STRENGTHENING OF R.C BEAMS WITH OPENINGS CREATED AFTER CASTING USING F.R.P

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ABSTRACT

Web openings in beams have found many applications in practice such as they provide convenient passages of electrical and mechanical conduits. Over the past several decades, many researchers exerted great efforts to predict and interpret the behavior of beams with web openings. They recommended convenient methods for the design of such beams. These methods are successfully used if openings were decided before casting of beams. But, what will be the case if it is required to provide new openings in existing beams? The current work aims to give a satisfactory answer for this question, in which CFRP were used to strengthen and improve the behavior of beams with created openings. Eighteen reinforced concrete beams with rectangular cross section (13 x 25 cm) were tested under two concentrated static load. Three of the beams were taken solid without openings as control beams. Each one of the other beams was provided with a rectangular web opening of 20cm length. CFRP was used to strengthen some beams. The variable parameters are the opening height, the percentage of cut web reinforcement, the distance between the opening edge and the nearest unaffected web reinforcement, the shear span to depth ratio and type of strengthening, as well as concrete strength. The pattern of cracks, final mode of failure, cracking load, failure load and deformational characteristics (deflection, and strains) were recorded, analyzed and discussed. Finally, some important conclusions were reported.

Keywords: created web openings, openings strengthening with CFRP, Percentage of cut stirrups ($\rho_s$), height of opening (h), and Concrete compressive strength $f_{cu}$.

1. Introduction

Transverse web openings are often provided through beams to accommodate utility ducts and pipes to be benefit from the unused space above the beam soffit. It is obvious that such openings are potential source of weakness in the beams. When the service systems are preplanned and the size and location of required openings decided upon well in advance, adequate strength and serviceability may be ensured during the design stage.

This, however, is not always the case. There are at least two circumstances that necessitate drilling of holes in an existing structure. The first is in a recently constructed building, when laying the service ducts, the M&E contractor frequently comes up with the request to drill an opening for the sake of simplifying the arrangement of pipes not carefully considered during the design stage.
The second circumstance arises in an old building. Where, the openings are created by removing concrete cores for structural assessment of the building. In such a case, however, the holes are generally filled in by non-shrink grout. If the structure is to remain, then the question is whether such a repair is adequate to restore the original level of safety and serviceability of the structure.


In the current work, an experimental study for beam with created web openings strengthened with CFRP laminates will be presented; the main object is to study the possibility of providing rectangular web openings in an existing solid beams. It aims to declare their effect on both strength and stiffness and try to decrease their bad effects by strengthening opening zone.

The main parameters taken into considerations are:

1- The height of opening (h);
2- The percentage of cut stirrups (\(\rho_s\));
3- The shear span to depth ratio a/d;
4- The concrete compressive strength $f_{cu}$.
5- Number of CFRP layers as a strengthening material for reinforced concrete beams.

2. Experimental work

1.1 Test specimens

In order to investigate the above points, eighteen reinforced concrete beams were prepared. All tested beams have the same total length of 2 m and overall cross section of $13 \times 25$ cm, as shown in Fig (1). They were simply supported with span of 1.8 m. The steel reinforcement of all beams was: two bars 12 mm diameter as tension reinforcement; two bars 10 mm diameter as compression reinforcement and stirrups 6 mm diameter with 14 cm spacing. The beams “B01, B02 and B03” were solid without any openings and were considered as a reference beams. Each of the other beams was provided with one opening of 20 cm length, and 8 cm height for beams (B2, B5, B6, B9, B10, B11, B12 and B13) and 10 cm height for (B3) and 12 cm height for beams (B4, B7, B8, B14, B15 and B16). Details for tested reinforced concrete beams are given in Fig (1) and table (1).

![Fig. 1. Typical Details of the Tested Beams](image)

Table 1.
Details of the tested beams

<table>
<thead>
<tr>
<th>Group No.</th>
<th>Beam No.</th>
<th>Opening height (h)</th>
<th>Concrete compressive strength $f_{cu}$ (Kg/cm²)</th>
<th>a/d</th>
<th>Open. Strengthening</th>
<th>$S$ (cm)</th>
<th>$\rho_{x} x 10^{-5}$</th>
<th>Ultimate load $(P_u)$ (Kg)</th>
<th>First shear crack Load $(P_{cr.sh})$ (Kg)</th>
<th>Deflection $\delta_u$ (mm)</th>
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<tr>
<td>Group (A)</td>
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<td>Reference without opening</td>
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<td>3.5</td>
<td>___</td>
<td>___</td>
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<td>7.30</td>
<td>3.50</td>
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<td></td>
<td>325</td>
<td>3.5</td>
<td>___</td>
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<td>Without layer</td>
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<td>Without layer</td>
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<td>a/d</td>
<td>Open. Strengthening S (cm)</td>
<td>ρs x 10^-5</td>
<td>Ultimate Load (P_u)</td>
<td>First shear crack Load(t) (P_cr.sh)</td>
<td>Deflection (μu (mm))</td>
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<td>Two layers</td>
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</table>

* a = distance between the load point and support of beam
* d = depth of beam.
* s = width of beam.
* S = distance between unaffected stirrups in the opening zone.
* ρs = cut Stirrups reinforcement ratio (A_st/b.s)

U-shape stirrups are used at the opening location to simulate the cut Stirrups when drilling a hole in an existing beam.

1.2 Strengthening scheme

The beams, “B01”, “B02” and “B03”, were solid and used as control beams, without any opening. In eight beams the opening was left without any strengthening to declare the effect of creating an opening in different situations. However in the other beams the opening was strengthened with CFRP sheets around it. See Table (1).

The external strengthening system using CFRP and epoxy adhesives were performed, according to the manufacture recommendation.

Variable number of layers has been used for strengthening. The inner surfaces of the opening and the beam surface adjacent to it were covered with one or two layers of CFRP sheets. The strip width was to cover the whole height of both the upper and lower chord. See Fig (2).
2. Test results

2.1 Pattern of cracks and modes of failure

The crack pattern for the solid beam “B01”, “B02” and “B03”. The crack pattern is shown in Fig (3) to Fig (5), and in photo (2) to (4); the first crack was initiated vertically at the mid span of the beam bottom face at a load of 2.0t, 2.5t and 4t respectively. As the load increased, other cracks initiated and extended towards the points of load application. Diagonal cracks were observed in the shear zones at mid height at a higher load of about 3.0t. The number of cracks increased with increasing the load and finally the mode of failure, was a typical flexural one; which was occurred due to yielding, the beam failed at load of 7.3t, 7.8t and 8.2t respectively.

2.1.1 Tested beams with variable opening height group (A)

The crack pattern for the beam “B2” with created unstrengthened openings and (h opening=8cm) is shown in Fig (6). The first crack was initiated at the mid span of beam at 1.5t, while the first shear crack was initiated at opening corner nearest to the support at a load of 2.0t. As the load increased, additional, new cracks were observed at the top and bottom chord of opening, and finally the beam failed at load of 4t by shear photo (5). In addition, the major cracks were located at the line joining the points of opening corner and either the nearest support or the point of load application.

Fig (7) and photo (6) show the pattern of cracks and modes of failure of beam “B3”. With created unstrengthened opening and (h opening=10cm), the first crack was initiated at the opening corner nearest to the support at a load of 1.5t, while first crack at the mid span of beam was initiated at 2.0t. As the load increased, new cracks were observed at the top and bottom chord of opening, the beam failed at load of 3.7t. The critical crack was formed at the line joining the points of opening corner and either the nearest support or the point of load application. The mode of failure, as indicated by photo (6) was a typical shear failure.

The crack pattern for beam “B4” with created unstrengthened opening and (h opening=12cm) was shown in Fig (8). The first crack was initiated at opening corner nearest to the support at a load of 1.0t. While the first crack at the mid span of beam was initiated at 2.0t.
As the load increased, new cracks were observed in the top and bottom chord of opening. The beam failed by shear at opening zone at load of 3.5t. The major crack was located at the line joining the points of opening corner and either the nearest support or the point of load application. The mode of failure, as indicated by photo (7) was also a typical shear failure.

![Crack pattern of beam "B01".](image1)

**Fig. 3.** Crack pattern of beam "B01".

![Crack pattern of beam "B01".](image2)

**Photo 2.** Crack pattern of beam "B01".

![Crack pattern of beam "B02".](image3)

**Fig. 4.** Crack pattern of beam "B02".

![Crack pattern of beam "B02".](image4)

**Photo 3.** Crack pattern of beam "B02".

![Crack pattern of beam "B03".](image5)

**Fig. 5.** Crack pattern of beam "B03"
Photo 4. Crack pattern of beam "B03".

Fig. 6. Crack pattern of beam "B2".

Photo 5. Crack pattern of beam "B2".

Fig. 7. Crack pattern of beam "B3".

Photo 6. Crack pattern of beam "B3".

Fig. 8. Crack pattern of beam "B4".
2.1.2 Tested beams with variable a/d ratio, group (B)

The pattern of cracks for beam “B2” with a/d=3.5 is mentioned before in item (2.1.1).

For beam “B5” with created unstrengthened opening and (a/d = 2.7) the crack pattern is shown in Fig (9). The first crack at the mid span of beam was initiated at 1.5t, However first crack at the shear zone was initiated at opening corner nearest to the support at a load level of about 2.5t. As the load increased, additional, new cracks were observed at the top and bottom chord of opening, the beam failed by shear at load of 4.9t. In addition, the major crack were located at the line joining the points of opening corners and either the nearest support or the point of load application. The mode of failure, as indicated by photo (8) was a typical shear failure.

For beam “B6” with created unstrengthened opening and (a/d = 1.8) was shown in Fig (10), the first crack was initiated at the mid span of beam at 2.5t, while the first crack at opening zone was initiated at the opening corner nearest to the support at a load of 3.5t. As the load increased, circumferential cracks were observed at the top and bottom chord of opening, the beam failed also by shear at load of 7.5t. The major cracks were located at the line joining the points of opening corner and either the nearest support or the point of load application. The mode of failure, as indicated by photo (9) was a typical shear failure.
2.1.3 Tested beams with unstrengthened opening and variable $F_{cu}$, group (C)

The pattern of cracks for beam “B4” with $F_{cu}=250\text{kg/cm}^2$ is mentioned before in item (2.1.1).

The crack pattern for beam “B7” with created unstrengthened opening and ($f_{cu}=325\text{kg/cm}^2$) shown in Fig (11), the first crack was initiated at the opening corner nearest to the support at a load of 1.5t, and first crack was initiated at the mid span of beam at 2.0t. As the load increased, other cracks were observed in the top and bottom chord of opening, the beam failed by shear at load of 3.6t. A horizontal crack in the bottom chord was formed prior to failure owing to the absence of effective transverse reinforcement. The mode of failure, as indicated by photo (10) was a typical shear failure, along the line joining the load point and the support through the opening.

The crack pattern for beam “B8” with created unstrengthened opening and ($f_{cu}=450\text{kg/cm}^2$) was shown in Fig (12), the first crack was initiated at the opening corner nearest to the support at a load of 1.5t, and first crack at the mid span of beam was initiated at 2.10t. As the load increased, other cracks were observed at the top and bottom chord of opening, the beam failed at load of 4.2t. A horizontal crack was formed in the bottom and top chord of the opening. The mode of failure, as indicated by photo (11) was a typical shear failure.
2.1.4 Tested beams with different strengthening scheme, group (D)

All the beams of this group “B9”, “B10” and “B11” have a created opening which cut two vertical stirrups.

The crack pattern for beam “B9” with created unstrengthened opening, is shown in Fig (13). The first crack was initiated vertically at the mid span of beam at 1.5t, while first crack at the opening corner nearest to the support was initiated at a load of 2.0t. As the load increased, new cracks were observed in the top and bottom chord of opening, the beam failed by shear at load of 2.4t. A horizontal crack was formed prior to failure. The mode of failure, as indicated by photo (12) was shear failure.

Concerning the crack pattern for beam “B10” with opening strengthened by one layer CFRP. The first crack was initiated at the mid span of beam at 2.5t. Fig (14). As the load increased, further flexural cracks were formed. Horizontal cracks were observed in the top and bottom chord of opening at a load of 4.5t, the beam failed at load of 5.5t. The major crack was vertical at mid span, accompanied by tearing of the CFRP layer in the top and bottom chord. The mode of failure is a typical shear-flexural failure. A sound like CFRP rupture it was heard prior to failure. See photo (13).

The crack pattern for beam “B11” having a strengthened opening with two CFRP layers. No cracks were observed at the opening zone, and first crack was initiated at the mid span of beam at 2.5t. As the load increased, other vertical cracks initiated and extended towards the points of load
application. The mode of failure, as indicated by photo (14) was a typical flexural one; the beam failed at load of 6.56t.

Fig. 13. Crack pattern of beam "B9".

Photo 12. Crack pattern of beam "B9".

Fig. 14. Crack pattern of beam "B10".

Photo 13. Crack pattern of beam "B10".

Fig. 15. Crack pattern of beam "B11".

Photo 14. Crack pattern of beam "B11".
2.1.5 Tested beams with different cut stirrups reinforcement ratio (ρ_s), group (E)

The beams of this group were provided with an opening which cut variable number of stirrups and have variable distance between unaffected (S_i) stirrups in the opening zone.

The pattern of cracks for beam “B11” with (S_i=42cm, ρ_s =5.13x10^{-5}) is mentioned before in item (2.1.4).

In the beam “B12” having an opening with one cut stirrups and (S_i=28cm, ρ_s =7.69x10^{-5}), strengthened with two layers from CFRP, is shown in Fig (16), the first crack was initiated at the mid span of beam at 2.6t. As the load increased, other flexural cracks initiated and extended towards the points of load application. Diagonal cracks were observed in the solid shear zones without opening at 4.5t. The mode of failure, as indicated by photo (15) was a typical flexural failure accompanied by crushing of concrete in the compression zone at load of 6.90t.

For beam “B13” having an opening with two cut stirrups and (ρ_s=4.49x10^{-5}), strengthened with two layers from CFRP as shown in Fig (17), the distance between unaffected stirrup in the opening zone= 48cm. No cracks was initiated at opening zone, and first crack was initiated at the mid of beam at 2.0t. As the load increased, other cracks initiated and extended towards the points of load application. Diagonal cracks were observed in the solid shear zones at 3.0t. Extended from a vertical crack, the mode of failure, as indicated by photo (16) was a typical flexural one. The beam failed at load of 6.0t.

Fig. 16. Crack pattern of beam "B12".

Photo 15. Crack pattern of beam "B12".

Fig. 17. Crack pattern of beam "B13".
2.1.6 Tested beams with strengthened opening and variable $F_{cu}$, group (F)

The crack pattern for beam “B14” having a strengthened opening with two layers from CFRP and ($f_{cu}$=250), is shown Fig (18), the first crack was initiated at the mid span of beam at 1.5t.

As the load increased, other cracks initiated and extended towards the points of load application. The mode of failure, as indicated by photo (17), was a typical shear failure accompanied by sound like CFRP rupture. The strengthening layers were removed to see the cracks in the concrete beneath them. Diagonal and horizontal cracks were observed in the top and bottom chord of opening.

However For beam “B15” having a strengthened the same strengthening scheme as in “B14” but with ($f_{cu}$=325 kg/cm$^2$), the first crack was initiated at the mid span of beam at load level of about 2.0t. As the load increased, other cracks were initiated and extended towards the beam failed at load of 7.3t. The mode of failure, as indicated by photo (18) was a typical shear and flexural failure accompanied by sound like CFRP rupture. Horizontal cracks were observed after the removal of the strengthening layer in the top and bottom chord of the opening.

The crack pattern for beam “B16” ($F_{cu}$=450 kg/cm$^2$) is shown in Fig (20). The first crack at the mid span of beam was initiated at 2.50t. As the load increased, other cracks were observed at the top and bottom chord of opening, the beam failed at load of 7.90t. Prior to failure horizontal cracks were formed in the strengthening at top and bottom chord of opening. The mode of failure, as indicated by photo (19) was a typical shear and flexural failure accompanied by sound like CFRP rupture.
2.2 Effect of opening on crack and ultimate load

For beams "B2", "B3" and "B4" with variable unstrengthened opening height the first shear cracks was initiated in the opening zone at a load 2t, 1.5t and 1t respectively. As the opening height increased the cracking and ultimate load decreased. In beam "B2" having an opening height of 8cm, the ultimate load was 4t, while for beam "B3" which has an opening height of 10cm, the ultimate load was 3.7t. Finally for beam "B4" with opening height of 12cm, the ultimate load was 3.5t. The value of ultimate loads of beams "B2", "B3" and "B4" compared with those of the solid reference beam "B01" were 54.79%, 50.68% and 47.95% respectively, see Fig (21) and Fig (22).
Fig. 21. Effect the opening height on the ultimate load and first shear cracks load.

Fig. 22. Ultimate and first shear crack load relative to those of "B01" versus opening height ratio h/d

Also, strengthening the interior faces of the openings and around the openings on both sides of the beams by using one or two layers vertical and horizontal CFRP laminates increased the ultimate load; first shear cracks load and relative ultimate load as shown in Fig (23) and Fig (24).

Fig. 23. Effect of Number of Layers CFRP Strengthening on the ultimate load and first shear cracks load.
Fig. 24. Effect of Number of Layers CFRP Strengthening on the relative ultimate load and relative first shear cracks load

For beams “B14”, “B15” and “B16”, the concrete compressive strength was 250, 325, and 450 and the first shear cracks was at loads of 3.5, 7.0t and 7.50t, respectively. As the concrete compressive strength \((f_{cu})\) increased the first shear cracks appeared later and ultimate load increased. The ultimate loads for the mentioned tested beams were 5.5t, 7.30t and 7.90t respectively.

2.3 Deflection

The measured values of mid span deflection at the bottom surface of the tested beams were plotted versus the corresponding applied load from zero loading up to failure, and are given in Fig (25) and Fig (26). As it was indicated in curves, the relation between the applied load and the corresponding deflection is approximately linear up to the cracking load. After cracking, deflection tends to deviate from linearity as the load increased, prior to failure, deflection increased rapidly and the curve became more flat.

The creation of openings had a noticeable effect on the mid span deflection. Deflection of the tested beams at any load level increased when providing an opening in their web compared with the solid beam Fig (25). In the same time as the opening height increased, the mid span deflection increased, the mid span deflection for beams B2, B3, B4 at about 50% of the failure load was 1.25, 2.20 and 3.31 mm respectively. See Fig (26).

Ductility factor is measured using various methods. It can be defined as the ratio of the ultimate deformation (curvature or deflection) to the deformation at first yield (or at the working stage). An accurate value of the ultimate deflection can be considered to that at 90% of failure load. The deflection at working load may be assumed to be that corresponding to about 50% of failure load. The ductility factor here was measured using the ratio of the deflection at load corresponding to about 90% of the failure load to that corresponding to about 50% of failure load. The ductility factor decreased as the opening height increased. Fig (27).

Strengthening of the opening zone noticeably reduced the mid span deflection, Fig (28). Mid span deflection for beam B12 strengthened with two layers at the opening zone was slightly smaller than that of the solid reference beam B01. This may attributed to the following reasons:
- CFRP sheets around openings help in resisting stress concentration at opening corners and compensate the cut web reinforcement thus delaying cracking and controlling cracks propagation, which as a result increase the stiffness of the beam.  
- The virtual area of CFRP sheets, which confining concrete section above and below opening helps to strengthen those sections to act as one which improves stiffness of beam.

![Fig. 25. Load-Deflection curves for beams "B2", "B3" and "B4" and "B01"

![Fig. 26. Relative deflection for beams "B2", "B3" and "B4"

![Fig. 27. Effect the opening height on Ductility]
3. Conclusions

From the tests carried out herein on reinforced concrete beams having opening created after casting, the following conclusions can be drawn:

1- Creating web opening in an existing R.C. beam largely increased mid span deflection, and decreased both the cracking and ultimate load. This effect increased as the opening height increased or as the number of cut stirrup increased.
2- Creating web opening in R.C. beams changed the pattern of cracks and the mode of failure from flexural to shear failure.
3- Strengthening openings with CFRP sheets contribute in reducing deflection, number of cracks; crack widths and can change the mode failure.
4- Strengthening the opening zone with CFRP sheets, improved the structural behavior of the perforated beams and can restore the original level of safety and serviceability of the beam within the range of variables considered in this work.
5- Improving the structural behavior of the perforated R.C. beam increasing as the number of strengthening layers increased.

**NOMERCLUTURE**

- $a/d$: Shear span to depth ratio.
- $h$: Opening length the beam
- $h_{ef}$: Effective height of FRP on the sides of the beam.
- $\delta_{cr}$: Maximum deflection at first cracking load
- $\delta_{ul}$: Maximum mid span deflection stirrups at ultimate load
- $d$: depth of beam
- $\rho_s$: Stirrups reinforcement ratio ($A_{st}/b.s$)
- $a$: distance between the force and support of beam
- $h$: opening height.
- $\delta$: Deflection
- $S^1$: distance between unaffected on the two sides of the opening
- $b$: width of beams cross sections
REFERENCES


تقوية الكمرات الخرسانية سابقة الصب بعد عمل فتحات بها

المختص العربى

ظهرت في الأعمال الإنشائية الحاجة إلى عمل فتحات خلال أعصاب الكمرات الخرسانية المسلحة بأشكال وأبعاد مختلفة لاستخدامها كمرات للتوصيلات الكهربائية والميكانيكية وخلافه. وعليه فإن وجود هذه الفتحات يؤثر بالسلب على مقاومة وصلابة هذه الكمرات، مما دعا العديد من الباحثين لدراسة السلوك الإنشائي لهذه الكمرات الخرسانية المسلحة ذات الفتحات لتحديد مدى كفاءتها وكيفية تسليحها لمقاومة الأجهادات المتولدة فيها نتيجة للأحمال الواقعة عليها.

وقد توصل الباحثون في هذا المجال لنتائج طيبة من حيث قدرتهم على تحديد الشكل والمقاس للفتحة وكذلك الموقع المناسب لهذه الفتحات بالنسبة لموضعها في الإتجاه الطولي لمحور الكمرة أو خلال عمقها. كذلك توصل الباحثون إلى نسب الأساليب لتسليح وتقوية هذه الفتحات قبل صب الكمرات ولكن كيف سيكون الحال إذا اقتضت الضرورة إلى استخدام فتحات في كمرات موجودة بالفعل؟

البحث القادم يحاول الإسهام في الإجابة عن السؤال حيث تم استخدام ألياف الكربون لتدريع وتحسين سلوك الفتحات في الكمرات.

ولذلك تم ضم ثمانية عشر كمرة ذات قطاع مستطيل وتم اختبارهم تحت حملين مركزين. وتم اخذ ثلاث كمرات نموذجية للضبط وباقي الكمرات تم استخدامها ببطول 20 سم وارتفاعات مختلفة (8 سم، 10 سم، 12 سم ) وقسمت إلى ستة مجموعات وتم اختيار جميع الكمرات ومن أهم النتائج التي تم التوصل إليها في هذا البحث ما يلي:

1- تدعيم الكمرات ذات الفتحات باستخدام ألياف الكربون يقلل من عدد الشروخ وحجمها.
2- تدعيم الكمرات ذات الفتحات باستخدام ألياف الكربون يصل بالحمل الأقصى للأنهار إلى درجة مقبولة مقارنة بحمل الأنهار ذات الكمرة في حالة عدم عمل فتحات بها.
3- كلما زاد عدد الكائنات المقطعة أثناء عمل الفتحات يؤدي ذلك لزيادة ظهور الشروخ.
4- تدعيم الكمرات ذات الفتحات باستخدام ألياف الكربون يقلل من قيم التترخيم.
5- زيادة ارتفاع الفتحات يؤثر تأثيراً كبيراً في ظهور الشروخ وحجمها والحمل الأقصى للأنهار.