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Improving Clay Brick Column's Compression Capacity using CFRP Sheets and Reinforced Concrete Jacketing

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ABSTRACT

Brick as a construction material can be considered one of the most common materials used for a very long time to construct buildings in iraq. The historic building represents one of the most important figures representing the rich history of iraq, which is built with bricks. Due to the aging of this type of building, a necessary improvement and retrofit need to occur. The paper investigates the ability to use different kinds of materials such as cfrp and srg to enhance the brick columns' structural capacity. From the results and discussions, it can be concluded that these materials are suitable to be used for this purpose with some limitations due to brick capacity itself.

Introduction

Unreinforced masonry buildings form the main type of buildings in Iraq. Most of the ancient buildings dated thousands of years before the century was constructed from clay bricks and different binder materials (tar, natural lime, or mud). Up to now, housings are built from brick with cement or lime binders. Like in many other countries, these masonry buildings are constructed to withstand gravity loads only. Therefore, most of them, if not all, are vulnerable to lateral loads from earthquakes, wind gusts, and manufactured forces (Indirli 2013, Coburn 2006, Ceroni 2012, and Asteris 2014). Also, deterioration resulted in buildings due to aging caused degradation in strength and stiffness. Therefore , enhancing the strength and ductility of these unreinforced masonries (URM) buildings becomes necessary, especially after issuing the Iraqi seismic code in (Iraqi Standard Specification 2017). An externally bounded strengthening technique using fiber-reinforced polymer (FRP) materials , enhancing the strength and ductility of these unreinforced masonries (URM) buildings becomes necessary, especially after issuing reinforced concrete and masonry buildings (Toutanji 2002, Maalej 2003, Saadatmanesh 1997, and Triantafillou 1998). The use of (FRP) materials provides several advantages comparing to traditional strengthening materials (steel and concrete) including but not limited to "high strength to weight ratio, ease and speed of application, corrosion resistance and a negligible change in weight and geometry" (Engindeniz 2005). To investigate the behavior and increase in compressive strength of the FRP confined masonry columns, researchers started exploring this technique in the last three decades considering the effect of different variables such as (the type and strength of masonry units, type, and strength of mortar, brick units' arrangements, column's aspect ratio, corner effects, number of layers in the confining jacket, … etc.), one of the pioneer studies on the behavior of externally jacketing masonry columns with FRP warps performed by (Kervaikas and Triantafillou in 2005). Their work involved testing forty-two FRP-confined clay brick masonry

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columns with different aspect ratios, multiple fiber layers, and different fiber types. The researchers formulated a design expression for the increase in strength and ultimate strain of FRP confined masonry columns based on their study results. (Corradi et al 2007) studied the compressive behavior of s carbon fiber reinforced polymer(CFRP) confined masonry columns. The study was performed on 24 columns constructed from solid clay bricks in square and octagonal cross-sections. The researchers proposed a formula to calculate the expected increase in compressive strength of masonry columns due to (FRP) confinement. In contrast,they adopted the formula proposed by (Campione and Mirgalia 2003) (which is derived for concrete) for the relation between axial and transversal strain in masonry. (Aiello et al 2009) tested 33 rectangular masonry columns, the factors considered in the test were the material of the column (clay or calcareous blocks), corners radius of the samples, number of (FRP) layers, an aspect ratio of the sections and the effect of a hollow core in the samples. The authors compared their results with the equations reported in the Italian guideline (CNR-DT 200/2004) and found good agreements. (Alecci et al 2009) investigated the reliability of the theoretical formulations available in the literature evaluate the effect of confinement on masonry column strength. The researchers compared the theoretical values from the available formulations with uniaxial and tri-axial experimental tests on (CFRP) warped masonry columns made of pressed bricks. Their main conclusion was that the available formulations were in general overestimate the ultimate strength of the confined masonry columns. (Di Ludovico et al in 2010) proposed a new formulation to evaluate the ultimate strength of (FRP) confined masonry columns. Their formulation was based on experimental results on masonry columns considering the material of the masonry (tuff units or clay bricks) and confinement (carbon, glass or basalt FRP) as variables. (Faella et al 2011) investigated the effects of the kind of confinement composite system on the ultimate strength of masonry columns. The researchers tested fifty-four masonry columns made of natural stone and artificial bricks and jacketed by three different composites. They then combined their experimental results with the database of experimental results available in the literature and checked them with the available formulations. The authors proposed a new general design formula for the ultimate strength of masonry columns based on comparison results. (Micelli et al 2014) studied the mechanical behavior of a scaled masonry column with circular cross-sections and built with calcareous stone. The researchers used glass and basalt (FRP) in continuous and discontinuous warping along the length of the specimens. Their main conclusion was that continuous warping produced higher strength and ductility compared to discontinuous warping. Also, the researchers compared their experimental results with the predicted results from (CNR DT-200-R1/2013) guidelines and found good agreements. In another research (Micelli et al 2014) tested full-scale square masonry columns made from limestone blocks and confined by the glass (FRP) under the uniaxial test. The authors compared the results of the full-scale columns to those of small or medium-scale columns and concluded that “the confinement effectiveness was not affected by the scale factor”, the experimental results were also compared to the theoretical ones from CNR DT-200-R1/2013, the recorded errors were less than 10%. (Lingola et al 2014) proposed a theoretical formulation for the prediction of increase in strength in (FRP) confined masonry columns. The proposed formulation was based on Mohr-Columb criterion and required the mechanical properties of the masonry or its continuant as an input. (Fossetti and Minafo 2017) experimentally tested two types of masonry columns constructed from commercial clay bricks with low grade and medium grade mortar binders. The corners of the columns were rounded to a radius of 25mm prior to the confinement. One layer of (CFRP) jacket was used for confinement. Comparing to the unconfined columns, the authors concluded that the strength of the mortar has an influenced effect on the strength increased “confinement are more effective with the lower strength masonry”, also by comparing the experimental results with the theoretical formulations available in the literatures, researchers showed that most of the formulations available are under estimate the actual strength increase in masonry columns confined by (CFRP). (Al Otaibi and Galal in 2017) investigated the influence of confinement on the strength and ductility of concrete block masonry columns. 19 scaled columns with fully grouted concrete blocks bounded by 5mm cement mortar were tested. All the columns had square sections. The study investigated the effect of the number of (CFRP) layers in the jacket and the corner radius of the columns on the strength and ductility increase. The authors concluded that increasing the thickness of the jacket and the corner radius increased the strength up to 79%and the axial strain up to 230%. Their results were compared to the analytical formulation of CNR DT-200R1/2013 and good correlations observed. (Sandoli et al 2019) experimentally investigated the influence of confinement with (CFRP) jackets on the stress-strain behavior of masonry columns made from yellow tuff stones. 12 columns were tested in the study half of them with regular arrangement of masonry and the others with irregular arrangement. The study focused on obtaining a constitutive axial and transversal stress-strain laws for the confined columns based on the unconfined one and the properties of the (CFRP) jacket. Results of the study showed that no stress-strain laws available in the literature can match the predicted one, also the variation in masonry properties (due to the variation in type of block, mortar quality, masonry arrangement, aspect ratio of the sample, brick strength to mortar strength ratio and the confining material properties) has a high influence on the confined stress-strain model, and therefore more work are still required in the subject.

Despite the benefits of using (FRP) as a strengthening technique for masonry columns, however, many engineers and researchers do not prefer this technique as it doesn't have good compatibility with the masonry substrates, does not provide good breathability and irreversibility. A cement-based mortar (organic binder) is used to replace the epoxy in the jacket to overcome these drawbacks. This system is called 'fiber-reinforced cementitious matrix (FRCM), steel-reinforced grout (SRG), or textile reinforced mortar (TRM)'.

(Carolini et al 2015) were pioneers in investigating the influence of (FRCM) confinement on solid clay masonry columns. The researchers performed experimental work on a total of 24 samples including the following parameters: 1- cross-sectional aspect ratio (1, 1.5, and 2), 2- the scale of masonry units (full-scale 200x90x380mm and reduced scale 100x47x30mm). a single layer of carbon fibers embedded in an 8mm mortar jacket was used to confine of all samples. Experimental results showed that the cross-sectional aspect ratio and brick patterns had a significant effect on the load-carrying capacity and ductility of the confined columns. (Ombres in 2015) investigated the effect of (CFRM) confining jacket on the strength and strain capacity of concentrically and eccentrically loaded masonry columns. The experimental program included testing five columns with a cross-section of 250x250mm and a height of 650mm; were unconfined, two were confined with one layer of carbon fiber, and the fifth was confined two layers of carbon fiber. One unconfined and one confined with one layer of carbon fiber were tested under concentric load. In contrast, the remaining were tested with an eccentric load of 20% of the height of the samples as an eccentricity. All the corners of the samples were rounded with a radius of 20mm. test results showed the effectiveness of the (FRCM) in enhancing the axial strength and strain of the concentrically loaded columns. The increase in axial strength was about, 79%while the increase in the axial strain was about 60%. (Al-Saidy et al 2017) studied the effect of confining stone walls and columns by textile reinforced mortars on their strength and ductility capacity. The materials used in the test were similar to those used in ancient buildings in Oman (limestone and sarooj mortar with compressive strength of 50MPa and 0.76MPa, respectively). Cement was added to sarooj mortar to improve its strength (increased to 18.12MPa in compression) and used with carbon fiber which was fully warped on columns for confining. Columns were then tested in a concentric compressive test to investigate the effect of confining technique on their strength and ductility. Test results showed that the confinement improved the strength and ductility by 600% and 130% respectively. (Santandrea et al 2017) tested twenty-one masonry columns experimentally with a square cross-sectional area of 250x250mm and a height of 770mm all. Six columns were left unconfined to be control columns. Ten columns were confined with basalt embedded in cement mortar, and the remaining five columns were confined with steel fiber embedded in cement mortar. In addition to the fiber type, the corner radius was used as another factor in the test (0 and 20mm). the conclusion drawn from the concentric compressive test was: confinement increased the strength of the columns by an average of 15% and 33% for the basalt and steel textiles respectively while the strains were also improved but in less range for both basalt and steel. No clear effect of the corner radius was noticed. (Menafo and Mendola 2018) implemented a monotonic compressive test on 11 column specimens constructed from calcarenite stone (with compressive strength of 11MPa) and masonry mortar composed of cement, lime, and sand with a proportion of 1:2:9 respectively and 20% of water to produce an average compressive strength of 2.5MPa. the test aimed to investigate the effect of mortar grade o the performance of the strengthening layer. The tested specimens were divided into four groups; the first group left unconfined to be a reference for the others (control). All the other groups consisted of 3 columns each and confined with a glass fiber mesh embedded in mortar with compressive strength of 8, 13 and 25MPa. All the columns had square sections of 250x250mm and a height of 500mm. the corners of the confined columns were rounded to a radius of 20mm. the main conclusion from the study was that the variation in mortar strength of the confining jacket had a minimal effect on the increase in strength due to confining. (Cascardi et al in 2018) studied the role of the cementitious matrix in the effectiveness of the confining jacket. The researchers used inorganic matrices with three different compressive strengths to confine masonry columns with poor quality. Eleven masonry columns with a reduced scale (250x250x500mm) built from natural limestone bricks were tested under concentric compression load. The three inorganic matrices used were: 1- lime-based mortar with compressive strength of 4MPa, 2- lime-based mortar with compressive strength of 7MPa, and 3- cement-based mortar with compressive strength of 23MPa. The fiber used with all types of matrices was alkaline resistant glass fiber grid. A radius of 30mm rounded the corners of the confined columns before confining. Experimental results confirmed the improvement in compressive strength of the masonry columns by 6%, 31%, and 87% due to the mortar strength of 4,7 and 23MPa respectively. The authors compared their results with the analytical formulation by (Cascardi et al 2017) and found that calibration was required for the formula to best fit with the experimental results. (Sneed et al 2019) studied the behavior of masonry columns constructed from solid clay bricks and confined with steel embedded in cement matrix (SRG). The study included testing 34 reduced scale columns (250x250x720mm) in the concentric compression test. Three columns were left unconfined for control, and the remaining thirty were confined with (SRG). The tested variables were: 1- corners radius (0, 9.5, and 38mm), 2- steel density (670 gm/m2 and 1200 gm/m2), and 3- matrix grade (lime matrix with compressive strength of 13MPa and cement matrix with compressive strength of 47.1MPa). test results showed that the most effective factor in the study was the corner radius. The grade of the matrix influenced the strength increased of the columns but not proportional to the matrix strength. Finally, no clear influence of the steel density variation on the strength increased in the columns. The authors also compared the results of the study with the theoretical formulas available in the literature, they concluded that no single formula can fit to all test results and therefore they confirmed the need for more experimental works. Table 1 summarized all equation that have been used in this research for comparison.

Table 1 previous prediction models.

Author	Equation
CNR-DT200 R1/2013	$f_{md} = f_{mdo} * \{1 + k1 * [\frac{f1}{f_{mdo}}]^{0.5}$ $k1 = \alpha 2 * (\frac{gm}{1000})$ gm= mass density of masonry
Faella et al. - Fet-1	$f_{mc}^{th} = fm\left[1 + \frac{g}{1000} * \left(\frac{f_{leff}}{f_m}\right)^{0.662}\right]$
Corradi et al - CO	$f_{md} = f_{mdo} + k1 * f'1 k1 = 2.4\left(\frac{f'1}{f_{mdo}}\right)^{-0.17}$
Di Ludovico -DIL	$f_{md} = f_{mdo} + k1 * f'1 k1 = 1.53\left(\frac{f'1}{f_{mdo}}\right)^{-0.1}$
Krevaikas et al. - K&T	$fmd=fmdo$ if f'1/fmdo ≤0.24 fmd=fmdo*(0.6+1.65*f'1/fmdo) if f'1/fmdo>0.24
Faella et al. -2	$f_{md} = 1 + 0.46 * k_{cnr}{}^{0.2064} * \left(\frac{f_{leff}}{f_{ref}}\right)^{0.507}$
Faella et al. -3	$f_{md} = 1 + k_{cnr} * \left(\frac{f_{leff}}{f_{ref}}\right)^{0.662}$

As a conclusion from the previous review, (CFRM) confining technique provides less effectiveness than (CFRP) technique in increasing the strength of masonry columns. However, (CFRM) is preferred on (CFRP) due to the benefits of inorganic cementitious matrix incompatibility with the base materials, reversibility, and fire protection ability. Also, due to the variability in masonry materials (bricks, mortars, and confining jackets), no single analytical or design model can fit all types of masonry constructions and confining techniques is available. Therefore, more studies are required on the subject.

The present study includes testing square reduced scale masonry columns in the concentric compression test. The columns are constructed from commercially available clay bricks in two types of mortar, the first is a local gypsum material available in the Iraqi markets called Juss, and the second is the cement-sand mortar. Two types of jackets are used to configure the columns. The first is carbon fiber reinforced polymer (CFRP) with either one or two layers of Carbone fiber mesh in the jacket, and the second type is steel reinforced grout matrix (SRG) with one layer of steel reinforcement. Test results compared with the analytical models available in the literature.

2. EXPERIMENTAL WORK

The experimental program includes: -

1- Testing the materials to characterize their properties.
2- Constructing and preparation of reduced scale masonry columns with the designated jacketing.
3- Testing the masonry columns under a concentric compression test.

2.1. TEST SPECIMENS

Commercially available clay bricks were used to construct 32 reduced-scale columns. These columns were divided into two groups, the first group consisted of 16 columns with dimensions of 230x230x760mm, and the second group consisted of 16 columns with dimensions of 350x350x760mm. Each group was divided into two main sub-groups with seven columns each. The first sub-group columns were constructed using cement-sand mortar as a binder material. The second group columns were made using gypsum (locally called Juss) as a binder material. Then the columns in each sub-group were also divided as following: -

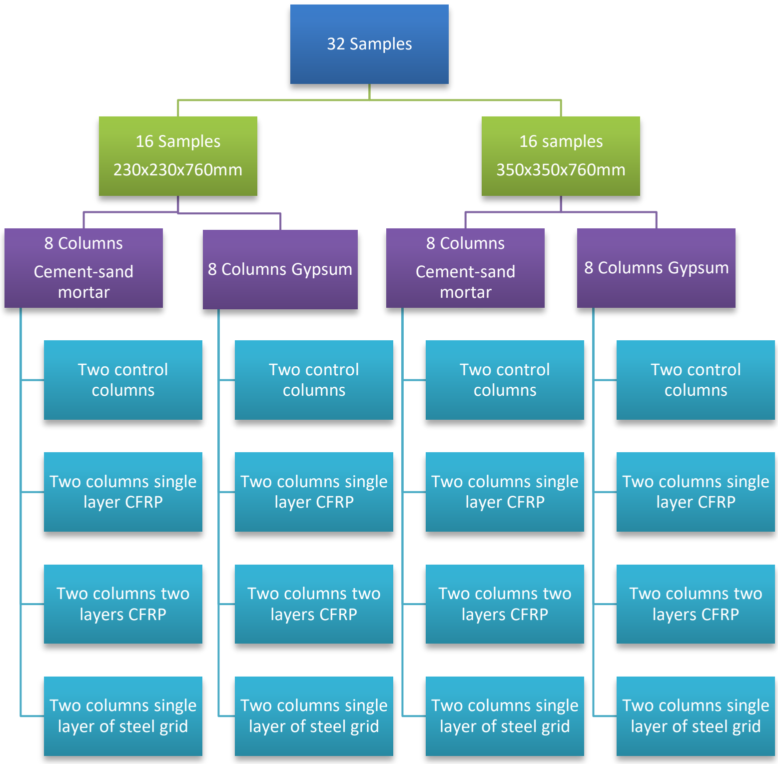

Fig. 1 Samples classifications

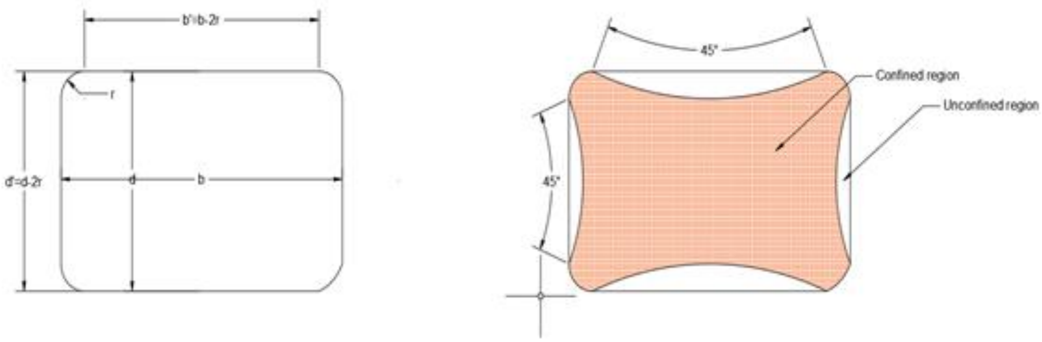

Fig.2 a. Sample's shape b. Effective confined area in masonry columns.

Two columns were left without jacketing for control, two columns were warped with a single layer of carbon fiber-reinforced polymer (CFRP), two columns were warped with two layers of (CFRP), and the last two columns were confined with a single layer of steel grid buried in the cementitious mortar of 10mm thickness "steel reinforced grout jacket SRJ".

Ten pieces of bricks were tested according to the (Iraqi standard No.25 in 1988), the average dimensions of bricks were 230x110x70mm, average voids area in brick was 6%, average compressive strength of bricks was 16.55MPa with a coefficient of variation of 3.4% and average water absorption was 23.35%. Hence bricks were classified as type B according to the Iraqi standard. Figure 2 shows the sample shape and effective confined area in masonry.

2.2. MATERIALS

Commercially available clay bricks were used as explain above. Ordinary Portland cement was used for the binding material and plaster in the confinement SRG jackets. The physical and chemical properties of the cement were tested and checked according to (Iraqi standard No.5 in 1984).
A natural source of fine aggregate (sand) was used and mixed with cement in a ratio of 1:3 (cement to sand respectively) for the binding mortar and a ratio of 1:1.75 for the plaster in the SRG jacket. The sand was tested and classified as class 2 according to (Iraqi specification No. 45 in 1984). According to (Iraqi Specification No.28 in 1984), the gypsum, or as called locally Juss, was sampled and tested. Compressive strength (average of 6 cubes 50x50x50mm) and flexural strength (average of 6 prisms 40x40x160mm) for Juss and cement mortars are given in table 2. All materials were tested in engineering college laboratories, university of Basrah.

Table 2. Compressive and flexural strength of Juss and cement-sand mortars

Material	Average compressive strength MPa	Covariance %	Average flexural strength MPa	Covariance %
Gypsum (Juss)	4.3	1.21	0.37	0.92
Cement-sand 1:3	8.63	1.93	1.83	2.1
Cement-sand 1:1.75	18.1	0.87	3.15	1.8

The (CFRP) jacketing materials Sika-warp 300C carbon fiber fabric was used, its specification considered in this work were given by the supplier (SikaWarp 300C CFRP 2018) and shown in table 3.

Table 3. properties of carbon fiber fabric (SikaWarp 300C CFRP 2018)

Areal weight	300 g/m2 +/- 5%
Fiber density	1.8 gm/cm3
Fabric design thickness	0.17mm
Tensile strength	3900 MPa
Tensile modulus of elasticity	230000 MPa
Strain at the break of fibers	1.5%

(Sikadur 330 2018) was used as impregnation resin to fix the carbon fiber fabric on the masonry columns; it is a two-component epoxy-based resin compatible with Sika-warp fabric. The last material used in this experimental program was the steel mesh for the (SRG) jacketing. A low carbon 1018 mild steel wire mesh was used, its properties (as given by the supplier) are shown in table 4.

Table 4. properties of steel wire mesh

Bar diameter	4.75 mm
Bars spacing (center to center)	50.8 mm
Ultimate tensile strength	440 MPa
Yield strength	370 MPa
Elongation	15%
Carbon content	0.18%

2.3. CONSTRUCTION AND PROPERTIES OF REDUCED SCALE MASONRY COLUMNS

An experienced mason builder was employed to construct 32 masonry columns. All the columns had the same height of 790mm. (ten rows of brick at 70mm and nine rows of the in-between binder at 10mm.). sixteen columns had a cross-section of 230x230mm. (consist of two bricks of 110 x 230mm plus 10 mm binder). The bricks in each row were perpendicularly oriented to the bricks in the next row. Half of the columns were constructed with cement-sand mortar in a proportion of 1:3 by volume. The second half of the columns were constructed with a Juss binder.

Similarly, the other 16 columns were built with a cross-section of 350 x 350mm. Eight columns were constructed with cement-sand mortar in a proportion of 1:3 by volume and the other eight columns were constructed with Juss. All the columns then topped and bottomed by 2cm thick of high-strength mortar to a better distribution of stress on the bricks and avoid stress concentration that may lead to an early failure. For all columns constructed with cement-based mortar, the clay bricks were immersed in water for 30 minutes before construction of columns, and then covered with wet fabric and kept wet for 28 days at room temperature (in the construction material laboratory of Basrah University). Bricks for columns constructed with Juss were kept dry before construction and then, columns were covered by plastic sheets and kept in the laboratory for 28 days before the test. Fig.no. 3 shows sample preparation before the test.

Fig.3 Sample's lab preparation

3. RESULTS AND DISCUSSION

In this section, experiment results will be represented and discussed in detail. In addition, study experiment results will be compared with previous prediction models to evaluate the results rationales. Table. 5 shows the experiment outcomes. The tables display the sample name, its compression capacity without any modification, modified compressions capacity using one layer of FRP, modified compressions capacity using two layers of FRP, and modified compressions capacity using mesh wires (Ferrocement) with enhancement ratio for each method. For samples that used cement mortar, it can be seen those columns with dimensions 230 x 230 mm their capacity increased significantly with an enhancement ratio of 100% for one layer and more than 200% for two layers. Despite the fact that its huge improvement in capacity, it has been noticed that during laboratory tests, after 50% enhancement, the masonry units start to crack. This behavior produces a huge risk to the overall structure safety. The same manner of behavior has been observed with the column with dimensions 360 mm x 360 mm with improvement in capacity 100% and 250% for one and two layers respectively. The upgrading using Ferro cements results in a less enhancement ratio compares to the FRP method. This method progresses column capacity by 50% for 230mmx 230mm columns and 20% for 360mm x 360mm columns. It has been perceived that a weak bond between mesh wires and masonry columns compare to the FRP method can be considered as the main reason for this small improvement in column capacity.

For samples that used lime mortar, it has been noticed that the augmentation is more than what has been gained in cement mortar. For columns with dimensions 230mm x 230mm, the improvement in compression capacity is around 160% for one layer of FRP and 310% for two layers of FRP. The same behavior of crashing masonry when capacity is raised to more than 50% of standard capacity. This behavior has its advantage and disadvantage. As it will prevent masonry columns from reach higher capacity levels due to confinement pressure (disadvantage). These actions can produce a very early warning that masonry columns are reaching a critical level without any sudden collapses (advantage). The Ferro cement method improves masonry column capacity more effectively with percentages of 100% and 120% for columns 230mmx 230mm and columns 360mm x 360mm. The improvement can be explained due to the small initial standards capacity which allows the strength to be improved. Table. 5 shows all the experiment results which contains 32 columns results as per sampling description in Fig. 1, in sample name BC represents brick with cement mortar, BL represents brick with Juss mortar. The number 24 and 36 represents the dimensions of the columns respectively. Finally, the number 1, 2 in the sample name represent the sample number.

Table 5. Experimental results

32 Samples							
16 Samples 230x230x760mm				**16 samples 350x350x760mm**			
8 Columns Cement-sand mortar		**8 Columns Gypsum**		**8 Columns Cement-sand mortar**		**8 Columns Gypsum**	
Smaple classification	Compressive resistance MPa	Smaple classification	Compressive resistance MPa	Smaple classification	Compressive resistance MPa	Smaple classification	Compressive resistance MPa
Two control columns	31	Two control columns	8	Two control columns	44	Two control columns	13
	26		7.5		58		11
Two columns single layer CFRP	62	Two columns single layer CFRP	22.5	Two columns single layer CFRP	92	Two columns single layer CFRP	37.3
	56		18.5		108		36
Two columns two layers CFRP	92	Two columns two layers CFRP	34	Two columns two layers CFRP	178	Two columns two layers CFRP	50
	98		30		185		57
Two columns single layer of steel grid	46	Two columns single layer of steel grid	13	Two columns single layer of steel grid	59	Two columns single layer of steel grid	24
	45		18		62		22

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Sample with CFRP during the test

Sample with mesh wire during the test

Sample with CFRP during the test

Sample with mesh wire during the test

Fig. shows failure tested samples and Tested samples

To validate the results of the experiments, these results are compared with previous prediction methods that have been developed by different researchers in this field as explained in the earlier sections. Fig 5 shows the results of column 230mm x230mm with cement mortar compression capacity improvement with CFRP. From figure 5, it can be observed that the result simulates most of the previous prediction models. However, it reaches the maximum prediction compression strength improvement a series caution needs to be implemented here and prevent the masonry column from reaching this level in any scenario.

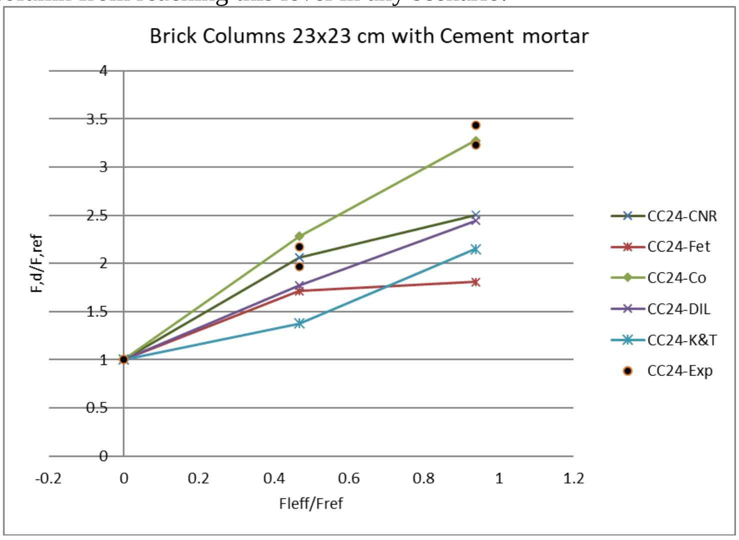

Fig.5 experiments results in comparison for 230mm x 230mm masonry column

Fig. no. 6 displays the results of column 360mm x 360mm with cement mortar. From the figure, it can be concluded that there are two patterns in the results. The first one, one layer of CFRP can improve the compression capacity as much as the prediction model estimate which means that the experimental results are reasonable. However, the second pattern which is uses two layers of CFRP provides improvement much more than the predictable models can produce. From these two comparison figures, it can be concluded that the experimental results are practical. However, the total improvement in the capacity not represents the actual amount that needs to be practically considered. The designer can increase the total masonry column compression capacity by around 50% more than the capacity of the column without confined pressure. This results as mentioned above due to the brick unit crashing under extreme compression pressure.

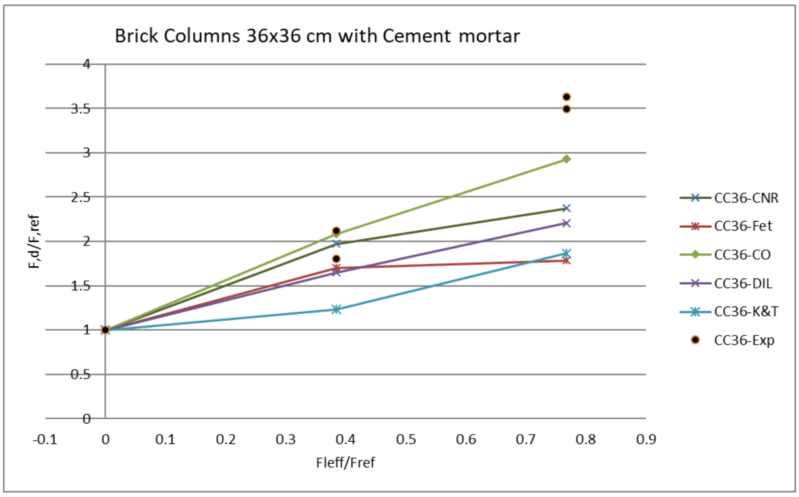

Fig.6 experiments results comparison for 360mm x 360mm masonry column

Figs. 7 and 8 show that the experiment outcomes for the masonry column using lime mortar match the prediction models significantly. Therefore, the masonry columns using lime as mortar can be improved in term of compression capacity, which will solve several difficulties for old and heritage buildings where the capacity needs to be modified without changing the dimension of the columns.

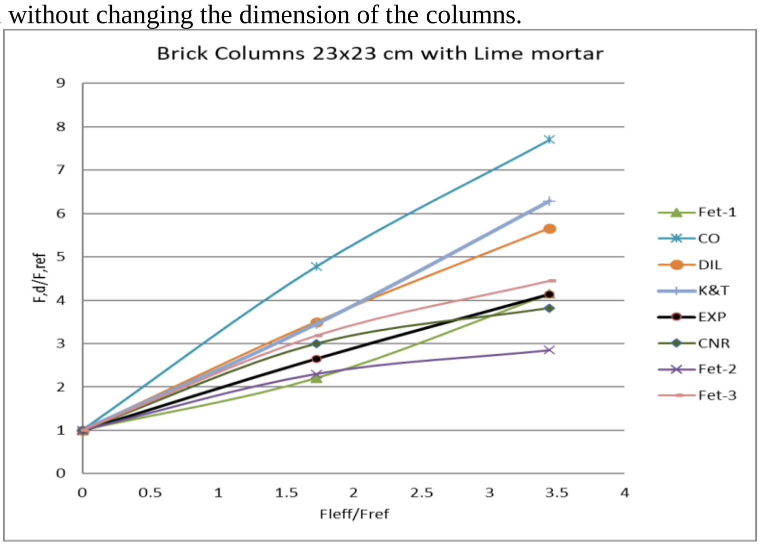

Fig.7 experiments results comparison for 230mm x 230mm masonry column

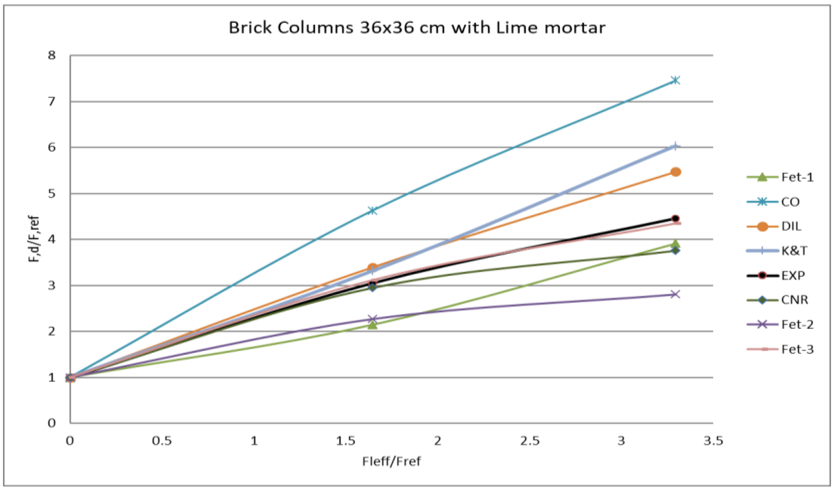

Fig.8 experiments results comparison for 360mm x 360mm masonry column

Figs. 9 and 10 display that using mesh wire to produce confined pressure will improve the capacity of the masonry column. The experimental outcomes are falling in the range of predication models which give these results a good rational percentage for both 230mm x 230mm columns and 360mm x 360mm columns.

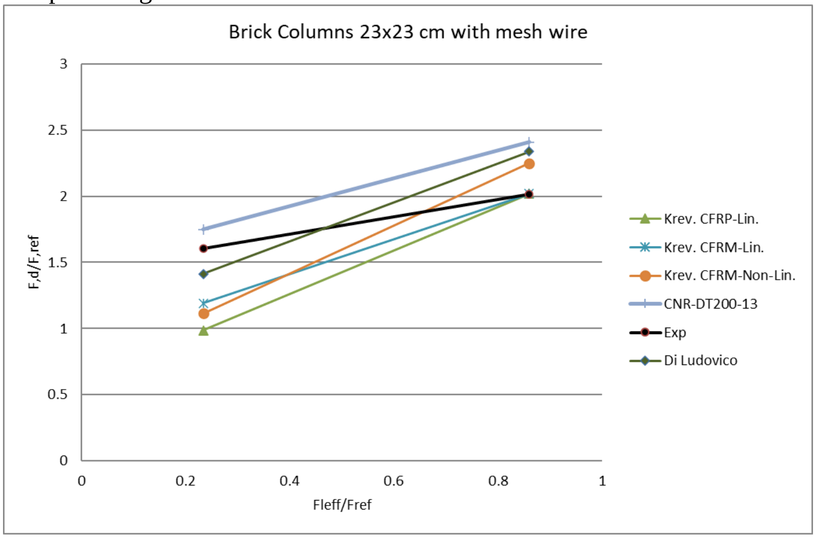

Fig.9 experiments results comparison for 230mm x 230mm masonry column using mesh wire

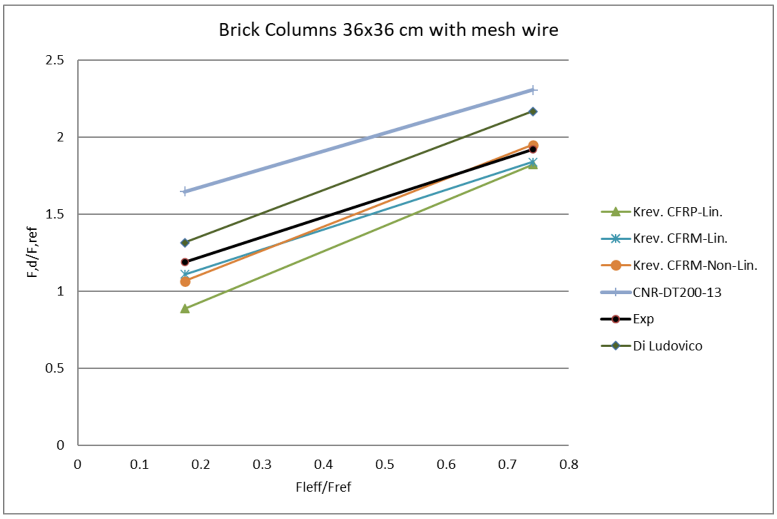

Fig.10 experiments results comparison for 360mm x 360mm masonry column using mesh wire

4. Conclusion and Recommendations

This study addresses the improvement of masonry column compression capacity via producing confined pressure. This confined pressure results from using one layer of CFRP, two layers of CFRP, and using mesh wiring. The following points can represent the conclusion that observed from this study:

- Providing confined pressure using CFRP can improve the compression capacity significantly.
- Increasing the no of layers of CRFP can also improve the compression capacity.
- Using mesh wiring refining the capacity with less magnitude comparing to CFRP.
- Columns with cement mortar improved much more than columns with lime mortar.
- The improvement percentage must be revisited for design purposes as masonry units are crashed before these improvement percentages have been reached.
- The experimental results have an excellent rationale as the comparison with previous prediction models reveals that.
- This study also recommends more studies to investigate the full-scale masonry structure and use FEM to model this structure.

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