## THESIS INFORMATION

### INTRODUCTION

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| Official thesis title: | **Flexural-strengthening efficiency of CFRP sheets for unbonded post-tensioned reinforced concrete beams** |
| Major: | Civil & Industrial Construction |
| Major code: | 62.58.02.08 |
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### ABSTRACT

Thanks to the outstanding technical characteristics of CFRP materials such as high strength, lightweight, non-conductivity, non-magnetism, non-corrosiveness, simple construction, the solution of using CFRP materials for retrofitting or strengthening of reinforced concrete (RC) and post-tensioned concrete (PC) structures has shown its high efficiency besides existing traditional solutions. However, the current limited studies on the flexural behavior of unbonded post-tensioned reinforced concrete (UPC) beams strengthened with CFRP sheets have not fully mentioned and quantified the influence of CFRP sheets for strengthening on the performance of the tendons and the beams, and the effects of repeated loads as well on the performance of UPC beams. Another pivotal factor controlling the effectiveness of the CFRP strengthening system for RC and PC beams is the interfacial bond behavior of CFRP sheets and concrete. However, this behavior has not been fully and systematically investigated in the published literature, especially in the case of PC beams using unbonded tendons. The problems mentioned above lead to the absence of design provisions for PC members using unbonded tendons in current design guidelines for strengthening concrete structures using FRP materials.

This thesis studies the interfacial bond behavior of CFRP-to-concrete joints and the flexural-strengthening efficiency of CFRP sheets on UPC beams. The main objectives of the thesis include: (1) experimentally analyze the interfacial bond behavior of CFRP sheets and concrete on UPC beams and clarifying the difference between this bond behavior and the CFRP-to-concrete bond behavior on single-lap shear specimens (the prevailing bond behavior) in a

systematic way; (2) experimentally investigate of the behavior and quantification of the flexural-strengthening efficiency of CFRP sheets on UPC beams, and (3) develop an interfacial bond-slip model of CFRP-to-concrete joints for UPC beams and propose a new formula for calculating the strain of unbonded tendons in UPC beams including the effect of CFRP sheets serving for the design procedure of flexural strengthening using CFRP sheets for UPC beams.

Regarding the experimental program, the test consisted of 20 large-scale UPC T-beams. The main survey parameters included the number of CFRP sheet layers (0, 2, 4, and 6 layers), beam condition before strengthened (uncracked and pre-cracked), loading type (monotonic and repeating loading), and CFRP U-wrap anchors type (concentrated and evenly distributed). In addition, to analyze and clarify the difference between the interfacial CFRP-to-concrete bond in UPC beams and that in single-lap shear specimens which are commonly used, a small test program was conducted on seven single-lap shear specimens.

The experimental results showed that the interfacial bond behavior in the beams was very different from that in the single-lap shear tests in terms of the debonding strain and strain distribution of CFRP sheets (up to 250% compared to the beams without U-wraps and 490% compared to beams with U-wraps). The test results also showed that the accuracy of some existing codes and models in estimating the bond strength of CFRP-to-concrete joints in UPC beams (especially with CFRP U-wrap anchor systems) are very low compare to experimental data (42% on average).

The experimental results on the flexural behavior of UPC T-beams strengthened with CFRP sheets under monotonic and repeated loads showed that the use of CFRP sheets and CFRP U-wrap anchors significantly affected the tendon strain. CFRP sheets significantly affected the beam flexural resistance (increased by up to 65%), crack width (decreased by up to 84% in the serviceability stage), and beam displacement (increased by up to 65%); however, this enhancement tended to decrease as the CFRP sheet ratio increased. The repeated loads considerably affected the residual load-carrying capacity, deflection, and crack width of the strengthened beams under post-repeated monotonic loading, particularly at the serviceability state but not at the ultimate state. For the serviceability state, the beams subjected to repeated loads showed a considerable decrease in the residual load-carrying capacity (by 19%), an increase in the final displacement (up to 34%), and an increase in the crack width (up to 21%), compared to those of identical beams under solely monotonic loadings; these reductions were proportional to the number of CFRP layers and load cycles. The U-wrap anchors with different layouts had a marked effect on the failure mode of the beam, increased the maximum strain of CFRP sheets and tendons, and enhanced the ductility of the beams. Debonding strain of CFRP sheets calculated from the current guidelines and design standards for strengthening of concrete structures using externally bonded FRP sheets, although give safe results; in general, it is currently underestimating the debonding strain value of the CFRP sheets for the case of UPC beams.

The tendon strain prediction formula including the influence of the CFRP sheet is the pioneering proposal, easy to use and give accurate and reliable compared to the experimental data. The model and formula proposed in this thesis can supplement the design provisions for flexural strengthening UPC beams with CFRP sheets which are lacking in current standards.

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