

UNIVERSITY OF TEHRAN
UNIVERSITY COLLEGE OF ENGINEERING
FACULTY OF CIVIL ENGINEERING

FLEXURAL STRENGTHENING OF PRESTRESSED CONCRETE BEAMS USING UN-STRESSED AND PRE-STRESSED CFRP STRIPS

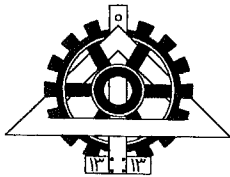
By:
Mohammad Reza Aram

Under supervision of:
Prof. Dr. M. Motavalli
Prof. Dr. M. S. Marefat

Co-Advisors:
Prof. Dr. S. Mohammadi
Christoph Czaderski

A thesis submitted to the Graduate Studies Office
in partial fulfillment of the requirements for
the degree of **PhD** in
Structural Engineering

Sep. 2007



دانشگاه تهران
پردیس دانشکده های فنی
دانشکده مهندسی عمران

تقویت خمشی تیرهای بتنی پیش تنیده با استفاده از نوارهای پیش تنیده و غیر پیش تنیده CFRP

نگارش:
محمد رضا آرم

اساتید راهنما:
دکتر مسعود متولی
دکتر محمد صادق معرفت

اساتید مشاور:
دکتر سهیل محمدی
کریستف چادرسکی

رساله برای دریافت درجه دکتری
در رشته مهندسی عمران - گرایش سازه

شهریور ۱۳۸۶

Abstract

Post-strengthening of reinforced concrete structures with Fiber Reinforced Polymer (FRP) plates, strips, fabrics and similar products is prevalent today. They can be used for the strengthening of concrete members in bending, shear or torsion as well as confinement. To take full advantage of FRP material, it is beneficial to apply prestressed FRP strips.

In this thesis, experimental, analytical and numerical investigation of prestressed concrete beams (small and large scale) strengthened using unstressed and prestressed CFRP strips is presented. Furthermore, Existing international codes and guidelines such as ACI, *fib*, ISIS, JSCE, SIA, TR55, etc. are presented and compared with the results from the experiments and calculations.

The gradient method was used for the anchorage of the prestressed CFRP strips. The results of the experiments showed that the gradient anchorage method was not effective for small beams because the gradient anchorage was in the shear spans with high shear stresses from loading. This method would be more effective for large span beams, like bridge girders, with enough of an un-cracked zone (anchorage length) or smaller shear stresses from loading.

In codes and guidelines plate end debonding can be avoided by limiting the FRP force at last crack. In order to prevent midspan debonding of the FRP plate, a limitation can be placed on the bond shear stress or the FRP strain. Large discrepancies in these limitations were seen in existing codes and guidelines. The FRP strain limitation is not accurate when the failure mode is debonding due to high shear stresses. The strain limitation is more accurate when the failure is debonding at flexural cracks. So the strain limitation should be combined with a suitable shear stress limitation to result in better correlation. The calculations showed that the tensile strength of concrete (f_{ct}) is convenient for shear stress limitation in combination with 0.008 strain limitation.

Different modeling solutions were described in this thesis such as cross-section analysis (CSA), closed form solutions, nonlinear finite elements analysis (FEA) and tension chord model (TCM). The tension chord model is capable of dealing with the nonlinear analytical modelling of bond shear stresses and slippage between reinforcements (cable, steel bar and laminate) and concrete. In this thesis the TCM was extended for prestressed concrete beams strengthened with FRP laminates. The main advantage of TCM is the possibility of calculating the slip between laminate and concrete in the pure bending region. Therefore the debonding failure load at flexural cracks can be deduced which is not possible with simple analytical methods such as cross-section analysis. However, TCM is not able to calculate debonding at shear cracks or strip end.

In experimental works of this investigation the slippage between FRP and concrete was measured. According to the existing models the debonding failure load is defined as the load at which the slip reaches the maximum allowable slip in the bond-slip relationship (S_{fl}) and the bond shear stress becomes zero. S_{fl} was measured 0.165 and 0.193 mm in the tests.

Besides mechanical and electronic strain gauges, three new approaches were also applied for strain measurements of CFRP strips which are: strain measurements using CFRP Resistance, Fiber Optic Sensors and Image Correlation. The CFRP Resistance strain measurement is more suitable for practical applications, but its results should be calibrated for each FRP type. Fiber Optic Sensors have advantages of small size and potential for structural monitoring with high resolution and accuracy. The Image Correlation method is more complex and not suitable for practical usages.