The shear strengthening of reinforced concrete beams by embedded through section technique -analytical study-

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Abstract. Five proposed simply supported RC beams were numerically tested by finite element method using ABAQUS software to investigate their behavior and shear strength when strengthened by embedded through section technique (ETS). All beams have the same dimensions of (160 × 250 × 1140) mm and were insufficient reinforced in shear. One beam is taken as a control beam. While, the other four beams were strengthened ETS CFRP bars and divided into two groups. The first group is with 13mm ETS CFRP bars (one bar per section). While, the second group is with 10mm ETS CFRP bars (two bars per section). For all groups, two styles of ETS inclination are considered, vertical and inclined by 45°. From the numerical tests, it was found that using ETS with 2ϕ10 inclined CFRP bars is the most effective technique for enhancing both the first cracking load about 100% and ultimate load capacity about 86%.

1. Introduction

Shear forces are the most common governance failure mechanism for reinforced concrete (RC) beams [1]. In recent decades, many attempts have been conducted to enhance the shear capacity of RC beams. The traditional methods for strengthening are by using steel plates or steel jacketing, fiber reinforced polymers (FRP) strips or laminates and near mounted surface (NMS) strengthening method with steel or FRP bars. In the last few decades, embedded through section technique (ETS) is a powerful method for strengthening beams in shear. The methodology of this method is by post-fabricated holes which drilled in the middle of beam section where maximum shearing cracks location [2]. the only disadvantage for this technique particularly from drilling of beams there is need more focus during practical work Because the slightest mistake is not to take action for example, "leave the hole wet while working, choose inappropriate epoxy , leave holes after completing the injection". This method is become common in use due to no debonding between concrete and the inserted strengthening bars would occur [3]. The material of inserting bars could be steel or FRP, since FRP materials are having high tensile strength more than steel, it could be more effectively in increasing shear strength of beams [4].

2. Research significant

This paper reveals on studying numerically by using the finite element analysis (FEA), the behavior of RC beams strengthening by using ETS method. Carbon Fiber Reinforced Polymer (CFRP) bars are implemented in this research as strengthening elements. The variables considered in this research are the inclination of ETS CFRP bars and their number within beams cross-sectional area. I will suggest the dimensions of these five beams as well show in figure 1.
3. Details of beam models

Five reinforced concrete beams were proposed to be numerically analyzed in this research. These proposed beams are with dimensions of (160 × 250 × 1140) mm. The longitudinal flexural tensile reinforcement is assumed to be designed with (4 Ø12 mm) deformed steel bars. The longitudinal compression reinforcement is assumed to be designed with (2 Ø6 mm) deformed steel bars. While, insufficient amount of shear reinforcement (stirrups) of (Ø4 @ 150 mm) is assumed. Proposed stirrups reinforcement aspects have been checked with Articles 9.6.1 and 9.6.2 of the ACI 318 – 19 Code [5] which is less than the acceptable limits. This is to insure rapid shear failure as well as to verify the suggested way for strengthening. One of these beams was unstrengthening (control). The other four beams were divided into two groups depending on numbers of ETS CFRP bars within beam cross section. Beams of Group I, are proposed to be strengthening with 1 Ø13 mm central CFRP bars per beam cross section. The beams of Group II are proposed to be strengthening with 2 Ø10 mm CFRP bars per beam cross section located at sides of beam cross section. For both grouped beams, two inclinations of CFRP bars (vertical and inclined by 45°) are proposed for the analysis. Table 1 illustrates the configurations of the analyzed proposed beams.

| Group | Specimen designation | CFRP Bar diameter (mm) | ETS style | No. of CFRP bars per beam cross section |
|-------|----------------------|-------------------------|-----------|----------------------------------------|
| Control beam | B150 | N. A | N. A | N. A |
| I | B150-E13-V | 13 | Vertical | 1 |
| | B150-E13-I | | Inclined | |
| II | B150-E10-V | 10 | vertical | 2 |
| | B150-E10-I | | Inclined | |

4. Finite Element modeling

Mechanical ABAQUSE software 2017 was used to create and analyzes the models in the current study. Material properties for all elements are specified in the current study. Here linear elasticity and nonlinear plasticity of steel bars and isotropic elasticity in combination with damaged plasticity model of concrete is adopted to depict a mechanical constitutive model.

4.1. Concrete modeling

The concrete model is a continuum, plasticity based, damaged model. The concrete compressive strength $f'_{c}$ is considered to be 39 MPa. Damaged plasticity is assumed to characterize the uniaxial tensile and compressive response of concrete. At early stages of loading, the stress-strain relationship is linearly elastic under uniaxial tension until it is reached its maximum limit. Failure stresses in concrete is converted to replace microcracks in it. Beyond the state of the failure stress in concrete, stress-strain response is designed by softening characteristic. Under uniaxial compression, the response is linear until the value of initial yield. After attaining the ultimate stress in the plastic zone, the response of concrete is characterized by the stress hardening followed by strain softening.

4.2. Steel reinforcement modeling

Steel bars have linear elastic behavior when their stiffness introduced by the Young’s modulus. At higher strain magnitudes, it begins to have nonlinear, inelastic behavior, which is referred to as plasticity. The shift from elastic to plastic behavior occurs at a yield point on a material stress-strain curve. Both elastic and plastic strains accumulate as the metal deforms in the post-yielding region. The stiffness of the steel decreases once the material yields. The steel yielding stress $f_y$ for Ø (6, 10, 12) mm are considered to
be 430, 500, 635 MPa respectively. While, the modulus of elasticity is assumed to be (Es = 205) GPa and Poisson’s ratio, ν = 0.3.

4.3. Carbon Fiber Reinforced Polymer (CFRP) bars modeling
the tensile behavior of CFRP bars is characterized as a linearly elastic stress-strain relationship up to failure. So that, it could be assumed linear with 2000 MPa tensile stress.

4.4. Modeling of specimens in ABAQUS software
As mentioned before, five proposed beam models were adopted in this research. The proposed groups of RC simply supported beams are implemented in the finite element analysis (FEA) using ABAQUS software. As mentioned before, each group is consisted of two specimen models, one is without strengthening (control beam) and the others are strengthened with CFRP 10- and 13-mm. figure 1 shows finite element model of proposed beams and details of steel and embedded CFRP reinforcement. Moreover, these beams are analytically subjected to one-point load up to failure.
a. The model of B150.

b. The model of B150-E13-V.
c. The model of B150-E13-I.

d. The model of B150-E10-V.
5. FE analysis results

5.1. First cracking and ultimate loads

Table 2 illustrates the results that obtained from the numerical results for first cracking and ultimate load capacity depending on CFRP inclination. It is obvious from this table that the inclination of ETS CFRP bars by 45 degree has a significant effect in increasing both the first cracking and ultimate loads than the vertical style as compared with the reference beam.

| Beam designation | First cracking load (kN) | % Increasing in first cracking load | Ultimate load (kN) | % Increasing in ultimate load |
|------------------|--------------------------|-----------------------------------|-------------------|-----------------------------|
| B150             | 22                       | ---                               | 112               | ---                         |
| B150-E13-V       | 28                       | 27.3                              | 122               | 8.9                         |
| B150-E13-I       | 37                       | 68.2                              | 191               | 70.5                        |
| B150-E10-V       | 30                       | 36.4                              | 127               | 13.4                        |
| B150-E10-I       | 44                       | 100.0                             | 209               | 86.6                        |

On the other hand, using 2ϕ10 CFRP bars instead than 1ϕ13 bar is more effective in enhance both of these capacities.
5.2. Load-Deflection response
Deflections are read at the center of the beam model. The load-deflection curves are plotted to show the behavior of the beams when using ETS CFRP bars as shown in figure 2, right for vertical and left for inclination. Also, the results showed there is a decrease in deflections when increasing the number of CFRP bars as well as when the orientation angle turned to 45 degree.

![Load Vs deflection curves for ETS bar with various ETS bar diameters.](image)

**Figure 2.** Load Vs deflection curves for ETS bar with various ETS bar diameters.

5.3. Cracks pattern
After reviewing the failure patterns of the models shown in figure 3, the following conclusions are noted;
1- For the beam model without strengthening, the cracks manifest clearly and with great intensity. This is because of insufficient amount of stirrups distribution.
2- The amount of cracks was decreased with increasing the number of ETS CFRP bars as compared with the reference beam. The ratio about 25% for inclined and 20% for vertical compare with control beam.
3- The amount of cracks was decreased with inclined CFRP as compared with the vertical CFRP as obtained ratio is 40%.
Figure 3. Cracks pattern for the analyzed beam models.

6. Conclusions

- The load carrying capacity of ETS strengthened beams increases as (15, 9, 87, 66.5) % for the (B150-E10-V, B150-E13-V, B150-E10-I, B150-E13-I) respectively compared with the control beam.
- The ETS shear strengthened beams have 100% increases in first cracking load when strengthened with 2ϕ10mm CFRP bars with inclined type.

7. References

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