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A REVIEW ON BEHAVIOR OF CONTINUOUS RC BEAMS HAVING WEB OPENINGS STRENGTHENED WITH FRP

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Abstract - *In recent studies, web opening are small openings which is constructed with continuous reinforced concrete beams (RC) to accommodate utility piping and cables. A web opening reduces the strength and stiffness of the RC beams. To ensure the safety of beams, strengthening system were provided around the web openings. This paper investigates the possibilities of strengthening continuous RC beams having web openings with Fiber Reinforced Polymer (FRP) sheets and they were performed using Finite Element Method. FRP have corrosion resistance, lightweight, and high strength. The use of FRP sheets as external reinforcement leads to improve both the capacity and ductility of the beams. FRP composites not only possess superior mechanical properties, but also easy to install, and maintain. Some Fiber Reinforced polymer types can also used to strengthening the beams having web openings such us Carbon Fibre Reinforced Polymer (CFRP), Glass Fibre Reinforced Polymer (GFRP), Aramid Fibre Reinforced Polymer (AFRP). From all the studies, we can concluded that continuous RC beams having web openings were strengthened using Fiber Reinforced Polymers and improvement of capacity and ductility of beams were takes place.*

Key Words: **Web opening, FRP, Strengthening, Continuous RC beams, CFRP**

1. INTRODUCTION

For the passage of utility pipes and ducts in new reinforced concrete (RC) structures, web openings in beams have been widely used. Using web openings allows to avoid additional storey heights for ducts and pipes, thereby reducing the overall building height. Web opening tends to reduction of the strength and stiffness of the beam. By the use of FRP composites as external reinforcement lead to improved structural performance and improve both the ultimate capacity and ductility of the beam. The FRP is unidirectional and the FRP material was modeled using a linear elastic isotropic failure after reaching its ultimate tensile strength. Fig 1 shows the web opening in beam and Fig 2 shows the FRP wrapping [1]. Reinforced concrete structures are strengthened by using fiber reinforced polymer (FRP) sheets. FRP have a good non- corrosive characteristics and the advantage of FRP reinforcement are good strength-to-weight ratio, good fatigue resistance etc. FRP sheets helps to prevent the crack around opening. FRP sheets are traditional methods for strengthening the beam [2].

Fig -1: Web opening in beam

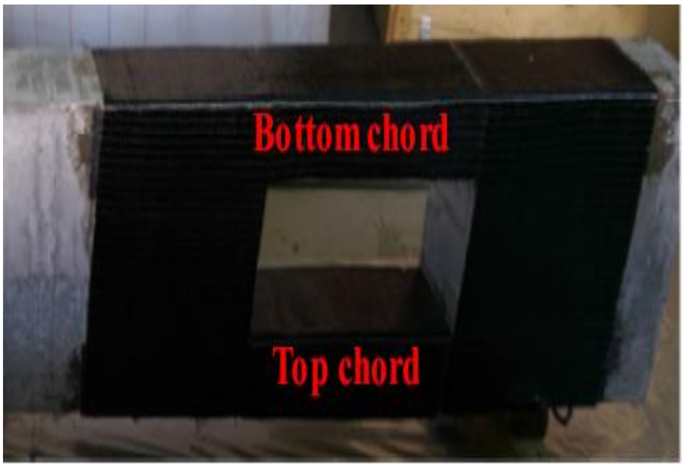

Fig -2: FRP wrapping

2. MATERIAL PROPERTIES

The concrete damage plasticity models (CDPM) were used to modeling concrete element. In compression and tension , CDPM simulate both the elastic and plastic properties of concrete. In tension and compression, the steel reinforcement acts as elastic-perfectly plastic material [1]. Steel reinforcements and stirrups are developed using bilinear isotropic material. Yield stress fy and the ultimate stress fu are shown in table 1. [9] .

Table -1: Mechanical properties of steel reinforcement

Nominal diameter(mm)	Measured Diameter(mm)	Area(m m²)	Yield stress fy [Mpa]	Ultimate stress fu [Mpa]
6	5.5	23.75	623.96	685.5
16	16	200.96	569.67	668.79

2.1 FRP Strengthening

To determine the feasibility of using externally bonded FRP for the strength loss caused by web openings. RC beams with FRP- strengthened rectangular web openings is analysed, which includes two models based on the brittle cracking theory of concrete .FRP strengthening system which entails the installation of vertical CFRP wraps on the top and bottom chords and on both sides of the opening [3] . A finite element (FE) analysis of RC beams with strengthened FRP web openings is presented to provide a more comprehensive and in-depth understanding the behavior of beams. There were two constitutive models studied for concrete, ie; concrete damaged plasticity (DP) and brittle cracking (BC). It was found that the DP model was most appropriate for specimens that failed in a flexural mode; however, the BC model with the secant modulus of concrete adopted was more accurate that failed in a shear mode [4] . Fig 3 shows the crack pattern at ultimate state.

Fig -3: Crack pattern at ultimate state

Investigate the effect of large rectangular openings in the shear area on the response of unstrengthened and improved reinforced concrete beams. In this study seven single-support RC beams were developed and tested under two point loads and six beams are developed with two large rectangular web openings. On the six beams with openings, two specimens were unstrengthened and four beams were strengthened with fiber reinforced polymer. In one of the schemes, two layers of CFRP sheets were used to strengthened the beam and in the second scheme consisting of GFRP sheets anchored by bolted steel plates. Chart 1 shows the Effect of strengthening scheme with respect to effective stiffness [5] .

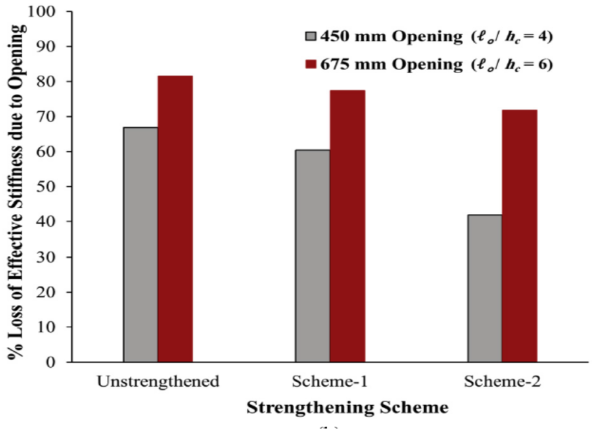

Chart -1: Effect of strengthening scheme with respect to effective stiffness

Deep beam is a beam having the span depth ratio of simply supported beam is less than 2 and the span depth ratio of continuous beam is less than 2.5. Due to the high depth of deep beams, web openings have been placed in these beams which reduced their load- bearing capacity. In this study RC deep beams with circular opening is strengthened by FRP composites installed by Externally Bounded Reinforcement (EBR) and Externally Bounded Reinforcement On Grooves (EBROG) methods. Strengthening of beam using carbon fiber reinforced polymer(CFRP) with resin. This study determines the influence of FRP sheets on the shear strength of deep beams, the effect of sheet configuration, assessing the effect of grooves on load bearing capacity and assessing the effect of symmetry and asymmetry of the circular openings. Fig 4 shows the Failure in deep beam with unsymmetrical opening [6] .

Fig -4: Failure in deep beam with unsymmetrical opening

Web opening reduces the cross sectional area and reduces the shear capacity. R/C beams with opening were strengthening by externally installing the FRP rods. Beams with square and circular openings were tested. For strengthening the beam, FRP rods are place enclosing the opening and one is to place diagonally throughout the depth of the beam and it was found that inclined rods are more effective than vertical [7] . Examine the flexural behavior and moment redistribution of reinforced high strength concrete (RHSC) beams reinforced with CFRP and GFRP sheets. By increasing the CFRP sheet layers, the ultimate strength increases while reducing the ductility, moment redistribution and ultimate strain. By using GFRP sheet for strengthening the beam which reduces the loss in ductility but not increase the ultimate strength of the continuous beam [8] .

2.2 CFRP Strengthening

Deep beams with different opening sizes, investigates the propagation of the first diagonal crack that occurs beneath the CFRP. It shows that the CFRP sheets improved flexural crack resistance as well as failure load capacity. In addition, the CFRP increases the load to cause a diagonal crack for models with (a/h) equal 0.9, whereas there is only a slight change for models with (a/h) equal 1.1.Fig 5 shows the CFRP on deep beam with opening. Fig 5 shows the CFRP on deep beam with opening [9] .

Fig -5: CFRP on deep beam with opening

Web opening in reinforced concrete deep beam is required to accommodate utility pipes and cables. But openings in beam lead to cracking and reduce the shear capacity and stiffness of the beam. The beam with web openings are strengthened in shear using carbon fiber reinforced polymer (CFRP) sheets. The purpose of this paper is develop 3D non linear finite element (FE) models for RC deep beams with web openings that were strengthened and upgrade the shear capacity with carbon fiber reinforced polymer (CFRP) [10]. Assess the shear behavior of T-section deep beams reinforced with CFRP sheets and also evaluate the effect of strengthening length, combination of fiber direction on the strength of CFRP sheets and a U-shaped anchorage on shear performance .CFRP sheets were partially delaminated in a triangular shape at the upper and corner center of sheet. Partially delaminated CFRP sheet failure due to shear – compression [19].

3. WEB OPENING

Pipes for water, electricity, phone, and internet cables are commonly routed through horizontal and vertical openings in the floor beams. In this paper investigate how the rectangular beams respond to vertical circular openings in the shear span. In this study, we examine the location, the number of openings, and the dimensions of the vertical openings. Fourty-one RC beams were placed beneath the point load location and tested. Three different sizes and locations of vertical circular openings, along with two dissimilar numbers of openings were investigated. This Study shows that the vertical opening diameter has a greater effect on the beam section width than the length of the shear span [11]. Study the shear behavior and strength of RC flanged deep beams with web opening and also assess the ultimate strength. In flanged beams, the crack occurred along the full width of the flange. It is found that opening in the beam not only affect the intial stiffness but also accelerated the occurrence of the first crack at lower loads. Fig 6 shows the Failure mode of flanged deep beam [12] .

Fig-6: Failure mode of flanged deep beam

4. CYCLIC LOAD BEHAVIOR

Openings have different shapes like rectangular, circular etc and sizes depending on the needs of a particular buildings. This study uses external bonded technology to evaluate the cyclic load behavior of beams with rectangular openings strengthened with carbon fiber reinforced polymer (CFRP) sheets. There were total six rectangular RC beams were casted and stirrups were provided to prevent cracks and study the effect of rectangular web opening in the shear-flexure location. Four bending points were used to apply slow reverse cyclic loading to the beam. The beams were strengthened using CFRP sheets can improve the stiffness capacity and beam beahavior under the cyclic loading. Carbon fiber reinforced polymer) CFRP helps to increase the ductility, strength and capacity of the beam and prevent the cracks by using suitable stirrups. Fig 7 shows the Hysteretic curve under cyclic loading: beam with opening in the shear zone [13] .

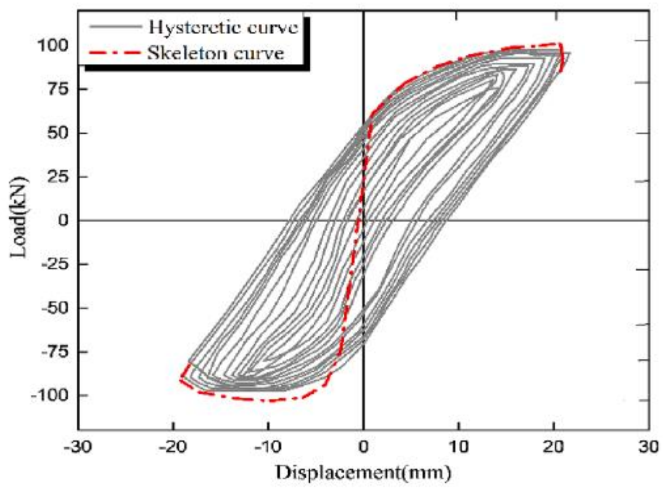

Fig -7: Hysteretic curve under cyclic loading: beam with opening in the shear zone

5. FLEXURAL –SHEAR STRENGTHENING

In this paper focuses on strengthened the RC beams with layers of FRP sheets under the flexural reinforcement ratio and shear reinforcement configurations .There were 7 concrete beams for flexural strengthening ,six beams were strengthened with two layers of CFRP sheets and one without retrofitting as a control beam. The beams were simply supported and tested under four-point loading .In these beams, strains on the main tensile steel were measured at midspan, loading points, and midspan, strain on the orthogonal internal stirrups and strains on FRP sheets. It has been found that flexural- shear strengthening is more effective than flexural strengthening at enhancing the stiffness, ultimate strength, and hardening properties of the beam. Fig 8 shows the Flexural failure [14].

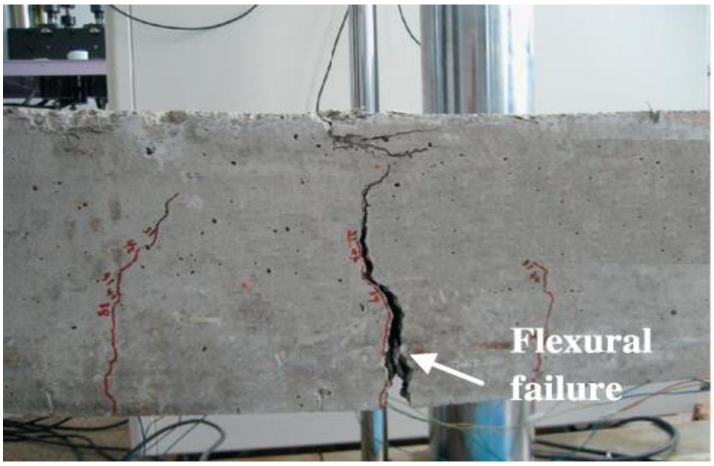

Fig -8: Flexural failure

An evaluation of NSM (Near surface mounted) and EBR (Externally bonded reinforcement) techniques are compared for strengthening reinforced concrete beams under flexural and shear. NSM have the ability to reduce the risk of harm, mechanical damages etc. NSM was the most effective for flexural strengthening when the longitudinal reinforcement ratio was increased. For shear strengthening, the NSM was most effective and easiest to apply of CFRP systems [15] .

6. SHEAR STRENGTHENING

In this paper shear strengthening of reinforced concrete deep beam with web opening is strengthened by using FRP composites. Deep beams are often used in offshore structures and in tall buildings transfer floors. Reinforced concrete deep beams with web openings can be strengthened by using externally bonded FRP sheets. Thirteen deep beams with web openings were constructed and tested under four-point bending. CFRP were used externally on the beam. Carbon fiber reinforced polymer (CFRP) sheets with fibers were wrapped vertically around the chords above and below at web openings. By wrapping the CFRP sheet around the web opening in the deep beam remarkable increase in the beam strength [16] .Fig 9 shows the Failure mode of CFRP- strengthened beam.

Fig -9: Failure mode of CFRP- strengthened beam

Assess the shear capacity of RC beams strengthened with externally bonded (EB) and Fiber reinforced polymer (FRP). The effectiveness of strengthening were analysed by static scheme, shear span-to-depth ratio, FRP strengthening configuration etc. [17].

7. FRP DEBONDING

This study develop a simple, accurate, and rational design proposal for shear strength of FRP- strengthened beams that fail due to FRP debonding. FRP composites have advantages such as strong strength-to-weight ratio, corrosion resistance and versatility in adapting sectional shapes and corners. Debonding failure occur in concrete near the concrete/adhesive interface with the concrete still attached to the debonded FRP [18] . A Fibre Reinforced polymer (FRP) systems were externally bonded in deficient deep beams to strengthen the structure. The major benefit of using FRP, strengthening existing structures with degraded or insufficient strength. To reduce diagonal crack growth, bonded FRP systems enhance the load- carrying capacity of the beam [20].

8. CONCLUSIONS

The FE Model were used in assessing the strength and stiffness of the beam. Fiber Reinforced Polymer or carbon fiber reinforced polymer layer helps to increase the strength and stiffness of the beams. As the web opening areas were decreased, the ultimate load capacity and stiffness were improved. The use of Fiber reinforced polymer (FRP) composites as external reinforcement leads to improve structural performance and FRP materials have high ultimate strength. This paper improves the application and performance of beams by using FRP sheets and CFRP sheets. The outcome of this paper can be summarized in below points:

- FRP have high tensile strength and helps to increase the ultimate strength of the RC beams.
- FRP materials have benefits to rebuild and repair aging and new structures.
- Increasing the size of the web openings leads to decrease the ultimate strength and cracking load and the ductility of beam. So minimize the web opening size to increase the strength of the beam.
- Web openings decreases the strength, ductility and capacity of the beam which is strengthened by using FRP or CFRP sheets around the web openings.
- Anchorages are determined by some factors such as the strengthening scheme, loading conditions.
- NSM technique is more effective than other techniques used for strengthening the beams.
- CFRP helps to strengthening the beams and improve shear capacity of the beams. When increasing the web opening size, decrease the shear capacity of the beam. By increasing the vertical CFRP sheets helps to increase the shear capacity.
- For increasing bond length, two layers of FRP sheets are used and restored the maximum load and energy absorption.
- Beams with same flexural –shear strengthening, improve the load carrying capacity and stiffness by higher concrete strength.
- For shear strengthening of RC beams, a new shear strength model was developed for debonding failures in FRP sheets.
- Increasing the number of CFRP layers which helps to increase the ultimate load capacity. But the deflection ductility index was decreased.
- Increased opening diameter caused a higher deflection at the mid span and opening which causes higher strains for mid-span steel bar.

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