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Analysis of Concrete Column Reinforced Internally 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 newly developed HCRS which provide enough inner confinement. Therefore, this study aims to determine the effect of HCRS of different cross sections and also the effect of change in position of its flanges on the axial performance of HCC analytically using ANSYS software.
Keywords: Hollow Concrete Column, Hollow Composite Reinforced Sections, GFRP bars, GFRP Spirals, 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. 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. Also the GFRP bars and spirals are a solution for the corrosion in steel reinforcement and both gives the sufficient longitudinal and lateral confinment for the column. So the study is to analytically evaluate the confining ability of Hollow Composite Reinforced Sections (HCRSs) by varying its cross section and by varying the position of flanges on these cross sections.

II. OBJECTIVE

A. To study the structural behaviour of Hollow Concrete Column internally reinforced with Hollow Composite Reinforced Section (HCRS) of different cross sections such as circle, square and rectangle.

B. To study the structural behaviour of column by varying the position of flange section of Hollow Composite Reinforced section (HCRS).

III.METHODOLOGY

This work deals with the analysis of columns internally reinforced with Hollow Composite Reinforced Sections (HCRS) of different cross sections, different position of flanges, 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

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The cross section of HCRS is given in Fig 2. The cross section of HCRS is circular and it has four external flanges. The flanges provide enough bonding with concrete. In order to determine the structural behaviour of column reinforced with Hollow Composite Sections (HCRS) of different cross sections, circular, square and rectangle shapes are selected for analysis and the areas of these cross sections are kept constant. The details are provided in Table II. The shape of flanges and its area is same for all specimens.

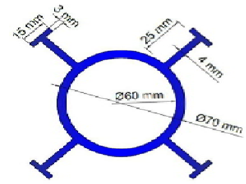

Fig. 2 Cross section of HCRS

Table II Dimensional Details of HCRS

Shape of HCRS	Size (mm)	Area of flanges (mm^2)	Total area (mm^2)
Circular	D_o-70 Di-60	580	1601
Square	56.05 x 56.05 46.05 x 46.05	580	1601
Rectangle	67.1 x 45 57.1 x 35	580	1601

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.

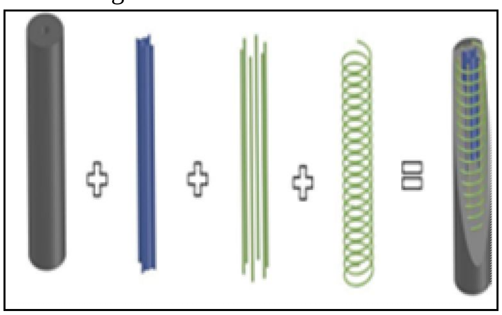

Fig. 3 Materials used in analyzing the column specimens

Table III 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 IV 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

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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 and spirals using LINK 180. Three models of Hollow Concrete Column having same dimensions, reinforcement and material properties. In order to analyse the structural behaviour of column reinforced with Hollow Composite Reinforced Section (HCRS) of different cross section, circular, square and rectangle shaped HCRS reinforced columns are modelled. The area of these cross sections is kept constant. The shape of flange sections of (HCRS) and its area is same for all models.

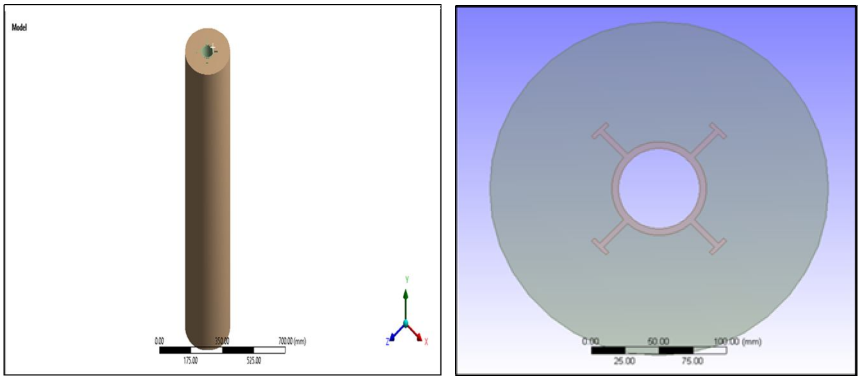

Fig. 4 Model and top view of column with circular HCRS

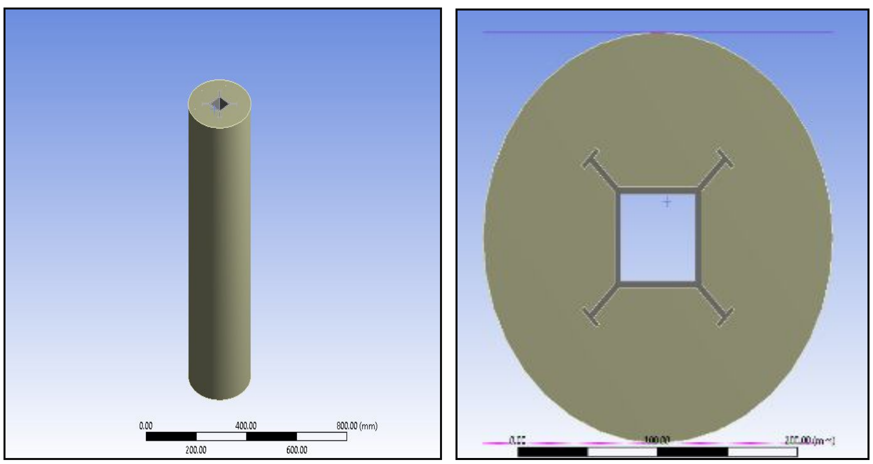

Fig. 5 Model and top view of column with square HCRS

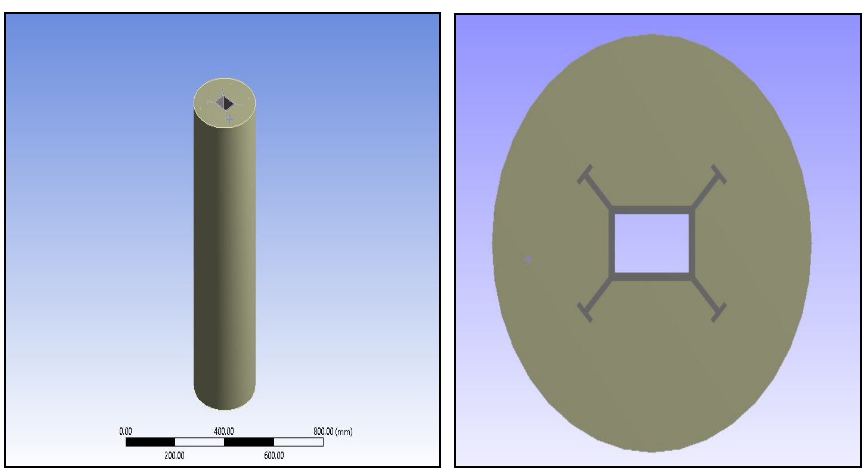

Fig. 6 Model and top view of column with rectangular HCRS

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.

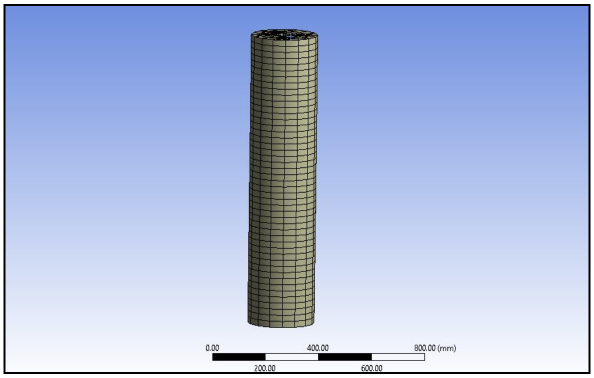

Fig. 7 Meshing

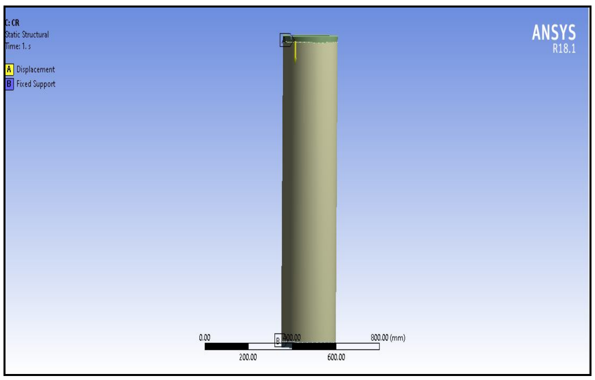

Fig. 8 Loading and Boundary Condition

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 of Different Cross Sections

The maximum load carried by column reinforced with different shaped HCRS is considered to determine the effective shape. The load and deformation values are given in Table V. The deformation diagrams of circular concrete hollow column reinforced with circular, square and rectangle shaped HCRS are shown below.

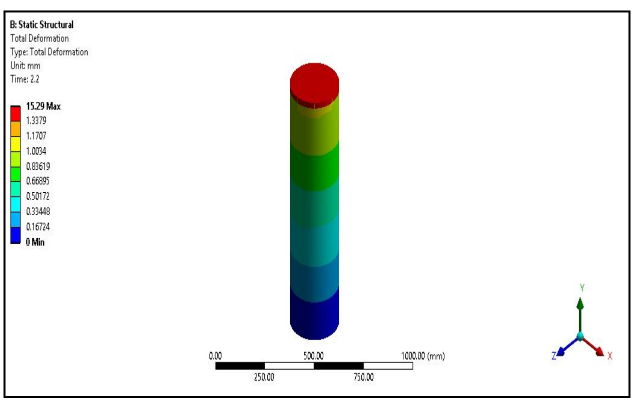

Fig.9 Deformation diagram of column with circular HCRS

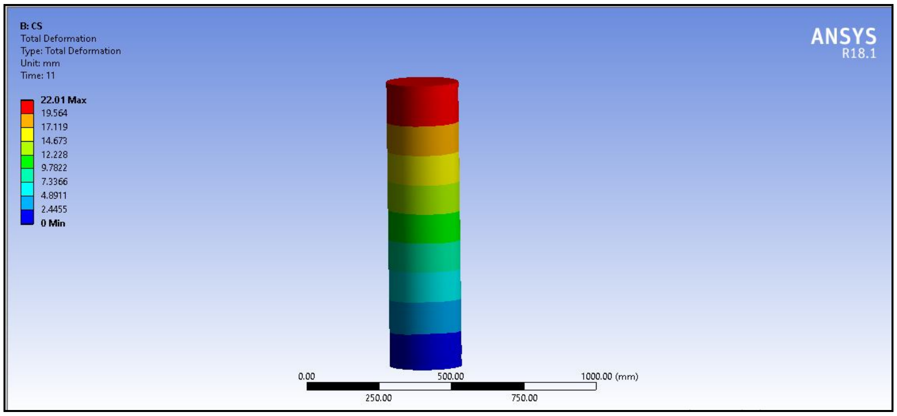

Fig. 10 Deformation diagram of column with square HCRS

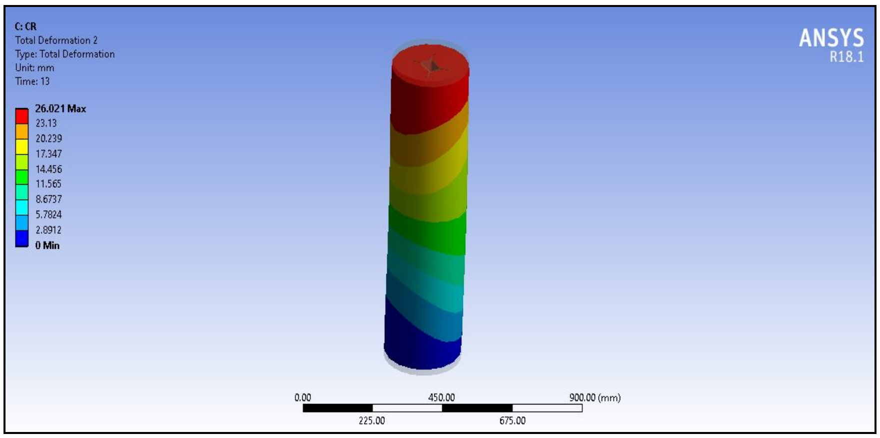

Fig. 11 Deformation diagram of column with rectangle HCRS

Table V Maximum Force And Deformation of Hollow Concrete Column with Different Shaped HCRS

Type of specimen	Load(kN)	Deformation(mm)	Stiffness (kN/mm)	Moment of Inertia (mm^4)
Column with Circular HCRS	2132	15.29	452.94	542415.6
Column with Square HCRS	2620	22.01	1493	447725.4
Column with rectangular HCRS	2867	26.051	1593	589924.8

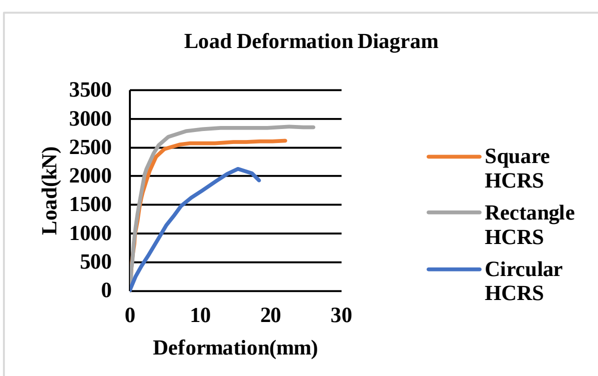

Fig. 12 Load Deflection Curve

Column internally reinforced with rectangle shaped HCRS have better load carrying capacity and undergo large deformation compared to that of square and circular HCRS. Column with rectangle shaped HCRS carries 25.6% more load as compared to circular shaped HCRS and 8.61% more load than square shaped HCRS. The stiffness of rectangle shaped HCRS confined column is higher than that of other two columns. Also, the moment of inertia is greater about one of its axes of rectangle shaped HCRS increasing the strength of column under axial loading and making more better than others.

B. Column Reinforced with HCRS of flanges in Different Position

The results from previous analysis show that the column internally reinforced with rectangle shaped HCRS have better load carrying capacity and undergo large deformation compared to that of square and circular HCRS. Further studies are carried out on that column. However, the flange sections of HCRS have a greater influence on the strength increase in the column because it provides enough bonding with the concrete. So, there is a need to study the effect in structural performance of column by varying the position of these flanges in HCRS. Here the modelling of column having same structural and material properties as previously modelled columns is done by varying the position of flange section of HCRS from center portion to the middle portion of its cross section. The model of the column reinforced with HCRS of middle flanges are given below which is analyzed using same mesh, load and support condition mentioned earlier. Static structural analysis is carried out in ANSYS software. Then maximum load and deformation is compared with column having HCRS of corner flanges mentioned earlier.

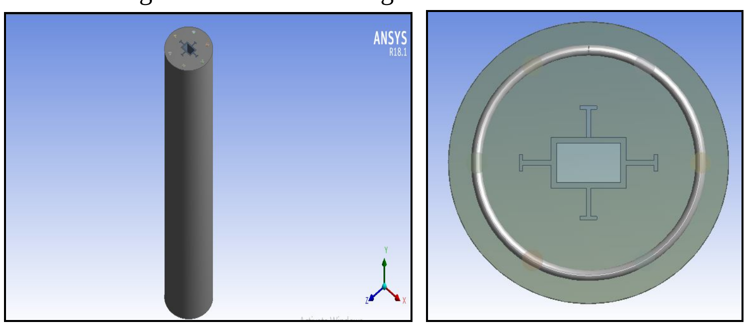

Fig. 13 Model and top view of column with rectangle HCRS of middle flanges

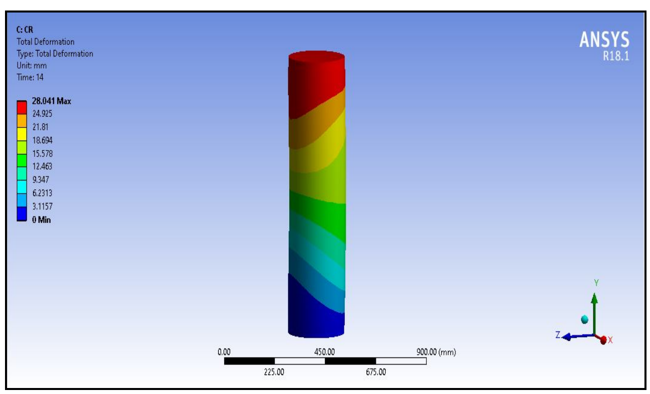

Fig. 14 Deformation diagram of column with HCRS of middle flanges

Table Vi Maximum force and Deformation of Column Reinforced with HCRS Having Flanges On different Positions

Type of Specimen	Load (kN)	Deformation (mm)	Contact Area (mm^2)
Column with rectangle HCRS having corner flanges	2867	26.051	545570
Column with rectangle HCRS having middle flanges	2758	25.185	536200

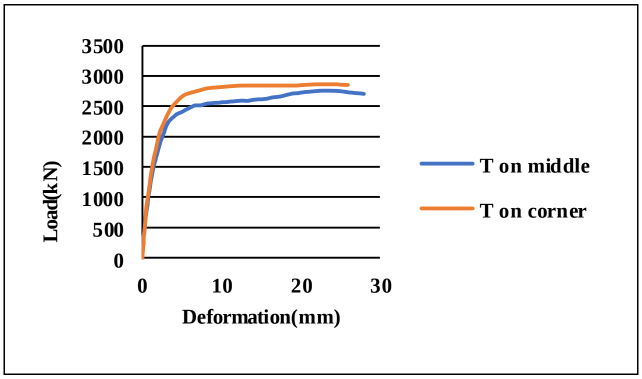

Fig 15 Load Deflection Curve

The column reinforced with HCRS of corner flanges carries only 3.8% more load as compared to column with HCRS of middle flanges. Also, the contact area covered by column with HCRS of corner flanges are 1.71% more than its counterpart. So, there is a slight difference in the case of load capacity of column and HCRS bonding with concrete for both cases. So, flanges on middle and corner have similar effect. The stiffness of column with HCRS flanges on middle portion is higher than that of column with flanges on corner, making efficient as those flanges on corner.

V. CONCLUSIONS

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

A. Hollow Concrete Column reinforced internally with rectangular HCRS shows better load carrying capacity and undergo large deformation compared to other columns.
B. Column reinforced with rectangle shaped HCRS carries 25.6% more load as compared to circular shaped HCRS and 8.61% more load than square shaped HCRS reinforced column.
C. The stiffness of rectangular HCRS reinforced column is also higher than that of columns reinforced with square and circular HCRS. Since moment of inertia about one axis is greater for rectangular HCRS, an effective shape for HCRS is rectangle than other two cross sections.
D. The column reinforced with rectangle HCRS of corner flanges carries only 3.8% more load as compared to column with rectangle HCRS of middle flanges. Also, the contact area covered by column with HCRS of corner flanges are 1.71% more than its counterpart.
E. So, there is a slight difference in the case of load capacity of column and HCRS bonding with concrete for both cases. So, flanges on middle and corner have similar effect.

VI. ACKNOWLEDGMENT

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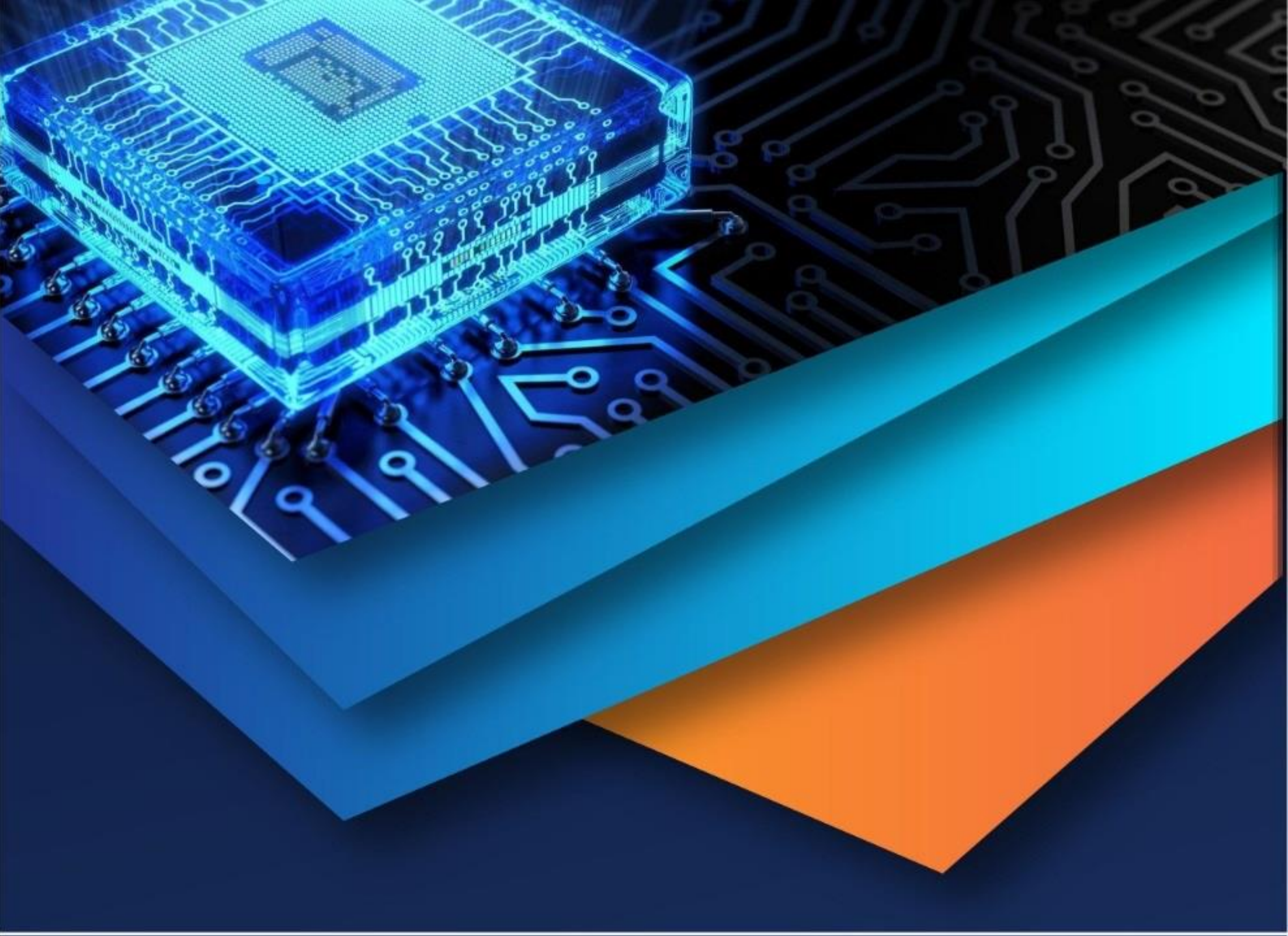

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