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Review Paper on Performance Improvement of RC Deep Beam for Maximising Permissible Web Opening Size Using FRP Wrapping at the Opening.

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Abstract : This study has been undertaken to investigate the maximum permissible web opening size in RC deep beam by improving performance using FRP wrappings at the opening This paper provides a review of some of the progress in strengthening of deep beam having opening in web area with the help of CFRP wrapping.

IndexTerms **– Deep beam with opening, CFRP wrapping, maximum permissible web opening.**

I. INTRODUCTION

Beams with large depths in relation to spans are known as Deep Beams. In accordance with IS-456 (2000) Clause 29, a simply supported beam is classified as Deep when the ratio of its effective span (L) to overall depth (D) is less than 2. Continuous beams are considered as Deep when the ratio L/D is less than 2.5. The effective span is defined as the centre-to-centre distance between the supports or 1.15 times the clear span, whichever is less. Deep Beams are often used as structural members in various Civil Engineering works like Water Tanks (side walls), Pile caps, Raft foundations, Bunkers and Silos, and Shear Walls. Because of the geometric proportions of Deep Beams, their strength is usually controlled by shear rather than flexure, if normal usual amounts of reinforcements are provided.

In the construction industry, the Deep Beams with openings are frequently used in tall buildings to facilitate essential services, such as conduits, network system access, ventilating as well as air conditioning even movement from one room to another. One of the challenges in strengthening of concrete structure is selection of strengthening method that will enhance the strength and serviceability of the structure. Structural strengthening may require due to many different situations, Following are the strengthening systems

- Section enlargement e.g. slab enlargement, column enlargement, beam enlargement
- Externally bonded system e.g. steel plate or jacket, Fibre Reinforced Polymer (FRP) fabric, FRP plate, Near Surface Mounted (NSM) Reinforcement.
- External Post tensioning system,
- Supplemental support e.g. span shortening, supplemental framing, support extension.

Strengthening system can improve the resistance of existence structure to internal forces in either passive or active manner. Passive strengthening system are typically engage only when additional load, beyond those existing at the time of installation, are applied to the structure. Bonding steel plates or FRP composites on structural member are example of passive strengthening system.

Fibre-reinforced polymer is a composite material made of a polymer matrix reinforced with fibres. The fibres are usually glass, carbon, aramid, or basalt. Rarely, other fibres such as paper, wood, or asbestos have been used. The FRP is used as an external shear strengthening. It is necessary for the FRP sheets to intercept the potential shear crack so that they can contribute effectively to the beam shear strength. Longitudinal FRP sheets are used to bond the concrete above and below each opening with fibres oriented in a direction parallel to the beam's longitudinal axis or in the direction perpendicular to the longitudinal axis of the beam.

The primary CFRP element is a carbon filament; produced from a precursor polymer such as polyacrylonitrile (PAN), rayon, or petroleum pitch. For synthetic polymers such as PAN or rayon, the precursor is first spun into filament yarns, using chemical and mechanical processes to initially align the polymer chains in a way to enhance the final physical properties of the completed carbon fibre. CFRP strengthening strips are generally bonded to the external surface of the element (shown in fig.1) to be strengthened with a thin layer (approximately 2mm thick) of epoxy adhesive. CFRP has many superior material properties, such as high tensile strength, low weight, good resistance to corrosion, creep and fatigue and low linear expansion coefficient.

Fig-1 Carbon wrapping to the external surface near opening

II. Literature Review

Waleed et al. (2020), investigated the propagation of the first diagonal crack, which takes place beneath the CFRP, by modelling sixteen RC Deep Beams with the opening size 200 × 200 mm and 230 x 230 mm. Two shear span (a) by depth (d) ratio is 0.9, and 1.1 was studied numerically using finite element analysis tool (ABAQUS). All models were validated using the concrete damage plasticity model. From the comparison between the experimental and the numerical results, it was observed that the numerical models are stiffer than the experimental ones at both linear and nonlinear parts of the behaviour. CFRP sheets increase the failure load capacity and the load at the flexural crack from about 21.3% -48.7% and 7.14% -33.3%, respectively. This study also shows that as the a/d ratio increases, the load required to causing the first diagonal crack, the flexural cracks, and the failure loads all decreases. The strength of the RC deep beam is dramatically affected by the size of openings. Based on the Finite Element result, the authors concluded that as the size of the opening is increased from 200 x 200 mm to 230 x 230 mm, the first diagonal cracking and the failure load all decrease.

Ibrahim et al. (2020), obtained concrete by partially replacing aggregate by polystyrene foam balls, this was resulted in a light weight concrete (LWC). Weight reduction of LWC beams in this research by approximately 30% compared to normal weight concrete. Dimensions and location of openings, transverse reinforcement ratio, and shear span to depth ratio (a/d) were studied in this article. This research was very promising and encouraging to build lighter Deep Beams of similar structural behaviour as that of NWC Deep Beams. The Dimensions of the openings had a significant effect on the behaviour of failure and shear strength of LWC and NWC Deep Beams. It was found that increasing the depth of the opening from 20 % to 40 % of the beam depth led to a reduction in the ultimate load by up to 46.4 %.

Mohammed Riyadh Khalaf et al. (2020), performed to examine the effectiveness of using externally prestressed strands for shear strengthening of reinforced concrete (RC) Deep Beams with large openings. A total of nine RC Deep Beams with large openings having a rectangular cross-section of 150 × 400 mm and a total length of 1600 mm were constructed and tested up to failure under three-point bending. The studied parameters were the opening ratio and the strengthening scheme using prestressed strands.. The reduction in tension reinforcement strain was in the range of 60–91%.While, the vertical scheme of strengthening had an insignificant effect on tension reinforcement strain. On the contrary, this scheme of strengthening showed a notable decrease in stirrups strain in the range of 142% – 158 %. Analytical solution using the strut and tie model (STM) has been modified to adjust the schemes of strengthening strands. The predicted shear strengths of RC Deep Beams with openings with and without strengthening were verified with the experimental results with a convergence of 0.93 on average.

Ahmed Ismail el- kassas et al. (2020) ,carried out an investigation on the behaviour of nine reinforced high-strength self-compacted concrete (RHSSCC) Deep Beams with longitudinal opening with different openings shape (square and circular), size (square 75 x 75 mm and 50 x 50 mm circle diameter 75 mm and 50 mm), and location (compression and tension zone).The load capacity, deflection, absorbed energy and cracks pattern were recorded and discussed. The experimental program shows that longitudinal openings makes a reduction in the loading capacity of RHSSCC Deep Beams, increase in opening size decreases capacity load of Deep Beams, the change in longitudinal opening shape slightly affected and the longitudinal opening located in compression zone gave more reduction than openings located in the tension zone. Comparing in term of shape, circular longitudinal opening offered nearly the same reduction as the square openings. In this article crack pattern were recorded at each load increment and it is noted that all beams were initiated by flexure cracks and propagated vertically upward, but did not meet the inclined compression strut. As the applied load increased, diagonal shear cracks appeared through the inclined compression strut. With increasing load, other shear cracks develop to the lower area near the support and the deep beam reached sudden failure through the inclined compression strut. The strength gain caused by the GFRP sheets was in the range of 68–125%. Finite element modelling of RC Deep Beams containing openings strengthened with GFRP sheets is studied using ANSYS and the results are compared with experimental findings.

Ceyhun Aksoylu et al. (2020), utilized two methods of CFRP applications to strengthen the shear deficient beams with circular holes and a comprehensive experimental program consisting of 11 ½ scaled specimens was undertaken. The beams with hole diameter (D)/beam height ratio (H) of 0.30, 0.44, 0.64 ratios, symmetrically drilled in shear span were tested under vertical loading. D/H ratio of 0.30 did cause not only a decrease in load carrying capacity but also increased the ductility of the beam. However, significant decreases in load carrying capacities were observed as the hole diameters increase. The load carrying capacity and ductility were significantly improved owing to different CFRP configurations. The fact that the hole diameter and CFRP strengthening method were very important parameters for strengthening was observed. Displacement ductility, initial stiffness and energy dissipation were the parameter considered in the evaluation of RC deep beam shown in fig.2. No CFRP strengthening alternative was successful in the beams with a D/H ratio of 0.64. A detailed macro and micro damage analyses were presented.

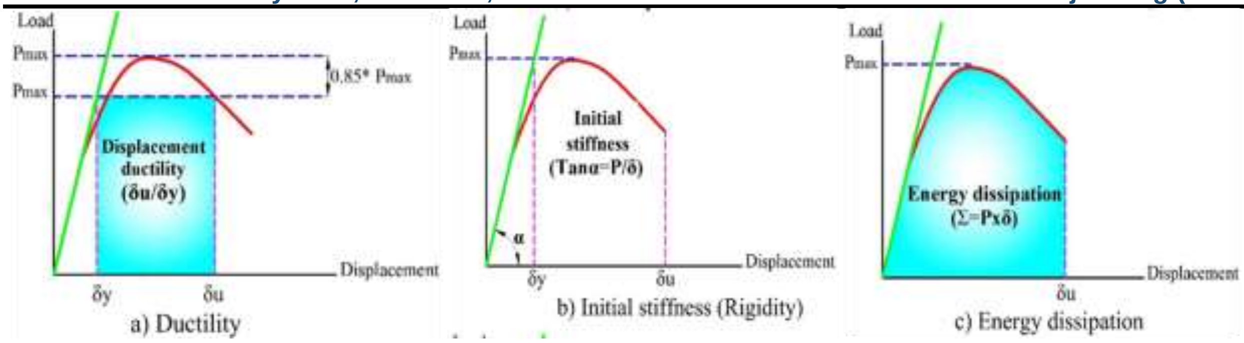


Fig-2 Parameter Considered in the evaluation of RC Deep Beam

Hassan Mohammed Hassan et al. (2019), investigated the behaviour of reinforced high-strength self compacted concrete Deep Beams (RHSSCC) with web opening. Sixty-one Deep Beams were cast to investigate the effect of size (75 mm and 50 mm two opening's size were used), shape (square, circular and rhombus shape) and location of openings with respect to a neutral axis (upper or lower N.A.) and with respect to the load path (in or out load path) on the behavior of RHSSCC deep beam with three types of web openings (symmetrical, unsymmetrical and centred web openings). Load deflection curves, crack pattern, absorbed energy and crack pattern for the tested beams were discussed. Increasing web opening size was lead to reduction in the ultimate and cracking load and the overall ductility of the deep beam. In terms of ultimate and cracking load values and absorbed energy, rhombus shape of opening gave better results than square shape in all cases and gave result close to the result of circular shape opening. When the opening meets the load path, it makes a disturbance in the natural flow of the load, so it offered more reduction in the loading capacity and ductility than that located out of the load path. Openings located below N.A. even symmetrical or unsymmetrical case presented less reduction in ultimate and cracking load than openings located above N.A. On the contrary, case with opening located above N.A. gave more reduction than opening located below N.A.

N. Nikoloutsopoulos et al (2018), investigated reinforced concrete beams can be strengthened in shear by externally bonded fibre reinforced Polymer (FRP) composites in the forms of side-bonded FRP strips, FRP U-jackets or FRP wraps. This research gave most efficient shear strengthening of beams with Fibre Reinforced Polymers (FRP) using the less possible drilling operations to the existing load bearing element and taking also into account the cost analysis. Theoretical and experimental investigation took place on different ways of beam strengthening with single and double carbon fibre ropes mounted on the notch at an angles of 45^0 and 90^0. Also, study of strengthening with carbon fibre fabric strips, rope anchored was performed.

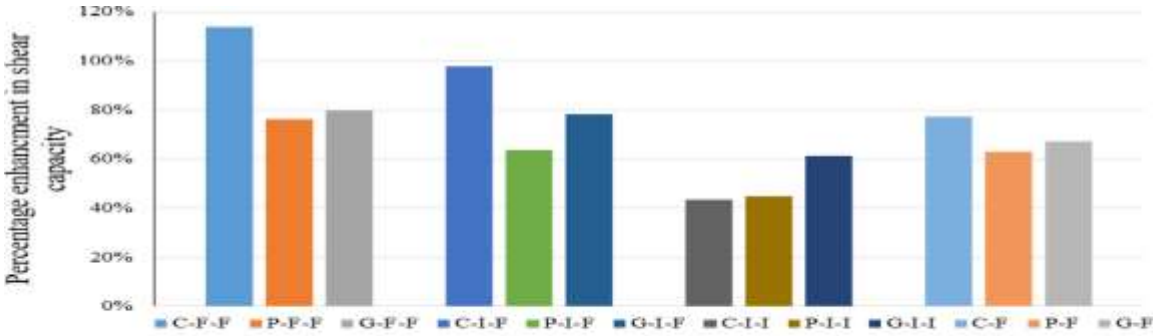
T.G. Wagjira and U. Ebead (2018), had used externally bonded (EB) Fibre Reinforced Polymer (FRP) successfully as a structural strengthening for various applications including flexural and shear strengthening of reinforced concrete (RC) beams, flexural strengthening of RC slabs and column confinement. They had present a reports on an experimental study on the efficacy of a pioneer form of hybrid Near Surface Embedded (NSE) and Externally Bonded (EB) technique using FRP composites for shear strengthening of RC beams. Thirteen shear-deficient medium-scale RC beams were constructed, strengthened in shear and tested under three-point bending test. The test parameters were:

- FRP type (polyparaphenylene benzobisoxazole(P), carbon(C), and glass(G)),
- Strengthening configuration (full versus intermittent strips),
- Number of fabric layers.

The percentage enhancement in the shear capacity of the beams ranged from 43% to 114% indicating the successful implementation of the strengthening methods provided. An average enhancement in shear capacity of 83%, 72% and 62% were observed in CFRP, GFRP and PFRP, respectively. The failure mode of the strengthened specimens was sensitive to the type and configuration of FRP in addition to the number of FRP layers. The strengthening systems also resulted in higher deflection at failure and energy absorption value of the strengthened beams with an average of 94% and 204% relative to the reference specimen, respectively. Experimental test result summery presented as shown in fig.3 and test matrix shown in table.

Reference	Fabric Type	Strengthening Scheme (NSE)	Strengthening Scheme (EB)
CFF	Carbon	Full	Full
CIF	Carbon	Intermediate	Intermediate
CII	Carbon	Intermediate	Intermediate
CF	Carbon	Full	-
PFF	PBO	Full	Full
PIF	PBO	Intermediate	Intermediate
PII	PBO	Intermediate	Intermediate
PF	PBO	Full	-

GFF	Glass	Full	Full
GIF	Glass	Intermediate	Intermediate
GII	Glass	Intermediate	Intermediate
GF	Glass	Full	-



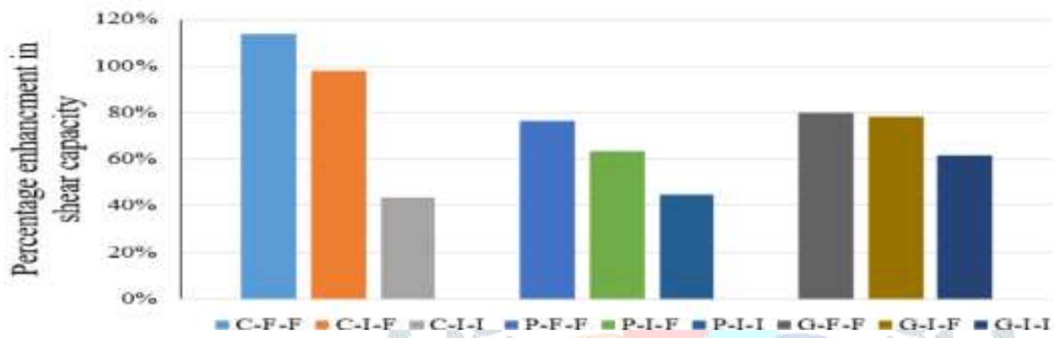


Fig: 3. The effect of various types of FRP on the shear capacity of the specimens.

Tong Foo Sheng (2015), investigated the structural behaviour, including the load deflection, cracking patterns, failure mode, and effectiveness of the CFRP wraps. n. The examined parameter was the effect of configurations of the CFRP wraps used for the shear strengthening. The inclusion of un-strengthened large rectangular openings in the shear zone of a reinforced concrete deep beam leads to a reduction of ultimate beam strength by approximately 70%. The application of CFRP wraps with the presented strengthening configurations restricted the propagation of the diagonal crack and effectively increases ultimate load-carrying capacity as well as the ductility of the beam. The strength re-gains by U-shaped strengthening configuration around the openings was approximately 36% as compared to the beam with un-strengthened openings. However, the deep beam with U-shaped CFRP with horizontal fibre strengthened at the top and bottom chords of the openings were not capable to restore the control beam's original structural strength remarkably. The beam only managed to re-gain about 41% of the control beam's capacity.

Giuseppe Campione et al. (2012), evaluated the influence of circular openings in reinforced concrete Deep Beams with low shear span-to-depth ratio experimentally and analytically. Twenty reinforced concrete small-scale Deep Beams with or without openings were tested in flexure under four-point loading. The beams had a small shear span-to-depth ratio in order to stress the shear behaviour. The specimens had different reinforcement arrangements and opening positions. The load was transmitted to the specimen with bearing plates having the same side length as the beam. Two LVDT's were arranged to record the transverse and axial strain of the theoretical struts forming in the beam. Additionally another device was mounted to measure the middle deflection of the beam. Comparative analysis of the experimental results shows that: the effect of the hole depends on its position in the beam; the benefit of the presence of reinforcement depends on its arrangement. An analytical model is proposed to predict the shear strength and corresponding deflection of Deep Beams with openings and the results are also compared with a non-linear finite element analysis showing good agreement.

Vengatachalapathy.V. and Ilangovan.R. (2010), studied Steel Fibre Reinforced Concrete Deep Beams with and without openings. The percentage of steel fibre was varied from 0 to1.0.The influence of fibre content in the concrete Deep Beams has been studied by measuring the deflection of the Deep Beams andby observing the crack patterns. The investigation also includes the study of steel fibre reinforced concrete Deep Beams with web reinforcement with and without openings. The ultimate load obtained by applying the modified Kong and Sharp's formula of Deep Beams are compared with the experimental values. The above study indicates that the location of openings and the amount of web reinforcement, either in the form of discrete fibres or as continuous reinforcement are the principal parameters that affect the behaviour and strength of Deep Beams.

Tamer EI Maaddawy et al. (2009) , presented the results of a research work aimed at examining the potential use of externally bonded carbon fiber reinforced polymer (CFRP) composite sheets as a strengthening solution to upgrade reinforced concrete (RC) Deep Beams with openings. A total of 13 Deep Beams with openings were constructed and tested under four-point bending. Test specimen had a cross section of 80 x 500 mm and a total length of 1200 mm. Two square openings, one in each shear span, were placed symmetrically about the mid-point of the beam. Test parameters included the opening size, location, and the presence of the CFRP sheets. The structural response of RC Deep Beams with openings was primarily dependent on the degree of the interruption of the natural load path. Externally bonded CFRP shear strengthening around the openings was found very effective in upgrading the shear strength of RC Deep Beams. The strength gain caused by the CFRP sheets was in the range of 35–73%. A method of analysis for shear strength prediction of RC Deep Beams containing openings strengthened with CFRP sheets was studied and examined against test results.

Keun-Hyeok Yang et al. (2006), estimated the influence of web openings in reinforced concrete Deep Beams experimentally and analytically. Thirty-two reinforced high-strength concrete Deep Beams with or without openings were tested under two-point top loading. Test variables included concrete strength, shear span-to-depth ratio, and the width and depth of the opening. Test results indicated that the strengths at diagonal crack and at peak were closely related to the angle of the inclined plane joining the support and the corner of the web opening. Also, the influence of concrete strength on the ultimate shear strength remarkably decreased in Deep Beams with openings rather than solid Deep Beams.

M. A. Mansur and W.A.M. Alwist (1984), were reported test results of 12 reinforced fibre concrete Deep Beams with rectangular openings in the web are reported. The beam dimensions and the size of openings were kept constant. The major parameters of the study were the volume fraction of fibres, opening location, shear span to effective depth ratio and the amount of web reinforcement. Test results indicate that the amount of web reinforcement, either in the form of discrete fibres or as continuous reinforcement, and the location of opening are the principal parameters that affect the behaviour and strength of Deep Beams. Available strength equations for non-fibre concrete Deep Beams are shown to provide a reasonable prediction of the ultimate strength for fibre concrete as well.

N. E. Shanmugam l and S. Swaddiwudhipongl (1988), proposed an empirical formula to predict the ultimate strength of fibre reinforced concrete Deep Beams containing openings. Experiments that have been carried out to study the effect of the position of openings and shear span to effective depth ratio on the strength of such beams were described. The beams were simply supported and tested to failure under two points loading. The results show that the ultimate strength primarily depends upon the extent to which the opening intercepts the natural load path. The experimental failure loads are compared with those obtained by using the proposed empirical formula.

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