Numerical Modeling of Hybrid FRP Strengthened Short Concrete Columns under Eccentric Compression

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Abstract

The paper deals with the numerical modelling of short columns under uniaxial eccentric compression. The objective of this study is to develop a non-linear microplane based model for evaluating the behavior of hybrid fiber reinforced polymer (FRP) strengthened columns under eccentric compression in terms of initial and post cracking stiffness, peak load, ultimate displacement and failure type. This study includes modelling three series of specimens namely (i) plain concrete columns (PC), (ii) control reinforced concrete (RC) column and (iii) hybrid FRP strengthened column which is a combination of near surface mounting (NSM) and external bonding (EB). The numerical results are compared with the experimental observations which are documented in the companion paper of authors [1]. Results reveal that the developed numerical model was able to predict the overall load – displacement behavior and failure mode in an accurate sense.

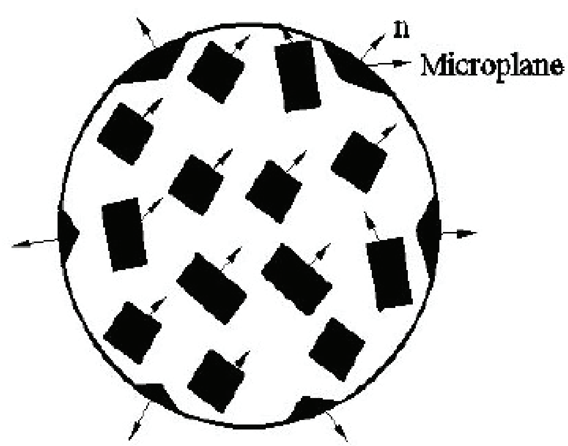
***Keywords*: Hybrid Strengthening; Microplane based Approach; Numerical Modelling; Short Columns.**

I. INTRODUCTION

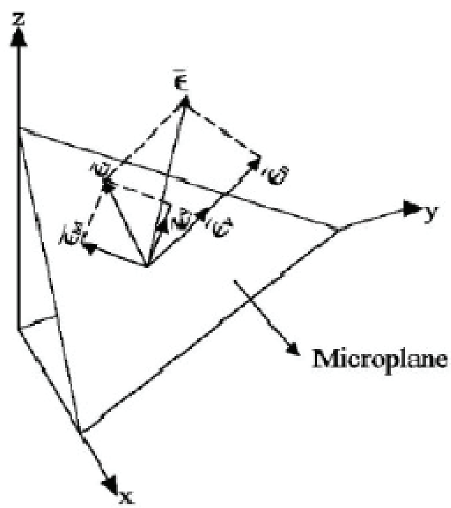
Reinforced Concrete (RC) columns are the key load bearing elements in a structure which often requires strengthening due to various reasons like (i) decrease in load carrying capacity of the structure (ii) additional service requirements (iii) change in the type of load (iv) natural/man-made disasters. Presence of significant amount of bending due to eccentricity can lead to reduction in strength, ductility and lead to sudden brittle failure. In such cases, strengthening of columns is essential to meet the design requirements. Strengthening of RC columns using FRP has been extensively studied by many researchers [2-5]. Moreover, modelling of RC elements using commercial finite element (FE) software has been carried out in the past. However, the accuracy of finite element predictions reduces due to cracking and associated brittleness. Moreover, FE models based on the continuum mechanics cannot represent the discontinuity. This study focuses on using a microplane based modeling approach for predicting the overall behavior of short columns under uniaxial eccentric compression.

II. MICROPLANE BASED MODELING OF CONCRETE

Microplane based modelling approach uses material characterisation represented by the relation between stress and strain components in the planes of various orientations. In this approach, the tensorial invariants are assumed to be located in an imaginary plane known as microplane[6-7]. The overall response can be calculated by superimposing all the components from the microplane i.e., the numerical integration over a number of microplane gives the macroscopic strain tensor which can be further integrated to determine the stress components (Fig. 1). More details of microplane based modeling can be found elsewhere [8-9].



(i) Integration Points in a Sphere



(ii) Strain Tensor in Microplane

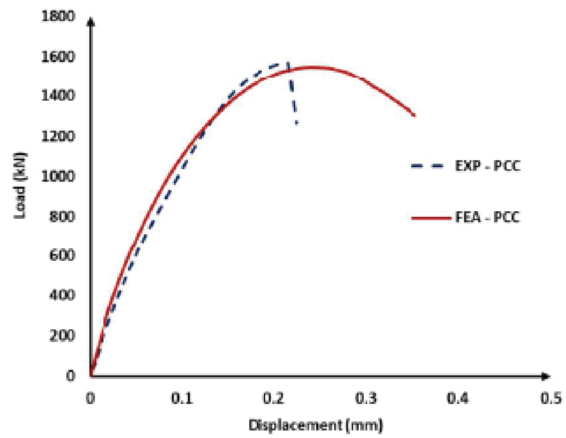
Fig. 1: Representation of microplane based modeling of concrete

III. MATERIAL PROPERTIES AND MODELING INPUTS

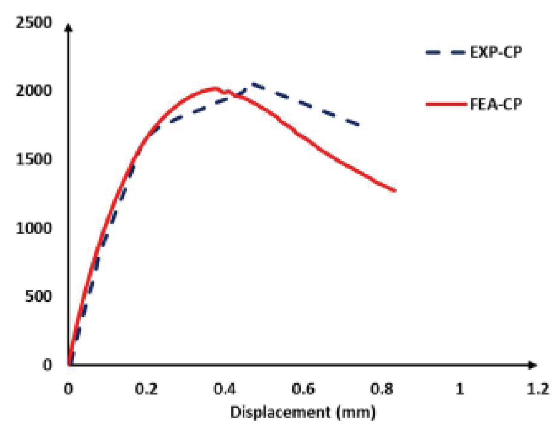
FE models are developed using a pre-processor FEMAP and the developed models are analysed using FE program MASA. Nonlinear behavior of concrete in tension and compression are given as input in the developed FE model. The stress-strain properties of steel obtained from the coupon test results are used in the modeling. In the case of FRP laminates, the behavior of the material is assumed linear elastic until rupture and the same is used for modeling. For modeling of FRP fabric, the properties of epoxy and fibers are defined separately which combines together to provide the composite properties. Mesh size of 25 mm is chosen from the mesh convergence study. Concrete is modeled using three dimensional eight node solid elements. Two node truss element is used to model the steel reinforcements. CFRP laminates are modeled as a two node rod element (truss element with bond definitions) in which the interface bond properties are defined. CFRP fabric is modeled as a three-dimensional solid element representing epoxy in which the carbon fibers are embedded as a one-dimensional truss element.

IV. RESULTS AND DISCUSSION

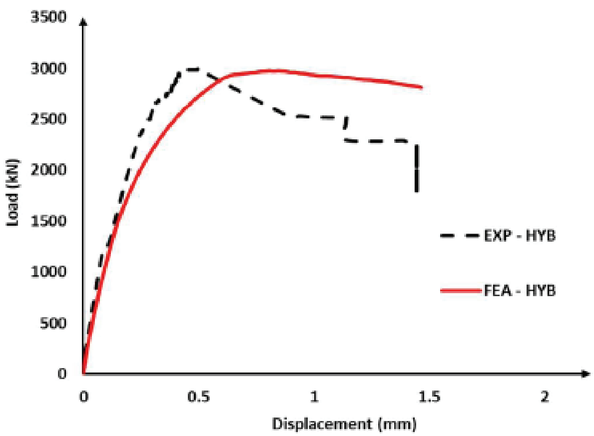
The numerical load –displacement behavior is compared with the test results and shown in Fig. 2. The developed FE model is able to predict the overall behavior in an accurate sense. The difference in peak strength for all the specimens are found to be less than 2% when compared to the experiments. Plain columns had sudden failure at a strain corresponding to its peak strength. Control RC column (CP) had a better peak strength and post-peak predictions. Hybrid strengthened specimens had improvement in peak strength and ductility by 46% and 64% respectively. The detailed experimental observations can be found elsewhere [1]. The failure mode observed for control column is compared with the experimental observation and shown in Fig. 3. The model had initial tension cracks after which the failure occurred near peak load due to severe crushing of concrete in the compression face (Fig. 3).



(i) Plain Concrete Column



(ii) Reinforced Concrete Column



(iii) Hybrid Strengthened Column

Fig. 2 Overall Load - Displacement Comparison of Short Columns

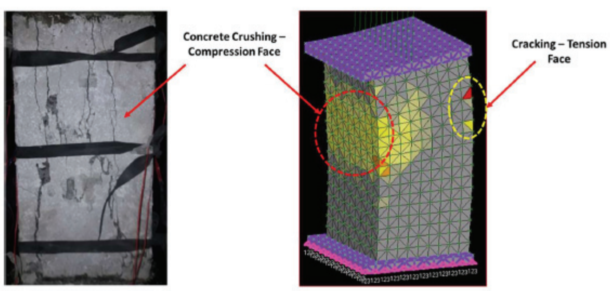


Fig. 3 Failure Mode Comparison of Control RC Column (CP)

V. SUMMARY

- The microplane based nonlinear finite element model developed in this study effectively captured the overall response of short columns under eccentric compression loading.
- Failure mode of columns are effectively captured using the developed numerical model.
- Hybrid FRP strengthened specimens had better performance in terms of improving the overall peak strength and ductility. The failure occurred due to rupture of FRP fabric in the compression face.

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