A., and Borri, A. (2007), "Confinement of brick masonry with CFRP materials." *Compos. Sci. Technol.,* 67(9), 1772– 1783.

Crawford, J. E., and Morrill, K. B. (2003) "Retrofit techniques using polymers and FRPs for preventing injurious wall debris." *6th Int. Conf. on Fibre-Reinforced Plastics for Reinforced Concrete Structures, K. H. Tan, ed., World Scientific, Singapore,* 1199–1208.

De Lorenzis, L., and Tepfers, R. (2003) "Comparative study of models on confinement of concrete cylinders with fiber-reinforced polymer composites." *J. Compos. Constr.,* 7~3!, 219–237.

Ehsani, M. R. (1995) "Strengthening of earthquake-damaged masonry structures with composite materials." *Non-metallic (FRP) reinforcement for concrete structures, L. Taerwe, ed., E&FN Spon, London,* 680–687.

Ehsani, M. R., Saadatmanesh, H., and Al-Saidy, A. (1997), "Shear behavior of URM retrofitted with FRP overlays." *J. Compos. Constr.,* 1(1), 17–25.

Faella, C., Martinelli, E., Nigro, E., and Paciello, S. (2004) "Prove sperimentali di compressionesucolonne in muraturaconfinate con FRP. Experimental compression tests on FRP confined masonry columns." *Proc., 2nd Congress on Mechanics of Masonry Structures Strengthened with FRP-Materials: Modeling, Testing, Design, Control, L. Ceriolo and V. Zerbo, eds., Cortina Ed., Padova, Italy,* (398– 407) in Italian.

Fam, A., Musiker, D., Kowalsky, M., and Rizkalla, S. (2002), "In-plane testing of damaged masonry wall repaired with FRP." *Advanced Composite Letters,* 11(6), 277–283. fib. (2001).

Hamilton III, H. R., and Dolan, C. W. (2001). "Flexural capacity of glass FRP strengthened concrete masonry walls." *J. Compos. Constr.,* 5(3), 170–178.

Hamoush, S. A., McGinley, M. W., Mlakar, P., and Murray, K. (2001). "Out-of-plane strengthening of masonry with reinforced composites." *J. Compos. Constr.,* 5(3), 139–145.

Krevaikas T.D. and Triantafillou T.C. (2005), Masonry confinement with Fiber Reinforced polymers. *J Compos Construct,* ASCE 2005; 3(4), 128–135.

Krevaikas, T. D., and Triantafillou, T. C. (2005), "Computer-aided strengthening of masonry walls using fibre-reinforced polymer strips." Mater. Struct. (in press).

Laursen, P. T., Seible, F., Hegemier, G. A., and Innamorato, D. (1995), "Seismic retrofit and repair of masonry walls with carbon overlays." *Non-metallic (FRP) reinforcement for concrete structures, L. Taerwe, ed., E&FN Spon, London,* 617–623.

Marcari, G., Manfredi, G., and Pecce, M. (2003), "Experimental behaviour of masonry panels strengthened with FRP sheets." *6th Int. Conf. on Fibre-Reinforced Plastics for Reinforced Concrete Structures, K. H. Tan, ed., World Scientific, Singapore,* 1209–1218.

Micelli F, De Lorenzis L, and La Tegola A. (2004), "FRP-confined masonry columns under axial loads: experimental results and analytical model" *Masonry Int 2004,* 17(3), 1134-1182.

Muszynski, L. C., and Purcell, M. R. (2003), "Use of composite reinforcement to strengthen concrete and air-entrained concrete masonry walls against air blast." *J. Compos. Constr.,* 7(2), 98–108.

Omar Chaallal, MunzerHasan, Michel LeBlanc(2006), "Circular columns confined withFRP: experimental versus predictions of models and guidelines", *J. Compos.Constr. ASCE (2006),* 5(2), 4–12.

Triantafillou, T. C. (1998), "Strengthening of masonry structures using epoxy-bonded FRP laminates." *J. Compos. Constr.,* 2(2), 96–104.

Triantafillou, T. C., and Fardis, M. N. (1993), "Advanced composites as strengthening materials of historic structures." *IABSE Symp. on Structural Preservation of the Architectural Heritage, International Association for Bridge and Structural Engineering, Lisbon, Portugal,* 541– 548.

Triantafillou, T. C., and Fardis, M. N. (1997), "Strengthening of historic masonry structures with composite materials." *Mater. Struct.,* 30, 486–486.

Tumialan, G., Huang, P.-C., Nanni, A., and Silva, P. (2001), "Strengthening of masonry walls by FRP structural repointing." *5th Int. Conf. on Fibre-Reinforced Plastics for Reinforced Concrete Structures, C. J. Burgoyne, ed., Thomas Telford, Cambridge, U.K.,* 1033–1042.

Valuzzi, M. R., Tinazzi, D., and Modena, C. (2002), "Shear behavior of masonry panels strengthened by FRP laminates." *Constr. Build. Mater.,* 16, 409–416.

Valuzzi, M. R., Tinazzi, D., and Modena, C. (2003), "Strengthening of masonry structures under compressive loads by using FRP strips" *6th Int. Conf. on Fibre-Reinforced Plastics for Reinforced Concrete Structures, K. H. Tan ed., World Scientific, Singapore*, 1249–1258.