Experimental Study on Load-Carrying Capacity and Failure Modes of Composite Double Skin Tubular Columns

Shaikh Ashfaq[1], D.V.Tanuja[2],

[1]*M.Tech Student, Department of Civil Engineering, Malla Reddy Engineering College, Secunderabad-500100, Telangana, India.*

[2]*Assistant Professor, Department of Civil Engineering, Malla Reddy Engineering College, Secunderabad-500100, Telangana, India.*

ABSTRACT:

The given research is an experimental research on the axial compressive performance of composite double-skin tubular columns, i.e. Steel-Confined Double Skin Tubular (SCDST) columns and Glass Fiber Reinforced Polymer-Steel Double Skin Tubular (GSDST) columns. The study is aimed at considering the impact of the following parameters on the load-carrying capacity, failure mechanism, and the load-strain behavior, including fiber orientation, diameter-thickness (Do/t) ratio, confinement thickness, hollow section ratio, and concrete grade. Axial compression tests were performed in the series on stub columns manufactured with different GFRP fiber orientations (0deg, 45deg and 0deg/90 deg) and with different confinement arrangements. It was found that experimental results showed that SCDST columns had a 30-40% higher ultimate load capacity than GSDST columns because of the better confinement of the steel. Nonetheless, GSDST columns exhibited high strength improvement when high fiber orientation and confinement thickness was used. GSDST specimens with an orientation of the fiber of 0deg and a Do/t ratio of 35 gave the highest load capacity of 1400 kN. Failures were different in nature with SCDST columns mainly failing through buckling of the outer steel tube, and GSDST column failing through fiber rupture, delamination, and splitting with respect to fiber orientation. The behavior of loads was nonlinear, and it was found to increase the level of stiffness and ductility with reduced Do/t ratios and increased confinement levels. Its results can be useful in optimizing composite tubular columns in case of high load and duration-sensitive structural issues.

Key words: Composite Columns, SCDST, GSDST, GFRP Confinement, Axial Compressive Behavior, Load-Carrying Capacity, Fiber Orientation.

I INTRODUCTION

The concept of composite structural systems has become extremely relevant in the contemporary civil engineering field because it allows incorporating the benefits of other construction materials into one efficient structural unit. Composite columns are stronger, better stiff, more ductile and could dissipate energy better as compared to traditional structures that are reinforced by concrete and steel. These are the features that predispose composite columns especially to high-rise buildings, bridges, offshore installations and seismic-resistant constructions. The interplay of steel, concrete, and fiber-reinforced polymers (FRP) is significant towards increasing load carrying capacity and slowing down the structural failure on extreme loading.

One of the biggest breakthroughs in the design of composite columns is concrete filled double skin tubular (CFDST) columns. These are columns that are filled with concrete between two concentric tubes made of steel making them have less self-weight, a higher section modulus, and enhanced stability. The local buckling of the steel is also slowed and the compressive strength and ductility of the concrete core are increased by the tightening of the steel tubes. CFDST columns have better seismic performance, increase in energy absorption and structural efficiency as compared to the traditional Concrete Filled Steel Tube (CFST) columns, making them a desirable choice when using several stories and earthquake-resistant buildings.

Structural behavior is further enhanced by the introduction of Steel-Confined Double Skin Tubular (SCDST) columns an inner tube made of steel is added to increase confinement and stiffness. The inner tube permits limited dilation of the concrete and enhances the resistance of the axial loads and postpones buckling of the outer tube. The columns have enhanced load-bearing capacity and regulated collapse of failure when compressed in the axial direction. SCDST columns are now being looked at as an alternative to be used in situations where the axial strength is needed and the deformation capability should be enhanced because of its strength and structural integrity.

During the last few years Glass Tubular: Glass Fiber Reinforced Polymer-Steel Double Skin Tubular (GSDST) columns have become a new alternative to all-steel systems. GSDST columns are columns that have an outer steel tube substituted or supplemented with a GFRP tube, which offers the effectiveness of confinement, but has such benefits as corrosion resistance, lightweight construction, and high strength to weight ratio. The parameters of strong influence on the performance of GSDST columns include the fiber orientation, confinement thickness, diameter to thickness ratio, and the concrete grade. These parameters can be optimized to a large extent to increase load capacity, stiffness, and ductility.

Tubular columns made of composites have the benefit of being structural despite compression in the axial direction but, as of today, its structural behavior has not been fully studied. The dissimilarity of the material arrangement, confinement, and geometrical variables results in varied failure, load strain responses. Thus, the proposed research is aimed at an experimental study of the axial compressive behavior of SCDST and GSDST columns. The main aim is to test their load carrying capacity, failure process and deformation behavior, which offers good information in designing and optimizing high performance composite column in structural engineering practice.

II SURVEY OF RESEARCH

It was an extensive experimental study of the compressive behavior on the circular, square and rectangular concentric concrete filled FRP tubes (CFFTs) during their axial compressive behavior (Ozbakkaloglu, 2013). The study quantified the effects of concrete strength, the properties of FRP materials, sectional shape and production techniques. It was found in the experiment that circular CFFT was highly confined and ductile compared to square and rectangular CFFT. It was observed that growth in concrete strength intensified stiffness but had a little impact on ductility due to extra brittle strength. During the research, it was also discovered that the manufacturing techniques did not have significant effects on the performance in the axis. Remarkably, it was observed that the axial performance of the FRP-wrapped cylinders of the concrete was equal to circular CFFTs. The paper reached a conclusion that the shape of the sections and the concrete strength are the significant parameters that govern the axial capacity and the deformation characteristics of the FRP-confined concrete columns.

Ozbakkaloglu and Oehlers (2013) studied the performance of the concrete filled FRP tube with a rectangular and square shape on the carbon fiber reinforced polymer (CFRP) tube. The parameters that were investigated during the study were such parameters as tube thickness, corner radius, aspect ratio and confinement effectiveness. The experiment outcomes revealed that the ductility and the post peaking behavior of the rectangular and square cross-sections were impaired by confinement of FRP to a great extent. The sharp corner confinement was however not as effective due to the concentration of stress. Failure and axial load capacity increased as tube thickness increased. The authors have brought out the effects of corner radius modification in order to increase the efficiency of confinement. The paper has determined that the strength and ductility of CFRP-confined concrete columns can be greatly enhanced in case of proper optimization of both geometrical and material parameters.

Mohamed and Masmoudi (2010) performed an experiment and monitored the behavior of the axial compressive of concrete-filled FRP tube under experiment where the FRP thickness, height to diameter ratio were varied. The number of specimens placed in the axial compression was 23. The results demonstrated that the failure primarily happened due to FRP rupture especially in a specimen where height and diameter ratio was in the range of 2 and 7. To arrive at a yield load the value was obtained to be approximately 54-60 percent of the ultimate load. High increment in load-carrying capacity and stiffness were achieved with thickening of FRP. The slenderness of the specimen was also revealed to decrease efficacy of confinement as indicated by the paper. The authors drew the conclusion that FRP tubes thickness and specimen geometry play a vital role in the control of the axial strength, as well as the failure mechanisms that affect concrete filled FRP tubular columns.

Vincent and Ozbakkanoglu (2015) also researched the axial compression behavior of circular concrete filled FRP tube through concretes of different grade of strength. The experiment program used 33 stub columns with various slenderness ratios. The results revealed that the increase in concrete strength contributed to the development of stiffness and maximum load capacity despite the fact that, the increase in the enlargement of the axial strain decreased with increasing slenderness ratio. The experiment indicated that short column confinement using FRP was superior in comparison to slender column confinement. The significant cause of failure was due to the rupture of FRP in the middle. The authors were able to conclude that slenderness ratio is a parameter of paramount importance to the axial deformation and confinement performance, it must be duly taken into consideration in the process of enacting the design of FRP-confined concrete columns under the conditions of the axial loading.

Mirmiran (1998) conducted an investigation on the behavior of columns made of FRP-constrained concrete of various shapes, lengths and bond conditions that were of different shapes. Circular, square, and rectangular specimens were used to find out confinement effectiveness. It was found that circular columns worked best in confinement since the compressive stress was evenly spread and the square and rectangular column had poor confinement at the corners. The ductility and the axial strength was significantly improved due to the mechanical bonding between the FRP and concrete. The lower confinement effectiveness of longer columns was due to the instability. The author had concluded that the shape of columns, bonding requirements and length have a significant influence on the performance of FRP-confined concrete in the axial sense and must be considered with utmost care when applying in designing.

Abdallah et al. (2018) focused on the effects on the axial compressive behavior of circular concrete-filled FRP tubular columns based on the slenderness ratio and FRP tube thickness. There was twelve slender specimens that were tested with a ratio of 8 to 20. Results showed that the columns with slenderness ratio greater than 14 fell due to global instability and the rest with low ratio due to local buckling and fracture of FRP. With a higher FRP tube thickness (2.9 mm to 6.4 mm), average load-carrying capacity improved and hoop stiffness improved by 50 percent and 55 percent, respectively. The study has reached the conclusion that both the slenderness ratio and the FRP thickness are the critical design parameters in the sense that optimal performance on axial is being met in FRP-confined concrete columns.

III MATERIALS AND METHODOLOGY

The paper is an experimental research that examined the axial compressive characteristics of composite double-skin tubular columns made of steel, concrete and glass fiber reinforced polymer (GFRP). Ordinary Portland Cement 53 grade (OPC) was used to prepare concrete grades M20, M30, M40 and M50 with the aid of fine aggregate in form of manufactured sand (M-sand) and coarse aggregate in form of crushed granite of coarse granite of sizes 12.5 mm and 20 mm. Mix design was done according to the guidelines of IS 10262:2019. The use of a carboxylic ether-based superplasticizer (Glenium SKY 8233) also helped to enhance workability and minimize water content. A rotating drum mixer was used to mix the materials and make them uniform.

The composite columns were made of GFRP tubes and steel tubes in the form of double-skin. Light sections as defined in IS 1161:1998 were used, which are mild steel tubes, and their mechanical properties have been checked in tensile coupon tests as per IS 1608 (Part 1):2018 by using a 1000 kN universal testing machine. External confinement was done using pre-manufactured GFRP tubes that were manufactured by filament winding process. The GFRP tubes were made in three fiber orientations 0 deg, 45 deg, and 0 deg /90 deg and 1.5 mm, 2.8 mm, 3.7 mm, and 5.2 mm thicknesses that represented a single to four FRP-layers.

In the experimental program, Steel-Confined Double Skin Tubular (SCDST) and GFRP-Steel Double Skin Tubular (GSDST) column specimen of different diameter/thickness ratios, hollow section/ratio ratios and confinement thickness was casted. The specimens were then tested under axial compression until failure after curing. One of the measurements was the load and strain responses to study load-carrying capacity, stiffness, and deformation behavior. The failure modes observed such as buckling, FRP rupture, delamination and axial splitting were noted with a keen eye to determine the effect of material configuration and geometric parameters on the column performance.

IV RESULTS EXPLANATION

The outcome of the axial compression test revealed that Steel-Confined Double Skin Tubular (SCDST) and Glass Fiber Reinforced Polymer-Steel Double Skin Tubular (GSDST) columns had high load-carrying capacity than traditional concrete columns. Nevertheless, SCDST columns were always found to have larger ultimate load capacity than GSDST columns because the inner steel tube provides additional confinement and stiffness to columns. It was observed through experiment that SCDST columns realized in-use that the axial strength was about 30-40 per cent greater, which showed that the steel confinement was effective in limiting dilation of concrete and postponing local buckling.

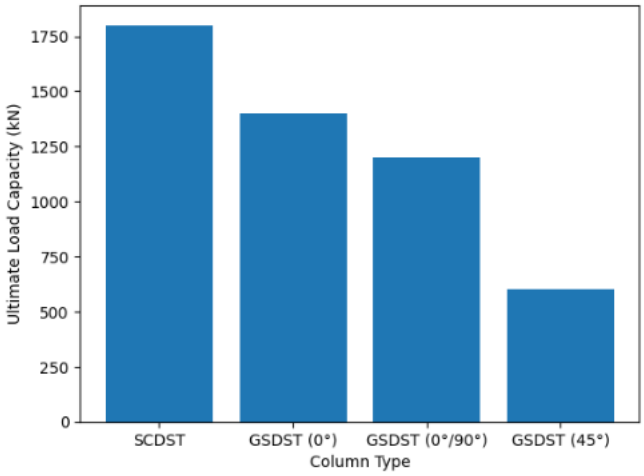

Fig. 1. Ultimate load capacity of SCDST and GSDST columns

This was because fiber orientation, diameter to thickness (Do/t) ratio and confinement thickness significantly affected the load bearing capacity of GSDST columns. Specimens having a Do/t ratio of 35 had better strength and stiffness than those having a Do/t ratio of 40. Of the various fiber orientations, GSDST columns with the fiber orientation of 0deg recorded the best ultimate load capacity of about 1400 kN. Specimens that are oriented in 0deg/90deg fiber orientation were also effective because of circumferential confinement and those that were oriented in 45deg fiber orientation exhibited a relatively lesser strength.

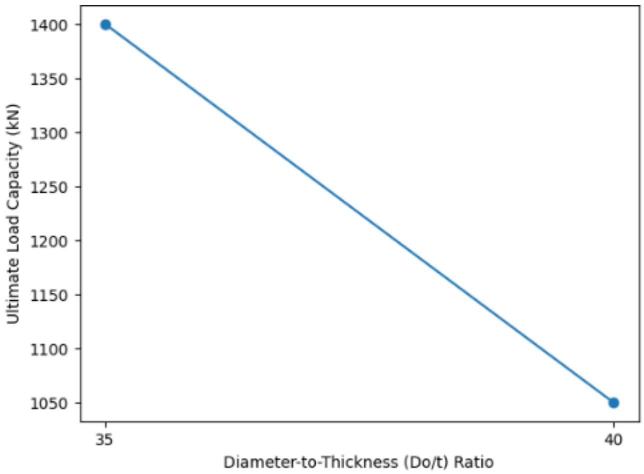

Fig. 2. Influence of Do/t ratio on axial capacity

Failure mode analysis demonstrated that there were differences in the behavior of the SCDST and GSDT specimen. The SCDST columns mostly collapsed because of the outward local buckling of the outer steel tube, and the inner tube postponed the crushing and instability of concrete. Conversely GSDST columns had failure modes including FRP rupture, fiber delamination, hoop tension failure and axial splitting with fiber orientation. Specimens that were oriented at 45deg fiber orientation failed prematurely as the fibers delaminated gradually but those whose fiber orientation was 0deg fiber orientation displayed progressive failure with improved energy absorption.

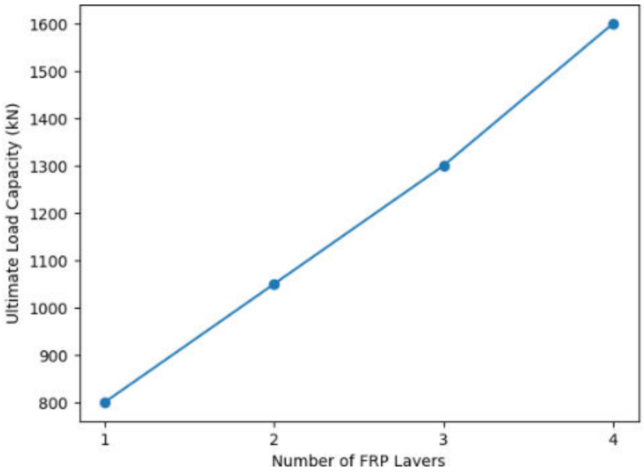

Fig. 3. Effect of FRP confinement thickness on load capacity

The axial load-strain response of all specifications was in the forms of initial linear elastic behavior and then nonlinear behavior in the process of cracking and confinement effects formation. The axial strain was always lower than the lateral strain which meant that there is good confinement action. Columns that were lower Do/t ratio and high confinement thickness had better stiffness and less axial deformation. Adding more layers of FRP led to an increment of strength by 20-30 percent per extra layer indicating a considerable contribution of the confinement thickness to the column performance.

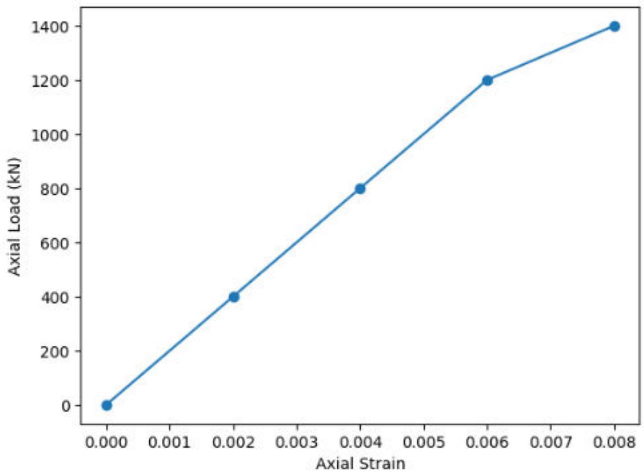

Fig. 4. Axial load–strain response of GSDST column

In general, the findings validate the fact that although SCDST columns have the highest resistance to axial loads, GSDST columns can yield considerable strength improvement in the event that the fiber orientation, confinement thickness, and geometric parameters are adjusted. The application of concrete of higher grades enhanced the rigidity, pliability and the capacity to carry loads even more. This indicates that the hybrid composite tubular columns are a promising structural element that can be utilized in areas where structure needs to achieve high strength, durability and controlled failure under the axial compression.

CONCLUSION

This was an experimental study that investigated the axial compressive behaviour of Steel-Confined Double Skin Tubular (SCDST), Glass Fiber Reinforced Polymer-Steel Double Skin Tubular (GSDST) columns. The findings indicate that SCDST columns have a higher ultimate load carrying capacity because the inner steel tube has better confinement that increases the strength by about 30-40 percent as compared to GSDST columns. Nevertheless, GSDST columns demonstrated high levels of performance when important parameters like orientation of fibers, diameter-thickness ratio, thickness of confinement, and the concrete grade wereSmartened. GSDST column specimens that attained the maximum load capacity had a Do/t ratio of 35 and an 0deg fiber orientation. Outer tube buckling in SCDST columns was found on failure mode analysis, whereas GSDST columns failed through FRP rupture, delamination, and axial splitting depending on the orientation of the fibers. Adding of more layers of FRP increased the stiffness, ductility and the axial strength. In general, the research establishes that the two columns SCDST and GSDST are effective composite structural elements, and GSDST columns have good potential corrosion resistance and designability to use in structures that are durable and of high performance.

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