IARJSET
ISSN (O) 2393-8021, ISSN (P) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
ISO 3297:2007 Certified ⁜ Impact Factor 8.066 ⁜ Peer-reviewed / Refereed journal ⁜ Vol. 10, Issue 8, August 2023
DOI: 10.17148/IARJSET.2023.10823

Openings in RC Beams and Strengthening With CFRP

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Abstract: In the construction of contemporary buildings, it's essential to incorporate numerous pipes and ducts to facilitate vital services like water supply, sewage, air-conditioning, electricity, telecommunications, and computer networking. Typically, these conduits are positioned beneath the beam's underside. The dimensions of these pipes or ducts can vary, ranging from a few centimetres to up to half a meter. The introduction of such openings inevitably results in reduced structural stiffness, increased cracking, excessive deflection, and diminished beam strength.

To address these challenges, the use of Carbon Fibre Reinforced Polymer (CFRP) sheets for retrofitting concrete structures has emerged as an economically viable and technologically advanced alternative to traditional methods. This approach offers several advantages, including impressive strength-to-weight ratio, resistance to corrosion, excellent fatigue resistance, straightforward and efficient installation, and minimal disruption to the existing structural layout.

The focus of this research paper is to examine the behaviour of a Reinforced Concrete (RCC) beam featuring a Rounded Rectangular opening located within the shear zone. The study aims to evaluate the effectiveness of three distinct CFRP reinforcement techniques. The analysis is performed using ANSYS software. The study involves five beams: one acting as a control beam without an opening in the shear zone, with opening in shear zone the other three strengthened using different CFRP techniques—applying CFRP inside the opening, around the opening, and both inside and around the opening. The results include deflection values corresponding to varying load levels, allowing for comparison among different loading scenarios. Furthermore, the study analyses the crack patterns associated with the various CFRP techniques employed.

Ultimately, among the approaches investigated, it becomes evident that the technique involving CFRP reinforcement both around and inside the opening proves to be the most effective. This method substantially enhances the beam's load-carrying capacity, surpassing that of the control beam by approximately threefold.

Keywords: Reinforced Concrete Beam, strengthening of beam, finite element analysis, application of ANSYS software, graphical representation of load versus deflection relationships**,** CFRP, Rounded rectangular Opening,

I. INTRODUCTION

Global transformations are occurring rapidly, driven by the increasing spectrum of human needs. Consequently, there is a growing necessity to adapt existing buildings to accommodate essential environmental services like power cables, air conditioning ducts, water supply, sewage, gas pipes, and computer networks. Many standing structures have limited vertical clearances, making it necessary to create openings in reinforced beams. Various shapes of openings have been incorporated into beams, including square, rectangular, circular, and other regular or irregular forms, although the ones mentioned earlier are the most common.

These openings are categorized into two sizes: small and large, depending on their proportions. Large openings have dimensions exceeding 0.4 times the overall beam depth, while small openings are smaller than 0.4 times and have minimal impact on beam behaviour. Large openings notably affect beam stiffness, deflection, and strength. Furthermore, sharp corners in square and rectangular openings lead to concentrated stress points that could initiate unsightly cracks. This study employs nonlinear numerical analysis to address challenges arising from creating openings in the reinforced concrete beams. These challenges encompass excessive localized cracking at corners, reduced stiffness and strength, and increased deflection. The research aims to overcome these issues and suggest solutions by investigating the reinforcement of openings using carbon fibre reinforced polymer (CFRP) laminates

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II. APPLICATION OF RESEARCH

Ideally, service pipes should be installed beneath the beams within a building's structure. However, there are often instances where clients and service consultants are not in favour of this arrangement. The installation of pipes in this manner would necessitate bending them, leading to a reduction in floor height. To illustrate, consider a 20-floor building for which the builder has obtained approval for a height of 60 meters. If a 150mm pipe were to be routed

III. MODELING

In this study, a linear analysis approach is adopted, assuming a seamless bond between the reinforcement and the steel components. The finite element analysis process is divided into three main stages: pre-processing, solution, and post-processing. In the pre-processing stage, appropriate element types are chosen, as outlined in Table 1.

Table 1: Element type

Material	Element Types
Concrete	Solid 65
Steel	Solid 186

During the study, the selected element types from Table 1 are employed to accurately model the behavior of concreteand steel components within the finite element analysis framework.

Table 2: Material properties of CFRP

Modulus of elasticity in x direction	Ex (Mpa)	2.3 x 10^5
Modulus of elasticity in y direction	Ey (Mpa)	1.79x10^4
Modulus of elasticity in z direction	Ez (Mpa)	1.79x10^4
Shear modulus in xy direction	Gxy (Mpa)	11790
Shear modulus in xz direction	Gxz (Mpa)	11790
Shear modulus in yz direction	Gyz (Mpa)	6880
Poisson’s ratio in xy direction	µxy	0.22
Poisson’s ratio in xz direction	µxz	0.22
Poisson’s ratio in yz direction	µyz	0.30

a) Geometric modellingFive beam models are created

- Solid beam (without opening)
- Beam with opening
- Strengthened beam with CFRP inside the opening
- Strengthened beam with CFRP around the opening
- Strengthened beam with CFRP both inside and around the opening

The examined beam has an overall length of 1600 mm and dimensions measuring 230 × 300 mm. The upper longitudinal reinforcement employs two 8mm diameter high-yield strength deformed bars, whereas the lower longitudinal reinforcement is composed of two 10mm diameter bars.

To provide structural support, 8mm diameter bars are utilized as stirrups, spaced at intervals of 300mm detailed information about the dimensions of the beam model and the arrangement of reinforcement can be found in Figure 1 and Figure 2.

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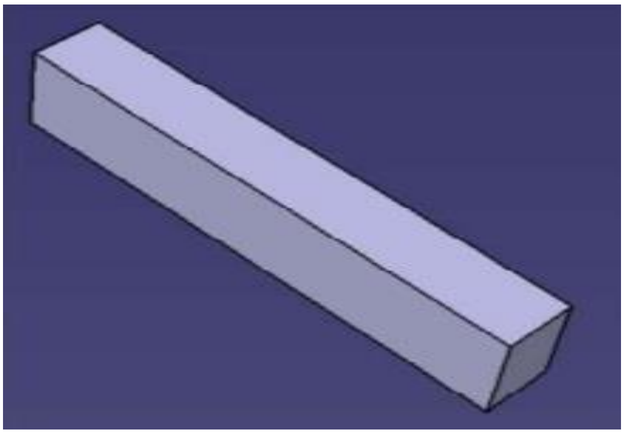

Figure1: Geometry of a beam

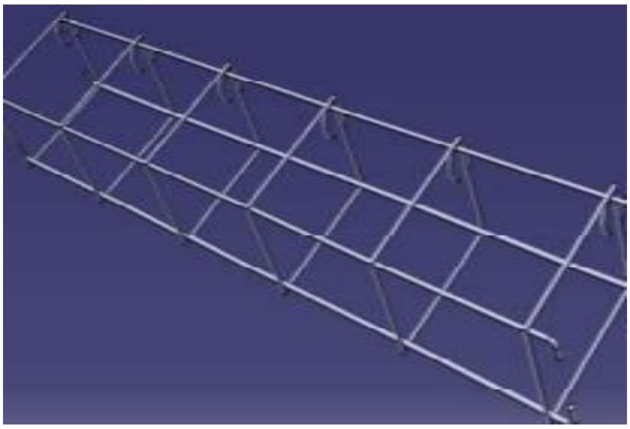

Figure2: reinforcement details of a beam

Beam is modelled with rounded rectangular opening in shear zone of dimension 150x100mm with a chamfer of 50mm

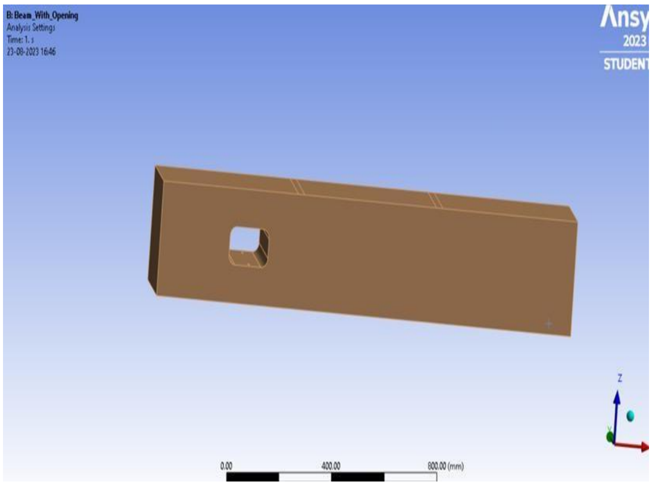

Figure 3: Beam with rounded rectangular opening

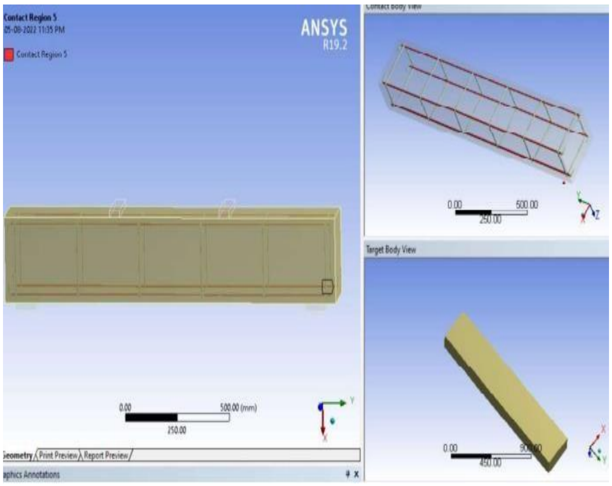

Figure 4: Contact between concrete and rebars

Interaction contacts were established manually between distinct types of elements. The process involved categorizing elements into groups using the named selection functionality, including designations for rebar, stirrups, concrete, and FRP. The sequence of contact establishment followed a specific procedure. Initially, the interaction between rebar and stirrups was defined, followed by extending the interaction to encompass reinforcement and concrete elements. In the context of static analysis, interactions were specified between the plates representing loading and support and the concrete. Finally, the contact between FRP and concrete was set up. This systematic approach ensured precise representation of interactions among the various structural components.

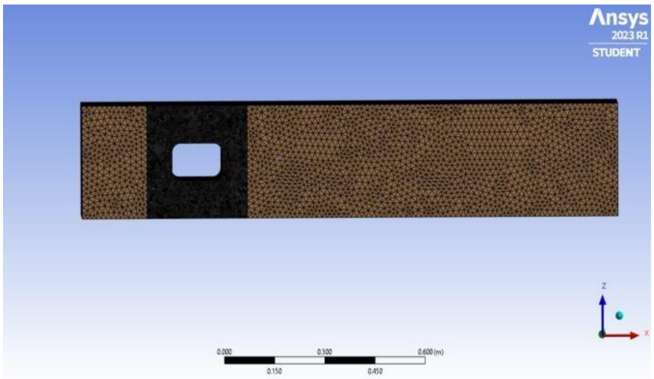

Figure 5: Meshing of a beam

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b) Load assignment and Boundary condition

To achieve precise outcomes, diverse boundary conditions are integrated into the finite element model. The FE model's displacement conditions are tailored to replicate the behavior exhibited by the real tested beam. Specifically, displacement boundary conditions are enforced in regions of symmetry, including the proximity of support and loading points. This strategic application of symmetric boundary conditions guarantees a harmonized and well-structured analysis setup.

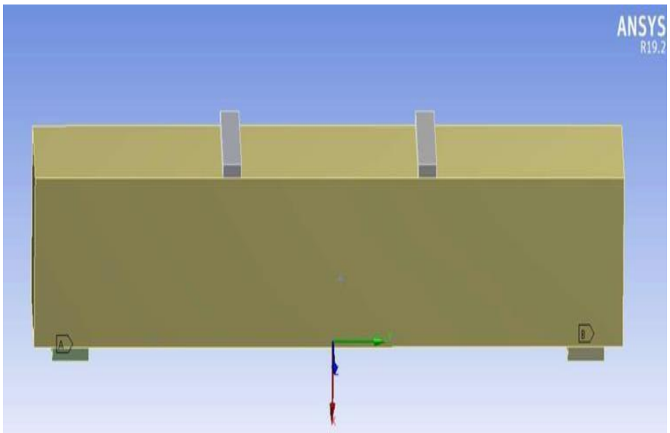

Figure 6: Support condition of a beam

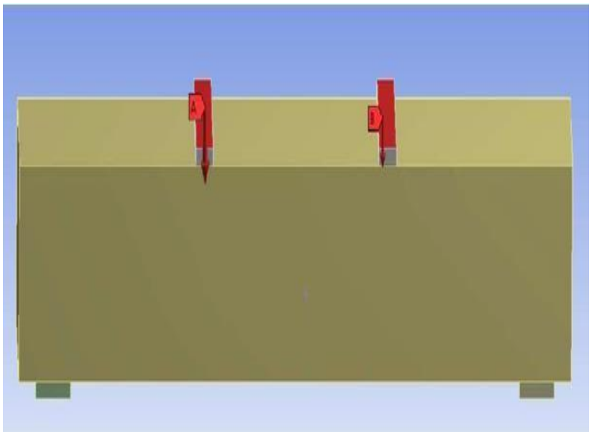

Figure7: Loads on beam

IV. ANALYSIS USING ANSYS

Analysing openings within the shear zone of beams holds significant importance as it sheds light on the intricate structural dynamics involved. The introduction of an opening in this zone can markedly disrupt shear force distribution, potentially influencing the beam's overall load-bearing capacity. To comprehend this phenomenon comprehensively, a thorough investigation is warranted, focusing on the alterations in shear flow, distribution of shear stress, and the possible emergence of shear-related failure modes.

Critical factors, including the opening's dimensions, placement, material properties of the beam, and applied loads, collectively determine the structural response. Such an analysis necessitates a blend of experimental testing and computational simulations like finite element analysis to effectively capture the nuanced interplay between modified geometry and shear forces.

Gaining insights into the behaviour of beams with shear zone openings is pivotal for crafting structures that are not only robust under diverse loading conditions but also ensure sustained structural integrity.

Deformation of all five beams is noted for incremental loads

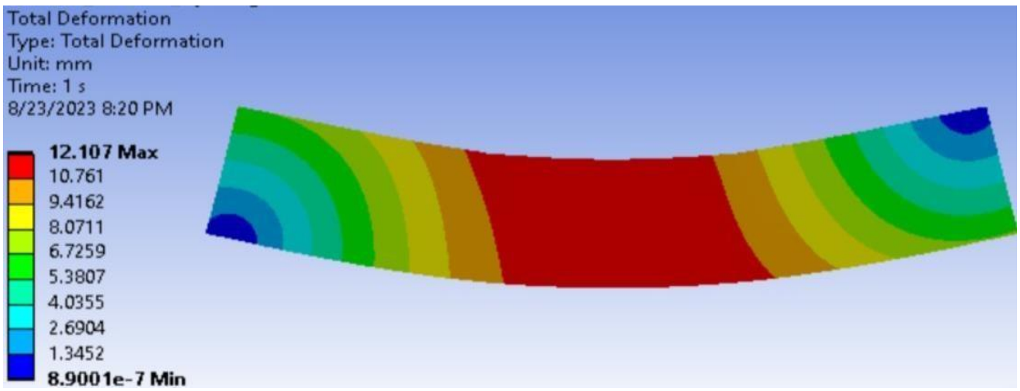

Figure 7: Deformation of beam without opening

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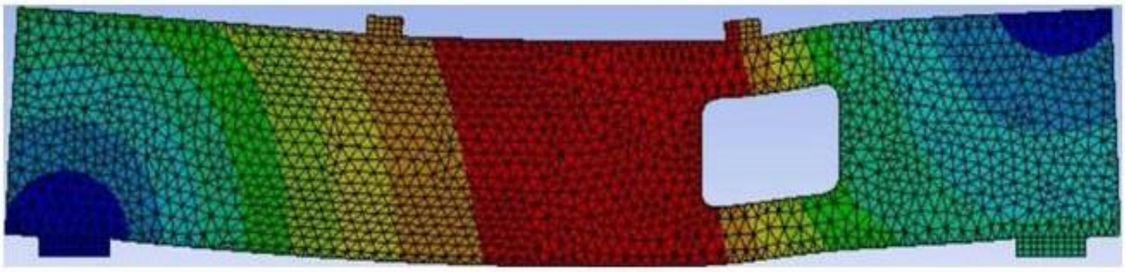

Figure 8: Deformation of beam with opening

Figure 9: Deformation of beam with CFRP inside wrapping of beam

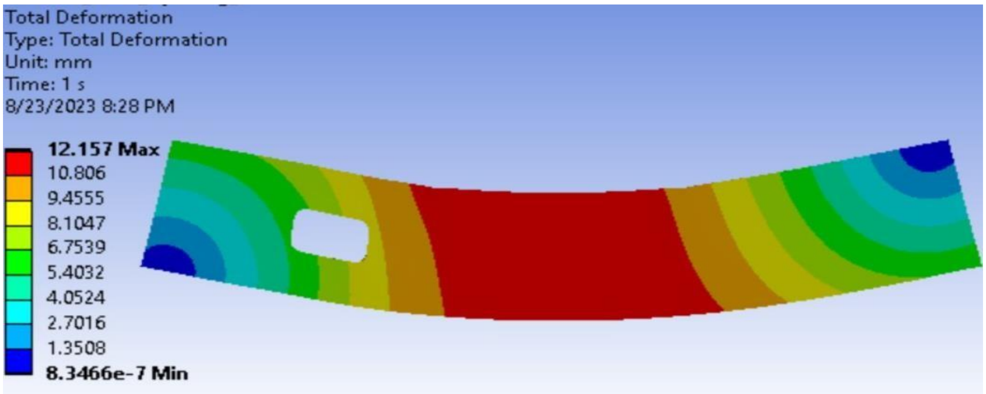

Figure 10: Deformation of beam with CFRP around wrapping of beam

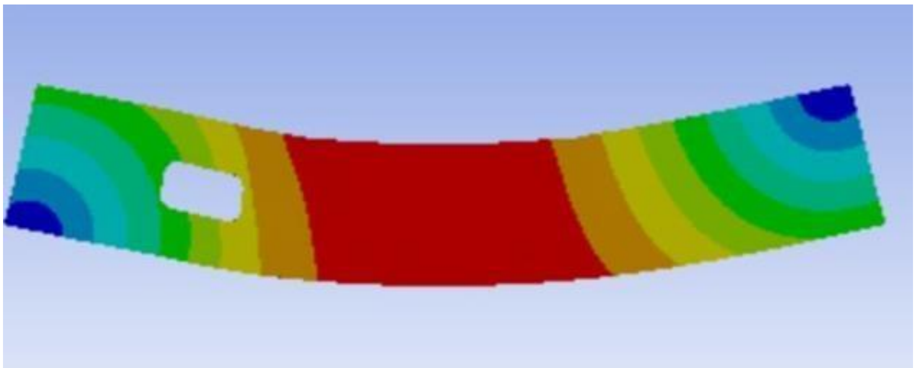

Figure 11: Deformation of beam with CFRP both inside and around wrapping of beam

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V. RESULT AND DISCUSSIONS

The outcomes of the investigation regarding openings within the shear zone of beams, combined with the utilization of CFRP reinforcement methodologies, offer valuable insights into structural behavior and potential enhancements. The introduction of openings in this zone is observed to trigger changes in shear force distribution and stress concentration. This adjustment affects the beam's load-bearing capacity and introduces the possibility of shear-driven failure modes. Strengthening the opening through CFRP techniques, including placement of CFRP within the opening, presents improved performance characterized by elevated load-bearing capacity and enhanced shear resistance.

This method effectively redistributes shear stresses and mitigates stress concentration in proximity to the opening, leading to an enhanced structural robustness. Furthermore, the application of CFRP around the opening contributes to the reinforcement of shear strength. This strategy curbs deformations, thwarts crack propagation, and proficiently transmits shear forces, culminating in a more resilient structural reaction. Furthermore, the simultaneous implementation of CFRP both inside the opening and around its perimeter yields the most substantial enhancement in terms of shear resistance.

This dual-pronged approach synergistically addresses stress concentration and shear redistribution, resulting in a significantly ameliorated load-carrying capacity compared to individual CFRP reinforcement techniques. The ensuing discussion underscores the potential efficacy of CFRP reinforcement in alleviating the detrimental effects stemming from openings within the shear zone of beams. It underscores the necessity of meticulous selection and tailoring of CFRP strengthening techniques to align with specific structural requisites.

The study underscores the holistic nature of structural analysis and reinforcement, offering practical implications for the design of beam openingssubjected to shear forces.

A comparison of load-deflection responses underscores the superiority of the combined CFRP approach, followed by perimeter strengthening and singular internal reinforcement. These findings underscore the efficacy of CFRP in addressing concerns associated with openings in shear zones and augmenting overall load-bearing capacity.

	Deflection(mm)		
Load	*CFRP inside*	*CFRP around*	*CFRP both inside and around*
0	0	0	0
10	0.3	0.29	0.29
20	0.8	0.72	0.7
30	1.4	1.2	1.2
40	2.8	2.2	2
50	4.1	3.6	2.2
60	5.4	3.8	3.2
70	6.2	4.2	3.8
80	6.9	5.6	4.2
90	8.2	6	4.6
100	8.8	6.2	5.9

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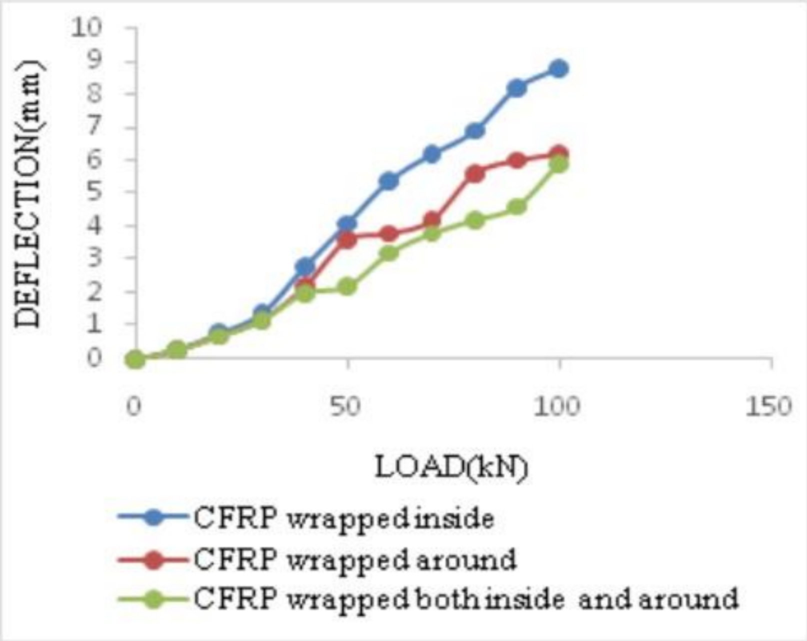

VI. CONCLUSION AND FUTURE SCOPE

- Impact of Openings: The research revealed the negative consequences of stress concentration due to openings in the shear zone. These openings directly affected the beam's load-carrying capability, shedding light on their significance in structural behavior.
- Load-Deflection Response: The load-deflection correlation showcased a distinct pattern. This pattern provides valuable insights into the beam's behavior under varying loads.
- CFRP inside the Opening: Incorporating CFRP reinforcement inside the opening notably improved the beam's load-carrying capacity and deflection upon failure. This enhancement was attributed to CFRP's ability to redistribute stresses, effectively slowing down the spread of cracks.
- Perimeter Strengthening with CFRP: The application of CFRP reinforcement around the opening's perimeter further elevated the beam's load-bearing capacity. This technique acted as a confinement mechanism, curtailing crack propagation and augmenting the overall structural performance.
- Combined Reinforcement Approach: Employing CFRP reinforcement both inside the opening and around its perimeter yielded a synergistic advantage. This approach adeptly mitigated stress concentrations, fostering increased beam ductility, and demonstrating the potency of a combined reinforcement strategy.
- Comparative Analysis: When evaluating load-deflection responses, the combined CFRP approach stood out, followed by perimeter strengthening, and then solitary internal reinforcement. This ranking underscores the potential of different CFRP strategies in handling challenges posed by openings.

FUTURE SCOPE

- Analyze the response of a beam with an opening in the flexural zone, employing different CFRP techniques.
- Strengthen beams using various types of FRP materials.
- Evaluate the potential of using steel plates as an alternative to FRP, aiming to address the challenge of FRPdebonding.
- Analyze the beam with various geometrical openings.
- Dynamic analysis of opening in beams.

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