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STUDYING THE EFFECT OF WRAPPING THE STEEL BARS USING CARBON FIBER STRIPS ON THE BEHAVIOR OF REINFORCED CONCRETE BEAMS SUBJECT TO CYCLIC LOADING

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The behavior of reinforced concrete beams subjected to cyclic loading was studied in this research to determine the impact of wrapping main reinforcing bars in carbon fibre (CFRB) strips. The objective of the present work included studying the impact of length and the number of layers of CFRB strips, that are used in wrapping main bars, on the overall response of reinforced concrete beams subjected to a cyclic load. Wrapping the reinforcing bars by Carbon fibre is a helpful substitute when there is no enough space to increase the quantity and size of these bars. For this purpose, five reinforced concrete beams were prepared and tested. One of these beams was a reference beam with unwrapped main reinforcement. Two beams have main steel bars wrapped along the mid third of the span with either single or two layers of CFRB. The main reinforcement for the remaining two beams was wrapped along their entire length with either single or double layers of CFRB. A nonlinear finite element analysis of the tested beams was carried out and the predicted results are compared with the experimental outcomes. The results show that CFRB significantly and effectively contributes to increasing the flexural strength and overall behavior of the reinforced concrete beam at different rates depending on the length and number of CFRB layers that wrapped the steel bars.

Keywords: carbon fibre, cyclic load, layers, mode of failure, reinforced concrete, wrapping

1 INTRODUCTION

Finding a means to raise the load capacity of structural members is always necessary because the safety of any structure is always correlated with the safety of its constituent parts. This increase is not based on increasing bearing only but also on improving its behavior such as ductility and durability [1,2]. The purpose of using CFRB is to increase strength and ductility, and it is suitable for use in the rehabilitation of damaged components [3,4]. The use of CFRB in the field of strengthening and rehabilitating damaged reinforced concrete (RC) members was the focus of many researches. Experimental research was conducted by Godat et al. [5] to determine the efficacy of external strengthening utilizing U-shaped CFRP to increase the shear capacity of seven RC beams. It was concluded that using CFRB sheets caused a larger effective load capacity. In order to investigate the cracking behavior of an RC beam strengthened with external carbon fiber sheets under static load, Lu and Gu [6] employed a finite element analysis. The results showed that the inclusion of carbon fiber increases the resistance of the beam. Using the same reinforcement ratio, the carbon fiber reinforced concrete beam exhibited good cracking and deformation behavior. Manju et al. [7] used ANSYS Software [8] to investigate the effect of wrapping the steel reinforcement by CFRB in improving the resistance of the RC beams. The results were compared with the experimental one. According to the findings, beams having steel bars wrapped with CFRB had a higher failure load than that with unwrapped steel bars. PAN et al. [9] investigated the effectiveness of using CFRB and polymer cement mortar for the enhancement of the flexural capacity of five RC beams. It was concluded that using CFRB caused an increase in the failure load. Increasing ratio of strengthening material led to the peeling mode of failure. Despite the findings of the study about the significance of employing CFRB in the outer strengthening of RC beams, the literature that is currently accessible indicates that there is a dearth of studies that are explicitly devoted to examining the effects of wrapping reinforcing bars in CFRB on the behavior of RC beams. The present work is focused on the effect of wrapping the main steel bars by using either single or double layers of CFRB on the behavior of RC beams under cyclic loading. The present study may serve as a roadmap for the next research and investigations. The concept of wrapping the main steel bars by CFRB was founded on the following principles:

- The impact of the number of CFRB layers and the location of wrapped steel bars on the strength of RC beams.
- The possibility for combining CFRB with the primary steel bars to improve the behavior and performance of those beams when there is a limited space for steel bars.

1.1 Aim of the research

1. Investigating the effect of wrapping steel bars by CFRB sheets on the behavior of RC beams under the effects of cyclic loading using either one or two layers of CFRB.
2. Comparing the RC beams with wrapped steel bars along its entire length with that in which the wrapping is limited in the mid-third of the beam span i.e., maximum pure moment zone. Both are compared with the reference beam.

3. Present the results of nonlinear finite element analysis of the tested RC beams and contrast the analytical results with the experimental results.

1.2 Materials

1.2.1 Cement:

Iraqi cement produced locally in the Badush Cement Factory (extension) in the Nineveh Governorate was used. It complies with the Iraqi Standard IQS No. 5, 1984 [10].

1.2.2 Water:

Tap water was used for mixing and curing the concrete.

1.2.3 Fine aggregate (sand):

A river sand was used which complies with the British Standard (B.S 882:1992) [11]. It is classified as medium-fine sand with a fineness modulus (2.8).

1.2.4 Coarse aggregate (Gravel):

A rounded shape of river gravel was used. The maximum aggregate size was (16mm) and it complies with the British Standards (BS 882:1992) [11].

1.2.5 Carbon Fiber:

The Sika Wrap Hex-230C type of CFRB was utilized [12]. The physical properties may be stated as fiber density equal to (1.78gm/cm3), fiber thickness (0.12mm), tensile strength (4100MPa), tensile elastic modulus (231000MPa), and strain at break of fiber equal to (1.7%). CFRB sheets are glued to the reinforcing bars using epoxy resin [12,13].

1.2.6 Concrete Mixture:

Trial mixes are made to determine the required concrete compressive strength (fc'=36MPa) based on American Specification (ASTM C39-04) [14]. The proper mix proportion (cement: sand: gravel: w/c) was (1:1.68:2.1:0.47).

1.2.7 Steel Reinforcement:

Steel bars with a diameter of (10mm) are used for the stirrups and the main reinforcement of the beams. The yield and ultimate strength of the used bars are (640MPa) and (740MPa) respectively.

2 DETAILS OF THE SPECIMENS

Each of the five concrete beams has dimensions of (1000x150x150mm). One of them was made as a reference beam and had reinforcing bars without wrapping in CFRB as shown in Figure (1). The main reinforcing bars of two beams are wrapped at the zone of the maximum pure moment with a length of (300mm), as depicted in Figure (2), the steel bars in one of these two beams are wrapped in a single layer of CFRB sheet, while the bars in the other beam are covered with two layers of CFRB sheets. The reinforcing bars in the remaining two beams are wrapped in either one or two layers of CFRB with a length of (900mm) as illustrated in Fig. (3).

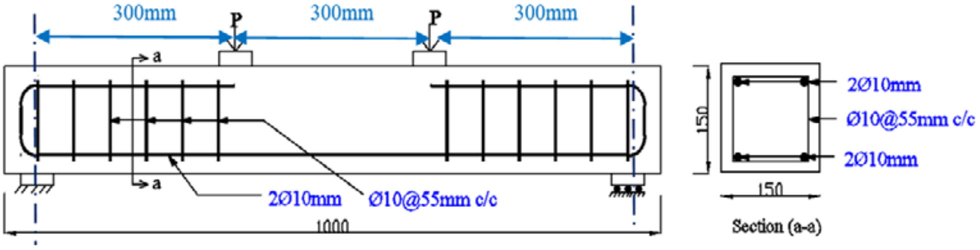


Fig. 1. Dimensions and details of the tested reference beams

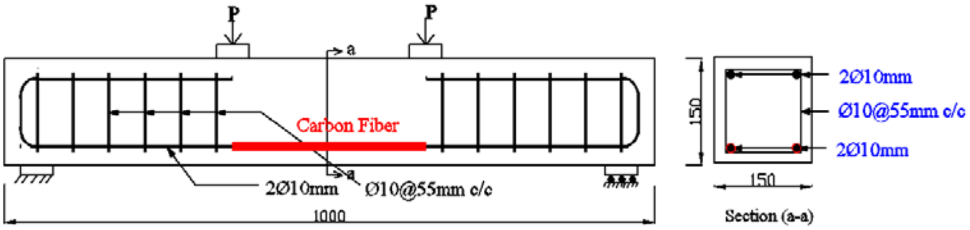


Fig. 2. Dimensions and details of the tested beams having reinforcing bars wrapped by CFRB in the maximum moment zone at a length of(300mm)

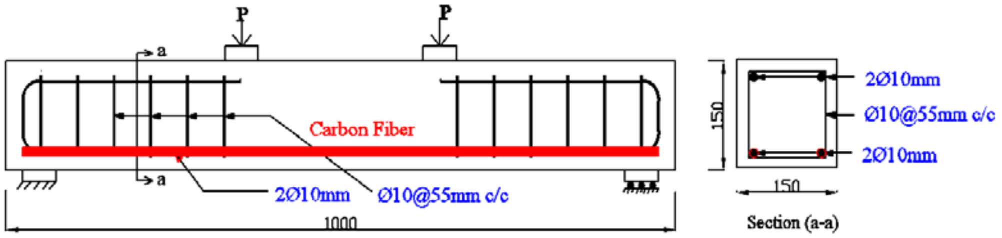


Fig. 3**.** dimensions and details of the tested beams having reinforcing bars wrapped by CFRB at a length of (900mm)

3 PROCEDURE OF TESTING

The tests are carried out in the Materials Testing Laboratory at the University of Mosul, the beams were put to the test in a four-point load bending test utilizing a universal testing device with a capacity of (500KN). The test setup depicted in Figure (4), included the following measurements.

1. The load capacity of the concrete beams under cyclic loading. The load in each successive cycle of loading was increased by an amount equal to (6.5kN) with a rate of loading equal to (1.5kN/second).
2. The deflection under the loading points and at the midspan of the beam using an electronic transducer each having an accuracy of (0.01mm).

Fig. 4. Test and loading setup

4 NUMERICAL ANALYSIS

In the present study, a nonlinear finite element analysis was conducted for the tested beams, using Midas FEA NX software [15]. The main objectives of this analysis are to demonstrate the variation of axial stresses in the ties and main steel bars as well as CFRB strips that cannot be observed experimentally and to predict the effect of wrapping the main steel bars with CFRB on the stresses of these bars from the initial stage of loading up to failure load. In this analysis, the concrete was modeled by 8 nodes brick elements having the size of (25×25×25mm), this element is capable of representing the nonlinear behavior of concrete that includes a nonlinear response in compression, cracking in tension, yielding, post cracking shear transfer and crushing in compression. The steel reinforcements, for both main bars and stirrups as well as CFRB strips are modeled by embedded truss elements in the concrete body. The embedment of steel bars and the CFRB in the concrete body insured a perfect bond between these three components. Concrete was given the same properties as the experimental one, with the compressive strength equal to (36MPa), initial elastic modulus equal to (28000MPa), and a Poisson's ratio of (0.17). The steel bars were assigned an initial elastic modulus equal to (200000MPa) and a yield stress of (640MPa), assuming an elastic perfectly plastic behavior. The same behavior was assumed for the CFRB with an initial elastic modulus equal to (231000MPa) and yield stress of (4100MPa). Two base plates are positioned at the same locations of the experimental setup, one at the support with a roller boundary condition assigned along its central nodes and the other one at the loading plate position, these plates are modeled by 8 node brick elements and assigned an elastic behavior with elastic modulus equal to (200000MPa) and Poisson's ratio of (0.3). Making use of the symmetries for geometry, loading, and boundary conditions, only half of the beam was considered in the analyses and the plane at the midspan of the beam was assigned freedom to move exclusively in the vertical direction only. Figure (5) displays the meshes for the concrete and base plates in the finite element model together with the boundary conditions and loading, whereas Figure (6) displays the mesh for the steel bars and CFRB elements. The five beams are analyzed under a monotonic load increased incrementally up to failure, using Newton Raphson's method to trace the nonlinear response of the beam and the bisection method to adjust the size of load increments. Failure was viewed to occur when convergence at a specific load increment was not met.

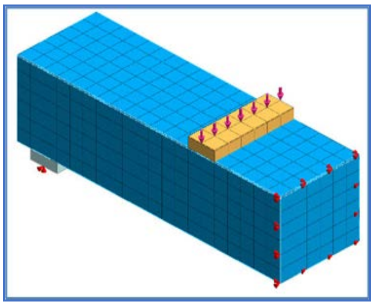


Fig. 5 Adopted finite element meshes for concrete and steel plates

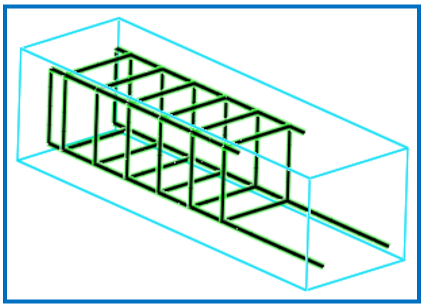


Fig. 6 Steel and CFRB attached to main bars

5 RESULTS AND DISCUSSION

5.1 The effect of wrapping the steel bars in CFRB strips on the failure load of beams

The experimental and predicted analytical load-deflection curves at the midspan of the tested beams are presented in Figure (7). By scrutinizing these curves, it is apparent that the beam flexural strength was enhanced when the main steel bares are wrapped in CFRB sheets. The greatest improvement was made by wrapping two layers of CFRB sheets over the full length of the main steel bars.

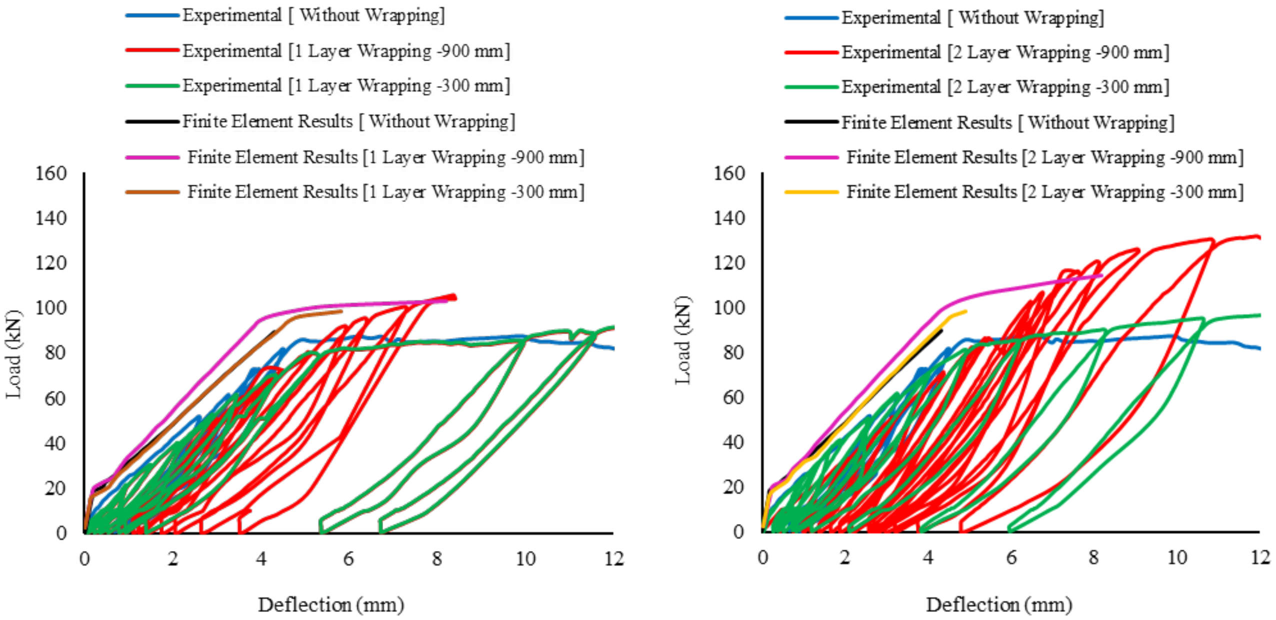


Fig. 7. Load-deflection curves at mid span for the tested beams

Table (1) shows that the percentage increase in the maximum load capacity of tested beams having wrapped reinforcement by CFRB with a length of (300mm) was (4.6%, and 10.7%) when one layer and two layers are used respectively compared to the reference beam. The Table also shows that wrapping the main steel bars along its entire length (900mm), caused an increase in the failure load compared to the reference beam by (21.3%, and 50.1%) when one and two layers are used respectively. The same table also shows a good matching, in terms of maximum load capacity, between experimental and analytical results. The analytical results of the beams shown in Figure (7) indicate a stiffer response compared to the experimental results. This flexible experimental response could be attributed to the flaws in the concrete brought on by microcracks, non-homogeneity of concrete, and slippage between steel bars and concrete. Another cause is the degradation in the stiffness of the concrete structure as a result of the cyclic stresses. The projected analytical results, however, fit the shape of the experimental load deflection envelope and fall within acceptable ranges in terms of failure load.

Table 1. Summary of the maximum loads and corresponding deflections

Beam Sample	Load (kN) Experimental	Load (kN) Analytical	Experimental deflection at midspan (mm)	Analytical deflection at midspan (mm)	% Increase in failure load
Reference Without Wrapping	87.40	89.6	9.78	3.96	---------

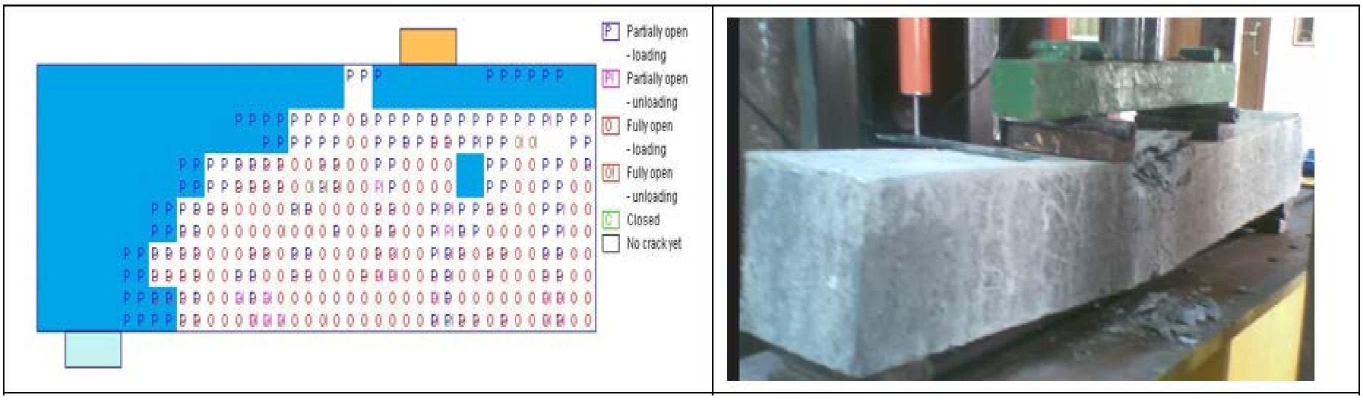
Beam Sample	Load (kN) Experimental	Load (kN) Analytical	Experimental deflection at midspan (mm)	Analytical deflection at midspan (mm)	% Increase in failure load
1 Layer Wrapping-300 mm	91.45	98.56	12	6	4.63
2 Layers Wrapping-300 mm	96.75	98.56	12	5	10.7
1 Layer Wrapping-900 mm	106.0	103	8.39	8.34	21.3
Layers Wrapping-900 mm	131.21	114.58	12	8.2	50.1

5.2 Mode of Failure

Figure (8) displays the mode of failure and crack patterns of the tested beams under cyclic loading accompanied with the predicted analytical crack patterns for the five beams at failure load. The figure shows that the tested reference beam collapsed through a flexural mechanism, whereas the beams with steel-bar wrapped in CFRB collapsed in shear, with the exception of the beam with its main steel bar wrapped in a single layer of CFRB along 900mm. The odd behavior of this beam is attributed to the local failure of concrete under the left loading plate causing a flexural failure at that section. The flexural failure started with flexural cracks in the zone of maximum moment accompanied by the crushing of concrete at the top face of the beam at the location of the extension of these flexural cracks. The shear failure for the two beams with two layers of wrapping started in the shear zone and extended to the loading plate at the top face of the beam. It can be inferred that by wrapping the primary bars in single or double layers of CFRB, particularly for beams with the full wrapping of its main steel bars, the beam's flexural strength was significantly boosted.

The variation of axial stresses with the load for the main bars and CFRB at midspan of the beams as well as maximum stresses in ties are presented in Figure (9). As depicted in this figure, the main bars for the reference beam attained yielding at a load of (82.13kN), whereas the beam with main bars wrapped in a single layer of CFRB reached yielding at a load equal to (85.12kN). For the beam with CFRB along its entire length there is a sudden increase in the stresses of both main bars and CFRB at a load of (20.8kN) at which the cracks are initiated, also the same can be noticed for the reference beam and beams with CFRB along its middle third of the span at the cracking load of (16.8kN). The same figure shows that the stresses in the CFRB started to develop progressively and quickly with a small increase in the applied load once the main bars, wrapped along their whole length (900mm), reached yielding stress.

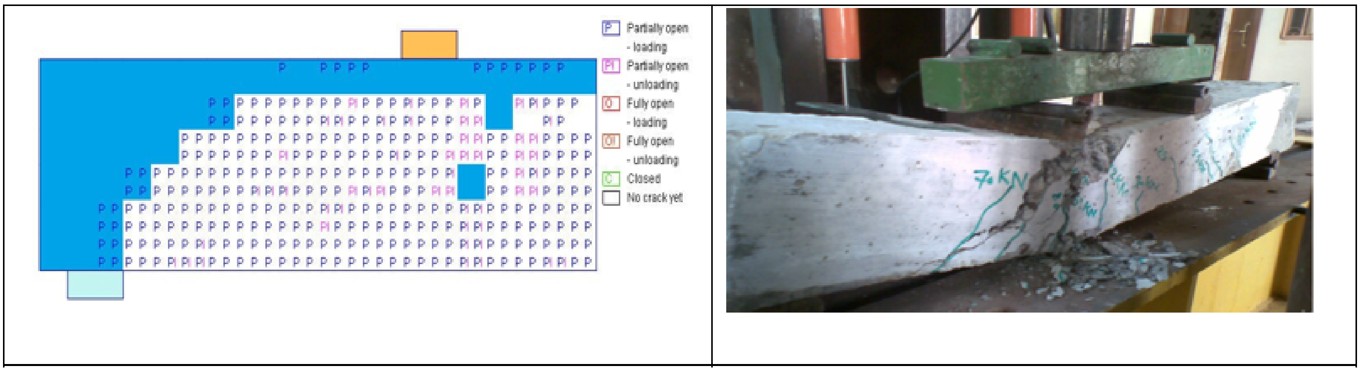
Figure (10) shows the steel stresses at a load step before the main bars reached yielding stress, as well as the stresses in CFRB. The figure demonstrated that the maximum stresses in the main steel bars are developed at the zone of the maximum moment, i.e., mid third of the beam span, whereas the highest axial stresses in the CFRB sheets occurred near the mid span of the beam where the maximum crack width is developed. When compared to that of the bottom main bars, the axial stress in the top bars and the maximum stresses in the ties at the shear zone has only marginal values range between (84 to 114MPa). The pattern of the third (3rd) principal stress distribution in the beam is what caused these marginal stresses in the ties. The contours of these third principal stresses are presented in Figure (11) for the five analyzed beams at two stages of loading. The first stage was at a constant load level of (11.2kN) prior to cracking which shows an identical contour for all the beams, while the second stage was at a load step prior to failure load. These contours show that for all the beams at both stages of loading, before cracking and at nearly failure load, the arching action between the supporting plate and loading plate is extremely evident. The low tensile stresses in the ties are mostly caused by this arching action. The low ratio of the shear span (300mm) to the beam depth (150mm), which is equal to (2), is the main cause for this arching action. Finding these stresses in reinforcing steel, CFRB, and concrete at various phases of loading is one advantage of utilizing the non-linear finite element analysis of reinforced concrete beams. This analytical method is typically employed since it is not practical to measure all these stresses in a lab setting.



Analytical cracking at failure

Experimental cracking at failure

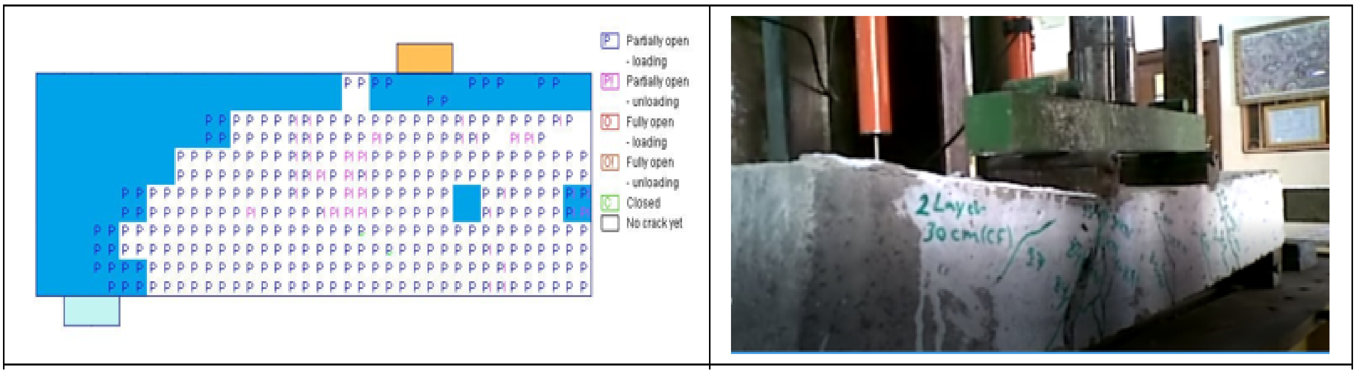
A. Reference Beam



Analytical cracking at failure

Experimental cracking at failure

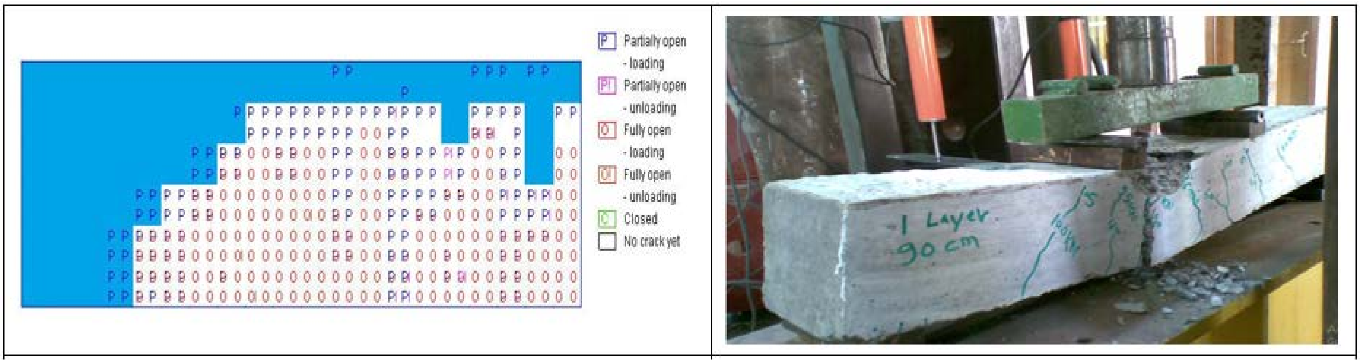
B. One Layer Wrapping -300mm



Analytical cracking at failure

Experimental cracking at failure

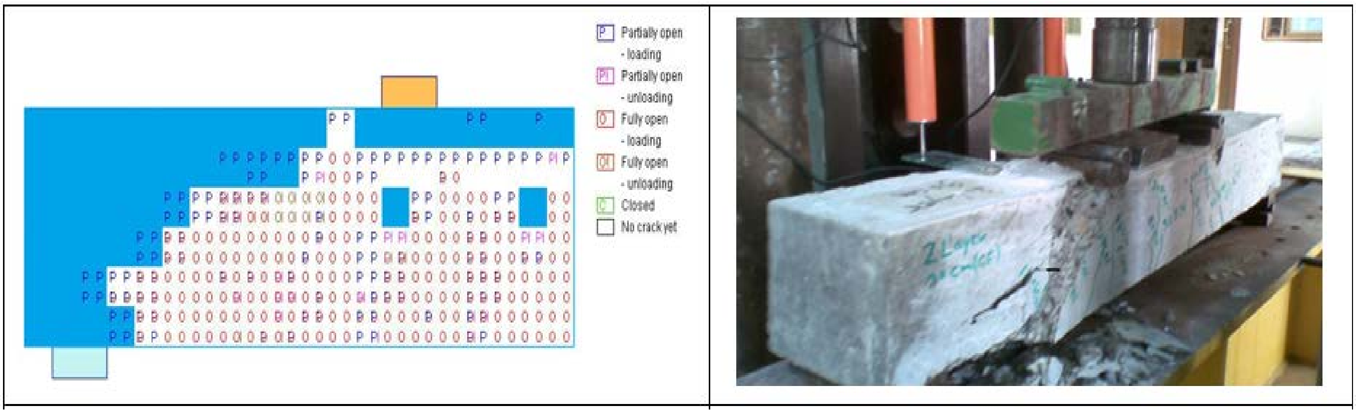
C. Two Layers Wrapping -300 mm



Analytical cracking at failure

Experimental cracking at failure

D. One Layer Wrapping -900 mm



Analytical cracking at failure
Experimental cracking at failure

E. Two Layers Wrapping -900 mm

Fig. 8. Mode of failure for the five beams

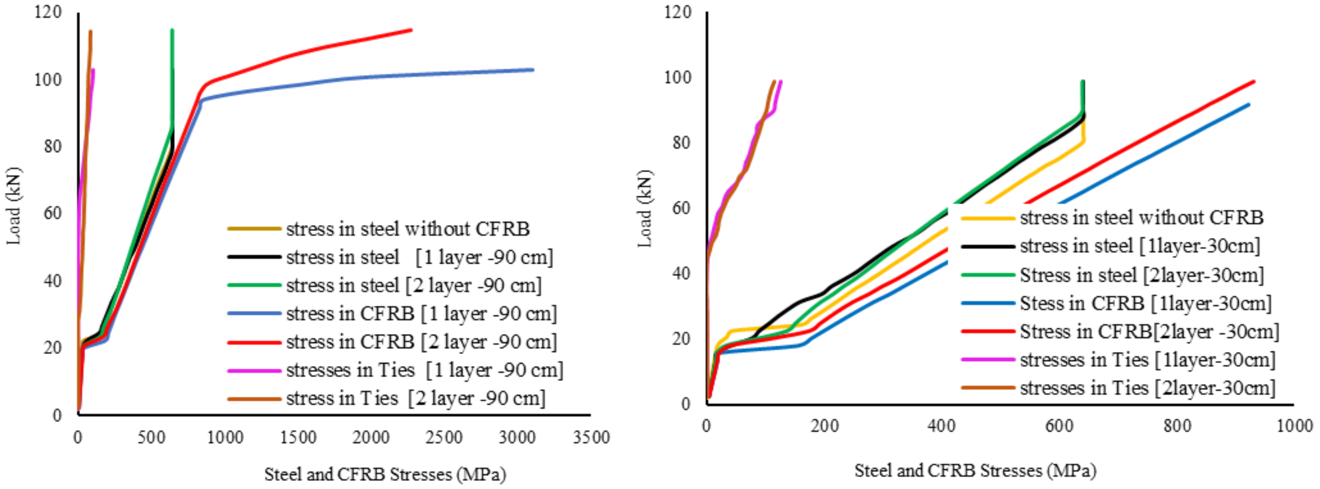
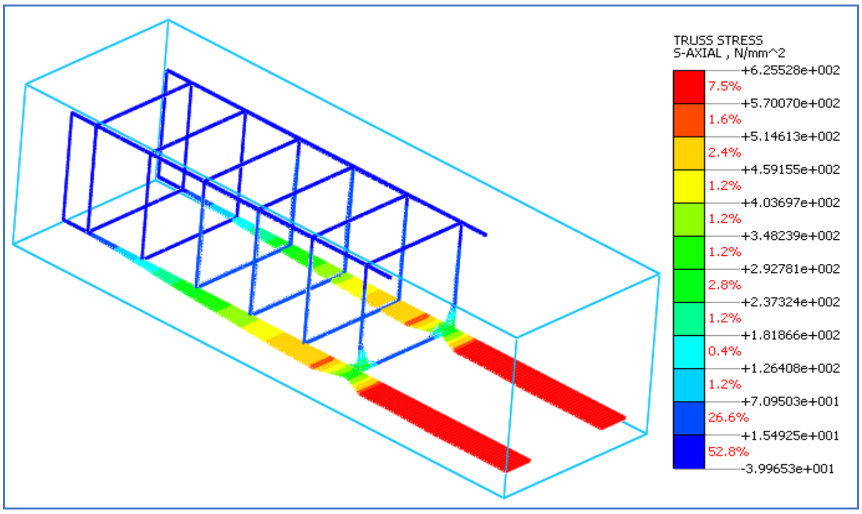
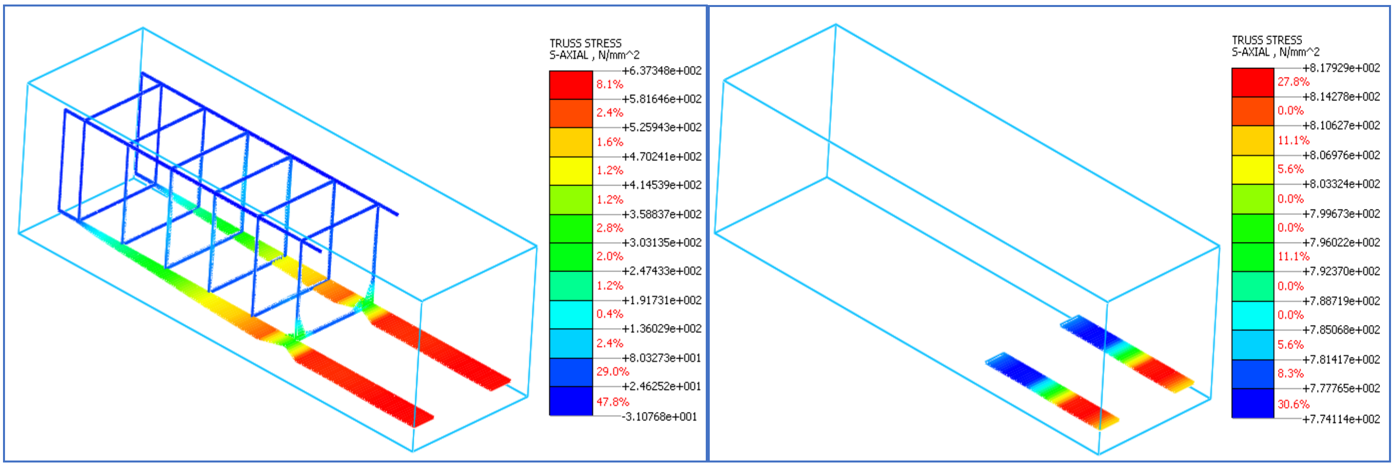


Fig. 9. Variation of stresses in main bars and CFRB at mid span and ties

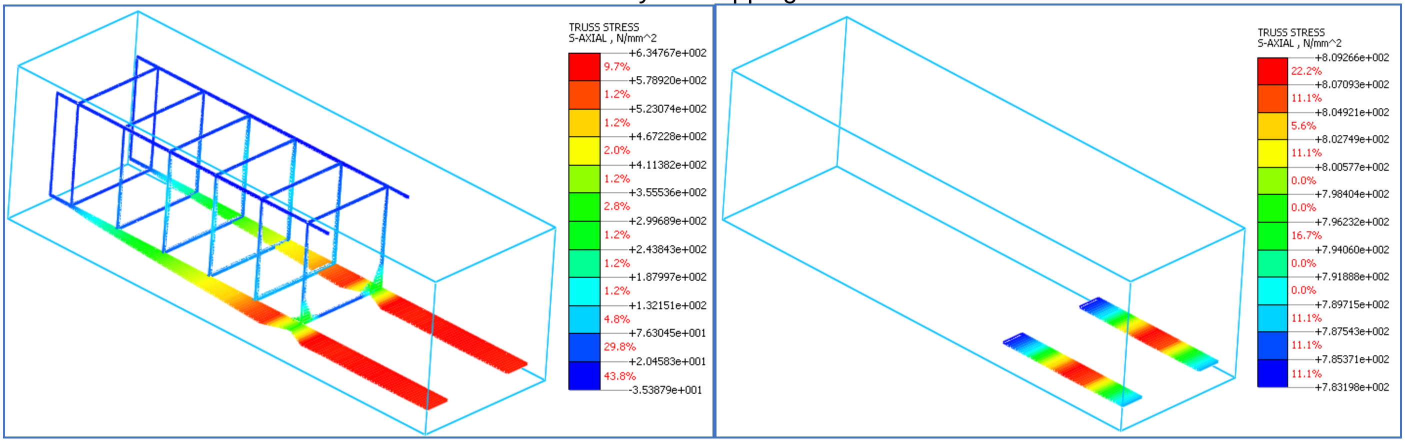


Without CFRB



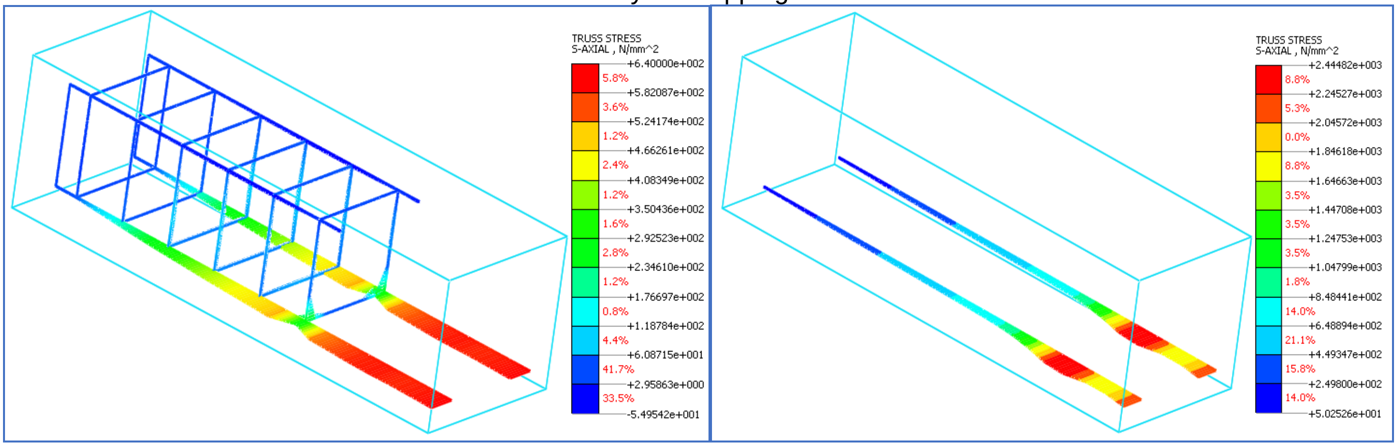
Stresses in reinforcing bars and ties Stresses in CFRB

One Layer Wrapping -300 mm



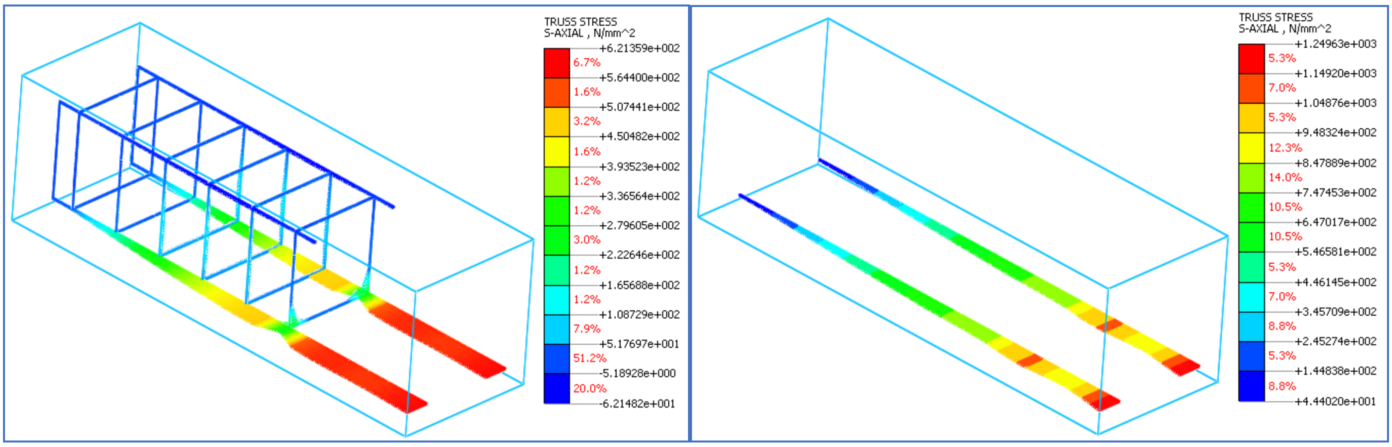
Stresses in reinforcing bars and ties Stresses in CFRB

two Layer Wrapping -300 mm



Stresses in reinforcing bars and ties Stresses in CFRB

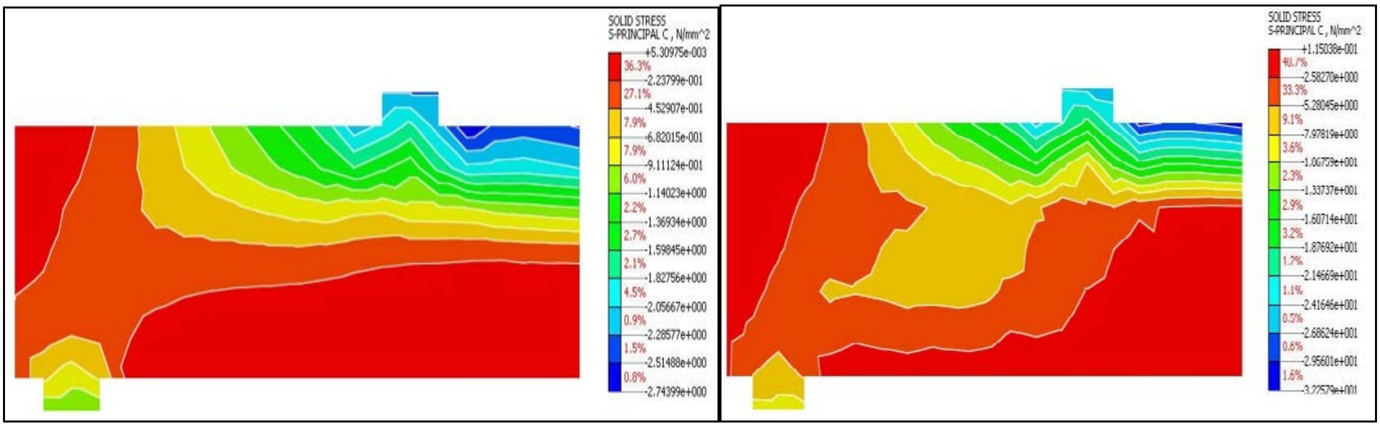
One Layer Wrapping -900 mm



Stresses in reinforcing bars and ties Stresses in CFRB

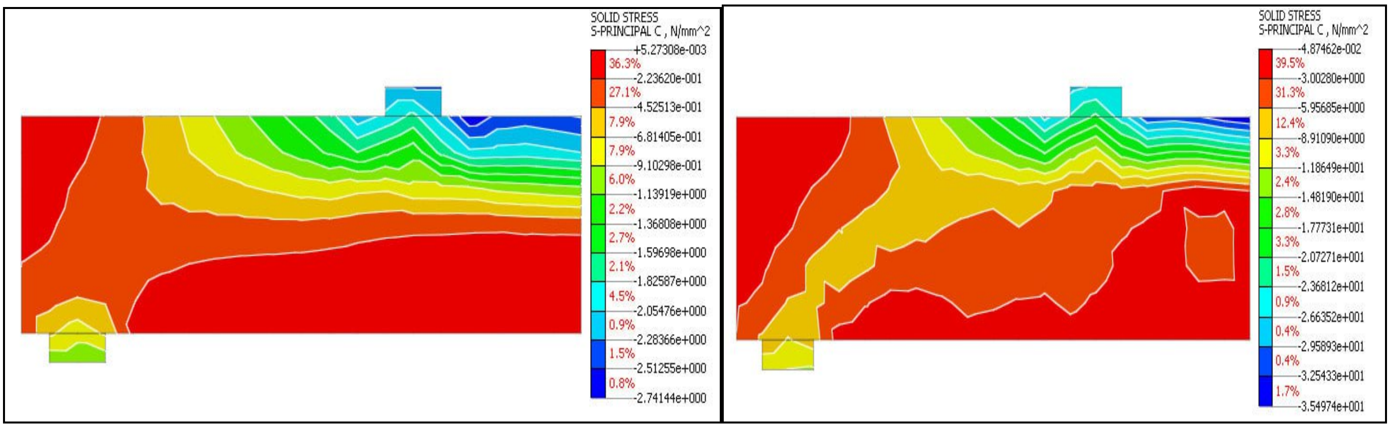
Two Layers Wrapping -900 mm

Fig. 10. Steel stress in reinforcing bars and CFRB



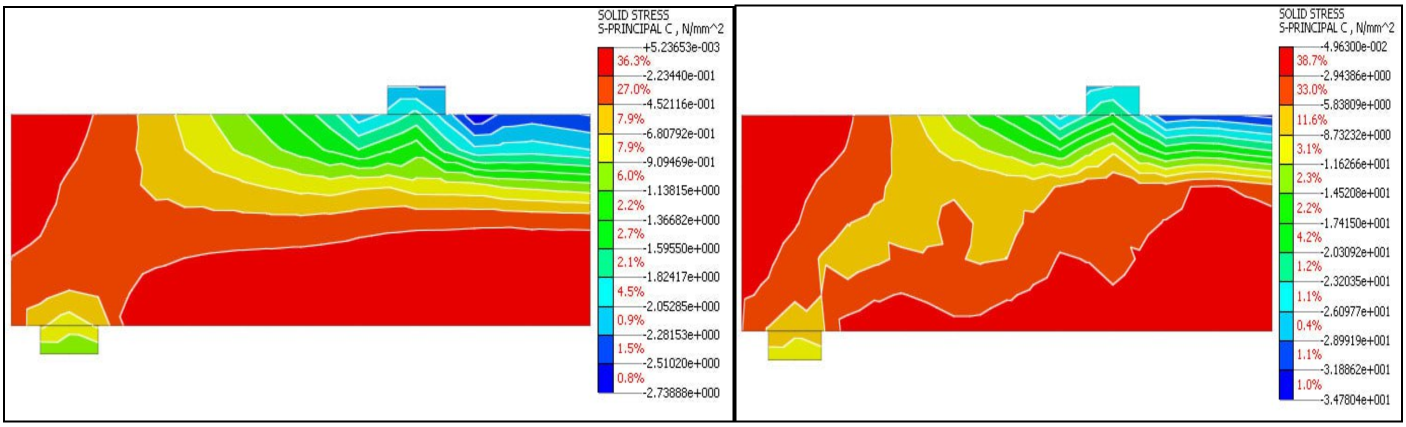
3rd principal stresses before cracking at 11.2kN 3rd principal stresses before failure load

A. Reference Beam



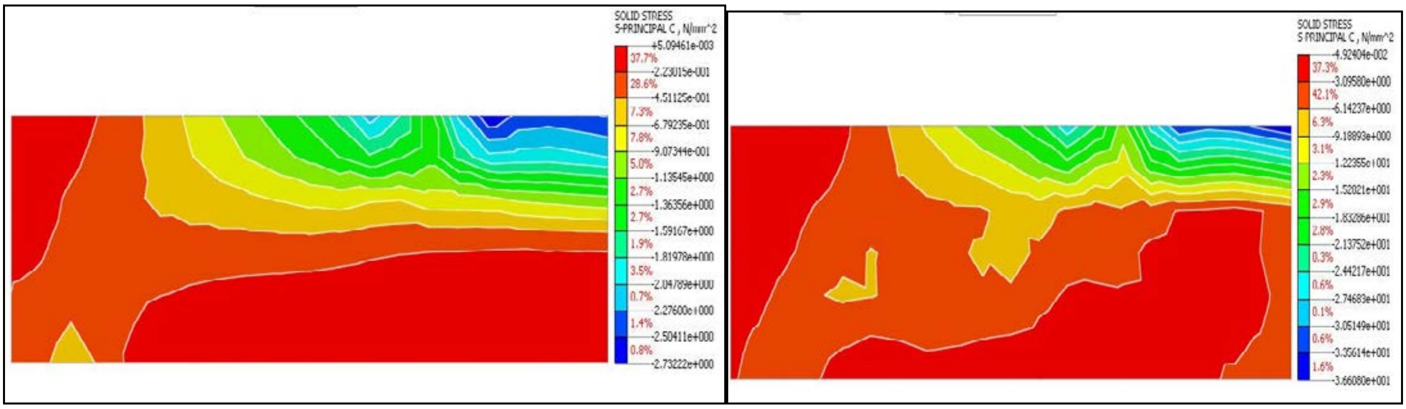
3rd principal stresses before cracking at 11.2kN 3rd principal stresses before failure load

B. One Layer Wrapping -300 mm



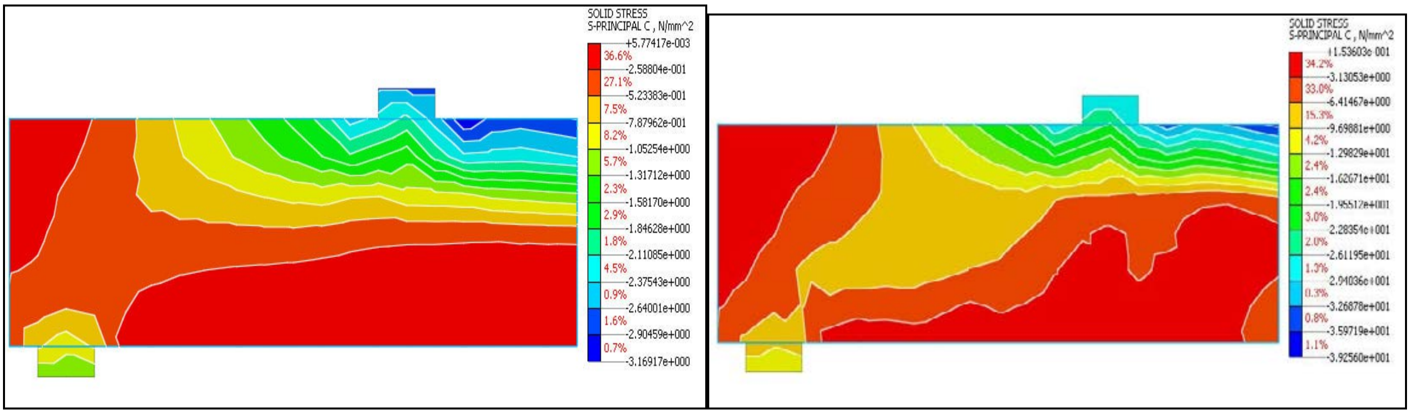
3rd principal stresses before cracking at 11.2kN 3rd principal stresses before failure load

C. Two Layers Wrapping -300 mm



3rd principal stresses before cracking at 11.2kN 3rd principal stresses before failure load

D. One Layer Wrapping -900 mm



3rd principal stress before cracking at load 13.2kN 3rd principal stresses before failure load

E. Two Layers Wrapping -900 mm

Fig. 11. Third principal stresses before cracking and before failure load for Beam

6 CONCLUSIONS

The current study reached the following conclusions after evaluating the experimental and analytical findings:

1. CFRB can effectively increase the failure load of RC beams. Wrapping main steel bars in CFRB strips causes an increase in the failure load of reinforced concrete beams at a rate ranging from (4.6%) to (50.1%) when compared to the reference beam. These percentages increase depend on the number of CFRB layers and the length of wrapping.
2. Wrapping the main steel bars of RC beams causes a significant change in the mode of failure of those beams. When two layers of CFRB are utilized to wrap the primary steel bars, whether along the middle third of the span or throughout its full length, the key changes in the mode of failure are from flexural failure to shear failure.

3. The second component that contributed to cause shear failure in most of the studied beams is arching action, which reduced the effectiveness of shear reinforcement.
4. The results of the nonlinear finite element analysis are in a good match to the outcomes of the tests, making it a technique with potential for additional study in the same field.

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