Ain Shams University
Faculty of Engineering
Department of Structural Engineering

Mechanical Anchorage to Enhance the Bond Strength of Prestressed CFRP Laminates Bonded to Structural Steel Beams

A Dissertation

Submitted in Partial Fulfilment for the Requirements of the de6gree of

Doctorate of Philosophy in Civil Engineering (Structural Engineering)

by
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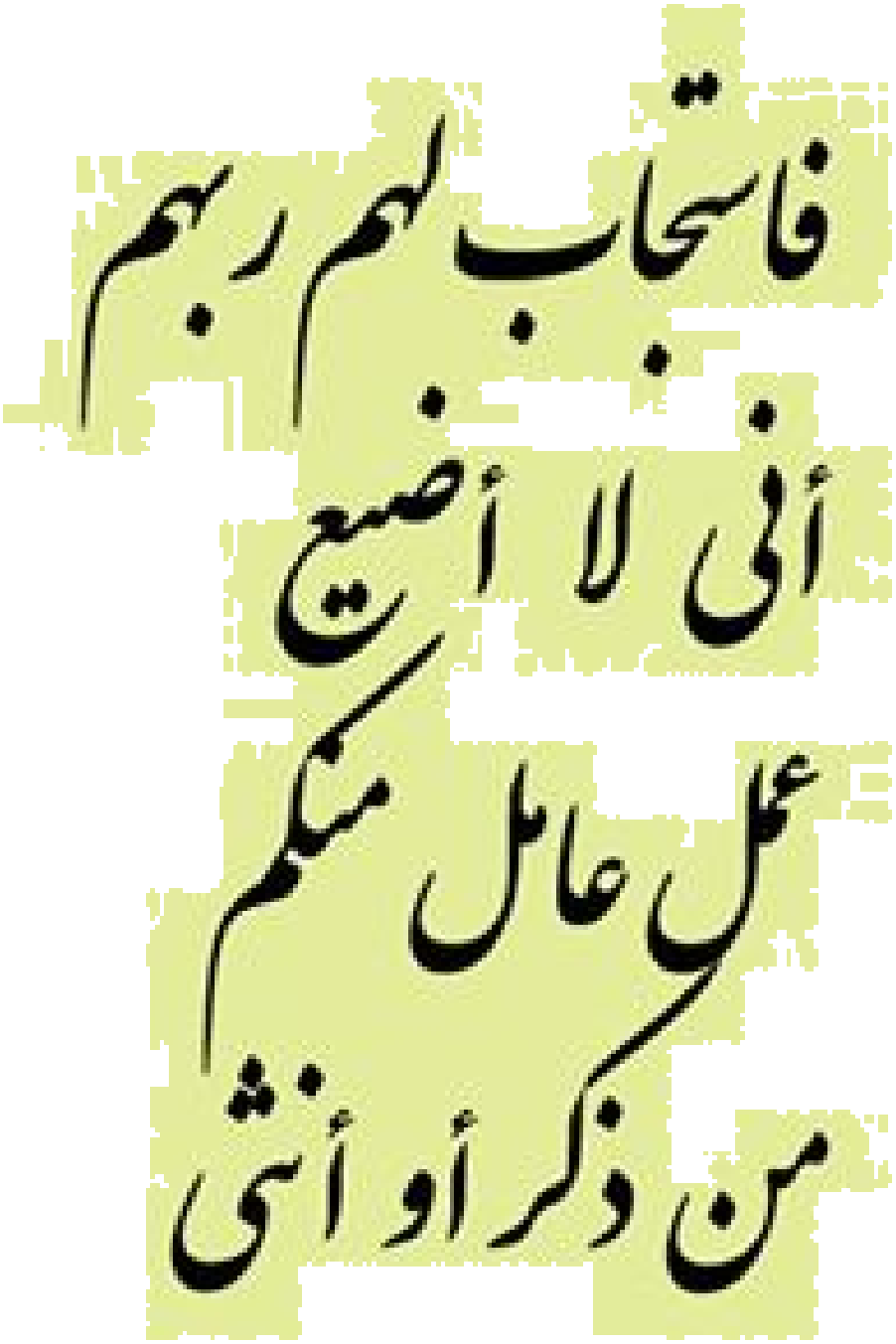

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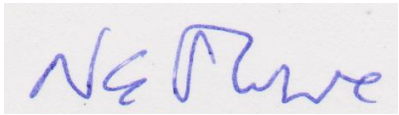
Prof. Nigel G. Shrive Professor, Dept. of Civil Engineering Schulich School of Engineering The University of Calgary, Calgary, Alberta, Canada.	
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STATEMENT

This thesis is submitted as a partial fulfilment of Doctor of Philosophy in Civil Engineering, (Structural Engineering), Faculty of Engineering, Ain shams University.

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or a qualification at any other scientific entity.

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Thesis Summary

The carbon fibers (CFRP) in the form of laminates can be applied to retrofit flexural concrete and steel members. However, interfacial stress between the CFRP and steel surface tend to be high especially at the edges of the laminates. Strengthening systems with prestressing is suggested in order to effectively utilize the CFRP to overcome the failure mode caused by debonding. Applying prestressing force to CFRP laminates bonded to steel or reinforced concrete beams can be done by using mechanical anchorage. Adding mechanical anchorages to the ends of the laminate can ensure a better ductile behaviour and can also increase the allowable level of prestressing. In the present research, a mechanical anchorage prestressing system is introduced in order to maintain the initial prestressing applied to the CFRP laminates, and delay the premature debonding failure. A numerical analysis and an experimental program was conducted on steel I-beam sections subjected to flexure and strengthened using prestressed CFRP laminate to evaluate the performance and the effectiveness of this technique. The experimental program consisted of testing 10 steel beams strengthened with bonded and unbonded prestressed CFRP laminate with and without mechanical end anchorage system. The results, failure modes and the observations of the experimental tests are illustrated and discussed. To predict the interfacial stress acting on the contact zone, an analytical model of beams with CFRP is developed. 4 beams are evaluated using the developed analytical model equations. A finite element analysis was conducted using the cohesive zone method (CZM) to extend the study. To verify the developed finite element model, the experimental tests results are compared to the finite element model outputs. The finite element model is used to evaluate the effect of increasing the prestressing level applied to the CFRP reinforcement. It was found that using the prestressed CFRP laminate with the mechanical anchorage system increases the overall strength of the beams, delays the premature debonding failure and enhances the serviceability of the composite section

Key words:

Steel Structure – CFRP – Prestressing – Mechanical Anchorage – CZM – Interfascial stresses

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ABSTRACT

The use of fibre reinforced Polymers (FRP) composites for rehabilitations of concrete structures and members is now a common and widely used practice. However, this method stills not a mainstream application when it comes to steel structural members because of economical and design reasons. The most important concern regarding the effective application of this strengthening technique to steel structures is the debonding failure mode.

Available commercial FRP products come mainly in two types, Glass fibres and carbon fibres. The carbon fibers (CFRP) with its high tensile modules enhanced mechanical properties and higher fibre volume in the form of laminates and strips can be beneficially applied to retrofit flexural steel members. However, CFRP laminates have a small width and a large thickness, thus, interfacial stress between the CFRP and steel surface tend to be high especially at the edges of the laminates.

Alternatively, strengthening systems with prestressing is suggested in order to effectively utilize the CFRP materials and overcome the brittle failure mode caused by debonding or delamination of the laminates; CFRP prestressing was successfully applied to reinforced concrete beams loaded in flexure but was not thought of for steel beams with CFRP laminates. Applying prestressing force to CFRP laminates bonded to steel or reinforced concrete beams can be done by many techniques. None of these techniques can be effective without using a mechanical anchorage because of the debonding phenomena associated with the adhesive layer. Adding mechanical anchorages to the ends of the laminate can ensure a better ductile behaviour and can also increase the allowable level of prestressing that can be applied. As a result, the use of a mechanical anchorage is thought to greatly improve the strength and serviceability of strengthened beams.

In the present research, a mechanical anchorage prestressing system is introduced in order to maintain the initial prestressing applied to the CFRP laminates, and delay the premature debonding failure. A numerical analysis and an experimental program was conducted on steel I-beam sections subjected to flexure and strengthened

using prestressed CFRP laminate to evaluate the performance and the effectiveness of this technique.

The experimental program consisted of testing 10 steel beams strengthened with bonded and unbonded prestressed CFRP laminate with and without mechanical end anchorage system. The results, failure modes and the observations of the experimental tests are illustrated and discussed. To predict the interfacial stress acting on the adhesive layer, an analytical model of steel beams with CFRP prestressed laminates and mechanical anchorage is developed. 4 beams described and tested in the experimental program are evaluated using the developed analytical model equations. The results of the analysis, with and without mechanical anchorage, are shown and discussed. A finite element analysis was conducted using the cohesive zone method (CZM) to extend the study. To verify the results of the developed finite element model, the measurements of the experimental tests are compared to the finite element model outputs. After verification, the finite element model is used to evaluate the effect of increasing the prestressing level applied to the CFRP reinforcement.

It was found that using the prestressed CFRP laminate with the mechanical anchorage system increases the overall strength of the beams, delays the premature debonding failure and eventually enhances the serviceability of the composite section.

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