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Experimental Behavior of Hollow Non-Prismatic Reinforced Concrete Beams Retrofit With CFRP Sheets.

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Abstract:

This study deal with five reinforced concrete non-prismatic beams hollows section retrofit with carbon fiber reinforced polymer (CFRP) under two point loads. These beams of dimension (length 1170 x height 260 x width 150mm) with different section (i.e. solid or hollow of two shapes) are investigated to evaluated the behavior at experimental test and to get capacity of beams retrofit with CFRP that similar to capacity of solid sections. The end support to provide all beams as simply supported. The four of R.C. beams are retrofit with CFRP strip (Sika CarboDurS512) and design to test up to failure. Also, it's have been explain the effect of Parameters which includes the effect of section (solid or hollow), hollow opening (shapes and materials) and effect of retrofitting with CFRP. Non prismatic beam with recess along length compared with non prismatic solid beam results show decreased in stiffness and an increased in the beam deflection by about (53% and 40% respectively). The square hollows are provided by steel pipe led to increased in load capacity and decrease in corresponding deflection compared with other materials (i.e PVC) by about (56%,33%), also the retrofit of beams by CFRP contributed to again in load capacity by about (27%) . Finally the comparisons between all beams are base on load carrying capacity, deflection, and crack pattern, strain of concrete and mode of failures.

Key words: Non-Prismatic Beams, Hollow, CFRP, Reinforced Concrete, and Retrofit.

السلوك العملي للعتبات الخرسانية المسلحة المجوفة الغير منتظمة المقطع المعززة بصفائح ألياف الكاربون البوليميرية.

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الخلاصة

هذه الدراسة تتعامل مع خمس عتبات خرسانية مسلحة غير منتظمة المقطع ومجوفة مقواة بألياف الكربون البوليميرية تحت تأثير حملين مركزيين ساكنه. ابعاد العتبات المفحوصة كانت (طول 1170ملم وارتفاع 260ملم وعرض

150 ملم) هذه العتبات فحصت مع مقاطع مجوفة وغير مجوفة وإشكال مختلفة بالنسبة للتجويف لتقييم الاستجابة وسلوك كل منها عمليا وللحصول على عتبات مقواة بألياف الكاربون تعطي نفس قابلية تحمل العتبات الغير مجوفة. كل العتبات بسيطة الإسناد. أربع من العتبات تم تقويتها في منطقة الشد باستخدام صفائح الكاربون نوع (Sika CarboDurS512)وصممت للفحص العملي لحد الفشل.كذلك الدراسة لبيان تأثير أكثر العوامل شاملة تأثير كل من المقطع مجوف أم غير مجوف وشكل التجويف والمادة الداخلة في تكوينه وكذلك تأثير ألياف الكاربون البوليميرية.من خلال الفحص العملي تبين إن العتبات التي تحوي تجويف على طولها تقل قابليه التحمل لها ويزداد الهطول بحوالي (53%، 40%) على التوالي بالمقارنة مع العتبات الغير مجوفة.التجويف المربع المجهز باستخدام أنبوب من الحديد كذلك يعطي زيادة في التحمل ونقصان في الهطول بمقدار (56%، 33%) بالمقارنة مع التجويف المجهز باستخدام (PVC PIPE) كذلك تبين ان ألياف الكاربون البوليميرية تحسن من قابلية التحمل للعتبات المقواة بها بحوالي (27%). أخيرا المقارنة بين العتبات كلها تمت على أساس قابلية تحمل الأحمال والهطول وأنماط التشقق والانفعال للكونكريت وأطوار الفشل.

1. Introduction:

The applications of structural hollow sections nearly cover all fields. Sometimes hollow sections are used because of the beauty of their shape, to express lightness or in other cases their geometrical properties determine their use. These sections are used for the various fields such that in buildings, hall, bridges, offshore structure and towers[5]. While there are many instances where beams made non-prismatic in cross section along its length. For example, in modern building where utility ducts and pipe are being accommodated below floor beams in the space above the false ceiling, the use of non-prismatic beam with a recess would allow these ducts to pass through the beam, eliminating a significant amount of dead space [1,6]. This would reduce the height of story, leading to substantial savings in the materials and construction costs. Similarly, non-prismatic beams could be appropriately used as ground beams in residential up-grading projects, where existing utility pipes often obstruct the construction of tie beams that connect the newly constructed beams to existing ones. The use of non-prismatic tie beams allows the construction to proceed without the need of relocating these pipes [1,2,3,4,6].

2. Significant Study:

The present study is carried out to evaluate the behavior of non-prismatic reinforced concrete beams with different section (solid or hollow), examined hollow (shape and materials), CFRP and shear reinforcement ratio on loading capacity, deflection, strains and failure mode under concentrated static load. In mainly to get equivalents hollow beams retrofit with CFRP that give same capacity of solid beam sections [7, 8, 14].

3. Experimental program:

The experimental program was conducted in the laboratory of the Civil Engineering Department at college of Engineering at the University of AL-Mustansiriya. Experiments consist of five reinforced concrete beam non prismatic section was performed to investigate the behavior of these beam retrofit with CFRP strip composite. The experimental program consist of work stages started with preparation of material and at end process of test the samples of Non-prismatic beams.

Materials:

The mix proportions of one cubic meter are obtained by series test of trial mixes [4]. The final adopted mix designs are shown in **Table (1).** The adopted mix these mixers give average standard of 28 days compressive strength of concrete f_c' about 25 to 27 MPa.

Table (1) Mix proportions for (1 m^3) of concrete.

Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Water/Cement Ratio	Water (kg/m^3)
420	630	1260	0.5	210

Four of reinforced concrete beams were retrofit by CFRP (Carbon fiber strip Sika CarboDurS512) with resin (Sikadur-30) [9]. The typical characteristic properties of CFRP are as follows: sheet length 700mm x width 50 mm, also other properties of CFRP are shown in **Table (2).** The resin system that was used to bond the CFRP Strip over the tensile region of beams in this work was the epoxy resin made of two parts, resin and hardener. The properties of the resin as shown in **Table (2)**

Table (2) Material Properties of (Sika CarboDurS512 and Sikadur-30 (Impregnating Resin)).

Carbon fiber strip (Sika CarboDurS512)		**Sikadur-30 (Impregnating Resin)**	
Fiber type	High strength carbon fibers	Appearance	Comp. A: white Comp. B: grey
Base	Carbon fiber reinforced plastic with an epoxy matrix	Density	1.65 kg/l (mixed)
CFRP plate cross sectional area	60 mm^2	Mixing ratio	A : B = 4 : 1 by weight
CFRP strip thickness	1.2 mm	Open time	30 min (at + 35°C)
Fiber volumetric content	>68%	Viscosity	Pasty, not flowable
Tensile strength of fibers	2800 MPa	Application temperature	+ 15°C to + 35°C (ambient and substrate)
Tensile E – modulus of fibers	165 GPa	Tensile strength	15 MPa (cured 7 days at +23°C)
Elongation at break	1.7 %	Flexural E-modulus	12800 MPa (cured 7 days at +23°C)
Fabric length/roll	≥ 45.7 m		
CFRP strip width	50 mm		

Beams Details:

Five beams with details shown in **Table (3.1)** were designed, fabricated and tested up to failure. All beams are simple support, four beams had a recess in the center as shown in Figure.(1,2). The resin system used in this work was made of two parts, namely, resin and hardener. The components were thoroughly hand mixed for at least 3 min. The concrete beams were cleaned and completely dried before the resin was applied. The coat of a thin resin layer of thick about 1.2 mm was applied and a CFRP strip was then applied to tension face at bottom of retrofit beams directly on the surface. Special attention was paid to ensure the absence of voids between the CFRP strips and concrete surface. A special roller was used to remove the entrapped air bubbles. After complete the retrofit of beams, the specimens were left at room temperature for more than 2 weeks for the epoxy to harden adequately before testing[9,10,11].

Table (3.1): Details of R.C. Non-prismatic Beams Specimens.

Beams Symbol	Bottom Reinforcing	Top Reinforcing	Stirrups Reinforcing	CFRP Size (mm)	Hollow size (mm)	Hollow Shape
B1	3Ø12	2Ø10	Ø4 @150	---	---	---
B2	3Ø12	2Ø10	Ø4 @150	50x700	Ø50	circle
B3	3Ø12	2Ø10	Ø4 @100	50x700	Ø50	circle
B4	3Ø12	2Ø10	Ø4 @150	50x700	50x50	Square
B5	3Ø12	2Ø10	Ø4 @100	50x700	50x50	Square

Table (3.2) Properties of Steel Reinforcement [12].

Nominal Diameter (mm)	Measured Diameter (mm)	A_s (mm^2)	Yield Tensile Strength f_y (MPa)	Ultimate Strength f_u (MPa)
4	4.13	13.39	395	480
10	9.88	76.67	421	520
12	12.2	116.89	480	570

Table (3.3) Compressive Strength of Concrete Cylinder (28 days) [13].

Sample No.	Diameter (mm)	Load, (kN)	Compressive Strength f_c, (MPa)	Average Strength (MPa)
1	150	442	25	26.63
2	150	512	28.9	26.63
3	150	460	26	26.63

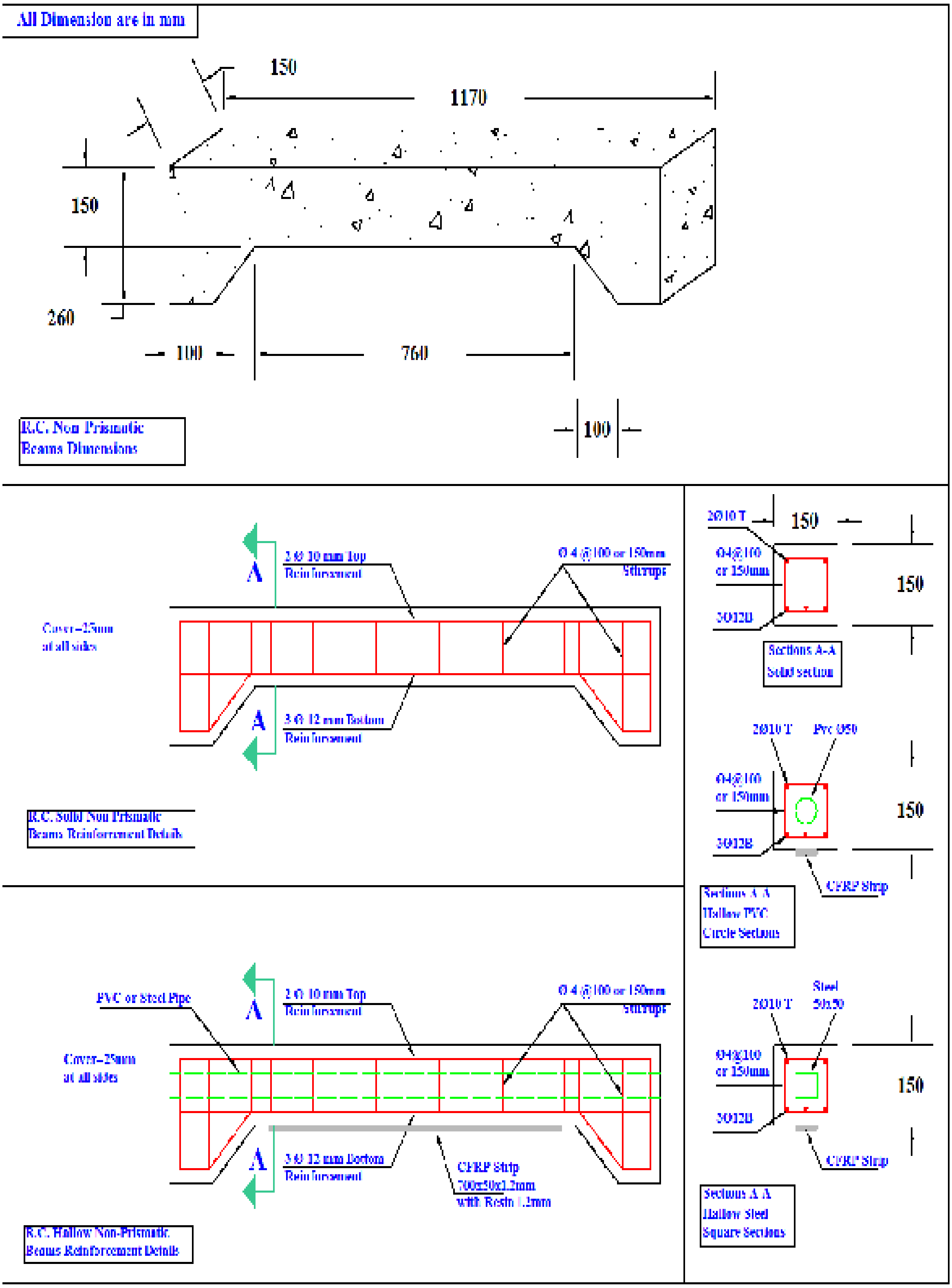


Fig.(1) Details of Non-Prismatic R.C. Beams Sections.

a. Mould of Solid Beam, (B1).

b. Mould of Hollow (PVC Circle) Beam, (B2&B3).

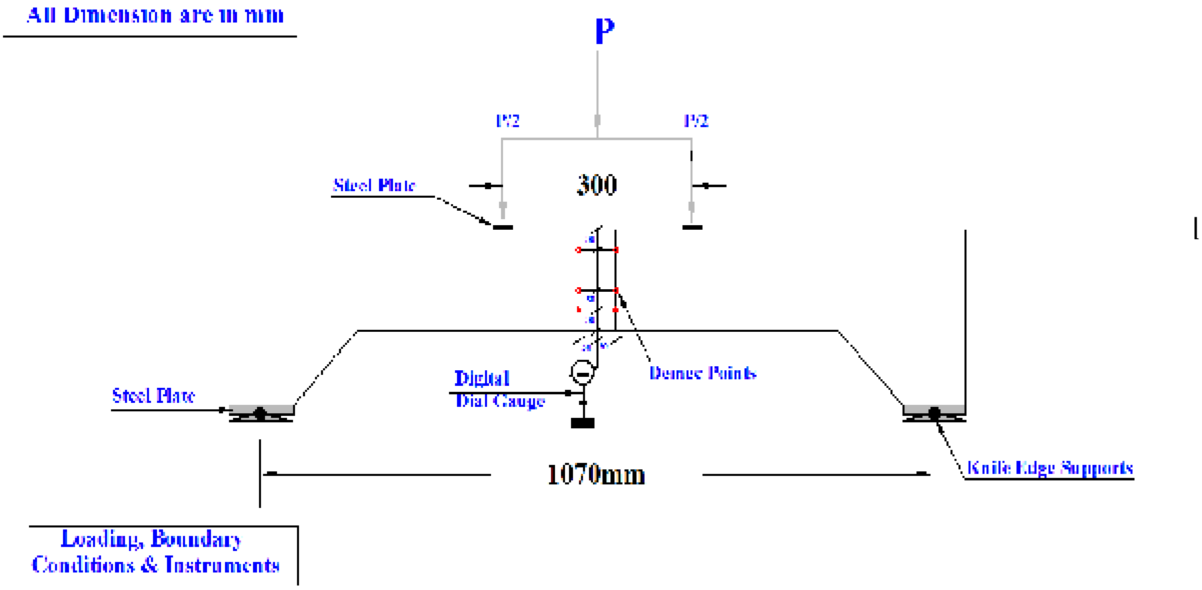
c. Mould of Hollow (Steel square) Beam, (B4 & B5).

Fig.(2) Moulds Details of Non-Prismatic R.C. Beams.

4. Instrumentation and Testing Procedure:

After complete the curing of beams (i.e. after the resin is final curing), the specimen is placed in position, and load was applied at the compression fiber of beam as shown in **Figure.(3).** The load was applied as two concentrated points load and increased gradually at increments of (5 kN). The deflections were measured at center of specimens at each load increments using Digital dial gauge of accuracy of (0.01). The strain in concrete also measured at center of top and bottom fiber at three locations of distance (60mm) between demec points as shown in **Figure.(3).** Test was carried and continued till failure. Failure mode and crack patterns were recorded. A schematic representation and photographs of the test setup (and instrumentation) are shown in **Figure.(3).**

a. Testing Machine and Sample



b. Sample Arrangements and Support.

Fig.(3) Loading, Boundary Conditions and Instruments

5. Experimental Results:

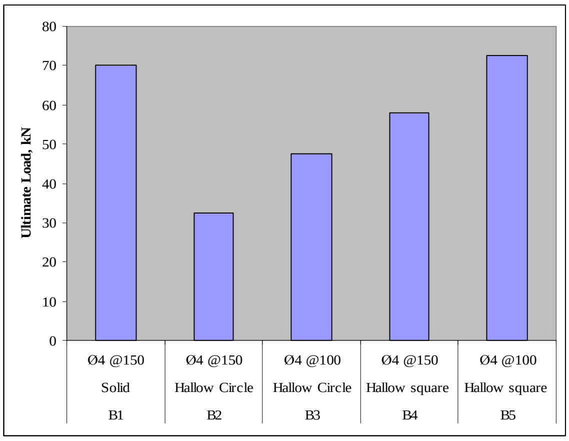
The test results of all specimens based on load carrying capacity, deflection, strain and crack pattern. The comparisons are shown in the following:

5.1 First Crack and Ultimate Load:

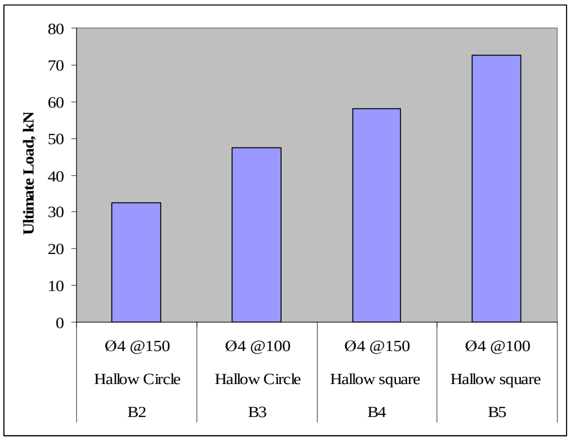
Table (4), show the hollow section decrease in load capacity and increase in corresponding deflection for the same properties, also when used steel tube to construct hollow zone in Non-prismatic give more load capacity and decrease in deflection. The used CFRP in strength also increased in capacity of beam a decrease in deflection

Table (4) Fist Crack, Ultimate Load and deflections.

Beam No.	First Crack Load kN	Ultimate Load, kN	Difference Load %	Deflection mm	Difference deflection %	Failure mode
B1	30	70	---	7.1	---	Shear
B2	15	32.5	-53	10.08	+42	Shear
B3	14.5	47.5	-32	12.18	+71.5	Shear
B4	25	58	-17	12.42	+75	Shear
B5	25	72.5	+3	10.	+40.8	Shear



Ultimate load of all Beams



Ultimate load of Retrofit Beams

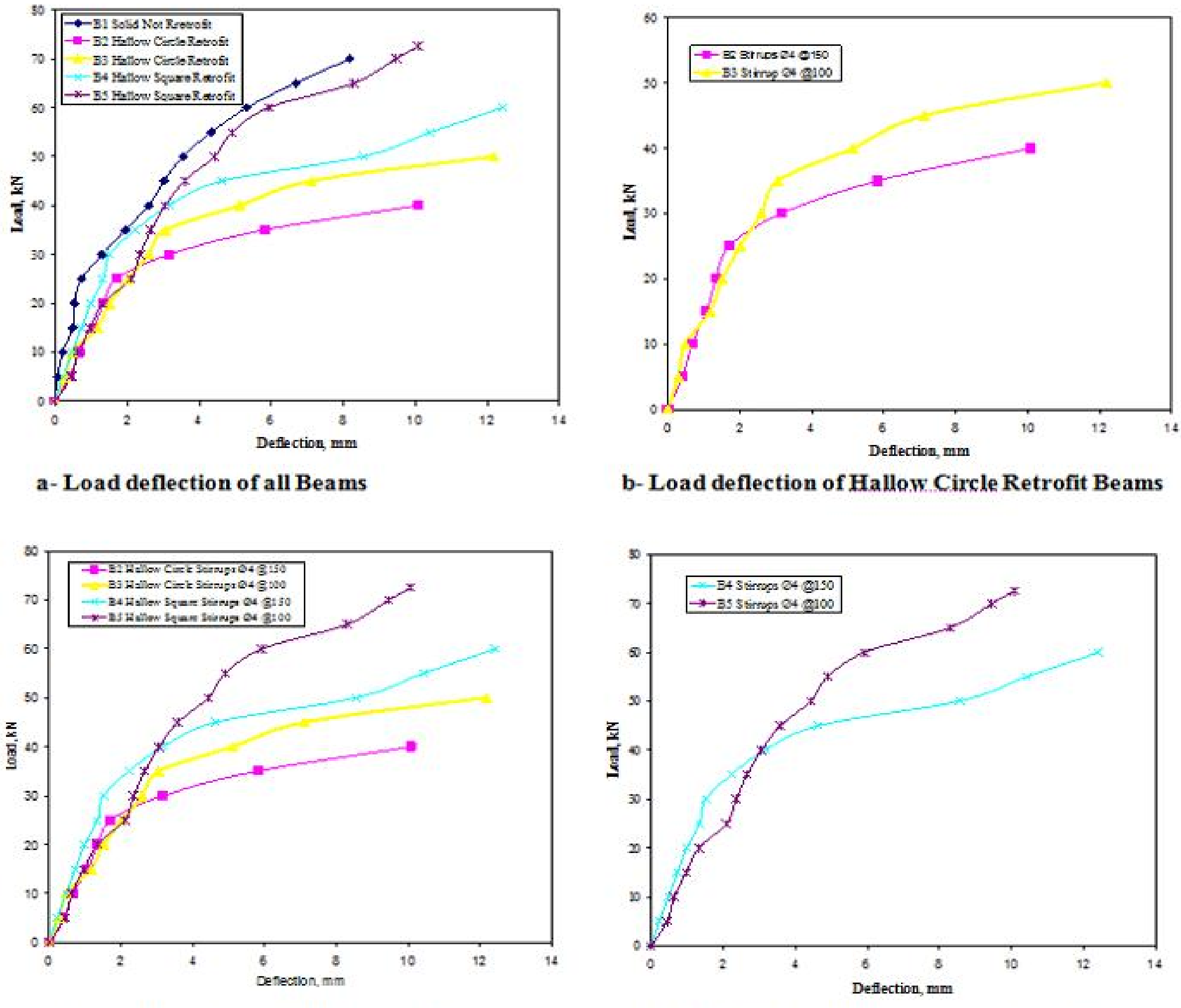
Fig.(4)Ultimate Load carrying Capacity

5.2 Crack Patterns:

It is clear that in all beams the hollow beams cracked at significantly lower loads than the solid ones. This indicates that the concrete core in the solid beams participates in increasing the cracking load. In general, the larger the applied loading relative to applied points loads, the larger the difference in the cracking loads as shown in Figure.(4).

Fig.(5) Crack Pattern of Tested Beam.

While the load deflection curves of Non-prismatic beams are shown in **Figure.(6 & 7).**



a- Load deflection of all Beams

b- Load deflection of Hallow Circle Retrofit Beams

d- Load deflection of Hallow Section Beams

c- Load deflection of Hallow Square Retrofit Beams

Fig.(6) Load deflection of Non-Prismatic Beams.

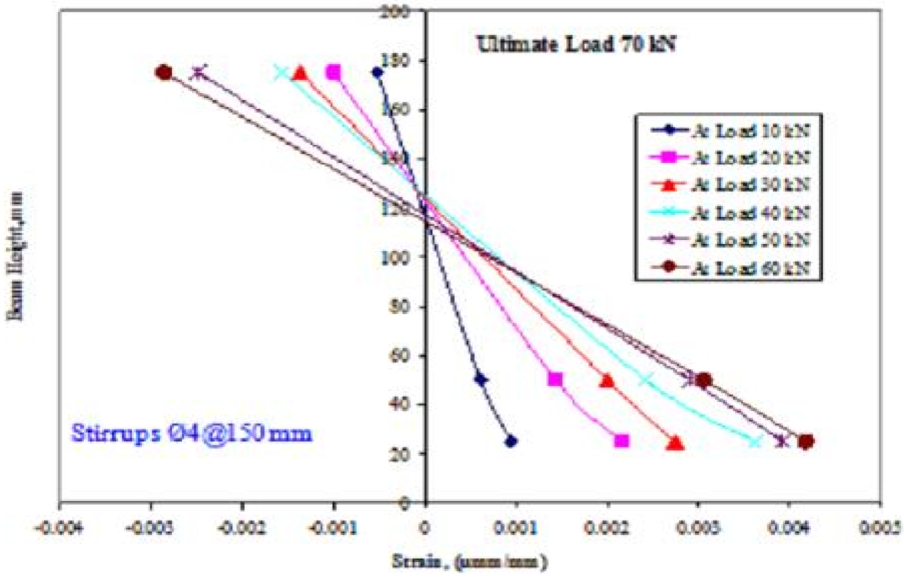


Fig.(7) Mid-Span Concrete Strain for B1 Control Solid, (Not Retrofit)

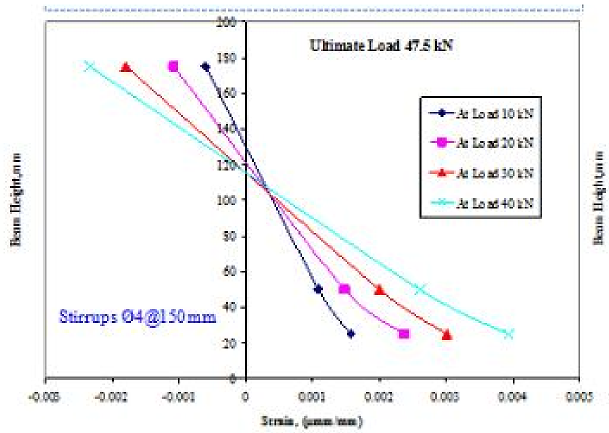


Fig.(8) Mid-Span Concrete Strain for B2 Hollow (PVC Circle)

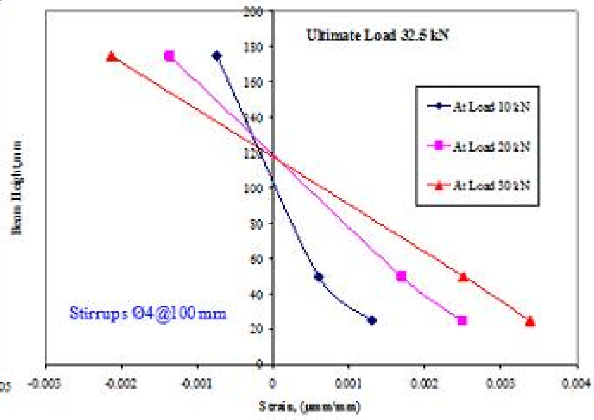


Fig.(9) Mid-Span Concrete Strain for B3 Hollow (PVC Circle)

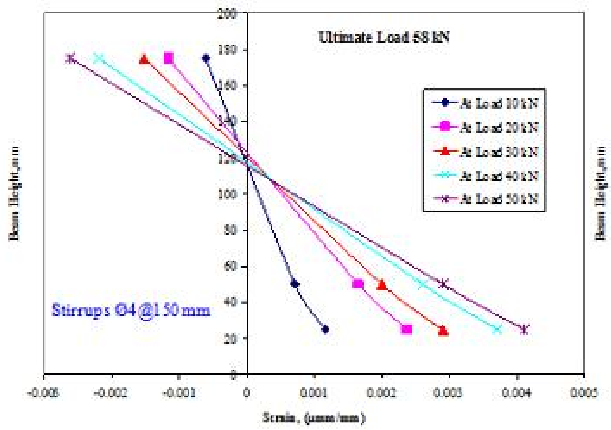


Fig.(10) Mid-Span Concrete Strain for B4 Hollow (Steel Square)

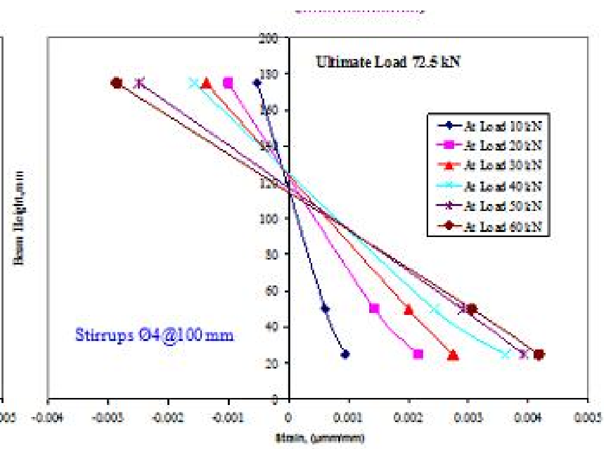


Fig.(11) Mid-Span Concrete Strain for B5 Hollow (Steel Square)

6. Conclusions:

A total of five hollow non-prismatic cross section beams were tested. Solid and hollow (Circle, square) beams subjected to two points concentrated load. The experimental work involved in this study was mainly to evaluate the effectiveness of external retrofitting by CFRP of hollow non-prismatic beams. Based on the experimental results, in terms of load-carrying capacity and strains in concrete, obtained from tests on concrete non-prismatic beams, retrofitting with external CFRP composite, it can be concluded that:

1. The (circle PVC pipe) is makes hollow recess in non-prismatic beams that contribute at decrease of load carrying capacity by about (53%) and increased in deflections and strain by about (40% and 25%) respectively compared with solid non-prismatic beams

for same properties. Also the (steel square pipe) that same function of PVC pipe but led to decrease in load carrying capacity by about (17%) and increased in deflection and strain by about (33% and 21%) respectively.

2. At two cases of hollow sections the increases in shear reinforcement led's to increases in load capacity by about (30%) and decrease in deflections by (24%).
3. Bonding CFRP to the bottom (tension) non-prismatic beams surface enhances load capacity and ductility of non-prismatic beams. The CFRP resists deformations due to the vertical concentrated loading, resulting in a confining stress to the concrete core, delaying rupture of the concrete and thereby enhancing both the ultimate compressive strength and the ultimate compressive strain of the concrete. The enhancements of CFRP by about (27%).
4. The steel square pipe that construct hollow section at non-prismatic beams retrofit with CFRP give more enhancement by about (56%) compared with circle PVC pipe for kept other properties. Also steel pipe is equivalent to solid non-prismatic beams that's result the steel pipe contributed in total steel reinforcement i.e. worked as composite section.
5. Crack are concentrated near support of non-prismatic beams retrofit with CFRP to formulated shear failure due to CFRP confined concrete at flexural zone and give more strength at this location to prevent failure of flexural.

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