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Research Article

Effect of Wrapping on Post-Tensioned Beams Strengthened with Natural Sisal and Jute FRP Using Finite Element Analysis

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Existing buildings are retrofitted to formulate them to be more resistant to seismic activity, earth motion, and other natural disasters. Many available reinforced concrete buildings across the globe are in desperate need of rehabilitation, repair, or replacement owing to degradation caused by a variety of reasons such as corrosion, lack of detailing, and failure of beam-column bonding, among others. In the construction sector, fibre reinforced polymer (FRP) composites have been recognized as a potential option for repairing and increasing the strength of existing structures. In this study, comparisons are done in terms of load bearing capability of the beams for configurations between FE model predictions and field data (experimental). To assess the FRP retrofit, structural responses for strengthened and control post tensioned concrete (PTC) beams are compared, with strengthening using various wrapping methods. The load bearing capacities of the beams retrofitted with sisal and jute fibre employing strip and full wrapping procedures around all four sides is increased by 35.55 percent and 42.85 percent for sisal FRP and 7.14 percent and 12.01 percent for jute FRP, respectively, as compared to the control specimen. The FRP retrofit model is expected to result in a considerable increase in structural performance.

1. Introduction and Background

Some structures have degraded as a result of a variety of issues ranging from corrosion to fatigue of reinforced concrete elements and are commonly found to be unable to support existing or new load levels put on the structure. Due to increased loading, a change in use, corrosion, and other factors, many structurally inadequate buildings need reinforcing/strengthening [1, 2]. A novel technique of retrofit has been researched and deployed to boost the capacity of reinforced concrete structural parts in recent years [3]. Among the list, one method is externally bonded fibre reinforced polymer (FRP) which may significantly boost a structural member's static load capacity and its performance [4–6]. Aramid, carbon, and glass FRPs were more common. Presently, researchers are working to create more ecologically friendly FRP materials to replace synthetic FRP materials as a result of current laws, increased public awareness of the need for environmental protection, and other factors [7, 8]. These fibres are the key reinforcing components in polymer matrices and transmit stress between them.

In recent years, the application of natural FRP reinforcement in the strengthening of flexure structures has grown in popularity. Awoyera et al. [9] used bamboo fibre laminate to undertake structural retrofitting of deteriorated reinforced concrete beams. Beams were initially subjected to corrosion studies, and then corroded beams were externally retrofitted using bamboo FRP. The ultimate load bearing capacity of the corroded beam was raised by 21.1 percent when bamboo laminate of single layer was used in the tensile zone, compared to the corroded beam without the retrofit. Raju and Mathew [10] and Sen and Jagannatha Reddy [11] compared behavior of natural and artificial FRP retrofitted beams via their maximum load bearing capacity. Zhang and

Teng [12] studied the RC beams strengthened with FRP for flexural strength with end cover separation.

Moreover, experimental study and finite element analysis (FEA) were performed in a few earlier works to examine the technology and relevance of using FRP composite to wrap concrete structures [13–15]. To simulate and analyze the outcomes of the experiments, FEA is used. Concrete beams which were retrofitted with carbon FRP sheets were analyzed by FEA and compared with experimental results [16–18], load deflection response, and failure modes were analyzed. Zhou et al. [19] demonstrated FE modeling of retrofitted beams employing carbon FRP laminates and a carbon flex. The peak load deflections of carbon flex retrofitted beams were found to be 67.8 percent and 73.1 percent greater than those of CFRP retrofitted beams, according to the study's findings. Damage mechanisms and loads bearing capabilities, strain/stress distributions, were quite similar to the experimental outcomes. Bouziadi et al. [20] studied creep response of carbon and glass FRP laminates externally reinforced concrete beams using nonlinear numerical analysis. The creep strain is greatly reduced when CFRP thickness is increased and orientation is altered. Also, the load improvement ratio mainly depends on the number of FRP layers used to retrofit the structures [21].

Haddad and Obaidat [22] verified the test data for shear deficient and heat damaged beams which were retrofitted with carbon FRP strips using near surface mounting technique using the FE model. Sen and Reddy [23] considered natural coir fibre composite to retrofit RCC beams and were simulated for ultimate load carrying capacity using FE analysis. Obaidat et al. [24] used the ABAQUS tool to verify FE analysis of carbon fibre reinforced plastic plate retrofitted beams with various lengths of FRP, with the experimental findings.

As on date, as per the literature data, a significant amount of experimental research works has been conducted in order to evaluate the behavior of structural elements reinforced with FRP. FE analyses on structures retrofitted with FRP plates have been carried out by the investigators. However, most of these studies are referred to RC beams. In this paper, the use of a 3D nonlinear FE method by the program ANSYS has been adapted to model the structural behavior of PTC beams unstrengthened and strengthened with S-FRP and J-FRP with different wrapping techniques. The current work focuses on wraping sisal and jute fibres on the surface of the beam material in two separate modes, strip wrapping and full length wrapping. Later, the parameters of the beam, such as deflection, were studied using ANSYS (commercially available finite element technique simulation software) with appropriate assumptions. The results were also compared to the experimental data. This study clarifies the behaviour of a beam in different wrapping modes. It is possible to investigate the effect of wrapping on a load-bearing capacity of beam.

2. Program of Study

2.1. Geometry of the Beam. The beams were 3400 mm long, 230 mm broad and 300 mm deep. Longitudinal steel bars: 2 nos. of diameter 10 mm each at the top and 2 nos. of diameter 12 mm each at bottom, and the sisal and jute FRP were used, having 3.62 mm thick approximately (supplied by Extra Weave Private Ltd., Cherthala, Kerala). The mix fraction for M-40 concrete was evaluated using the mix design described in IS: 10262-2009. River sand that was readily accessible in the area and the OPC 53 grade that complied with IS: 12269-1987 and IS: 8112-1989 were utilized as fine aggregate. In compliance with IS: 383-1970, a coarse aggregate measuring 12 mm was employed. In accordance with IS: 9103-1999 and IS: 456-2000, CONPLAST SP430, supplied by Fosroc Pvt. Ltd., was utilized as the super plasticizer. According to IS: 10262-2009 specifications and a design strength of 40 N/mm^2, calculated amounts of water, cement, coarse aggregate, and fine aggregate were combined in a ratio of 0.4 : 1 : 2.13 : 1.27 to prepare a concrete. At various time intervals, the average compression strength was tested and found to be 22.7 N/mm^2 for a 7-day cure, 38.95 N/mm^2 for a 14-day cure, and 43.34 N/mm^2 for a 28-day cure. Fe-500 HYSD bars having a tensile strength of 500 N/mm^2 were also employed as reinforcement, was used according to IS: 1786-2008 standards. The flexural reinforcements were intended to withstand the overall loads and prevent flexural failure. Figure 1 shows the geometrical features of the beams.

2.2. Strengthening Scheme. Scheme "A" represents no strengthening. Under wrapping, two different wrapping schemes (a) full wrapping (b) strip wrapping with SFRP and JFRP were performed in the experimental program. Strengthening scheme- B1 is one layer jute fibre full wrapping with U shape, strengthening scheme- C1 is one layer jute strip wrapping with U shape and strengthening schemes- B2 and C2 are same of schemes B1 and C1, respectively, but with sisal fibre with U shape. Fibre laminate thickness is 3.62 mm approximately. The strengthening details are shown in Figures 2–4.

The experimental work of all these beams was conducted at the Structural Laboratory of the Department of Civil Engineering, Bangalore Institute of Technology, Bengaluru, details are shown in Figures 5 and 6. ASTM C 293 (center-point loading) was followed and the loading applied was at a rate of 5 kN/min

3. Numerical Analysis

Using the FE program ANSYS 18.1, 3D FE models of beams were analyzed. The fracture and failure analysis of all the FRP strengthened PSC beams of different wrappings were compared with controlled beams. Beams were modeled as similar to existing ones that were tested (as shown in Figure 1). To describe the behavior of concrete, steel reinforcement, and epoxy resin JFRP and SFRP laminates, suitable material models were used in the study. Concrete, reinforcement, jute/sisal FRP, and loading/boundary conditions are all factors to include in a standard FE model. Each of these components must be accurately represented in order to reflect the distinct qualities that each of them has. Modeling of concrete is done using a 3D brick, also known as

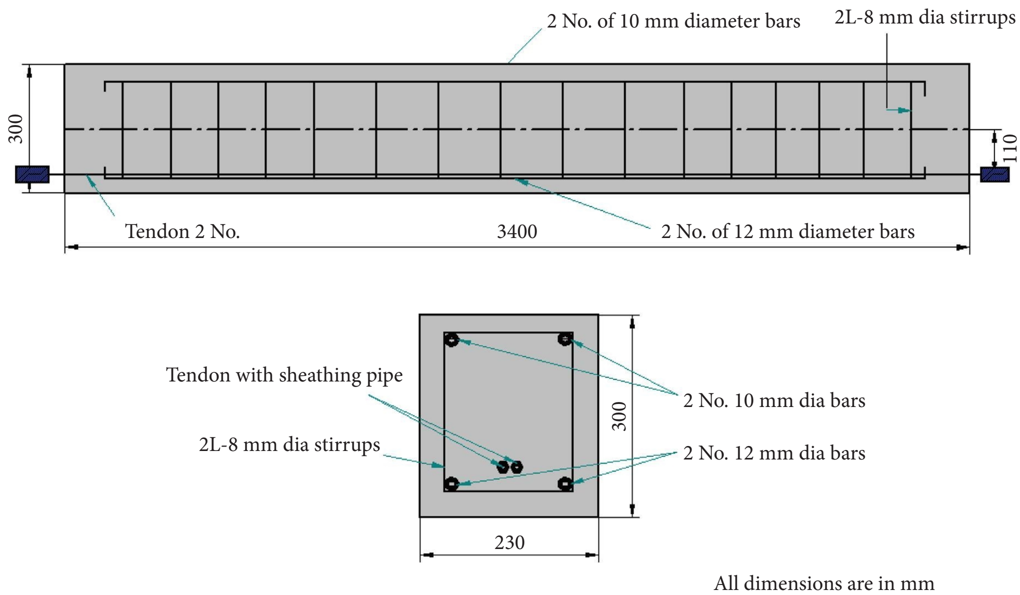


Figure 1: Geometrical details of beams.

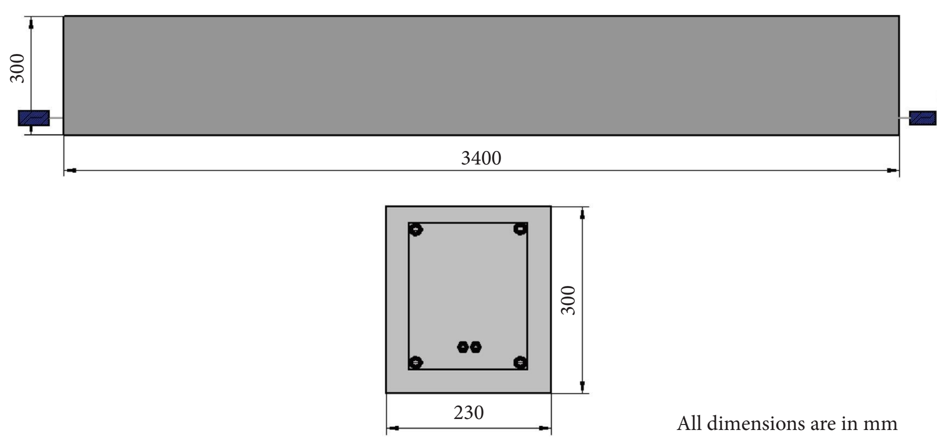


Figure 2: Control beams—no strengthening.

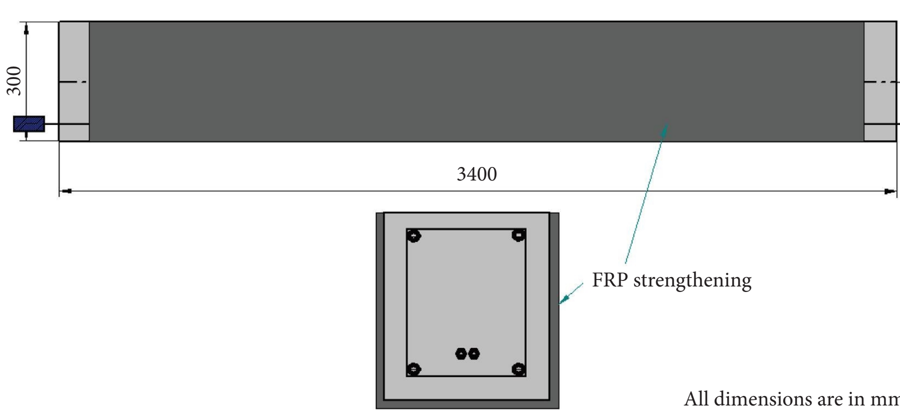


Figure 3: Strengthening scheme-1 full wrapping.

a solid element-designated as SOLID65 in ANSYS. This solid cubic element is having eight nodes, each having three DOF and translations in x, y, and z directions. This element type uses the mathematical material model of William and Warnk [25] and can represent cracking, crushing, plastic deformation, and creep [26]. In addition, the element may

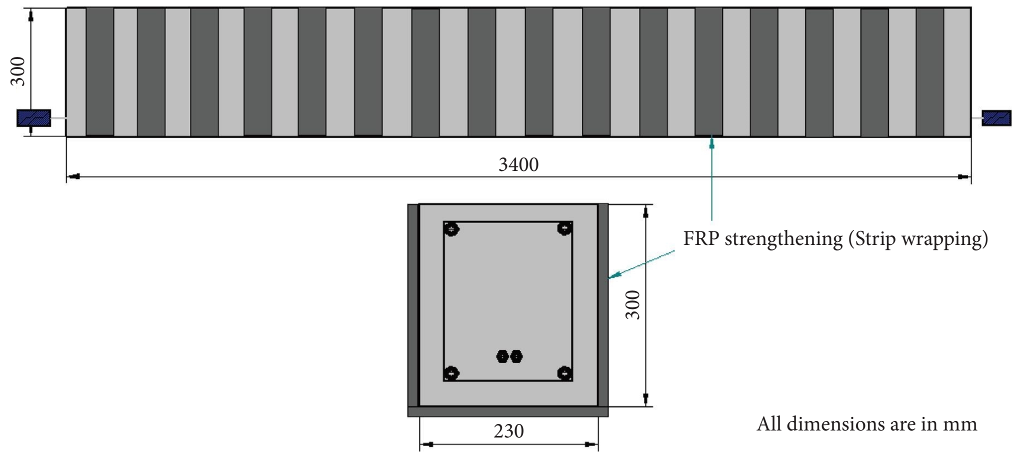
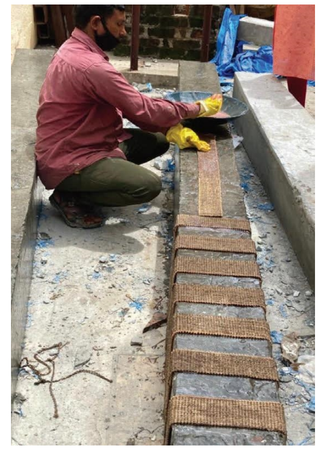


Figure 4: Strengthening scheme-2 strip wrapping.

(a) (b) (c) (d) (e) (f) (g) (h)

Figure 5: Continued.

(i)



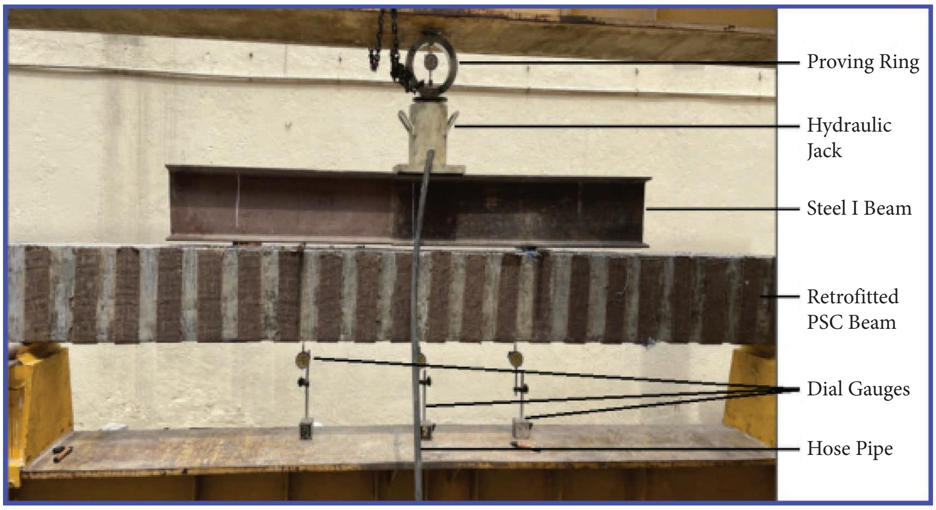
(j)

Figure 5: Experimental procedure followed (a) reinforcement, (b) sheathing pipe positioning, (c) reinforcement for installation, (d) positioned in shuttering, (e) concrete filling and compaction, (f) curing, (g) post tensioning, (h) filler application, (i) resin preparation, and (j) retrofitting with FRP.

(a)

(b)

Figure 6: Continued.



(c)

FIGURE 6: Laboratory setup (courtesy: Structural Laboratory, Department of Civil Engineering, Bangalore Institute of Technology, Bengaluru, India) (a) control beam, (b) full wrapping configuration, and (c) strip wrapping configuration.

simulate plastic deformation, cracking in three orthogonal dimensions, and crushing in three orthogonal directions. Steel reinforcement is represented in ANSYS using the spar/link element, which is designated as LINK8. Two nodes with three degrees of freedom translations in the x, y, and z axes make up this uniaxial bar-like element. Plasticity, creep, swelling, stress stiffening, and significant deflection are all examples of nonlinear phenomena that such reinforcing materials might simulate. A single layer Solid 45 element was utilized to signify FRP composites in the retrofitted beam and have been correlated to the FE model as shown in Figure 6. In general, solid brick elements (represented as SOLID45 or SOLID185 in ANSYS) may be utilized for 3D modeling of FRP sheets, bonding agents, and loading/end supports. A number of load increments (or) load steps were used to split the total load applied. Within tolerance limitations, at the end of each load increase, Newton–Raphson equilibrium iterations provide convergence. The solid 45 element nodes were linked to solid 65 element nodes at the interface to imitate flawless bonding of FRP sheets with concrete, as a result, inter connectivity was established.

3.1. Finite Element Model. The strengthening details shown in Figures 2–4, the meshed control and PSC beam models with the coupled FRP, are shown in Figure 7, as done in the ANSYS software platform.

3.2. Input Data, Loading, and Boundary Conditions. The material input data was derived from trial results of experiments, values supplied by the FRP laminate manufacturer, and data from the literature. Concrete compressive strength = 40 MPa, concrete elastic modulus = 31622.8 N/mm^2, and Poisson's ratio = 0.2 were used as material parameters for the concrete model. The yield strength of the reinforcing steel is 500 MPa, and the Poisson's ratio is 0.3, according to the material characteristics. The mean elastic modulus and tensile strength of sisal fibres were about 19 GPa and 400 MPa, respectively, with a Poisson's ratio of 0.3 [27]. Young's modulus and tensile strength of jute fibres were about 20 GPa and 393 MPa, respectively, with a Poisson's ratio of 0.38 [28]. Simply supported, cantilever, or continuous conditions may be used to group the beams. As a result, to effectively describe the actual setup, the produced FE model must include realistic boundary conditions. Beam was modeled in symmetry. This may be accomplished by restraining the beam with rollers along the symmetry axis. The load combinations and supports were specified to be spread across an area relating to the metal plates and rollers employed in the testing, minimizing excessive stress concentrations. Surface pressures at the upper surface of the beams were used to determine the load combinations. Restraints were imposed to all nodes positioned anywhere along axis of the support rollers in order to accurately recreate the displacements and rotations for the supports, i.e., UY and UZ degree of freedom restrictions were imposed to all nodes orientated on the axis of the support rollers.

4. Results and Discussion

The FE and experimental data must be compared to determine the validity and predictability of the FE model. Throughout the loading application, the mid span deflection predicted from the FE analysis and observed in experimentation is compared to see whether predictions match experiment observations. The predicted and experimental outcomes are in close match. Loads were applied progressively with minimal load increases in concrete cracking, steel yielding, and the final phase in which a significant number of cracks occur. All beams are subjected to nonlinear static analysis. Figures 8(a)–8(d) depict the failure crack formation and load deflection details for the controlled

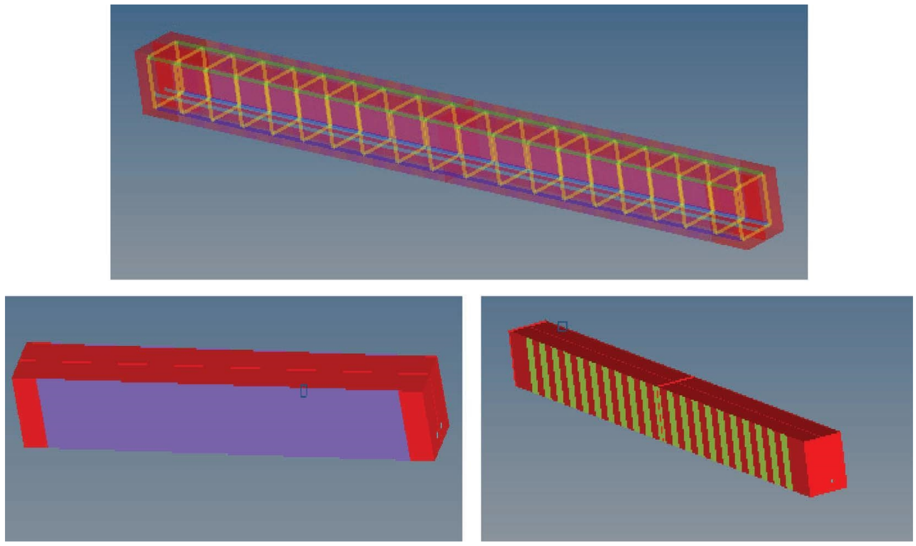


Figure 7: Meshed model of control and PTC beams with the coupled FRP.

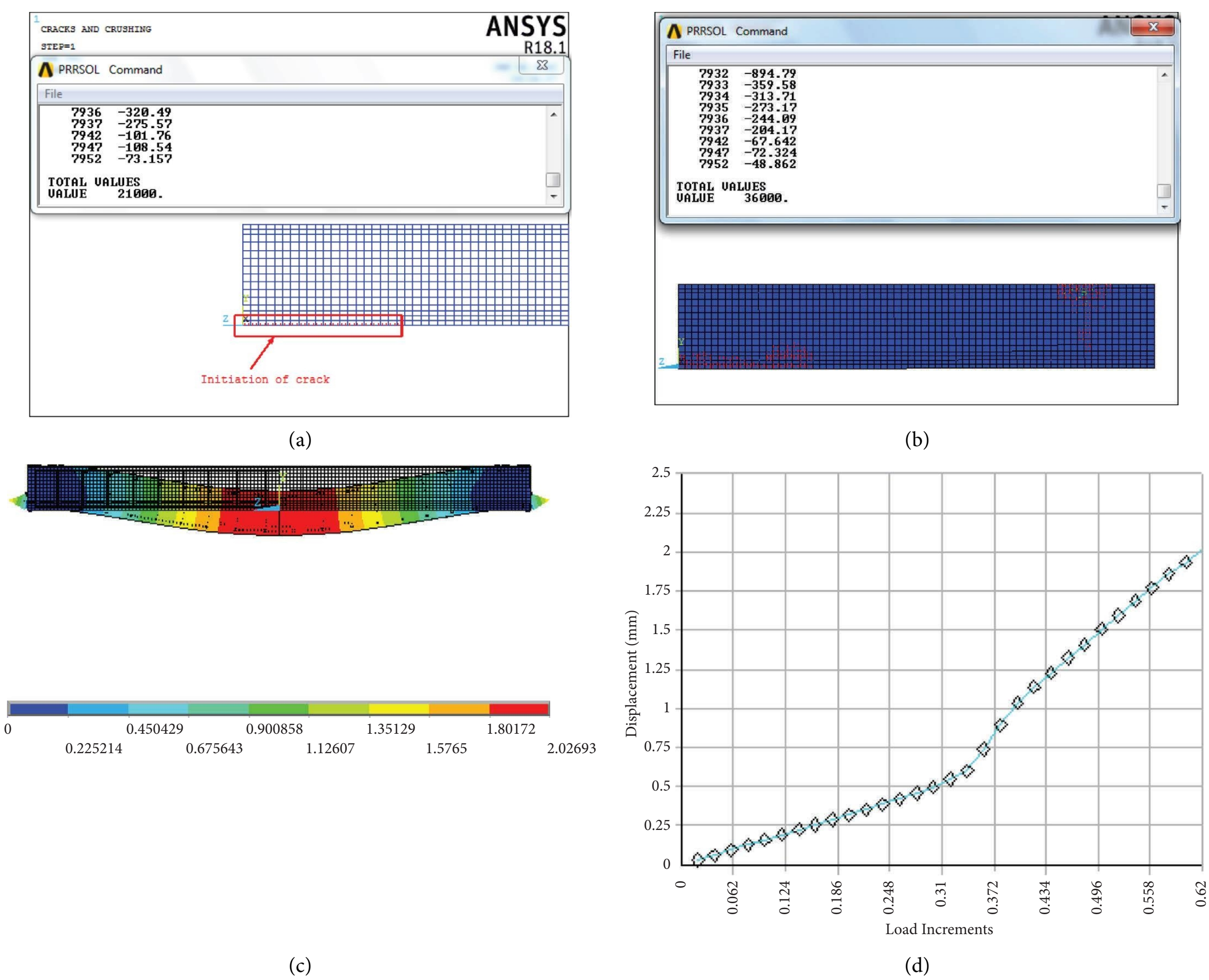


Figure 8: Predicted results from ANSYS for control beams. (a) Initial cracking behaviour, (b) intermediate cracking behaviour, (c) deflection contour of CB (FE), and (d) load deflection curve.

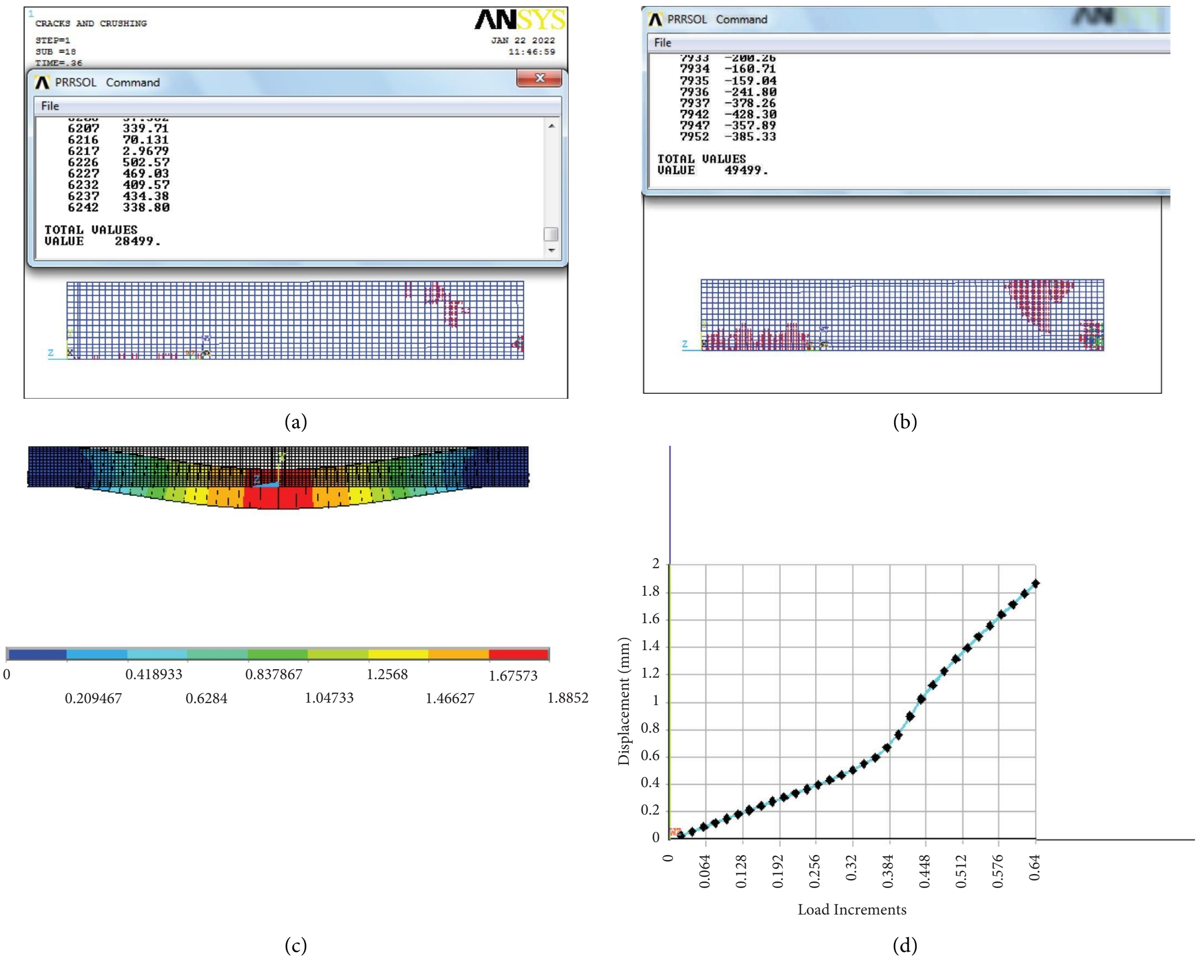


Figure 9: Predicted results from ANSYS for SFRP reinforced beams (strip wrapping). (a) Initial cracking behaviour, (b) intermediate cracking behaviour, (c) deflection contour, and (d) load deflection curve.

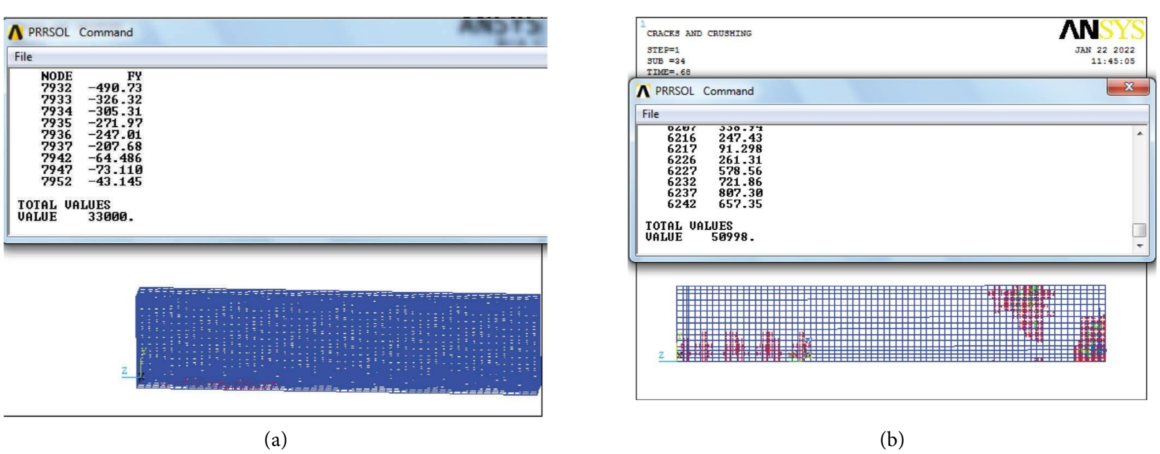
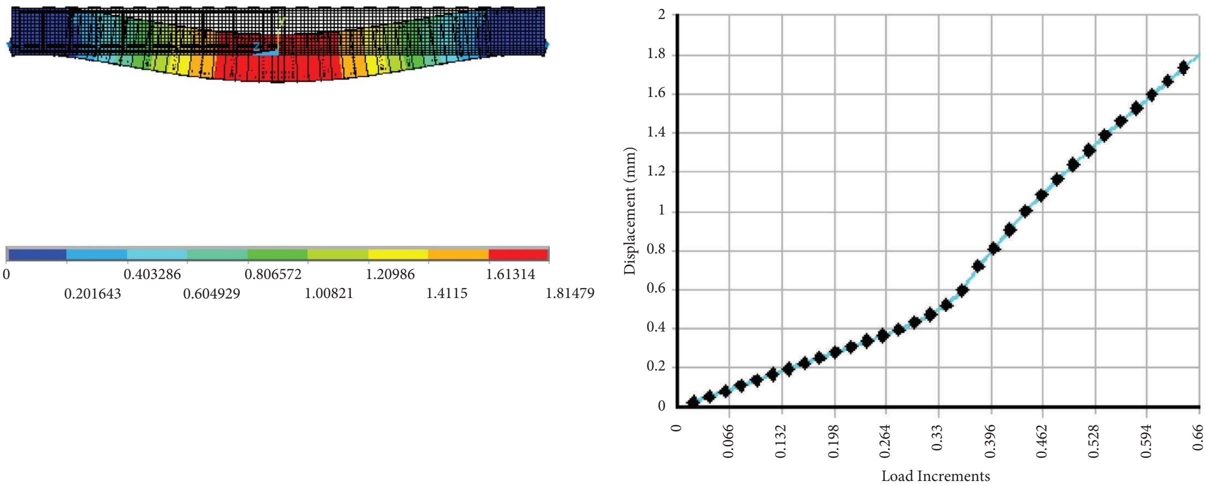
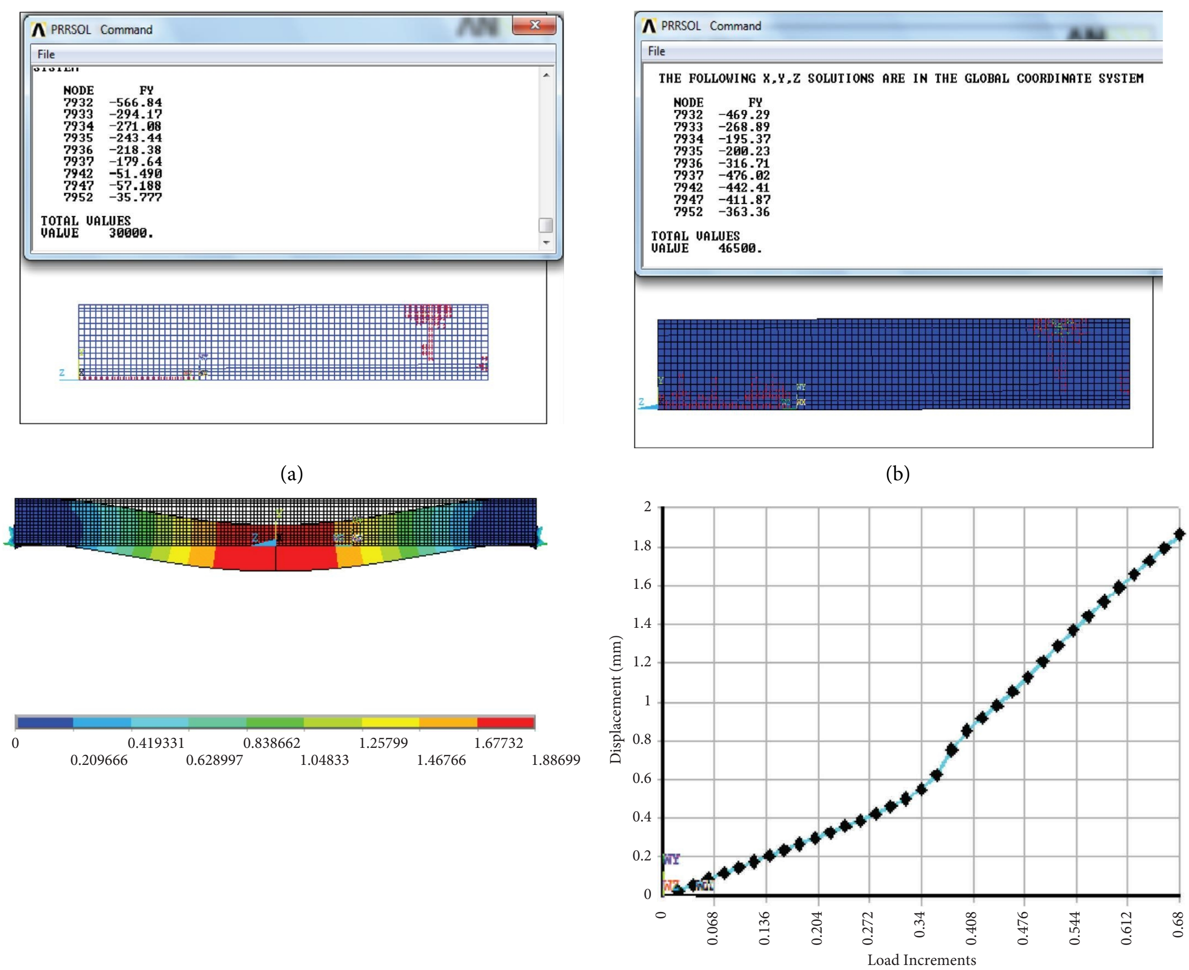


Figure 10: Continued.



(c) (d)

Figure 10: Predicted results from ANSYS for SFRP reinforced beams (full wrapping). (a) Initial cracking behaviour, (b) intermediate cracking behaviour, (c) deflection contour, and (d) load deflection curve.



(c) (d)

Figure 11: Predicted results from ANSYS for JFRP reinforced beams (strip wrapping). (a) Initial cracking behaviour, (b) intermediate cracking behaviour (c) deflection contour, and (d) load deflection curve.

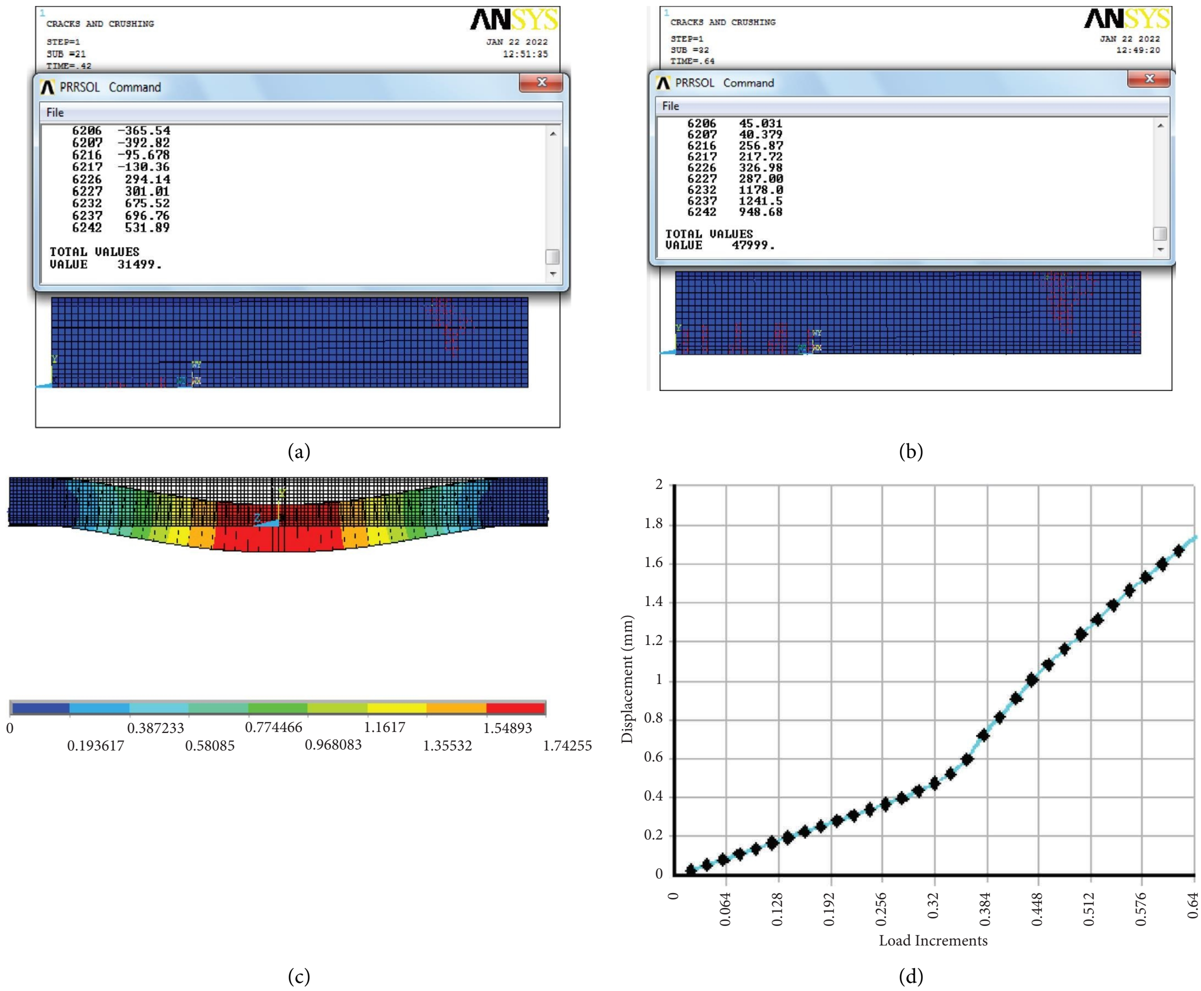


Figure 12: Predicted results from ANSYS for JFRP reinforced beams (full wrapping). (a) Initial cracking behaviour, (b) intermediate cracking behaviour, (c) deflection contour, and (d) load deflection curve.

Table 1: Comparative analysis between experimental and analysis results.

Sl. no.	Details	$(P_u)_{Exp}$ (N)	$(P_u)_{FE}$ (N)	% error
(1)	*Control beam*			
	Initial crack load	97500	84000	16
	Final crack load	154000	144000	7
(2)	*Sisal strip wrapping*			
	Initial crack load	130000	113996	14
	Final crack load	208750	197996	5.5
(3)	*Sisal full wrapping*			
	Initial crack load	114000	132000	14
	Final crack load	220000	203992	8
(4)	*Jute strip wrapping*			
	Initial crack load	113000	120000	6
	Final crack load	165000	186000	11
(5)	*Jute full wrapping*			
	Initial crack load	125000	125996	1
	Final crack load	172500	191996	10

beam (without any FRP retrofitting), which reveals cracks in the flexure zone. The failure crack pattern for the sisal FRP (strip wrapped), Figures 9(a)–9(d) sisal FRP (strip wrapped) retrofitted PSC beam is clearly visible, with fracture spreading from the right support through the applied load and concrete disruption in the zone. The crack pattern

Figure 13: Crack propagation pattern of the experimental beams.

depicting the behavior of the sisal FRP retrofitting beam is quite close to the fracture pattern indicated by the experiments. Figures 10(a)–10(d) show the failure crack pattern for the sisal FRP (full wrapped) and jute FRP (full wrapped) retrofitted PSC beams. It shows the cracks as well as the concrete disruption in the flexure zone. The behavior of the controlled and retrofitted beams as illustrated by the crack outline is extremely close to the crack outline as demonstrated by the experiments in [29]. The failure crack pattern for the jute FRP (strip wrapped), Figures 11(a)–11(d) jute FRP (strip wrapped) retrofitted PSC beam, the crack pattern depicting the behavior of the jute FRP retrofitting beam is quite close to the fracture pattern indicated by the experiments. The failure crack pattern for the jute FRP (full wrapped), Figures 12(a)–12(d) jute FRP (full wrapped) retrofitted PSC beam, the crack pattern depicting the behavior of the jute FRP retrofitting beam is quite close to the fracture pattern. In terms of the quality point of view, the predicted results provided by the damaged model match the observed behavior extremely well. Table 1 represents the comparative structure of experimental and analysis results obtained from ANSYS. Figure 13 demonstrates the crack propagation in the beams during experimentation.

5. Conclusion

In the study, 18 specimens were fabricated, strengthened using SFRP and JFRP with different wrapping configuration, and successfully tested under a 4-point bending test. In general, the results indicate that all externally strengthening beams have significantly improved the load-carrying capacity and performance in comparison with control beams. To simulate the response in flexure of control and strengthened PTC beams using SFRPs and JFRPs, a 3D nonlinear FE model was developed. The suggested model was tested against the experimental data; the following conclusions may be taken based on the findings of the current study:

(1) When compared to control specimens, the load bearing capability of PTC beam models may be improved by retrofitting sisal and jute fibres

(2) Overall, the computational and experimental findings were in excellent agreement when comparing ultimate load bearing capacity and mid-span deflection at failure

(3) As compared to the control specimen, the load bearing capability of the beam modified with sisal fibre using strip and complete wrapping processes around in all four sides is increased by 35.55 percent and 42.85 percent, respectively

(4) In comparison to the control specimen, the load bearing capability of the beam retrofitted with jute fibre using strip and complete wrapping processes around all four sides is increased by 7.14 percent and 12.01 percent, respectively.

The study may be further extended for measuring efficacy of strengthening of beam (under both flexural and shear) can be measured by using other available bio composites in various degrees of wrapping configurations (60° and 45°).

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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