# REVIEW ON SHEAR STRENGTHENING OF RC DEEP BEAMS WITH OPENINGS

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**Abstract -** Reinforced concrete deep beams are widely used as transfer girders in offshore structures and foundations, walls of bunkers and load bearing walls in buildings. The presence of web openings in such beams is frequently required to provide accessibility such as doors and windows or to accommodate essential services such as ventilating and air conditioning ducts. Enlargement of openings due to architectural/mechanical requirements or a change in the building's function would reduce the element's shear capacity, thus rendering a severe safety hazard. When such enlargement is unavoidable adequate measures should be taken to strengthen the beam and counteract the strength reduction.

This review aims to investigate how to increase the structural strength of reinforced concrete deep beam with openings. Two approaches are under consideration; internal strengthening and external strengthening, the first is the effect of steel reinforcement bars near the opening, and the second is attaching FRP layers around the opening.
The FRP strengthened structures may fail by de-bonding of fibers from the concrete surface. Mechanical anchoring systems has been introduced in order to prevent the de-bonding of FRP composite sheets from the beam surface.
**Keywords:** Deep Beam, Opening, Strengthening, FRP, Mechanical Anchoring System.

## 1. INTRODUCTION

A beam with the depth comparable to the span length is considered as a deep beam. Reinforced concrete deep beams find its applications in offshore structures, tall buildings, walls of bunkers, foundations etc. The creation of web openings is often required for the accommodation of electrical and mechanical conduits. The existence of openings cause geometric discontinuity and also the current code of practices do not include the provision for design of deep beams with openings. The presence of web openings in deep beams leads to early diagonal cracking and also in the significant reduction in the shear strength. There are two types of openings 1) Pre planned openings 2) Post planned openings. In pre-planned openings the size and location of the opening will be known during the design stage itself. In this case adequate internal strengthening can be provided during the design stage itself. But in the case of post planned openings internal strengthening is not applicable. The only possible criteria is to externally strengthen the structural element using fibre reinforced polymer. This is the only method which can be used to regain the strength of the element up to the original capacity. From the previous experimental studies it is clear that reinforced concrete deep beams strengthened by FRP composites fail by de bonding of the fibres from the beam surface. To avoid such failures mechanical anchoring systems has been introduced to securely attach the FRP to the beam surface.

There are 2 methods to strengthen the RC deep beams with opening which including internal strengthening and external strengthening. Internal strengthening used the different patterns and quantities of steel bar erected around the opening while external strengthening material by pasting the externally bonded composite materials around the opening in varying arrangement and configuration schemes. Internal Strengthening Method is favourable when the opening is pre-planned before the construction or during the design stage. The location and size of opening are known in advanced. The web reinforcement played an effective role in controlling the propagation of crack width, upgrading the ultimate shear strength, and deflection that due to stress concentration around the openings. The existence of longitudinal bars on the upper and lower of the opening are very effective in controlling the flexural strains and cracks around the opening. In order to increase the ultimate strength and decrease the deflection of the deep beams with opening, diagonal bars were installed for corner reinforcement as well as the small stirrups at the openings top and bottom. External Strengthening Method is much beneficial when the opening is introduced after the construction which cannot meet any design consideration and analysis about the opening. The openings were drilled in an existing structure while the problem may arise during and after the process. This happened often due to the M&E engineers re-locate the opening location to simplify the arrangements of ducts and pipes in order to achieve the huge savings in term of costs, materials and time. External strengthening can be classified into traditional method and modern method. Referring to the traditional method, steel plate can be installed on to the RC beams by adhesive bonding and bolted construction. This can increases the serviceability & ultimate load capacity of the RC beam section and available for maintenance & inspection. Disadvantages of using steel plate as external strengthening are taking part of corrosion that become heavy when come in bigger size and need specialized in handling & installation.

## 2. LITERATURE REVIEW

**A. K. Sachan *et al*. (1990)** performed an experimental study on "Behaviour of Fibre Reinforced Concrete Deep Beams", a total of 14 concrete deep beams were tested to failure and the effects of fibre content, percentage reinforcement and the type of loading were studied. It was found that the addition of steel fibres to concrete results in a significant increase in ultimate strength of deep beams. It was also observed that the failure of fibre reinforced concrete beams was more ductile and gradual compared with the failure of plain and reinforced concrete beams.

**Keun-Hyeok Yang et al. (2003)** worked on"Shear Characteristics of High Strength Concrete Deep Beams without Shear Reinforcements". A total of 21 beam specimens were tested to investigate their shear characteristics with the variables of concrete strength, shear span/depth ratio, and overall depth. Experimental results showed that the decrease in shear span/depth ratio and the increase in overall depth under the same shear span/depth ratio led to more brittle failure with wide diagonal cracks and high energy release rate related to size effects. The high-strength concrete deep beams exhibited more remarkable size effects with regard to brittle behavior.

**M. R. Islam *et al.* (2005)** conducted an experimental study on "Shear strengthening of RC deep beams using externally bonded FRP systems". The experimental study was conducted to find out whether strengthening of deep beams in shear with externally bonded FRP reinforcement is possible or not and finding out the effectiveness of different types of FRP systems. Parameters considered are three different FRP systems which have been used to strengthen the basic beams. These are: fibre wraps, strips and grids, all made up of carbon fibre. Figure 2.1 shows the mid-span deflection of the beam and figure 2.2 shows the measured maximum crack widths are plotted against the applied load.

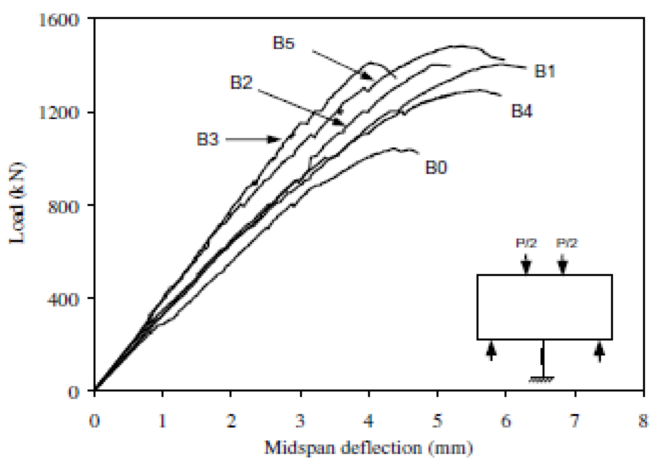


**Fig 2.1 Load-deflection behaviour**

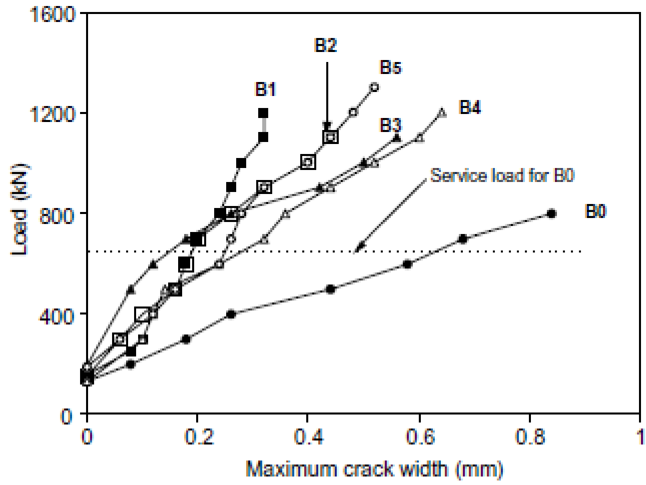


**Fig 2.2 Maximum crack widths at different loads**

It was concluded from the test results that the use of a bonded FRP system leads to a much slower growth of the critical diagonal cracks and enhances the load-carrying capacity of the beam to a level quite sufficient to meet most of the practical upgrading requirements.

**Wen-Yao Lu(2006)** studied on "Shear Strength prediction for Steel Reinforced Concrete Deep Beams". In the paper the study on analytical method for determining the shear strengths of steel reinforced concrete deep beams under the failure mode of concrete crushing originally based on the softened strut-and-tie modal was carried out. By comparing the predictions of the proposed method with the available test results from the literature, it was found that the proposed method is capable of predicting the shear strengths for steel reinforced concrete deep beams with sufficient accuracy.

**Keun-Hyeok Yang *et al.* (2006)** worked on "The influence of web openings on the structural behaviour of reinforced high-strength concrete deep beams". The work was done to experimentally and analytically estimate the influence of web openings in reinforced concrete deep beams. Thirty-two reinforced high-strength concrete deep beams with or without openings were tested under two-point top loading. Concrete strength, shear span-to-depth ratio, and the width and depth of the opening are the test variables included. The main findings are the width and depth of opening did not affect the mid-span deflection at initial loading stages, but it significantly affected the deflection after the occurrence of diagonal cracks. The concrete strength did not largely affect the rigidity of beams with web opening due to the existence of the web opening. The slope of inclined plane to exhibit maximum crack width decreased with the increase in concrete strength, opening size and shear span-to-depth ratio.

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. From comparisons of predictions and test results, the equations proposed by Kong and Sharp, and Tan, Tong and Tang would be suitable for reinforced high-strength concrete deep beams with openings.

**Sangdon Park(2009)** worked on "Strut-and-Tie Method (STM) for CFRP Strengthened Deep RC Members". STM was used for the analysis of CFRP strengthened deep reinforced concrete members since a bonded CFRP element acts as an addition tension tie. A practical analysis and design process for CFRP strengthened deep RC members using the STM was presented in the paper. In addition, seven effective factor models accounting for reduction of strength in cracked concrete were also investigated. A total of 17 experimental deep beam test results were compared with the proposed STM approach results. It has been shown that the proposed STM approach with an effective factor model depending on the strut angle provides the best agreement with the test results.

**Tamer El Maaddawy *et al.* (2009)** worked on "FRP composites for shear strengthening of reinforced concrete deep beams with openings". The use of externally bonded carbon fibre reinforced polymer (CFRP) composite sheets for strengthening reinforced concrete deep beams were studied. A total of 13 deep beams with openings were constructed and tested under four-point bending. Two square openings, one in each shear span, were placed symmetrically about the mid-point of the beam. Opening size, location and the presence of CFRP sheets were the parameters examined. Figure2.3 shows the mid-span deflection of specimen.

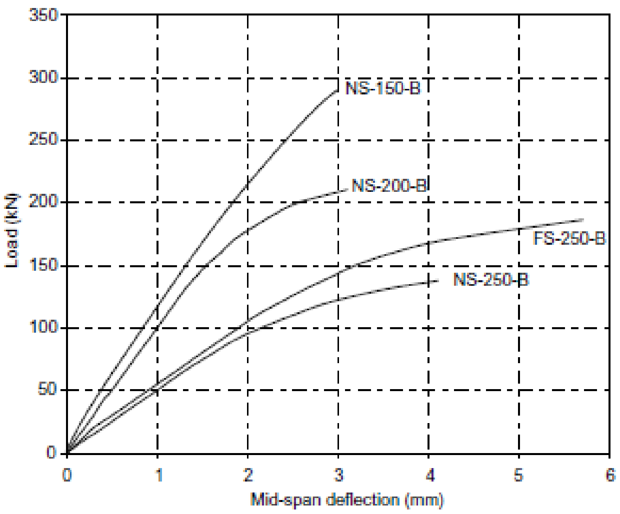


**Fig 2.3 Load mid span deflection curves of specimen**

It was concluded from the test results that externally bonded CFRP shear strengthening around the opening was found to be very effective in enhancing the shear strength of RC deep beams. The increase in the strength due to CFRP 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.

**H. K. Lee *et al.* (2011)** worked on "Behaviour and Performance of RC T-Section Deep Beams Externally Strengthened in Shear with CFRP sheets". The work was done to investigate the behaviour and performance of reinforced concrete (RC) T-section deep beams strengthened in shear with CFRP sheets. Fourteen RC T-section deep beams were designed to be deficient in shear with a shear span-to-effective depth ratio ($a/d$) of 1.22. Strengthening length, fibre direction combination of CFRP sheets and an anchorage using U-wrapped CFRP sheets are the parameters considered. Crack patterns and behaviour of the tested deep beams were observed during four-point loading tests. It was concluded from the test results that the key variables of strengthening length, fibre direction combination, and anchorage have significant influence on the shear performance of strengthened deep beams. In addition, a series of comparative studies between the present experimental data and theoretical results in accordance with the commonly applied design codes were made to evaluate the shear strength of a control beam and deep beams strengthened with CFRP sheets.

**H. S. Kim *et al.* (2011)** worked on "Structural Behaviours of Deep RC Beams under Combined Axial and Bending Force". The paper presents experimental studies of deep reinforced concrete (RC) beam behaviours under combined axial and bending loads. In order to investigate the effect of axial loads on the structural behaviours of the deep RC beams, specimens were prepared to have different shear span-to-depth ratios and subjected to axial loads of 235kN or 470kN. From the experiments, structural behaviours such as failure modes, load-deflection relationships, and strains of steel bar and concrete are observed. As results, for the deep beam with shear span-to-depth ratio of 0.5, load at the beam failure decreases as applied axial load increases, while the deep beams with shear span-to-depth ratios of 1.0 and 1.5 shows that the applied axial load delays the beam failure. In addition, failure mode of the deep beam changes from shear failure to concrete crushing due to compressive stress at the top corners of RC beams as shear span-to-depth ratio decreases. From the experiments, it is important to notice that deep beam with relatively small span-to-depth ratio under axial load shows early failure due to concrete crushing, which cannot be directly applied to widely known design method for deep beam, strut-to-tie model.

**Rami A. Hawileh *et al.*(2012)** conducted a numerical study on "Nonlinear finite element modelling of concrete deep beams with openings strengthened with externally-bonded composites". In the paper they developed a 3D nonlinear finite element (FE) models for reinforced concrete (RC) deep beams containing web openings and strengthened in shear with carbon fiber reinforced polymer (CFRP) composite sheets. A total of twelve models were developed in ANSYS software. The examined parameters includes the size and location of openings and different strengthening configurations. Solid elements for concrete, multilayer shell elements for CFRP and link 8 element for steel reinforcement were used to simulate the models. From the results it can be concluded that the developed FE models can be taken into consideration and can be used for the performance prediction of RC deep beams strengthened in shear using CFRP.

**Giuseppe Campion, Giovanni Minafo (2012)** worked on "Behavior of concrete deep beams with openings and low shear span-to-depth ratio". The objective of the work is to experimentally and analytically evaluate the influence of circular openings in reinforced concrete deep beams with low shear span-to-depth ratio. 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 main parameters considered were the location of the opening and the amount of reinforcement. Two different opening locations and four different arrangements of horizontal and vertical reinforcement were considered. Finally, analytical predictions of the load-carrying capacity were made with different methods and compared with the experimental results.
The failure mode and first cracking load mainly depend on the presence and position of the hole. If the opening is placed in the mid-span section, it does not influence the response of the beam. If the opening is placed within the shear span, a reduction in load-carrying capacity occurs in the range 18–30%. The presence of vertical stirrups increases the ultimate load by about 15% in solid deep beams or in beams with an opening placed in the centre. Diffused horizontal stirrups are not very efficient in solid deep beams or in beams with an opening placed in the centre. If the hole is placed within the shear span, vertical stirrups are inefficient and only the presence of horizontal stirrups increases the load-carrying capacity, by about 20%. 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.

**Ashraf Mohamed *et al.* (2014)** worked on "Prediction of the behaviour of reinforced concrete deep beams with web openings using the finite element method". The work was done to study the behaviour of reinforced concrete deep beams with and without web openings using finite element method. To study the effect of the reinforcement distribution on the beam overall capacity and compared to the Egyptian code guidelines. The loading scheme, the location of web openings and the reinforcement distribution are the parameters considered. The web openings crossing the expected compression struts should be avoided, and the depth of the opening should not exceed 20% of the beam overall depth. The reinforcement distribution should be in the range of 0.1–0.2 beam depth for simply supported deep beams.

**Fadzil *et al.*(2015)** worked on " Experimental Study on Shear Strengthening of RC Deep Beams with Large Openings Using CFRP". The work was done to experimentally study the behavior of reinforced concrete (RC) deep beams with large circular openings and openings strengthened using externally bonded Carbon Fiber Reinforced Polymer (CFRP) composites in shear. To investigate the structural behavior including the load deflection behavior, crack pattern, failure mode as well as strengthening configuration. One of the test parameters presented in this paper was surface strengthening method. A total of three (3) RC deep beams were considered in this study. The beams include a solid beam as the reference beam while the remaining beams were with openings located at the middle of the shear span. All the beams had a cross-section of 120 mm x 600 mm and a length of 2400 mm. It was concluded that the RC deep beam with large circular opening experienced substantial strength loss with a reduction of 51% as compared to the beam capacity of the control beam. Surface strengthening using CFRP wrap around the opening could increase the ultimate load capacity, about 15.32% as compared to the un-strengthened beam. Comparing with the reference beam, this strengthening method could only re-gain the beam capacity up to 56%.

**Ibrahim M. Metwally *et al.*(2015)** conducted a numerical study on "Three-dimensional nonlinear finite element analysis of concrete deep beam reinforced with GFRP bars". In the paper the use of GFRP bars as internal reinforcement in deep beams were studied. Twelve reinforced concrete deep beams were selected from the literature. Objective of the study is to investigate capabilities of the finite element simulation for further study on GFRP-reinforced concrete deep beam behaviour instead of conducting expensive time consuming experimental works of large-scale structural elements. Shear span to depth ratio, reinforcement ratio, effective depth, concrete strength were the parameters examined. The load deflection behaviour, failure mode, failure load, crack propagation, GFRP reinforcement strain, concrete strain distribution etc were obtained. From the results it was concluded that the developed models were efficient in predicting the behaviour of GFRP reinforced concrete deep beams.

## 3. CONCLUSIONS

From the above literatures it is find out that, structural behaviour of deep beam with openings depends a lot of factors which includes, Shear span to depth ratio, reinforcement ratio, effective depth, concrete strength, opening size, shape and location. The external strengthening with FRP was remarkably effective to increase the ultimate load of the RC deep beams with openings. The RC deep beams strengthened by FRP composites fail by de bonding of the fibres from the beam surface. Researches on the study of introducing mechanical anchoring systems in order to prevent the de-bonding of FRP composite sheets from the beam surface are to be done. Studies on internal strengthening of deep beam with opening are to be done.

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