A REVIEW OF OPENED REINFORCED CONCRETE BEAMS WITH AND WITHOUT STRENGTHENING

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Abstract

The transverse holes in the webs of beams in buildings are necessary for the passage of service ducts and piping in order to minimize the story height and to attain economic requirements. Use of externally bonded Fiber-Reinforced Polymer (FRP) sheets, strips or/and steel plates is a modern and convenient way for strengthening of RC beams. Several researchers have been carried out on reinforced concrete beams with web openings strengthened with fiber-reinforced polymer composite. Some of them focused on shear strengthening compared with flexural strengthening that had the largest shear and others studied the effect of openings on shear and flexural separately. This paper attempts to address an important practical issue that is encountered in shear strengthening of opened reinforced concrete beams with carbon fiber reinforced polymer (CFRP) laminate. A simple technique of applying fiber-reinforced polymer contributed with steel plate for strengthening the RC beams with openings under different load application proposed in this paper.

Keyword- *carbon fiber reinforced polymer,web opening, concrete beams, shear strengthening*

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Introduction

Recently develop fiber reinforced polymer (FRP) composite materials and became available for a wide range of applications, including seismic retrofit of reinforced concrete beam. FRP wrapping has many advantages, including extremely low weight-to strength ratios, resistance to corrosion, high elastic modulus, and ease of application. And also, unidirectional FRP confining can improve structural ductility without considerable stiffness amplification, thereby maintaining the bridge dynamic properties.

Transverse opening in Reinforced concrete beams in practice is a facility, which allows the utility line to pass through the structure. This type of design encourages the designer to reduce the height of the structure, which leads to an economical design. Because of sudden changes in the dimension of cross-section of the beam; the corners of opening would be subjected to stress concentration, and it is possible to induce transverse cracks in the beam. The maintenance, rehabilitation and upgrading of structural members, is perhaps one of the most crucial problems in civil engineering applications. Moreover, a large number of structures constructed in the past using the older design codes in different parts of the world are structurally unsafe according to the new design codes. Since replacement of such deficient elements of structures incurs a huge amount of public amount and time, strengthening has become the acceptable way of improving their load carrying capacity and extending their service lives (GyuseonKim,et al 2008). The use of fiber-reinforced polymer (FRP) materials in civil infrastructure for the repair and strengthening of reinforced concrete structures and also for new construction has become common practice. The most efficient technique for improving the shear strength of deteriorated RC member is to externally bond fiber-reinforced polymer (FRP) plates or sheets. FRP composite materialshave experienced a continuous increase of use in structural strengthening and repair applications around the world, in the last decade (ISIS 2007).

In addition, when the FRP was compared with steel materials, it was found that it provided unique opportunities to develop the shapes and forms to facilitate their use in construction. Although, the materials used in FRP, for example, fiber and resins are relatively expensive when compared with traditional materials, noting that the crises of equipment for the installation of FRP systems are lower in cost.

Strengthening Importance

A structural strengthening is needed when a structure has been built to resist to a particular system of loads and when this system of loads has changed with time. For example, this can happen for bridges when the traffic loads increase as the number of heavy vehicle's increases, or when the deck has to be widened in order to have an additional lane. In these cases, the bridge has to be strengthened. The same with buildings: a room designed for an office, for example, needs to be strengthened if we change its function into a storage room. A strengthening can also be needed when new regulations come up with more restrictive safety factors.

Carbon Fiber Strengthening

Strengthening by carbon fiber is very interesting when the loads to be taken are not too large. This strengthening method is relatively easy and fast to put in place, because carbon is a very light material and the application is very simple. Moreover, contrary to a strengthening with steel, the carbon fiber composite is not sensible to corrosion, which is favorable from a durability point of view.

some proposals or recommendations have been adopted in different countries for the design of reinforced concrete structures reinforced or strengthened with FRP sheets, such as ACI 440 (2008), ACI 318-95(1995), *ACI 440.2R-02(2002)*, ACI 318-05(2005).

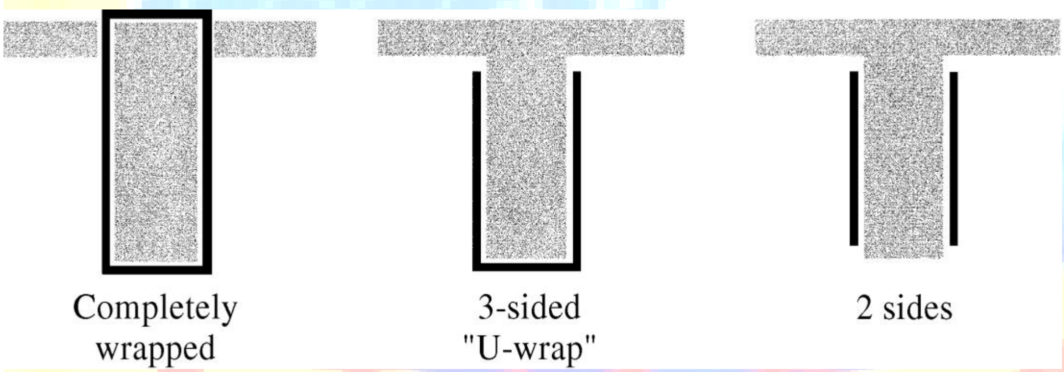

Figure. 1. Typical wrapping schemes for shear strengthening using FRP laminates.

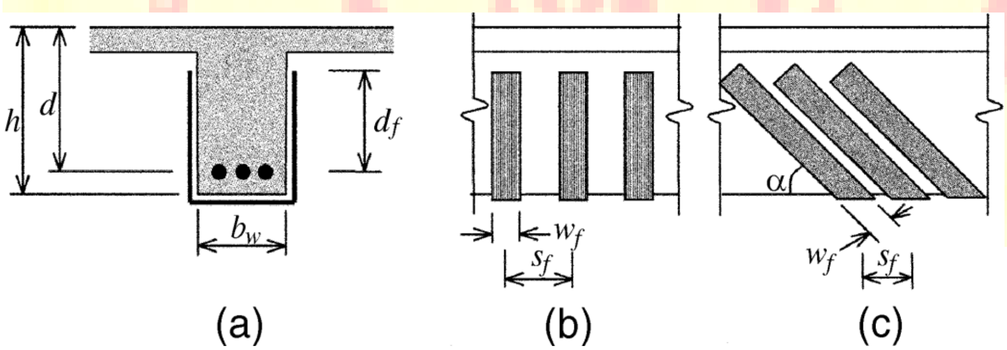

Figure. 2. Illustration of the dimensional variables used in shear-strengthening calculations for repair, retrofit, or strengthening using FRP laminates*(* ACI 440.2R-02)

Figure.3.Strengthening of RC girder by CFRP laminates in shear(M.B.S Alferjani et al 2013).

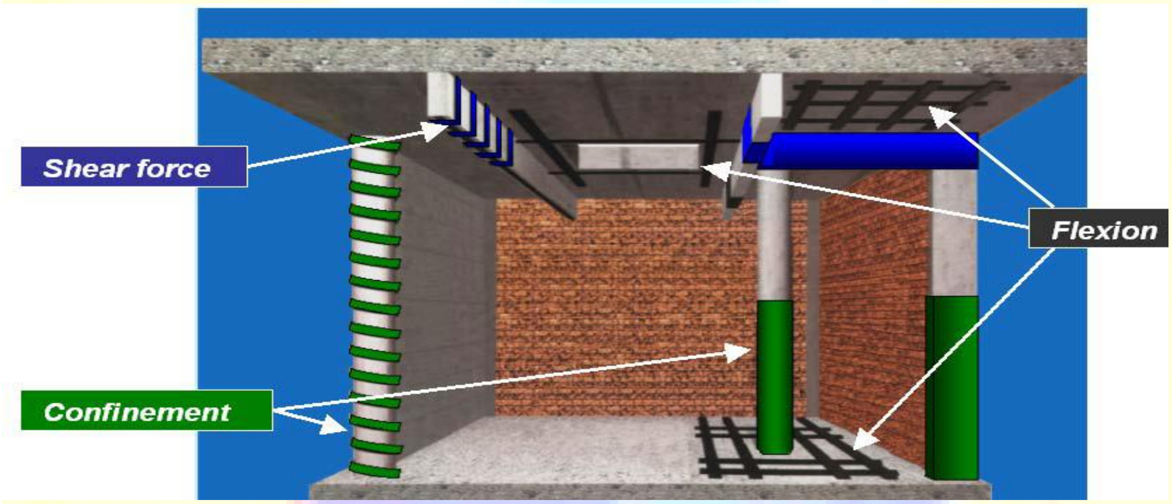

Figure. 4. Different kinds of carbon fiber strengthening (AmélieGrésille 2009)

Previous Researches on R.C Beams with Openings

Nonlinear finite element modeling and analysis of steel fiber reinforced concrete (SFRC) deep beams with and without openings in web subjected to two- point loading was presented by *HayderQaisMajeed(2012).* The percentage of steel fiber used in the study was varied from 0 to 1.0%. The study concluded that the location of openings and the amount steel fiber are affects to the behavior and strength of deep beams. The results obtained by using finite element analysis are very close to that obtained by experimental work.*HayderQaisMajeed (2012) studied the* experimental and nonlinear finite element (ANSYS 11) analysis to creating square openings in existing RC beams and strengthening with CFRP laminate. The results indicated that the strengthened beam recorded the highest failure load and its mode of failure was ductile. *Vengatachalapathy.V, et al (2010)*studied experimentallythe behavior and ultimate strength of steel fiber reinforced concrete (SFRC)deep beams with and without openings in web subjected to two- point loading, nine concrete deep beams of dimensions 750mm×350mm×75mm thickness were tested to destruction by applying gradually increased load. The theoretical formula obtained by Kong and Sharp's was modified to calculate the ultimate load which compared by experimental results. The results was gave clear indicator that the behavior and strength of deep beam affected by the location of openings and the amount of web reinforcement, either in the form of discrete fibers or as continuous reinforcement. In terms of experimental application several studies were performed to study the behavior of retrofitted beams with openings and analyzed the various parameters influencing their behavior. *WU Yan, et al (2004)* investigated two reinforced concrete frames with openings beam to study many parameters such as to research failure pattern, dynamic response , hysteresis curves , energy dissipation and rigidity degeneration of RCframe with openings. Their results show that the openings do not affect the seismic behavior of reinforced concrete frame.The seismic resistance mechanism of two full-scale Single-span Holed Frame-supported Wall-beams was experimentally studied by *QUA N X ueoyou et al (2009)*. Test results show that when only the vertical load exerted on top of the brick-wall, both symmetrically holed and non-symmetrically holed wall-beams displayed an evident composite arch action. The lower corner aside the hole of coup led w all may experience compression crushing, the beam end may have shear failure and the brick coup ling beam will be subjected to serious shear failure. The supporting beam suffered flexural failure around the holed span or splitting failure along the longitudinal bars between opening edge and the nearest beam end.*Huang Tai-yun et al (2008)*investigated 20 simply supported reinforced concrete beams with rectangular openings under concentrated load. Their Experimental results show that the shear capacity of beams was increased by strengthening stirrups and the bent-up steel bars at the opening sides, and the shear-compression failure can be avoided if the transverse reinforcements and the stirrups of chords are large enough.

*Qiongjuan Zhao (2012)*investigated by the ANSYS finite element analysis software the effect of variation of opening diameter, opening position and stirrup ratio around the hole on the mechanical behavior and shear capacity in reinforced concrete beam. Their results show that the opening location has a great effect on shear capacity of the beam and results calculated by the formula agrees well with the experimental data in literatureand that obtained by using ANSYS for RC beams strengthened by FRP.

*JIN Guo-fang, et al (2011)*studied the loading test and finite element analysis of beams with hole. Results of stress variety and distributing were discussed and provided that if the beams designed with openings need to be strengthened and how to strengthen them.

The behavior of steel reinforced concrete (SRC) beams with an opening, including the effects of various opening shapes and different values of moment to shear ratio on the strengthwere investigated by*C.-C. Che, et al (2008)*.the experimental study showed the failure of the specimens with low moment to shear ratio by shear cracking, and specimens with high moment to shear ratio demonstrated ductile behavior due to the confinement attributed to the stirrup and structural steel. The effect of small circular opening on the shear and flexural and ultimate strength of beams have been studied *by Nilesh, et al (2013)*. The changes of diameter and openings positions are the main factors of their study. Their results showed that the presence of diagonal reinforcement and stirrups in top and bottom of opening is useful.

Seismic behaviors of steel moment resisting frame including opening in beam web was investigated by *libo, yang qing-shan, et al (2009), JIANGHua, et al (2008) and CHEN Hui-rong (2009)*.Experimental results show that steel moment resisting frame (MRF) including opening in beam web closed to connection can satisfy the design requirement. Results shown that, rotations around beam-to-column connection decrease and brittle weld fracture can be avoided and seismic behaviors of steel MRF are improved due to opening in beam web. Analysis results show that with appearance of opening in beam web, the rigid of steel MRF is not weakened, and the failure mode of a ductile frame is formed.An experimental study of 29 simply supported RC beams with circular web openings under concentrated loads was carried out *by CaiJian, et al(2009)* to investigate influence the mechanical properties ofthe beams with circular web openings, including the size, location and eccentricity, spacing of web openings, ratio ofshear span to effective section depth, and form and amount of reinforcement around the openings on shear capacity. Their results show that the openings size and location has great effect on shear behavior of reinforced concrete beams.

Factors that influence the mechanical behavior of 42 simply supported reinforced beams with openings, such as height andlength of the opening, position of opening, eccentricity of opening, spacing of opening,ratio of shear span to effectivedepth of section, form and amount of reinforcement around the openings were investigated experimentally by *Huang Taiyun, et al (2009). Their* conclusions provided experimental proofs for the establishment of mechanical model and design method for this kind of reinforced concrete beam with opening.The effect of introducing openings in existing reinforced concrete beams were carried out by *CaiJian, et al (1997.I, II, and III)and Yang Yu-hua,et al (1997, 2001)*.Results obtained from experimental work were compared with theoretical results and gave clear evident that is useful for engineering practice. They concluded that the presence of diagonal reinforcement was increased the shear capacity of beams and reduced the cracks width with low strain value around the opening. The results s how that the behavior of the beams is also affected by the size of the opening and yet it is not markedly affected by the double circular openings, which have a distance of more t ha n 1 time of the diameter of opening from its side t o t he side of the circular openings.*M.A. Mansur (2006)*summarized the analysis and designs of such beams under the most commonly encountered loading case of bending and shear. It has been shown that the design method for beams with large openings can be further simplified without sacrificing rationality and having unreasonable additional cost, and he was explained how to creating an opening in an already constructed beam and how to deal with multiple openings.

The design specifications of openings in the web for simply supported reinforced concrete (RC) beams and rectangular concrete beams conducted by previous researchers was reviewed by*SoroushAmiri, et al (2011)*, and they were discussedand described the previous researches which are related to the openings in the web of reinforced concrete (RC) beams.*Ammar Y. Ali, et al (2011)* investigated the effect of the shape and dimensions of opening on the behavior of R.C beams and they was examined the effectiveness of CFRP reinforcement in enhancing the flexural capacity of RC beams with opening at the flexural region. Results obtained from the study show that the (L/h) ratio and FRP sheets has great effect to increase the stiffness and capacity of all beams.

Strengthening R/C beams with large circular and square opening located at flexure zone by Carbon Fiber Reinforced Polymer (CFRP) laminates was studied by *S.C. Chin, N. Shafiq, et al (2011)*. They were explained clearly from the Test results that large opening at flexure reduces the beam capacity and stiffness; and increases cracking and deflection. Test results showed that large opening at flexure reduces the beam capacity and stiffness; and increases cracking and deflection. Investigation of the strength losses in RC beam due to the presence of large square openings placed at two different locations in shear region was examined by *S.C. Chin,et al (2012)*. Also, in order to re-gain the beam structural capacity loss due to the openings, strengthening by CFRP laminates around the openings were studied. Nonlinear finite element program ATENA was used to validate the results. the mid-span deflection and cracks patterns of tested beams obtained by finite element model show good agreement with the experimental data.

The effects of opening shape and location on the structural strength of R.C. deep beams with opening was studied by*Haider M. Alsaeq (2013)*. The FE program Used in this study shown fair agreement with the experimental results, with a difference of no more than 20%. The present work concludes that the opening location has more effect on the structural strength than the opening shape. It was concluded that placing the openings near the upper corners of the deep beam may double the strength, and the use of a rectangular narrow opening, with the long sides in the horizontal save up to 40% of structural strength of the deep beam.*Nilesh H. Saksena, et al (2013) used* finite element method using ANSYS 14.0 to simulate the simply supported concrete beams consisting of circular openings with varying diameters at different locations. Numerous models of simply supported reinforced concrete rectangular section beams with circular opening were loaded monotonically with two incremental concentrated loads. The beams were simulated to obtain the load-deflection behavior and compared with the solid concrete beam. The results obtained from this study showed that the performance of the beams with circular openings at center of span has lesser effect on the ultimate load capacity of the RC rectangular section beams. Introducing the circular opening of diameter of 45% of depth near the support reduces the ultimate load capacity of the

RC rectangular section beams at least 32% compared to solid beam. An extensive experimental program consisting of testing eleven full scale RC beams were carried out by *sreelathavuggumudi (2013)*. The variables investigated in this study included steel stirrups, shear span-to-depth ratio, GFRP amount. The test results illustrated in the present study showed that the external strengthening with GFRP composites can be used to increase the shear capacity of RC T-beams, but the efficiency varies depending on the test variables such as fiber orientations, wrapping schemes, number of layers and anchorage scheme. The shear capacity of these beams has increased compared to the control beam which can be further improved if the debonding failure is prevented.

Grahamsrichardsharp (1977) was concerned with the general behavior in shear of single-span reinforced concrete deep beams and in particular the effects of web openings on their ultimate strength and serviceability. The test specimens comprised seventy-five lightweight and sixteen normal weight reinforced concrete deep beams with span/depth ratios ranging from one to two. The effects of a varied range of web openings on deflections, crack widths, cracking loads, failure modes, and ultimate shear strengths were studied, and the influence of web reinforcement was investigated. Eleven full scale RC beams was carried out experimentally by *SreelathaVuggumudi (2013)*to investigate the shear performance and failure modes of RC T-beams strengthened with externally bonded GFRP sheets. Results indicated that the contribution of externally bonded GFRP to the shear capacity is significant and depends on the variable investigated. The debonding failures of FRP sheets followed by brittle shear failure are initiated failures of strengthened beams. The method of anchorage technique by using GFRP plates has been used to prevent the premature failures. A theoretical study is also proposed by using ACI guidelines for computing the shear capacity of the strengthened beams. The shear capacity of these beams has increased as compared to the control beam which can be further improved if the debonding failure is prevented.*Mansur,M.A., et al (1999) they*wrote this book to compile the state-of-the-art information on the behavior, analysis, and design concrete beams that contain transverse openings through the web. The behavior of such beams under bending, shear, and torsion is treated in the book. Design methods based on plastic hinge mechanism, plasticity truss and strut-and-tie models, and skew-bending theory are described and illustrated with numerical example.

A set of simple and reliable design equations for high strength concrete deep beams with opening was developed by *Tae Min Yoo (2011)*. Deep beams with web opening but without web reinforcement are given particular attention in his investigation. The finite element method was used to conduct a series of parametric studies and the failure mechanism of concrete deep beams with opening was offered by numerical analysis through detailed examination of their ultimate load versus crack patterns and deflection response. Analyses the Eigen frequency of castellated beams with hexagon holes using Rayleigh method and the finite element analysis software were simulated by *Xia Zhicheng, Cao Ji andXu*

Duo (2009). The effect s of the opening ratio, height distensible times, the ratio of height to span and displacement constraint on the natural frequency of castellated beams are studied. result s indicate that; castellated beams have better aseismic performance than the non-heightened H-type steel beams and the use of castellated beams is more economical than that of the plain web girders with the same section height in the large span.two single-bay and single story RC frames with opening beam with The pseudo-dynamic test was carried out by *WU Yan-hai and CHENG Hao-de (2004)* to investigate the failure pattern , dynamic response , hysteresis curves and energy dissipation and rigidity degeneration of RC frame with opening beam. They reported that the presence of openings in the beam frame structure does not affect the overall seismic performance and failure modes of the structure.The duration earthquake seismic waves wasdirectly affect the cumulative damage to the frame structure under earthquake, showing structural role in the larger amplitude without cracking, but instead in the subsequent cracking of small amplitude.The mechanism of the structural destruction of the steel reinforced concrete when the openings are located in the bending shear sections is analyzed by *GU Song and PAN Wen (2003)*. Results compared with some simplified design methods and using of reinforcement about upper and bottom - chord around openings was recommended.

CUI Hong-jian and WANG Feng-chao (2009) and WANG Yao (2005) presented an analytical discussion of current research and findings on reinforced concrete beams with openings at home and abroadcovering its classification, mechanical property, modes of collapse, calculation of shear strength, deflection and crack characteristics. Finite element analysis method is introduced and results compared with that obtained from the seismic performance analysis. The characteristics of the cracks and the collapse modes were summarized to provide more references for the design and the calculation of this kind of the beams.Beams made by normal and high strength concrete were studied by *Javadvaseghi amiri1et al (2004)*. *They* investigated the effect of small circular opening on the shear and flexural and ultimate strength. Main factors of the investigation are the changes of diameter, the position of opening and the type and location of reinforcement around the opening and changes in the strength of concrete. Their results showed that the presence of diagonal reinforcement and stirrups in top and bottom of opening is useful.*Kiang-Hwee Tan, et al (2001)*examined the adequacy of the ACI Code approach, modified for the inclusion of transverse openings and for shear design of a beam with circular openings. Their Test results indicated that crack control and preservation of ultimate strength may be achieved by providing reinforcement around the opening, then the premature crushing of the concrete can avoided by reduce the high stress in the compression chord by using Diagonal bars.

Nonlinear finite element analyses of three concrete beams with large rectangular openings in fixed place inside the flexural-shear section were carried out by *Liu Hongmei, et al (2005)*. The beam′s stress,strain, deflection, crack and the ultimate carrying capacity with different diameter reinforced bars under alterable loads was computed and compared with tests results.The effect of opening Sizes and Locations on the Shear strength behavior of reinforced concrete deep beams without web reinforcement was studied by *HawrazKarim M. Amin, et al (2013)*. Many parameters effect the behavior of beam such as (l/d, a/d, f_c and maximum size of aggregate) was taken in to account. The finite element method with (Ansys+CivilFEM) release 12.0 program was used to predict the main parameters. From the results they were reported that the main parameters were effected the behavior of deep beam. The behavior of R.C.C. beam with rectangular opening strengthened by CFRP and GFRP sheets were studied by*RakeshDiggikar, et al (2013)*. beams were strengthened externally by Carbon fiber reinforced polymer (CFRP) and Glass fiber reinforced polymer (GFRP) sheets with different strengthening techniques i.e. around the opening, inside the opening, inside and around the opening and double layer around the opening. From their experimental results it is concluded that the ultimate load carrying capacity of the R.C.C. beam with opening strengthened with GFRP sheets of different schemes were increased in the range of 3.74 to 37.41% and beams strengthened with CFRP sheets increased in the range of 9.35% to 50.50%. *S.C. Chin, et al (2012)* presented two dimensional nonlinear finite element analyses of R.C beams to validate against the laboratory test results. The results of the finite element model show good agreement with that of the experimental beams.

Evaluation of Some Equation Presented In Some Codes:

The analytical equations determining the ultimate strength beams with opening
According to ACI and AIJ codes and method are:

1- ACI code[28]: shear strength of section with opening given from equation below,

$$V = V_c + V_s + V_f \quad (1)$$

$$V_c = \frac{1}{6}\sqrt{f_c'}\, b_w\,(d - d_0) \quad (2)$$

$$V_s = v_{sv} + v_{sd} = \frac{A_v f_{yv}}{s}(d_v - d_0) + A_d f_{yv} \sin\propto \quad (3)$$

$$V_f = A_{fv} f_{fe}(\cos\beta + \sin\beta) d_{frp} \text{ (Khalifa et al1998) } (4)$$

Where, A_{fv} = 2n $t_{frp} w_{frp}$

V_f is Contribution of CFRP reinforcement, d and d_0 are effective depth and diameter of opening respectively, A_v and A_d cross section of vertical and diagonal reinforcement respectively in (mm^2),dv the distance between longitudinal bars on top and bottom, b_w the width of section and s the distance between stirrups in mm, f_c' is ultimate compressive strength of concrete and F_{yv} is yielding stress of shear reinforcement in N/mm^2, α slope angle of diagonal reinforcement.(ACI 318-95), (ACI 318-05), (ACI 318M-08), *(ACI 440.2R-02), (ACI 440.2R-08) and Ahmed M. Sayed1; et al (2013)*

2- The Japanese code (AIJ) will use a formula of shear strength of beam with opening by estimation as below,*(AIJ- 1994)*

$$V_n = \left[\frac{0.092 k_u k_p \left(f_c^{/}+17.7\right)}{\frac{M}{v.d}+0.12}\left(1-\frac{1.61 d_0}{h}\right)+0.846\sqrt{\rho_w f_{yv}}\right] b d_v (5)$$

Where, ρ_w is ratio of shear reinforcement around the opening, k_u and k_p, are factors dependent to the height of section to longitudinal reinforcement ratio respectively.

The shear strength of beam with opening obtained from plastic truss method through the following equations:

$$V_n = b d_{tw} \rho_v f_{yv} \cot \emptyset_s (6)$$

Where, $d_{tw} = d_v - \frac{d_0}{\cos \emptyset_s} - S_v \tan \emptyset_s (7)$

3- ISIS Education Committee: Canada*(ISIS- 2004)*

The shear resistance is given as sum of the contributions from the steel, concrete and the FRP,

$$V_r = V_c + V_s + V_f (8)$$

$$V_c = 0.2\lambda\emptyset_c\sqrt{f_c} bd \ for\ d \le 300mm \quad (9)$$

$$V_c = \left[\frac{260}{1000+d}\right]\lambda\emptyset_c\sqrt{f_c} bd \ for\ d \ge 300\ (10)$$

But $V_c > 0.1\ \lambda\emptyset_c\sqrt{f_c} bd$ (11) $V_s = \frac{\emptyset_s A_v f_{yv} d}{s}$ (12)

The shear contribution of V_f can be determined using following expression,

$$V_f = \frac{\emptyset_f A_f E_f \varepsilon_f d_f (\sin\beta + \cos\beta)}{s_f} (13)$$

$A_f = 2 t_f w_f (14)$ $s_f, w_f\ and\ \beta$ are the spacing, width and angle of the shear reinforcement to the longitudinal axis of beam respectively. d_f is the effective depth of FRP, ε_f *is* effective strain of FRP.

ε_f=R.$\varepsilon_{fu} \le 0.004$(15)

where R is reduction factor.

$R=\alpha\lambda_1\left[\frac{f_c^{2/3}}{\rho_f E_f}\right]^{\lambda_2}$ (16)

α is reduction coefficient foreffective strain, $\lambda_1 and\ \lambda_2$are the experimentally derived parameters. The FRP reinforcement ratio can be determined from:

$\rho_f=\left(\frac{2t_f}{b}\right)\left(\frac{w_f}{s_f}\right)$ (17)

For the buildings, the maximum allowable shear strengthening is described as follow

$V_r \leq V_c + 0.8\lambda\emptyset_c\sqrt{f_c}bd$ (18)

Conclusions and Recommendation for Future Research:

This paper reviewed the existing research works on opening reinforced concrete beams strengthened by fiber reinforcement polymer (FRP. conclusions and directions for future work in order to fill the gaps which exist in the work carried out thus far presented below.

-Future research is needed for a complete awareness for strengthening reinforced concrete beams with opening with FRP and steel plate under static or dynamic load, with the aim to efficiently contribute in the concrete structures repair tasks as well as, to decrease the structure dimensional stability.

-The contribution of strengthening materials such as FRP and steel plate in reinforced concrete beams with openings allows engineers to evaluate safety depending on required design life, environmental and stress conditions and generic FRP type.

-study the effect of different coefficients of thermal expansion between FRP system and the structure members.

- study the parameters including failure mode, opening size and location, end of anchorage, FRP orientation, number of FRP layer, spacing, strength scheme and shear capacity must be investigated under dynamic load.

- more laboratory testing should be carried out on different type of reinforced concrete beams with openings other than simply supported, such as continuous beams, steel orientation and pre-stressed beams. And,

- Improve the understanding of reinforced concrete beams with openings strengthened with CFRP or steel plate subjected to different loading type.

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