TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

DEPARTMENT OF CIVIL ENGINEERING

M. Sc. PROGRAM IN STRUCTURAL ENGINEERING

Thesis no: SS00126

ANALYTICAL STUDY OF FLEXURAL STRENGTHENING OF REINFORCED CONCRETE BEAMS BY USING EXTERNALLY BONDED CFRP SHEETS

RABINDRA KUMAR SHARMA

April, 2009

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A thesis submitted by
RABINDRA KUMAR SHARMA

In partial fulfillment of the requirement for the degree of

MASTERS OF SCIENCE
IN
STRUCTURAL ENGINEERING

April, 2009

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CERTIFICATE

This is to certify that the work contained in this thesis entitled "Analytical Study of Flexural Strengthening of Reinforced Concrete Beams by Using Externally Bonded CFRP Sheets", in partial fulfillment of the degree of Master of Science in Structural Engineering, as a record of research work, has been carried out by Mr. Rabindra Kumar Sharma (063/Mss/r/107) under our supervision and guidance in the Institute of Engineering, Pulchowk Campus, Lalitpur, Nepal. The work embodied in this thesis has not been submitted elsewhere for a degree.

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ABSTRACT

Externally bonding carbon fiber reinforced polymer (CFRP) sheets with an epoxy resin is an effective technique for strengthening and repairing reinforced concrete (RC) beams under monotonic loads. In this study, three types of beam were adopted. They are Laboratory scale Beam (4000x150x300 mm), Building Specific Beam (5000x300x450 mm) & Bridge Specific Beam (20000x500x1800 mm). A total of seventy eight RC beams were analyzed. For the study of effective percentage of CFRP, six control beams, eighteen beams reinforced with 0.17% to 1.0% CFRP corresponding to 0.33% rebar and eighteen beams reinforced with 0.17% to 1.0% CFRP corresponding to 0.75% rebar are analyzed. For the study of effect of offset of CFRP from support, twenty seven beams with 0% to 40% offset of CFRP from support corresponding to 0.5% CFRP & 0.33% rebar and nine beams with 0% to 40% offset of CFRP from support corresponding to 0.17% CFRP & 0.75% rebar on Laboratory scale beam are analyzed. The percentage of rebar and CFRP are expressed in terms of cross-section of beam and percentage of offset of CFRP is expressed in terms of span of beam. All specimens were subjected to a four-point bending test under monotonic loading where load, defection, mid-span strain and failure mode were recorded up to failure. Analysis of beam is done with the help of non-linear FEM software Marc2003.

From analytical study it was found that the load carrying capacity of the strengthened beam increases from 30% to 50% at cracking, 25% to 95% at yielding and 80% to 200% at ultimate, the increment of load carrying capacity of the beam depends on the geometry of the beam, percentage of rebar and percentage of CFRP. The failure mode of the beam depends on the amount of rebar and CFRP. From analysis it was found that the optimum percentage of CFRP for fully utilization is 0.5% corresponding to the 0.33% rebar and 0.17% corresponding to 0.17% rebar. The load carrying capacity of the beam, corresponding to the final deflection allowed in the design (IS 456-2000), can be increased from 12% to 80%. From analysis, it was seen that keeping offset of CFRP from the support more than 25% is not good. On the other hand, by keeping offset of CFRP less than 25%, it increases the cost only but not strength. With the increase in percentage of CFRP, the mid-span deflection of the beam is reduced. With the increase in offset of CFRP from the support more than 25%, the mid-span deflection of beam is increased.

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f_c’	=Maximum compressive strength of concrete
f_t	=Ultimate uniaxial tensile strength of concrete
E_c	=Elastic modulus of concrete
μ, ν	=Poisson’s ratio
β_t	=Shear transfer coefficient
f	=Stress of concrete at any strain ε
ε	=Strain of concrete
ε_o	=Strain of concrete corresponding to ultimate compressive strength
E_s	=Elastic modulus of steel
f_y	=Yield stress of steel
ν_{xy}	=Minor Poisson’s ratio
ν_{yx}	=Major Poisson’s ratio
E_x	=Elastic modulus of FRP in X-direction
E_y	= Elastic modulus of FRP in Y-direction
G	= Shear modulus of FRP

List of Abbreviations Used

FRP	=Fiber reinforced polymer
CFRP	=Carbon Fiber reinforced polymer
GFRP	=Glass Fiber reinforced polymer
AFRP	=Aramid Fiber reinforced polymer
RC	=Reinforced Concrete
Mc	=Cracking moment
My	=Yielding moment
Mu	=Ultimate moment
ΔMc	=Change in cracking moment
ΔMy	=Change in yielding moment
ΔMu	=Change in ultimate moment