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Experimental studies on strengthening of RC Beams with openings by CFRP Laminates - A Review

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Abstract: This paper presents the review of studies performed to investigate the behaviour of Reinforced Concrete (RC) beams containing different types of openings. For the last 4 decades, research works involved the investigation of the member strength and development of the design approach for simply supported, continuous and T-beams containing large rectangular openings subjected to torsion, bending and shear forces. In recent years, Fibre Reinforced Polymers (FRP) have been widely used as an external bonded reinforcement system for upgrading and retrofitting of concrete structures. FRP as externally bonded reinforcement mainly used to repair and retrofit the damaged reinforced concrete member. However, very limited studies showed the application of the FRP laminates as external reinforcement around openings. Carbon fibre reinforced polymer (CFRP) as an external reinforcement is used extensively to address the strength requirements related to flexure and shear in structural systems.

Keywords: CFRP laminates, opening in beams, RC beams, strengthening methods.

I.INTRODUCTION

The shapes of transverse apertures in concrete beams might vary. Although a great number of transverse apertures of various shapes and sizes may be used, it is preferable to utilise circular forms to create rooms for service pipes, such as electrical supply and plumping, and rectangular transverse openings to accommodate rectangular air conditioner ducts.

Problems with transverse apertures through beams can be avoided if utility service placements are planned and taken into account ahead of construction, however this is not always the case. Drilling holes are most commonly required during utility installation in newly constructed buildings and in existing structures. The impact of concrete beam apertures on serviceability and durability.

1.1 EFFECT OF OPENING IN BEAMS ON SERVICIABILITY

EFFECT ON CRACK AND CRACK WIDTH

In general, flexural fractures appear before shear cracks, but in beams with holes, this trend is reversed. Loads that induce diagonal cracks and crack width will decrease when opening size is raised. Furthermore, crack width is bigger in beams with openings than in solid beams, and crack width exceeds crack width constraints regardless of location and size of holes. It is obvious from this that the serviceability of fractures can be greatly altered by openings. Furthermore, various techniques such as filling holes with unshrinking grouts and externally bonded fibre reinforced polymer plate are utilised to repair beams that have been drilled for assessment purposes. In comparison to the former, the latter strategy proved to be far more effective. Beams upgraded with an externally bonded approach have significantly better crack control than grouted beams and are even better than solid beams. Furthermore, the location of openings in beams has an impact on diagonal cracks, and shifting locations could result in crack width narrowing when openings are close to the centre stub.

EFFECT ON STIFFNESS AND DEFLECTION

Openings have a significant impact on beam stiffness after cracking, and any increase in hole size will result in a direct decrease in beam stiffness. On the contrary, the opening location has no discernible effect on the rigidity of the beam. Openings in beams will cause increased deflection if the size and position of the openings are not considered. As a result, the serviceability of the beams may be jeopardised. It should be noted that strengthening a beam with an externally

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bonded plate approach eliminates all weaknesses caused by openings. Furthermore, while grouting improvements may improve the situation, they are still far from ideal.

1.2 EFFECT OF OPENING IN BEAMS ON STRENGTH

EFFECT ON ULTIMATE STRENGTH

Increasing the size of the openings and moving them farther from the centre stub of the beam reduces the final strength of the beams. The ultimate strength of beams having openings near to the beam supports to skip the failure plane reduces by more than ten percent when compared to beams without openings. This could be due to the removal of one or more stirrups, reducing the capacity to carry a significant amount of applied shear. Different technologies, such as externally bonded fibre reinforced polymer plate, grouting with non-shrinking cement, or any other approach, can be used to regain the ultimate strength of the elements in situations where openings are drilled for assessing the performance of historic buildings. Grouting may help to restore beam strength to some extent. However, it is around 20% weaker than the original strength. The use of an externally bonded FRP plate will help to restore the strength that has been lost as a result of the openings. Finally, when an opening is made in an existing beam, it is recommended to use a large safety factor in the original design or to use a promising approach such as externally bonded FRP plate for restoring strength.

II.LITERATURE REVIEW

Aya waleed Naqe(1), The behaviour of four reinforced rectangular concrete MD beams with web circular holes tested under two-point load was studied using the non-linear finite element approach. This strategy aids in obtaining approximate solutions to more difficult issues in a more practical manner. To investigate the behaviour of MD beams, the ABAQUS /CAE was used. It also investigates the impact of the circular apertures of MD beams on their size and shape. The strengthening strategy employed in this article is externally strengthening the MD beams using CFRP around the opening. To obtain concrete mix constituents with a strength of 30 MPa, the concrete mixture was designed using the (ACI) approach. In terms of ultimate load failure, the numerical findings were compared to the experimental data. The result concluded that the presence of eight and four openings give a high strength than the two circles opening in spite of the equivalent area of the opening because of the higher depth of the top and bottom chord member for the eight and four openings and also the CFRP stretched for long distance on the surface of the beam. The ultimate loads from the experimental results less than the final loads from the FE analyses with differences (4.1 to 10.2 %) these are acceptable. The FE/EXP results indicate good agreement between the experimental and FE results of maximum deflection.

S.C. Chin(2), Carbon Fibre Reinforced Polymer (CFRP) laminates were used to reinforce R/C beams with big circular and square openings placed at the flexure zone in this study. The structural behaviour of five beams was investigated using four-point loading to determine crack patterns, failure mode, ultimate load, and load deflection behaviour. In this study, large circular and square shape of opening was considered. The size for square opening was 210 x 210mm whereas the opening size for circular opening was 230mm in diameter. The ratio of circular and square opening area to the beam's effective depth was 0.82 and 0.75,. The concrete used in the experimental study was readymixed concrete designed for 28 days compressive strength of 35 MPa. The water cement ratio was 0.54. The findings of the tests demonstrate that a wide flexure aperture reduces beam capacity and stiffness while also increasing cracking and deflection. Based on the crack patterns of the un-strengthened beams, a strengthening arrangement was created. CFRP laminates significantly increase the beam capacity of a beam with a wide circular opening at the flexure point, but only 10% of the beam capacity of a beam with a square hole is restored. The use of CFRP laminates with the designed strengthening configuration could significantly reduce excessive cracking and deflection and increase the ultimate capacity and stiffness of beam.

Rania Salih(3), In this study, the cyclic behaviour of reinforced concrete (RC) beam with openings strengthened using carbon fibre-reinforced polymers (FRPs) was experimentally investigated. Seven rectangular RC beams were cast and strengthened through external bonding of carbon fibre-reinforced polymer (CFRP) sheets around the beam web opening with different orientations to evaluate the maximum resistance, secant stiffness, strength degradation, ductility, energy dissipation capacity and behaviour of the specimens' failure mode under cyclic load. All rectangular section beams have the same cross-section with 140 mm width, 250 mm height, a total length of 2000 mm. The clear span of the beam is 1700 mm, and the effective depth is 220 mm. The circular opening has a diameter of 130 mm. The ratio of opening size to the overall beam depth is 0.52, confirming the large opening and ensuring sufficient reduction in the total capacity of the beam. Thus, the efficiency of the strengthening technique can be assessed. One solid beam without an opening (i.e., control specimen) and six beams constructed with circular web openings typically located in the middle of the beam and adjacent to the supports were used in the experiments. Among the six specimens with opening configuration, two beams were unstrengthened, and the remaining four specimens were strengthened with two layers of FRP sheets with vertical and inclined scheme orientation. Two beams were unstrengthened among the six examples with opening configuration, while the remaining four specimens were fortified with two layers of FRP sheets oriented vertically and inclinedly. ABAQUS software was used to conduct numerical investigations, and the results of finite element modelling analysis were verified through experiments. The introduction of FRP sheets improved the maximum strength and ultimate displacement of RC beams by roughly 66.67 percent and 77.14 percent, respectively, according to the results. The validated finite element models are used as a numerical platform for conducting advantageous parametric tests to evaluate the impacts of opening size and bond length.

Nurul Izzati Rahim(4), The structural behaviour of deep reinforced concrete (RC) beams that strengthen the web holes with externally connected carbon fibre reinforced polymer (CFRP) composite in the shear zone was given in this experimental investigation. This study included a control RC deep beam and nine RC deep beams with an opening in the shear zone. All the 10 deep beams had a 130 mm (b) × 500 mm (h) cross-section and were 2000 mm long (L). Based on the size of openings including 150 mm (Group B1), 200 mm (Group B2) and 250 mm (Group B3). Each group consists of 3 beams (a–c) with various numbers of CFRP layers; one (a), two (b) and three (c) layers .The failure mode, cracking pattern, load deflection responses, stress concentration, and reinforcement factor were all evaluated as part of the structural behaviour. A total of nine reinforced concrete deep beams with CFRP-enhanced openings and one control beam without an opening were cast and tested until failure under a static four-point bending stress. The experimental results showed that increasing the aperture size caused a 30% loss in shear strength. As a result, the larger the openings, the lower the load-carrying capacity, even though an increase in the number of CFRP layers could improve the load-carrying capacity. As a result, the CFRP layer wrapping technology improved the shear behaviour of reinforced concrete deep beams by roughly 10% to 40%. Two layers and three layers were shown to be the most effective number of CFRP layers for deep beams with aperture diameters of 150 mm and 200 mm, respectively.

Abbas A Allawi(5), A total of 18 specimens were manufactured and tested until they failed in order to assess structural performance in terms of cracking, deformation, and load-carrying capability. All tested specimens were with 1500-mm length, 500-mm cross-sectional deep, and 150-mm wide. The opening size was adopted to be 200 x 200 mm dimensions in eight deep beams, while it was considered to be 230 x 230 mm dimensions in the other eight specimens. In eight specimens the opening was located at the center of the shear span, while in the other eight beams the opening was attached to the interior edge of the shear span. Carbon fiber–reinforced polymer sheets were installed around openings to compensate for the cutout area of concrete. To compensate for the concrete cut-out region, carbon fibre–reinforced polymer sheets were put around openings. The results of the experimental test revealed that openings in shear spans have an effect on load-carrying capacity, with a 66 percent reduction in the failure load for specimens with the opening but no strengthening compared to deep beams without openings. Strengthening with carbon fibre– reinforced polymer sheets for beams with openings, on the other hand, raised the failure load by 20%–47% when compared to the same deep beam without strengthening. A significant contribution of carbon fibre–reinforced polymer sheets in restricting the deformability of deep beams was observed.

Khaled Fawzy(6), The purpose of this paper is to investigate how externally bonded fibre reinforced polymers (EB-FRP) can be used to reinforce beams with wide web openings that are subjected to pure torsion. An experiment was conducted to study the torsional behaviour of nine reinforced concrete beams with the same dimensions and reinforcement up to failure. One solid beam tested to be a control beam with cross-section 100 mm x 350 mm and 1780 mm in length. The remaining eight beams have the same dimensions in addition to an opening located in the center of the beam web with dimensions equal to 150 mm and 520 mm in the height and length of the open, respectively. One of the remaining eight beams was tested without any strengthening, while the other seven were strengthened using carbon fibre reinforced polymer (CFRP) in various schemes. The experimental results showed that the beam reinforced by wrapping around the chords and solid components near the opening region at a complete 90° angle to the beam axis offers the best results and has the highest torsional strength.

S.C. Chin(7), The experimental research and numerical analysis of Reinforced Concrete (RC) beams with large square apertures situated in the shear area, at a distance of 0.5d and d from the support, and reinforced with Carbon Fiber Reinforced Polymer (CFRP) laminates are presented in this paper. The goal of this study is to look at the strength losses in RC beams caused by huge square apertures in two different places in the shear area. Control beams, un-strengthened and strengthened RC beams with big square apertures in the shear region at a distance of 0.5d and d away from the

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support were all tested to failure under four-point loading. The test specimen was 2000 mm long with a rectangular cross section of 120×300 mm. The effective depth to the main reinforcement was 280 mm while the effective span of the beam was 1800 mm. , large square opening was considered. The size of the square opening was 210×210 mm. The ratio of the opening size to the beam's effective depth was 0.75 in which researchers may consider it as large opening .The entire wrapping system around the square apertures was the CFRP strengthening configuration investigated in this study. ATENA, a nonlinear finite element tool, was used to validate the results of the tested beams. Comparisons between finite element forecasts and experimental data are given in terms of fracture patterns and load deflection relationships. The crack pattern results from the finite element model agree well with the experimental data. The load midspan deflection curves of the finite element models were stiffer than those of the experimental beams

Dr. Ban Sahib Abduljalil(8), The behaviour and performance of reinforced concrete deep beams with externally bonded CFRP strips that failed under shear are reported in this research. Eight reinforced concrete deep beams are being tested as part of the research The variables considered in the experimental study include the effect of fiber orientation (90º or 45º CFRP strips with respect to beam longitudinal axis), the effect of using longitudinal CFRP strips with vertical CFRP strips and effect of anchoring the vertical CFRP strips. A total of eight reinforced concrete deep beams were tested under two concentrated loads. Each beam was 800 mm long with an overall cross – section of 80 mm x 320 mm. The beams were simply supported on a span L of 660 mm giving an L/D ratio of 2, which is less than 4 as recommended by the provisions of the ACI code 318 – 08 for deep beam requirements. Beams contained two square opening, 65 mm x 65 mm, one in each shear span. They were located symmetrically about the beam axes . The shear resistance – mid span deflection, CFRP strain, and maximum fracture width of beams – test findings were described. External CFRP strips can greatly raise the ultimate shear capacity, limit the shear crack breadth, and increase the stiffness of deep beams with opening, according to experimental results.

Mohammed J. Altaee(9), The purpose of this study is to present a novel application of carbon fibre reinforced polymer (CFRP) to the problem of strengthening web holes, utilising the material's ease of handling, high strength-to-weight ratio, and corrosion resistance. An experimental study involving 4 full scale universal beams was conducted in order to investigate the ability of CFRP to recover the strength and stiffness of beams following the introduction of web openings. In the experiments, all of the specimens were subjected to 6-point bending. The experimental series consisted of 4 no. 305×102×25 UKBs with 3m clear span; one without an opening acting as the control , and three with rectangular web openings in different locations .The equivalent test series without the addition of strengthening was numerically modelled using finite element analysis for further comparison. The effectiveness of the strengthening technique was demonstrated with increases in the load carrying capacity over the un-altered beam of between 5 and 20% being achieved.

Tamer El-Maaddawy (10),This paper presents test results of 16 reinforced concrete (RC) beams with web openings strengthened in shear with externally bonded carbon fiber reinforced polymer (CFRP) composite sheets. Test specimen was 2,600 mm long with a cross section of 85 mm × 400 mm and a shear span to beam depth ratio of a=h ¼ 2. All specimens had the same geometry and main longitudinal top and bottom reinforcement. No internal web reinforcement was provided in the test region to resemble the case of inclusion or enlargement of an opening in an existing beam which would typically result in cutting the internal web reinforcement around the opening. The test parameters were the width and depth of the opening and the amount of the CFRP sheets used for shear strengthening. Test results showed that the inclusion of web openings drastically reduced the beam shear capacity and stiffness. External strengthening with CFRP sheets around the opening was found to be very effective in improving the beam shear resistance and stiffness. Increasing the opening width or depth reduced the gain in the shear capacity caused by the CFRP. Doubling the amount of the vertical CFRP sheets from one to two layers increased the shear capacity but the additional shear capacity gain was not in proportion to the added amount of the CFRP.

Mohammed J. Abed (11), This paper presents an experimental assessment of the repair effectiveness of Carbon Fibre Reinforced Polymer (CFRP) laminate for damaged Reinforced Concrete (RC) beams with a circular web opening at the shear zones. The study highlights the effect of the opening diameter on CFRP repair effectiveness by examining the effect on the ultimate load capacity, deflection, steel strain, CFRP laminate strain and failure modes. In the experimental programme, a total of four beams were used inclusive of one solid beam used as a control beam. The other three beams were designed with different opening diameters and were exposed to damage at the pre-repair stage, up to their ultimate capacity. A solid beam without any opening which was considered as a control beam. Each beam had a clear span of 2.2 m, with the beam cross section measuring 150 mm in width and 400 mm in depth. The RC beams with a circular opening in the shear zone were designed ,where the beams were reinforced with two 16 mm diameter deformed steel bars. In

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contrast, the solid beam was designed according to ACI 318 (2008) code requirements. Damaged beams were repaired using externally bonded CFRP laminate around the openings. The results concluded that the CFRP laminate repair system was effective regardless of the web opening diameter. It was found that the increase in the opening diameter resulted in a higher deflection as well as higher strain values for the mid-span reinforcement and shear stirrups. The CFRP repaired beams behaviour transformed from brittle at the pre-repair stage to ductile at the post-repair stage. The failure mode of the CFRP repaired beams with a smaller opening diameter changed from shear failure to flexural failure, while the larger opening diameter beams failure mode was governed by CFRP deboning at the shear zone.

Said M. Allam (12),This paper presents results from an experimental study including testing nine reinforced concrete beams in order to investigate the efficiency of external strengthening of such beams when provided with large openings within their shear zones.All tested beams had a rectangular cross section of 150 mm width and 400 mm height. All tested beams had a total length of 3200 mm and a clear span of 3000 mm. The length of the opening was 450 mm and its height was 150 mm. The openings were located within the shear zone of the beams starting at a distance of 300 mm from the support .Firstly three beams were considered. One of these beams was solid without any openings and was considered as a control beam. The second beam was provided with one opening within the shear zone but without any strengthening and was also considered as a control beam whereas the third beam was provided with an opening at the same location and having the same dimensions. However, such third beam was internally strengthened with steel reinforcement along opening edges. Secondly, six beams provided with openings at the same location and having the same dimensions like the second and the third beams were considered. Such six beams were externally strengthened with steel plates or Carbon Fiber Reinforced Plastics (CFRP) sheets along the opening edges. Test results revealed that the efficiency of external strengthening of beams with openings increased significantly when such strengthening was applied to both inside and outside edges of the beam opening than that in the case of strengthening the outside edges only. Furthermore, it was found that using steel plates for strengthening beams with openings is much more efficient than that in the case of CFRP sheets. Using steel plates not only restored the beam full shear strength but also changed the mode of failure from shear mode to flexural one. Finally, theoretical analysis was performed for all tested beams with openings in order to calculate the ultimate shear force carried by such beams.

III.CONCLUSION

It can be concluded that increasing the number of CFRP layer can significantly lead to a reduction in the deflection at mid-span, due to an increase of member stiffness from about 10% to 40%. Moreover, increasing the size of the opening can decrease the deflection at mid-span, as a consequence of a high shear strength reduction of up to 30%. Hence, the larger the size of the opening, the lower the load carrying ability. For small circular openings in the (shear/bending) zones of RC beams, the effect of opening size represents loss of strength, stiffness and energy absorption. The opening is remarkably smaller and within the appropriate range compared with that of solid beams.

The impact of apertures in terms of shape (circular, square, and rectangular), size (bending, shear, and torsion), and location (bending, shear, and torsion) on the strength and stiffness of RC beams have been the subject of intensive research over the last five decades.

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