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Repairing of Reactive Powder Concrete T-Beams Containing Web Opening by CFRP Strips

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A B S T R A C T

In modern buildings, transverse openings are often used beams for the purpose of supplying and service pipes. Due to the presence of the openings in the concrete beams lead to the formation of cracks around the openings due to the stresses concentration in a small area above and below of the opening. The repairing, maintenance, and upgrading of structural members, are maybe one of the most pivotal problems in civil engineering applications. In this research, an experimental work is conducted to study the behavior of the reinforced RPC T-beams that containing openings and repair this beams using CFRP strips. The Experimental program of the present study includes two parts, the first part includes testing of seven reinforced reactive powder concrete RPC T-beams, which casted and tested, one beam is without opening as a reference beam and the rest, were provided with an opening. and these beams are divided into two groups. The first group was used to study the effect of the openings shape (circular and square) and the second group was used to study the effect of the openings locations, which consists three locations (Lc/2, Lc/3 and Lc/4). These are measured from the support center to the openings center. While the second part including a repaired all beams in the first part the using carbon fiber polymer. The test results indicated that the presence of openings in the beams web caused a reduction in the reinforced RPC T-beams ultimate load carrying capacity with about (10-55)%, Also lead to increasing in deflection compared to control beam before repairing at same loading. Studying the shape effect showed that the beams with square openings have average ultimate load carrying capacity lower by 36% compared with the control beams. While beams with containing circular openings have average ultimate load carrying capacity lower 29%. From the test results, it could be concluded that the presence of the openings in the shear region led to a decrease in ultimate load carrying capacity a about 38% to 49% for opening of opening at (Lc/3 and Lc/4) respectively. While the presence of openings in the flexural region led to a decrease in the ultimate load carrying capacity rate of 11%. Related to the repairing study part it was found that the average ultimate load carrying capacity for repairing beams was 103% compared with the not repaired beams.

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اصلاح عتبات خرسانة المساحيق الفعالة ذات المقطع T الحاوية على فتحات في منطقة الجذع بشرائح الالياف

الخلاصة

في المباني الحديثة غالبا ما يتم استخدام الفتحات المستعرضة في العتبات لغرض مد القنوات والانابيب الخدمية. نتيجة لوجود الفتحات في العتبات الخرسانية فأن ذلك يؤدي الى تولد شقوق فيها حول الفتحات نتيجة لتركيز الاجهادات في منطقة حول الفتحة. واحدة من أكثر المشاكل المحورية في تطبيقات الهندسة المدنية هي إمكانية إعادة

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تأهيل الأعضاء الانشائية وتصليحها وتقويتها. في هذا البحث تم اجراء دراسة تجريبية لدراسة سلوك عتبات خرسانة مساحيق فعالة ذات المقطع T الحاوية على فتحات في منطقة الجذع وإصلاح هذه العتبات باستعمال الياف الكاربون البوليميرية . تضمن البرنامج العملي للدراسة الحالية جزئيين الجزء الأول تضمن فحص سبع عتبات خرسانية ومن ضمنها عتبة سيطرة بدون فتحات. وقسمت هذه العتبات الى مجموعتين الأولى استخدمت لمعرفة تأثير موقع الفتحات حيث تتألف من ثلاث مواقع على مسافات مختلفة وهي (Lc/3, Lc/2 و Lc/4)مقاسة من المسند الى مركز الفتحة اما المجموعة الثانية فقد استخدمت لدراسة تأثير شكل الفتحة (دائرية او مربعة). اما الجزء الثاني فتضمن اصلاح كافة العتبات المذكورة في الجزء الأول بعد فحصها وتحميلها للفشل باستعمال الياف الكاربون البوليمرية. أشارت نتائج الاختبار نتيجة وجود فتحات في شبكة الحزم أدى إلى انخفاض في قدرة تحمل عتبات خرسانة المساحيق الفعالة بنسبة (10-55)٪، كما يؤدي إلى زيادة في الانحراف مقارنة بحزمة التحكم قبل الإصلاح عند نفس الحمل. في دراسة تأثير الشكل وجد أن العتبات ذات الفتحات المربعة لها متوسط قدرة تحمل بنسبة 36٪ مقارنة مع عتبة السيطرة بينما العتبات التي تحتوي على فتحات دائرية لها متوسط قدرة تحمل أقل بنسبة 29٪مقارنة مع عتبة السيطرة بينما العتبات. من نتائج الاختبار، يمكن أن نستنتج أن الفتحات الموجودة في منطقة القص أدت إلى انخفاض في قدرة التحمل بنسبة 38٪ إلى 49٪ للفتحات الدائرية والمربعة عند المواقع (Lc / 3 و Lc / 4) على التوالي ، في حين أدى وجود فتحات في منطقة الانثناء أدى إلى انخفاض في قدرة تحمل العتبات بنسبة 11 ٪ مقارنة مع عتبة السيطرة. وفيما يتعلق بجزء دراسة التصليح ، فقد وجد أن متوسط قدرة التحمل القصوى لإصلاح العتبات كانت 103٪ مقارنة بالعتبات قبل الاصلاح.

1. INTRODUCTION

For modern buildings, the existence of openings inside beams are more often used to supply passage for utility ducts and pipes which are necessary to supply the essential services. The services including of water supply, air conditioning, telephone line, power accommodate, sewerage and computer network. These openings could have various sections and sizes such as rectangular, circular or square [1].

In the present time, the phenomenon of the construction of openings inside the concrete beams has spread without considering the design requirements for the effect of the existing of openings. As a result of the creation of these openings without any precautionary measures, for example reducing the load on the structures, which leads to a failure in these beams and in this case, we will study the possibility of repairing of these beams using CFRP laminates and the role of these fibers in the beams repair.

According Somes and Corley [2], A circular opening may be considered small when its diameter less than 0.25 of the height of the web while, the opening may be considered large when the diameter more than 0.25 times the height of the web. However, the presence of the opening in the web of the reinforced concrete beams leads to many problems in the beam behavior including the reduction in beam stiffness, excessive cracking and deflection, reduction in beam capacity. Furthermore, the inclusion of openings leads to high-stress concentration around it, especially at the opening corners for square opening. The reduction of area in the total cross-sectional dimension of a beam changes the simple beam behavior to a more complex one [3,4].

Nilesh and Patel [5], studied the behavior of RC beam with openings web. The variables which dependent in this study are the size of openings 90 and 110 mm and the location of the opening L/8 and L/4. Five RC beams in this research one of these beams without opening was used as a control beam and the rest were containing opening. The tested results showed that increasing the diameter of opening caused the increase in reduction of ultimate strength 60.11% and 32.19% for beams with diameter of openings 110 and 90 mm respectively. For location at L/8 compared with solid beam, while for beams with opening at locations L/4 was 48.14% and 24.14% for 110 and 90 mm diameter of opening, respectively compared to solid beam and the mode of failure of the beam changed as well as the failure mode of the beam changed when increasing diameter of an opening.

Majeed [6] experimental and numerical study of the effect of the openings in concrete beams and strengthening using CFRP laminates. Three specimens of beams were made of reinforced concrete. The first specimens are without of opening and it is the control beam. for the other two specimens were containing openings at the shear zone, one of which is strengthening with CFRP laminates. These specimens were also modeled using nonlinear analysis FEM. The results showed that the presence of openings in the beams led to a decrease in the strength of the RC beam 16.18%, while for the strengthened beam, the decrease in the strength of the RC beam by 3% compared with control beam. The deflection of the beam with opening decreases 25% compared with the control beam. While the deflection for strengthening beam increase about 92.3% compared to control beam. Al-Sulayfani and Al-Hamdani [7], Studied the behavior of RC –beams with an opening in the shear area under repeated loading. Its experimental program includes two variables cross section of the opening (circular, square and rectangular) and the effect of the diameter change of the circular openings (100, 125 and 150) mm. The results showed that the presence of openings in the beams led to a decrease in the strength of the RC beam 14-50% and causes an increased a deflection 25.5-39.2% compared to the reference beams.

AL-Sheikh [8], Studied the flexural behavior of reinforced rectangular concrete beams with an opening. The variables that have been adopted in his study are the effect of the size of openings with different locations on ultimate failure load and failure mode. If the results show that the sharp reduction in ultimate load of the beams that contain openings in the shear zone either in the beams with openings in the flexural zone show a low reduction in the ultimate load.

Al Allaf and Belal [9], studied the effect of the presence of openings in the RC Beams on the shear strength. The variables that have been adopted in their study are the effect of the length of the opening on the behavior of the RC-beams with distance from support to the center of an opening was constant. The study showed that presence an opening in the shear zone of beams caused the reduction in the strength of beams and effect on the shear failure mode, and any increas in the depth of the opening lead to early cracking, more deflections, and the less ultimate load of failure.

Meikandaan and Murthy [10], they studied repair of damaged reinforced concrete beams using CFRP laminates. Were cast Six the specimens, out of these six specimens three specimens were tested until failure while the remaining three samples were tested for up to 70% of ultimate load and these three specimens were then repaired using CFRP laminates. the test results showed when using FRP laminate improves from the ultimate load carrying capacity; retard crack formation and energy absorption capability of reinforced beam with FRP laminates.

2. MATERIALS

2.1. Cement

The used cement in mix was "Ordinary Portland cement" (type1) from Sulymania Almas manufactory. The chemical composition and physical properties of this type of cement are conformed by the Iraqi Specification No.5/1984 [10].

2.2. Fine Aggregate (quartz sand)

The used sand in mix was (Quartz sand) with maximum particle size 0.6mm which is a standard used sand for producing reactive powder concrete. This type of sand is produced by CONMIX Company in UAE The grading of this sand type is stratifying the Iraqi Specification No.45/1984 [11].

2.3. Silica Fume

Silica fume is a highly active pozzolanic material and is made as by-product from the manufacture of Silicon or Ferro-silicon metal from CONMIX company. The mineral admixture added to the mixtures of the research as partial replacement weight of cement. The chemical composition and physical properties of silica fume stratify to requirements of ASTM C1240-04 [12].

2.4. Superplasticizer (S.P.)

The used superplasticizer in this work is commercially called MegaFlow110, the properties of the superplasticizer conform the requirements of ASTM C494 Type A and F [13].

2.5. Mixing Water

For mixing and curing ordinary tab water was used for all the concrete specimens in this work.

2.6. Steel Reinforcement

Deformed steel bars of nominal diameter (ϕ8mm) with 680MPa yield stress were used as beams main reinforcing bars in tension face, while (ϕ6mm) deformed steel bars with 672MPa yield stress were used as stirrups, compression reinforcement and transverse reinforcement of flange stratify to requirements of ASTM A615M-05a [14].

2.7. Carbon Fiber Reinforced Polymer CFRP Laminates

For the purpose of repairing the damaged concrete beams, unidirectional CFRP laminates type sika warp-301C were used with thickness of 0.168 mm. Both yield strength, tensile strength, elasticity modulus and percentage of ultimate elongation until at failure were adopted from the manufacture datasheet.

2.8. Epoxy Adhesive

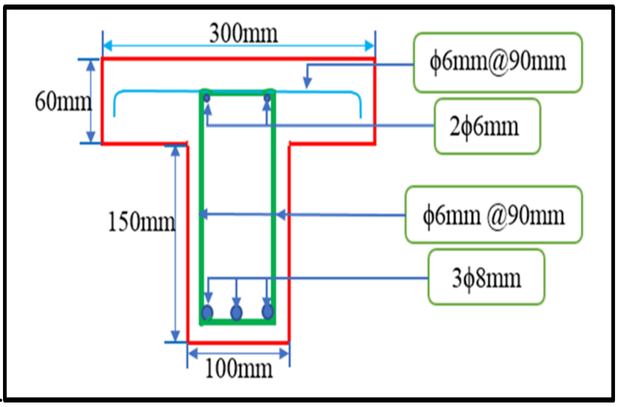
Sikadur®-330 is recommended by CFRP manufacturer to bond CFRP to the concrete. The mixing ratio of the epoxy was four parts resin of component A (white paste) to one-part hardener component B (grey paste) by weight.

3. REACTIVE POWDER CONCRETE MIXES

"Reactive Powder Concrete" mixes consist of cement, fine sand (quartz sand), silica fume, superplasticizers and water were used to cast RPC T-beams. Materials Proportions of mix are listed in Table 1. Many trail mix proportions were conducted to get the best trail proportion according to its compressive strength.

4. BEAMS DETAILS

The tested beams were designed according to ACI318M-14 specification code, with a suitable dimension that can be manufactured, handled, and tested as easy as possible. The dimensions of the tested beams were 1000 mm in overall length, thick of flange 60 mm, width of flange 300 mm, width of web 100 mm and 150 mm depth of web. Fig. 1 shows the details of the tested beams. All beams are simply supported with net span of 900 mm tested under the action of two-point loads as shown in Fig. 2.



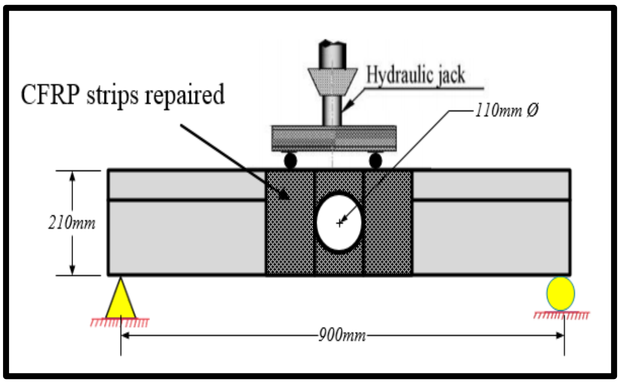
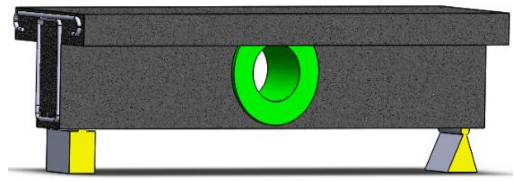


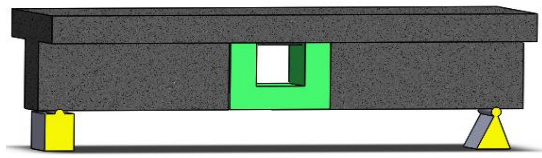
Fig. 1. Schematic of the beam test.

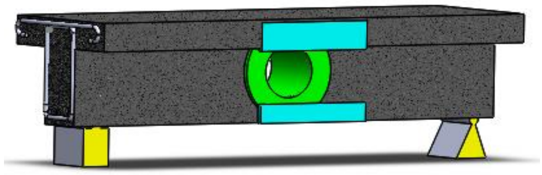
Table 1
Mix proportions.

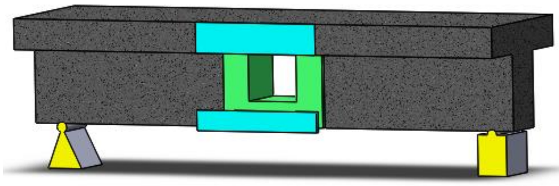
Ingredient	Quartz sand (600 µm)	Cementitious		Water **	SP ***
		Cement	Silica fume *		
Quantities (kg/m^3)	1000	900	100	220	18

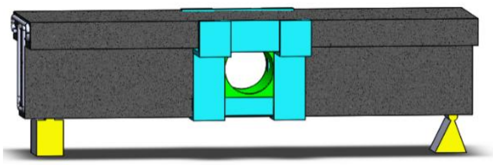
* 10% Silica Replacement ratio of cement weight.
** water/cementitious material (w/cm) = 0.22.
*** 1.8% of cementitious materials (cement + silica fume) by weight.


1. Configuration of a circle opening internal face strips.


1. Configuration of a square opening internal face strips.


2. Configuration of horizontal strips.


2. Configuration of horizontal strips.


3.Configuration of vertical and horizontal strips.

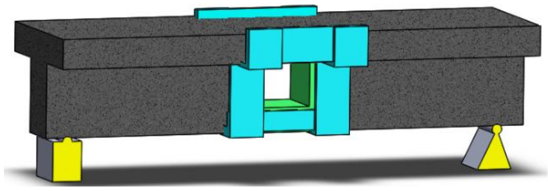

3. Configuration of vertical and horizontal strips.

Fig. 2. CFRP Laminates Repaire configuration of tested beams.

Table 2
Test beams.

Beam Specimen	Opening	Dimensions (mm)	Location (mm)
B1solid	NO	-	-
BC-CNS	Circular	110	450
BC-BNS	Circular	110	300
BC-ANS	Circular	110	225
BS-CNS	Square	100×100	450
BS-BNS	Square	100×100	300
BS-ANS	Square	100×100	225

In order to make it easy to recognize the description of each beam, abbreviation of words had been used. So alphabetic letter "B" will refer to the beam; and the second letter "C and S" will refer to the shape of opening that is circular and square, respectively. While the third letter "C, B and A" will refer to opening location that is mid of clear span, one third of clear span and quarter of clear span, respectively.

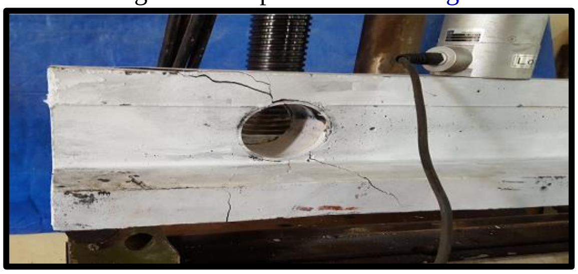
5. EXPERIMENTAL PROGRAM

The experimental program in this work includes a parametric study to investigate the behavior and load carrying capacity of singly reinforced RPC T-beams with openings. The studied parameters are:

1. Effect of opening shape where two shape are studied, circular opening with diameter 110mm and square opening with dimension 100x100mm
2. Effect opening location, where three locations (for circular and square openings) (Lc/2, Lc/3%and Lc/4) were used to investigate the influence of the opening location on the behavior of RPC T-beams.
3. The using of CFRP to repair pre-tested beams mentioned in (1) and (2).

6. REPAIR METHODOLOGY

Repair process of the beams is shown in Fig.3, including steps which are: cleaning the beams, injecting and filling the cracks using epoxy and finally application of CFRP strips. Seven beams were wrapped on the area of failure using CFRP strips as shown in Fig. 3.



(a) Before repaired.

(b) After repairing around the opening.
Fig. 3. The beam testing.

7. BEAMS TEST

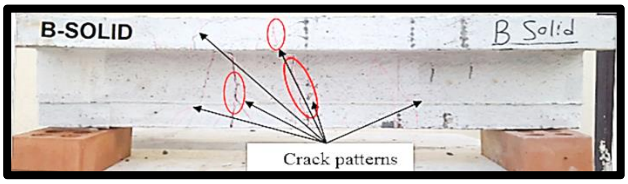
All beams were cured for 28 days period, and then coated with white color so that cracks can be easily detected. All beams were tested using a universal testing machine of 2500kN capacity under static loads until failure. A dial gauge of 0.002 mm accuracy was attached securely to the bottom of the tension face of mid-span to measured deflection in beams. The tested beams were simply supported over an effective span of (900mm) and loaded at two-point, load Fig. 4.

Fig. 4. Beams under testing.

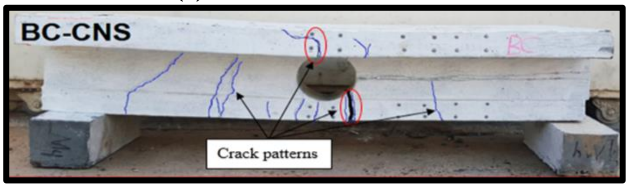
8. RESULTS AND DISCUSSION

8.1. Crack pattern

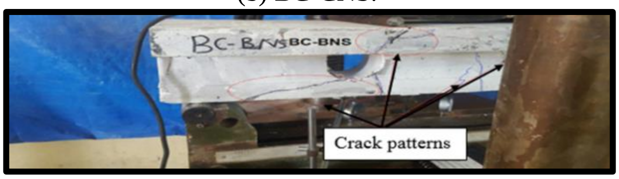
The references beams without transverse opening BSOLID were failed in flexural failure as observed. In the test, cracks appeared at the tension zone and growing vertically up to the neutral axis of the beam. Also it was observed that the



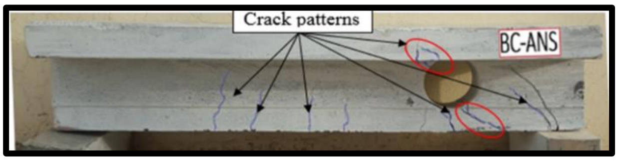
(a) The references beam.



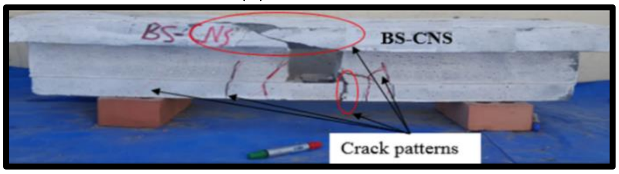
(b) BC-CNS.



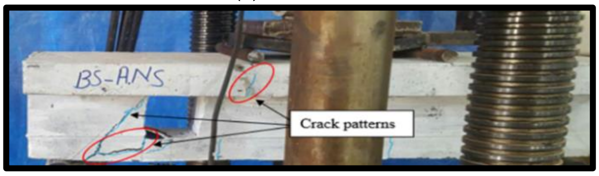
(c) BC-BNS.



(d) BC-ANS.



(e) BS-CNS.



(f) BS-ANS.
Fig. 5. The mode of failure and crack pattern of beams.

number of flexural cracks was increased. The flexural failure was visible started at the tension face between the applied load to the top face. Similar failure mode was identified for both reference beam, B solid. Fig. 5(a) show the mode of failure and crack pattern of references beam.

Beam BC-CNS is a beam with circular openings in the mid span of the beam, at a distance Lc/2 away from the support face. Initially, a crack was observed at the bottom chord opening and top chord. The mode of failure and crack pattern of beam BC-CNS is showed in Fig. 5(b).

The beams with opening, BC-BNS and BC-ANS represents a RPC T-beam containing circular openings are placed in the shear zone of the beam, at a distance (Lc/3 and Lc/4) away from the support respectively. at firstly, A crack at the bottom left face and top right face was observed. The mode of failure and crack pattern of beams BC-BNS and BC-ANS are illustrated in Fig. 5(c) and (d).

Beam BS-CNS represents RPC T- beam containing square openings placed in the flexural zone of the beam, at a distance Lc/2 measured from the support to the opening center. at first, a crack was observed at the bottom right opening corner and top left opening corner. Similarly, were observed minor cracks at the four corners of the square opening near the right support. The mode of failure and crack pattern of beam BS-CNS is showed in Fig. 5(e).

The beams with opening, BS-BNS and BS-ANS represents RPC T-beam containing square openings placed in the shear zone of the beam, at a distance (Lc/3 and Lc/4) measured from the support to the opening center respectively. at first, observed a crack was at the top right opening corner and bottom left opening corner followed by the remaining corners of the square opening near the left support. Similarly, minor cracks were observed at the four corners of the square opening near the right support. However, the crack condition is not as sharp as the left opening. The mode of failure and crack pattern of beams BS-BNS and BS-ANS are illustrated in Fig. 5(f).

8.2. Cracking Load, Ultimate Load and Defection

The cracking load, ultimate load and deflection of the beams are summarized in Table 3. In this table, the variety in the ultimate load between the load that gained for each beam and the ultimate load of references beams are provided. Also, shows the decrease in strength of the beams. The presence of circular openings in the shear zone at distance Lc/3 and Lc/4 measured from the support to the opening center in the RPC T-beams, BC-BNS and BC-ANS respectively causes a fundamental decrease in beam carrying capacity, approximately 35 and 41% respectively. While the presence of a circular openings in the flexural region at distance Lc/2 away from the support in the reinforced RPC T-beams, BC-CNS causes a decrease in beam capacity, approximately 12%.

The existence of the square openings in the shear zone at distance Lc/3 and Lc/4 measured from the support to the opening center in the RPC T-beams, BS-BNS and BS-ANS respectively causes a substantial decrease in the beam carrying capacity, approximately 41 and 55% respectively. While the exiztence of square openings in the flexural zone at distance Lc/2 measured from the support to the opening center in the RPC T-beams, BC-CNS causes a decrease in the beam carrying capacity, approximately 10%. Obviously, the openings existence at a distance Lc/4 is much more effected compared with the a distance Lc/3 and Lc/2 as shown Table 3.

Table 3
Test results.

Beam Specimen	Cracking load (Pcr)(kN)	Ultimate load (Pu) (kN)	Max. Deflection (mm)	Decrease in strength (%)	Failure Mode
B1 solid	67.92	195.6	6.12	-	(flexural failure)
BC-CNS	47	171.2	5.6	12	(flexural failure)
BC-BNS	44.1	127.4	4.1	35	(shear failure)
BC-ANS	37.4	115.5	3.85	41	(shear failure)
BS-CNS	49	176.3	5.8	10	(flexural failure)
BS-BNS	39.4	115	4.3	41	(shear failure)
BS-ANS	32	88.2	3.4	55	(shear failure)

8.3. Load – Deflection Relationships

8.3.1 Effect of Openings Location

To study the effect of the opening location, a three different locations were investigated (Lc/2, Lc/3, and Lc/4) measured from the support to opening center. The test results showed that providing an opening at Lc/4 caused the sharp reduction in beam strength by (48%) while providing an opening at Lc/3 caused the reduction in beam strength about (38%) whereas providing an opening at Lc/2 caused reduction in the ultimate load about (11%). as shown in Figs. 6 and 7.

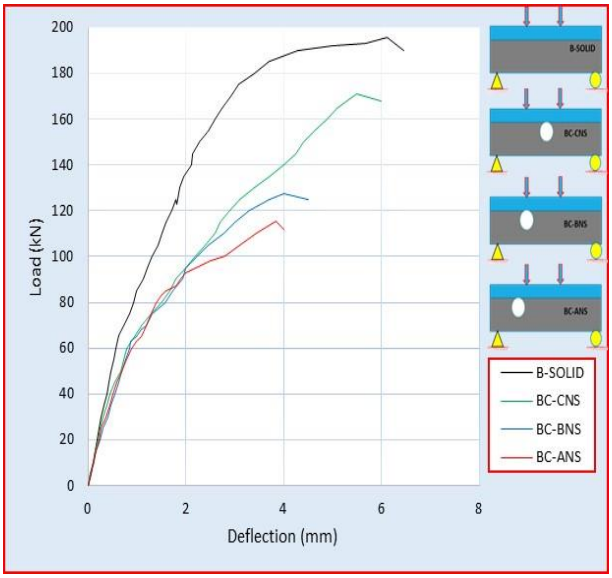


Fig. 6. Load - deflection curve for beams with circular opening at different locations.

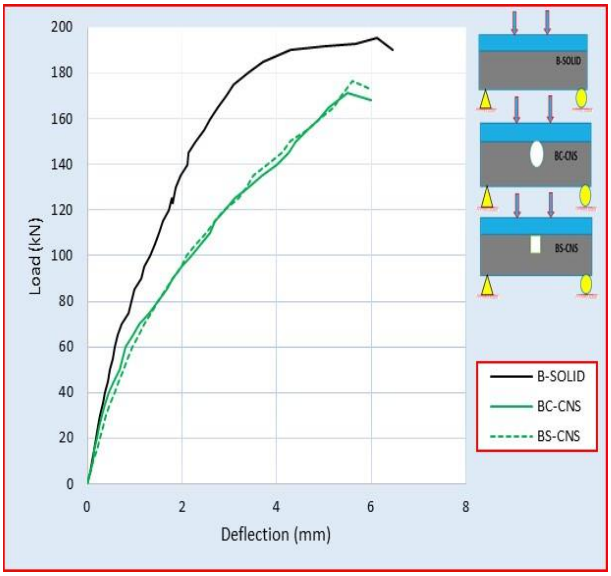


Fig. 8. Load - deflection curve for beams with circular and square opening at Lc/2.

8.3.2 Effect of Openings shape

Two opening section shapes were are used in this study. A circular section with 110 mm diameter and a square section with dimension of (100x100)mm, haves, the two section have the same area. The test results showed that providing a square opening at different locations caused a reduction in the ultimate load by about (55%,41%, and 10%) at (Lc/4, Lc/3, and Lc/2) respectively. while providing a circular opening caused a reduction in the ultimate load less than a square opening.

The reason behind that reduction for the square opening is that the existing orthogonal corners caused more stress concentration at these corners. The sudden change in the dimension of the cross-section of the led to the high-stress concentration at the corners of square opening that may lead to undesirable cracks as shown in Figs. 8-10.

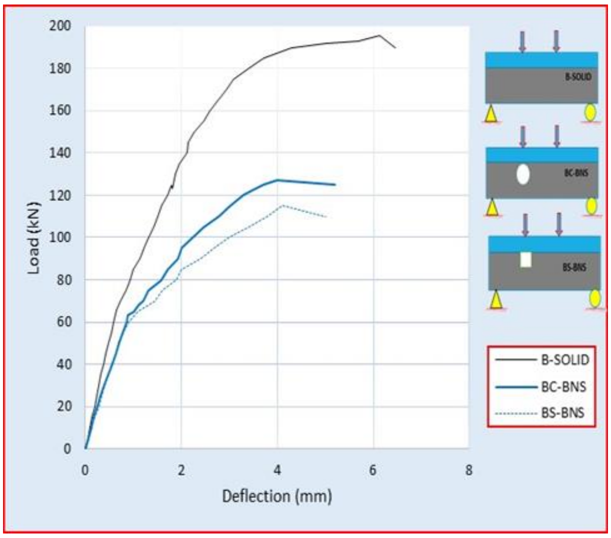


Fig. 9. Load - deflection curve for beams with circular and square opening at Lc/3.

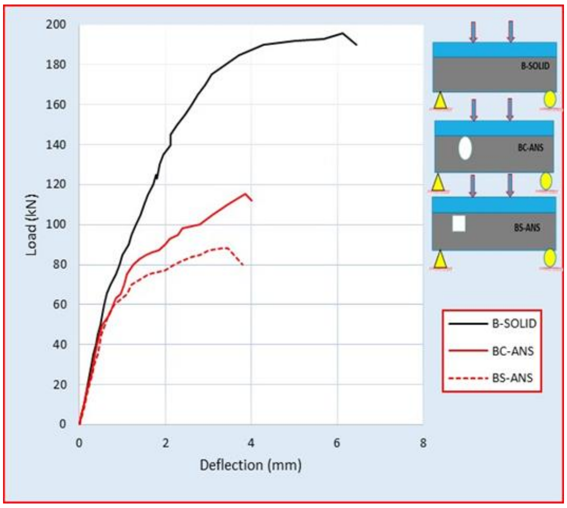


Fig. 10. Load-deflection curve for beams with circular and square opening at Lc/4.

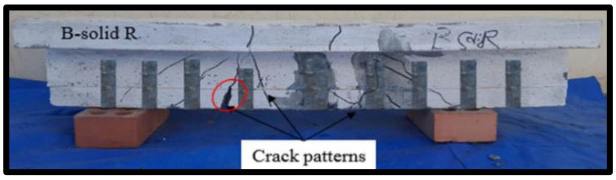
8.4. Repairing

8.4.1. Cracking load, ultimate load and mode of failure

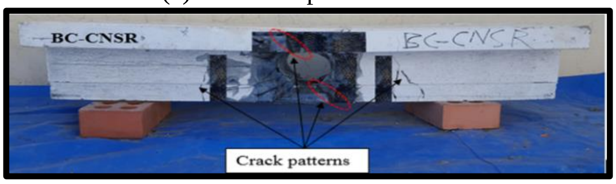
In this part, seven beams have been repaired using carbon fiber reinforced polymer CFRP, for beams contain opening as well as the control beam without openings. These beams were divided into two groups: the first group consisted of three concrete beams with circular openings of 110 mm diameter and different locations at (Lc/2, Lc/3, and Lc/4). The second group also consists of three concrete beams with square openings of (100×100) mm at different locations (Lc/2, Lc/3, Lc/4) in additional to the reference beam. Through the results shown in Table 4, it can be seen that the role of CFRP in the repairing field is greater than its role in the strengthening field. This is attributed to the efficiency of the carbon fiber, which is significant for the beams that have little resistance, at the damaged beams the resistance is non-exist before repairing the carbon fiber with a bonding material. The one that carrying load the post-repaired specimens. The failure of the specimens is the rupture of carbon fiber and the occurrence of failure in the place of the same failure before repairing shown as in figs. 11(a)-(g).

Table 4
Summaries of repaired beams.

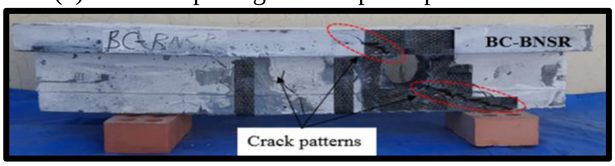
Beam Specimen	Cracking load (Pcr)(kN)	Ultimate load (Pu) (kN)	Max. Deflection	Decrease in strength (%)	Failure Mode
B1solidR	58	181.3	4.6	-	**(flexural failure)**
BC-CNSR	45.2	174.4	5.8	12	**(flexural failure)**
BC-BNSR	41.4	130	3.95	35	**(shear failure)**
BC-ANSR	35.1	120	3.5	41	**(shear failure)**
BS-CNSR	45	172.5	6	10	**(flexural failure)**
BS-BNSR	37.2	113.5	3.85	41	**(shear failure)**
BS-ANSR	30.3	102.2	2.65	55	**(shear failure)**



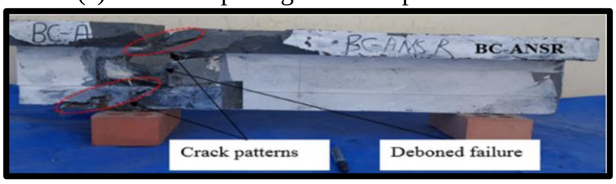
(a) Control repaired beams.



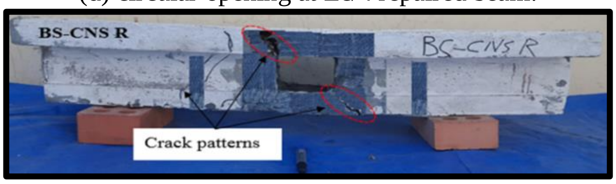
(b) circular opening in mid span repaired beam.



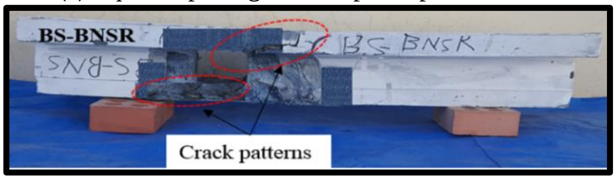
(c) Circular opening at Lc/3 repaired beam.



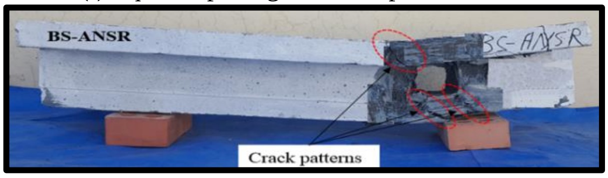
(d) circular opening at Lc/4 repaired beam.



(e) Square opening in mid span repaired beam.



(f) Square opening at Lc/3 repaired beam.



(g) Square opening at Lc/4 repaired beam.

Fig. 11. Crack pattern and failure modes.

8.4.2. Load-deflection relationships

General test results show that the repaired beams with CFRP laminates gain high efficiency in ultimate strength. The ultimate load of the reference beam after repairing is less than the ultimate load of the reference beam before repairing, as well as the deformation of reference repaired beam was greater. As for the beams that containing the openings, it was observed that the ultimate load of the repaired beams is more than the ultimate load the same beams before repair and this indicates the efficiency of carbon fiber in the repairing of beams. The ultimate load is recovered for the repaired solid beams was about 92%. While the ultimate load for the beams with openings were from about 98% to 115% compared with the same beams before the repaired as shown in Figs. 12-18.

From the load-mid span deflection curves, it was found that the presence of an opening in beams decreased the ductility of RPC beams (the ductility index is the ratio between the deflections at ultimate load to deflection at the yielding load). For the control beam, the ductility index is equal to 3.6. For group one, for the circular opening, the

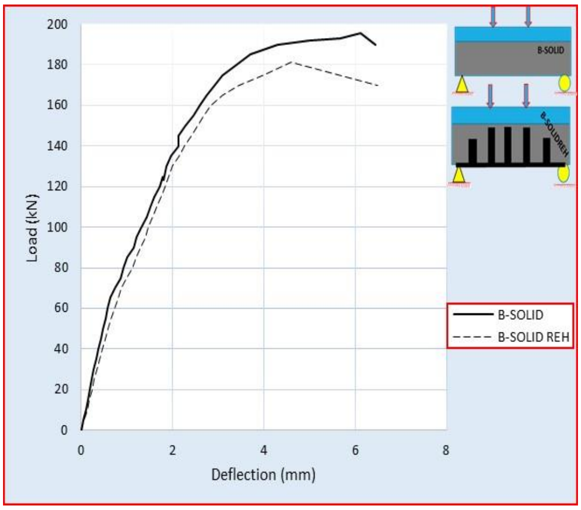


Fig. 13. Load-deflection of control repaired beam.

repaired beam.

8.5. Ductility

ductility index for tested specimens BC-CNS, BC-BNS, and BC-ANS were equal to 3.5, 3.41 and 3.34, respectively. In the other side, for group two, with square opening, the ductility index for tested specimens BS-CNS, BS-BNS, and BS-ANS were equal to 3.29 3.07 and 3.09, respectively. Also, through (load- deflection) curved of the rehabilitated beams, it is noted that these beams are less ductility than the undamaged beams. The reason behind this decrease is due to the presence of cracks in the rehabilitated beams before test as shown in Fig. 20.

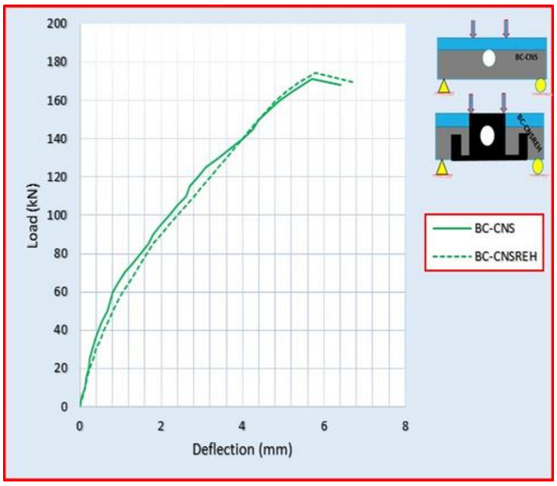


Fig. 14. Load-deflection of circular opening in mid span repaired beam.

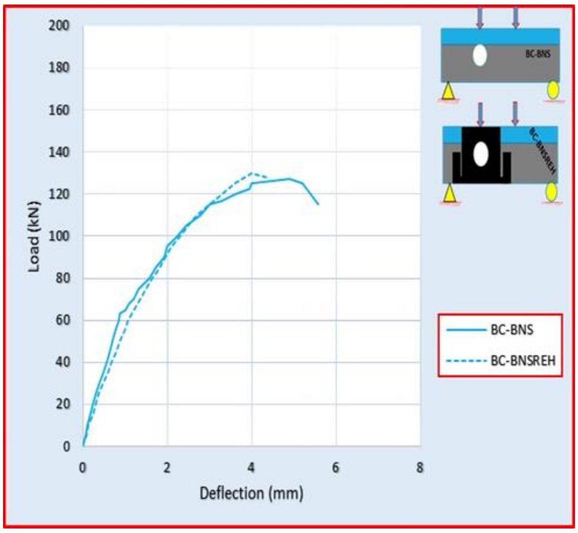


Fig. 15. Load- deflection of circular opening at Lc/3 repaired beam.

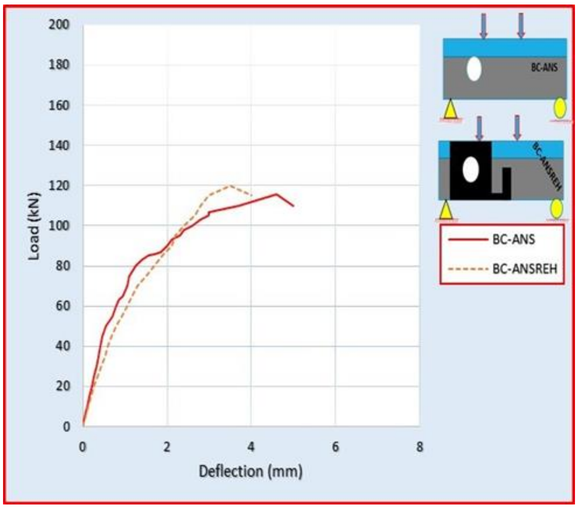


Fig. 16. Load-deflection of circular opening at Lc/4 repaired beam.

8.6. Stiffness

From the (load-deflection) curves it was found that the presence of an opening in beams decreased the stiffness of RPC beams (the stiffness is the ratio between the 45% from ultimate load to deflection at the 45% from ultimate load). For the control beam, the stiffness is equal to 80.73. For group one, for a circular opening, the stiffness for the tested specimens BC-CNS, BC-BNS and BC-ANS were equal to 73.37, 66.67 and 61.14 respectively. In the other side, for group two, with square opening the stiffness for the tested specimens BS-CNS, BS-BNS and BS-ANS were equal to 68.98, 64.68 and 54.30, respectively.

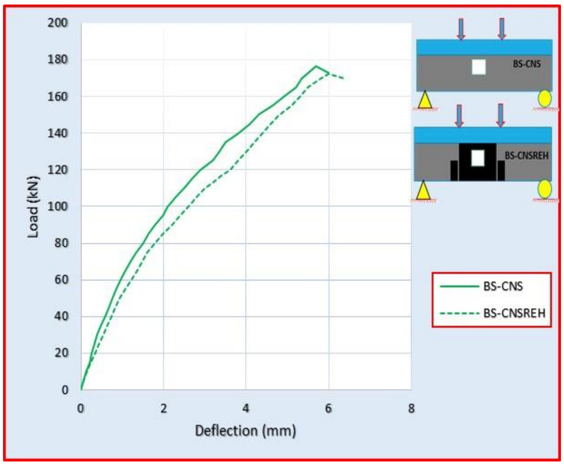


Fig. 17. Load-deflection of square opening in mid span repaired beam.

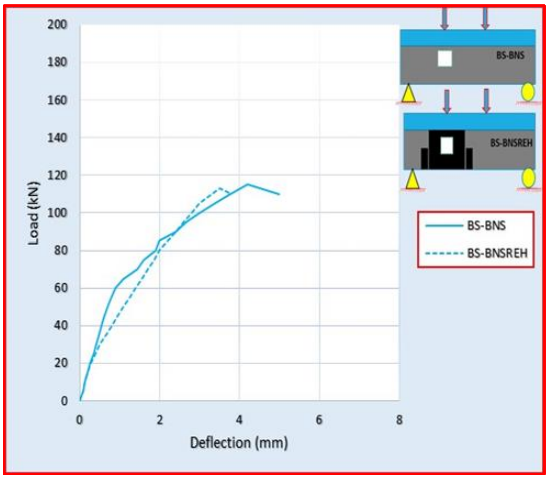


Fig. 18. Load-deflection of square opening at Lc/3 repaired beam.

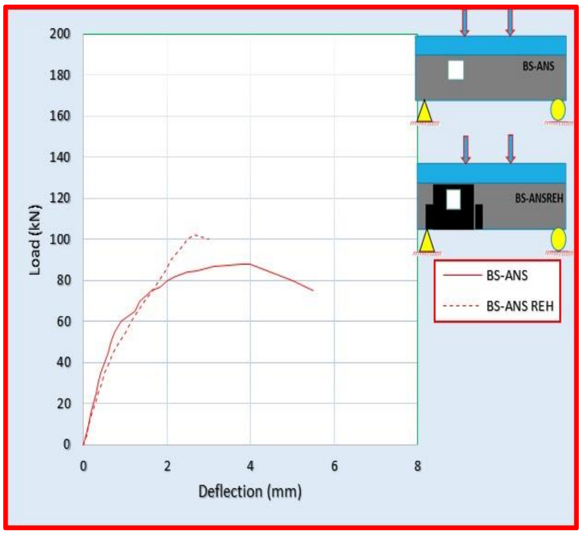


Fig. 19. Load-deflection of square opening at Lc/4

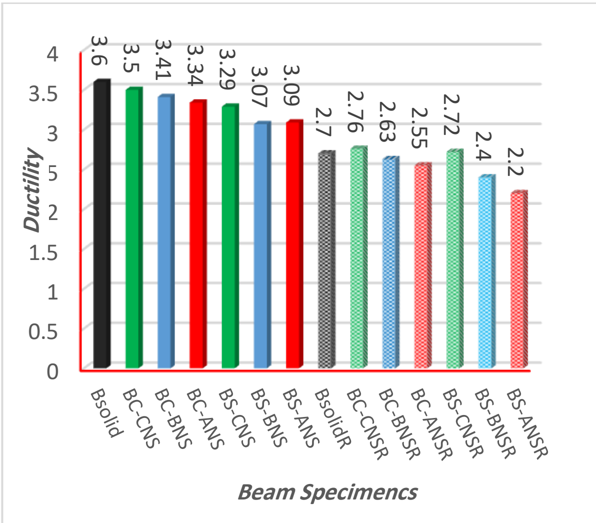


Fig. 20. Ductility in beams.

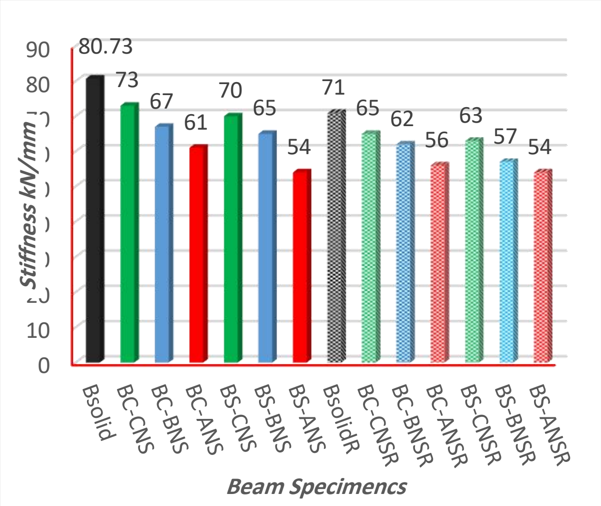


Fig. 21. Stiffness in beams.

The reason behind this decrease is the moment of inertia due to opening. Also, through (load- deflection) curves of the repairing beams, it is noted that these beams are less stiffness than the undamaged beams. The reason behind this decrease due to the presence of cracks in the rehabilitated beams before test and decreasing the moment of inertia due to opening as shown in Fig. 21.

8.7. Toughness

From the (load-deflection) curves it was found found that the presence of an opening in beams decrease the toughness of RPC beams (the toughness is the area under the curve). For the control beam, the toughness is equal to 974.11kN.mm. For group one, for a circular opening, the stiffness for tested specimens BC-CNS, BC-BNS and BC-ANS were equal to (716.019, 525.549 and 420.506) kN.mm, respectively. In the other side, for group two, with square opening the stiffness for the tested specimens BS-CNS, BS-BNS and BS-ANS were equal to (653.80, 419.46 and 360.52) kN.mm, respectively. Also, through curved (load- deflection) of the rehabilitated beams, it is noted that these beams are less toughness than the undamaged beams. The reason behind this decrease due to the presence of the openings which reduce the resistance of the first crack and also lead to the extended cracks and make it wider and thus reduce the amount of energy absorbed and, in this case, reduces the toughness as shown in Fig. 22.

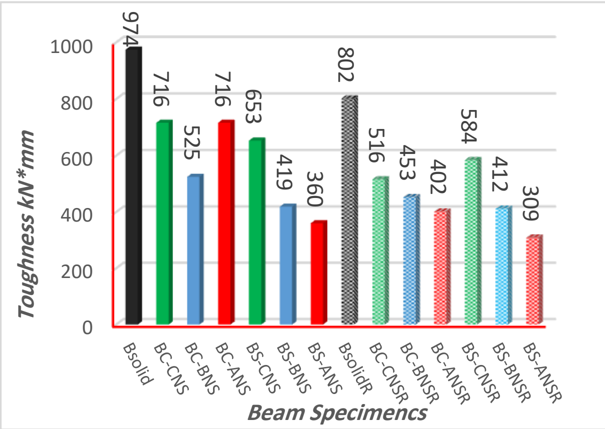


Fig. 22. Toughness in beams.

9. CONCLUSIONS

Based on the results of this experimental investigation of tested RPC T-beams, the following conclusions can be drawn:

1. The openings location has a great effect on the beam strength, where this effect is the largest when openings location is at shear zone (Lc/4 &Lc/3) (near the supported) and a slight effect when openings location is at flexure zone (Lc/2), so the better place for the opening location in these beams at Lc/2.
2. The circular shape of opening showed to be the better shape according to the beam strength.
3. In reinforced RPC T-beams with opening at flexure zone, excessive flexural cracks were found at the tension zone around the openings. The failure mode was in flexure. Providing opening in RPC T-beam decreased the ultimate loading about (12%) for circular opening. However, in terms of square opening, the ultimate load decreased by (10%) compared with the control beam.
4. In reinforced RPC T-beams with (circular and square) openings at shear zone in locations (Lc/3 &Lc/4), excessive shear cracks were found around the openings and the failure mode was in shear. Providing of RPC T-beam with circular opening in locations (Lc/3 &Lc/4), caused decreased in the ultimate by load about (35% and 41%) respectively. However, in terms of beam with square opening in (Lc/3 & Lc/4) decreased in ultimate load by about (41% and 55%) compared with the control beam, without opening.
5. The repairing of the pre-tested beams which contain circular openings at locations (Lc/4, Lc/3 and Lc/2) achieved an increase of the ultimate load with ratio (4%, 2% and 2%) respectively.
6. The repairing of the pre-tested beams which contain square openings at locations (Lc/4, Lc/3 and Lc/2) achieved an increase of the ultimate load with ratio (14%, 2% and 2%) respectively.
7. The repaired reinforced RPC T-beams have relatively high strength which reflects the efficiency of the used repairing technique by CFRP strips.

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