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COMPRESSIVE STRENGH OF FRP-CONFINED CONCRETE COLUMNS UNDER THE ECCENTRIC LOADS

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ABSTRACT: In recent years, due to some excellent properties of fiber reinforced polymer (FRP) composites, the use of FRP sheets for strengthening the weak concrete columns have become increasingly popular. Axial loading is the basic assumption in most of the models that are presented for estimating the compression strength of confined concrete columns. However a large number of weak concrete columns in the bending frames are under the combination of both axial and flexural loads. This paper presents the results of an experimental study on the effects of eccentricity of load on the compressive strength of concrete columns confined by FRP sheets. This research shows that the eccentricity of compression load affects decreasingly the performance of confining FRP jacket in confined columns.

Keywords: Concrete Columns; Confinement; FRP Sheets; Compression Strength

1. INTRODUCTION

Earthquake damages in many reinforced concrete columns in bridges and buildings have indicated inadequate strength and deformation of many old reinforced concrete columns and urgent need to retrofit them. These structures were rather constructed according to older codes or without an adequate construction practice. The structural members of this type of buildings may experience several damages due to low deformability and axial capacity. The initial application for retrofitting of weak columns involved the use of steel hoops and straps to provide lateral confinement. Some analytical models have been developed to provide a theoretical base for retrofitting concrete columns. These models are satisfactory for the prediction of strength and ductility of concrete columns confined by steel stirrups. Rather to some disadvantages of steel jacket, such as heavy weight and high potential for corrosion, the use of fiber reinforced polymer (FRP) composites has been developed in recent decades. This material has some unique properties such as light weight, high stiffness and high strength to weight ratio [1]. Moreover, FRP has a great resistance to corrosion. These new materials have shown a great potential in replacing the traditional steel reinforcement as retrofit material. Based on the results of many experimental researches, when reinforced concrete columns confined laterally with FRP sheets, its ductility and axial load capacity will be enhanced [2].

2. CONFINING EFFECTS OF FRP

The strength enhancement in columns using lateral FRP sheets may be the confinement effect of transverse fiber sheets. When a concrete column is affected by axial compressive load, concrete core will expand laterally. In jacketed column, however, lateral expansion is limited by the effect of lateral confining material. In these cases concrete core of the column section will be affected by a kind of passive pressure named confining stress. An important aspect of the behavior of confined concrete is that at the rupture of FRP, the hoop strain reached in the jacket is generally considerably smaller than the ultimate tensile strain found from flat coupon tensile tests. The FRP efficiency factor had been suggested for calculation of the actual hoop rupture strain of FRP jacket.

According to the stress distribution of confined circular section (Fig. 1), confining pressure provided by the transverse FRP sheet (f_l) is given by Eq. 1 [3]:

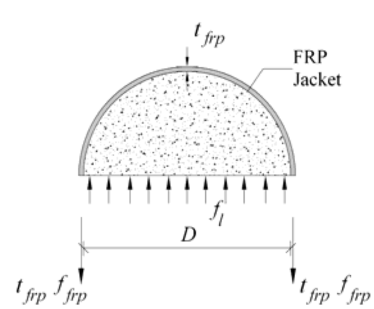

Fig. 1. Stress distribution of confined circular section.

Table 1. Estimating models for compressive strength of confined concrete column.

Model's Name	Compressive strength of confined concrete column
Al-Salloum	$f'_{cc0} = \left(1 + 3.14 \frac{f_l}{f'_{c0}}\right) f'_{c0}$ $k_\varepsilon = \left(\frac{2a}{\left(\sqrt{2}a - 2r\left(\sqrt{2} - 1\right)\right)^2}\right)\left(1 - \frac{2}{3}\left[\frac{(1 - 2(r/a))^2}{1 - (4 - \pi)(r/a)^2}\right]\right)$ $k_s = 1.00$
Lam and Teng	$f'_{cc0} = \left(1 + 3.3 \frac{f_l}{f'_{c0}}\right) f'_{c0}$ $(\frac{b}{a})^2 \left(\frac{2}{\sqrt{a^2 + b^2}}\right)\left[\left(1 - \frac{(b/a)(a - 2r)^2 + (a/b)(b - 2r)^2}{3\left(ab - (4 - \pi)r^2\right)}\right]$ $k_s = 0.57$
Pantelides and Yan	$f'_{cco} = \begin{cases} \left(-4.322 + 4.271\sqrt{1 + 4.193 \frac{f_l}{f'_{c0}}} - 2\frac{f_l}{f'_{co}}\right) f'_{c0} & \frac{f_l}{f'_{co}} \geq 0.2 \\ MAX\left[\left(\frac{-4.322 + 4.271\sqrt{1 + 4.193 \frac{f_l}{f'_{c0}}} - 2\frac{f_l}{f'_{co}}}{0.0768 \ln(\frac{f_l}{f'_{co}}) + 1.122}\right) f'_{c0} \, , f'_{c0}\right] & \frac{f_l}{f'_{co}} < 0.2 \end{cases}$ $k_s = \left(1 - \frac{(a - 2r)^2 + (b - 2r)^2}{3ab}\right)\left(\frac{(a + b)}{ab}\right)$ $k_s = 0.50$

$$f_l = \left(\frac{2}{D}\right) E_{FRP} k_\varepsilon \varepsilon_{FRP} t_{FRP} \tag{1}$$

Where D = diameter of column section, t_{FRP} = whole thickness of FRP sheets, k_ε = FRP efficiency factor and E_{FRP} and ε_{FRP} = the modulus of elasticity and ultimate tension strain of FRP sheet. Based on experimental results the advantages of FRP in circular section column are different from rectangular section. In a circular concrete column, the confining pressure is constant around circumference and small variation due to factors such as in homogeneity of concrete is ignored. In rectangular section of columns, the confining pressure of FRP does not distribute uniformly over the section and only a portion of the section is affected by confining pressure (Fig. 2). Because of that the performances of FRP in this kind of sections are different and lower than that of FRP-confined circular sections [4].

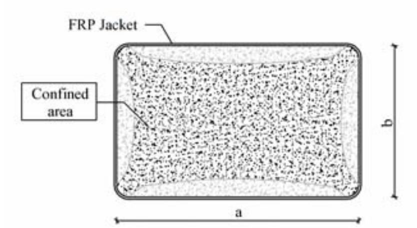

Fig. 2. Confined area in a rectangular section

In rectangular section, due to stress concentration in FRP jacket, premature failure of FRP occurs and whole capacity of FRP is not used. In this section, the confining pressure provided by the FRP sheet must be decreased by introducing the shape factor that is equal or less than 1.0. In rectangular sections it is given by [5]:

$$f_l = k_s k_\varepsilon E_{FRP} \varepsilon_{FRP} t_{FRP} \tag{2}$$

Where k_s = shape factor of section and is related on section's geometrical dimensions and often different in each model.

3. COMPRESSIVE STRENGTH OF FRP-CONFINED CONCRETE

Most of the available models for evaluating the compressive strength of FRP-confined concrete columns are based on the confinement model that was derived experimentally for specimens under active hydrostatic pressure [6]. In this paper, three models for rectangular and square columns are selected for compressive strength of FRP-confined concrete. Those models had been presented by Al-Salloum [7], Lam and Teng [8], and Pantelides and Yan [9] as presented in Table 1. *a*, *b*, and r in this table are large having a small dimension and corner radius of cross section. f'_{cc0} is compressive strength of confined concrete. Lateral confining pressure (f_l) in each model is calculated from Eq. (2). Those models just such as many other ones are specifically for concrete columns that bearing only axial load. However a large number of weak concrete columns in concrete bending frames are subjected under axial load and bending moment combination. It is important point that if we can use such mentioned models for estimation the compressive strength of FRP-confined concrete columns under axial load and bending moment combination.

4. EXPERIENCE PROGRAM

An experimental study has been scheduled for achieving the answer of mentioned question. In this study, specimens consist of six square concrete columns retrofitted by FRP-confining methods. Details of experimental specimen are shown in Fig. 3. Each column has the wide equal 200 mm and the length equal 700 mm. For prevention of stress concentration in FRP jacket, edges of cross section rounded. The corner radius of cross section is 20 mm.

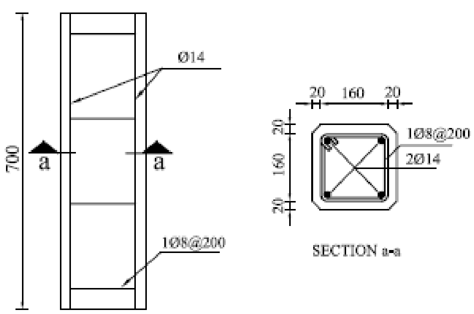

Fig. 3. Geometrical details of the experimental specimens

5. MATERIALS

Columns have been constructed in three series. Compressive strength of unconfined concrete is 23.2, 20.1, and 21.8 MPa for series I, II, III. The yield tension stress of longitudinal bars is 370 MPa. In this experience one directional fiber of carbon fiber reinforced polymer (CFRP) have been used. Mechanical properties of CFRP are observable in Table2.

Table 2. CFRP Mechanical properties

Fiber Type	C-Sheet240
Thickness (mm)	0.176
Ultimate strain (%)	1.23
Tensile strength (MPa)	2876
Tensile modulus (GPa)	234

6. INSTRUMENTATION

The position of concrete column under the hydraulic jack has been shown in Fig. 4.

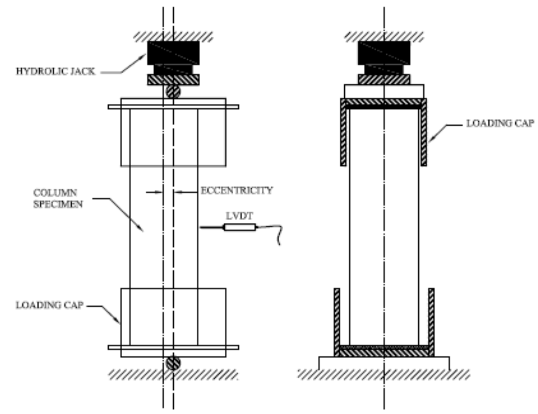

Fig. 4. Applying load details

The testing program of each specimen also is presented in Table 3.

Table 3. Test program

Series	Specimen	Eccentricity (mm)
I	BC-E3-W	30
	BC-E3.5-W	35
II	BC-E1-W	10
	BC-E1.5-W	15
III	BC-E2-W	20
	BC-E2.5-W	25

7. TEST RESULTS AND OBSERVATIONS

Regarding to increase applied load, some noises was hear because of corrosion of concrete core. A noticeable point was brittle failure in all specimens. This failure takes place by sudden failure of lateral FRP wrap with high sound. Lateral FRP broken in corner area of cross section because of high tensile stress concentration. A view of failure of concrete column is presented in Fig. 5

Fig. 5. Failure of confined concrete column.

Ultimate compressive load are achieved from experience are presented for each columns in Table 4.

Table 4. Test results

Specimen	ultimate compressive load (kN)
BC-E1-W	841.521
BC-E1.5-W	783.150
BC-E2-W	759.287
BC-E2.5-W	693.824
BC-E3-W	674.581
BC-E3.5-W	585.807

8. RESULTS ANALYZING

When concrete column subjected to an eccentric compressive load, the distribution of stress and strain in its section is such as that shown in Fig. 6.

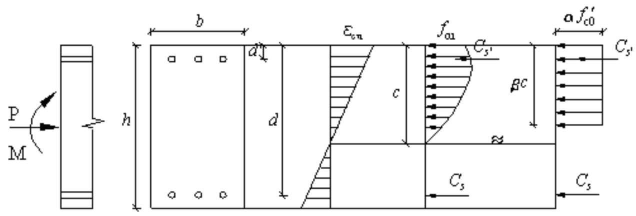

Fig. 6. Distribution of stress and strain in section

α and β in Fig. 6 are tow constant factor and their amount are specified According to the ACI Cods [20]. ε_{c0} is the ultimate compressive strain and equal to 0.003 according to the ACI Cods. f'_{c0} is compressive strength of unconfined concrete. By attention to the force equilibrium in section, ultimate compressive load and its eccentricity can be presented. In order to calculate the ultimate compressive load in confined concrete column, f'_{c0} will be replaced by compressive strength of confined concrete (f'_{cc0}). A comparison between experimental results and which are obtained from mentioned model is presented in Fig. 7. In those diagrams ultimate axial load in different ratio of eccentric to section dimension (e/a) is exhibited. According to the Fig. 7, when eccentricity of load increases, prediction of each model achieves to an insecure results. In those cases ultimate compressive load has been predicted more than as one as obtained from experience. More differences between experience and prediction among investigated models is in BC-E3.5-W. This specimen bore compression load whit most eccentricity and however in this case the role of bending moment in its combination whit axial load is strong.

Applying bending moment on confined concrete column has tow decreasing effects in its compressive capacity. The first one is depend on the effect of compressive load and bending moment combination, just similar to other unconfined concrete columns.

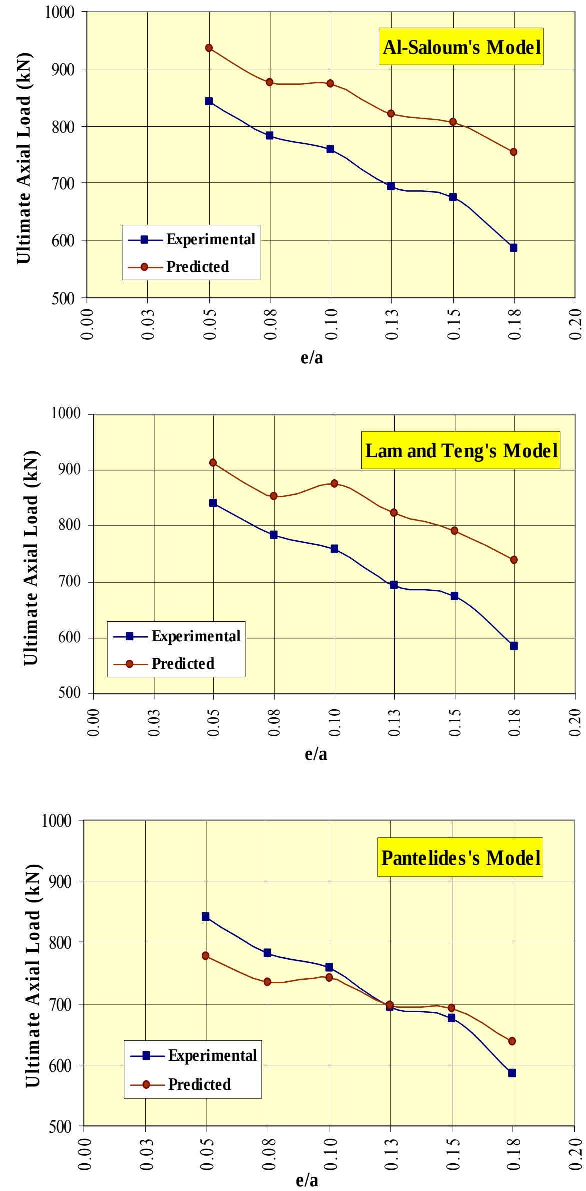

Fig. 7. Prediction of models in different eccentricities.

The second effect is particular for confined concrete columns. Bending moment causes an uneven compressive strain in the column's cross section and thus lateral expansion of Column section will be unequal. Lateral confining pressure of FRP wrap depends to lateral expansion of column's section. However by increasing the amount of bending moment in the section, lateral confining pressure of FRP will be decrease and applies unequally to the concrete core. In this case concentration of tensile stress in FRP sheet accelerates its failure.

9. CONCLUSION

This paper presents the results of an experimental study on the effects of eccentricity of load on the compressive strength of concrete columns confined by FRP sheets. For this purpose six concrete columns subjected to a compressive load with different eccentricity and the ultimate compressive load for each specimen was measured. Obtained experimental results were comparison with results which had been predicted by three models for estimating the compressive strength of concrete confined by FRP. Those models had been suggested previously by some other researchers. this comparison shows that decreasing effect of bending moment on confined concrete column couldn't be observed in selected models and any other similar models which produced in pour compressive load condition. Important point in this section is that many weak concrete columns are in bending frame and bearing a combination of axial load and bending moment. Thus in a retrofit and redesign program, taking advantage of compressive strength estimator models without using any decreasing factor may results unsafe estimation.

10. REFERENCES

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