Experimental Study of Pre-Cast Reinforced Concrete Deep Beams (Hallow Core section) Retrofitting with Carbon Fiber Reinforced Polymer (CFRP)

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ABSTRACT:

Experimental programs based test results has been used as a means to find out the response of individual elements of structure. In the present study involves investigated behavior of five reinforced concrete deep beams of dimension (length 1200 x height 300 x width150mm) under two points concentrated load with shear span to depth ratio of (1.52), four of these beams with hallow core and retrofit with carbon fiber reinforced polymer CFRP (with single or double or sides Strips). Two shapes of hallow are investigated (circle and square section) to evaluated the response of beams in case experimental behavior. Test on simply supported beam was performed in the laboratory & load-deflection, strain of concrete data and crack pattern of those five reinforced concrete beams was recorded. Parametric studies are also conducted in this study includes the effect of hallow opening (shapes and materials), and CFRP ratio (single, double strips and side horizontal stirrups). Comparisons of test results from experimental data are based on load capacity, deflection, crack pattern and strain of concrete for all beams. From this comparison it was found that hallow effect on strength capacity i.e. decrease by about (13%) and increased in deflection and strain by about (18%, 24%) respectively compared with solid section. Also find that CFRP give more enhancements in loading capacity by about (33 to 66%) and decreased deflection for same applied load by about (26%). Test results that show when sides of beams retrofit with CFRP strip against horizontal shear increased strength by about by (20%). Finally the using double CFRP strips for hallow section gives equivalent or more than strength capacity of solid section.

KEY WORDS: Hallow Core, Deep beams, First Crack, Deflection, CFRP (Single, Double & Sides) and Crack Pattern.

الدراسة العملية للعتبات الخرسانيةالمسلحة العميقة المسبقة الصب والمجوفة المقطع المعززة بألياف الكاربون البوليميرية

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الخلاصة:

البرامج العملية التي اساسها نتائج الفحوصات تستخدم لمعرفة الاستجابة للعناصرالمختلفة من المنشاء. هذه الدراسة شملت تحري سلوك خمس عتبات خرسانية مسلحة عميقة وبابعاد (الطول 1200ملم والارتفاع 300ملم والعرض 150ملم) تحت حملين مركزيين ونسبة فضاء القص إلى العمق كان (1.52). اربع من هذه العتبات كانت مجوفة المقطع ومعززة بالياف الكاربون البوليميرية (مفردة او مزدوجة او جانبية). تم تحري شكلين من التجويف (مربع ودائري) لتقييم الاستجابة لهذه العتبات عند الفحص العملي. الفحص تم في المختبر وبيانات الحمل الهطول والانفعال للخرسانة وانماط التشقق للعتبات الخرسانية المسلحة العميقة تم تسجيلة. المتغيرات في هذه الدراسة أخذت تأثير كل من التجويف (شكلة ومادتة) وتاثير التعزيز بالياف الكاربون البوليميرية. المقارنة للنتائج العملية تمت على اساس قابلية التحمل ومقدار الهطول وانماط التشقق وانفعال الخرسانة. من خلال المقارنة تم ايجاد ان المقطع المجوف يقلل من قابلية التحمل ويزداد الهطول والانفعال للخرسانة بمقدار (13%،18%،24%) على التوالي. كذلك وجد ان الياف الكاربون البوليميرية تعطي تحسينات أكثر في قابلية التحمل بحدود(33%-66%) وتقلل الهطول المقابل لنفس الاحمال بمقدار (26%). نتائج الفحص بينت عند

استخدام الياف الكاربون البوليميرية لتقوية جوانب العتبات لمقاومة قوى القص الافقية تزيد من مقاومة العتبات بمقدار (20%). اخيرا استخدام صفائح مزدوجة من الياف الكاربون البوليميرية ولمقطع مجوف تعطي قابلية تحمل مكافئة او اكبر من العتبات الغير مجوفة .

الكلمات الرئيسية: اللب المجوف ،العتبات العميقة ،التشقق الأولي ،الهطول ،ألياف الكاربون البوليميرية (مفردة ومزدوجة وجانبية)،أنماط التشقق
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INTRODUCTION

Concrete structural components exist in buildings and bridges in different forms. Understanding the response of these components during loading is crucial to the development of an overall efficient and safe structure. Different methods have been utilized to study the response of structural components. Experimental based testing has been widely used as a means to analyze individual elements and the effects of concrete strength under loading. While this is a method that produces real life response, it is extremely time consuming and the use of materials can be quite costly.

Long span bridges with very large size beams are constructed to accommodate high moment and shear demands. In particular, bridge beams with hallow section are designed in accordance with serve and maintain all part and mechanical or electrical i.e. all services. Many parameters may influence the overall hollow beams response such as: the shape of the section, the amount of the longitudinal and transverse reinforcement, the cross section thickness, effect of loading and finally the material strength of concrete and reinforcement. This research program focuses on circular and rectangular hollow cross sections and investigates the beams behavior under a state of two point concentrated load. Since the end of the Second World War, many advanced military technologies and products have been transferred to the civil engineering industry. FRP applied to structure retrofitting is one of the most successfully transferred technologies. During the last decades, the use of FRP has gained increasing popularity due to several properties such as: high strength to weight ratio; corrosion resistance; ease and speed of application; minimal change of cross-sections; possibility of installation without interruption of structure functions. For these reasons, FRP has been widely used in the retrofitting and strengthening of reinforced concrete structures, especially in regions under high seismic risk.

2. IMPORTANCE OF STUDY:

The objective of this study was to investigate and evaluate the use of hallow section that give same load carrying capacity of solid beam section, also to show effect of shear reinforcing, hollow materials (PVC or Steel) and CFRP on load carrying capacity, deflection, strain crack pattern and failure mode. At summery the evaluating is compared based on load, deflection, strain and crack patterns for both section solid or hallow section.

3. METHODOLOGY:

The experimental investigation involves the following:

1. Mix design of concrete for desired strength
2. Casting of beams with same proportion as concrete cylinder
3. Test of concrete cylinder at 28 days
4. Test of mild steel
5. Appling CFRP Strip after 28days
6. Test of beams after 2 weeks from applying CFRP Strips with resin.

4. EXPERIMENTAL PROGRAM:

Experimental program consist of test five R.C. beams, four with hallow core retrofit with CFRP with different parameters. The experimental program was conducted in the structural laboratory of the Civil Engineering Department at College of Engineering at the University of AL-Mustansiriya. The test beams dimensions of (length 1200 x height 300 and width 150mm) and properties are shown in Table (1). All beams were simply supported at bottom edges over clear length of (1100mm) and effective depth of (263mm). All specimens of shear span to depth ratio “a/d” equal to (1.52).

A schematic representation and photographs of the moulds and test setup and instrumentation are shown in Figs.(1,2,3&4).

After the specimen is placed in position, load was applied at the top face of beam by two points concentrated as shown in Fig.(4). The load was increased gradually at increments of (10 kN). The deflections were measured at center of specimens at each load increments using digital dial gauge accuracy of (0.01). The strain in concrete also measured at mid span with distance between centers of demec are (100mm) as shown in Fig.(4). Test was carried on continued till failure. Failure mode and crack patterns were recorded.

The mixing ratio is bases on some series test carried on trail mixed to give the compressive strength of cylinder concrete in range about (27 MPa). The mixing ratio that used in this study is (cement 1: sand 1.5: gravel 3) as shown in Table (2).

The deep beams retrofit with CFRP at three layouts i.e. one strip, double strips and sides strips as shown in Figs.(2 & 3) each strip of dimension (length 700 x width 50 x thick 1.2 mm), Four of reinforced concrete deep beams were retrofit by CFRP (Carbon fiber strip Sika CarboDurS512) applied with resin (Sikadur-30). The typical characteristic properties of CFRP are shown in Table (3). The resin system that was used to bond the CFRP Strip over the bottom and two side regions of beams in this work was the epoxy resin made of two parts, resin and hardener. The properties of the resin are shown in Table (3) “Arockiasamy”.

The use of make hole of diameter (150mm) at CFRP strips for all retrofit with CFRP led to not fail of CFRP, due to give good interlocking or good anchorage between CFRP and Resin and give good technique to construct. The main effect of these holes is to increase the reliability and repeatability of the failure behaviors to avoid failure of CFRP.

4.1The Process of Installation Procedures of CFRP Strip.

“Nimnim”, CFRP Strips were installed onto the concrete surface by manual lay-up in two steps. First, the primer was applied to the concrete surface. Next, the putty was used to level the surface. Then, the saturated, followed by the carbon fiber sheet and push lightly by hand applied. The components of the strengthening system are illustrated in Figs.(2 & 3) and the installation details of CFRP sheets are as follows:

1. Surface Preparation. Round the edges of specimens at the positions of strips. Next, sandblast the concrete surface until the surface of the concrete should be free of loose and unsound materials.
2. Application of the Primer resin. Apply a layer of epoxy-based primer to the prepared concrete surface using a short nap roller to penetrate the concrete pores and to provide an improved substrate for the saturating resin.
3. Application of the Putty. After the primer has become tack-free, apply a thin layer of putty using a trowel to level the concrete surface and to patch the small holes.
4. Application of Fiber Sheets. Each fiber sheet is measured and pre-cut prior to installation. Each sheet is then placed on the concrete surface and gently pressed into the primer resin. Prior to removing the backing paper, a trowel is used to remove any air void. After the backing paper is removed, a ribbed roller is rolled in the fiber direction to facilitate impregnation by separating the fibers.

5. TESTING PROCEDURE AND TESTING EQUIPMENTS:

The beams were tested after complete curing of concrete 28 days and after 2 weeks from apply CFRP composite materials to retrofit of hallow reinforced concrete deep beams to gives equivalents section that give same or more capacity of solid deep beams. These where tested under static loading conditions using a universal testing machine of capacity 3000 kN. Testing machine was used to apply the load by two concentrated points. Each deep beams of the clear spans of 1100mm to be tested was simply supported by two ends roller, two-inch diameter steel rollers located two inches from each end of the beam. A steel plate was inserted between the concrete and the steel roller to ensure that local failure did not occur at the support. For the point loading condition, a one-inch diameter steel ball bearing suspended between two steel plates was used to transfer the load evenly from the universal testing machine to the surface of the test specimen. To measured deflection used digital dial gauge of accuracy (0.01mm) at mid span under the beam, while strain of concrete measuring using demec points of distance (100mm) between centers of its and (50mm) from concrete edges . Fig.(4) shows the typical set-up used for the two-point loading conditions.

6. TEST RESULTS OF EXPERIMENTAL SPECIMENS:

Test results for each specimen are reported. Table (4) shows the measured cracking loads, ultimate loads, vertical displacement at mid span of beams and strain of concrete at top and bottom zone of all the specimens. The comparison between results are shown in Fig.(5) Figs.(6 & 7) shows the crack patterns of all specimens. The load deflection curves at points of mid span are illustrated in Figs.(8).

6.1 First Crack and Ultimate Load:

The first crack load and ultimate carrying capacity increased when used CFRP Strips to retrofit these beams, and when used steel square pipe to construct hallow zone and also led to give decreased in corresponding deflection. While the using pipe(PVC & Steel) to construct the hallow section decrease the load capacity and increase in corresponding deflection for the same properties. Also when used double strips of CFRP to retrofit of beams give more load capacity and decrease in deflection. These results can show in Table (4) and comparison shown in Fig.(5).

6.2 Crack Patterns of Tested Beams:

The failure of these Beams has occurred at the near support of the hollow beams, in Correspondence with Cores due to the change from the solid section of the deep beams core to the hollow section. The failure was particularly brittle with sudden crush of the concrete in compression and concrete cover spalling nears supports Figs.(6&7).

Fig.(7) show that crack begins increased of its width with increased applied load, also the retrofit flexural zone (tension face at bottom of all beams) give more enhancement of flexural.

Capacity and therefore shear stress concentrated at shear zone led's to shear failure. For all beams retrofit with CFRP no failure mode of (debonding or peeling off or …etc). Finally the retrofit of flexural zone led to that beam fail in shear.

6.3 Load Deflection and Strain Curves Behavior:

The comparison based on load-deflection at mid span at bottom of beams, which describe the behaviors of all tested specimens are shown in Fig.(8). The load-deflection curves are almost linear at the beginning of the loading, then getting inclination before the ultimate load. While the strain through depth are shown in Fig.(9).

7. CONCLUSIONS:

A total of five reinforced concrete deep beams were tested. One solid and the other of hallow (square steel or circle PVC pipes). All deep beams subjected to two points concentrated load, and shear span to depth ratio “a/d” equal to (1.52).Based on the test results for the range of the studied factors the following conclusions and observations can be made:

1. The existence of hallow (opening) at the center core part of the beam (along the beam) when used steel pipe retrofit with single strips of CFRP influenced the ultimate load value more than the existence of the opening at other case when retrofit with double strips or single strip with sides strips of CFRP of different hallow sections, where in the first case the load decreased by about 13% compared to the solid beam, although this beam retrofit with single strips of CFRP, while in the other case the load increased at different rates. This is because hallow in the first case intersects the flow of the force.
2. The first crack occurred at a load ranging from about 30 % to 36 % of the ultimate load depending on many factors (solid, hallow and Retrofit by CFRP).
3. Diagonal cracks at almost 45 degree formed within the third part at end near supports (shear span).
4. After shear crack occurred, the load decreased slowly, which attribute to shear interlocking and dowel action. Near ultimate load, the load is increased in a slow rate, while there is big increase in deflection.

5. All tested deep beams exhibited a shear failure mode of behavior characterized by diagonal cracks at almost 45 degree.
6. The experimental test result shown that presence of CFRP has important rule to increase the strength capacity even in the linear stage by about (33 to 66.7%) for single and double strip of CFRP.
7. The construction of reinforced hollow deep beams is feasible since they possess load carrying capacity approximately equal or more to that of reinforced concrete solid deep beams when used PVC pipe with retrofit single and side CFRP strips i.e. specimen of (DB5).
8. Also it is recommended to used Steel or PVC pipe to construct hallow section of Deep beams specimens(DB3& DB4) retrofit with double CFRP Strips at tension zone, these are feasible since they possess load carrying capacity approximately more to that of reinforced concrete solid deep beams by about (106.7%, 66.7%) respectively.
9. The use of make hole of diameter (150mm) at CFRP strips for all retrofit with CFRP led to not fail of CFRP, due to give good interlocking or good anchorage between CFRP and Resin and give good technique to construct. The main effect of these holes is to increase the reliability and repeatability of the failure behaviors to avoid failure of CFRP.
10. Ductility is increased by about (390 to 2170 kN.mm) in all cases for flexural loadings capacity when using CFRP to retrofit the reinforced concrete deep beams.

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Table (1): Details of R.C. Beams Specimens:

Specimen No.	Bottom Reinforced	Top Reinforced	Reinforced Stirrup	CFRP Size (mm)	Hallow size (mm)	Hallow Shape
DB1	3Ø12	2Ø12	Ø6 @150	---	---	---
DB2	3Ø12	2Ø12	Ø6 @150	700x50 Single	50x50	Square
DB3	3Ø12	2Ø12	Ø6 @150	700x50 Double	50x50	Square
DB4	3Ø12	2Ø12	Ø6 @150	700x50 Double	Ø50	circle
DB5**	3Ø12	2Ø12	Ø6 @150	700x50 Single	Ø50	circle

** This mean the beam retrofit with sides CFRP (Horizontal strips).

Table (2) Mix proportions for (1 m^3) of concrete (1: 1.5: 3) by Weight.

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

Table (3) 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		

Table (4) Properties of steel reinforcement

Nominal Diameter (mm)	Measured Diameter (mm)	A_s (mm^2)	Yield Stress f_y (MPa)	Tensile 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 (5) Compressive Strength of Concrete Cylinder (28 days).

Sample No.	Diameter (mm)	Load, (kN)	Strength, (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) Typical Moulds of Reinforced Concrete Deep Beams.

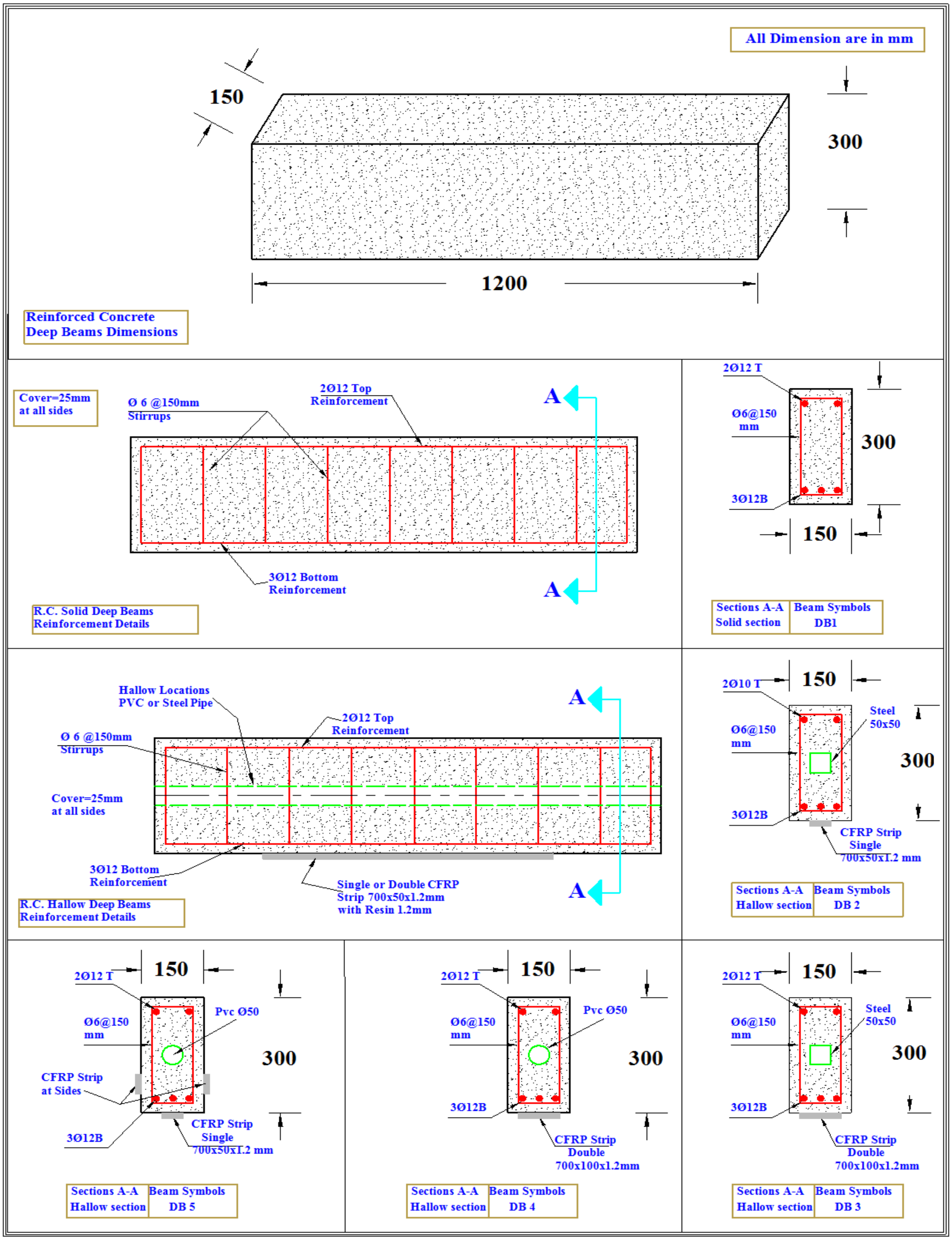


Fig.(2.1) Details of Reinforced Concrete Deep Beams

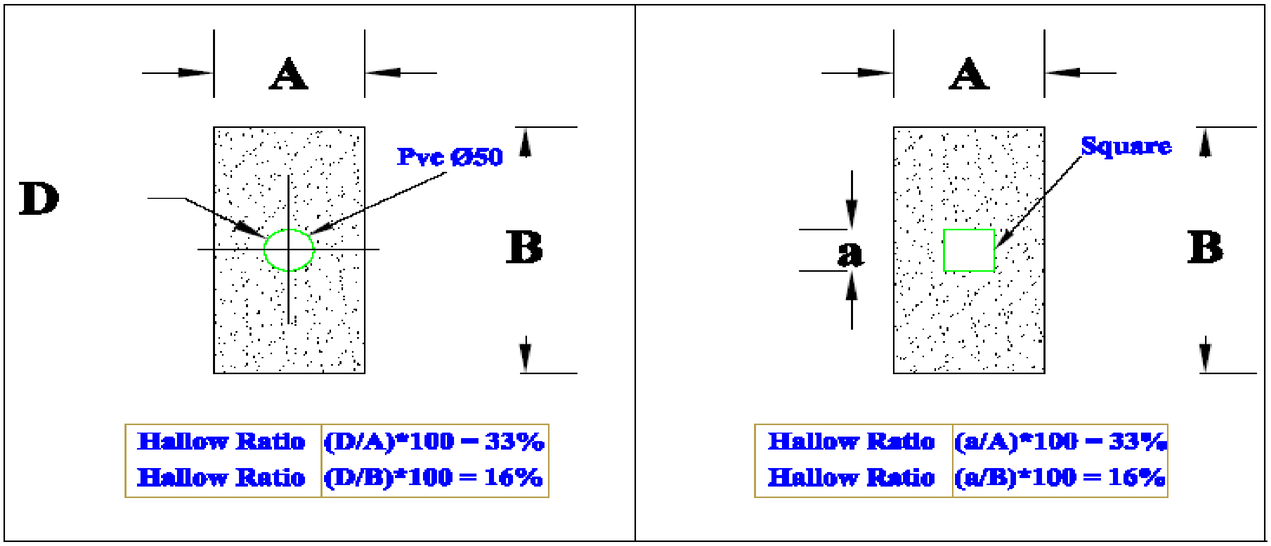


Fig.(2.2) Details of Hallow Ratio & Location (at center of cross section).

Retrofit Single Strip CFRP (DB2, DB5)

Retrofit Double Strips CFRP (DB3, DB4)

Retrofit Sides Strips CFRP with single. (DB5)

Fig.(3) Retrofit Systems Layout of Deep Beams used in this Study.

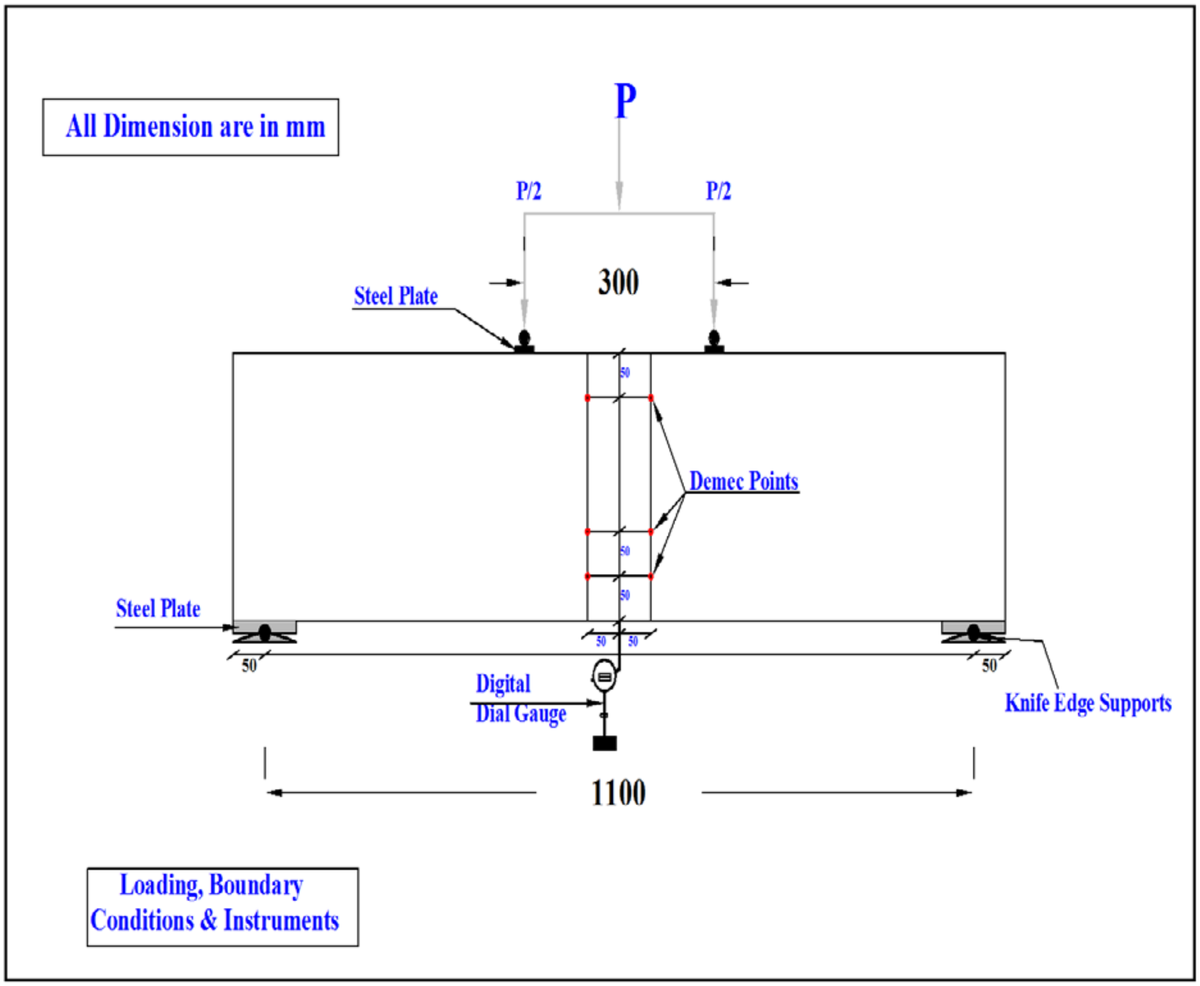
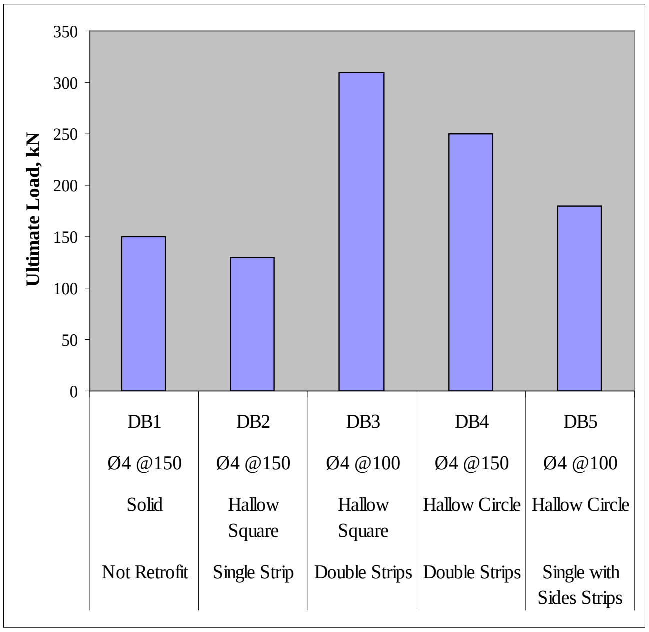


Fig.(4) Arrangement Specimens of Two-Point Loading and Instrumentation.

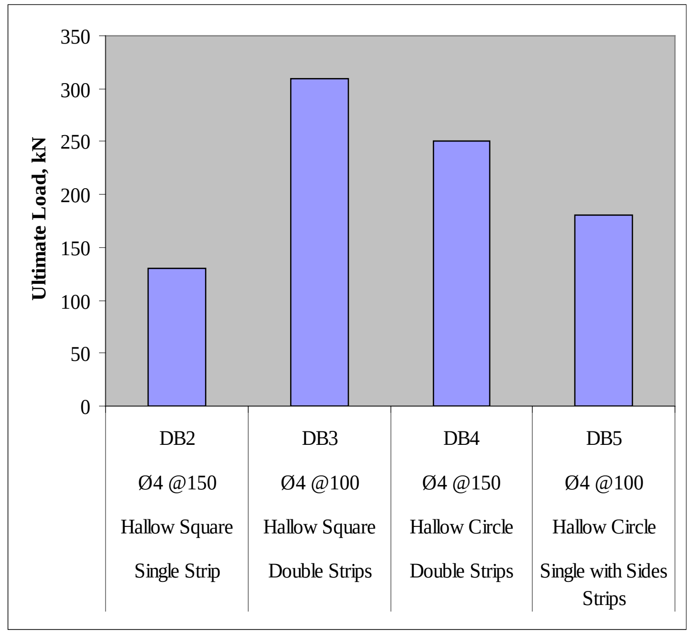
Table (4) Fist Crack, Ultimate Load and deflections

Beam No.	First Crack Load kN	Deflection mm at First Crack Load	Failure Load, kN	Deflection mm at Failure Load	Increased in Failure Load%	Failure mode
DB1*	45	0.95	150	8.43	----	Shear
DB2	40	1.34	130	6.02	-13.3***	Shear
DB3	90	1.01	310	14.31	106.7	Shear
DB4	83	0.81	250	8.67	66.7	Shear
DB5	65	0.76	180	8.82	20	Shear

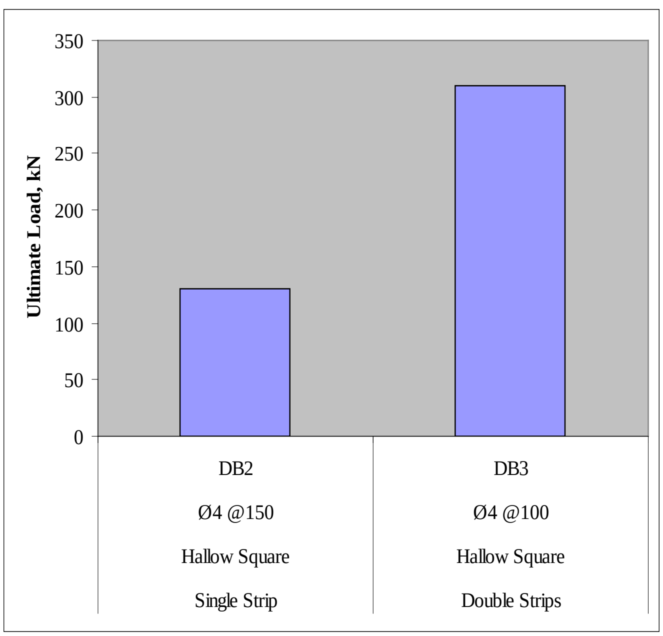
* This beam reference beam.
*** This mean decrease in failure load although this beam retrofit with CFRP due to hallow section and the CFRP ratio not enough to give strength capacity equivalent to solid deep beams.



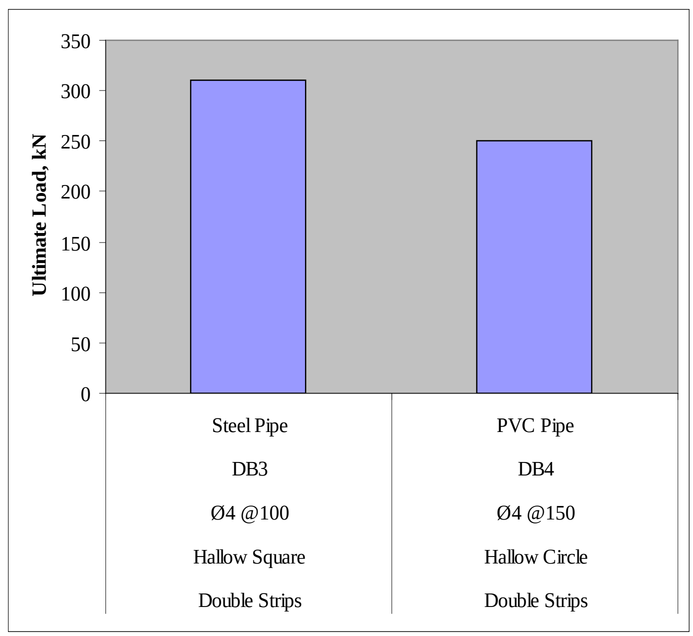
A- Ultimate load of all Beams



B- Ultimate load of Retrofit Beams



C- Ultimate Load of Hallow (Steel), Retrofit Beams



D- Ultimate Load of Hallow (Steel& PVC), Retrofit Beams

Fig.(5) Comparison of Ultimate Load carrying Capacity for Different Cases.

Fig.(6) Crack Pattern of Experimental Tested Retrofit Beams under Two Points Concentrated Load (at Tension Zone).

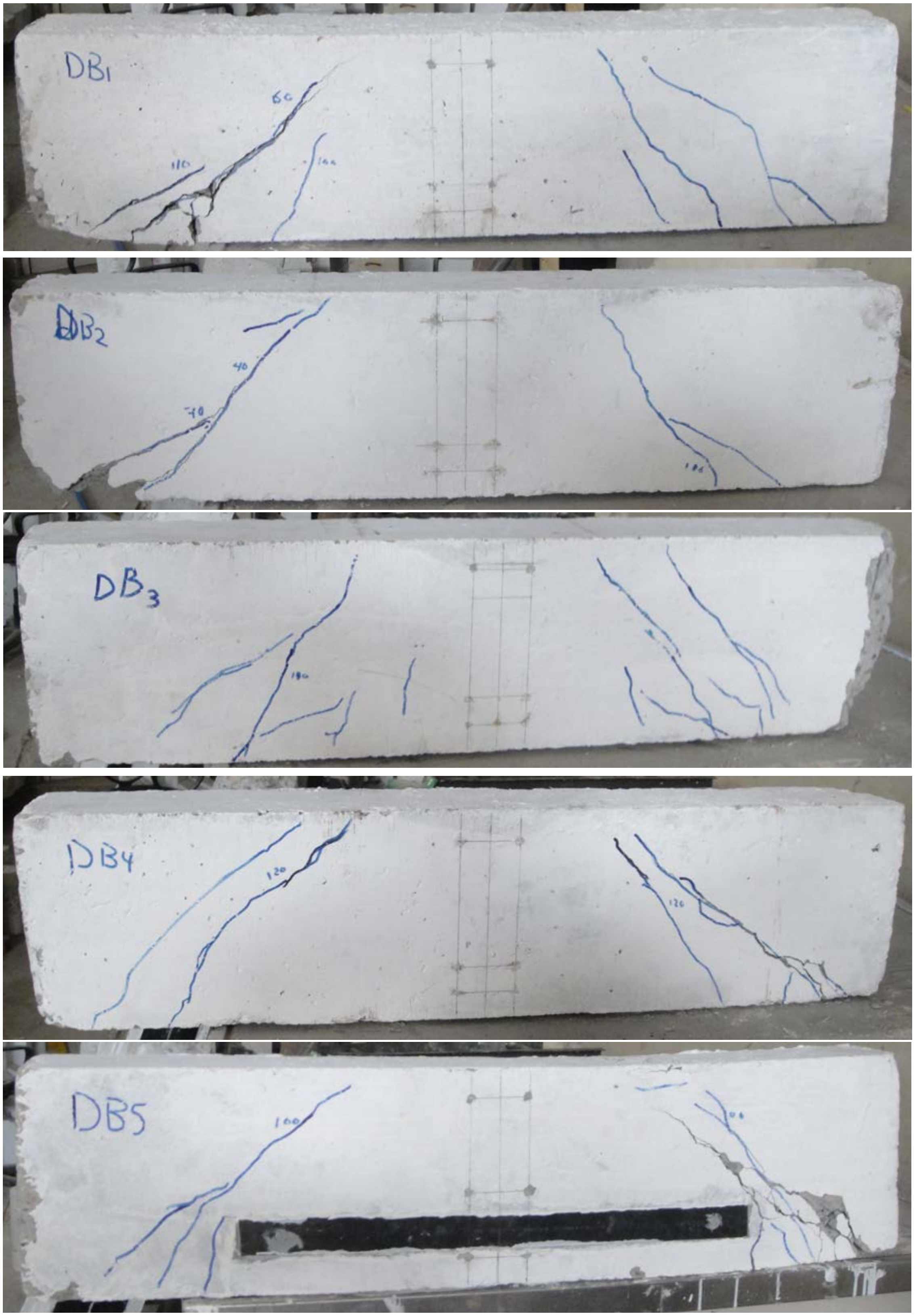
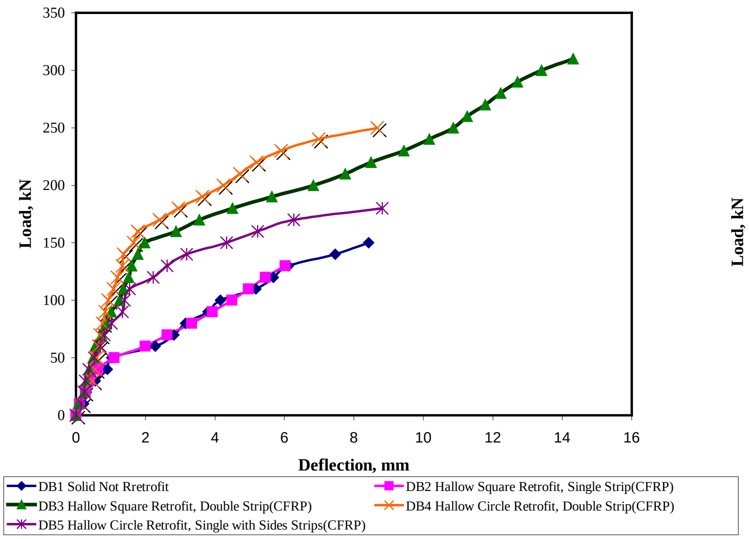
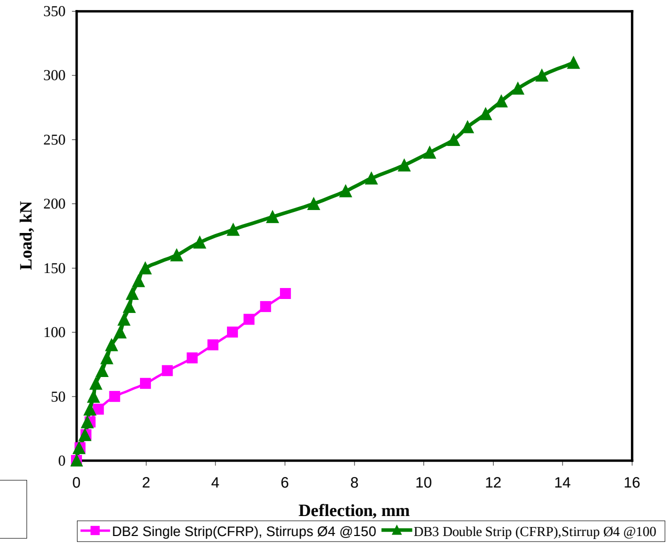


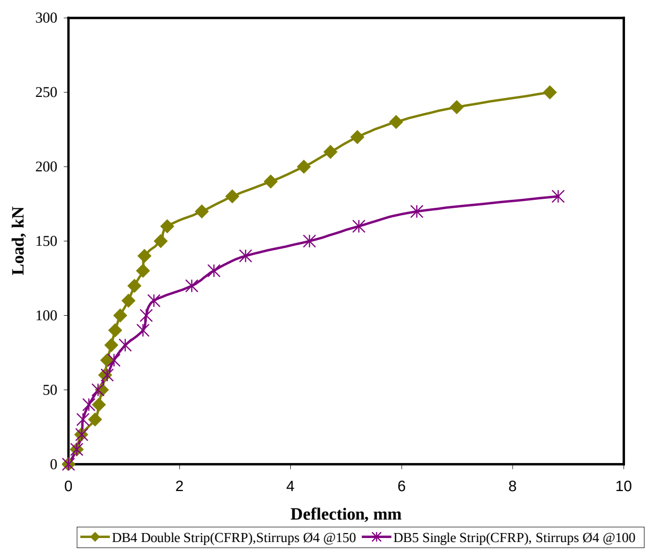
Fig.(7) Crack Pattern of Experimental Tested under Two Points Concentrated Load.



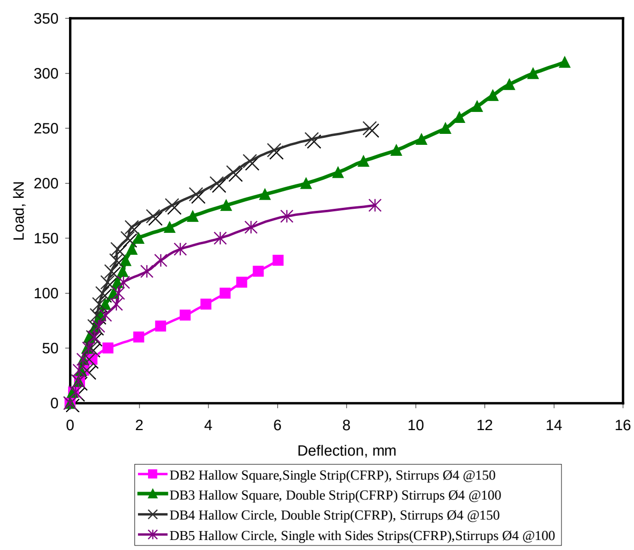
A- Load deflection of all Beams



B- Load deflection of Hallow Square (steel) Retrofit Beams



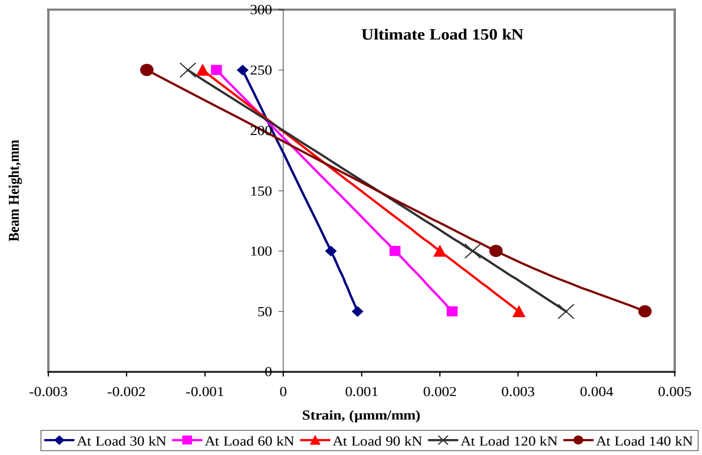
C- Load deflection of Hallow Circle (PVC Pipe) Retrofit Beams



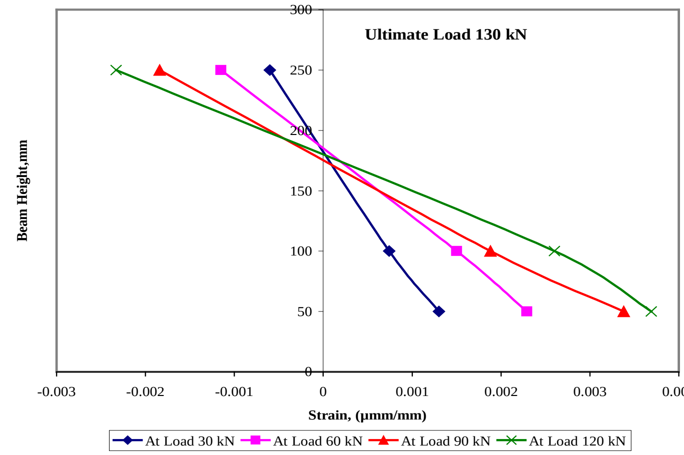
D- Load deflection of Hallow Section Beams

Fig.(8) Load deflection Curve of all Deep Beams.

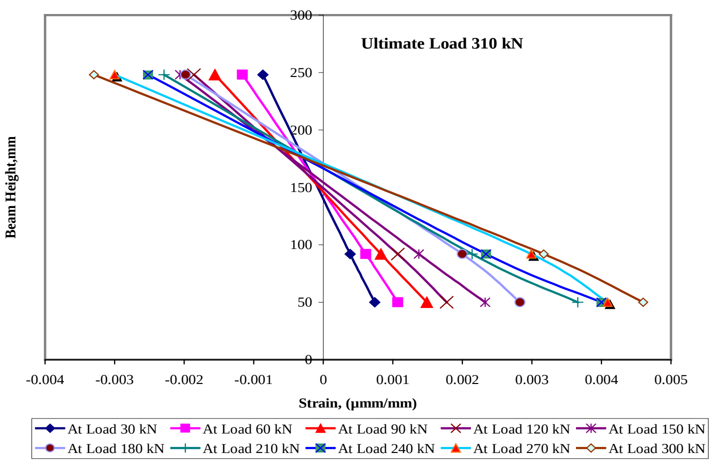
6.4 Mid Span Concrete Strains:



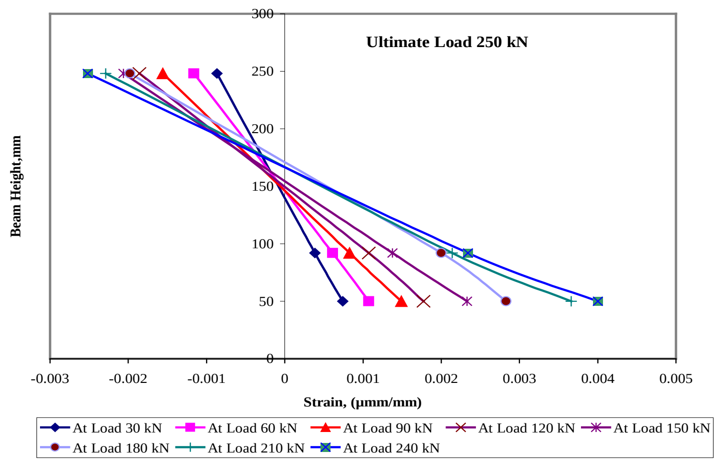
(1) Strain-Height Variation for DB1
Control Solid, (Not Retrofit)



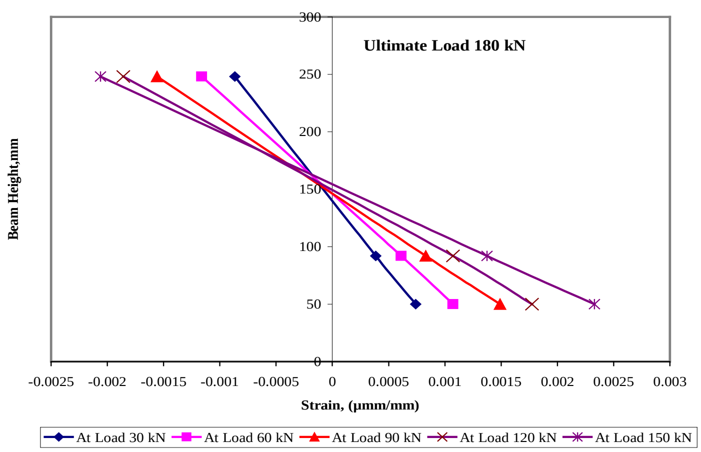
(2) Strain-Height Variation for DB2
Hallow (Steel Square), Single Strip (CFRP)



(3) Strain-Height Variation for DB3
Hallow (Steel Square), Double Strip (CFRP).



(4) Strain-Height Variation for DB4
Hallow (PVC Circle), Double Strip (CFRP).



(5) Strain-Height Variation for DB5
Hallow (PVC Circle), Single Strip (CFRP).

Fig.(9) Mid-Span Concrete Strain of all Deep Beams.