Journal of Materials and Engineering Structures

Research Paper

# Experimental Behavior and Analysis of Hybrid Low-High Strength Reinforced Concrete Columns

*Taghreed Kh. Mohammed Ali **

*Department of Architecture, Faculty of Engineering, Koya University, Koya KOY45, Kurdistan Region – F.R. Iraq*

ARTICLE INFO

*Article history :*

Received : 23 March 2020

Revised : 1 June 2020

Accepted : 3 June 2020

Keywords:

Column

Eccentricity

High strength concrete

Hybrid section

ABSTRACT

In this paper, the behavior of hybrid short columns made from low strength reinforced concrete core and an outer skin made from high strength concrete was studied. For this purpose, laboratory tests were carried out on ten small-scale column specimens. For bonding, the outer skin portion to the main column epoxy resin was used. Results revealed that bonding low strength concrete core with high strength outer skin was successful and able to produce a hybrid section. For the same section area, load capacity increased by 28% to 80% depending on the compressive strength of the provided outer skin, for concentrically loaded columns. In general, the behavior of eccentrically loaded hybrid specimens was good, indicating that the process of making hybrid columns according to the technique presented in this paper is successful and can be used in practice.

## 1 Introduction

A number of column strengthening techniques, such as steel jacketing, use of composite materials jackets, and jacketing with additional reinforced concrete, have been investigated by many researchers[1-4] and have been used in practice as reported by Yashinky [5]. Also, square columns were confined with ultra-high-strength steel reinforcement with yield strength of 1430 N/mm$^2$ as lateral reinforcement and with ordinary-strength steel reinforcement of yield strength of 404 N/mm$^2$ as longitudinal reinforcement by Sato and Yamaguchi [6]. The influence of the lateral confinement on the compressive strength of concrete by taking different values of the parameters of volume ratio of hoops to the confined volume of column core, yield strength of transverse reinforcement, compressive strength of concrete, a spacing of hoops, longitudinal reinforcement, and hoop pattern was studied by Khaleek et al. [7]. Square columns were confined using welding grids of different volumetric ratios, spacing, and arrangement of welded reinforcement grids by Saatcioglu and Grira [8].

---

* *Corresponding author. Tel.:* +964771428729.
E-mail address: taghreed.khaleefa@koyauniversity.org

e-ISSN: 2170-127X,

RESEARCH REVIEW of Sciences and Technologies

Fiber-reinforced polymer composite tubes were used for the confinement of concrete by many researchers with performing experimental studies. Confined concrete columns having different length/diameter ratios were tested by Mirmiran and Sahaway [9]. Tao et al. [10], Fitzwilliam and Bisby [11] and Bisby and Ranger [12] tested fiber-reinforced polymer -confined RC columns with a length/diameter ratio up to 20. In addition, De Lorenzis et al. [13] and Tamuzs et al. [14-15] tested slender fiber-reinforced polymer -confined concrete columns without steel reinforcement subjected to concentric compression to investigate the solidity of these columns. The concrete column was strengthened by using the Un-plasticized Poly-Vinyl Chloride tube as an outer confining layer in order to increase the load-carrying capacity, ductility, and durability of a column by Gupta [16].

Mohammed Ali et al. [17] studied the effect of usage reactive powder concrete (RPC) and carbon fiber-reinforced polymer (CFRP) as a retrofitting method for axially loaded short reinforced concrete columns. They found that retrofitting columns by (RPC+CFRP) is stiffer than retrofitting columns with RPC only. The ultimate loads of retrofitted columns with (RPC) and (RPC+CFRP) are more than those of normal reinforced concrete short columns, and the failure happened at or nearby to the ultimate loading with little residual capacity for the two retrofitting methods.

Perceka et al. [18] studied the effect of utilizing steel fibers and ordinary transverse rebar as hybrid reinforcement for strengthening high strength concrete columns. Their results showed that the effectiveness of steel fibers was depended on the spacing of reinforced transverse bars, and the steel fibers are more efficient when the spacing of transverse bars was in the limit of (0.25–1) of column’s effective depth. Mirmiran et al. [19] conducted a study on the slenderness bounds for uniaxial loaded hybrid columns made of concrete-filled FRP tube. Where the slenderness limits varied from 4 to 36. They found that strength is decreased through up to 71% of the corresponding short column, and the transverse and axial strains are decreased by 87% and 85% respectively. Taranu et al. [20] studied reinforced concrete columns confined by carbon FRP films subjected to uniaxial loading. Their results showed that the uniaxial loaded columns failed in the compressing zone, and the failure of these columns is depended on FRP films' rupture.

Mohammed Ali et al. [21] conducted research on the performance of axial short RPC columns confined with CFRP. All tested columns had a square cross-section of 100 mm × 100 mm and a length of 400 mm. They studied the effect of the number of CFRP's layers and normal reinforcing steel bars on the confining of columns. Their results showed that the increase of stiffness of confined columns by CFRP. The ultimate load of the RPC columns that contained 2% micro steel fiber and minimum normal reinforcement with two layers of CFRP was 1.333 more than the RPC columns that contained 2% micro steel fiber and minimum normal reinforcement.

Balanji [22] conducted a study on the performance of columns made by high strength concrete and strengthened by, macro steel fibers, micro steel fibers and hybrid steel fibers that subjected to various loadings (axial load, uniaxial load and pure bending moment). He found that using hybrid steel fibers and micro steel fibers can improve ductility and strength for columns subjected to uniaxial loads. While using macro steel fibers can be improved the ductility and decrease the strength.

Resheq [23] studied the influence of the ratio of external to internal diameter for the axially loaded concrete columns that compound of normal concrete (NC) and self-compacted concrete (SCC). His results indicated that the carrying capacity of columns augmented by 70% if the internal diameter of NC reduced and the external diameter of SCC were increased. This increasing ratio was 20% if the internal diameter of SCC reduced and the external diameter of NC augmented.

Wang et al. [24] investigated the concrete column consists of concrete core confined by glass FRP (GFRP) tubes, external concrete, and stirrups. Their results indicated that the mode of failure of these columns is tension rupture of the GFRP tube if both stirrups and external concrete used or not. Where, the ductility and strength increased by 500% and 20% respectively.

Investigation on the possibility to employ the same concrete of high strength is necessary as an alternative method to improve the retrofitting process for a vast number of existing structurally deficient RC columns throughout the world.

In this paper, a technique was presented to fabricate a hybrid section made from low strength reinforced concrete core and high strength concrete for the outer skin. The specimens were tested as a column. Some specimens were tested under eccentric loading. The behavior of such hybrid section columns was fairly studied in the present research. A model was presented to calculate the load-deformation relationship of hybrid square columns subjected to concentric loading. Theoretical predictions were compared with the test data and the influence of important parameters was discussed.

## 2 Research significance

Developments occurred in the aspect of construction technology resulted to use new structural sections to resist different types of stresses, not been utilized using conventional concrete. Structural sections made from more than two materials may have a promised future. Producing reinforced concrete sections consisting of two types of concretes in a form of precast units in the concrete factories is an important task but the properties of such new concrete material should be assessed and studied well trough laboratory tests. Different structural properties of the precast units made from hybrid materials and their response should be understood when they subject to different types of loads or moments. Other forms of hybrid section are the case of strengthening any existing low strength structural member with externally provided layers of higher strength concrete. The behavior of hybrid low-high strength concrete columns was fairly studied in this paper, but this is an attempt and not sufficient. Before practical applications of this type of concrete, many researches should be carried out to learn more about various structural properties of this type of concrete.

## 3 Investigation scheme

### *3.1 Ingredients and mixture proportion*

Ordinary Portland cement manufactured by Tasluja cement factory-Iraq was utilized. Clean river sand locally available, with medium grading and specific gravity equal to 2.75, passed by 100% on 3.75 mm sieve was used in this study. The coarse crushed aggregate of maximum size equal to 10 mm for high strength concrete mixes and of maximum size equal to 20 mm for low strength concrete mixes was utilized. Steel reinforcement bars of 8 mm diameter and of yield stress equal to 420 MPa were used. High range water reducer (superplasticizer) of Glenum ACE 30 type was used for high strength concrete mixes. Epoxy resin of 32 Hi types was used for bonding the two concretes; the properties of used epoxy resin can be seen in Table 1 which is gotten from [25]. Mix proportions of concretes utilized in the present study are shown in Table 2.

**Table 1: The properties of used epoxy resin**

| **Components of epoxy resin** | **Performance Criteria** | |
|---|---|---|
| | **Properties of the mixed epoxy resin adhesive** | **Properties of the cured epoxy resin adhesive** |
| Component A" shall be a modified epoxy resin of the epichlorohydrin bisphenol A type containing suitable viscosity control agents. | 1. Pot Life: 30 minutes (60 gram mass) at 73F | 1. Compressive Properties (ASTM D-695) at 28 days<br>a. Compressive Strength: 12,200 psi (84.1 MPa) |
| Component B" shall be primarily a reaction product of a selected amine blend with an epoxy resin of the epichlorohydrin bisphenol A type containing suitable viscosity control agents, pigments and accelerators. | 2. Tack-Free Time to Touch (3-5 mils): 3-5 hours | 2. Tensile Properties (ASTM D-638) at 7 days<br>a. Tensile Strength: 6,900 psi (48 MPa)<br>b. Elongation at Break: 1.9%<br>c. Modulus of Elasticity, 14 day : 540,000 psi (3,723.3 MPa) |
| The ratio of Component A": Component B" shall be 1:1 by volume | 3. Initial Viscosity (Brookfield Viscometer, Spindle #3; Speed 100) : 3,000 cps | 3. Flexural Properties (ASTM D-790) at 14 days<br>a. Flexural Strength: 7,00 psi (48.3 MPa)<br>b. Tangent Modulus of Elasticity in Bending: 690,000 psi (4,800 MPa) |
| | 4. Color: Concrete gray | 4. Shear Strength (ASTM D-732) at 14 days: 6,200 psi (43 MPa) |
| | | 5. Total Water Absorption (ASTM D-570) at 7 days: 0.21% ( 2 hour boil, 24 hour) |
| | | 6. Bond Strength (ASTM C-882)<br>a. Hardened Concrete to Hardened Concrete<br>(1) 2 day (dry cure): 2,000 psi (13.8 MPa)<br>(2) 14 day (moist cure): 2,000 psi ( 13.8 MPa) |
| | | 7. Deflection Temperature (ASTM D-648) at 14 days: 122F (fiber stress loading = 264 psi) |

**Table 2: Proportion of Material**

| **Mixing no.** | **Mixing Proportion** | **Quantity of Cement kg/m3** | **w/c Ratio** | **Super-plasticizer L/m3** | **Design Compressive Strength[MPa]** |
|---|---|---|---|---|---|
| 1 | 1:2.5:5 | 274 | 0.55 | 0 | 20 |
| 2 | 1: 1.5 :3 | 428 | 0.35 | 4.3 | 40 |
| 3 | 1:1.25:1.75 | 579 | 0.30 | 5.8 | 60 |

### *3.2 Test program*

A total of ten square RC columns were cast and tested in the present study, two specimens were tested as control specimens. Column specimens were divided into two groups depending on the cross-section dimension (Figure 1). Every group consists of four-column specimens. Two of them were strengthened using an HSC layer of constant thickness equal to 15 mm and two different strengths of 40 and 60 MPa, provided around the external perimeter of the control specimen. Six specimens were tested under uniaxial load and the remained were tested under load with an eccentricity ratio (e/h) equal to 0.083. The way of nomination specimens is as follows. Starting from left, the first letter is C denotes the column. The second part is number 12 or 15 which means composite cross-section dimension 120 mm or 150 mm. The third part is number 40 or 60 which means the outer skin concrete strength, the last letter E is for those specimens loaded with eccentric loading. The Concrete compressive strength of all control column specimens was constant and was 20 MPa. For concrete compressive strength 100 mm cubes were cast for each mix batch.

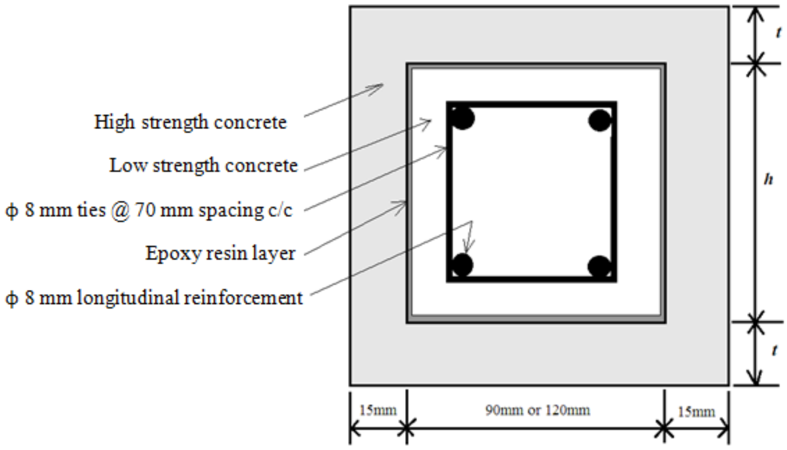

*Fig. 1- Dimensions and details of hybrid section*

### *3.3 Specimens preparation*

The column specimens were cast horizontally in a wood mold of 750 mm length. The interior surface of the mold was thoroughly oiled before casting. Firstly, the reinforcement cage consists of four longitudinal bars and lateral ties arranged at 70 mm spacing shown in Figure 2 were put inside the mold. Concrete mixes were mixed by using an electric concrete mixer. Cement and fine aggregate were mixed in a dry form until uniformity was achieved and lastly coarse aggregate was added. Then, water containing super-plasticizer (in high strength concrete mixes) was sprinkled and mixed thoroughly until a uniform mix was obtained. The concrete was then placed at three layers of equal thickness, and each layer was compacted by hand compaction. The specimens were de-molded after 24 h, then they were roughened and a layer of epoxy was provided on four edges of the specimens. After (5-30) minutes depending on laboratory temperature degree, specimens were put in a larger mold, then concrete was placed and compacted at three equal layers for four sides. After 24 hours, the mold was removed and the specimen was put in a water tank for curing till the age of testing (28 days). Thus, the thickness of the confinement layer was 15 mm around the specimen perimeter. The ratios of slenderness in terms (length /least cross-section) were 6, 25 and 5 for the tested two groups. Table 3 shows the specimen's details and Figure 3 shows one hybrid column ready for curing.

*Figure 2 Steel reinforcement cages and the mold*

*(a)* *(b)*

*Figure 3: Column specimen after casting, (a) inside the mold, (b) outside the mold*

**Table 3: Details of specimens and test and calculated ultimate load of hybrid columns**

| Beam | Section dimensions [mm] | e/h | Cube compressive strength(Outer skin) [MPa] | Test $P_u$ [kN] | Calculated $P_u$ [kN] | Test/Calculated $P_u$ |
|---|---|---|---|---|---|---|
| C12 | 120 x 120 | 0 | - | 250 | 218.1 | 1.15 |
| C12-40 | = | 0 | 42 | 320 | 328.7 | 0.97 |
| C12-40E | = | 0.083 | 42 | 254 | - | - |
| C12-60 | = | 0 | 62 | 450 | 379.8 | 1.18 |
| C12-60E | = | 0.083 | 62 | 410 | - | - |
| C15 | 150 x 150 | 0 | - | 430 | 326.9 | 1.32 |
| C15-40 | = | 0 | 42 | 540 | 470.7 | 1.15 |
| C15-40E | = | 0.167 | 42 | 375 | - | - |
| C15-60 | = | 0 | 62 | 560 | 534.5 | 1.05 |
| C15-60E | = | 0.167 | 62 | 390 | - | - |
| Mean | | | | | | 1.14 |

### *3.4 The test*

Specimens were loaded under the universal testing machine shown in Figure 4. Two dial gauges were used for measuring axial and lateral deformations. The load was applied in small increments under displacement control. Visual observation was made throughout the test. Each sample took 15-20 minutes for testing on an average. The column specimens were tested under two situations of loads. Concentric load and load with eccentricity (e/h) equal to 0.083 for 120 x 120 mm specimens and 0.167 for 150 x 150 mm specimens. Figure 4 shows a one-column sample that prepared for the test.

***Figure 4: A one-column sample that prepared for the test***

## 4 Results and discussion

Test results of the concrete specimen’s compressive strength and column’s load capacity are shown in Table 3. Figure 5 through 8 illustrates the load-deformation relationship for axially loaded columns. In general, the mode of failure for column specimens was concrete crushing, and the de-bonding of high strength concrete skin and low strength core was not observed. Indicating that the bond which delivered by the epoxy layer between the two concretes is excellent. The mechanism of this type of bonding can be illustrated. The high bond strength regarded as both chemical and mechanical bonding. The nature of mechanical bonding can be known from Figure 9 which illustrates a hybrid material subjected to tensile force and shear force. The low strength core of one-day-old after saturating with epoxy resin can absorb some amount of epoxy material resulted to produce a rough surface between them (as shown in figure 9) and as a result, the mechanical bond is high. However; since the outer skin is provided at flesh state to the epoxy resin the two materials are connected in the fresh state a slowly harden together. As a result, the interaction between the two surfaces increases and the mechanical bond will be higher as illustrated from Figure 9. Depending on the study of the gotten experimental data, the success of the procedure that used for making a compound section using epoxy resin for the connexion can be evaluated. Hybrid columns showed the compound act closely till the failure and in some of the tested composite columns, afterload ability was got.

From the results of Table 3, the ratio of load capacity of the C12-40 sample to C12 is 1.28, indicating that there is 28% increase in the ultimate load as a result of providing the outer skin. This ratio is considerably useful for an outer skin of only 40 MPa compressive strength. For the 60 MPa outer skin, the load capacity was increased by 80% and this ratio is fairly important for practical applications. It should be noted that for the first group of specimens (120x120 mm) the ratio of the skin area to the core area is 77.8%. The ratio of load capacity of the C12-40E column to that of the control specimen is 1.0 and that for the C12-60E column is 1.64 indicating that using this type of hybrid columns is useful for the case of eccentric loading, and able to resist bending moment in addition to the axial load successfully.

With regard to the larger section specimens (150x150 mm dimensions), the performance of the hybrid section is slightly lower compared with the smaller section specimens, because the ratio of the outer skin area for this case is only 56.3%. This area is considerably smaller than 77.8%. Figure 10 illustrates the role of the area of outer skin for making a hybrid section. It is obvious that the compressive strength of the skin is quite important for the load capacity, and when the area is increased for any skin with higher strength the resulted load enhancement will be increased considerably. Thus, it is recommended to provide the outer skin with moderated thickness but with higher compressive strength to obtain a strong hybrid section for both cases of concentric and eccentric loading.

Comparing the present results with the findings of Resheq [23] who used a different way to get hybrid columns via utilizing a steel tube; were his results showed an increase of 26% of ultimate load when the ratio of the outer skin to the inner core of cross-section is 2 which be less efficient, tricky and more expensive than the present study. Also, it can be seen that using the CFRP and epoxy resin in [21] led to increasing the loading capacity by 33% compared with the increase of 28% and 80% at the current study; where the procedure of [21] is more costly than the used technique in this study. While the usage of RPC and CFRP together for getting hybrid columns [17] had been led to just a 29.5% increase of ultimate load which was also more costly and less effective than the technique in the present study.

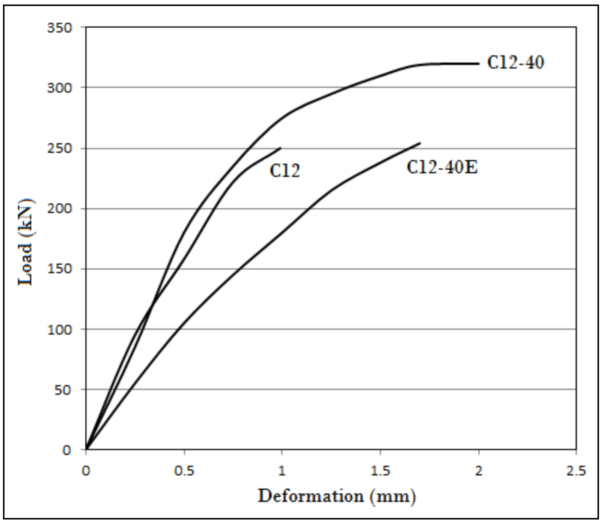

*Figure 5: Load-deformation relationship of column samples*

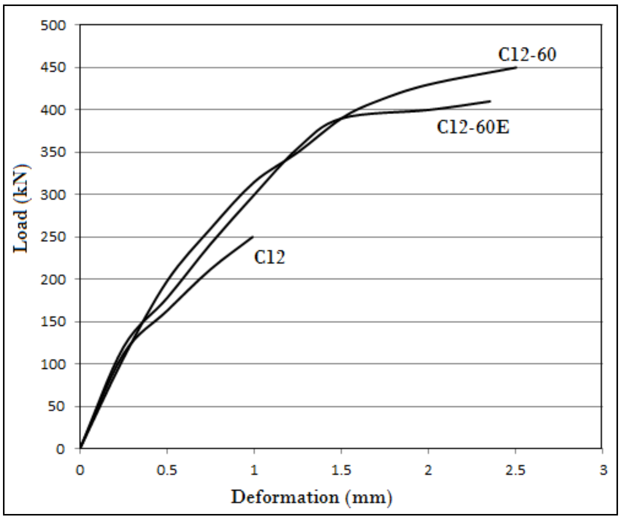

*Figure 6: Load-deformation relationship of column samples*

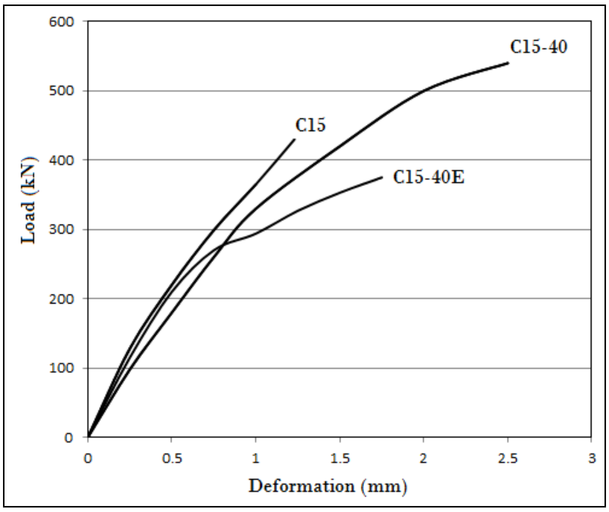

*Figure 7: Load-deformation relationship of column samples*

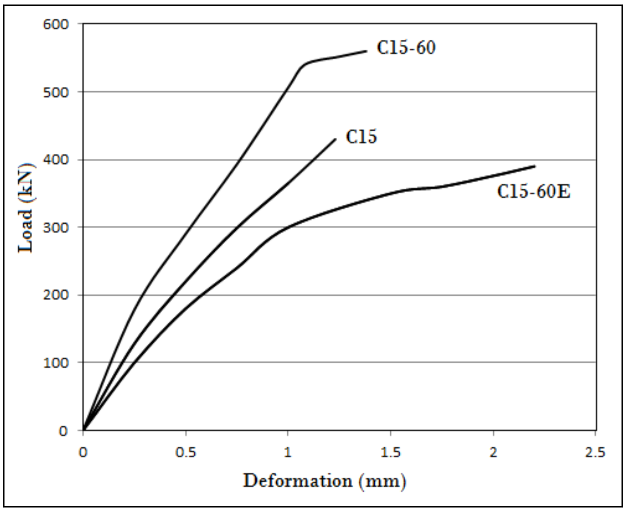

*Figure 8: Load-deformation relationship of column samples*

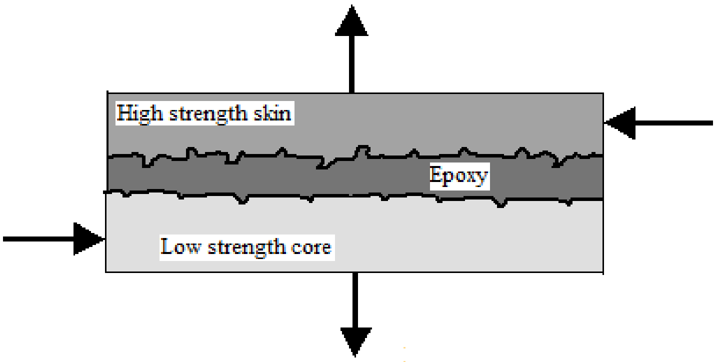

*Figure 9: Mechanism of load resisting hybrid epoxy-concrete material*

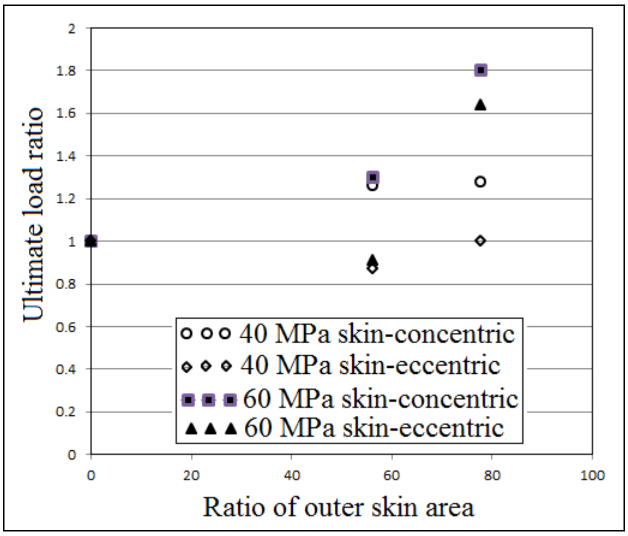

*Figure 10: Variation of ultimate load ratio with the ratio of outer skin area*

## 5 Analysis

Now, an attempt is made to develop a simple model for calculating the load-deflection relationship of a hybrid column subjected to uniaxial loading, from which the ultimate load capacity can be known. For simplifying the analysis the following assumptions are made

a- The hybrid column is considered to be a short column.

b- There is a complete bond among steel reinforcement, low strength concrete core and high strength outer skin, and accordingly, all materials were subjected to the same axial strain, or strain compatibility condition is valid.

c- The outer skin consists of moderate thick walls able to resist axial compressive stress.

d- The column is assumed to fail with concrete crushing or steel yielding and other types of failure will not occur.

### *5.1 Materials Idealization*

In order to present a model for predicting the complete load-deformation relationship of the concentrically loaded column, the compressive stress-strain relationship of the constitutive materials (low strength concrete, high strength concrete, and steel) must be known. Figure 11 shows the idealized compressive stress-strain relationship. For the low strength concrete core, the equation of the compressive stress-strain relationship can be given by:

$$f_{c1} = fc'\left[2\left(\frac{\varepsilon}{\varepsilon_0}\right)-\left(\frac{\varepsilon}{\varepsilon_0}\right)^2\right] \qquad (1)$$

In which $f_{c1}$ is the compressive stress of low strength core, $f_c'$ is the compressive strength, $\varepsilon$ is compressive strain and $\varepsilon_o$ is the strain corresponding to peak compressive stress.

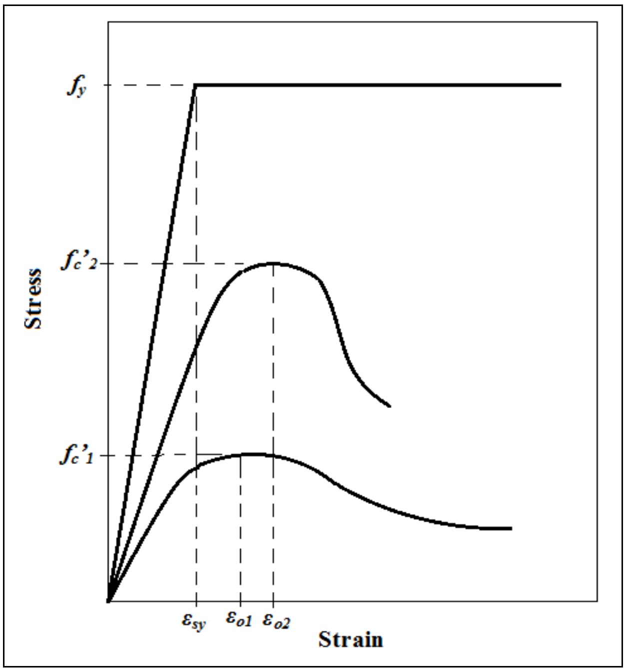

***Figure 11: Idealized compressive stress-strain relationships for steel, high strength concrete and low strength concrete***

For the outer skin, compressive stress-strain relationship which used for high strength concrete is used and given by [26]

$$f_{c2} = fc'\left[\frac{\beta\left(\dfrac{\varepsilon}{\varepsilon_0}\right)}{\beta-1+\left(\dfrac{\varepsilon}{\varepsilon_0}\right)\beta}\right] \tag{2}$$

In which $f_{c2}$ is the compressive stress of high strength concrete, β is a parameter given by

$$\beta = \frac{1}{1-\left(\dfrac{fc'}{\varepsilon_0 E_{it}}\right)} \tag{3}$$

$E_{it}$ is the tangent elastic modulus given by

$$E_{it} = 22000\left(\frac{fc'}{10}\right)^{0.3} \tag{4}$$

The strain at peak stress is given by

$$\varepsilon_0 = (1680 + 7.1fc')10^{-6} \tag{5}$$

For the elastic range of steel, stress is given by

$$f_s = E_s\varepsilon \tag{6}$$

### *5.2 Procedure for Analysis*

The following calculation steps are required to obtain the load-deformation relationship of the hybrid square column concentrically loaded.

1- Assume an initial small value of strain, ε.
2- Calculate compressive stresses, $f_{c1}$, $f_{c2}$ and $f_s$.
3- Calculate loads $P_{c1}$, $P_{c2}$, and $P_s$ as follows:

$$P_{c1} = f_{c1}h^2$$

$$P_{c2} = f_{c2}\left[4t\left(h+t\right)\right]$$

$$P_s = A_s f_s$$

$$P = P_{c1} + P_{c2} + P_s$$

$\Delta = \varepsilon$ L

$\Delta$ is axial deformation and is the column height.

4- Check the limit of $\varepsilon < \varepsilon_{sy}$. For $\varepsilon \geq \varepsilon y$ the stress in steel will be $f_s = f_y$

5- Increase $\varepsilon$ and repeat the calculation,

The calculated ultimate load based on the procedure presented above was made for concentrically loaded columns and compared with the test ultimate load to check the accuracy of the analysis. Table 3 shows the results of calculated and test the ultimate load for the six-column. It is shown that the test/calculated ultimate load ratio varies between 0.97 and 1.32 indicating that the analysis is safe and moderately accurate. The mean value of the test/calculated ultimate load capacity is 1.14. This value can be considered useful for the analysis and design of hybrid sections with a reasonably good safety factor. Figs. 12 and 13 show a load-deformation relationship for the two groups of the column.

The procedure discussed above is simple and accurate and can be used for the design of hybrid concentrically loaded columns.

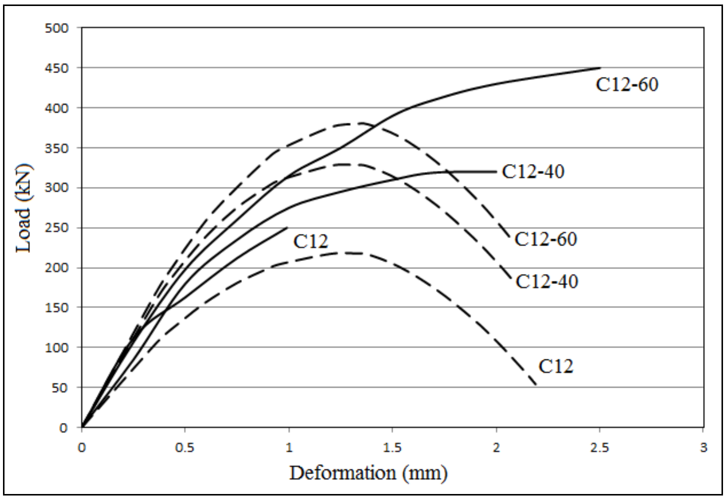

*Figure 12: Test versus calculated load-deformation relationship of columns.*

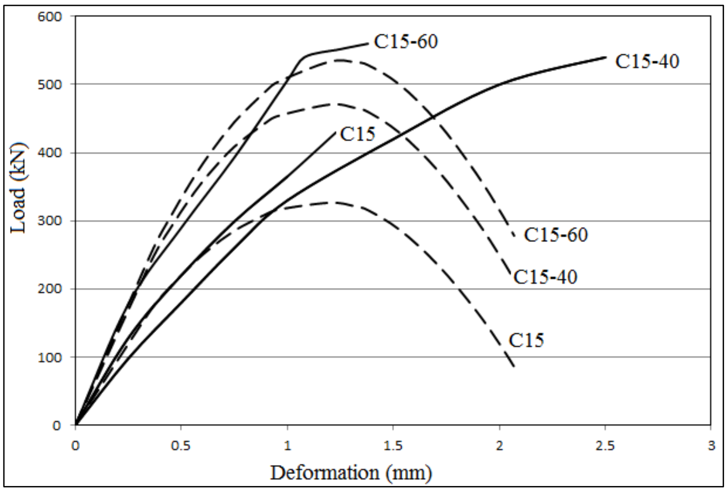

*Figure 13: Test versus calculated load-deformation relationship of columns.*

## 6 Conclusions

In this research, it is found that there is a good chance to fabricate hybrid section and used as columns based on bonding low strength concrete to high strength outer skin using epoxy resin following the technique discussed in this paper. Where Load capacity of the hybrid column is fairly high and the ratio was found to be 1.28 to 1.8 of the control column. The area of confinement has a significant role in increasing the carrying capacity of columns. The increasing load capacity was also dependent on the state of loading if axial or uniaxial. Also, it is seen that the strength of outer skin has an important effect on the strength of outer skin. As well as, the load capacity of the hybrid column can be calculated from simple steps presented in this research and the calculated load is fairly accurate with a test/calculated load equal to 1.14.

### Acknowledgments

The author would like to express appreciation and thanks to the concrete laboratory staff of Sulaimani University for their supporting throughout testing concrete specimens especially Dr. Azad, Eng. Aso, Eng. Muhammed, Eng. Eveen. Eng. Eiwara, and Eng. Esmaeel.

## REFERENCE

[1]- J. Masukawa, H. Akiyama, H. Saito, Retrofitted of Existing Reinforced Concrete Piers by Using Carbon Fiber Sheet and Aramid Fiber Sheet. In: Proceedings of the Third International Symposium on Non-Metallic (FRP) Reinforcement for Concrete Structures, October 1997, pp.411-418.

[2]- M.J.N. Priestley, F. Sieble, Y. Xiao, R. Verma, Steel Jacket Retrofitting of Reinforced Concrete Bridge Columns for Enhanced Shear Strength - Part II: Test Results and Comparison with Theory. ACI Struct. J. 91(5) (1994) 537-551.

[3]- M. Rodriquez, R. Park, Seismic Load Test on Reinforced Concrete Columns Strengthened by Jacketing. ACI Struct. J. 91(2) (1994) 150-159.

[4]- H. Saadatmanesh, M.R. Ehsani, M.W. Li, Strength and Ductility of Concrete Columns Externally Reinforced with Fiber Composite Strap. ACI Struct. J. 91(4) (1994) 434-447.

[5]- M. Yashinky, Performance of Bridges Seismic Retrofits during Northridge Earthquake. J. Bridge Eng. 3(1) (1998) 1-14. doi:10.1061/(ASCE)1084-0702(1998)3:1(1)

[6]- H. Sato, K. Yamaguchi, Stress-Strain Behaviour of Square Confined Concrete Column. conference. In 12WCEE 2000: Proceedings of the 12th World Conference on Earthquake Engineering, Auckland, New Zeland, February 2000, pp. 2284-2292.

[7]- A. Khaleek, R.K. Yadav, C. Rajeev, Effect of Lateral Confinement on Strength of Concrete. ISCA J. Eng. Sci. 1(1) (2012) 40-44.

[8]- M. Saatcioglu, M. Grira, Confinement of reinforced concrete columns with welded reinforcement grids. ACI Struct. J. 96(1) (1999) 29-39.

[9]- A. Mirmiran, M. Sahaway, Behaviour of Concrete columns Confined by Fibre Composites. J. Struct. Eng 123(5) (1997) 583–590. doi:10.1061/(ASCE)0733-9445(1997)123:5(583)

[10]- Z. Tao, JG. Teng, LH, L. Lam, Experimental behaviour of FRP confined slender RC columns under eccentric loading. In: Proceedings, Second International Conference on Advanced Polymer Composites for Structural Applications in Construction, University of Surrey, Guildford, UK., (2004) 203–212

[11]- J. Fitzwilliam, L.A. Bisby, Slenderness effects on circular CFRP confined reinforced concrete columns. J. Compos. Constr. 14(3) (2010) 280–288. doi:10.1061/(ASCE)CC.1943-5614.0000073

[12]- LA. Bisby, M. Ranger, Axial-flexural interaction in circular FRP confined reinforced concrete columns. Constr. Build. Mater. 24(9) (2010) 1672–1681. doi:10.1016/j.conbuildmat.2010.02.024

[13]- L. De Lorenzis, V. Tamuzs, R. Tepfers, V. Valdmanis, U. Vilks, Stability of CFRP-confined columns. In: Proceedings of the First International Conference on Innovative Materials and Technologies for Construction and Restoration, 6–9 June, 2004. Universita degli Studi di, Lecce, Italy, 2004, pp.327–342.

[14]- V. Tamuzs, R. Tepfers, E. Zile, V. Valdmanis, Stability of round concrete columns confined by composite wrappings. Mech. Compos. Mater. 43(5) (2007) 445–452. doi:10.1007/s11029-007-0042-y

[15]- V. Tamuzs, V. Valdmanis, R. Tepfers, K. Gylltoft, Stability analysis of CFRP-wrapped concrete columns

strengthened with external longitudinal CFRP sheets. Mech Compos Mater 44(3) (2008) 199–208. doi:10.1007/s11029-008-9012-2

[16]- P.K. Gupta, Confinement of concrete columns with un-plasticized Poly-vinyl chloride tubes. Int. J. Adv. Struct. Eng. 5(2013) 19. doi:10.1186/2008-6695-5-19

[17]- T.Kh. Mohammad Ali, M.M.S. Ridha, L.A.Gh. Yaseen, Z. Asaad, Retrofitting Short Reinforced Concrete Columns with RPC and CFRP. Zanco J. Pure Appl. Sci. 25(2) (2013) 22-31.

[18]- W. Perceka, W.-Ch. Liao, Y.-D. Wang, High Strength Concrete Columns under Axial Compression Load: Hybrid Confinement Efficiency of High Strength Transverse Reinforcement and Steel Fibers. J. Mater. 9(264) (2016) 1-25. doi:10.3390/ma9040264www.

[19]- A. Mirmiran, M. Shahawy, T. Beitleman, Slenderness limit for hybrid FRP-concrete columns. J. Compos. Constr. 5(1) (2001) 26-34. doi:10.1061/(ASCE)1090-0268(2001)5:1(26)

[20]- N. Taranu, C-I.Cozmanciuc, R. Oltean, Experimental Study of Reinforced Concrete Columns Confined With Composite Membranes. Bul. Polytech. Inst. Jassy- Constr. Architecture Section 3 (2011) 33-45.

[21]- T. Kh. Mohammad Ali, M.M.S. Ridha, Z. Asaad, L.A.Gh. Yaseen, Comparison Study of Axial Behavior of RPC-CFRP Short Columns. J. Mater. Eng. Struct. 2(2015) 57–67.

[22]- E. Balanji, Behaviour of Circular High Strength Concrete Columns Reinforced with Micro, Macro and Hybrid Steel Fibers Under Different Loading Conditions. PhD Thesis, School of Civil, Mining and Environmental Engineering, University of Wollongong, 2017.

[23]- A. Resheq, Behavior of hybrid concrete columns under axial compression loads. MATEC Web of Conferences 162(2018) 04021. doi:10.1051/matecconf/201816204021.

[24]- X. Wang, Y. Qi, Y. Sun, Z. Xei, W. Lim, Compressive Behavior of Composite Concrete Columns with Encased FRP Confined Concrete Cores. Sensors-Basel 19(8) (2019) 1792. doi:10.3390/s19081792

[25]- Specification Component: SC-023-03/10, Sikadur 32, Hi-Mod, Sika Concrete Restoration Systems. https://www.buildsite.com/pdf/sika/Sikadur-32-Hi-Mod-Guide-Specifications-1855654.PDF.

[26]- D.J. Carriera, K.H. Chu, Stress-strain relationship for plain concrete in compression. ACI J. 82(6) (1985) 797-804.