A state of the art review on transverse web opening for reinforced concrete beams with and without strengthening method

Oday Hashim Abbas¹, Hesham A. Numan²
¹,² Civil Engineering Department, Faculty of Engineering, Mustansiriyah University, Baghdad 10052, Iraq
*corresponding author: email address: Odayh2021@gmail.com

Abstract. To erect modern constructions needs many ducts and pipes to accommodate essential services such as telephone, electricity, air conditioning, and computer network. Transverse web openings throughout the Reinforced Concrete (RC) beams enable the installation of these services. In recent decades, the researchers suggested several strategies for improving the structural behavior for deep, continuous, and simply-supported beams; involving transverse web-holes underwent shear forces, bending, torsion, and cyclic loads by utilizing supplementary internal steel reinforcing bars, Fiber Reinforced Polymer (FRP) rods or plates, steel fiber, and Carbon Fiber Reinforced Polymer (CFRP) sheets. The current paper presents the previous investigations on the structural action of the RC-beams with the transverse web-openings. The effect of the shape, size, position of the opening, and type of strengthening on the structural performance of RC beams highlight and discussed in this paper. It found when the diameter of circle opening equal or greater than 40% of the depth of beam attributed by reducing in beam strength and earlier cracks occurred. Besides, the deflection of beams was rose when the openings settled below the centroid of the section. Finally, this study proves that the few previous studies discussed the RC beam's behavior with openings under cyclic loading. However, this paper aims to develop insights for future studies about assessing and strengthening methods for the RC beams with the transverse web opening.

Keywords: Reinforced concrete beams, transverse web-opening, internal strengthening, Fiber reinforced polymer.

1. Introduction
Auxiliary ducts and tubing have required in building utilities, such as sanitation, heating, air conditioning, air conditioning power, and communication supply. In previous practices, such ducts and tubing had generally been suspending under the concrete plate covered by the hanging roof, which created a wasted area [1]. Also, it has become common practice to provide transverse holes in the RC-beams for the crossing of utilities and tubing to prevent the headroom issue caused by hanging tubing. However, the presence opening raised several questions about the structural efficiency of the structural beams. The behavior of RC beam with opening becomes more complicated than conventional beams complicated because of the change happening in the dimensions of the cross-sectional beam. Hence, the stress level significantly increased at the aperture edges that cause aesthetically inadmissible cracks [2].
With openings in the RC-beams, many matters and questions were touched upon, which have inspired numerous scholars to investigate this research area more and more. Consequently, many investigations dealt with the performance in RC-beams, involving openings of various types and dimensions in continuous spans, simply-supported beams with T-sections [3]. Moreover, different approaches and equations to surmise the constructive performance in RC-beams with openings under bending, shear, or torsion behavior had developed from the experimental data produced by Houst and Lees [4]. Generally, the existence of openings through the web of RC decreases its rigidity, causing earlier incisions and increase vertical displacement, and seriously affecting its stiffness [5]. RC beams with openings should be strength tested or the area near the holes should be reinforced to restore the missing strength capacity [6,7]. From this point, several experimental and numerical investigations were conducted to capture the nature of the necessary stiffeners around the opening in the RC element [8,9].

Due to the features and characteristics of FRP laminates, they have been vastly embraced by the construction technology all over the world for strengthening and rehabilitation of the structural elements [10,11,12]. Some of the studies have shown the influences of FRP substances for strengthening RC-beam under flexural behavior [13-20], and others investigated the shear behavior such as [21-23]. Other numbers of restricted research on RC-beams with web-opening have been documented utilization of FRP substances in some comprehensive details [24-28]. Experiments backed by the theoretical study carried out in this research field had also proposed by [25-27]. Nonlinear behavior through Finite Elements Analysis (FEA) validated with experiments studies introduced by [28,29]. However, all research acknowledged that most FRP laminates could use externally to enhance the structural performance of RC beams effectively.

The primary target of this article is to reinforce the popular matters and questions addressed during the opening literature in the RC beam research. The ongoing research studies the structure, dimensions, and locations of single or multiple orifices using nonlinear computational methods and the simulations through experimental experiments.

2. Past experience analyses
2.1 Structural response RC beams with openings
Lorensten [30] conducted four simply-supported beams and T-sections with a single-sizeable web rectangular-opening. Reagan and Warwaruk [31] also conducted an experimental study on six T-beams simply-supported having many large rectangular web openings. Additionally, Lorensten's work was expanded by Nasser et al. [32] by examining nine simply-supported beams and rectangular sections with two rectangular openings. All these researches stated that the beam's strength improved with extra bars around the rectangle opening; however, the rigidity was still less than the RC beams without web apertures.

The joist floors with the light-weight concrete, Somes and Corley [33] studied the action of continual beams circular-opening. They have stated that circular openings could accommodate without expensive strengthening. Within the same context, McMullen and Daniel [34] proposed formulas for estimating the torsion strength for RC-longitudinal beams comprising the lengthy and stumpy-rectangular openings with and without around the corner.

Also, systematic research conducted by Mansur et al. [6] to test RC-beams with big-rectangular apertures underwent torsion. They disclosed that both torsion resistance and the beam rigidity reduced as increase depth or length of web openings, but its eccentricities had a marginal effect. Besides, they pointed out that the failure beam mechanism achieves by creating four hinges at each opening corner. They analyzed the torsion behavior using a collapse load simulation to predict the RC beam capacity with a rectangular opening. Mansur and Paramasivam [35] adopted the famihar skew-bending model for evaluating RC beam strengths that have a small web-circular aperture undergone the incorporated effects of torsion and bending. The principles of limit analysis are used by Alwis and Mansur [36] to
predict the torsional strength of an RC beam containing a sizable rectangular-aperture underwent torsion and bending together effects. Additionally, Hasnat and Akhtaruzzaman [37] have presented a series of formulas utilizing the bending-skew models to emulate RC-beams with or without rectangular transverse web-aperture in torsional strength and failure mode.

Mansur et al. [38] examined RC-continual beams with a big-opening to express the load-deflection response. The test parameters were: span length, opening's dimensions, as well, the sites. They indicated that four distinct divisions in the relation between load and vertical displacement of the continuous beam. Also, they pointed out that a raise in opening depth from 0.140 mm to 0.220 mm caused decreasing in collapse load from 240 kN to 180 kN. Moreover, through assigning reduced shear and flexural rigidities to the parts containing the large rectangular opening in the RC beam, the deflection of these beams can be evaluated approximately [39]. The design guidelines for the response and serviceability limit states for RC beams involving large openings introduced by Tan and Mansur, [40]. Subsequently, the shear behavior of beams with a small opening has studied by Mansur [41]. The author categorized the web opening (small or large size) relative to the overall beam depth. The researcher also divided the form of diagonal failure into beam-type and frame-type for small web openings.

Most investigations have discussed the RC beam behavior with web openings under static loading, but very few researchers have investigated the performance of such beams under cyclic load effect [42-44]. Additionally, an experimental study has conducted by Al-Shaarbaif and Abdurridha [45] to simulate the response of high strength RC deep beams with web openings under monotonic and static repeated-loading states. They indicated that the ultimate load capacities for specimens examined under four different repeated loading systems reduce in the range between 2% and 19% regards to reference specimens which tested under monotonic loading system.

The prim conclusion of the study introduced by El Ame et al. [46] was that when the transverse circle opening with a diameter greater than or equal to 40% of the beam depth results in earlier cracks and a lowering in the beam strength. Figure 1 depicts the relationships between the load with maximal mid-span deflection of the beam for the three groups of the vertical location of the opening (0.5, 0.55, and 0.6 from the beam depth, respectively) according to El Ame et al., [46].

![Figure 1](image)

**Figure 1.** Load against maximum deflection at the middle span of the RC beam: (a) Group 1, (b) Group 2, (c) Group 2 [46]

It could sum up that; over the past 25-30 years, attempts made to simulate the action of the RC-beams through the inclusion of apertures in diverse sizes, shapes, and configurations (one or more and at various positions of the beam). In such experiments, Tee and rectangular-shapes of beams are
investigated with shear, bending, and torsion loads in a single span and multiple spans. Also, different analytical patterns have developed with or without experimental findings. In general, the field of beams with transverse openings had vastly studied. The next section of this research reviews the various strategies used for strengthening transverse web-openings (reinforcing web apertures utilizing inner strengthening or exterior by utilized FRP sheets in RC beams).

2.2 RC beams with opening strengthening
2.2.1 Using internal reinforcement in strengthening

It also acknowledged previous researches in this paper; the existing opening in the web of RC beams was adverse effects on the structure's performance of these beams, including decreasing the ultimate load capacity, stiffness reduction, and a large deflection response. Therefore, adding reinforcement internally or around the openings in RC beams is considered a necessary strategy to increase the strength's capacity of these structural elements, either in the planning and erection phases or in constructed RC-beams. This elicitation is the result of the comprehensive survey carried by the authors. In this section, the main conclusions of the internal reinforcing bar around the web openings had reviewed.

The rational design approaches were proposed by Mansur et al.[8] for the RC beams big rectangular-openings and strengthened in the shear and flexure zones. Twelve-beams were prepared and examined with a single-point load using this approach. They suggested the parameter variables including: coverage length, the section depth, load eccentricity, the opening's positions, and the quantity and distribution of nook strengthening. The researchers stated that diagonal bars control cracking and deflection effectively than vertical stirrups as corner reinforcement.

Tan et al. [47] investigated the procedure for shear design of RC-beams with circular-holes to modify the existing method in the American Concrete Institute (ACI). Seven beams with Tee-sectional and circular-web holes for temperate to high-shear strength had checked inverted to replicate the negative-moment circumstances in a continual RC-beam. The scholars discovered that the ultimate strength accomplished and controlled on the cracks through strengthening the opening by steel reinforcement bars. Also, they pointed out that the diagonal bars were formed lower high compression chord stresses, thereby preventing premature concrete crushing. On the other hand, the stretch of the lower steel reinforcing bar reduced with a raise in the depth or length of the hole; as well as, the maximum load and post-cracking strength rose with increment in the compressive strength of concrete [48].

The performance and capacity of the deep-beam were influenced by the amount of web reinforcement and the location of openings, whether in the constitute of separate fibers or as continual strengthening [49]. The amount of steel fiber and the location of openings are significant effects on the behavior and strength of RC deep beams [50]. Based on the study by Saksena and Patel [51] proved that the existence of supplementary reinforcement and stirrups in the upper and lower of the opening is more vital to the ultimate strength of beams.

The behavior of RC beams with redoubled transverse web-holes had studied by Aykac et al. [52]. They simulated the influence of using diagonal reinforcement around the holes, the longitudinal-steel bars proportion, longitudinal-stirrups placed between the holes, and opening geometry on the bending response of RC-beams with holes. The obtained results from the study of Aykac et al. [52] proved that to avert the Vierendeel-truss influence and thereby prevented shear failure and allow a beam to improve its ductility and bending capacity using the posts between the openings. Details of reinforcing steel bars and dimensions of the specimens used by Aykac et al. [52]; shown in Figure 2.
As shown in Figure 3, the steel plate with internal radial bars (studs) used to strengthen a web opening in the RC deep beam had suggested by Abdul-Razzaq et al. [53]. They disclosed that the decrease in size of the unstrengthened square openings by (25-50) % caused the raise ultimate load capacity by (11-17) %. Additionally, they found that the increase in the plate thickness from 4mm to 8mm, caused to increase in the ultimate load capacity by 10 %.

**Figure 3.** The used steel plates and studs for strengthening the openings [53]

### 2.2.2 FRP Strengthening Around Openings

This section reviews the past articles concerned with strengthening the RC with transverse web opening externally by FRP laminates and focuses on the type of CFRP. Mansur et al. (1999) [2] investigated a specified number of continuous RC beams with a total length of 2.9 m, and they contained circular openings, as shown in Figure 4(a). They applied a truss arrangement of FRP plates’ technique around the circular opening in the RC beam. The researchers used a coring method to achieve the web-opening in the beam with maintaining the integrity of concrete around the web opening. A truss of FRP plates was used around the web opening to preserve the beam’s original strength. To avoid premature de-bonding, double-horizontal sheets with a span screw strengthening on each side with three diagonal sheets illustrate in Figure 4(b).
The findings of the study Mansur et al. [2] demonstrated that reinforcing truss FRP sheets around the web opening may be controlled both the large deflection and excessive cracks; also avoid the loss in the maximum strength. The role of the FRP plates $V_F$ to the maximum shear capacity extracted from the test results of the reinforced beams:

$$V_F = A_F F_{FS} \sin \alpha \left(\frac{E_s}{E_F}\right)$$

Where, $A_F$, $F_{FS}$ and $\alpha$ are the cross-sectional area, tensile stress, and deviation angle of the FRP sheets, respectively; and $E_s$, $E_F$ and are Young’s modulus of the stirrups, and FRP sheets, respectively. The reckoning of $F_{FS}$ had done according to the mean strains recorded for the FRP sheets at the utmost situation.

Abdalla et al. (2003) [25] used FRP sheets to reinforce the opening region of RC beams. The openings have situated in the shear territory with a distance of 0.2 m from the support. Figure 5(a) shows the geometrical dimensions and configurations of RC beams used by Abdalla et al. [25]. They discussed three parameters, including the opening size and the FRP sheets quantity and arranging. Ten simply-supported beams with a section (0.1 m × 0.250 m) and a net length of 0.2 m tested under a two-point loading. The height of the opening represented 60% of beam deepness. An analysis process had developed to estimate the beam’s behavior through vertical-displacement, stress, utmost load outcomes, and cracks.

Figure 5(b) depicts the arrangement of CFRP laminated at the opening of the RC beam. The shearing fails at the chords of the reinforced web apertures that they revealed by integrating the shear cracking of the concrete and the bonding failure of the glued FRP sheets. The shear strength of the beams with reinforced apertures was effectively calculating by a cautious design process. They concluded that an aperture in the shear zone resulted in a large decrease in the ultimate beam capacity. Moreover, the reinforcement technique used work to minimize vertical displacement and cracks throughout the web-aperture and increased the utmost beam capacity.

![Figure 4. Beam configurations: (a) specifics of reinforcement in Beams, (b) distribution of FRP for beam D15X4-F [2].](image-url)
Figure 5. Dimensions specifics of the examined beams: (a) internal steel reinforcement, (b) kinds of CFRP external retrofitting [25].

With a total number of RC beams was nine and single span, Allam [11] was studied the effect of externally reinforcing rectangular openings in RC beams. The scholar used two means of reinforcement that are steel plate and CFRP sheets. These beams had test under two concentrated loads till failure. The scholar confirmed that the formation of a shear zone opening significantly reduces its capacity. Figure 6 illustrates the combined external reinforcement of CFRP and steel plates around the opening in RC beams. The scholar explained the causes for using this strengthening return to the steel has identical substance properties, besides the orientation carbon texture was uni-directionally in the CFRP sheets.

Additionally, a theoretical study has conducted by Allam [11]; the shear potential for beams in the shear zone ($V_c$) measured based on the Egyptian Code of Practice (ECP 203-2007, 2007) [54] as:

$$V_c = 0.24 \sqrt{f_{cu} \delta_c (bd)}$$  \hspace{1cm} (2)

$$\delta_c = 1 + 0.7 \frac{N_c}{A_c}$$  \hspace{1cm} (3)

Where $\delta_c$ symbolizes the raise in the shear force capability result in the impact of the axial compressive force ($N_c$). On the other hand, $A_c$ is the cross-section area of the concrete section, $b$ is the width of the beam, $d$ is the efficient depth of the beam, $f_{cu}$ is the cubic compressive strength, and $\gamma_c$ is the concrete density.
Figure 6. Reinforcing configurations on all sides of opening utilizing CFRP and Steel Plates [11]

The contribution of the strengthening using steel plates, $V_p$, can be estimated using Eq. (4), whereas Eq. (5) used to determine the contribution of the FRP laminates, $V_f$.

$$V_p = 2 \tau \left( \frac{dh_p}{2} \right)$$

$$V_f = 2 t_f f_{fe} d_f$$

Where $h_p$ is the height of steel plate, $t_f$ is the thickness of the fiber, $f_{fe}$ is the effective tensile, and $d_f$ is the effective depth of the fiber.

To upgrade RC deep beams with openings, El Maaddawy and Sherif [27] used CFRP composite sheets as a strengthening solution. El Maaddawy and Sherif [27] used the cross-section beam (0.08 mm × 0.50 m), while the span length is 1.20 m. The researcher proposed two-square hole, one for each the shear zone, were put identical about mid-point of the beam. They studied factors, included the opening size, the position, and CFRP sheet presence. It concluded that strengthening the CFRP around the opening contributes to increasing the shear potential by thirty-five to seventy-three percentages. The empirical findings compared with the structural sample idealism of RC -deep beams with holes. Figure 7 depicts the structural layout for RC-deep beams having holes by El Maaddawy and Sherif [27]. The shear strength of the RC-beam with the hole ($V_{ani}$) could evaluate through:

$$V_{ani} = V_c + V_{sd} + V_f$$

Where $V_c$, $V_{sd}$, and $V_f$ denotes the shear strength of concrete, tension-steel (dowel action), and CFRP sheets, respectively.
Figure 7. Layout of structural performance with opening [27]

Madkour [29] clarified the non-linearity behavior of retrofitted RC-beams comprise rectangular web-openings. The researcher applied the numerical application of the deterioration-non-linearity elastic hypothesis to investigate the non-linear behavior of beams. They suggested two parametric studies; the opening height and the reinforcing layouts utilizing CFRP around the web opening. The numerical application estimated the three-dimension ambit to specify the economic and activity of reinforcement layout. A good agreement had achieved between the numerical results with empirical findings in the literature of the study. Besides, for each strengthening scheme, the mode of failure was introduced.

Pimanmas [28] conducted experimental and numerical studies to emulate the influence of opening RC beams reinforcing by FRP rods. Thirteen RC beams tested with circular and square opening. Two styles of strengthening by FRP rod carried out: one is to put FRP rods diagonally throughout the entire depth of the beam, and the other is to place FRP rods enclosing the opening, as shown in Figure 8. It disclosed that simply putting FRP rods around the opening is not the entirely efficient result of a diagonal crack can propagate through the beam with the crack path diverted to avoid intersecting with the FRP rod. Moreover, a significant development in ductility and loading capacity had achieved when FRP rods had put throughout the entire beam’s depth. It also found that the shear capacity of the beam has significantly reduced with the opening presence.

Figure 8. Distribution of FRP rods: (a) enclosing the opening, (b) diagonally throughout the entire depth of the beam [28]
Nie et al. [55] utilized eight full-scale RC beams with a T-section to assess the influences of an opening on bending capacity, and to study the reinforcing in shear capacity. They used the CFRP U-jackets with a CFRP spike for strengthening a large rectangular web opening. The specimens subjected to central-point load and the outcomes demonstrated that the convenient web-opening girth in the beam’s layout could efficaciously decrease the bending ability. Also, CFRP retrofitting is indispensable to confine the web chord generated by the opening guarantees the flexible action for the beam also avoiding shear failure.

An experimental investigation was conducted by Salih et al. [56] for the RC beam with the circular openings strengthened using CFRP sheets under cyclic load. Different orientations of CFRP had used to assess: the secant stiffness, ultimate strength, ductility, strength retreating, energy squandering capacity, mode of failure in beams. They confirmed that utilizing FRP sheets have a notable impact on these beams by developing the utmost beam strength to roughly 66.67%.

Repaired RC-beams with a circular web-opening at the shear parts by CFRP had studied by Abed et al. [57]. The researchers indicated that the repair regime by CFRP laminate was efficient with all diameters of the web-opening. Also, they disclosed that with a smaller opening diameter, the failure style of the CFRP repaired beams transformed from shear to flexural, whereas, in the shear region, the CFRP de-bonding occurred with a larger opening diameter.

Increasing CFRP layers led to decreasing mid-span vertical displacement of the deep RC beam that contains a web opening in the shear zone. This result based on the experimental investigation was conducted by (Rahim et al. 2020). Figure 9 shows the middle span deflection behavior against the load for strengthening RC deep beams with layers number of CFRP and the control beam [58].

![Figure 9](image)

**Figure 9.** Load-mid span deflection curve for RC deep specimens with different number of CFRP layers (set 1) and control specimen

3. Conclusions

In the last five decades, the previous works dealt with the impacts of openings on the strength and rigidity of RC beams in terms of their shape under different loadings. The key gaps are the consequences of the sizable square and circular openings at crucial sites in shear and flexural. However, the prime conclusions of this study can be summarized as follows:
1. Due to the FRP sheet properties, such as (low cost, lightweight, superior thermo-mechanical, and ease in fixing) made it is an appropriate choice for rehabilitation or strengthening RC beam contains transverse web opening than the other methods.

2. It found numerous studies have emulated the performance of RC beam with openings under immobile loads, but very minimal investigations have assessed the performance of these beams under periodical loads. Therefore, the simulation fatigue load becomes very vital for such structural elements.

4. The existence of longitudinal stirrups in the posts between the openings was a significant factor for preventing shear failure and increase the flexural capacity of strengthening RC beam contains multiple holes. Also, the appearance of diagonal-rebar and stirrups in the upper and lower of the opening is important by developing the ultimate strength of beams.

6. It found that when the diameter of circle opening equal or greater than 40% of the depth of beam caused reducing in beam strength and earlier cracks occurred. Besides, the deflection of beams increased when the openings locating below the centroid of the section.

7. Very few studies concentrated on strengthening openings of the RC beams under the truss arrangement of FRP plates. Also, rare works investigated the influence of drilling openings in existing RC beams.

Based on the above points, the authors suggested an optimized (internally and externally) reinforcement diagram to control the cracks and increase the ultimate load capacity of beam regard to opening strengthening; and studying the effects of drilling openings process for existing RC beams. The authors also recommended conducting a study that clarifies the differences of using internal or external strengthening in structural performance for such elements.

5. Acknowledgment

The authors thank and gratitude to Mustansiryah University that presents all facilities and necessary scientific support for completing this work.

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