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Behaviour of Steel Reinforced Concrete Section with CFRP Wrapping Under Axial Compression

Mounika Kethireddy, Srija Juluru

Abstract*: *The composite structural element under study is a carbon fiber wrapped, steel I section reinforced concrete column. The wrapped CFRP is under tension and reinforced concrete under radial compression. The aim of the research is to determine the behavior of the composite structural element under axial loads. The Stress-strain characteristics and load bearing capacity of control and CFRP wrapped tubular columns were determined experimentally. Further, Finite element analysis of steel, reinforced concrete and CFRP wrapped concrete columns sections, was conducted using ANSYS Workbench 15.0 software. The experimental and analytical results were compared.

Keywords*: *CFRP tubular test, Composite column, stress-strain, Ultimate strength

I. INTRODUCTION

Recently various types of composite materials are being used to improve the strength, stiffness, ductility and dynamic resistance of RCC columns. Some of these composite columns are strengthen by fiber tubes, such as Kevlar, glass fiber, aramid, carbon fibers etc. During the past decade, the use of fiber reinforced polymer (FRP) composites have become one of the most successful confining composite material for reinforced concrete (RC) column [1]. There are two main types of composite columns namely; concrete encased within a steel section and steel section embedded as reinforcement in concrete columns which are tubular in general. In case of concrete-encased column, the steel will improve the shear resistance and it is effective against buckling locally and in overall. But the main disadvantage of this column is that it requires extensive formwork during construction. In case of steel section embedded RC tubular column, it requires no cage and formwork.. The continuous embedment of the steel section improves the ductility, strength, stiffness of normal and high strength concrete columns.

In recent years the carbon fiber composite materials are used to construct various types of structures such as off-shore platforms, buildings, bridges decks, columns, beam strengthening etc. Recently number of studies have been done to find the behaviour of concrete filled-fiber tubular columns [2][3]. Here an attempt has made to study the behavior of steel reinforced concrete-filled column with carbon fiber reinforced polymer (CFRP) tubes under axial compression. For this purpose numerical analysis and experimental works are carried out on control and filled CFRP tubular columns. In this paper a control column and a wrapped CFRP tubular column are studied under axial load by conducting numerical analysis using ANSYS Workbench 15.0. The results were validated by conducting experiments

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* Correspondence Author

Mounika Kethireddy, Post Graduate student at department of civil engineering, SRM University, Chennai, India

Srija Juluru, Assistant Professor at department of Civil Engineering, AVIT, Chennai, India. Email: srija.civil@avit.ac.in

II. EXPERIMENTAL PROGRAM

A. Materials

1. Mix design of concrete

The ordinary Portland cement is widely used among all cements. In this present work OPC 35 grade is used in concrete and it must satisfy the requirement and has a specific gravity of 3.1. The nominal coarse aggregate of size 12.5mm is used in concrete as per IS383-1970 and has a specific gravity of 2.66[4]. Here river sand, a suitable fine aggregate has been sieved through 4.75mm and confirmed to Zone 3 according to IS383-1970 specification. Fine aggregate is having a specific gravity of 2.57. The mix design for M35 grade conforming to IS 10262-2009 [5], for concrete mix ratio is 1:1.40:2.29:0.4 having a cement content of 493 kg/m3. The compressive strength of cube at 28 days for this type of concrete was 45MPa

2. Steel I section

In this present work the hot rolled ISMB100 steel I section is used for test, the geometrical dimensions for steel I section are given in fig.1 and tabulated in table I

Table-I: Geometrical parameters of steel I section

Section	h/mm	d/mm	b/mm
ISMB100	75	4.0	7.2

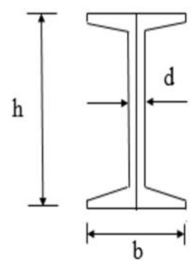

Fig.1 Cross section of steel I section

3. CFRP material

The carbon fiber reinforced polymer (CFRP) tubes with diameter of 125mm, thickness of 2mm and 500mm height of the column were used. The CFRP parameters are listed in Table II, as per the manufacture.

Table II: CFRP material properties

Item	Specification	Test data
Flexural strength (MPa)	≥700	718.6
Shear strength (MPa)	≥45	45.8
Tensile strength (MPa)	≥3000	3245
Tensile modulus of elasticity (MPa)	≥210000	224000
Elongation (%)	≥1.5	1.71
Weight per unit area (g/m2)	≥300	305

B. Fabrication, Instrumentation and Test procedure

To the required length the steel I section was machined. Before doing casting, one end was covered by plastic sheet At the center of the tube steel I section was inserted as given in fig.2,. Then the prepared concrete mix is poured. After de-moulding one of the specimens was wrapped by CFRP and properly bonded with epoxy. Before applying CFRP, the concrete column was wire brushed to remove dust particles and then the surface was roughened by the sand paper to make the surface evenly[6]. After that surface was coated with epoxy to enhance the bond between concrete and the CFRP material as shown in fig.3

Fig. 2. Casting and demoulding of control column

Fig. 3 Application of CFRP process

A 3000 KN capacity of Universal testing machine was used for the compression test for both control and CFRP tubular columns. The axial deformation and the strain corresponding to the applied axial compression load was measured at every regular intervals of 20 KN by a strain indicator and a dial gauge of accuracy 0.01mm. The test specimens and the location of strain gauge, dial gauge and strain indicator are shown in fig.4 and fig 5.

The axial load is applied in an increments of 20KN until ultimate load was observed and at each load increment the deformation and the strain readings was tabulated at the falling of load after the attainment of ultimate load[7].

Fig.4. Location for stain gauge and test setup for control column

Fig.5 Test setup for CFRP column in UTM

III. TEST RESULTS AND DISCUSSION

In order to understand behavior of reinforced concrete-filled column with carbon fiber reinforced (CFRP), two groups of columns were tested and results herein presented.. The control specimen and the reinforced concrete filled CFRP wrapped column are compared and discussed in this paper to consider the conduct of the two specimens.

A. Axial load-displacement curve

The test results were plotted between axial load and displacement is presented in fig.5. From the graph it is inferred that CFRP column withstands more load and has greater stiffness but gives less displacement on contrary to this the control specimen is able to carry less load and has lower stiffness although it gives higher displacement.

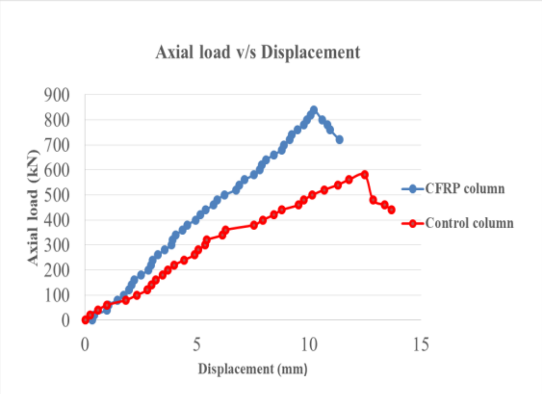

Fig.5.Comparison of the axial load-displacement curves between CFRP and control column

B. Failure modes

The nature of failure of control and CFRP wrapped columns are shown in fig.6 and fig.7. It was observed that there was an outward buckling in both the columns. This is due to outer concrete and inner steel I section arrangement. For control column at about 50-60 % of the ultimate load, cracking sounds were heard, indicating failure of concrete core. Similar observations are seen in literature[8]. For CFRP wrapped column, it was found that around 75% of the ultimate load there was a buckling, cracking along the fiber, due to stress developed in the periphery of the column.

Fig.6 Failure mode of control and CFRP columns

Fig.7. Failure of concrete core

IV. COLUMN MODELLING

A composite column is modeled in ANSYS Workbench 15.0 software which can perform design and analysis of column. Instead of CFRP wrapped column, CFRP tube enclosed column was modeled. The materials properties of steel I section, concrete, CFRP tube were included in the analytical model.

A. Material properties

1.Hot rolled Steel I section

The steel section is taken as a load bearing member in a composite column, and along with concrete it resist the external loading by interacting together by bond and friction. The steel section is modeled as an elasto-plastic material with strain hardening after yield strength. Modulus of Elasticity, Poisson's ratio, yield strength and strain hardening coefficient of the steel I section were chosen from steel tables and input to the material model.

2. Concrete

The concrete model assumes the compressive crushing failure mode, therefore the stress-strain characteristics of concrete core is required. The multi linear stress-strain characteristics of CFRP tube enclosed concrete modal is adopted in this investigation[9]. It estimates the strength of concrete and ductility. The model is useful to predict axial load-displacement and stress-strain curve. Poisson's ratio under axial compression during the elastic regime ranges from 0.15 to 0.29. Therefore Poisson's ratio is taken as 0.2 for concrete. The remaining properties of concrete are as in ANSYS workbench database.

B. Meshing and boundary conditions

Convergence study was undertaken to select the appropriate mesh size, for accurate results. A mesh size of 30mm was found optimal for concrete, CFRP tube and steel I section. The load was given along negative Z direction and column is fixed at end. Fig.8 shows the meshing of composite column.

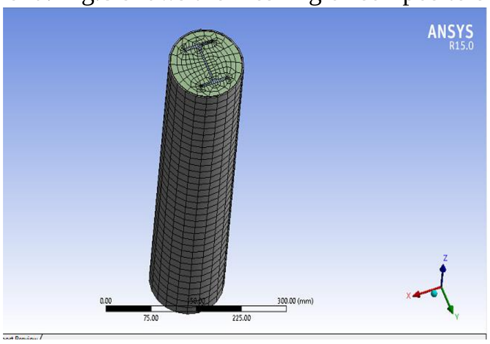

Fig.8.Meshing of composite column

V. MODAL VALIDATION

Based on the result from ANSYS Workbench, a graph is plotted between load-displacement it inferred that the effect of with and without CFRP column behaviors were compared in fig.9. Similar behavior is observed in both the columns during the initial stages.

The response of control column becomes non-linear at a lower load and reaches its ultimate load with greater displacement vis-à-vis CFRP tube enclosed column. The ultimate load for with CFRP column is much higher than the control column and therefore CFRP contributes the high load bearing capacity.

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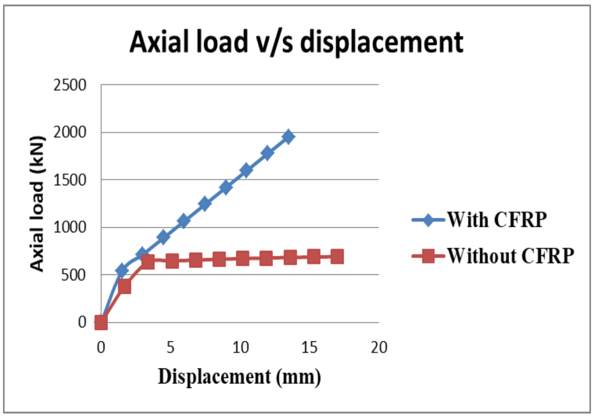

Fig.9 Comparison between the axial load-displacement curve between with and without CFRP

VI. CONCLUSION

The following conclusions are made after scrutiny of experimental and numerical analysis results:

1) Failure mode for both control column and CFRP column was the local buckling mode and it is in outer direction because of the concrete filled in CFRP tubular column.
2) Both the experimental and the analytical result show that the column with CFRP has more stiffness and load carrying capacity, than the column without CFRP.
3) It was also observed that the strain at the ultimate load increases when the column has been strengthened with CFRP tube.
4) Based on the validation it can be concluded that the steel reinforced concrete filled in CFRP tubular columns behave in a ductile manner under axially compressive loads.
5) From the above observations the wrapping of CFRP improves the structural element of steel embedded concrete column

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AUTHORS PROFILE

Mounika Kethireddy: She completed her Masters in Structural Engineering from S.R.M University in 2017, and currently working as Design Engineer, in WAPCOS Ltd., Chennai. She is involved in structural analysis of concrete and steel structures.

Srija Juluru: She completed her Masters in Structural Engineering from S.R.M University in 2017, and currently working as Assistant Professor, in AVIT, Chennai. She has conducted research in Concrete mixes using alternative materials.

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