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Effect of Different Lateral Reinforcement and its Spacing on Column Reinforced with Hollow Composite Sections

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Abstract: Hollow Concrete Columns (HCCs) are one of the preferred construction systems in civil infrastructures including bridge piers, ground piles, and utility poles to minimize the overall weight and costs. HCCs are also considered a solution to increase the strength to mass ratio of structures. However, HCCs are subjected to brittle failure behaviour by concrete crushing means that the displacement capacity and the strength after steel yielding in HCCs are decreasing due to the unconfined concrete core. Absence of the concrete core changes the inner stress formation in HCCs from triaxial to biaxial causes lower strength. A new type of Hollow Composite Reinforcing System (HCRS) has recently been designed and developed to create voids in structural members. This reinforcing system has four external flanges to facilitate mechanical bonding and interaction with concrete. Therefore, providing the inner Hollow Composite Reinforced Sections (HCRS) can significantly increase strength by providing a higher reinforcement ratio and confining the inner concrete core triaxially. The corrosion of steel is also a notable factor in the case of steel reinforced HCCs which became more critical because their outer and inner surfaces exposing more concrete surface area. An alternative reinforcement is Glass Fibre Reinforced Polymer (GFRP) bars, can overcome the brittle behaviour of steel reinforced HCC. In previous studies, HCC shows high strength capacity, when appropriate reinforcement in the form of longitudinal GFRP bars, laterally using GFRP spirals and internally using rectangular HCRS which provide enough inner confinement. However, the spirals laterally restrict the expansion of the concrete core and limit the buckling of the longitudinal bars, allowing the columns to keep resisting applied loads and gives maximum strength. Therefore, in this study, the spirals are replaced by discrete hoops as lateral reinforcement to analyse the effect on structural behaviour of HCC reinforced with rectangle shaped HCRS under axial load using ANSYS software. The results show that column laterally reinforced with spiral attained insignificant increase in strength than their counterpart specimens confined with hoops. So, the circular hoops were found to be as efficient in confining concrete as spirals in a column reinforced internally with rectangle shaped HCRS. The increase in volumetric ratio can be achieved by reducing the spacing between lateral reinforcement. So, this study also investigates the effectiveness of reducing the spiral spacing in HCC reinforced with HCRS, three models with lateral spacing of 50mm, 40mm and 30mm are modelled and analysed. The results show that columns with closer spiral spacing attained more axial stability.

Keywords: Hollow Concrete Column, Rectangular Hollow Composite Reinforced Sections, GFRP Spirals, GFRP Hoops, Nonlinear Static Analysis, ANSYS.

I. INTRODUCTION

Steel Reinforced Hollow Concrete Columns (HCCs) comprise a structurally efficient construction system for marine and offshore structures. Generating a hollow section reduces the amount of materials used in the columns and decreasing the self-weight, thereby it becomes structurally efficient. When HCCs are compared with Solid Concrete Columns (SCCs) with the same concrete area, the HCCS has enhanced structural efficiency, higher strength and stiffness to mass ratios. The structural behaviour of Reinforced Hollow Concrete Column (HCC) is controlled by several critical design parameters, such as inner to outer diameter ratio, reinforcement ratio, volumetric ratio, and concrete compressive strength. These parameters were more important in the case of HCCs than the Solid Concrete Columns (SCCs), due to the lack of concrete confinement in HCCs compared to SCCs. Hollow Composite Columns (HCCs) have low deformation capacity and experience a sudden decrease in strength causes brittle failure. This brittle failure behaviour is normally caused by defective design resulting in the buckling of the reinforcement or crushing of the inner unconfined concrete wall due to inadequate concrete strength and also due to yielding of longitudinal bars. HCCs with steel reinforcement can be detailed appropriately if the longitudinal bars are held by the concrete wall and confined by lateral reinforcement until failure. Therefore, the design parameters should be carefully considered to make the HCCs functional, sustainable and ductile.

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The corrosion of steel reinforcement is also a notable factor in the case of steel-reinforced SCCs and HCCs which became more critical in HCCs than SCCs because their outer and inner surfaces exposing more concrete surface area. Steel corrosion can reduce column strength and eliminate the confinement of the lateral reinforcement, causes brittle failure. So, there is a need to explore non-corroding reinforcing options that can overcome the limited strain and strength capacities of HCCs. One such alternative reinforcement is Glass Fibre Reinforced Polymer (GFRP) bar. The use of Glass Fiber Reinforced Polymer (GFRP) composite bars as internal reinforcement in concrete structures has now increased due to their superior mechanical and environmental resistance properties. This non-corrosive reinforcement can reduce the cost of the maintenance and repairing of reinforcement in concrete beams, slabs and walls due to their high strength and modulus of elasticity is almost like that of concrete. Recently, GFRP bars have been used in concrete columns also. In most of studies, concrete columns with longitudinal and transverse GFRP reinforcement under axial load shows better performance and more stable behaviour than that of steel reinforced columns after the concrete's peak strength has been reached. This can be attributed to the high strength and linear elastic behaviour of GFRP longitudinal and transverse reinforcement, which continue to resist axial and lateral loads, until failure without any decrease in their stiffness. Because of this behaviour, GFRP reinforcement can overcome the brittle behaviour of steel reinforced HCC. Similarly, the displacement capacity and the strength after steel yielding in HCCs are generally low due
to the unconfined concrete core. Absence of the concrete core changes the inner stress formation in HCCs from triaxial to biaxial causes lower strength. Therefore, providing the inner Hollow Composite Reinforced Section (HCRS) can significantly increase strength by providing a higher reinforcement ratio without causing concrete segregation and confining the inner concrete core triaxially. A new type of hollow Composite Reinforcing System (CRS) has recently been designed and developed to create voids in structural members. This reinforcing system has four external flanges to facilitate mechanical bonding and interaction with concrete. The Hollow Composite Reinforced Sections shown in Fig 1 was made by Composite Reinforcement Solutions in Australia. This material was manufactured through the pultrusion process and composed of glass fibre reinforcements (mostly unidirectional) embedded with vinyl ester resin. It also contains additives such as pigments, UV inhibitors, and fire retardant.

Fig. 1 Hollow Composite Reinforced Section (HCRS)

The previous studies are experimental investigations, concluding that Hollow Composite sections can eliminate the problem of void in Hollow Concrete Columns by confining the inner concrete core and also GFRP bars, spirals are a solution for the corrosion in steel reinforcement and both gives the sufficient longitudinal and lateral confinment for the column. The previous studies also shows that rectangle shaped HCRS with corner flanges will give better strength to hollow concrete column. This study is carried on rectangle shaped HCRS reinforced column to determine the effect of different lateral reinforcement configuration and various lateral reinforcement spacing.

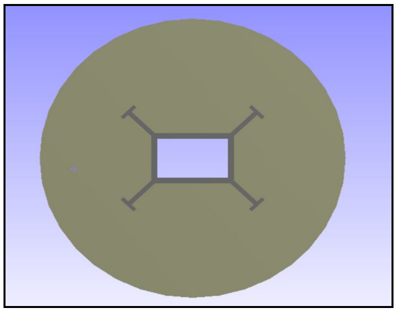

Fig. 2 Top view of column with rectangular HCRS

II. OBJECTIVE

A. To study the structural behaviour of column reinforced with rectangular HCRS by varying the lateral reinforcement configuration.

B. To investigate the effect of confinement on column reinforced with rectangular HCRS under various lateral reinforcement spacing.

III.METHODOLOGY

This work deals with the analysis of columns internally reinforced with Hollow Composite Reinforced Sections (HCRS) of different lateral reinforcement configuration and various lateral reinforcement spacing, using ANSYS software.

A. Structural Details

Hollow columns of 1m in height and diameter of 250mm. All columns are laterally reinforced with GFRP spirals of 10mm diameter for enough lateral confinement, longitudinally reinforced with six number of GFRP bars having 20mm diameter and reinforced internally with Hollow Composite Reinforced Section (HCRS). The details of column are provided in the Table I.

Table I Structural Details Of Circular Hollow Concrete Column

Geometry	Dimensions (mm)
Length of Column	1000
Diameter	250
GFRP Bars	6#20mm ø
GFRP Spirals	10mm @ 50mm spacing

The cross section of HCRS is given in Fig 2. The cross section of HCRS is rectangular and it has four external flanges. The flanges provide enough bonding with concrete. The shape of flanges and its area is same for all specimens.

B. Material Properties

The materials used in column analysis are M30 grade concrete, Hollow Composite Sections (HCRS), GFRP bars and spirals are shown in Fig 3. The properties of these materials are given in the Table III and Table IV.

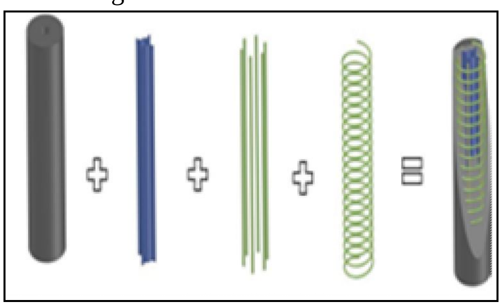

Fig. 3 Materials used in analyzing the column specimens

Table II Material Properties Of Concrete And Hcrs

Materials	Poisson's Ratio(μ)	Elastic Modulus (MPa)	Compressive strength (MPa)
Concrete	0.18	27477	30.2
HCRS	0.29	32200	120.4

Table III Material Properties of GFRP Bars And Spirals

Materials	Poisson's Ratio (μ)	Elastic Modulus (MPa)	Tensile strength (MPa)
GFRP Bars	0.25	60500	1270
GFRP Spirals	0.25	62500	1315

C. Modelling

The models are created using ANSYS 18.1 software package. The modelling of the column is done by using SOLID 65 element type for concrete, Hollow Composite Reinforced Section (HCRS) using SHELL 181, Glass Fibre Reinforced Polymer (GFRP) bars, spirals and hoops using LINK 180. Two models of Hollow Concrete Column having same dimensions, reinforcement and material properties.

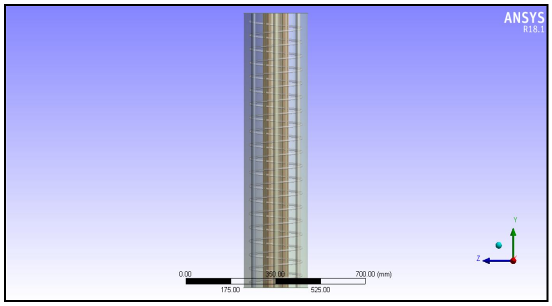

Fig. 4 Model of column with lateral hoops

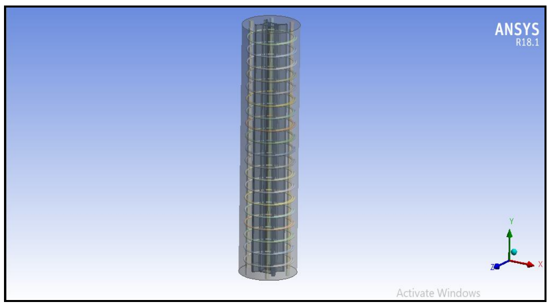

Fig. 5 Model of column with lateral hoops

D. Meshing and Loading

It is very important to select the mesh size in Finite Element Analysis. All columns are modelled using quadrilateral mesh. The element size of mesh provided for concrete and HCRS is 20 mm. Load is applied as displacement according to displacement convergence method. Displacement of 30 mm is given as axial load on the top area of all column with a fixed support condition.

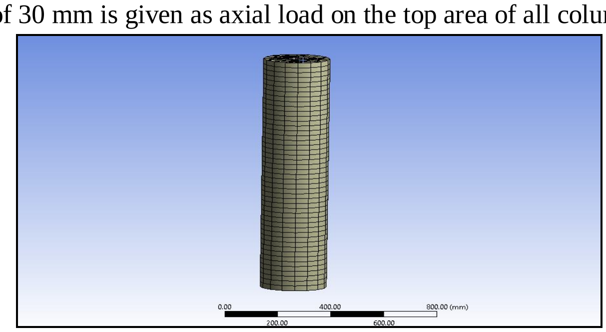

Fig. 6 Meshing

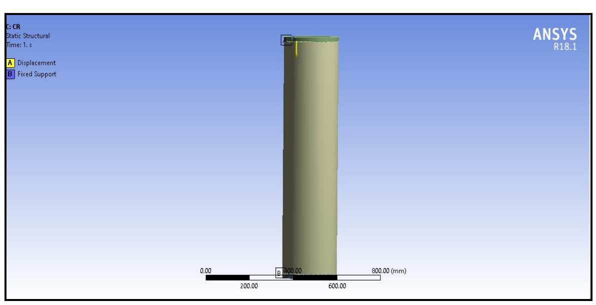

Fig. 7 Loading and Boundary Condition

E. Analysis

Static structural analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads. Static structural analysis is carried out in ANSYS software. Deformation and load carrying capacity is studied.

IV. RESULTS AND DISCUSSIONS

A. Column reinforced with HCRS by varying Lateral Reinforcement Configuration

The maximum load carried by the columns reinforced with Hollow Composite Reinforced Sections under various lateral reinforcement configuration such as spiral and hoop were considered. The load and deformation values are given in Table V. The deformation diagrams are shown below.

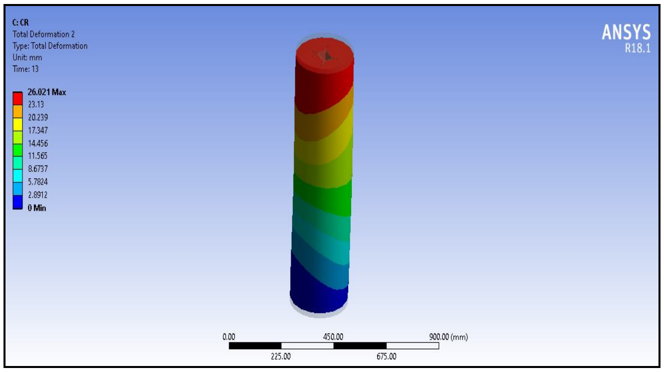

Fig. 8 Deformation diagram of column with lateral hoops

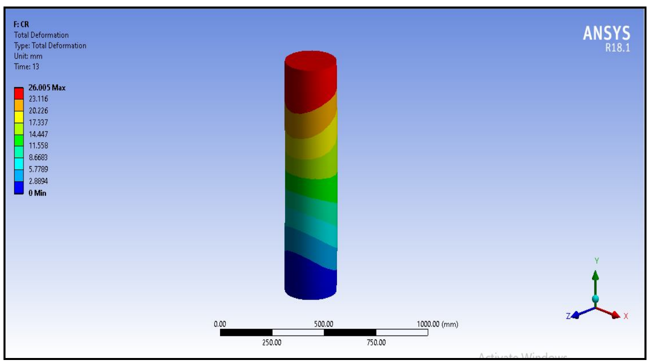

Fig. 9 Deformation diagram of column with lateral hoops

Table IV Maximum Force and Deformation of Column With Different Lateral Reinforcement Configuration

Type of specimen	Load(kN)	Deformation(mm)
Column with lateral spirals	2867	26.051
Column with lateral hoops	2753	26.005

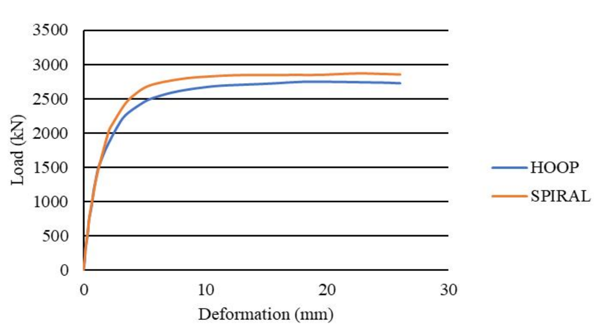

Fig. 10 Load Deflection Curve

The column laterally reinforced with spiral attained insignificant increase in strength than their counterpart specimens confined with hoops. So, the circular hoops were found to be as efficient in confining concrete as spirals in a column reinforced internally with HCRS. Both spirals and hoop can be used as lateral reinforcement according to situations. Because both have importance in seismic critical elements and seismic design.

B. Column Reinforced with HCRS by Varying Lateral Reinforcement Spacing.

From previous analysis spirals as lateral reinforcement shows better performance than hoop. The parameters such as volumetric ratio ρ_v and spacing between lateral reinforcement was the second most important parameter in case of Hollow Concrete Column. Providing high volumetric ratio increases the resistance of the lateral reinforcement by confining the concrete core to delay the failure and/or increase the axial strength capacity in advance of the characterized strength. The increase in ρ_v by reducing the spacing of the lateral reinforcement was found to yield higher ductility than increasing the diameter of the lateral reinforcement. This is because reducing the spacing of the lateral reinforcement confined the concrete while increasing the crushing strength of the concrete core and the buckling strength of the longitudinal bars.

It is therefore essential to determine the effects of reducing spiral spacing on the behaviour of HCCs reinforced internally with Hollow Composite Reinforced Sections and longitudinally with GFRP bars. The modelling details, meshing and loading is like the previously modelled columns by considering the lateral reinforcement configuration with different spiral spacing such as 50mm, 40mm and 30mm for each model.

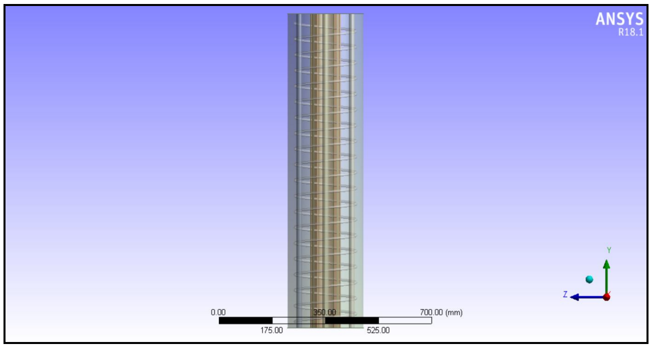

Fig. 11 Model of column with spirals of 50mm spacing

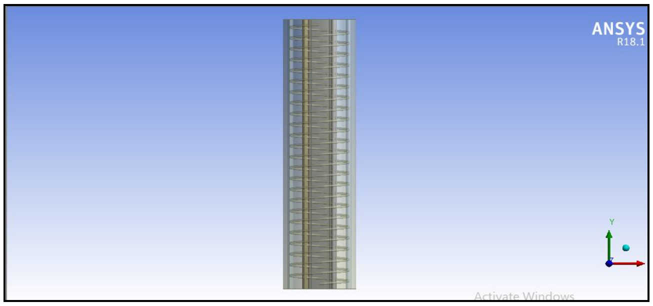

Fig. 12 Model of column with spirals of 40mm spacing

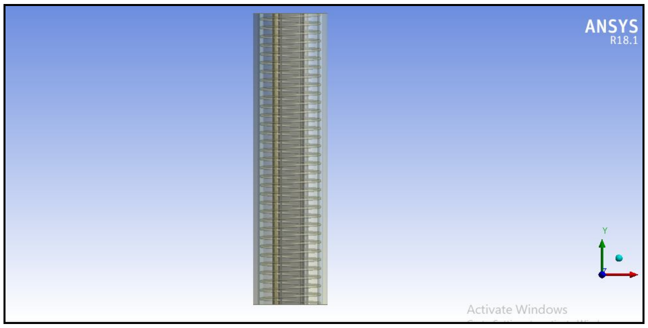

Fig. 13 Model of column with spirals of 30mm spacing

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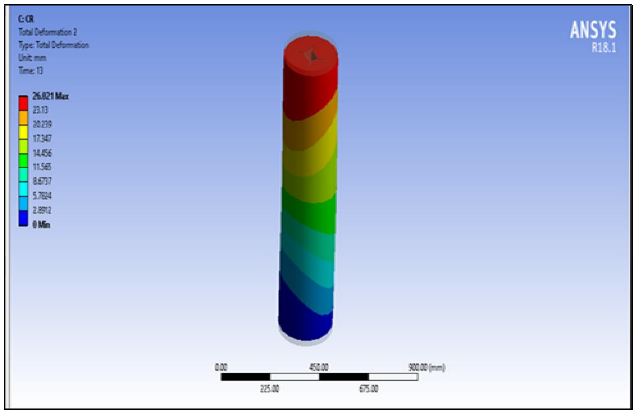

Fig. 14 Deformation diagram of column with spirals of 50mm spacing

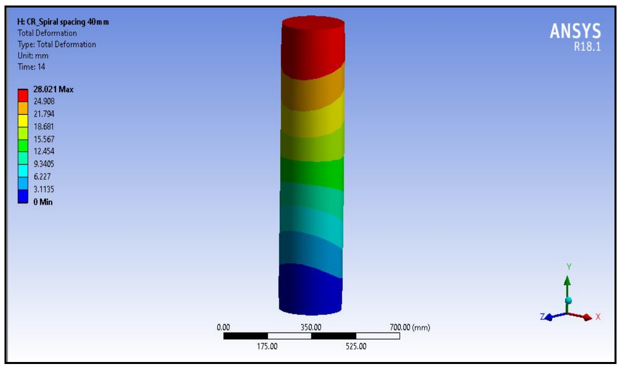

Fig. 15 Deformation diagram of column with spirals of 40mm spacing

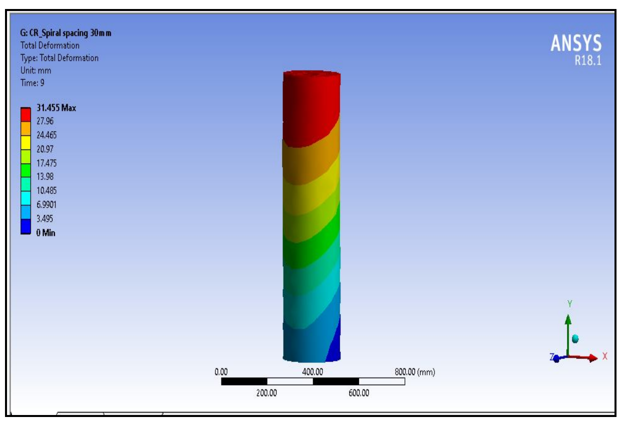

Fig. 16 Deformation diagram of column with spirals of 30mm spacing

Table V Maximum Force And Deformation Of Hollow Concrete Column With Different Lateral Reinforcement Spacing

Spiral Spacing	Load (kN)	Deformation (mm)
50	2867	26.051
40	3070	28.051
30	3320	31.445

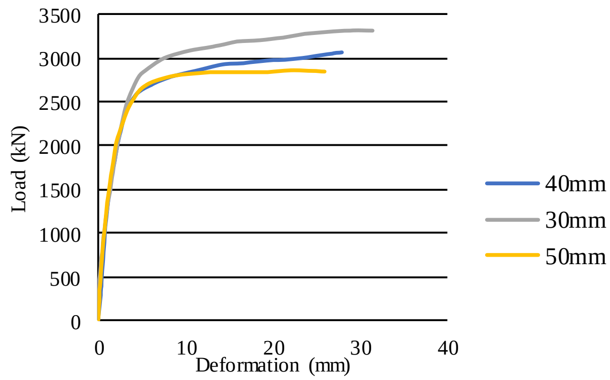

Fig. 17 Load Deflection Curve

The spiral spacing is a critical design parameter that control the behaviour of Hollow Concrete Column such as the load displacement, confined strength, and ductility behaviour. Here the column laterally reinforced with spirals with spacing of 30mm attains 7.5% higher strength than that of column with spiral spacing of 40mm. Also, when comparing with that of column having spiral spacing of 50mm, it carries 13.64% more load. So, the columns with closer spiral spacing, however, had more axial stability than those columns with wider spiral spacing due to the early activation of confinement.

V. CONCLUSIONS

Hollow Concrete column is analyzed in ANSYS software and the results were compared.

A. The column laterally reinforced with spirals attained only 3.97% higher strength than their counterpart specimens confined with hoops. So, the circular hoops were found to be as efficient in confining concrete as spirals.
B. The load deflection characteristics of both are almost same. In conclusion, both spirals and hoop can be used as lateral reinforcement according to situations. Because both have importance in seismic critical elements and seismic design.
C. Column laterally reinforced with spirals with spacing of 30mm attains 7.5% higher strength than that of column with spiral spacing of 40mm, 13.64% more load than 50mm.
D. Columns with closer spiral spacing, however, had more axial stability than those columns with wider spiral spacing due to the early activation of confinement.

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