EXPERIMENTAL ANALYSIS OF CURVED RC BEAMS STRENGTHENED WITH CARBON FIBRE FOR FLEXURAL AND SHEAR CAPACITY ENHANCEMENT

Ruwan Pathirana Dasith Sithira Premalal

(168920N)

Degree of Master of Science

Department of Civil Engineering

University of Moratuwa
Sri Lanka

January 2022

EXPERIMENTAL ANALYSIS OF CURVED RC BEAMS STRENGTHENED WITH CARBON FIBRE FOR FLEXURAL AND SHEAR CAPACITY ENHANCEMENT

Ruwan Pathirana Dasith Sithira Premalal

(168920N)

Thesis submitted in partial fulfilment of the requirements for the

degree Master of Science in Civil Engineering

Department of Civil Engineering

University of Moratuwa
Sri Lanka

January 2022

DECLARATION

I declare that this is my work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to the University of Moratuwa the non-exclusive right to reproduce and distribute the thesis, in whole or in part in print, electronic or other media. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature: Date:

The above candidate has carried out research for the Masters under my supervision

Name of the supervisor: Prof. (Mrs.) J.C.P.H. Gamage

Signature of the supervisor: Date:

ACKNOWLEDGEMENT

I would like to express my heartfelt gratitude to my research supervisor **Prof. (Mrs.) J.C.P.H. Gamage**, Senior Lecturer at the Department of Civil Engineering, University of Moratuwa for her continuous guidance and support extended throughout my research study period. The motivation provided by her held me to modify relevant parts effectively and to be inline with the time schedule to finish.

Next, I am thankful to the technical staff of Structural Testing and Building Materials Laboratory of the University of Moratuwa for their assistance and support extended during the experimental work.

Then I would like to thank my batch mates of MSc. Degree in Structural engineering 2016/2017, N.R.D. Senarathne and K.R.T.H. Indrachapa for immense support provided to me during beam casting and testing stages.

In addition, the overall arrangement of the research proceedings by Dr. H.M.Y.C. Mallikarachchi, Coordinator, MSc. in Structural Engineering is greatly appreciated. Also the assistance and encouragement given by Eng. S.D.G.L.Jayatilaka and Eng. N.D. Amarasinghe, Ceylon Electricity Board (CEB) to continue my research work during this period of 24 months immensely helped me to complete this research, parallel to work at CEB.

R. P. D. S. Premalal
MSc. Degree in Structural Engineering
Department of Civil Engineering
University of Moratuwa
31.01.2022

ABSTRACT

Among the concrete strengthening applications, Carbon Fibre Reinforced Polymer (CFRP) systems offer better mechanical properties than other alternatives, such as stronger tensile strength, stiffness, and durability. Most of the studies have been focused on strengthening or retrofitting straight Reinforced Concrete (RC) beams using CFRP, fewer on the horizontally curved out of plane loaded RC beams, which are present in novel featured structures worldwide. In contrast to straight beams, the curved beam behaviour possess combined effect of bending, torsion and shear where CFRP application requires a careful selection based on the intended capacity enhancement.

The experimental program includes total 6 nos. of RC beam specimens of fixed curvature casted, 2 beams weak under shear and 2 beams weak under flexure and their control beams. The CFRP strengthening was applied as relevant to evaluate the effectiveness of flexural and shear enhancement. The NSM CFRP plate application and end anchored NSM CFRP for flexure strengthening along with $45^0/135^0$ oriented CFRP fabrics at beam sides and increased area of fabric for shear strengthening was focused. The specimens were tested using four point bending test and the ultimate failure load, crack patterns, failure modes and deflection was observed.

The experimental results under flexure concluded that NSM CFRP enhance flexural strength according to the initial cracking load observations. Where end anchored CFRP fabric provided it contribute to additional flexure strength and reduce overall deflection by 23%. Ultimate load carrying capacity of NSM CFRP retrofitted beams were enhanced by 12.1% and 8.4% for respective application. NSM CFRP retrofitted beams showed, lesser crack density and widths. Propagation of the crack which was in the direction of NSM CFRP plate corners is restrained with the use of end anchored CFRP, although its effect over shear capacity enhancement is insignificant. The experimental flexural enhancements are 28.8% and 29.3% less than the theoretically predicted values by ACI 440.2R-17 guide, respectively for NSM CFRP only and end anchored beams, which may have occurred due to the contribution of additionally induced torsional stresses.

The experimental results under shear concluded that ultimate load carrying capacity of shear retrofitted beams were enhanced by 20 % and 30%. The influence of CFRP retrofitting is higher when the CFRP application area is increased at inner shear span. The experimental shear enhancements are 35.4% and 20.3% less than the theoretically predicted values by ACI 440.2R-17 guide, respectively for side laminated and extra side laminated beams. The intermediate debonding and induced additional torsional stresses may have caused this capacity reduction.

Table of Contents

List of Figures

List of Tables