

Strengthening of RC Beam with Large Square Opening Using CFRP

Aya w.Naqe

M.Sc. Student

Department of Civil Engineering, University of
Baghdad,

Baghdad, Iraq,

E-mail: ayawaleed971@gmail.com

Dr. Alaa H. Al-zuhairi

Assist. Professor

Department of Civil Engineering, University of
Baghdad,

Baghdad, Iraq,

E-mail: alaalwn@yahoo.com

ABSTRACT

The use of essential services in modern constructions, such pipes, and ducts, became important, placing these pipes and ducts underneath the soffit of the beam. They made a ceiling sandwich, and that causes to reduce the height of the floor, so the presence of the opening in the beam saves the height of the floor. In this paper, the investigation of the beam response of reinforced concrete simply supported rectangle beams with square web openings is presented, including a number of the web openings (two, four, and eight), in addition to its use in strengthening the member at the openings (when the beam is planned before casting, internal deformation steel bar is used, and in case of the opening is existing in the beam, (CFRP) fabric is used.). The test results indicated that the opening Strengthening of beams might compensate for the decrease of the beam load capacity because of the existence of the openings in the shear zone. The compensation of beam capacity depends on the strengthening method, which was adopted. The shear crack loads of the strengthened with externally CFRP specimen's reduction ranging from (15.38 to 38.46%) of their failure loads while the shear crack load of internally reinforced strengthened ranging from (15.38 to 30.76%).

Keywords: Concrete beams, Weep openings, Square opening, Strengthening.

**تقوية العتبات الخرسانية المسلحة الحاوية على فتحات مربعة كبيرة في فضاءاتها باستعمال ألياف التسليح
كاربون- بوليمر**

اية وليد نقى

قسم الهندسة المدنية - كلية الهندسة - جامعة بغداد

أ.م.د علاء حسين الزهيري

قسم الهندسة المدنية - كلية الهندسة - جامعة بغداد

الخلاصة

استخدام الخدمات الأساسية في الإنشاءات الحديثة ، تصبح هذه الأنابيب والأنابيب مهمة في وضع هذه الأنابيب والقنوات تحت فتحة الشعاع وصنع شظيرة في السقف وتؤدي إلى تقليل ارتفاع الأرضية وبالتالي يحفظ وجود الفتحة في الشعاع ارتفاع الأرض. في هذه الورقة ، تم تقديم دراسة عن استجابة الشعاع للخرسانة المسلحة عوارض المستطيل المدعومة ببساطة مع فتحات شبكة مربعة. بما في ذلك عدد فتحات

*Corresponding author

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الويب (اثنان ، أربعة وثمانية) والاستخدام في تقوية العضو في الفتحات) عندما يتم تخطيط الحزمة قبل الصب ، في هذه الحالة ، استخدم قضيب فولاذي داخلي للتشوه وفي حالة وجود فتحة في شعاع استخدام (CFRP) النسيج .(أشارت نتائج الاختبار إلى أن تقوية فتح الحزم قد تعوض عن انخفاض سعة تحميل الحزمة بسبب وجود الفتحات في منطقة القص. يعتمد تعويض قدرة الحزمة على طريقة التعزيز التي تم اعتمادها. أحمال صدع القص في المقوى مع انخفاض عينة CFRP خارجيًا تتراوح بين (15.38 إلى 38.46٪) من أحمال عطلها ، في حين أن حمولة صدع القص من المقواة داخليًا تتراوح من (15.38 إلى 30.76٪).

الكلمات الرئيسية: العتبة الكونكريتية ، الفتحات ، الفتحات المربعة ، التقوية.

1. INTRODUCTION

Pipes and ducts are necessary to accommodate essential services in a building, so openings are needed, which can be circular, square, or rectangular. The presence of an opening in reinforcing concrete beam makes many problems in the web of beam behavior and that affect beam stiffness and cause an increase in the cracks and the deflection and an increase in the reduction of the capacity of the beam and also increase in the stress at the corners of the opening (**Mansur, September 2006**). There are many kinds of strengthening. In this search, two kinds were used. The first one, when the beam is planned before casting, where the internal steel rebar is used above and below the opening of the beam. The second one, when the opening is existing in the beam which used (FRP) materials, can be used to restore the original capacity. The combined with low weight and fiber-reinforced polymer (FRP) material with high strength to weight ratio is advantageous for this type of material.

Furthermore, FRP materials with high corrosion resistance are satisfactory in terms of the requirement of durability. Typically, the FRP materials are in the form of rods, strips, sheets, and laminates or fabric. Carbon Fibre Reinforced Polymer (CFRP) fabric was used as a reinforcement material in this research. A detailed research program was carried out. However, a great deal of work has been found in the literature aimed at examining the reinforcement of beams with openings. (**Mansur et al., 2006**) investigated the use of FRP plates for strengthening reinforced concrete T-beams with small circular opening. (**Abdalla et al., 2003**) studied shear strengthening with the rectangular opening of reinforced concrete beams using FRP sheets. (**Maaddawy and Sherif, 2009**) studied the use of FRP sheets for shear strengthening of deep concrete beams with square openings. At the same time (**Pimanmas, 2010**) investigated the Strengthening of concrete beams with square opening by FRP rods mounted externally.

2. MATERIALS PROPERTIES

2.1 Cement

The cement used in this study was ordinary Portland cement, produced by (Tasluja-Bazian) United Cement Company) in Al-Sulaymaniyah / Iraq (IQ.S.No40, 1984).

2.2 Fine Aggregate

As a fine aggregate, natural and normal weight sand from the Al-Akhaidher area was used. The results of fine aggregate indicated zone 2 according to the requirements of the (IQ.S. No45, 1980), as showing in **Fig. (1a)** (**ASTM Standards, July 2003**).

2.3 Coarse Aggregate

Gravel using the maximum size (19) mm (AL-Anbar, Iraq) of the Al-Niba'ee area was used as a coarse aggregate for concrete mixtures only. **Fig. (1b)** shows the requirements specification limits of coarse aggregate.

2.4 Water

The clean tap water was used in this experiment and throughout this study in both mixing and curing of all specimens of beams.

2.5 Superplasticizer

Supaflo (PC200) is a high performance, polycarboxylic-based super plasticizing admixture. **PC200, 2014.**

2.6 Steel Reinforcement

The tested beams employed four sizes of steel reinforcing bars, as longitudinal reinforcement sized deformed bars (Ø16) mm and (Ø10) mm were used. And closed stirrups deformed-size steel bars (Ø 8) mm were used, and for diagonal reinforcement the size of bars (Ø12) mm.

2.7 Carbon Fiber Reinforced Polymer (CFRP)

Strengthening of unidirectional woven carbon fiber in this fabric known as Sika Wrap-900c (CFRP, October 2017) was used for external analysis, as showing in **Fig. (2).**

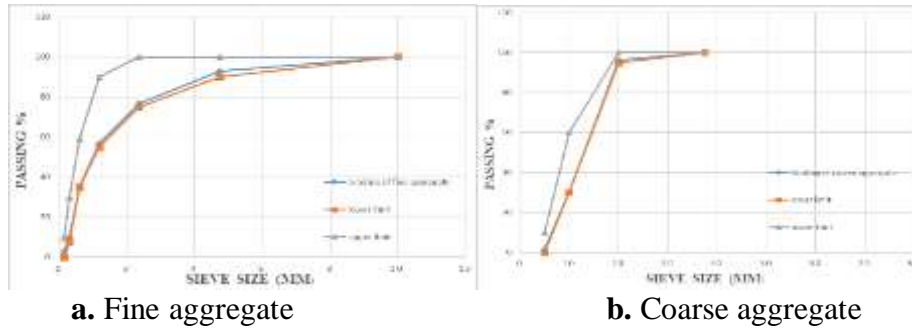


Figure1. Specification limits of aggregate.



Figure 2. (CFRP) Sika Wrap-900c.

3. CONCRETE MIX DESIGN

The concrete mixture was designed using (ACI) (318, 2014) method to obtain the concrete mix constituents that achieve a strength of 30 N/mm^2 . The concrete mix is designed depending on the strength of concrete according to the requirement of the (ACI) (318, 2014) code that was adopted to get a suitable concrete mix permitting to test the result of sand and gravel. The final mix used is showing in **Table 1.** Before casting was started, the molds were lubricated with oil for easy removal of specimens from the molds. Once the mold has been prepared and arranged, the concrete was delivered and gradually poured into the mold.

Table 1. Concrete Mix Design.

For 1 m ³ of concrete	Cement (Kg)	Sand (Kg)	Gravel (Kg)	Water (L)	Superplasticizer (L)
	380	850	1005	165	5



4. TEST SPECIMENS

The use of additional reinforcement (longitudinal near the top and bottom of beam opening edge) and the stirrups (in both top and bottom and next to the opening end) was to maintain the beam integrity beyond cracking without any failure, the design of this reinforcement is according to (ACI) (318, 2014).

A series of six reinforced concrete beams with stirrups (8) mm bars and the space of (70) mm from the end of beams and with concrete cover (15) mm was used for all tested beams as showing in Fig. (3)to (6).

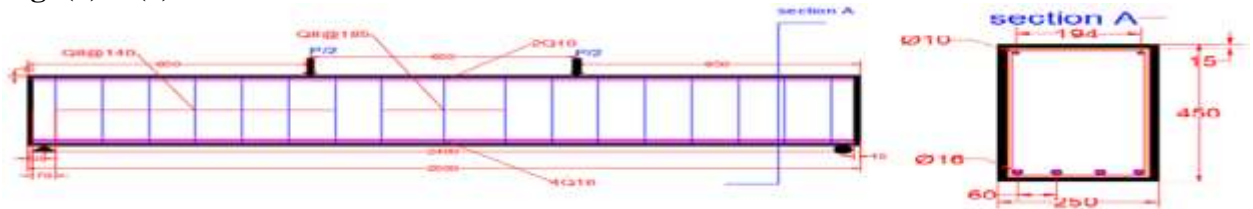
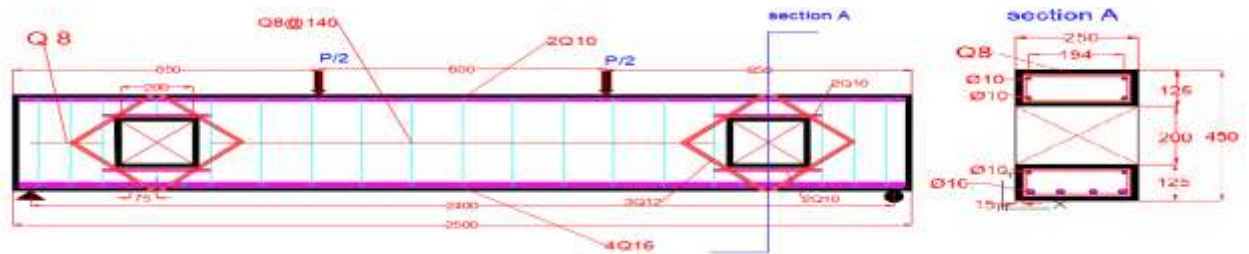
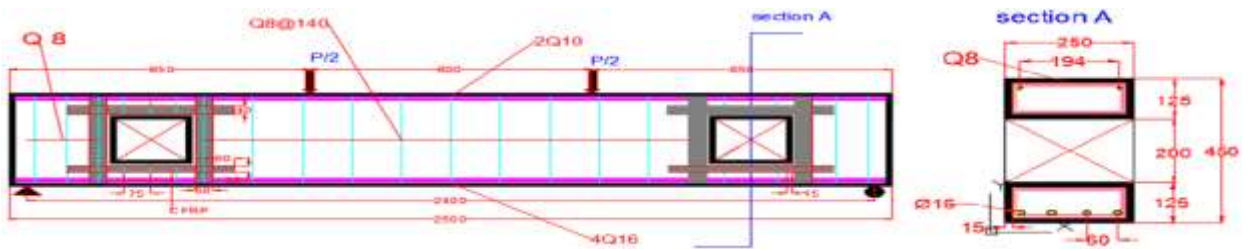


Figure 3: Details of Controlled Beam

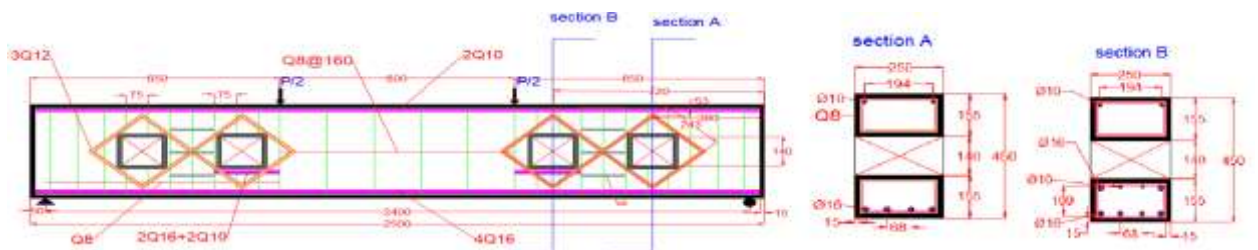


a. Internally reinforced

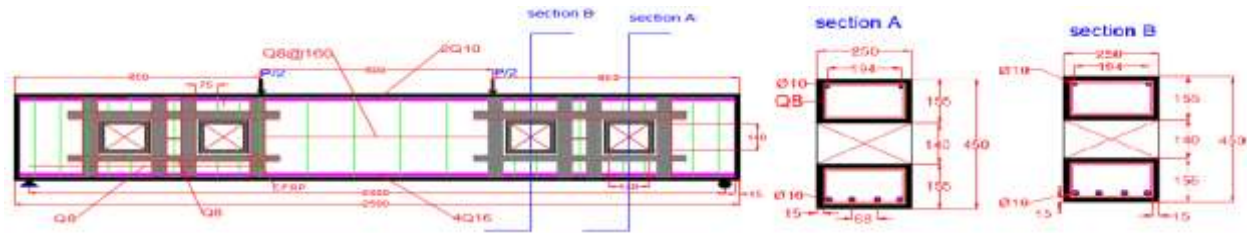


b. Externally strengthening using (CFRP)

Figure 4. Details of Beam with Two Square Opening.

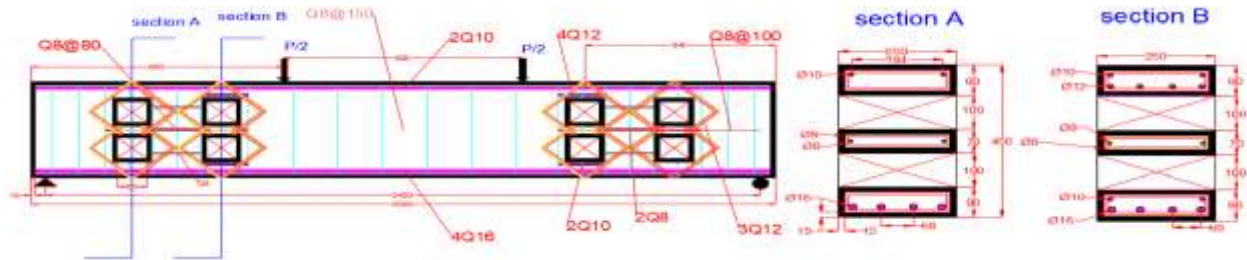


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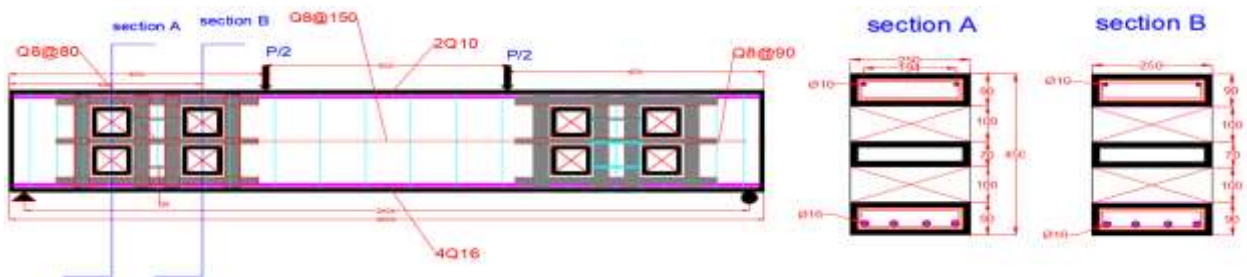


b. Externally strengthening using (CFRP)

Figure 5. Detailing of Beam with four Square Opening.



a. Internally reinforced



b. Externally strengthening using (CFRP)

Figure 6. Details of Beam with eight Square Opening.

All beams have the same interior steel reinforcement. The longitudinal flexural tensile reinforcement is (4 ϕ 16) deformed steel bars, the longitudinal compression reinforcement is (2 ϕ 10) deformed steel bars. While the vertical shear reinforcement (stirrups) is design with (ϕ 8 @ 140 mm) as shown in **Table 2**.

Table 2. The Steel Reinforcement Detail.

NO.	Specimen symbols	Main Rebar details	Transverse Rebar details	stirrups	CFRP
1	C.B	4Q16	2Q10	Q8@140mm	without
2	RCBSO2	4Q16	2Q10	Q8@140mm	without
3	RCBSO4	4Q16	2Q10	Q8@160mm	without
4	RCBSO8	4Q16	2Q10	Q8@150mm	without
8	RCBSO,2	4Q16	2Q10	Q8@140mm	with



9	RCBSO,4	4Q16	2Q10	Q8@160mm	with
10	RCBSO,8	4Q16	2Q10	Q8@150mm	with

All beams have the same size of (250×450×2500) mm, the clear span L_n is taken (2300) mm. One of the beams was solid as a reference beam, and (6) with an opening. The square opening is with cross-section [(200x200), (140x140), (100x100)]. All openings have additional reinforcement above and below and have a small stirrup. Additional rebar in the top and bottom chord member, and the design detail of each beam is shown in **Table 3**.

Table 3. Detailing of Top and Bottom Chords Member.

NO.	Specimen symbols	first opening rebar			second opening rebar		
		top chord	Between opening	Bottom chord	top chord	Between opening	Bottom chord
1	C.B						
2	RCBSO2	2Q10		2Q10			
3	RCBSO4						2Q16+2Q10
4	RCBSO8		2Q8		4Q12	2Q8	2Q10

The distance between the start of the first opening and the support was (210) mm, which is approximately half the specimen's effective depth. And in the post for beams with 4 or 8 (multiple web openings) fail (i.e., the dimensions between the two openings when those openings are closed) (**Shammari, 23 October 2015**). If the width of the post is less than (3/8) the depth of the web, the post width for two and square opening was about (3.8/8) of the area as shown in **Fig. (7)**.

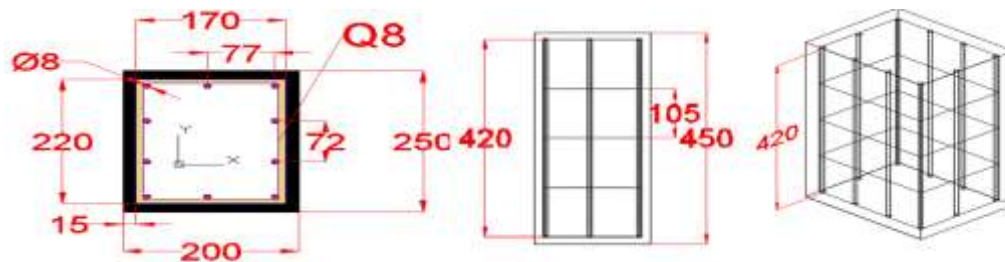


Figure7. Details of Beam with four or More Opening Post.

For the beam reinforced with carbon fiber, after 28 days from casting the beams, the CFRP sheets applied around the opening of beams were strengthened with CFRP (SikaWrap-900C type) (**CFRP, October 2017**). They were cut into segments and placed top and bottom as horizontal layers, and next to the same opening in the vertical layer making one square layer around the square openings beam, as in **Fig. (8)**.



Figure 8. Application of Carbon Fiber Reinforced on opening .

5. MATERIAL PROPERTIES

Table 4 shows the properties of reinforced concrete, steel, and fiber-reinforced polymer used in this research.

Table 4. Properties of the materials.

Material	Diameter, (mm) Thickness, (mm)	Yield strength,(MPa)	Compressive strength,(MPa)	Tensile strength,(MPa)	Modulus of elasticity,(GPa)
concrete	----	----	30	3	26
steel	8	392.52	----	589.97	200
	10	600.25	----	693.25	
	12	578.91	----	686.48	
	16	576.68	----	673.22	
CFRP	0.478	----	----	3800	242
Epoxy resin	----	----	----	45 (7 days at +23°C)	3.5 (7 days at +23°C)

6. TEST SETUP AND INSTRUMENTATIONS

1. All beams were tested using a universal (load-cell) testing machine (MFL system) with a maximum capacity of (1000kN) used to test the control and beam specimens bonded with a load data logger (**Ahmed, S., Ali, 2007**). Various factors, such as the type of loading, influence the effectiveness on the beam, the boundary conditions at the simply supported beam that was used in this study (**Rafa'a, Mahmood Abbas, 2015**).
2. Using a mechanical dial gauge of (0.01) mm accuracy, the vertical deflections were measured at the mid-beam span. The gauge is positioned under the bottom of the measured beam during the test procedure.
3. In the present study, strains have been measured carefully by using a data logger (strain indicator Datalogger) used for measuring strains in steel and concrete reinforcements. It is a multichannel, automated data logger for reading strain gauges and transducers, it connects to the computer, and we install a special Data logger program and the readings of the mechanical strain gauge shown in the computer in the form of Excel files.
4. After (28) days of curing, as shown in **Fig. (9)** the surfaces of the specimens were painted with color white to simplify the identification and notating of cracks during the loading process. Each beam has been tested individually. Rectangle beams specimens were placed inside the testing frame and adjusted so that the centerline of point loading, supports, and dial gauges were fixed in the correct locations. Strains using both mechanical strain gauge and data logger, crack width, and deflections were recorded at the end of each load increment.



Figure 9. Rectangle Beams Specimens Ready to Test.

7. EXPERIMENTAL RESULTS AND DISCUSSIONS

7.1 Cracking Behavior and Mode of Failure

Gradually, the solid beam shown in **Fig. (10)**, was tested to be a control beam to compare its behavior with other beams containing openings. In the tension zone of the beam experiment, the crack lines appeared and propagated vertically to the neutral axis. The flexural cracks increased by increasing the load and followed by diagonal cracks, which eventually lead to a sudden brittle, shear zone failure.

The openings significantly influenced the presence and distribution of cracks in the shear span area as showing in **Fig. (11)** compared to the solid beam. At earlier loads, as the load increased, inclined shear cracks developed from the diagonal edges of the opening and then propagated to the support and load points of all beams. Such cracks were simultaneously introduced with a distinct harsh sound at both sides of the beams above and below the openings. With a few increments, bending cracks began to form from the soffit of the beam. The test results showed that for the reinforced specimens, the appearance of shear cracks was somewhat later than the reference beam. This is related to the increase in stiffness due to the restraining effect of the strips.

Initial cracks at the four corners of the square opening were redirected into flexural cracks formed along the beam's tension line, due to the presence of CFRP around the opening. The presence of CFRP laminates disturbs the propagation path that required higher energy to redirect the cracks into flexural cracks along the mid-span. Hence, compared with unstrengthened beams, greater beam efficiency was achieved. It's clear that circle opening strengthened with CFRP takes comparatively more load than that of square opening beams, and the load-bearing capability of the reinforced beams primarily exceeds that of the control beams. The load-carrying capacity is therefore improved by the externally bonded CFRP composites.



Figure 10. crack patterns of the solid beam.



Figure 11. crack patterns of beams with opening.

7.2 Load-Strain Relationships

The strain was measured for concrete and steel. In general, when the load increases, the distributions of strain change from linear approximate at lower load to nonlinear at higher load, and because of that, the neutral axes move upward slightly to the compression face in the cross-section of the beam and because of that development of tension cracks as showing in **Fig. (12)**.

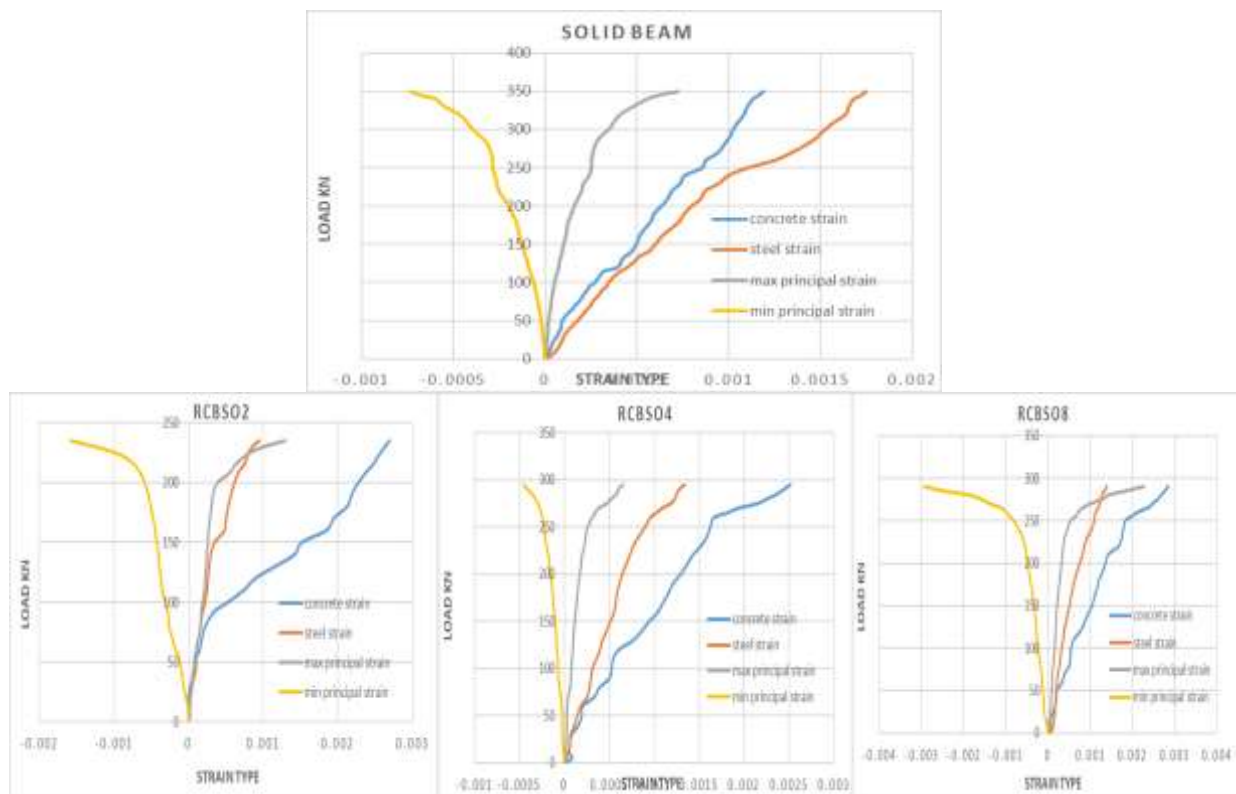




Figure 12. The experimental test of beams strain.

7.3 Load-Deflection Relationship

Table 5 shows load-mid-span, shear cracks, and flexural load-deflection relationships at dial gauge at mid-span. The use of reinforcing steel as an internal reinforcement is sufficient than the use of carbon fibers reinforcing polymer fibers due to the results shown in Fig. (13), where The application of the strengthening technique introduced in this study greatly increases beam deflection, monitor cracks around the openings, and reduce the total beam load capacity. Comparing the results, it can be seen that the addition of the reinforcement above and below the square opening decreases the ultimate deflection capacity of the beam and also increases the stiffness of the square opening in the beam.

Table 5. Test results of Load-Deflection.

Group	Beam symbols	Shear Force Effects		Flexural Force Effects		Ultimate Force Stage		Pcrs /Pu %
		Pcrs kN	Δcrs mm	Pcrf kN	Δcrf mm	Pu kN	Δu mm	
Solid beam	C.B	130	1.3	85	0.73	350	7.12	37.14
Opening beam	RCBSO2	90	1.05	80	0.91	235	5.93	38.29
	RCBSO4	110	0.69	80	0.45	295	6.22	37.28
	RCBSO8	100	0.7	90	0.62	290	6.65	33.89
	RCBSO,2	80	0.95	110	1.39	175	4.73	45.7
	RCBSO, 4	100	0.91	100	0.91	245	6.12	40.8
	RCBSO,8	100	1.05	80	0.89	225	5	44.44

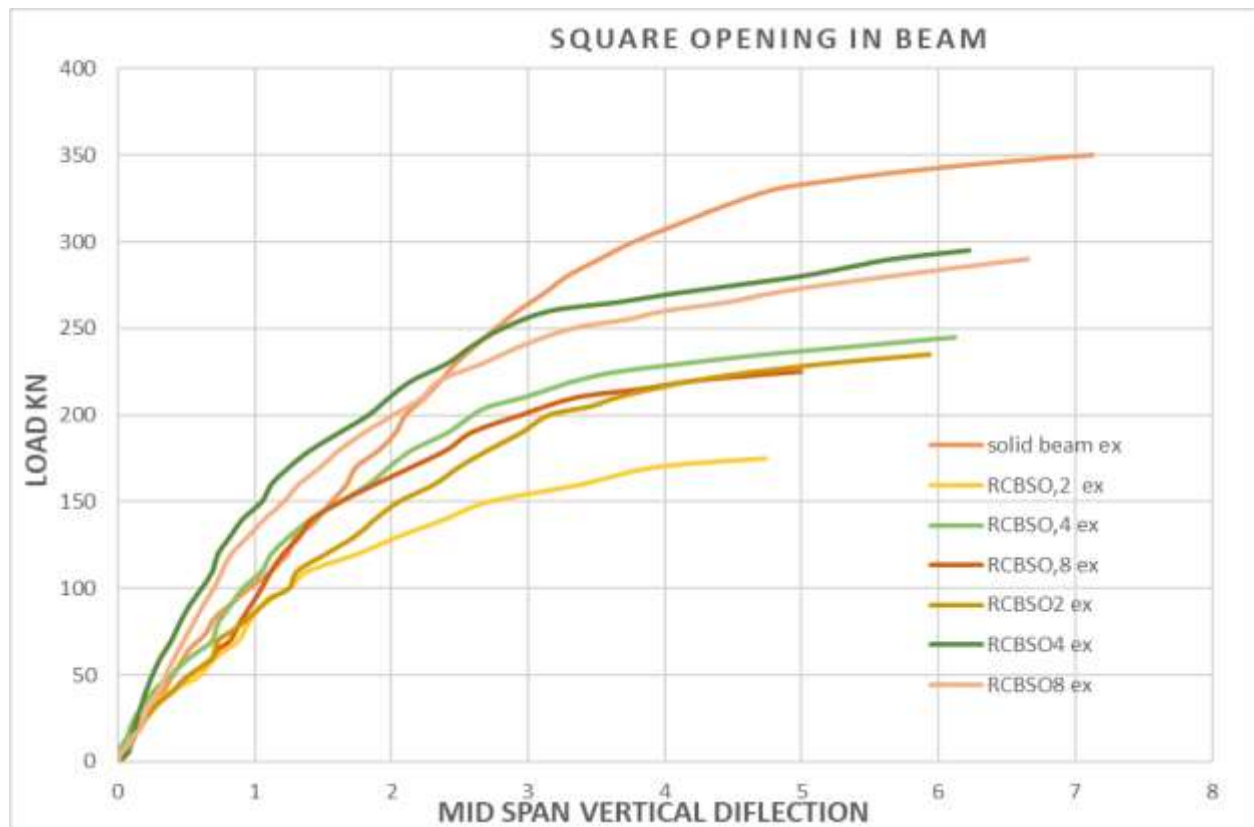


Figure 13. Load- deflection curve of strengthening reinforced concrete beam.

8. CONCLUSIONS

1. All of the tested beams in this research had failed in shear. This failure in the solid beam was marked by a diagonal split type, which occurred along the load path (i.e., a line connecting the outer edge of the bearing plate and the inner edge of the supporting bearing plate). For the beam with opening, the failure occurred by splitting along the diagonal crack connecting the load positions and the support positions with the opening tangents against the loading points.
2. All strengthened specimens have shown a little drop in surface strain values distribution than the reference beams.
3. The bonding in the shear region between the CFRP strips and the concrete beams slightly delayed diagonal cracks and gave them good control of their subsequent expansion.
4. The presence of openings in the shear influenced the behavior of the beam. It was evident that the reduction in shear crack loads to the ultimate load-carrying capacity of the beam with openings ranging from (33.89 to 45.7%).

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