



**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, deflection, 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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## List of Symbols

$f_c'$	=Maximum compressive strength of concrete
$f_t$	=Ultimate uniaxial tensile strength of concrete
$E_c$	=Elastic modulus of concrete
$\mu,$	=Poisson's ratio
$t$	=Shear transfer coefficient
$f$	=Stress of concrete at any strain
	=Strain of concrete
$\epsilon_o$	=Strain of concrete corresponding to ultimate compressive strength
$E_s$	=Elastic modulus of steel
$f_y$	=Yield stress of steel
$\nu_{xy}$	=Minor Poisson's ratio
$\nu_{yx}$	=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
$M_c$	=Cracking moment
$M_y$	=Yielding moment
$M_u$	=Ultimate moment
$\Delta M_c$	=Change in cracking moment
$\Delta M_y$	=Change in yielding moment
$\Delta M_u$	=Change in ultimate moment