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Identification of Optimum Retrofitting Approach for Strengthening RC Beams using CFRP Sheets

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Abstract: Recently the formation of disasters like earthquakes, Tsunami, etc., are quite common in all parts of the world. Due to the disasters the existence of loss to property as well as human life is quite common and more to avoid/decrease the damage due to disasters, strengthening a structure is one parameter. Retrofitting is the use of revolutionary technology to reinforce the structural elements to resist the upcoming damage due to disaster. In this paper carbon fiber reinforced polymer strengthening is considered for retrofitting technique. Carbon fiber reinforced polymer sheets of 50 mm width are used and wrapped on the beams with four different orientations like 0^0, 45^0, 60^0 and 90^0. Experimentally ten beams are casted in which two beams are marked as control beams and in remaining eight beam, every two beams are used for each orientation. The beams are subjected to four-point loading, and the greatest deflections and cracks at the beam center are recorded. The beams are tested for flexural loading and studied different parameters like maximum deflection, maximum load, Initial crack load etc are compared. With an emphasis on RC beams specifically, the goal of this work is to close the current research gap by examining the behavior of fiber reinforced polymer orientation in concrete elements. A beam covered with 50 mm strips at a 45-degree angle produced better results than the remaining beams.

Keywords: CFRP Wrapped, Retrofitted R.C.C Beam, Actuator, Carbon fiber reinforced polymer sheets,

1. Introduction

Over the past two decades, there has been a remarkable increase in the adoption of Fiber-Reinforced Polymer composites effectively improves their performance, resulting in significant capacity enhancements under various damage levels [1]. Fiber Reinforced Polymer (FRP) composites have revolutionized civil engineering and construction industries, offering innovative solutions. A significant application of FRP is strengthening beams through wrapping, where FRP strips are externally bonded to existing beams to improve their load-carrying capacity and overall structural performance. Advancements in materials and technologies have spurred researchers to explore diverse designs and materials to enhance the strength of shear-critical Reinforced Concrete (RC) beams [2-5]. Structural beams may encounter various challenges over time, such as corrosion-induced deterioration and increased loads. Wrapping beams with FRP presents a cost-effective and efficient solution to address these issues, enabling engineers to prolong the service life of existing structures without resorting to major demolition and reconstruction efforts. A wide array of materials, designs, wrapping methods, and mechanical anchors have been investigated to augment the strength of existing RC elements, with a focus on deferring or mitigating the debonding process in externally bonded FRP members [6-9]. While substantial experimental research has been conducted in this domain, there has been limited utilization of Finite Element Method (FEM) to comprehend the behavior of Carbon Fiber Reinforced Polymer (CFRP) containing RC beams subjected to parallel loading and varying CFRP orientations [10-13]. The wrapping of beams with CFRP not only enhances the load-carrying capacity but also improves corrosion resistance. Previous studies have primarily employed FRP strips as reinforcement on the faces of RC beams [14].

The typical FRP scheme types that have been employed in research the most commonly arei) 90_ strip ii) 45_ strip and iii) U-shape full length wraps. The strength, transfer of energy from structures, and stiffness parameters of the poorly detailed RC joints in the shear zone are all improved by the retrofitting of beam column junctions with FRP. The study's outcomes indicate that preventing the wrapping from debonding too soon is largely dependent on the mechanical anchorage. It also aids in a number of other things, such the area fraction of FRP and the bonding of FRP between beam-column joints [15]. A novel approach to retrofitting beam-column joints is adopted with the aim of enhancing the storey shear capacity [16-18]. The retrofitted and control specimens as well as the original beam column specimens were examined for lateral loading. It is discovered that in control specimens, the column fails by passing through the joints, and the specimen fails by the longitudinal bars in the beams giving. Following retrofitting, it was discovered that the yield stiffness of the modified specimen increased by 14% and the storey shear increased by 7% in comparison to the control specimen. A minimum percentage improvement is also made to the hysteresis loop form [19]. According to an analysis conducted through experimentation, beams were cast, which had FRP retrofitted. A static load was applied to test those specimens, and test results were obtained. Based on the findings, they deduced that while reinforcing the reinforced concrete beams in the flexural zone offers the specimen more strength, it also makes the specimen brittle and increases the risk of catastrophic failure. It also starts the steel from yielding in beams, which is followed by the FRP sheets rupturing [20]. Using conventional methods, FRP is a user-friendly, durable, and simple material to install. It also has little effect on the structure's weight and dimensions [21].

The strength, energy dissipation from structures, and stiffness parameters of the poorly detailed RC joints in the shear zone are all improved by the retrofitting of beam column junctions with FRP. The study's outcomes indicate that preventing the wrapping from debonding too soon is largely dependent on the mechanical anchorage. It also aids in a number of other things, such the area fraction of FRP and the bonding of FRP between beam-column joints [22]. In order to prevent shear or brittle failure in the connection between the beam and column under earthquake strain, a variety of materials are used. Additionally, they discovered that shear strength is effectively provided by retrofitting with FRP sheets in areas where shear strength is quite low [23]. With this approach, brittle junction failure is also prevented. It was discovered that CFRP sheets fastened to the bottom beam functioned well with a suitable anchoring system in place. The FRP sheets performed well under high compressive and tensile loads. A novel approach to retrofitting beam-column joints is adopted with the aim of enhancing the storey shear capacity [24, 25]. The retrofitted and control specimens as well as the original beam column specimens were examined for lateral loading. It is discovered that in control specimens, the column fails by passing through the joints, and the specimen fails by the longitudinal bars in the beams [26]. Following retrofitting, it was discovered that the yield stiffness of the modified specimen increased by 14% and the storey shear increased by 7% in comparison to the control specimen. A minimum percentage improvement is also made to the hysteresis loop form. According to an analysis conducted through experimentation, nine specimens of beams were cast, six of which had FRP retrofitted, and three of which had not. A static load was applied to test those nine specimens, and test results were obtained. The shear capacity of reinforced concrete beams strengthened with externally bonded FRP, showcasing accuracy in predicting shear strength without requiring post hoc calibration [27]. A new design equation for predicting the shear strength of strengthened RC beam-column joints using CFRP, incorporating interfacial bond and CFRP sheet end conditions [28]. Utilization of performance factor derived from deformability and strength factors, to achieve stable and controlled progressive failure in strengthened RC beams [29]. The flexural behavior of externally strengthened RC beams using crimpled steel fiber polymer, aiming to enhance durability and serviceability, providing insights into the effectiveness of the strengthening method and its impact on energy absorption [30]. The NSM steel bars strengthening technique can be considered as a good method to be used in strengthening the high strength RC corbels [31-33].

Based on a review of the relevant studies, it was found that more research investigated the effect of FRP composites on the RC beams casted with all coarse aggregate, cement and fine aggregate i.e., manufactured sand. The primary objective of the study aims to find the best-retrofitted configuration using FRP materials to make the structural element safe from loads. In addition, this investigation is conducted to determine the load carrying capacity of beams with respect to applied load.

2. Experimental Work

2.1 Materials

In this research Portland pozzolona cement was utilized. The properties of Portland pozzolona cement is listed in Table 1.

Table 1. Properties of Cement

Sl.No	Description	Results	I.S Limits
1	Fineness	6%	<10% (IS-4031part 2)
2	Initial setting time	Intial: 110 min.	>30min. (IS-4031 Part-5)
3	Soundness	4 mm	<10mm (IS-4031 Part-3)
4	Consistency	32%	IS-4031 Part-4
5	Specific gravity	3.10 cm^2/gm	IS-4031 Part-11

Table 2. Properties of Coarse aggregates

S.No.	Property	Results
1	Specific gravity	2.67
2	Bulk density(t/m^3)	1.54
3	Water absorption (%)	2.05
4	Flakiness Index (%)	37.8
5	Elongation Index (%)	10.5

Table 3. Properties of epoxy bond agent

Name of epoxy bond agent	MasterBrace 1414
Compressive strength @ 23^{0}C	65 MPa @ 7 days
Tensile strength@ 23°C	25MPa @ 7 days
Mixed viscosity @ 25°C	2450 ± 450 cps
Pot life	2 hours @ 25°C
	1 hour @ 40°C
Recoat time	8 hours @ 25°C
	6 hours @ 40°C
Slant shear bond strength (BS 6319 part 4)	>11 MPa (Concrete failure)
Bond strength	>2.5 MPa (concrete failure)
Setting time	150 minutes @25°C
Mix Ratio	83:17 pbw
Density (Mixed)	1.48kg/L
Application Temperature	15°C - 35°C

Table 4. Properties of CFRP

S.No.	Property	Results
1	Tensile Strength (MPa)	3700
2	Modulus (GPa)	230
3	Density (g/cm^3)	1.8
4	Thickness	0.208

For fine aggregates, Due to overexploitation, environmental concerns, regulatory restrictions, rising demand, illegal mining, and alternative uses, there is a large scarcity for natural sand then manufactured sand with specific gravity of 2.53 is preferred. By careful selection of materials, appropriate mix design, and quality control measures can help ensure that concrete with manufactured sand meets the required performance criteria for specific applications.

2.2 Specimen Details

Flexural test was conducted on ten beams. The beam is 200 mm by 115 mm in dimension and has a total length of 2500 mm. Figure. 1 displays the beam's reinforcement features.

In all types of wrapping methods 50 mm width CFRP wrapping sheets are considered. For finding the best retrofitting of beams, five different types of wrapping techniques are implemented.

From the ten specimens, two specimens were taken as control beam and remaining eight were wrapped with different types wrapping techniques are mentioned in the table 6 below

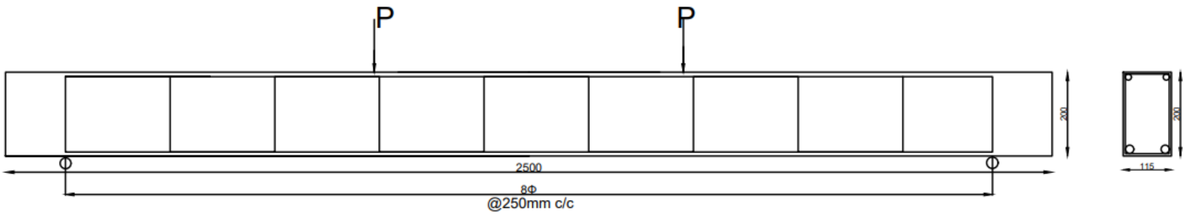
The test setup includes a loading frame and a hydraulic actuator with a 150 kN capacity. A hydraulic jack with a 75 kN capability for applying loads is part of the loading frame.

The actuator's job was to apply cyclic load as well as static load to the specimens upto the failure of specimen. In this experimental study, static load is applied on to the casted beam specimens through the spreader beam where the maximum load in all the beams not exceeded to 75 kN. Linear Voltage Differential Transducers (LVDTs) are employed and connected at five separate locations i.e., a distance of L=0 m, L=0.84 m, L=1.25 m, L= 1.68 m, L=2.5 m for observing the lateral displacement measurement at the bottom of the beam. The set-up for the beam without wrapping (Control Beam)-C1 were shown in Figure.3a.

The observed mode of failure for control specimen is shown in Figure. 4. The specimen without FRP confinement (C-1), crushing as well as cracks on concrete is noted as the failure of the beam.

2.3 Experimental Testing

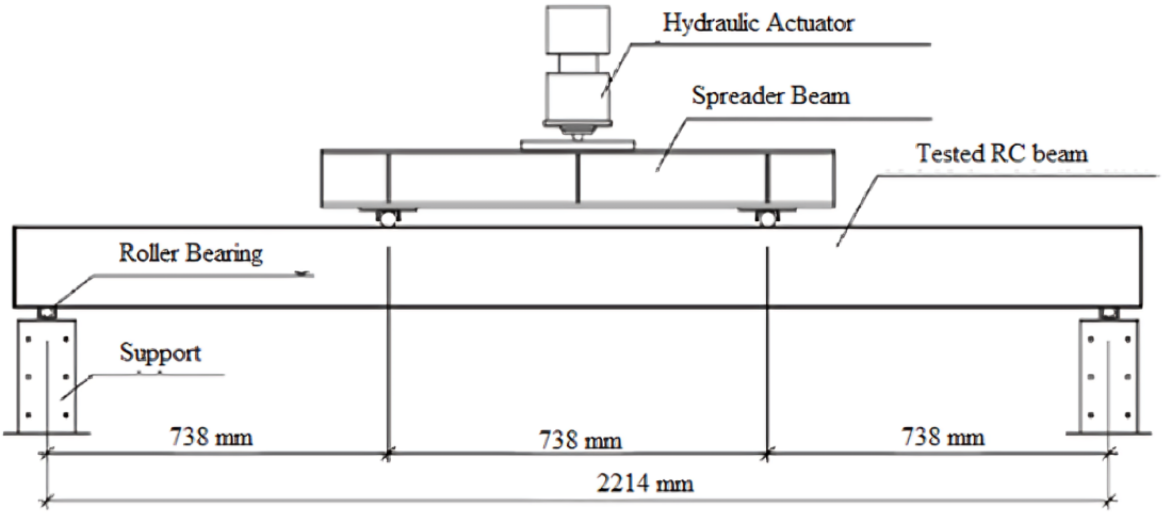
In the remaining cases from 2 to 5, Small cracks developed along the beam's depth, as shown by the specimen and seen in Figures. 3, 4, 5, and 6. Because of the increased stress concentration in certain areas, the de-bonding of CFRP at the beam is the primary cause of failure in wrapped specimens [29-30]. In the different cases stated above, the failure of beam was due to the de-bonding and rupture of the FRP jacket, which in turn is associated with concrete crushing.



Figures 1. Beam Cross Section Details

Table 5. Experimental data

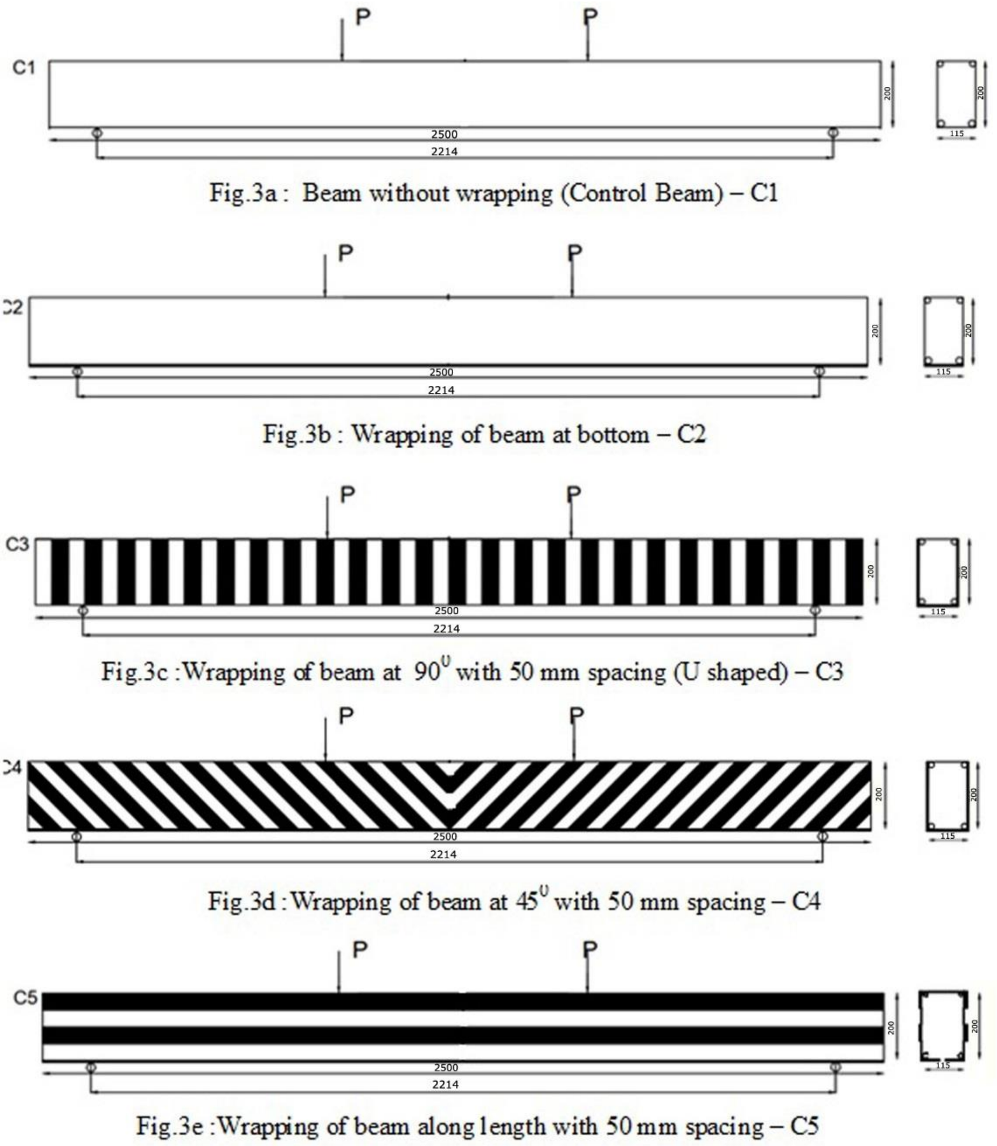
Grade of Concrete	M30
Longitudinal reinforcement	10 mm
Stirrups	8 mm @ 250 mm c/c
Grade of steel	550 MPa
Size of beam	200 mm x 115 mm
Length of beam	2.5 m



Figures 2. Loading diagram

Table 6. wrapping orientations

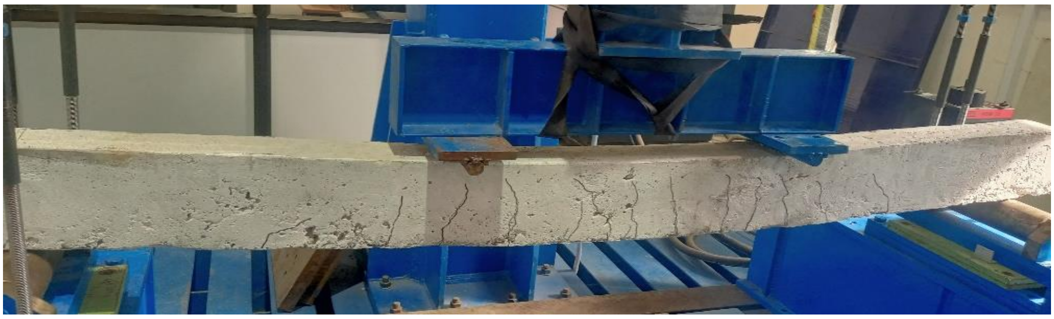
Wrapping Method	Notation
Beam without wrapping (Control)	C1
Beam with wrapping at bottom	C2
Beam with wrapping at 90^0 with 50 mm spacing (U shaped)	C3
Beam with wrapping at 45^0 with 50 mm spacing	C4
Beam with wrapping along length with 50 mm spacing	C5



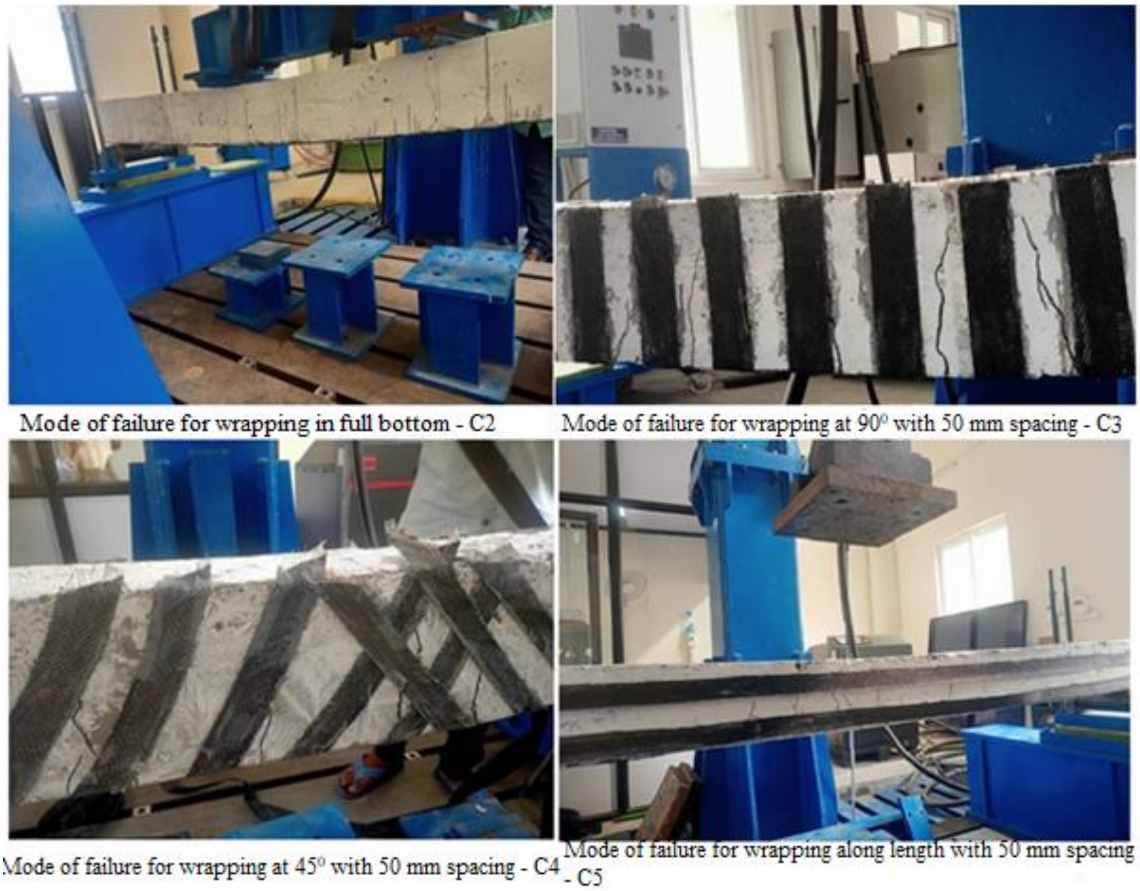
Figures 3. Pictorial representation of wrapping in different orientations

After application of load, beams will form failure pattern in different cracks like flexure and in the middle of the beam, shear cracks with observable crack widths were found. By using the main mark crack gauge, the maximum crack widths are noted on the beam. The maximum crack widths of the different cases are listed below.

The identification and assessment of crack width in RC beams are important tasks in structural engineering and maintenance. Cracks in RC beams can be indicators of structural distress, and their width can provide valuable information about the integrity and safety of the beam. The crack width is typically measured to evaluate the severity of cracking and to ensure that it remains within acceptable limits for the structural element's serviceability and durability [31-32].



Figures 4. Mode of Failure for No wrapping (Control Beam) – C1



Figures 5. Mode of Failure for different cases

Table 7. Crack Width of all Specimens

S.No.	*Specimen*	*Crack Width in mm*
1	C1	2.5
2	C2	3.0
3	C3	1.5
4	C4	2.0
5	C5	1.0

3. Results and Discussions

Experimentally the initial crack load, Axial Displacement and ultimate load are identified for each case are graphically represented below.

From the Figure. 6, it is clearly identified that the beams wrapping in full bottom i.e., C2 will have 21 % more bearing capacity to avoid formation of cracks when compared to control beam i.e., C1. As beam fails due to compression at top, in bottom CFRP wrapping may tend to oppose the cracking. From the Figure. 7, it is clearly identified that the beams wrapping at 45^0 with 50 mm spacing i.e., C4 will have 53 % more ultimate load bearing capacity before damaging the beam.

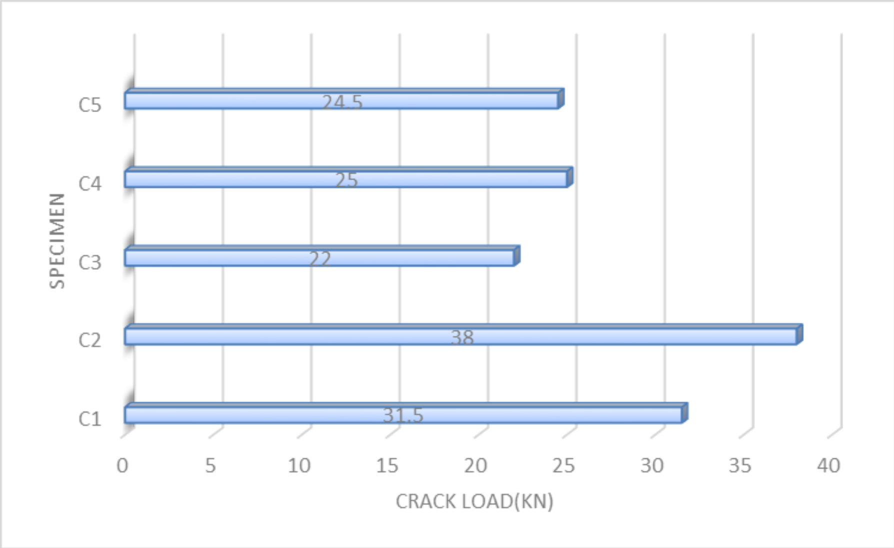


Figure 6. Initial Crack load of five different cases of beams

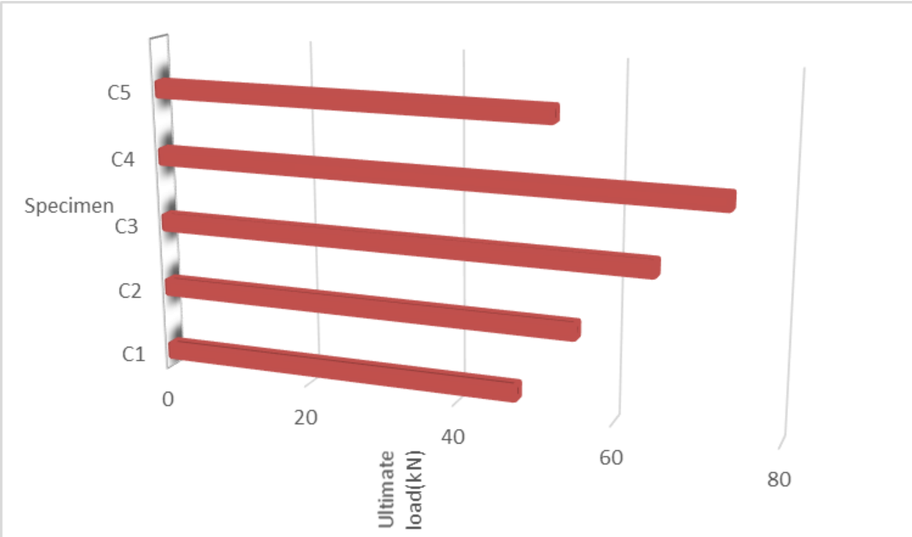


Figure 7. Ultimate load of five different cases of beams

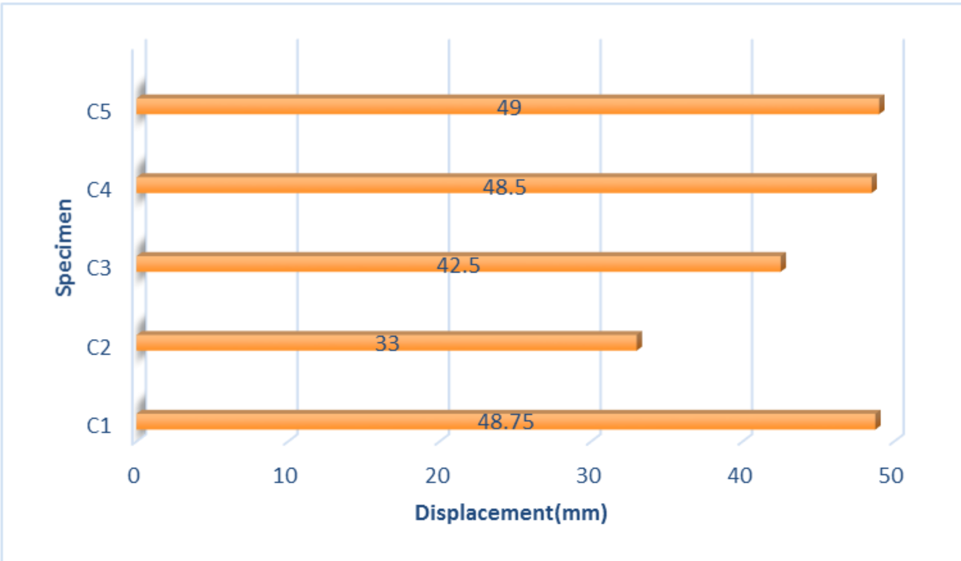


Figure 8. Axial displacement of five different cases of beams

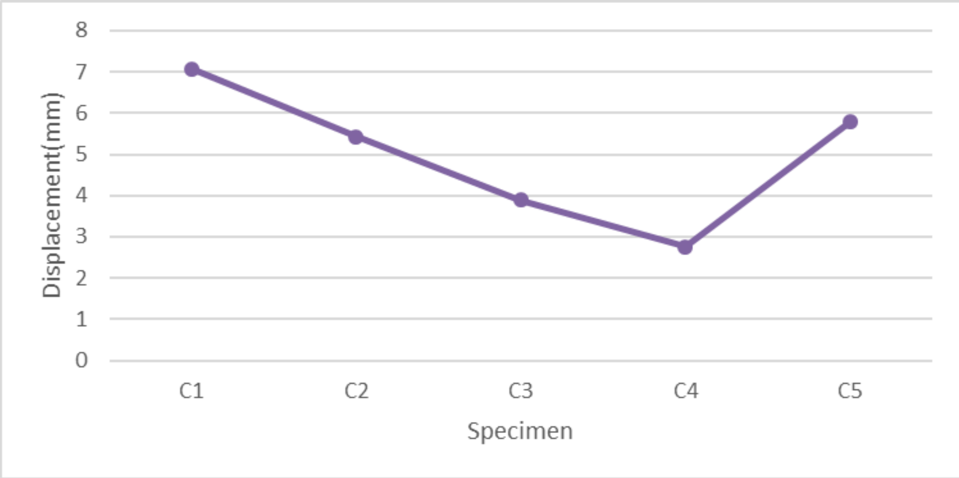


Figure 9. Displacement at Centre of beam

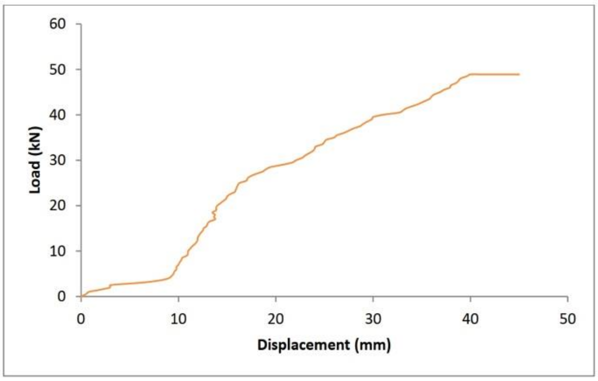


Fig. 10a : Load vs Displacement curve at centre of beam C1

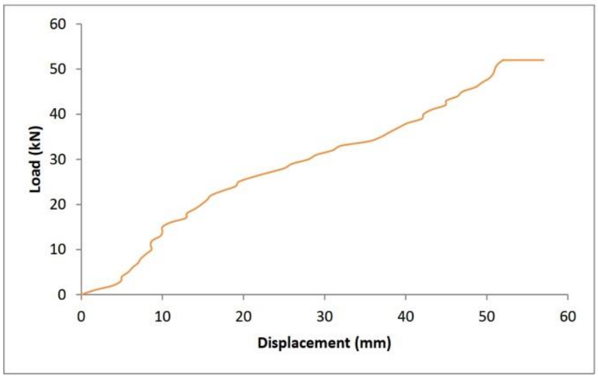


Fig. 10b : Load vs Displacement curve at centre of beam C2

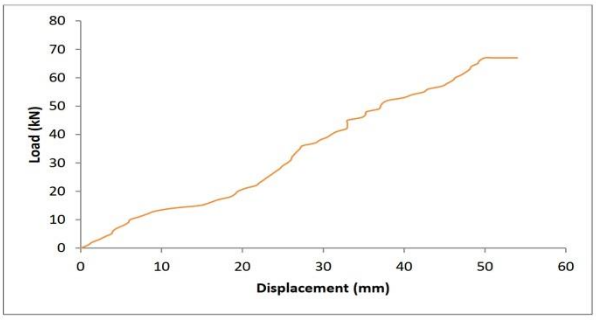


Fig. 10c : Load vs Displacement curve at centre of beam C3

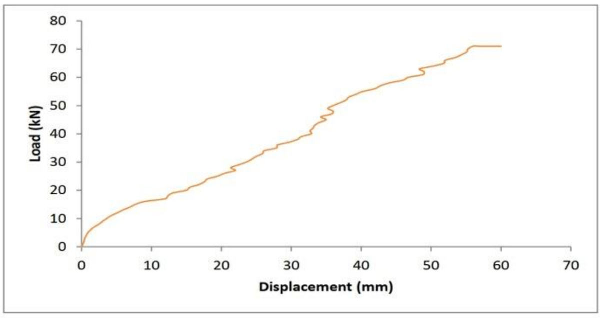


Fig. 10d : Load vs Displacement curve at centre of beam C4

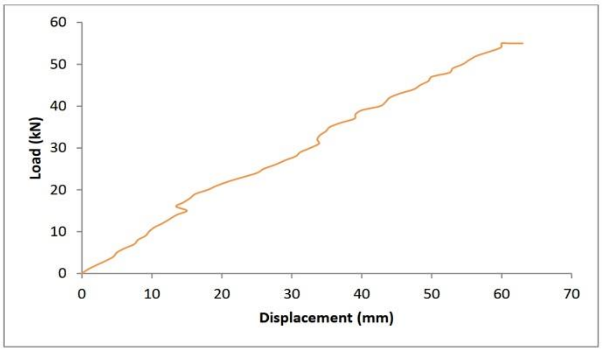


Fig. 10e : Load vs Displacement curve at centre of beam C5

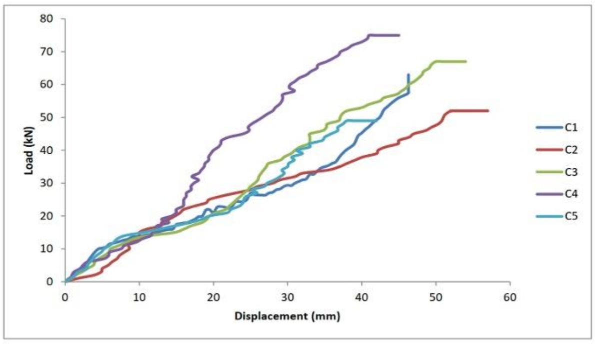


Fig. 10f : Load vs Displacement curve at centre for all cases

Figure 10. Load vs Displacement curves for different orientations of wrapping

The remaining wrapped beams also bear the load more or less equal to the load carried by the control beam. From the Figure. 8, it is clearly identified that the beams totally wrapped entire bottom i.e., C2 has 33 %

less displacement when compared to Control beam. The same beam is modeled in abaqus software to find the exact deflections and stresses at constant increment of 1 kN upto 50 kN. From the Figure. 9, it is clearly identified that the beams wrapping at 45^0 with 50 mm spacing i.e., C4 will have 61 % less displacement at center after applying the load. After that the beams wrapping at 90^0 with 50 mm spacing i.e., C3 will have 45 % less displacement at center. The remaining wrapped beams have 20% less displacement w.r.t control beam.

From the experimental testing of beams with different cases under actuator, the deflections under the beam at centre of beam are recorded. The Fig. 13a represents the displacement variation of beam C1. Figure 10a represents the load displacement curve for control beam C1. The control beam C1 displaced upto 40 mm with a maximum load of 48 kN. The deflection curve is not linear between 15-40 kN as the deflection is increased rapidly. Figure 10b represents the load displacement curve for beam C2. The beam C2 displaced upto 52 mm with a maximum load of 52 kN. The deflection curve is more varied upto 30 mm displacements. Afterwards the curve is linearly increasing. For specimen C2 the load bearing capacity is increased by 12% when compared to control beam C1. Figure 10c represents the load displacement curve for beam C3. For specimen C3 the load bearing capacity is increased by 44.7% when compared to control beam C1 and displacement also reduced by 13.0% when compared to C1. Figure 10d represents the load displacement curve for beam C4. For specimen C4 the load bearing capacity is increased by 53.3% when compared to control beam C1 and displacement also reduced by 2.6% when compared to C1. Figure 10e represents the load displacement curve for beam C5. For specimen C5 the load bearing capacity is increased by 5.83% when compared to control beam C1 and displacement also decreased by 33.9% when compared to C1. Figure 10f represents the load displacement curve for all beam specimens. From this it is observed that beam C4 has more load bearing capacity due to the applications of CFRPs in inclined position. For case 4 displacements increased drastically but the maximum displacement is restricted 30% less when compared to the remaining cases.

4. Conclusion

From the all above experimental results, it is identified that

1. By using the main mark crack gauge the crack width with respect to the applied load is identified and the crack width of all five cases is considered and identified that CFRP wrapping along length with 50 mm spacing is the better when compared to the other.
2. By the axial displacements given by the actuator, It is understood that ultimate load carrying system of the beam wrapped at 45^0 with 50 mm spacing is 50% more when compared to the control beam.
3. By the Initial crack load given by the actuator, It is understood that Initial crack load of the beam wrapped at 90^0 with 50 mm spacing is 32% less when compared to the control beam.
4. For displacement at center, the Beam with wrapping at 45^0 with 50 mm spacing is having 60% less displacement when compared to the control beam.
5. From the load versus displacement curves at centre, it is concluded that the beams with wrapping will give less displacements when compared to the control beam.
6. The load bearing capacity is increased 50% more for C4, C2 when compared to the remaining specimens.

From the all above results, It is concluded that the beams wrapped at 45^0 with 50 mm spacing is giving better strength gaining wrapping method for the structural elements.

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Authors Contribution Statement

Gandla Nanabala Sreekanth: Conceptualisation, Methodology, Investigation, Data curation, Writing - original draft, Writing - review & editing. S. Balamurugan- Conceptualisation, Methodology, Investigation, Supervision, Validation, Writing - original draft, Writing - review & editing.

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Data Availability

The data generated during this study will be made available on reasonable request from corresponding author.

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