Evaluation of Behaviour and Failure Modes of FRP-Strengthened RC Girders

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Abstract

This paper analyzes the effect of the different material properties on the response and failure modes of FRP-strengthened RC beams. A nonlinear RC beam element model with bond-slip between the concrete and the FRP laminates is used to analyze several test specimens and to investigate the corresponding failure mode, and whether it is due to FRP rupture, epoxy debonding, or concrete crushing.

1 Introduction

Externally bonded carbon fibre reinforced polymer (CFRP) laminates are a feasible and economical alternative to traditional methods for strengthening and stiffening deficient reinforced concrete and prestressed concrete girders as shown in Fig. (1). Although extensive research has already been undertaken to investigate the behaviour of CFRP strengthened reinforced concrete girders, the majority of work conducted to date has been experimental in nature which does not provide sufficient details to all parameters influencing the behaviour. Furthermore, while some studies have proposed design models and methodologies to identify the necessary number of laminates to achieve a target strength or stiffness, many important design issues still remain unresolved, particularly issues related to delamination and degradation under reversed cyclic loading typical of seismic excitations.

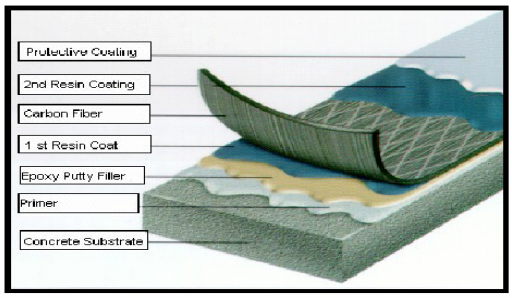

Fig. 1. External Bonding with CFRP

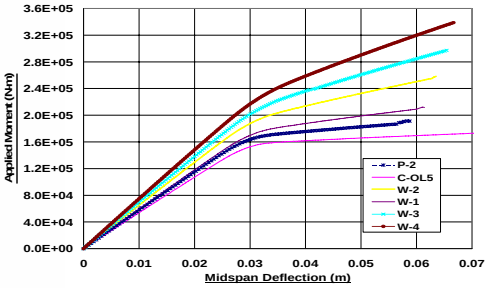

Fig. 2. Behaviour of CFRP-Strengthened RC Laminates Girders with different number of layers

2 Objective

The objective of the work is to evaluate the effect of different parameters influencing the behaviour of CFRP-strengthened RC girders. To accomplish this task, a nonlinear numerical software package for analysis of such structures that accounts for all possible failure modes was developed. The model was based on section discretization into fibres. Nonlinear constitutive material laws were assigned to the concrete, steel and CFRP fibres. In addition, a continuous interface element was developed to model the interfacial bond between the CFRP laminate and concrete.

3 Validation of Analytical Model

The software was used to model a series of CFRP-strengthened concrete girders with different number of layers tested in the laboratory under monotonically increasing load.

The model successfully described the global inelastic behaviour of the girders and the corresponding stress and stiffness gain along with the distribution of flexural, axial and bond

stresses along the girder length, as shown in Figure (2). The model in this form could be used by designers to evaluate the stress in the CFRP sheets, the necessary number of layers to achieve a certain level of strength; and to detect the failure mode and whether it's due to bond delamination, FRP rupture, or concrete crushing.

4 Evaluation of Effect of Material Parameters on Failure

Several analysis of RC specimens revealed that the failure mode is typically due to delamination of the FRP sheets. The ACI 440.2R-02 [1] proposed the use of a design factor (k_m) to account for this premature failure mode. The factor is a function of the ratio of the maximum FRP stress at debonding (f_{fe}) and the FRP design strength (f_{fu}). Figures (3) to (5) show the effect of different parameters, namely the epoxy bond strength, the FRP modulus, and the concrete compressive strength on the value of this ratio. Finally, Figure (6) shows the analytically derived k_m factor accounting for the different failure modes.

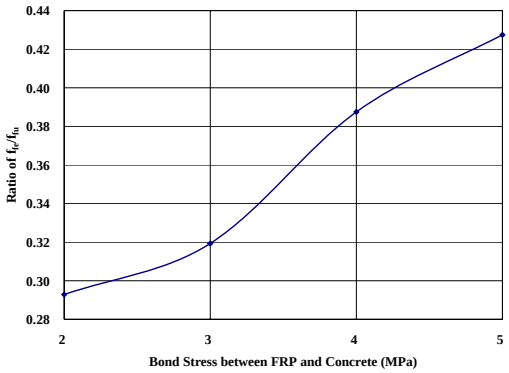

Fig.3. Bond Strength Effect on ACI Ratio

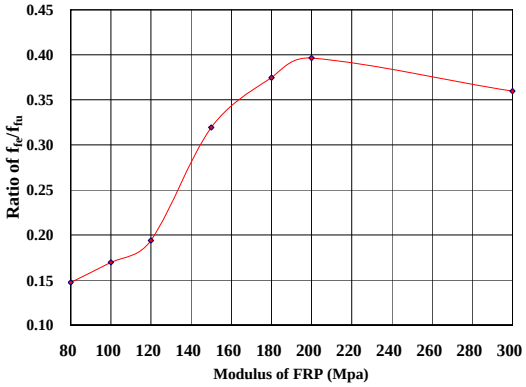

Fig.4. FRP Modulus Effect on ACI Ratio

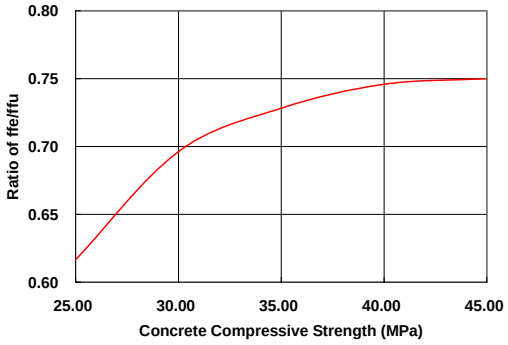

Fig.5. Concrete Strength Effect on ACI Ratio

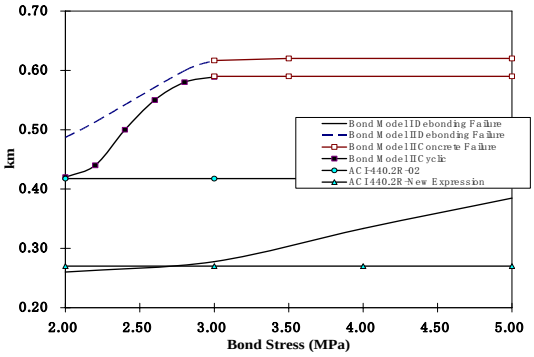

Fig. 6. Evaluation of ACI km Factor

5 Conclusion

A new numerical model was developed to investigate the effect of different material properties on the behavior of CFRP-strengthened RC girders. The model was used to evaluate the effect of different material properties on the failure modes of specimens.

6 Acknowledgment

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7 References

1. ACI Committee 440 (2002). "Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures" (440.2R-02), American Concrete Institute, Farmington Hills, Michigan.