Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (43) No. (2) April . 2021

State of Art of the Behavior of hollow reinforced concrete columns

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ملخص البحث:

العمود هو العضو الهيكلي العمودي الذي يدعم الأحمال الانضغاطية المحورية، مع أو بدون عزوم انحناء. الأعمدة تنقل الأحمال الرأسية من الأرضيات والأسقف إلى الأساسات. قدرة تحمل الاعمدة تعتمد على خواص المواد المستخدمه وطولها وشكل مقطعها العرضي والقيود المطبقة على نهاياتها. ولأن الأعمدة تعتبر من اكثر العناصر الأنشائية حساسية في المنشىء، انهيار الاعمدة يسبب الانهيار التدريجي للأرضيات المجاورة ثم الانهيار التام النهائي للمبنى.

نظرا للتطور الحالى و التقدم فى جميع المجالات تحتاج معظم المبانى للخضوع للعديد من التعديلات فى تصميماتها لتواكب الاستخدامات الحالية. تشمل هذه التعديلات الحاجة الى العديد من الفتحات فى جميع العناصر الانشائية. الاعمده الخرسانية المسلحة هي احد الأعضاء الهيكلية الأساسية والتى نحتاج الى تصميم بعض الفتحات فيها لاسباب كثيرة و نذكر منها الفتحات الطولية وهى فتحات بطول الأعمدة مصممة لوضع مواسير بداخلها التى تسمح بمرور التوصيلات الكهربائية او مواسير الصرف او غيرها.

Abstract:

Columns are vertical structural element that supports compression axial loads, with or without moment. Column transfers vertical loads from floors and slabs to the foundations. The ability of columns to withstand loads depends on the properties of the used materials, their length, their cross-sectional area and their upper and lower bracing. Because columns are considered one of the most critical structural elements in structures their collapse cause the collapse of the neighboring floors then the full collapse of the whole building.

Due to development nowadays and progress in all fields most structures require many modifications in their designs to cope with their uses. These modifications include the need of cutting openings in all structural elements. Columns are one of the main structural elements that we need to design some openings in them for many reasons; for example, longitudinal openings. The behavior of columns with longitudinal openings have been studied from different points of view. Openings reduce the cross-sectional areas of the columns therefore reduce their abilities to withstand compression loads.

Keywords: Finite Element analysis, Columns, hollow column, FRP, opening.

Introduction

Many researchers studied the behavior of hollow reinforced concrete columns, despite this fact their behavior still remains unpredictable. Hollow concrete columns reinforced with ordinary reinforcing steel bars have been used widely for piers, piles, and utility poles as their use lessens the utilized materials and provide higher structural efficacy compared to solid concrete columns with the same area. Many experimental programs have been performed to evaluate the behavior of Hollow concrete columns under different loading conditions. They reached that the structural execution of Hollow concrete columns is critically affected by many design parameters. If not designed properly, Hollow concrete columns reveal brittle failure behavior, due to longitudinal bars. In addition, the corrosion of steel bars has become an issue in reinforced-concrete structures. As a result, this paper reviews the various design parameters that affect the performance of HCCs and identifies new opportunities for the safe design and effective use of this construction system. In addition, the use of FRPs as strengthening in hollow concrete columns is explored with the aim of developing structurally dependable construction system.

Many researches used finite element analysis to analyze the behavior [1, 2, 7, 8, 15]. Most of the work carried out on that field focused on studying the effect of using various types of confinement to make up for the columns' lost capacity due to the openings [2, 4-6]. The CFRP was one of the main suggested and used strengthening techniques to enhance the columns performance [2, 4-6] other promoted using GFRP instead due to its low cost compared to the CFRP [17]. In order to create the holes in the columns various techniques were adopted. Using PVC pipes was one of the techniques frequently used [3, 12] while others used steel pipes [10]. It was noted that the type of the used pipe affected the test results dramatically [12] as some authors recommended using steel pipes instead of polypropylene pipes.

The number of the used fiber plies was one of the amin issues that was studied extensively. [2] used two plies of CFRP wraps on the other hand [4] used CFRP at different orientation 45˚changing the geometry of the specimen on the column. The used concrete mix was modified [16] or using a composite section to improve the column behavior [9].

FRP confined hollow square columns

Park J.W., Yeom H.J., and Yoo J.H. [2], investigated the performance of hollow reinforced concrete square columns by testing eight specimens. The main investigated parameters include width-thickness ratio (b/t), the number of CFRP layers, and the CFRP sheet orientation. The specimens were tested under axial concentric loading then the experimental results were compared with a constructed FEM analytical model. The mode of failure of specimens is illustrated in figure (1).

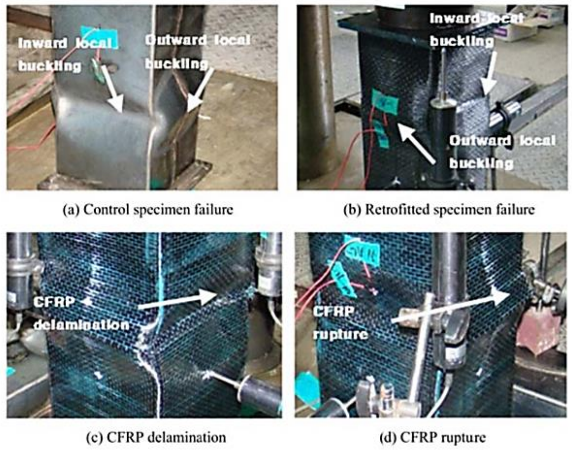

Figure (1): Failure modes of the tested specimens by **Park J.W., Yeom H.J., and Yoo J.H.** [2].

Hadi, M. N. S., and Le, T. D. [4], performed an experimental investigation on twelve hollow core square columns strengthened with CFRP to study the columns behavior. The studied parameters include effect of fiber orientation on the performance of specimens that were tested under concentric and eccentric loading. The twelve examined specimens were divided into four groups (RC, HF, VHF and AHF) those four groups were named after the strengthening orientations. The specimens of the first group (RC Group) without any FRP wraps served as reference specimens. The specimens of the second group (HF Group) were laterally wrapped with three CFRP layers with respect to the specimen's axial axis. The specimens of the third group (VHF Group) were vertically wrapped with one CFRP layer along the specimen's axial axis, and then horizontally wrapped with two CFRP layers. All the specimens of the last group (AHF Group) were wrapped with two CFRP layers oriented at ±45 with respect to specimen's axial axis, and then horizontally wrapped with one layer of CFRP. The failure modes of all specimens are clarified in figure (2).

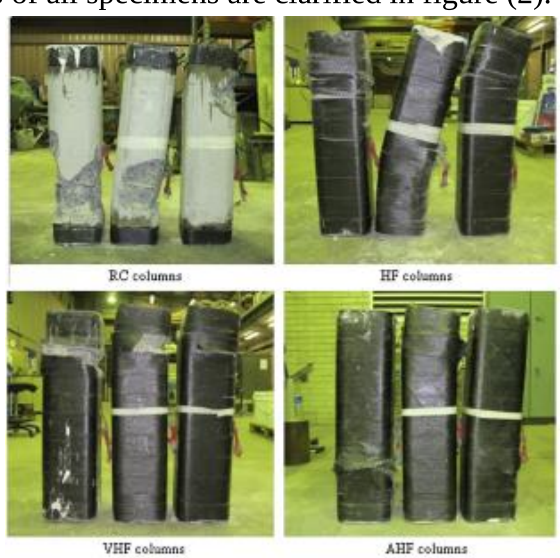

Figure (2); Modes of failure of columns.

From the study it was concluded that the Full wrapping of columns with fiber as a ring around the column increased the ductility of hollow core square reinforced concrete columns under concentric or eccentric loading. It was noticed that hollow column can with stand much larger deformation before failure Compared to solid column. However, the increment of the compressive strength of FRP-confined hollow core columns is very small and un noticed. When columns were tested under eccentric loading, the contribution of vertical and ±45 angle layers were evident in resisting the bending moment. Using one layer of CFRP did not show a serious increase in deflections of the columns under both concentric and eccentric testing. One explanation to that is that the contribution of axial loading is more than that of bending in their investigation.

Ismail R., Rashid R.S.M., and Jaafar M.S. [5], offered a comprehensive review specifically on hollow reinforced concrete strengthened with Carbon Fiber Reinforced Polymer (CFRP). In their research they discussed in detail the strengthening techniques and the advantages and disadvantages of the application of CFRP for hollow reinforced concrete column. They stated that reviewing other research work that has been used CFRP in strengthening hollow reinforced concrete column will contribute significant impact to the used of fiber one of the main paper outcomes.

Ismail R., Rashid R.S.M., Zakwan F.A.A., and Hejazi F. [6], performed an experimental investigation including 6 full-scale circular hollow reinforced concrete columns with 2 m height, 250 mm outer diameter, and 110 mm of inner diameter. A comparison was carried out between un-strengthened circular hollow column and partially confined hollow columns. The columns were strengthened with CFRP and tested under axial loading. The cracks patterns of the columns are shown in figures (3 and 4).

Figure (3): Cracks patterns of un-strengthened concentrically loaded columns by **Ismail R., Rashid R.S.M., Zakwan F.A.A., and Hejazi F.** [6].

Figure (4): Cracks patterns of CFRP strengthened concentrically loaded columns by **Ismail R., Rashid R.S.M., Zakwan F.A.A., and Hejazi F.** [6].

From the test results it was concluded that the CFRP succeeded in improving both the failure patterns of the columns, the strain values in the concrete were reduced and displacement was controlled. CFRP is one of the very effective used strengthening schemes that could make up for the loss in the area attained by hollow columns.

Liang, X., and Sritharan, S. [7], carried out a computational study to study the effect of confinement effect on hollow sections, they highlighted two main parameters which were the concrete dilation and confining pressure. In order to make sure their study results were sufficient, they summed up the results in table (1) from previous researches.

Table (1): Summary of previous experimental studies on hollow RC columns by **Liang, X., and Sritharan, S.** [7].

Researchers	Section type	Wall thickness:section diameter/width ratio	Axial load ratio[a]	Aspect ratio	Longitudinal reinforcement ratio[a]	Transverse reinforcement amount (ratio[a])	Confinement configurations
Zahn et al. (1990)	Circular	0.14–0.24	0.05–0.28	4.5	2.56%	10–12 mm dia. @ 75–90 mm (1.13–1.36%)	One layer
Kawashima (1992)	Circular	0.18	0	3.1	0.8 and 1.3%	9 mm dia. @ 200 mm (0.18%)	One layer
Hoshikuma and Priestley (2000)	Circular	0.092	0.04	4.3	0.48 and 1.06%	6.35 mm dia. @ 35 mm (0.22%)	One layer
Ranzo and Priestley (2001)	Circular	0.097 0.091	0.02 0.05	2.5	0.49% 0.8%	6.35 mm dia. @ 70 mm (0.12%)	One layer
Yeh et al. (2002)	Square	0.2	0.05	4.33.0	1.1%	13 mm dia. @ 80 mm 10 mm dia. @ 120 mm (0.56–1.52%)	Two layers with crossties
Mo et al. (2003)	Square	0.2	0.12 0.06 0.07	4.0	0.7%	4 mm dia. @ 40 mm 4 mm dia. @ 80 mm (0.45–0.9%)	Two layers with crossties

Their results showed that the confinement effect on solid and hollow sections was completely divergent. This was due to variations in concrete dilation and the distribution of confining pressure across the cross section. It also showed that for circular hollow columns with a wall thickness ratio of 0.1, one layer of transverse reinforcement provides a satisfactory confining effect. For columns with larger wall thickness ratios up to 0.2, two layers of reinforcement connected with crossties are more appropriate, with an inner to outer reinforcement ratio of 1:9.

Fanggi, B. A. L., and Ozbakkaloglu, T. [9], performed an experimental program to investigate the effects of the presence of an inner steel steel tubes and inner concrete filling on the compressive and behavior of fiber reinforced polymer (FRP)-concrete-steel composite columns. The columns were manufactured with S-Glass FRP tubes. The research program included the investigation of 24 hollow and concrete-filled double-skin tubular columns (DSTCs), two concrete-filled FRP tubes (CFFTs), and six CFFTs with inner voids (H-CFFTs). The modes of failure of the column are clearly illustrated in figure (5).

Figure (5): Modes of failure of specimens by **Fanggi, B. A. L., and Ozbakkaloglu, T.** [9].

The results indicated that the concrete-filling the inner steel tubes increased the compressive strength of confined concrete, compared to that of the companion specimens with hollow inner steel tubes. It was observed that cyclically loaded DSTCs exhibited slightly higher strength and strain enhancements compared to their monotonically loaded counterparts. The results also showed that H-CFFTs acted in bad behavior compared to DSTCs and CFFTs. The last to mentioned types of columns' performance, deteriorated with increasing the diameter of the inner tube.

Liu S., Ding X., Li X., Liu Y., and Zhao S. [10], studied the influence of filling high strength steel fiber reinforced concrete rectangular section columns with steel tubes. The aim of the research was to improve the compressive capacity of composite hollow columns. The experimental program included testing ten columns. Those columns were divided as follows nine rectangular-sectional SFRC-filled steel tube columns and one normal concrete-filled steel tube column. The columns were tested under axial compression till failure. The research parameters include the compressive strength of concrete, the volume fraction of steel fiber, the type of internal longitudinal stiffener and the spacing of circular holes, in addition the failure modes, axial load-deformation curves, energy dissipation capacity, axial bearing capacity, and ductility index are presented.

The results revealed that steel fiber delayed the local buckling of columns and increased their ductility and energy dissipation capacity especially when the volume fraction of steel fiber was not less than 0.8%.

The longitudinal internal stiffening ribs and their type changed the failure modes of the local buckling of steel tube, and increased the ductility and energy dissipation capacity to some degree. The compressive strength of SFRC failed to change the failure modes, but had a significant impact on the energy dissipation capacity, bearing capacity, and ductility.

Kassim, M. M., and Ahmad, S. A. [11], examined sixteen hollow square columns to study the effect of holes cross section ratio on the compressive strength of concrete and load carrying capacity of columns. The experimental program included investigating twelve columns with holes and four solid reinforced concrete columns. The sixteen specimens were divided such that each column was tested twice for each influencing factor then the mean, the standard deviation and coefficient of variation were calculated for each two specimens.

Two holes diameters were used 25mm and 15mm respectively, both holes were created by embedding a PVC pipe of thickness 1mm inside the column, in the centre of their cross section. Two concrete mixes were utilized in casting the columns with compressive strength 27.8 MPa and 40 MPa, they were used to study the effect of changing the compressive strength on the bearing capacity of columns with longitudinal holes.

Figure (6): Failure modes of short braced concrete columns with longitudinal holes by **Kassim, M. M., and Ahmad, S. A.** [11].

From their research, they came to a conclusion that using high strength concrete for columns with longitudinal embedded pipes minimizes the negative effects on the load bearing capacity of columns, it is also worth mentioning that decreasing the hole diameter did not increase the load bearing capacity of the columns. They also, recommended that more research should be carried out to investigate the effect of holes on the load carrying capacity of the column to be approved by ACI code provisions. Moreover, they suggested a modification in the equation used to calculate the ultimate load for columns with longitudinal holes.

Bakhteri et al. [12], performed an experimental program on fourteen reinforced concrete columns with drain pipes positioned at the centre of their cross section. The study was designed to explore the effect of using PVC pipes of different cross-sectional areas and correspondingly changing the columns reinforcement (i.e., changing the diameters of the used bars in other words increasing the reinforcing area) on the behaviour of reinforced concrete mainly the load bearing capacity. The study also investigated the factors of safety suggested by different codes, by comparing between the experimental ultimate loads and the design loads suggested by those codes.

They came to conclusion that pipes reduced the carrying capacity of columns in addition the suggested factors of safety were less than the nominal values. They recommended decreasing the strength of the column when using the design equation or using alternative solution by replacing PVC pipes with steel pipes just if concealing pipes in columns is required.

Shin, M. et al. [14], carried out an experimental program to assess the shear behaviour of hollow rectangular columns. For this purpose, a total of thirteen 1=4-scale RC rectangular hollow columns, with no transverse reinforcement, were examined under lateral load. The test variables were the column aspect ratio, longitudinal reinforcement ratio, portion of hollow section.

Table (2): Measured and calculated lateral strengths of specimens tested by **Shin, M. et al.** [14].

Specimen	Flexural strength, V_{flex} (kN)	Yield strength, V_{yield} (kN)	Maximum load, $V_{c,exp}$ (kN)	$\tau_{c,exp}$ (MPa)	$\frac{V_{c,exp}}{b_w d}$ (MPa)	$\frac{\tau_{c,exp}}{\sqrt{f_c'}}$	Failure mode
H40A1.5	620	471	525	1.63	3.37	0.33	Flexure-shear
H40A2.0	464	338	445	1.38	3.05	0.28	Flexure-shear
H40A2.5	371	268	341	1.06	2.34	0.21	Flexure-shear
H40A3.0	310	224	259	0.80	1.78	0.16	Flexure-shear
H60A1.5	619	474	337	1.57	3.76	0.32	Shear
H40A1.5WF1.8	616	463	522	1.61	3.33	0.32	Flexure-shear
H40A2.0C	471	338	368	1.43	2.53	0.29	Flexure-shear
H30B1.5	461	350	458	1.21	2.39	0.29	Flexure-shear
H40B1.5	461	346	392	1.22	2.51	0.29	Flexure-shear
H40B2.0	346	263	334	1.04	2.14	0.24	Flexure-shear
H40B2.5	277	208	269	0.83	1.72	0.20	Flexure-shear
H40B3.0	231	171	203	0.63	1.30	0.15	Flexure-shear
H40B1.5T	459	340	381	1.18	2.44	0.28	Flexure-shear

Note: 1 kN = 0.225 kips; 1 MPa = 145 psi; $\tau_{c,exp} = V_{c,exp}/(A_g$ or $0.8A_g)$, $0.8A_g$ is used only for H40A2.0C.

It was concluded that the shear strength contributed by concrete decreased generally in a linear proportion to the column aspect ratio. The reduction in the maximum load was likely because the principal stresses were greater in the specimen with the larger aspect ratio for a given lateral load, due to the higher bending moment. Also, it was observed that the current ACI 318 shear model provided quite conservative design strengths for hollow column specimens with lower displacement ductility, while it showed relatively good correlations for columns with higher ductility.

Thote, M. et Al. [17], examined three groups of reinforced concrete rectangular columns each consisting of three columns, one group was casted with M20 grade concrete. The second group was fully wrapped with a layer of GFRP and the third group was partially strengthened with GFRP. The results of all the tests were analysed and compared to each other. From the test results it was noted that the compressive strength of hollow R.C. columns covered with GFRP were higher than that of columns without reinforcement. The ultimate load carrying capacity of R.C. columns strengthened with different schemes of GFRP varied.

FE Modelling of FRP confined hollow square columns

Park J.W., Yeom H.J., and Yoo J.H. [2], performed finite element analysis to model slender steel hollow square section (SHS) strengthened with carbon fiber reinforced polymers (CFRP) sheets. 4-node kinematic shell was constructed, the support conditions were designed to be fixed end to prevent any local buckling or rotations at the ends of the columns. From the model, that stiffness value was affected by the presence of CFRP. In general, the results of the analysis and the experimental test were in good correlation. Which means that Ansys 14.5 workbench could be used to model hollow square section columns.

Basravi [13]**,** carried out finite element three dimensions modelling using LUSAS® to study the effect of positioning centre holes on the load carrying capacity of rectangular and square axially load reinforced concrete columns. The models were created to verify an experimental program. At the end of the program, it was concluded that holes affected the columns integrity and load carrying capacity widely. He suggested adding some guidelines for casting columns with holes in various popular design codes.

Papanikolaou, V. K. et al. [15], suggested a 3D finite element model to confine both solid and hollow reinforced concrete piers. The aim was to investigate the most efficient arrangement of the transverse reinforcement such that it improved the strength and ductility, as well as ease of construction and cost-effectiveness. Constitutive laws, modelling techniques, post-processing issues and preliminary applications are first introduced, and a large parametric model setup for rectangular bridge piers of solid and hollow section, is subsequently presented.

From the research they concluded that finite element modelling could make a probable substitute to empirical confinement models as it is unrestricted in terms of section geometry and reinforcement arrangement complexities. It could also consider as a cost-effective counterpart to experimental testing towards the assessment and design of (especially hollow) reinforced concrete bridge piers.

Khamees, S. S. [16], Studied the influence of using hollow cross section and changing the section shape on the behaviour of hollow slurry infiltrated fibre concrete (SIFCON) columns and normal strength concrete (NSC) columns. For this purpose, two groups of columns were tested each consisting of six columns. These six columns have different hollow ratios (b = 0, 25% and 50%) for SIFCON columns and (b = 0, 25% and 33%) for NSC columns. Figure (7) shows the failure mode of SIFCON and NSC columns.

Figure (7): The failure mode of SIFCON and NSC columns by **Khamees, S. S.** [16].

The results proved that the SIFCON columns had a spectacular overall performance compared to the NSC columns in terms of load-carrying capacity, ductility, and energy absorption capacity. however, SIFCON columns have less stiffness than NSC columns. When the hollow ratio increases, the load carrying capacity, ductility, and stiffness were reduced.

Results from FE Modelling of FRP confined hollow square columns

Kim T.H., Seong D.J., and Shin H.M. [1], investigated the performance of hollow reinforced concrete square columns to provide data for developing improved design criteria. Nonlinear finite element analysis program (RCAHEST (Reinforced Concrete Analysis in Higher Evaluation System Technology)) was used to analyze reinforced concrete hollow columns. Tensile, compressive and shear models of cracked concrete and models of reinforcing were used to account for the material nonlinearity of reinforced concrete. The smeared crack approach was incorporated. The columns were tested under seismic dynamic loading.

From the results of the analytical studies, the following conclusions were reached; nonlinear finite element analysis may be used to investigate the design details and the load–deflection response of hollow reinforced concrete, failure modes and ductility may be checked as well. The comparison between the analytical and experimental model is shown in figure (8).

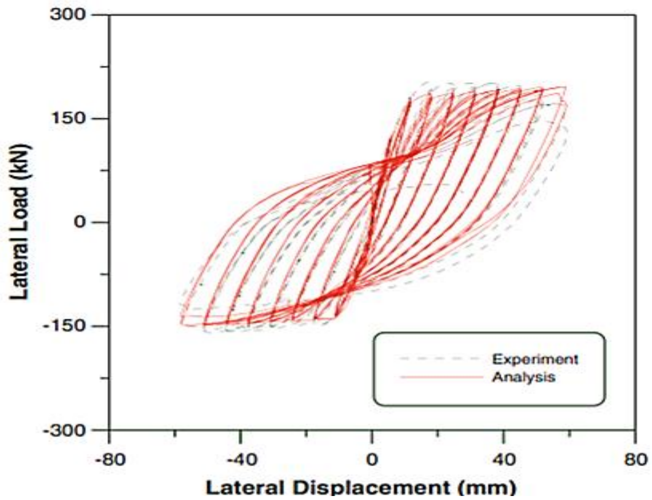

Figure (8): Load-displacement comparison between analytical and experimental results by **Kim T.H., Seong D.J., and Shin H.M.** [1].

Park J.W., Yeom H.J., and Yoo J.H. [2], from FEM analysis, it was concluded that the typical mode of failure slender steel hollow square section (SHS) strengthened with carbon fiber reinforced polymers (CFRP) sheets was the buckling of its two sides to the outwards while the two other side would buckle inward of that two sides would typically buckle outward and the other two sides would buckle inward. In this study, it was noted that the buckling occurred before reaching the cross-sectional yield load. The results of comparing the failure load are clearly illustrated in figure (9).

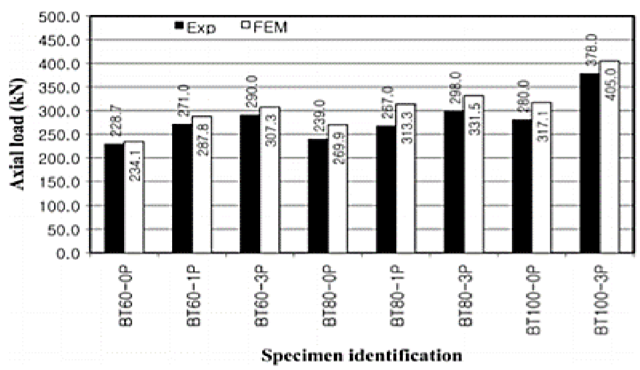

Figure (9): Comparison between experimental results and FEM results calculated by **Park J.W., Yeom H.J., and Yoo J.H.** [2].

Experimentally tested hollow square columns

Gamal A.A. [3], performed an experimental program to study the effect of variable strengthening techniques of hollow core concrete columns. herein, a comparison was carried out between hollow concrete unreinforced column containing steel and columns with reinforced with different number of steel bars containing PVC pipe. The results of the examined groups are shown in figure (10).

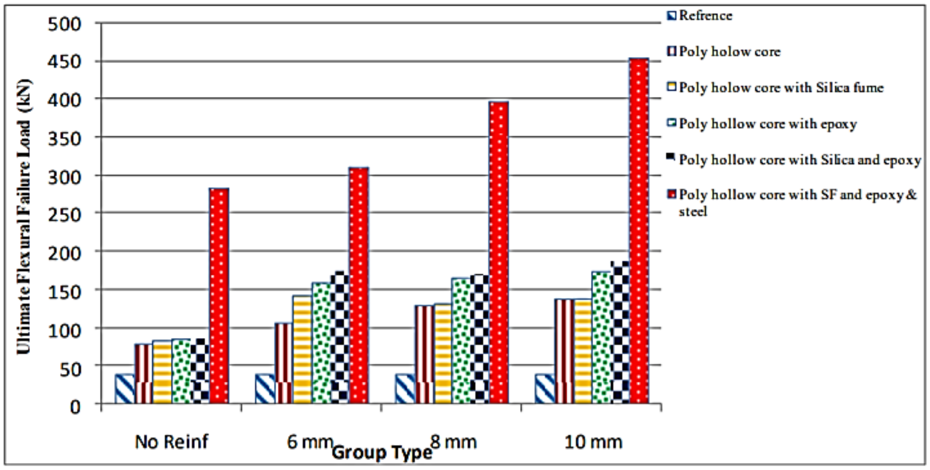

Figure (10): Ultimate Flexure strength attained by different groups of specimens as in **Gamal A.A.** [3].

The following findings were concluded from the study; for concrete specimens with Polypropylene hollow core, it was noted that existence of hollow core reduced the bulk density by up to 19.3 % with respect to the reference specimen. Adding Silica Fume and Epoxy improved the compressive strength by up to 215.4% with respect to Polypropylene hollow core cubes. Introduction of steel pipes improved the compressive strength by 270.7 % compared to Polypropylene hollow core cubes. Addition of steel reinforcement showed a continuous increase in the compressive strength up to 569.35% compared to polypropylene hollow core cubes using Ø 10mm steel reinforcement.

Hadi, M. N. S., and Le, T. D. [4], an experimental investigation including twelve hollow core square columns strengthened with CFRP was run to study the columns behavior. The studied parameters include effect of fiber orientation on the performance of specimens that were tested under concentric and eccentric loading.

Suku Y.L., and Je k. [8], used Abaqus to create a model to analyze the effect of holes in reinforced concrete column structures examined under lateral loads. The experimental information was obtained from the reference frame structure of the previous researcher, those researches contained various centric column holes of 0%, 2%, 4%, 6%, 8%, 10%, and 12%, respectively to the column cross-sectional area. In addition, a parametric study was conducted this study included investigating a hole with a ratio of 4% to the column cross-sectional area. This hole was situated at 5and10 mm eccentric to the center of column cross-section to study the effect of holes position in the perforated column.

The result showed that the maximum load, displacement, and crack pattern resulted from the model were nearly equivalent to the experimental program. The results of the analysis showed that with the hole size of 2% to 12% of the column cross-sectional area, the frame strength was reduced by 5.43% to 15.56%. The frame strength was also reduced by 2.77% and 6.14% when the hole was placed at a distance of 5mm and 10 mm from the center of the column. The displacement also decreased the strength by 59.63% to 74.60% when the holes ratio was 2% to 12% of the column cross-sectional area. The existence of eccentric holes on the column reduced the performance of the frame structure, by decreasing its strength, displacement and ductility.

Abdulazeez, M. M. [18], studied the behaviour of hollow core fibre reinforced polymer concrete steel columns numerically. The study was carried out under combined axial and lateral loading. A parametric study was designed using the given models. This study concentrated on investigating the wall thickness, the steel pipe width to thickness ratio, strengthening percent, concrete compressive strength and local buckling behaviour of columns, the design of the parametric study is shown in table (3).

Table (3): Summary of parametric study models by **Abdulazeez, M. M.** [18].

Group	Column	Parameter	Parameter value	Steel tube width {B [mm (in.)]}	FRP tube thickness {t_f [mm (in.)]}	Minimum concrete wall thickness {t_c [mm (in.)]}	Steel tube thickness {t_s [mm (in.)]}
A	C1	Minimum concrete wall thickness	152.4 (6)	864 (34)	8.5 (0.34)	152.4 (6)	7.2 (0.28)
	C2	{t_c [mm (in.)]}	203.2 (8)	788 (31)		203.2 (8)	6.6 (0.26)
	C0		254 (10)	712 (28)		254 (10)	6 (0.23)
	C3		305 (12)	635 (25)		305 (12)	5.4 (0.21)
	C4		381 (15)	539 (21)		381 (15)	4.5 (0.18)
B	C5	B/t_s	30	712 (28)	8.5 (0.34)	254 (10)	24 (0.93)
	C6		60				12 (0.47)
	C7		90				8 (0.31)
	C0		120				6 (0.23)
	C8		180				4 (0.16)
C	C9	Confinement ratio	0.05	712 (28)	4.7 (0.19)	254 (10)	6 (0.23)
	C0		0.10		8.5 (0.34)		
	C10		0.15		14.2 (0.56)		
	C11		0.20		19 (0.75)		
	C12		0.25		23.7 (0.93)		
D	C13	f'_c [MPa (ksi)]	20.7 (3)	712 (28)	5.2 (0.2)	254 (10)	6 (0.23)
	C0		34.5 (5)		8.5 (0.34)		
	C14		48.3 (7)		12.1 (0.48)		
	C15		68.9 (10)		17.3 (0.7)		
	C16		89.6 (13)		22.5 (0.9)		
E	C17	Load level (% P_o)	5	712 (28)	8.5 (0.34)	254 (10)	6 (0.23)
	C18		15				
	C19		25				
	C0		35				
	C20		45				

This study revealed that the behaviour of HC-FCS columns is complicated due to the interaction of the stiffness of the three different materials: concrete, steel, and FRP. In general, in the HC-FCS columns with square steel tubes, failure was triggered by local buckling of the steel tube followed by FRP rupture. The presence of the concrete wall restrained by the outer FRP and inner steel tubes significantly affected the steel tube buckling.

Conclusion

In general, the behavior of reinforced concrete hollow square columns is complicated, their behavior is unexpected. Despite the many studies carried out to investigate their behavior and determine their reflexes no one could assure a certain behavior for them.

It could be concluded from all the previous literature that FRP enhanced the behaviour of hollow square columns i.e., the load carrying capacity of columns strengthened with FRPs is higher than hollow un-strengthened columns. As the hollow portion ratio increase the bearing capacity of the column decrease. Despite the ability of the FRPs to enhance the columns capacity they failed to enhance their ductility.

Finite element analysis could be reliable in predicting the behaviour of hollow square reinforced concrete columns. They could minimize the cost and cut down the resources required to determine the columns behaviour. Using steel pipes as a hollow tube instead of hollow concrete sections improved the columns capacity.

Design codes as ACI 318 or BS8110-97 need to set fewer preservative equations in order to predict the bearing capacities of hollow columns.

More studies need to be carried out to study the behaviour of R.C. columns with different shapes (circular or square) and different strengthening schemes whether with FRPs or with strengthening schemes other than FRP normal wrapping. Finite element analysis should be used more frequently to determine the columns' behaviour.

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