IARJSET ISSN (O) 2393-8021, ISSN (P)

International Advanced Research Journal in Science, Engineering and Technology

ISO 3297:2007 Certified ⁜ Impact Factor 8.066 ⁜ Peer-reviewed / Refereed journal ⁜ Vol. 10, Issue 9, September 2023

DOI: 10.17148/IARJSET.2023.10927

EXPERIMENTAL STUDIES ON RECTANGULAR OPENING IN BEAMS

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Abstract: This article presents a comprehensive overview of research conducted on the behavior of Reinforced Concrete (RC) beams containing various types of openings. Over the last forty years, extensive investigations have been carried out to assess the structural integrity of different types of beams, including simply supported, continuous, and T-beams with large rectangular openings, subjected to torsion, bending, and shear forces. More recently, there has been a growing trend in utilizing Fibre Reinforced Polymers (FRP) as an external reinforcement system to enhance and refurbish concrete structures.

FRP is commonly employed as an external reinforcement method for the repair and retrofitting of damaged reinforced concrete components. However, there has been limited research on the application of FRP laminates as external reinforcement specifically around openings. Carbon fiber reinforced polymer (CFRP) is a prevalent choice for external reinforcement to meet the strength requirements associated with flexural and shear forces in structural systems.

Keywords: Reinforced Concrete Beam, strengthening of rcc beam, CFRP, Beam Openings, Retrofitting.

I. INTRODUCTION

In practical situations, it may be necessary to create openings in certain parts of a building, such as ceilings or beams, to allow utility lines to pass through using ducts and canals. However, this process can result in a decrease in stiffness due to concentrated stresses that arise from the cracks that form at the edges of the openings, altering the cross-section dimensions. This reduced stiffness can lead to high deflection, whereas this study focuses on the behavior of elliptical openings in RC beams. Previous research has explored the use of openings in concrete structures, with some studies investigating elliptical shapes.

For example, Eskandarinadaf and Esfahani conducted a study on a full-scale two-way RC strengthened slab with an opening at its center, comparing it to a reference slab without an opening. The slabs were strengthened using either outwardly fastened glass fiber reinforced polymer or embedded additional steel bars at the tension side of the slabs.

The study found that embedding additional steel bars did not significantly increase the load-carrying capacity of the slab to that of a continuous slab, whereas using glass fiber reinforced polymer led to a substantial increase in the ultimate strength and flexural stiffness of the slabs.

II. SCOPE

The scope for using various shapes of openings in RCC (Reinforced Concrete) beams is broad and multifaceted. Architects and designers have the creative freedom to incorporate different shapes, from circular to rectangular, to enhance the visual appeal of structures while maintaining functionality. Structural considerations are crucial, as each opening must not compromise the beam's load-bearing capacity. Complex shapes may require meticulous design and reinforcement.

Utility integration is another key factor, with openings accommodating utility lines such as electrical conduits and plumbing. Practical construction aspects, like form work and reinforcement, influence shape selection. Building codes and regulations provide guidelines for size, location, and reinforcement.

In summary, the scope for diverse opening shapes in RCC beams involves balancing aesthetics, safety, utility, construction practicality, regulations, engineering analysis, material suitability, cost, and innovation. Expert guidance is essential for informed decisions in construction projects.

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III. LITERATURE REVIEW

Ghada Gamal Ahmed and Venees Faied Gerges(2020): The purpose of this research is to identify the key factors that can significantly impact the analysis outcomes when selecting the location of openings in concrete beams. To achieve this goal, the study considers several parameters that can help avoid errors or additional costs during the design and construction stages. The researchers use simulation models in ANSYS 15.0 software, which are verified against previous experimental studies. The effectiveness of the confinement is evaluated by analyzing the results of the study. The key parameters examined in this research include the location of the opening in the beam, the use of CFRP strengthening with varying layers, the type of cross-section of the beam (Rectangular and L-section), and the compressive strength of the concrete.

Tarek Almusallam and Yousef Al-Salloum(2018): The main objective of this paper is to investigate the behavior of reinforced concrete (RC) beams containing large rectangular web openings in the flexure zone that are strengthened with fiber reinforced polymer (FRP). The study examines the effect of different parameters such as loading type, opening size, and strengthening scheme. Seven RC beams were tested and categorized into two groups. The first group consisted of two beams, one solid without openings and one with a large rectangular web opening in the pure flexure zone, both tested under four-point bending. The second group consisted of five beams, one solid reference beam and four beams with large rectangular web openings in the maximum-moment region, two of which were strengthened with different FRP schemes while the other two were left unstrengthened. A numerical study was also conducted and the results of analysis were validated with experiments. The calibrated analysis was then used for some useful parametric studies to investigate the effect of different parameters.It is noted in the paper that the finite element (FE) modeling used in the study was appropriate for evaluating the flexural strength of both the unstrengthened and FRP-strengthened RC beams with web openings in the flexure zone. The validity of the modeling approach was demonstrated, indicating that it can be reliably used in future research related to the use of FRP strengthening for RC structural members.It highlights the importance of considering the depth of the top chord in determining the need for strengthening. However, it also acknowledges the need for further research to determine the most effective strengthening scheme in cases where strengthening is required.

Stefan Ehmann & Martina Schnellenbach-Held(2001): This survey of recent research findings reveals that when dealing with reinforced concrete beams with large openings, two new parameters need to be taken into account. For openings close to the supports, a detailed computation of the shear force distribution on the chords can be used. Additionally, the influence of an eccentric location of the contraflexure point in the tension chord should be considered to obtain proper and economical results, such as a suitable amount of reinforcement. The ultimate load, which is characterized by the formation of the first plastic hinge, can be reliably determined. However, further efforts to increase the ultimate load should be avoided since the prediction of the shear force distribution becomes unreliable. Furthermore, it is assumed that in many cases, the first plastic hinge arises before the serviceability limit state. For future work, the design concept will be transferred to different geometrical dimensions of the concrete beam's chords, and a large series of T-beams has already been computed using DIANA.Concrete beams with large openings are often designed in a simplified and global way, which may overlook important parameters. To identify and evaluate these parameters, a comprehensive study was conducted using the Finite Element Method with nonlinear material properties, simulating an innovative testing scheme. The study mainly focused on openings located in areas with high shear stresses, where little information is available. The results of the study demonstrate that the design of beams with large openings can be carried out in a more reliable way in the future. As a result, a practical design concept will be developed that satisfies both the ultimate and serviceability limit state.

Shen Yaohui(2017) : The author of this paper compares the crack changes, bearing capacity, and deflection of three types of beams: normal beams, beams with openings, and beams with openings reinforced with steel sleeves. Finite element modeling is used to conduct this analysis. By analyzing the mechanism of crack formation and combining it with theoretical concepts, the author finds that the commonly used method of reinforcing concrete beams with steel casings has significant drawbacks. As a result, this paper offers suggestions for improvement.

Bashir H. Osman and Erjun Wu(2016): The strengthening of reinforced concrete (RC) beams using externally bonded fiber reinforced polymer (FRP) sheets, strips, or steel plates is a contemporary and convenient method. Research has been conducted on RC beams with web openings that have been reinforced using fiber reinforced polymer composite. Most studies have focused on shear strengthening rather than flexural strengthening, while others have examined the effects of openings on shear and flexural separately with different loads. This paper examines the impact of more than 60 articles on the reinforcement of RC beams with and without openings using FRP. Additionally, important practical issues related to shear strengthening of beams with various techniques, such as steel plate and FRP laminate, and detailed with various design approaches, are discussed.

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Moreover, a simple method of applying fiber reinforced polymer with a steel plate for strengthening RC beams with openings under various load applications is concluded. Finally, directions for future research based on the existing gaps in the present work are presented.

Dhiaa Neama Jabbar and Ali Al-Rifaie(2002): This study conducted experiments on four reinforced concrete beams with square cross-sectional area, which were subjected to three-point loads until failure. Three of the beams were designed to have small web openings of different shapes (square, rectangular, and circular), while the fourth beam had no openings and was used as a control for comparison. Load-deflection data was collected for all specimens. The findings suggest that adding small web openings to reinforced concrete beams results in a slight reduction in ultimate load and an increase in ultimate deflection. Additionally, it was found that beams with circular web openings had better shear resistance than those with other shapes.

Nazar K. Oukaili and Abeer H. Shammari (2013): Web openings are commonly used in beams to provide easy passage of electrical and mechanical ducts, but they can cause shear failure or reduce the flexural strength. In this study, the response of reinforced concrete T-beams with multiple circular web openings is investigated. Seven T-beams were tested under incremental concentrated static loads, with two design parameters: number of web openings and method of strengthening at the openings. The results showed that strengthening beams at the openings can compensate for the decrease in beam capacity caused by the openings. The amount of compensation depended on the strengthening method used, with shear capacity gains ranging from 27% to 92%. The results were validated using a nonlinear finite element program, which showed good agreement with the experimental results.

Ting-jin Liu and Si-wei Chen(2020): This study explores the effects of multiple transverse web openings on the flexural behavior of reinforced concrete (RC) beams in underground metro stations. The issue is highlighted with a real engineering project where the RC beam's web opening violates current specifications. Five beams with varying numbers of web openings are constructed and tested under both static and cyclic loading to simulate unfavorable conditions during operation. The results indicate that the openings reduce the load-bearing capacity, stiffness, ductility, and energy dissipation ability of the RC beams, with the corners of the openings being the weakest points. However, additional reinforcements around the openings can partially mitigate these effects on the beams' seismic and load-bearing performance. The laboratory experiments provide guidance for using RC beams with web openings in underground engineering projects and also help improve related design specifications.

Sarah Jabbar and Farzad Hejazi(2016): The paper explores the impact of square openings of different sizes in the web of hollow beams on their behavior when exposed to different loading types, and compares it to that of solid beams. The study utilized high-strength concrete and ultra-high performance concrete. To achieve this, the hollow beam with various opening sizes was modeled using the finite element method, and nonlinear analysis was conducted on the developed models under torsional, flexural, and cyclic loads.Hollow sections are commonly used in the construction of buildings, bridges, offshore structures, and towers to pass electrical and mechanical pipes or other utilities. However, torsion caused by external force is a weakness of hollow sections that has received little attention in previous research. In particular, the behavior of hollow sections made of high-strength concrete (HSC) and ultra-high performance concrete (UHPC) has not been well studied. This study aims to examine the behavior of a reinforced concrete hollow beam with an opening and compare it to a hollow beam without an opening. The finite element method is used to model the hollow beam with an opening and analyze its behavior under torsional, flexural, and cyclic loading with both HSC and UHPC materials. The effect of the opening section size on the behavior of the hollow beam is also evaluated. The study found that the openings created in the web of hollow beams led to a decrease in beam capacity, although a hollow beam with a small opening can carry almost the same load as a hollow beam without an opening. Additionally, the capacity of UHPC beams for twisting is twice that of HSC beams.

Surya Sunder S, Nisha Babu, and Dinu Paulose(2016): The paper describes the use of openings in beams for accommodating various services such as water supply, air-conditioning, electricity, telephone, and computer network. The purpose of such openings is to reduce the weight and height of the structure. However, these openings can cause stress concentrations near them, which can affect the overall stability of the structure. To overcome this issue, the text discusses an experimental study that uses BFRP wrapping system to strengthen circular openings with singular and double openings at shear zones. The study evaluates the effectiveness of BFRP sheets with different openings based on factors such as initial crack load, ultimate failure load, cracking pattern, and deflection. The results indicate that beams with double circular openings perform better than those with a singular circular opening. Therefore, circular openings are preferred over rectangular ones for accommodating ducts, pipes, etc.This method involves using a BFRP wrapping system inside and around the opening to provide additional reinforcement. The purpose of this study is to find a solution to the instability caused by openings in structures.

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Mithun Kumar, Shivaraj Mangalagi, and Rajendrakumar Harsoor(2013): This paper presents an experimental study on the behavior of reinforced concrete (RCC) beams with circular openings that have been externally strengthened using glass fiber reinforced polymer (GFRP) and carbon fiber reinforced polymer (CFRP) sheets. Ten beams were cast, including a solid beam and a control beam with a circular post opening, and eight beams were externally strengthened using various schemes of GFRP and CFRP sheets (i.e., around the opening, inside the opening, inside and around the opening, and double layer around the opening). The beams were simply supported and tested under two-point loading in a loading frame. The load carrying capacity, load-deflection behavior, and cracking patterns of the beams were evaluated. The results showed that the ultimate load carrying capacity of the strengthened RCC beams with GFRP sheets increased in the range of 8.13% to 45.56%, and those with CFRP sheets increased in the range of 13.01% to 55.32%. Among all the strengthening schemes, the CFRP strengthening around and inside the opening was found to be the most effective in improving the ultimate load carrying capacity of the beams.

Javad Vaseghi Amiri , Morteza Hosseinalibygie(2004): This investigation explores the impact of small circular openings on the shear, flexural, and ultimate strength of beams constructed with normal and high strength concrete. The main factors examined in this study include changes in diameter, the position of the opening, the type and location of reinforcement around the opening, and variations in the strength of concrete. Nine beams were made with normal concrete and five with high strength concrete, and one solid beam filled with normal concrete was used as a reference for comparison. The beams were loaded as a simple beam with two concentrated and symmetrical loads. In the beams constructed with ordinary concrete, when the diameter of the opening exceeded 1.3 times the depth of the beam, the reduction in ultimate strength increased, and the pattern of cracking and mode of failure of the beam changed. The impact of concrete strength depended on parameters such as diameter and position of the opening. To control the cracks and limit their width, diagonal shear reinforcement is recommended. To increase the ultimate shear strength of the beam, the use of diagonal reinforcement and stirrups at the top and bottom of the opening is suggested. Finally, the test results were compared to the equations provided in various codes.

IV. CONCLUSION

This review paper explores research pertaining to the utilization of CFRP (Carbon Fiber Reinforced Polymer) lining as a method for reinforcing reinforced concrete (RC) beams that incorporate openings. In summary, the application of CFRP lining has proven to be a successful approach for fortifying RCC beams with openings. Implementing CFRP lining significantly augments the beam's capacity to bear loads, enhances its flexural strength, and improves its ability to deform without failure, thereby alleviating the detrimental effects of cutting openings in the beam's core on its structural behavior.

The experimental results underscore the potential of CFRP lining as a pragmatic strategy for renovating and restoring existing structures. The merits of employing CFRP lining, including its impressive strength-to-weight ratio, resistance to corrosion, and ease of installation, position it as a promising solution for augmenting the structural performance of compromised or weakened RCC beams.

Reinforcing the area around the beam's opening with FRP (Fiber Reinforced Polymer) sheets can also boost overall rigidity and recover a portion of the stiffness lost during the process of creating the opening. Consequently, the adoption of CFRP lining to reinforce RCC beams with openings presents a viable and efficient solution for the construction industry.

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