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Behavior of Using CFRP Bars, GFRP Bars and Steel Bars in Circular Concrete Columns under Concentric Loading

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ملخص البحث

يقدم هذا البحث نتائج برنامج عملى لاستكشاف سلوك الأعمدة الدائرية الخرسانية المسلحة باسياخ فايبرواعمدة مسلحة بحديد تسليح تحت تاثير احمال محورية ، كحل للتغلب على مشاكل التآكل، .تم اختبار مجموعة من الاعمدة ١٢عمود يتم تحميلهم باحمال راسية .حيث ان لكل الأعمدة نفس القطر ١٥٠مم ولكن اطوال مختلفة وحيث ان عدد الاعمدة ١٢منهم 6 بطول ٦٠٠ مم و٦ بطول ١٠٠٠مم ، التسليح الرئيسي لكل الاعمده ٦ Ø ١٠مم، وكانات حلزونية ٦Ø @٣٠مم بكامل العمود .وكانت النقاط الرئيسية المدروسة سلوك أنواع اسياخ التسليح اثناء التحميل ، وارتفاع العمود . وجد ان كل الاعمده لها نفس السلوك فى الانهيار ووجد ان فى حالة الاعمده المستخدم بها الحديد تعطى نتائج افضل فى حالات التحميل المحورى ثم يلية عينات عينات الكاربون فايبر ثم عينات الفايبر الجلاس وقد تم عمل مقارنة بنتائج المعادلات الموجوده بالكود الكندى والكود الامريكى ومعادلة مقترحة لباحث فى جامعة كندية وجد ان النواتج تمثل ٢٠٠% بالنسبة لمعادلات الكود الكندى و١٥٠% بالنسبة لمعادلات الكود الامريكى و١٢٠% بالنسبة للمعادلة المقترحة من الباحث فى الجامعه الكندية.

1.ABSTRACT

This paper presents the results of an experimental investigation of the axial behavior of circular reinforced concrete columns with fiber reinforced polymer (FRP) bars, as a solution to overcome the corrosion problems, where this material represents a relatively new technology; Therefore much research is needed to determine its characteristics and gain confidence to be accepted by engineers for practical application. A series of 12-column was tested in a vertical position. Where all columns had the same diameter 150 mm and different in height which 6 specimens have 600mm height and 6 specimens have 1000 mm height, main reinforcement 6ø10mm, the transverse reinforcement was ø6@30mm spiral stirrups along column. The major parameters included in this research the main reinforcement types, the column height which we consider that columns 600mm short column and 1000mm consider long column, concrete compressive strength and the spiral stirrups behavior with different type of longitudinal reinforcement. The test results and experimental investigation were presented and discussed in the form of; axial load capacity, mode of failure, longitudinal, and stirrups strains, ductility, load/stress–strain response, axial and horizontal displacement. These results were used to evaluate the validity of the confinement models and design equations of the North America codes and design guidelines for the

predication of GFRP and CFRP circular concrete columns capacities in case of concentric columns

Keywords: Behavior, Column, Fiber, polymer, glass, carbon, compressive strength and ductility

2.Introduction

Deterioration of reinforced concrete structures has become a serious problem in the last decade; This situation is mainly due to corrosion of steel reinforcement embedded in concrete. Fiber reinforced polymer (FRP) is increasingly used for reinforcing new structures, and strengthening existing structures. FRP composites, in the form of sheets, cables, rods, and plates, have proven to be a cost-effective alternative to steel reinforcements because of their low weight to strength ratio, corrosion resistance, and flexibility. The most common types of FRP are aramid, glass, and carbon; AFRP, GFRP, and CFRP respectively.

There are many bridge structures all over the world as applications of structures with FRP reinforcement for example:

1- In China; there are now eight GFRP bridges in China. These bridges were generally constructed by hand lay-up of glass fibers in a polyester resin using a honeycomb form of deck structure, as the Miyun Bridge, the Xianyyong bridge, and Hulan River Bridge.

2- In Germany; the Lünensche Gasse pedestrian bridge, the Ulenbergstrasse Bridge, and the Schiessbergstrasse Bridge.

3- In Japan; the Shinmiya Highway Bridge, the Bachi-Minami-Bashir highway bridge, the Nagatsugawa pedestrian Bridge, Tochigi Prefecture Bridge, and Ibaraki Prefecture Bridge.

4- In Canada; the Beddigton Trail Bridge, the Headingley Bridge, Wotton Bridge, and Magog

5- In United States: the McKinleyville Bridge, and the Morristown Bridge (Nicholas et al., 2003, Halcrow et al., 1996, OU et al., 2003, EL-Salakawy et al., 2003).

Unfortunately, there was a lack of data about using FRP as reinforcement; The lack of a comprehensive database on FRP materials makes it difficult for the practicing civil engineer and designer to use FRP composites on a routine basis. Although a number of reviews have been published recently related to durability and test methods. The focus of each has been to summarize the state of knowledge in general without emphasizing or attempting to prioritize critical areas in which needs are the greatest for collection, assimilation, and dissemination of data (Karbhari et al., 2003).

3. Previous Research

Paramanantham, (1993) tested 14 concrete beam-columns reinforced with glass fiber-reinforced polymer (GFRP) reinforcing bars. The study reported that the GFRP reinforcing bars would only be stressed up to 20 to 30% of their ultimate compression strength in pure axial compression, and up to 70% of their tensile strength in pure flexure. (Kawaguchi, 1993) performed similar tests with concrete member reinforced with aramid fiber- reinforced polymer (AFRP) reinforcing bars. Both studies showed that concrete compression members reinforced with FRP reinforcing bars can be analyzed by applying the same principles and procedures used for concrete columns with steel reinforcement. (Deitz et al., 2003) tested GFRP reinforcing bars that had an outside diameter of 15 mm (3/5 in.) in compression, and reported that the ultimate compression strength of the bars was approximately 50% of the ultimate tensile strength. In general, the compressive strength of FRP reinforcing bars is lower than the tensile strength. In contrast to the vast database available on FRP-RC beams and slabs, literature on FRP-RC columns with FRP bars is infrequent and limited. So this study aims to study the behavior of reinforced concrete columns with CFRP and GFRP bars. The results and observations presented in this paper are useful to practicing engineers who must predict the enhanced compressive strength of concrete columns reinforced with CFRP and GFRP bars.

1. Experimental Program

1.1 Description of Test Program

In this research, tests were carried out on 12-column specimens, Tested specimens were divided into three groups. All columns have the same diameter 150mm with main reinforcement 6ø10mm and spiral stirrups ø6@30mm:

Group 1: These group Consists of four columns reinforced with CFRP bars two of them 600 mm and the others were 1000 mm, one of each short and long columns have concrete compressive strength 300 kg/cm² N.S.C and the others have concrete compressive strength 450 kg/cm² H.S.C.

Group 2: These group Consists of four columns reinforced with GFRP bars two of them 600 mm and the others were 1000 mm, one of each short and long columns have concrete compressive strength 300 kg/cm² N.S.C and the others have concrete compressive strength 450 kg/cm² H.S.C.

Group 3: These group Consists of four columns reinforced with STEEL bars two of them 600 mm and the others were 1000 mm, one of each short and long columns have concrete compressive strength 300 kg/cm² N.S.C and the others have concrete compressive strength 450 kg/cm² H.S.C.

Table1: shows the details of tested specimens, figure 1 shows the load arrangement on specimens, and figure 2 shows the details of reinforcement of columns.

Each specimen take name consists of 4 letters: First letter refer loading type on the specimen, Second letter refer to type of reinforcement bars, Third letter refer to type of concrete strength, and the fourth letter refers to column height length.

Table 1: Details of Tested Columns Specimens

Type of Reinforcement Bars	f_{cu} (Mpa)	f_c' (MPa)*	H (mm)	Specimen Designation	Group Name
Carbon Fiber Reinforced Bars	30	24	600	CCNS	**G1**
			1000	CCNL	
	45	36	600	CCHS	
			1000	CCHL	
Glass Fiber Reinforced Bars	30	24	600	CGNS	**G2**
			1000	CGNL	
	45	36	600	CGHS	
			1000	CGHL	
Steel Reinforced Bars	30	24	600	CSNS	**G3**
			1000	CSNL	
	45	36	600	CSHS	
			1000	CSHL	

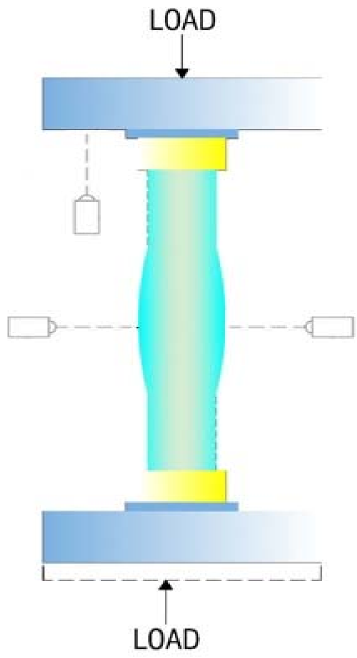

Figure 1: Loading arrangement on Specimens

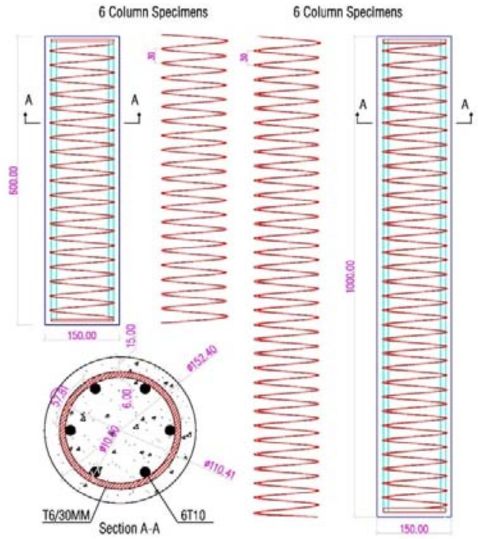

Figure 2: Reinforcement Details of the Specimens

4.2 Material Properties

The material used was from the local available materials in Cairo. Natural sand and crushed limestone (Dolomite) were used as fine and coarse aggregate. It was cleaned and freed from organic material. Drinking water has been used for mixing with water-cement ratio of about 0.5 for concrete 300 kg/cm² and 0.35 for concrete 450 kg/cm² as show in table 2. The curing of all specimens was done under relatively humidity of 95%.Dry sand and cement were mixed mechanically, and then water was added and mixed thoroughly. Mixing operation was continued after adding water until a uniformly color is obtained. The mixing proportion of different materials was by weight. Normal Portland cement product was used for all specimens. The fineness of used cement was 8% which is less than 10% according to the limits of Egyptian specification. The initial setting time is 90 min. and final is 5 hours. The slump test was made according to ASTM C143 and ranged from 43-76 mm for concrete, no segregation was observed. Coarse aggregate with maximum nominal size of 10 mm was used in order to ensure good compaction of concrete. Cubes of 150 mm side length were used. The mean values of cubic strengths were ranged from 30 to 31.5 MPa for concrete 300kg/cm² and ranged from 45.6 to 46.6 MPa for concrete 450 kg/cm².About fiber bar fabrication it was in El-Asher men Ramadan [Badr manufactory], for glass fiber rolls from E-glass fiber and carbon fiber bar we used from Carbon Sika wrap 300C material its properties show in table 3 and the resin matrix consist of polyester, Vinylester and epoxy resins.

Table 2: Concrete Proportions and Properties

f_{cu} (MPa)	w/c ratio	Cement (kg/m^3)	Coarse Aggregate (kg/m^3)	Fine Aggregate (kg/m^3)
300	0.5	335	1196	644
450	0.35	480	1150	541

Table 3: Properties of Fiber Reinforced Polymer Wrap GFRP

Fiber type	Thickness tj(mm)	Weight wj (g/m^2)	Density ρj (g/cm^3)	Young's modules Ej(MPa)	Tensile strength fju(MPa)
Carbon Fiber	0.117	300	1.79	240000	3900
Glass Fiber	0.17	445	2.56	65000	1700

4.3 Test instrumentation

The columns were tested using an incremental monotonic loading procedure. Digital load cell of capacity of 1500 KN and having accuracy of 0.1 KN was used to measure the applied load and the values were recorded by measure unit connected to the load cell. Three electrical strain gauges were used. Two were of mid height of the main reinforcement, and the other was at the middle of stirrup at distance equal half of depth from the support. As mentioned shows the position of the load cell and LVDT gauges for specimens

5 Results and Discussion

The main parameters included in this research were the main reinforcement types, the column height which we consider that columns 600 mm short column and 1000 mm consider long column, concrete compressive strength and the spiral stirrups behavior with different type of longitudinal reinforcement. The test results such as the recorded failure loads, the strains at the mid-span and deflections and the effect of loading type and other parameter are presented in Table 4.□□***exp*** is the experimental axial strain of columns.

Table 4- The load failure and Axial, horizontal displacement and axial strain of tested specimens

Type of Reinforcement Bars	f_{cu} (MPa)	h (mm)	Specimen Designation	At Failure			Axial Compressive Stress	□□exp	Stirrups Strain
				Failure Load (KN)	Axial Delta (mm)	Hz Delta (mm)			
Carbon Fiber Reinforced Bars	30	600	CCNS	709	3.614	4.29	39.39	0.881	0.0052
		1000	CCNL	632	4.7	5.11	35.11	0.469	0.0043
	45	600	CCHS	790	2.387	0.87	43.86	0.517	0.0043
		1000	CCHL	670.8	4.322	8.34	38.86	0.435	0.0032
Glass Fiber Reinforced Bars	30	600	CGNS	660	4.739	6.08	36.64	0.786	0.005
		1000	CGNL	553	5.3	8.32	30.68	0.529	0.0076
	45	600	CGHS	690	3.051	1.29	38.31	0.516	0.0071
		1000	CGHL	635	3.93	6.89	35.25	0.392	0.0045
Steel Reinforced Bars	30	600	CSNS	871.3	5.29	4.73	48.35	0.602	0.0047
		1000	CSNL	819.5	6.3	8.5	45.49	0.631	0.0013
	45	600	CSHS	926.8	3.971	1.8	51.87	0.766	0.0028
		1000	CSHL	851	5.46	6.9	47.21	0.546	0.0083

5.1 Stress-Strain Response of Column Specimens

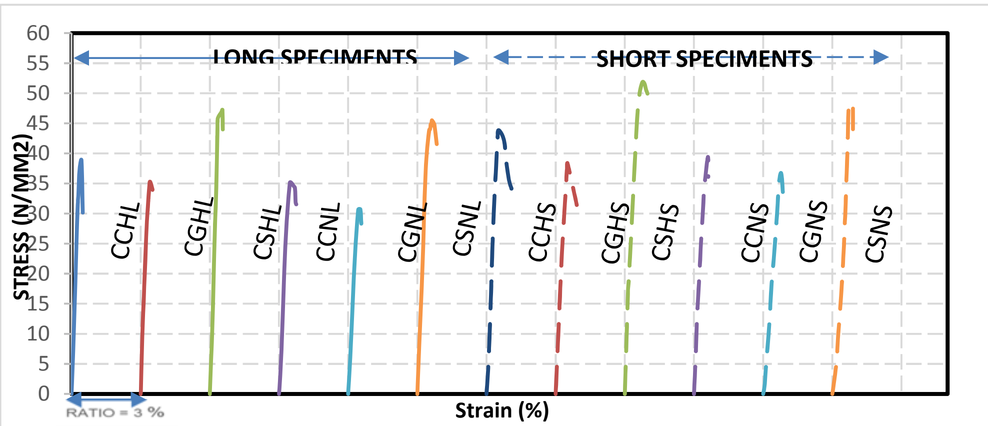

Figure 3: Overview Stress versus axial strain curves of all concentric loading specimens

The stress – strain curves as show in figure 3 of circular concrete columns specimens tested under concentric axial loading and manufactured with Normal strength Concrete and High strength Concrete.

Besides, the effect of concrete compressive strength on that behavior was also studied.

5.1.1 Stress–Strain Response of Normal Strength Concrete Columns

The experimental results present the axial compressive strength and axial strain for tested columns, at case of normal strength concrete it was found as demonstrated in the figure 3 that short columns CSNS, CCNS and CGNS sustained a compressive strength of 48.35, 39.39 and 36.64 MPa with corresponding axial strain of 0.60, 0.881 and 0.786 respectively. Also, long column specimens CSNL, CCNL and CGNL made with same previous concrete compressive strength a compressive strength of 45.49, 35.11 and 30.68 MPa with corresponding axial strain of 0.63, 0.469 and 0.52923, respectively. These results show that short columns axial strain more than long columns at cases of CFRP and GFRP columns with ratios 46.6% and 32.7 %, respectively. But short column axial strain in case of STEEL columns decrease with ratio 4.60 % compare with long column.

5.1.2 Stress–Strain Response of High Strength Concrete Columns

It was found as mentioned in the figure 3 that short columns CSHS, CCHS and CGHS sustained a compressive strength of 51.87, 43.86 and 38.31 MPa with corresponding axial strain of 0.766, 0.517 and 0.516 respectively. Also, long column specimens CSHL, CCHL and CGHL made with same previous concrete compressive strength a compressive strength of 47.21, 38.86 and 35.25 MPa with corresponding ultimate strain of 0.546, 0.432 and 0.392, respectively. These results show that short columns axial strain more than long columns at cases of STEEL, CFRP and GFRP columns with ratios 28.7%, 16.53 % and 23.9%, respectively.

In case of short columns if we compare between normal and high strength concrete columns we will found that in case of STEEL columns CSNS and CSHS we found increase in CSHS axial strain with ratio 27.28% compare with CSNS axial strain. In case of CFRP columns CCNS and CCHS we found decrease in CCHS axial strain with ratio 41.23% compare with CCNS axial strain. In case of GFRP columns CGNS and CGHS we found that decrease in CGHS axial strain with ratio 34.3% compare with CGNS axial strain. We can say that concrete compressive strength have a major effect in STEEL columns more than CFRP and GFRP columns.

In case of long columns if we compare between normal and high strength concrete columns we will found that in case of STEEL columns CSNL and CSHL we found decrease in CSHL axial strain with ratio 13.26 % compare with CSNL axial strain. In case of CFRP columns CCNL and CCHL we found decrease in CCHL axial strain with ratio 8.03 % compare with CCNL axial strain .In case of GFRP columns CGNL and CGHL we found that decrease in CGHL axial strain with ratio 25.74 % compare with CGNL axial strain.

5.2 Column Horizontal Displacement Response of Column Specimens

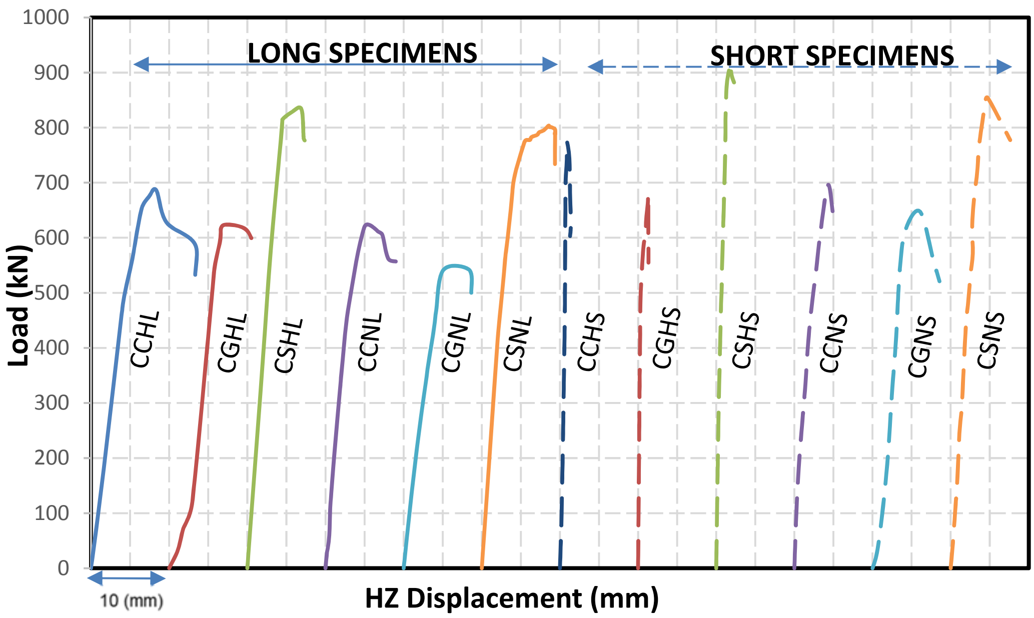

Figure 4: *Overview Loads versus Horizontal Displacement curves at concentric loading case*

As can be seen in Figure 4 the normal strength concrete specimens under concentric loading had load-carrying capacity more than that high strength concrete specimens under concentric loading.

5.2.1 Load-Horizontal Displacement Response of Normal Strength Concrete Columns

For normal strength concrete specimen, the axial load versus mid Span displacement curve was linear until the yield load was reached. This linearity was followed by a sudden drop, leading to crushing the concrete in the compression region the specimens deflected extensively before failure occurred.

Figure 4 shows loads versus horizontal displacement curves for short loaded Specimens CSNS, CCNS and CGNS. The slopes of the axial load versus deflection were ascending until reaching the ultimate load. Due to crushing of concrete, the load-carrying capacity of the specimens decreased slightly with corresponding horizontal displacement of 4.73, 4.299 and 6.08 mm, respectively.

Also, long column specimens CSNL, CCNL and CGNL with corresponding horizontal displacement of 8.54, 5.11 and 8.31 mm, respectively. These results show that long column have horizontal displacement values greater than short column specimens at cases of STEEL CFRP and GFRP columns by 79.7%, 19.1% and 36.6%, respectively. These results may be attributed to fiber characterize and concrete type. After the cracking of concrete at mid-height, there was a steep drop in the load-carrying capacity of the specimens to failure. Max horizontal displacement of Specimens CSNS, CCNS and CGNS won't exceed 6 mm before failure of the specimens.

In general we found that the axial Load-horizontal displacement curves for both short columns CSNS, CCNS, CGNS and long columns CSNL, CCNL, CGNL have almost similar behavior. But the difference between both was that long columns after achieving the ultimate load, the load-capacity of the long columns curve decreased quicker than that of the short columns load-capacity curve.

5.2.2 Load-Horizontal Displacement Response of High Strength Concrete Columns

For High strength concrete columns, as shown in Figure 4, the axial load versus horizontal displacement curves was linear until the yield load was reached. Horizontal displacement of short columns CSHS, CCHS and CGHS was 1.8, 0.87 and 1.29 mm, respectively. At the case of long columns it was found that horizontal displacement of columns CSHL, CCHL and CGHL with corresponding horizontal displacement of 6.9, 8.34 and 6.89 mm, respectively.

In case of short columns in comparison between normal and high strength concrete columns we found that in case of STEEL columns CSHS and CSNS we found decrease in CSHS horizontal displacement with ratio 61.9% compare with CSNS horizontal displacement. In case of CFRP columns CCNS and CCHS we found decrease in CCHS horizontal displacement with ratio 79.7 % compare with CCNS horizontal displacement. In case of GFRP columns CGNS and CGHS we found that decrease in CGHS horizontal displacement with ratio 78.7 % compare with CGNS horizontal displacement.

In case of long columns if we compare between normal and high strength concrete columns we will found that in case of STEEL columns CSNL and CSHL we found decrease in CSHL horizontal displacement with ratio 18.8 % compare with CSNL horizontal displacement. In case of CFRP columns CCNL and CCHL we found increase in CCHL horizontal displacement with ratio 63.2 % compare with CCNL horizontal displacement. In case of GFRP columns CGNL and CGHL we found that decrease in CGHL horizontal displacement with ratio 17% compare with CGNL horizontal displacement.

Finally we should say that concrete compressive strength have obvious big role on the columns horizontal displacement.

5.3 Stirrups Strain of Column Specimens.

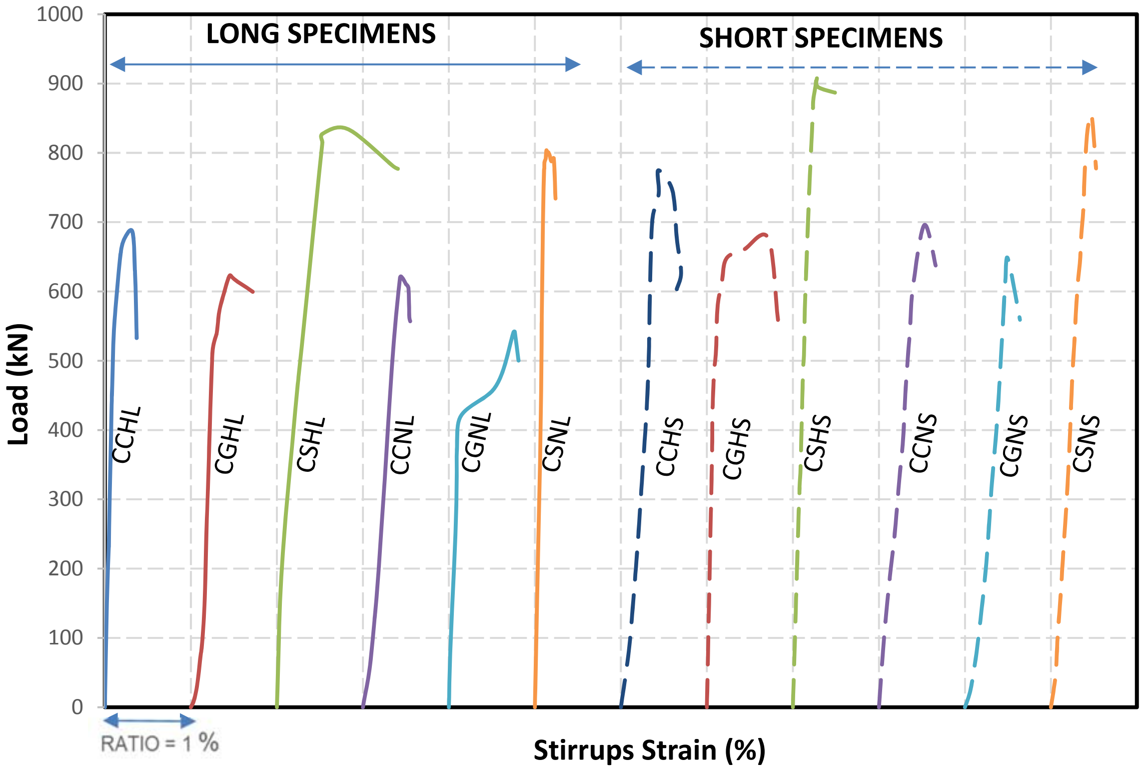

Figure 5: *Overview Loads versus Stirrups Strain curves of all concentric loading specimens*

5.3.1 Load-Stirrups Strain Response of Normal Strength Concrete Columns

This behavior of stirrups demonstrated in the load–strain curves figure 5. For short columns CSNS, CCNS and CGNS have corresponding stirrups strain 0.00475, 0.00528 and 0.005, respectively. Also, long columns CSNL, CCNL and CGNL have corresponding stirrups strain 0.00134, 0.00433 and 0.00765, these results show that long columns stirrups strain values more than short columns stirrups strain in cases of STEEL and CFRP columns by 71.7% and 17.9 % respectively. In case of GFRP columns the long columns stirrups strain values less than short columns stirrups strain with ratio 53 %.

5.3.2 Load-Stirrups Strain Response of High Strength Concrete Columns

Experimental study show the behavior in case of using high strength concrete we found that the stirrups strain of columns CSHS, CCHS and CGHS was 0.0028, 0.00435 and 0.00714 respectively. Also, long columns CSHL, CCHL and CGHL have stirrups strain 0.0083, 0.0032 and 0.0045, respectively.

In case of short columns if we compare between normal and high strength concrete columns we will found that in case of STEEL columns CSNS and CSHS we found decrease in CSHS stirrups strain with ratio 41% compare with CSNS stirrups strain. In case of CFRP columns CCNS and CCHS we found decrease in CCHS stirrups strain with ratio 17.6 % compare with CCNS stirrups strain .In case of GFRP columns CGNS and CGHS we found that increase in CGHS stirrups strain with ratio 42.8 % compare with CGNS stirrups strain. We can say that concrete compressive strength have a major effect with normal strength columns more than high strength concrete columns and in GFRP columns more than STEEL and CFRP columns.

In case of long columns if we compare between normal and high strength concrete columns we will found that in case of STEEL columns CSNL and CSHL we found increase in CSHL stirrups strain with ratio 519.4% compare with CSNL stirrups strain. In case of CFRP columns CCNL and CCHL we found decrease in CCHL stirrups strain with ratio 26.1% compare with CCNL stirrups strain .In case of GFRP columns CGNL and CGHL we found that decrease in CGHL stirrups strain with ratio 41.1% compare with CGNL stirrups strain. We can say that concrete compressive strength have a major effect in GFRP columns more than STEEL and CFRP columns.

6. Theoretical analysis

Nowadays, the Canadian code CSA S806-12 permits the use of FRP bars as longitudinal reinforcement in columns subjected to axial load only, ignoring the contribution of FRP bars in the ultimate capacity of the columns, as shown in Equation1. Study used two other equations (Equations 2 and 3) to predict the nominal axial capacity of the GFRP RC columns (M.Zaki et al. 2013). Equation 2 presents the ACI 318-11 design equation, ignoring the contribution of the GFRP bars and using the 0.85 reduction factor. Equation 3 was introduced to account for the contribution of GFRP bars using the reduction factor (α_g):

$$P_o = \alpha_1 f_c'(A_g - A_F) \qquad \text{Equation 1}$$

$$P_o = 0.85 f_c' \ (A_g - A_F) \qquad \text{Equation 2}$$

$$P_o = 0.85 f_c' \ (A_g - A_F) + \alpha_g f_{fu} A_F \qquad \text{Equation 3}$$

Where $\alpha_1 = 0.85 - 0.0015 f_c' \geq 0.67$. A new factor ($\alpha_g$) was introduced to account for the reduction in the compressive strength of the GFRP bar as function of its tensile strength. This factor was assumed to be equal to 0.35 based on the data in the literature (Tobbi et al. 2012; Kobayashi and Fujisaki 1995). Figure 6 presents the ratios of experimental

It was found that the ratios of the experimental maximum load to predicted values (P_{max} / P_o) using Equation 3 ranged from 0.98 to 1.08. These values indicate that this equation provided accurate and conservative predictions of the nominal capacity of the GFRP RC columns. Ignoring the contribution of the FRP longitudinal bars in Equations1 and 2 underestimated the maximum capacity on average by 35% and 25 %, respectively.

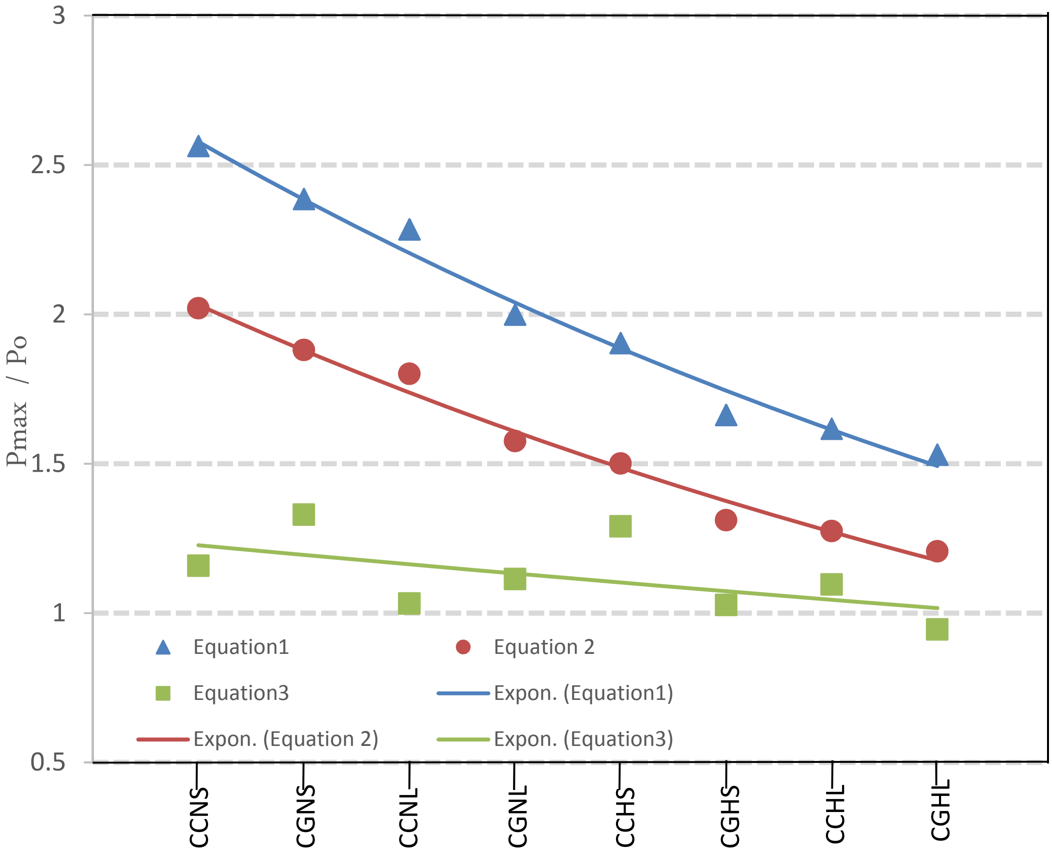

Figure 6: Experimental loads to predicted values for the CFRP and GFRP RC columns

Figure 6 insure that using the factor (α_g) in the equation 3 give exact results for fiber columns design.

7. Conclusion:

The experimental results from 12 reinforced concrete columns demonstrate the influences of the main reinforcement type, effect of column height with different types of reinforcement type and effect of increasing strength of concrete on the ultimate loads. Ultimate strain and initial cracking loads mentioned based on the experimental results presented in this study the following conclusions illustrate the results:

- In short columns the axial load of the GFRP RC columns were on average 24.9% lower than their steel RC counterparts. While, the CFRP RC columns resulted axial load on average 16.6 % lower than their steel RC specimens.
- In long columns the axial load of the GFRP RC columns were on average 28.9% lower than their steel RC counterparts. While, the CFRP RC columns resulted axial load on average 22.1 % lower than their steel RC specimens.

- For normal strength concrete columns at concentric load, short columns have good behavior in the axial load which reach in case of CFRP RC columns to 81.4% from steel axial load and reach in case of GFRP RC columns to 75.7% from steel axial load but for long columns it reach in case of CFRP RC columns to 77.13% from steel axial load and reach in case of GFRP RC columns to 67.5% from steel axial load
- For high strength concrete columns at concentric load, short columns have good behavior in the axial load which reach in case of CFRP RC columns to 85.3% from steel axial load and reach in case of GFRP RC columns to 74.5% from steel axial load but for long columns it reach in case of CFRP RC columns to 78.8% from steel axial load and reach in case of GFRP RC columns to 74.6% from steel axial load
- Since GFRP reinforcement is more economical than CFRP bars, it is more attractive and recommended to be used in field applications.

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