Numerical Simulations of Composite Materials

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Abstract: Throughout the last decade, the usage of fiber reinforced polymer (FRP) reinforcements in civil infrastructure has risen exponentially, owing to its superior corrosion protection, high durability, and non-magnetization characteristics. Furthermore, as a result of the poor modulus of elasticity of the FRP composites and its non-yielding properties, significant deflection and broad fractures are seen in the FRP reinforced concrete components under consideration. The emphasis of present study is on the behavior of FRP-reinforced concrete beams. The total of nine finite element-based simulations were carried out (ABAQUS). The concrete damage plasticity modelling was considered while performing the analysis. Three different kinds of FRP bars such as CFRP, BFRP, and GFRP, were utilized as reinforcement in longitudinal and transverse direction for concrete beams. Literature was used to validate the numerical findings, and the parametric research has been carried out for varying factors, such as the diameter size, number of bars, the kind of FRP bars used, and the longitudinal arrangement of FRP bars. When CFRP bars were utilized, the load capacity increased by anywhere from 8.88% to 62.92%. Beams that have been reinforced with CFRP carry more weight than beams reinforced with GFRP and BFRP. The increase in CFRP bars tends to give some ductility to the beam via the bi-linear load-to-ductility curve. In similarly, the GFRP reinforced beams improve the ductility of the structure as a whole.

Keywords: ABAQUS; Finite Element Analysis; FRPs; Load-deflection Curve; Ductility.

1. Introduction
During the course of their service life, reinforced concrete buildings are often subjected to modifications and improvements in their performance. In addition to modifications in their usage, new design requirements, corrosion of steel owing to exposure to a hostile environment, and natural disasters like earthquakes are among the most significant contributing causes. It is possible to enhance the performance of RC members throughout their service lives by strengthening, retrofitting, and repairing the member's components. Replacement of the structure may have some drawbacks, such as higher material and labor costs, a greater environmental effect, and annoyance as a result of the building's inability to operate properly. As a result, it prefers to restore or rehabilitate the member rather than replace him. The use of carbon fiber reinforced plastic (CFRP) to reinforce rebar beams is a popular form of strengthening in the area of structural engineering. Obaidat, [1]. Bodzak, [2] the utilization of CFRP as reinforcement in RC beams has emerged as a significant alternative technique that is more successful than other ways such as steel plate reinforcement. Obaidat and colleagues [3] found that CFRP has excellent mechanical characteristics, including strong corrosion resistance and a greater strength-to-density ratio, and the ability
to be installed more quickly and with lower maintenance costs El Gamal et al., [4]. According to (Barros et al., [5], El Gamal et al., [4] presented the RC beams are strengthening by CFRP using near-surface mounted (NSM) increased the load bearing strength of RC beams by up to 114 percent, approximately, the same conclusion has been adapted by (Attari et al., [6]; Khalifa, [7]) demonstrated that the strengthening of He discovered that the beams strengthened with NSM laminate were able to withstand a greater maximum load than the beams strengthened with EBR when the area of CFRP was the same. According to the findings of (Hong et al., [8]) and (El-Hacha and Rizkalla, [9]), the failure mechanism of RC beams reinforced by CFRP strips is often caused by CFRP strip rupture, which is followed with compression failure of concrete. Although 65–75% of strips do not fully fracture, the remaining 15% do. Several researchers (De Lorenzis et al., [10]) found that the impact of groove size on structural characteristics of carbon fiber reinforced plastic (CFRP) beams. It was discovered that increasing the groove size resulted in increased binding strength. From 5/8 in. to 3/4 in., the maximum load rose by 8 percent and by 24 percent, respectively, as the groove size grew. Hassan and Rizkalla [11] discovered that CFRP strips outperform CFRP rods in the strengthening of RC beams using NSM methods when the axial stiffness is the same because the strips have a greater bond strength and thus are more durable. According to the findings of an experimental research conducted by Hassan and Rizkalla [12] to reinforce RC beams using NSM, the minimum clear distance between the strip grooves must equal or exceed two and a half times the diameter of the bar. In addition, the nominal edge distance shall not be less than four times the diameter of the bar being used. (2011) shown that the CFRP composite may be utilized as an exterior reinforced and cathodic protection (CP) system for steel in concrete components, as demonstrated by Lee et al. (13). Zaki and Rasheed, [14] showed that the use of CFRP sheets in conjunction with both anchoring systems substantially improved the flexural capacity of the specimens compared to unanchored and U-wrap anchored samples. (2018) revealed that RC beam’s ultimate bearing capacity of with openings was unaffected by the opening in the pure flexural zone when the depth of the top chord was equivalent to or higher than the depth of the concrete stress block Almusallam et al., [15]. (2018) discovered that the orthotropic or isotropic characteristics of CFRP have no significant effect on beam responses such as stresses, displacements, and damage response when applied loadings are applied. Zhang and colleagues, [16] developed a finite element method (FEM) model to demonstrate the impact of localized fractures on the response of CFRP sheets used to reinforce an RC beam. Zhang and colleagues, [16] they came to the conclusion that finite element modelling (FEM) may be utilized to predict fracture propagation in structures under basic circumstances. The majority of earlier research involving the reinforcement of concrete beams using CFRP to make sure flexural is increased in RC beams was conducted as testing studies. Understanding the behavior of CFRP-RC beams requires additional theoretical and numerical investigations, which are presented in more detail in this paper. The number of empirical examinations on the behavior of CFRP reinforced in flexure that have been conducted using the software ABAQUS is currently limited. To determine the accuracy of the finite element modelling technique (FEM) to model RC beams retrofitted by using CFRP while subjected to flexural loading, this research was conducted. With this article, we will build FEM to explore the compressive behavior of RC beams that have been reinforced with fiber reinforced plastic (FRP) bars. Their FE modelling is also being used to compute and investigate the response at flexural of fiber reinforced concrete (FRP) RC beams. The current study will examine the effects of various reinforcement ratios and detailing options.

2. Research Significance

Even though some regulations and recommendations for constructing concrete components reinforced with FRP bars has recently been published, numerical study is needed to verify the applicability of those particular concrete parts reinforced with FRP rebars. The findings of testing of fiber reinforced plastic or polymer reinforced beams are presented in this article. This research looks at a variety of different habits.
3. Methodology

3.1 FEM validation
To certify the precision of the FE models, the experimental outputs of these beams, as described in Ref. [19], are utilized. The load-displacement graphs for beams 2X10B, 2X12B, and 3X16B, as well as the FE produced load-displacement curves, are as seen in illustration Figure 1. Based on Figure 6 all of the FEM findings were in excellent harmony with the past experimental data. Notably, the FE graphs are consistent with those previous experimental curves in the most of the cases.

![Figure 1. Load v/s Deflection for literature model and finite element analysis](image)

3.2 FEM
The nonlinear numerical stimulation of a beam reinforced with FRP reinforcements were used to examine time-dependent features of the beam (ABAQUS 6.17 [17]). Notably, the FE model used in this study was built on the foundations of a model created by Jiang et al. [18], but it has been updated and modified to better represent the complicated mechanics of reinforced concrete. The effects of concrete ageing were incorporated, and methods for determining the time-dependent interfacial stress as well as developing a new procedure for analyzing the dynamics of the structural system have been developed. Figure 2 depicts the abstracted workflows for beam modelling that could be accomplished with the use of ABAQUS software.
3.3 Modeling

Figure 3 illustrates the dimensions of the beams, which are 250 mm by 150 mm with a span of 2400 mm. As a precaution against failure caused by shear, all beams are strengthened in the lateral direction with 8φ. Over that 10φ of steel and 10φ, 12φ, 16φ of BFRP bars are used. The geometrical representation of beam is in Table 1.
Using the specimens, it was discovered that the mean concrete compressive strength ($f'_{c}$) was 45 MPa. Furthermore, tensile tests on BFRP bars are carried out, and the mean tensile strength and Young's modulus are 1200 MPa and 50 GPa, respectively. Additional properties include 200Gpa Young’s modulus and 460Mpa Yield strength for steel bars.

### 3.3.1 Material characteristic

The Damaged Plasticity Model of Concrete is used in order to define the non-linearity of the concrete material under consideration. The values of the concrete plasticity parameters, as defined in ABAQUS, are given in Table 2 for reference. Figure 4 shows how compressive and tensile stress-strain curves for concrete are generated using the concrete's compressive strength as the basis for the creation of the curves. The failure of all specimens examined, according to Ref. [17], was caused by concrete crushing as the most frequent cause of failure. The nature of steel is deemed to be elastic-perfectly plastic as the result of this, the yield strength is put into ABAQUS to explain the inelastic behavior. The CDP Model is utilized in order to elucidate the non-linearity of the concrete under consideration. The values used as CDP parameters are established in ABAQUS, are provided in Table 2 for reference. Concrete stress-strain graphs, as shown in Figure 4, are generated based on compressive strength of concrete. Tensile stress-strain curves for concrete are also created in the same manner. The failure of all specimens examined, according to Ref. [17], was caused by concrete crushing as the most frequent cause of failure. Consequently, the ultimate tensile strength of the FRP bars was not achieved. Table 3 provides the properties of reinforcements.

### Table 1. Beam naming

| Naming   | Reinforcing          | Details                                |
|----------|----------------------|----------------------------------------|
| 2X10B    | 10mm*2               | Basalt Fiber Reinforced Polymer bars   |
| 2X12B    | 12mm*2               | Basalt Fiber Reinforced Polymer bars   |
| 3X16B    | 16mm*3               | Basalt Fiber Reinforced Polymer bars   |

### Table 2. Concrete Damage Plasticity (CDP) parameters

| Dilation Angle | Eccentricity | $f'_{b0}/f'_{c0}$ | K     | Viscosity |
|----------------|--------------|-------------------|-------|-----------|
| 36             | 0.1          | 1.16              | 0.667 | 0.00001   |

$f'_{b0}$ is compressive strength of concrete in biaxial.
$f'_{c0}$ is compressive strength of concrete in uniaxial.
K determines the yield shape
(a) Inelastic compressive and (b) tensile behaviors.

Table 3. Material properties of reinforcements

| Reinforcement | Density (gm/cm$^3$) | Tensile Strength (MPa) | Young’s Modulus (GPa) |
|---------------|---------------------|------------------------|-----------------------|
| Steel         | 7.9                 | 500                    | 200                   |
| CFRP          | 2                   | 1700                   | 500                   |
| BFRP          | 1.9                 | 1035                   | 100                   |
| GFRP          | 1.5                 | 480                    | 85                    |

3.3.2 Meshing and Geometry

In this model, steel and fiber glass rebars are in the form of 2-noded linear 3-D truss elements (T3D2) implanted inside the concrete area. An 8-noded linear solid 3D element by decreased integration is used to represent the concrete portion of the structure (C3D8R: Eight-node brick element with reduced integration). It is necessary to do mesh related sensitivity analysis in order to choose the most suitable and best simulate experimental findings and mesh with the least amount of computing period. In my study, 40 mm is deemed optimal mesh size too few beams and is used throughout. Figure 5 and 6 depicts the beam with two BFRP rebars and the mesh arrangement to the beams modelled in present research, as well as the reinforcement cage for the beam. It is necessary to add four rigid plates into the model in order to apply them to the boundary conditions and decrease stress on the beam in certain regions. Surface-to-surface contact is represent as the interaction between them, where beam acts as slave surface while plate as master surface. A pin and a roller serve as the boundary constraints of the structure. Additional to this, a vertical displacement is given to upper part in order to simulate the imposed load on the beam.
4. Result

Parametric studies are performed using the proven models. Different types of reinforcement and reinforcements are incorporated, and the flexural conduct of each model is examined. Figure 7(a) shows the deflection as a function of load on the flexural behavior of the FE models while studying the reinforcement ratio’s effect on beam behavior. To support the beams, reinforcement was installed using different thicknesses of BFRP. By the result of concrete influencing the behavior of the beam, the beams have the same pre-cracking stiffness until the first crack. The rigidity was greater for the higher-reinforced fracture beams. Nevertheless, the increase in stiffness does not correlate with the amount of reinforcing.

On the other side, graph represents the FE models' loads vs. mid span deflection. On the left, the flexural behavior of the beams is displayed on the right in Fig. 7. The flexural behavior is affected by the kind of reinforcement indicated in the figure 7(b). Carbon fiber reinforced plastic (CFRP) have increased flexural capacity. Until the initial breaking force is applied, the beams will stay rigid. Next, stiffness is dictated by the FRP reinforcement's strength. Reinforcement in BFRP beams is somewhat less flexible, but still far more stiff than GFRP. The CFRP reinforced beam is stiffer than the reinforced beams that use BFRP and
GFRP. A significant link can be established between the behavior of CFRP reinforced beam as well as the high strength properties of CFRP bars.

Figure 7(a). Load v/s Deflection for Beams.

Figure 7(b). Load v/s Deflection for different FRP reinforced beams.

Figure 8 Deformed shape of FE model PEEQT
Cracks are properly measured by the FE models, which not only work for the complicated nature of the system but also successfully map out the length of the beam. Figure 8 illustrates the fracture pattern of beam 3X16B from the FE simulation and the PEEQT resulting from the numerical simulations.

Figure (9-a) depicts an example of the results of Mises stress for beams, which was used in the study. Greater stress is located at the support as well as surrounding the loading plate and shows as a deviation from maximum stress to minimum stress. The stress distribution between two supports is similar to the stress distribution of the beam with web reinforcing. Stress-induced arches since the beam shoulder's compression strength is limited, Mises stress is also limited, and is lower for the beam under the influence of reinforcement (FRP) Look at Figure (9-b). The temporal variability of nodes in the center and their displacement, both in relation to the case load, is shown in Figure (9-c). The span deflection growth was shown to progressively accelerate after a longer computation period. A beam made out of reinforced concrete enters the elastic phase with high strength and stiffness, so that the mid-span deflection is initially low; however, once the material enters the plastic phase, the property of reinforced concrete starts to decrease, so the deflection starts to rise more quickly. But the failures pattern is illustrated in Figure (9-d)

![Figure 9(a) Normal stresses in CFRP reinforced beam](image1)

![Figure 9(b) Deflection of CFRP reinforced beam](image2)
5. Conclusion

Using the finite element analysis programmer ABAQUS, this research examined the behavior of a reinforced concrete beam that had been strengthened with fiberglass reinforcement bars. To corroborate modelling, previously conducted experimental work was used. Parametric comparisons were made via the analysis of several graphs. The following is the overall conclusion reached by this research.

- The computational modelling of reinforced beams revealed that the increasing diameter of the bar can increase beams’ loading capacity and reduce their ductility.
- An increase in the number of bars can increase a beam's load-displacement pattern. However, this pattern can also lead to a failure if the beams have a small displacement.
- Various studies proven that the effectiveness of reinforced beams using various kinds of bars such as CFRP and GFRP increases as the reinforcement quantity is increased.
- The load bearing capacity of a beam when reinforced with CFRP bars (8.88 to 62.92) was higher than its load carrying capacity when it was reinforced with GFRP(10% change). However, when reinforced with CFRP, the capacity of the beams remained the same.
- While the number of bars remained the same, the diameter of the CFRP bars grew significantly. This increased the load bearing capacity of beams over 51%.
- The increase in CFRP bars tends to give some ductility to the beam via the bi-linear load-to-ductility curve.
- When it comes to improving the capacity of a beam, CFRP bars are better than BFRP bars and GFRP bars.
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