



AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
STRUCTURAL ENGINEERING DEPARTMENT

FLEXURAL BEHAVIOUR OF RC BEAMS STRENGTHENED BY NEAR SURFACE MOUNTED FRP BARS

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STATEMENT

This thesis is submitted to Ain Shams University in partial fulfilment of the requirements for the degree of Master of Science in Civil Engineering (Structural).

The work included was carried out by the author.

No part of this thesis has been submitted for a degree or a qualification at any other university or institution.

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IN THE NAME OF ALLAH

ABSTRACT OF THESIS

FLEXURAL BEHAVIOUR OF RC BEAMS STRENGTHENED BY NEAR SURFACE MOUNTED FRP BARS

Strengthening with near-surface-mounted (NSM) fiber-reinforced-polymer (FRP) reinforcement has become a well-known technique, which provides a strong bond between the FRP element and concrete. However, one of the most common failure modes of NSM-FRP strengthened beams is concrete cover separation (CCS). In this research, the flexural behavior of RC beams strengthened with fully and partially bonded NSM CFRP bars was studied. Two different bar configurations with straight and hooked ends were used. The hooked ends were used to act as end anchors, which might delay or prevent the CCS failure. The results indicated that the end anchoring was very effective in delaying the CCS and increasing the ultimate carrying capacity. The ultimate load of the beams strengthened with two straight NSM CFRP bars increased by 157.3%, while that of the corresponding beam having end anchorage increased by 197.9% compared to the unstrengthened beam. On the other hand, unbonding the NSM bars along the constant moment zone did not decrease the ultimate load compared with the fully bonded bars, however it slightly increased the beam deformability. Extending the unbonded length into the shear span shifted the failure mode from CCS to shear failure, which is not preferred from the point of view of the structural safety.

A numerical investigation utilizes the non-linear finite element (FE) modeling was performed using ANSYS®. The developed FE model considered the nonlinear constitutive material properties of concrete, yielding of steel reinforcement, and bond slip of non-anchored NSM bars with adjacent epoxy surface. Progressive continuum damage mechanics (CDM) along with the fracture concepts were employed to simulate the damage initiation and propagation at the epoxy-concrete interface. A strain-based failure criteria was proposed to predict the CCS failure. The developed models were validated by comparing the numerical and experimental results in terms of load-deflection behavior, load-CFRP strain response, and failure modes. Overall, a good agreement was obtained with a Mean Absolute Percentage Error (MAPE) of 2.58% for the ultimate loads. The developed models were then used to study

effects of extra parameters. The effect of the NSM CFRP bar length, axial stiffness of the NSM reinforcement $(EA)_{frp}$, corrosion of tension steel, compressive strength of concrete, and prestressing of the NSM reinforcement were evaluated.

With respect to the ultimate load, it was indicated that increasing the axial stiffness of the NSM reinforcement *via* the bar diameter had a superior effect than increasing the material modulus. Increasing the NSM bar length over 175 times the bar diameter did not have a significant effect neither on the ultimate load, nor on the beam deformability. In contrast with the non-prestressed systems, prestressing of the NSM reinforcement enhanced the service performance of the strengthened beams by reducing deflections at different load stages. However, it did not enhance the ultimate loads due to rupture of the FRP bars. Increasing the axial stiffness of the prestressed NSM reinforcement significantly enhanced the ultimate loads of the strengthened members by either delaying the FR rupture or shifting the failure mode to concrete crushing.

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