Nonlinear Finite Element Analysis of Concrete Beam Reinforced with Fiber Reinforced Polymer (FRM)

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Abstract. Due to the corrosion that occurs in internal steel reinforcement; many of steel reinforced concrete structure are at risk of collapse. The budget that will be developed to address this risk in terms of replacement or repair of damaged concrete structures will be very high for the owner or responsible authorities. Alternatives to bare steel have been used including stainless steel, galvanized steel, epoxy-coated steel and cathodic protection, with limited effectiveness. The characteristics of fiber reinforced polymer (FRP) bars like the high tensile strength, inability to corrode, and light weight; it has become the focus of decision-makers to use it instead of steel in internal reinforcement for future concrete structures. In this research, we have investigated flexural behavior in reinforced concrete beams with bars from bars from carbon fiber-reinforced polymer (CFRP), bars from high tensile steel (HTS), and glass fiber-reinforced polymer (GFRP) under static load. Two groups from samples were used, in the first group will show the effect of the type of reinforcement. In the second group will show the effect of the type of reinforcement with different concrete strength. It found these kinds of materials to be very is effective to deal with analysis and the proposed simulation of the material in this study are able of forecast the real behavior of reinforced concrete beam by FRP bars in terms of failure load, and load - deflection behavior.

1. Introduction
Concrete is one of materials which used widely as building materials in the world due to its low cost, ease in production and longevity. Iron rods were used initially to reinforce concrete since 19th century and steel is used as reinforcement at the present time. One of the biggest problems with concrete reinforced with steel is its durability and corrosion. In harsh environments, the concrete matrix around the embedded steel bars is insufficient for protection. When steel bars corrode, the surrounding concrete will degrade causing the need for very expensive and time-consuming repair works or replacement. The major drawback with concrete is its low tensile strength. When tension develops in concrete, it undergoes cracking leading to brittle failures which can be catastrophic [1]. Many existing reinforced concrete structures experience deterioration due to the corrosion of internal steel reinforcement. Alternatives to bare steel have been used including stainless steel, galvanized steel, epoxy-coated steel and cathodes protection, with limited effectiveness. Replace the steel rebar used in concrete structural with materials such as fiber reinforced polymer (FRP) bars has become a main interest for owner because this material has lightweight, inability to corrode and high tensile. These materials have been used until now effectively as internal reinforcement in concrete structures that are exposed to highly corrosive environments including bridge decks, barrier walls, parking garage slabs, and containment structures housing corrosive materials. FRP are a composite material in the form of resin matrix; it is consisting from high strength fiber. The fiber has a very small diameter compared to its length; it is considered continuous in length with diameters range of 3-25 micrometers. These fibers have high tensile strength
and provide a stiffness and strength of the FRP. The two most common FRP materials used for structural applications include carbon fiber reinforced polymers (CFRP), and glass fiber reinforced polymers (GFRP) which utilize glass and carbon fibers, respectively. Aramid fiber reinforced polymers (AFRP) have also been developed but are not used extensively in the world [2].

Due to the superior durability properties of FRP composites; it is become a favorite from a steel reinforcement with future concrete structures where the steel reinforced concrete structures are an easy target to corrosion. Figure 1 presents four examples of reinforced concrete structures that are highly susceptible to corrosion and have successfully used FRP reinforcement.

There are numbers of works about the use of FRP bars with construction materials by various experimental and theoretical studies for application in the civil engineering field. The most important of these works by A.F. Ashour [3], A. Masmoudi [4], B. Saikia [5], C. Barris [6], F. Micelli [7] , Iman [8], I.F. Kara [9], Gravina and Smith [10], [11] Grace, Soliman, and Abdel-Sayed.

![Figure 1. Various Applications of FRP Reinforcement](image)

2. Materials and methodology

2.1. General description of beams

Aly Abdel Zaher Elsayed et al. [1] tested a Fifteen reinforced beam were prepared with main reinforcement (GFRP) or (CFRP) or steel bars (H.T.S) having rectangular cross section equal to 120×300 mm. The considered spans for all tested beams were 2400 mm as showed in figure 2. The study takes in to consideration the following parameters as show in table 1. In this research the author selected six beams divided in two groups each group have separate comparison case. The two groups changing in concrete strength value $f_c = 40$ MPa and 65 MPa by the same $Agf & Acf & As$.

- **Group A** This group consisted of three beams simply supported $b = 120$ mm, $h =$ 30 cm, concrete compressive strength ($f_c = 40$ MPa). $Agf & Acf & As = 2012, A`s, = 2010, st. Ø8 @ 150 mm$

- **Group B** This group consisted of three beams simply supported $b = 120$ mm, $h =$ 30 cm, concrete compressive strength ($f_c = 60$ MPa). $Agf & Acf & As = 2012, A`s, = 2010, st. Ø8 @ 150 mm$
2.2. Finite element modeling

2.2.1. Modeling of Components.
In this section, all modeling will be compared and discussed also other details will be involved. The materials characteristics and dimensions are supplied for the structure details at section 4.2.

2.2.1.1. Beam modeling.
According to the structural drawing, the concrete beam will be modeled. A model consisting of 3 dimensional solid elements was created to gain a better understanding of the behavior of simply supported beam reinforced with fiber bars. The model developed by Elsayed et al. [1]. Figure 3 shows the concrete beam model which was formed using a solid component. The initial step of modeling involves creating the cross section then inserting depth of beam. The loading and bearing plates were included monolithically on the concrete beam. However, the place of loading and bearing plates is made up of materials with similar characteristics of the loading and bearing materials.

Table 1. Details of selected beams.

| Group | Beam No. | Reinforcement type | $b$ (mm) | $h$ (mm) | $A_r$ (mm$^2$) | $f_c$ (MPa) |
|-------|----------|-------------------|---------|---------|---------------|-------------|
| A     | AG       | GFRP              | 120     | 300     | 2Ø13         | 40         |
|       | AC       | CFRP              | 120     | 300     | 2Ø13         | 40         |
|       | AS       | Steel             | 120     | 300     | 2Ø12         | 40         |
| B     | BG       | GFRP              | 120     | 300     | 2Ø13         | 65         |
|       | BC       | CFRP              | 120     | 300     | 2Ø13         | 65         |
|       | BS       | Steel             | 120     | 300     | 2Ø12         | 65         |
2.2.1.2. Reinforcement modeling.
For the prototype structure and test unit, the mechanism of modeling used is the same for all different lengths and size of reinforcing bars. The piece of wire uses instead of reinforcing bars (Carbon fiber, Glass fiber, and steel) to draw a length of the bar. Manually, the elements were converted from beam element to truss element and the mesh was applied. For design the bar size accurately, the truss section was chosen, and the bar size defines along with the appropriate selection of material properties. The reinforcing of the bar was modeled after the section was applied to the part. The differences in the bars were the same difference in the wire elements and the area defined in the section module. Figure 4 shows modeling of reinforcement in ABAQUS.

2.2.1.3. Meshing of beam.
After fixed the sizes, an F.E. analysis requires of the model. Where the model divides into small elements to obtain good results. The mesh used is shown in figure 5 and the number of elements is shown in table 2.

Figure 3. AG beam modeling.

Figure 4. FRP and steel reinforcement modeling.
Figure 5. Mesh of AG beam.

Table 2. Total number of elements and nodes for (AG).

| Structural Component         | Number of Elements | Number of nodes |
|------------------------------|--------------------|-----------------|
| Concrete (beam and plates)   | 7260               | 9534            |
| Top Reinforcement (steel)    | 224                | 226             |
| Bottom Reinforcement (GFRP)  | 224                | 226             |
| Stirrup                      | 510                | 510             |

2.2.2 Loads and boundary condition.
Conditions of displacement boundary are needed to restrict the model to get a unique solution. Conditions of the boundary are required to be applied on the points and where the loadings exist and its supports.

The supports models are formed as a hinge and roller. In simple, this study is supported the beam. To model the roller, a single line of nodes on the support is a constraint in the vertical direction (Uy) and constraints in the longitudinal and vertical direction give as hinge support ((Ux, Uy, Uy) = 0). The load is defined as a surface load as shown in figure (6). A small bearing plate was used between the concrete slab and the loading for the external load to barring the concentration of stresses in the contact area of concrete slabs.

Figure 6. Boundary Condition of AG.
3. Results and Discussion
The load conveys capacity of the developed models and the forecast load-mid span deflection reaction compared with the results gated from the experimental tests of Elsayed et al [1]. Figures (7) to (12) show the finite element and results of experimental for the six beam samples. In addition, the measured results for the load and deflection at failure are given in the table (3). The figures and tables obviously indicate that the response of the predicted finite element results is compatible with the experimental data. Thus, we can conclude that the models which are developed in this study could be used to check the performance of concrete beams reinforced with FRP bars with reasonable accuracy, and a hybrid combination of steel. In addition, the figures illustrate that the tensile strength of the FRP bars enhances the load-carrying capacity of the beam sample.

As expected, as the result of the linear-elastic behavior of the FRP rebar, there is no yielding with the FRP reinforced beams used. The curves rose almost linearly until crushing the concrete. The FEM analysis predicts the beam to be somewhat stiffer than the experimental work shows. This can be attributed to the fact that perfect bond between concrete and steel was assumed and the estimation of the behavior of the interface between FRP and concrete; with a perfect bond between FRP and concrete.

![Figure 7. Load-Deflection curve for AG](image7)

![Figure 8. Load-Deflection curve for AC](image8)

![Figure 9. Load-Deflection curve for AG.](image9)

![Figure 10. Load-Deflection curve for AC.](image10)
Figure 11. Load-Deflection curve for BC.

Figure 12. Load-Deflection curve for BS.

Also, deflected shapes for all beams are shown in figures from (13) to (18). Table (3) shows Comparison between this value ($P_u_{FEM}$) and the ultimate load of experimental test beam ($P_u_{EXP}$).

Figure 13. Deflected shape for beam AG at load = 105.3 kN.

Figure 14. Deflected shape for beam AC at load = 132.2 kN.
Figure 15. Deflected shape for beam AS at load = 93.2 kN.

Figure 16. Deflected shape for beam BG at load = 109.4 kN.

Figure 17. Deflected shape for beam BC at load = 158.8 kN.
Figure 18. Deflected shape for Beam (BS) at load = 94.2 kN

Table 3 Comparison of experimental results with numerical results for all selected beams.

| Analytic and test beam | Ultimate load (kN) | Deflection (mm) | (Pu)_{FEM} | (Pu)_{EXP} | (Δ)_{FEM} | (Δ)_{EXP} |
|------------------------|--------------------|-----------------|------------|------------|------------|------------|
|                        | (Pu)_{FEM}         | (Pu)_{EXP}      | (Δ)_{FEM}  | (Δ)_{EXP}  |            |            |
| AG                     | 105.3              | 109.6           | 44.3       | 47.5       | 0.96       | 0.93       |
| AC                     | 132.2              | 147.5           | 27.2       | 31         | 0.89       | 0.88       |
| AS                     | 93.2               | 95.7            | 15         | 18         | 0.97       | 0.83       |
| BG                     | 109.4              | 114.6           | 46         | 45         | 0.95       | 1.02       |
| BC                     | 158.8              | 167.4           | 28         | 32         | 0.95       | 0.88       |
| BS                     | 94.2               | 99.6            | 16.7       | 17         | 0.94       | 0.98       |

4. Conclusions
The analysis is based on the finite element method by using ABAQUS computer program (version 6.14). A non-linear finite element in a three-dimensional analysis is carried out to check the general behavior of a simply supported beam reinforced with FRP rebar. The five conclusions can be drawn from the numerical results.

1. There are very well agree between the finite element simulation results and experimental observations, especially with the load-deflection response, these illustrate that the models used for FRP bars and concrete by ABAQUS be able to capture the fracture habit of FRP-reinforced beam exactly. In the end, we can use this method for the nonlinear analysis and design these elements in more efficiently.

2. Generally, the experimental results by ABAQUS for the FEM analysis and FRP-reinforced concrete deep beams were remarkably consistent, where the mean ratios of predicted to experimental values for ultimate load capacities equal 0.94 and 0.92 of deflection.

3. From the numerical analysis carried out to study the effect of compressive strength of concrete on the strength behavior; the compressive strength of concrete is increased from 40 N/mm² to 65 N/mm² the ultimate load capacity is increased by about 3.9%, 20%, for glass and carbon fiber rebars respectively.

4. The curvature of reinforced sections made by FRP bars decreased with increasing the concrete compressive.

5. The low modulus of elasticity for FRP reinforced concrete sections show up a softening in the moment-curvature compared with high modulus of elasticity (steel).
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