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Study on behavior of concrete encased composite columns under axial load.

Estudio del comportamiento de pilares mixtos revestidos de hormigón bajo carga axial.

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ABSTRACT

A Concrete encased steel (CES) composite column is an alternative to pure steel reinforced column. The application of such columns can be found in basement construction and metro railway stations. In this study, structural behavior of both partially encased composite (PEC) column and fully encased composite column (FEC) were investigated. A total of 12 specimens of partially encased steel composite column and fully encased composite column were analyzed. Analysis of columns was done in Ansys workbench. Steel profile used in the columns is H-section and cruciform section. The effects of some key parameters such as steel contribution ratio, end condition, and thickness of steel profiles on the performance of proposed column sections were investigated in terms of load-deformation relationship and strain behavior. Partially encased composite columns are found to be most efficient compared to fully encased composite columns. Flange thickness has a greater influence on load carrying capacity of the composite columns.

Keywords— Encased composite column, transverse links, flange width, steel contribution ratio.

RESUMEN

Una columna compuesta de acero revestido de hormigón (CES) es una alternativa a la columna reforzada de acero puro. La aplicación de tales columnas se puede encontrar en la construcción de sótanos y en las estaciones de metro. En este estudio, se investigó el comportamiento estructural tanto de la columna compuesta parcialmente revestida (PEC) como de la columna compuesta totalmente revestida (FEC). Se analizaron un total de 12 muestras de columna compuesta de acero parcialmente revestida y columna compuesta totalmente revestida. El análisis de las columnas se realizó en el banco de trabajo Ansys. El perfil de acero utilizado en las columnas es de sección en H y sección cruciforme. Se investigaron los efectos de algunos parámetros clave, como la relación de contribución del acero, la condición del extremo y el espesor de los perfiles de acero sobre el rendimiento de las secciones de columna propuestas, en términos de la relación carga-deformación y el comportamiento de deformación. Las columnas compuestas parcialmente revestidas resultan más eficientes en comparación con las columnas compuestas totalmente revestidas. El espesor de la brida tiene una mayor influencia en la capacidad de carga de las columnas compuestas.

Palabras clave: columna compuesta encajada, eslabones transversales, ancho de ala, relación de contribución de acero.

INTRODUCTION

Concrete encased steel (CES) composite columns are an alternative to pure steel and reinforced concrete (RC) columns due to their higher strength, stiffness and durability. The application of such columns can be found in basement construction of high-rise buildings and metro railway stations in which such columns are used to resist the dynamic load due to train movement. FEC column typically has similar geometric configurations to conventional Reinforced Concrete (RC) column except for the presence of steel section, which can be H-shaped, cruciform-shaped and even consists of several steel sections depending on specific structural requirement or the beam column connection details. FEC columns outperform Concrete Filled Tubular (CFT) members in terms of fire and corrosion resistance, as the steel section is completely covered with concrete. For PEC column, concrete is filled in between the steel flanges of the section. As the steel flange is not externally restrained by the concrete, an additional check is needed on the plate slenderness ratio to avoid local buckling. Main objectives of this study are to conduct a comparative study of Partially Encased Composite (PEC) column and Fully Encased Composite (FEC) column and to analyze action of axial load on both PEC and FEC.

Mahbuba *et al*., (2016) reports experimental and numerical investigations of the behavior of concrete encased Steel Square shaped composite columns under short-term axial load. Concrete is observed to provide around 57% of the total axial capacity of the column whereas; the steel I-sections contribute to the rest of the capacity as well as ductility of the overall system. The axial capacity of FEC columns increased significantly by increasing the strength of concrete.Ming *et al*., (2019) states that the axial compressive behavior of high strength Concrete Encased Steel (CES) composite short columns. The major parameters affecting the ultimate strength of composite columns include concrete strength, spacing of transverse reinforcement bars, and the inclusion of steel fibers in the high strength concrete. By decreasing the transverse reinforcement spacing, the ultimate load capacity of high strength CES columns can be improved due to better concrete confinement but the failure is still brittle with abrupt unloading from the peak load. Zhao *et al*., (2019) stated that the steel-concrete composite members incorporating demolished concrete lumps DCLs have been devised to provide a novel alternative to recycling old concrete. A closer link spacing of s≤0.3d is recommended for PEC columns containing DCLs. The model takes into accounts for the gain in strength due to concrete encasement and the loss due to flange buckling. Use of thick steel flanges is beneficial to PEC columns for better axial performance. Xiong *et al*., (2020) stated that the axial load capacity of concrete encased steel composite stub columns with high strength concrete and steel materials. In view of the brittleness of high strength concrete, the maximum concrete grade allowed in concrete encased steel composite columns shall be conservatively capped at C100 and corresponding structural steel grade shall be limited to S550 based on the material compatibility criterion. The adoption of cruciform steel profile and stirrups with cross ties or spiral loops enhances the axial capacity of fully encased composite sections. Worakarn *et al*., (2020) presents axial compression behavior of bare and concrete encased cellular steel (CECS) short columns. The results of the test on bare cellular steel columns showed that the failure was due to local buckling at the steel flanges and web at the hole section. The bare cellular columns exhibited the load-deformation relationship with a lower hardening behavior than the parent steel column. The weakening effect due to the circular openings was minimized by concrete encasement. The compressive strength of the CECS and CES columns increased as spacing of the closed stirrups decreased. Jianyang *et al*., (2020) states that the seismic performance of High-strength Concrete Encased Steel columns with Rectangular spiral Stirrups (HCESRS) is investigated. The composite specimen was tested under reverse cyclic loading and simulated numerically using the finite element method. If the axial compression ratio of the HCESRS column was greater than a certain value, the bearing capacity of the test model was decreased and the ductility decreased. The bearing capacity and ductility of the model have been improved by increasing the steel content and yield strength of section steel.

MATERIALS AND METHODS

In this study both partially encased composite columns and fully encased composite columns are designed on the basis of steel contribution ratio by simplified design method according to Euro code 4 (EC4). Steel contribution ratio, βa is the steel contributed to axial load is an important design parameter of composite construction which is defined in EC4. Indian Standards for composite construction (IS: 11384-1985) does not make any specific reference to composite columns. The provisions contained in IS: 456 - 2000 are often invoked for design of composite structures. Finite element (FE) modeling and analysis of steel encased composite column with H-shaped steel section was developed using the software ANSYS Workbench. The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. In this study PEC column and FEC column of 400 mm × 400 mm × 2000 mm size with 40 mm cover, 12 mm diameter bars as reinforcement and for FEC 8mm lateral ties are analysed under axial load. M 40 concrete, Fe 415 reinforcing steel and Fe 250 structural steel are used. Steel end plates 20mm thick were welded at the top and bottom of each specimen for a more uniform load introduction and distribution in the composite column. Then the variation of axial strain and deformation in each composite column models is studied.

A.Concrete grade= M40, Grade of steel = steel 250 as per IS code

B. H-shaped steel PEC column

The H-shaped steel PEC columns were modelled by using solid elements; SOLID 65 is used for the 3-D modelling of solid structures and cross section of PEC is shown in figure.1. Dimensions used for the structural steel are shown in table 1.

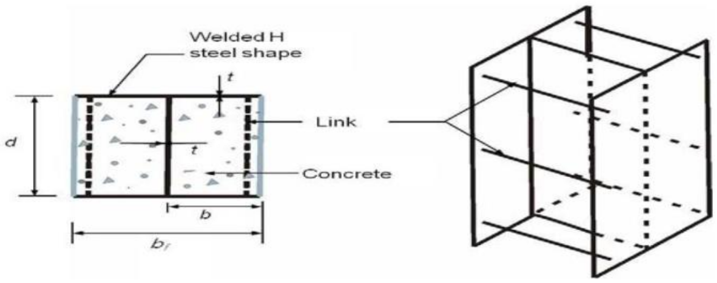

Fig .1. Cross section of H-section and schematic diagram of PEC column

Table.1. Details of H-section structural steel used in PEC column

Section	Thickness of web, t_w (mm)	Thickness of flange, t_f (mm)	Steel contribution ratio
ISMB 400	8.9	16	0.3
ISWB 400	8.6	13	0.32
ISHB 400	9.1	12.7	0.35

C. H-shaped steel FEC column

The H-shaped steel FEC columns were modelled by using solid elements; SOLID 65 and cross section of PEC are shown in fig.2. Dimensions used for the structural steel are shown in table .2.

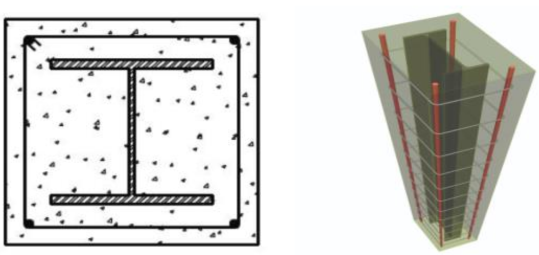

Fig .2. Cross section of H-section and schematic diagram of FEC column

Table.2. Details of H-section structural steel used in FEC columns

Section	Thickness of web, t_w (mm)	Thickness of Flange, t_f (mm)	Steel contribution ratio
ISMB 300	7.5	12.4	0.3
ISWB 300	7.4	10	0.32
ISHB 300	9.4	10.6	0.35

C. Boundary and Loading condition

As per the clause E-3 Table no 28, IS 456 two end conditions are considered and they are

- Effectively held in position and restrained against rotation at one end and at the other restrained against rotation but not held in position
- Effectively held in position at one end but not restrained against rotation, and at the other end and restrained against rotation but not held in position

For Case 1: Effectively held in position and restrained against rotation at one end and at the other restrained against rotation but not held in position, The compressive load was applied to a rigid plate that was placed on the upper end of the column, where the load was applied in the form of displacement of 50mm. In regard to pure compression loading, all degrees of freedom and displacement at bottom of the column were constrained so as to provide fixed condition. And at the top of the column, only rotation is constrained. And for Case 2: Effectively held in position at one end but not restrained against rotation, and at the other end and restrained against rotation but not held in position, In regard to pure compression loading, translation at the bottom of column is constrained and at the top of the column, only rotation is constrained.

RESULTS

Graphical representation of axial load versus deformation of H-shaped PEC and FEC for both boundary conditions is shown in Fig.3. and Fig.4.And also strain distribution is shown in Fig.5.

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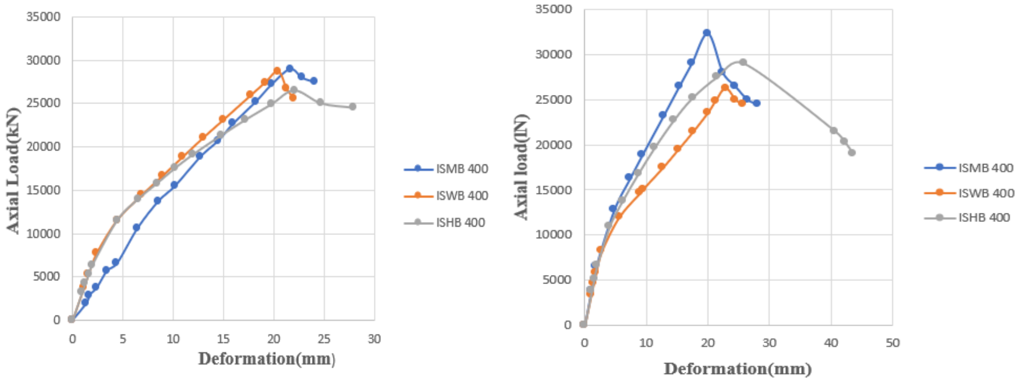

Fig.3. (a) Load versus deformation of H-shaped PEC for case 1, (b) Load versus deformation of H-shaped PEC for case 2

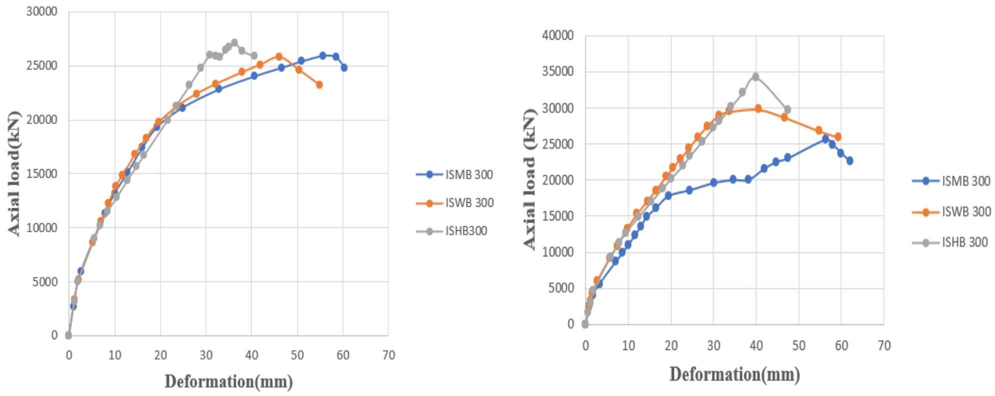

Fig.4. (a) Load versus deformation H-shaped FEC for case 1 (b) Load versus deformation of of H-shaped FEC for case 2

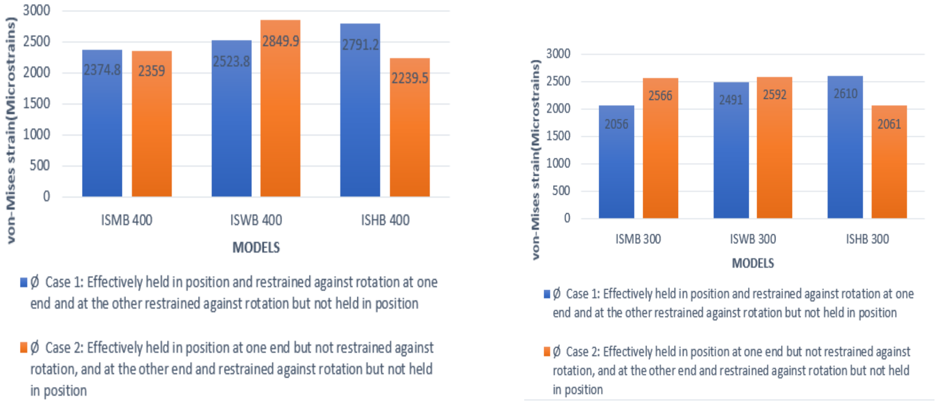

Fig.5. (a) Graphical comparison of von-Mises strain values of H-shaped PEC, (b) Graphical comparison of von-Mises strain values of H-shaped

FEC: The analytical results for von Mises strain and maximum principal strain of concrete are found to be within the limit of 0.002 and 0.0035 respectively. Partially encased composite column with a H-section having the least values of deflection, von Mises strain, von Mises stress, maximum principal stress values ie; ISMB 400. As the flange thickness increases deflection of the models decreases and axial load carrying capacity were increased.

A Partially encased composite (PEC) column shows better results than a fully encased composite column (FEC) because the PEC has a larger structural steel area and has higher a load carrying capacity. Thin flanges are very sensitive to load buckling of the flanges, so for higher thickness, which indicates the yielding of steel plates was responsible for the load carrying capacity.

By comparing the deformation values of composite columns in case 1 and case 2 boundary conditions, case 1 having the least values. So effective length 1l having better results than effective length 2l.

As conclusions, This study addressed the numerical results of a study on PEC and FEC under axial load. The failure of steel PEC and FEC columns under axial loading lies in the crushing of concrete. The behaviour of the composite column was studied under the ultimate limit state. The following was concluded from this study. 1) Partially encased composite columns are found to be most efficient compared to fully encased composite columns. 2) Composite columns with case 1 boundary condition shows a minimum value of deflection compared to that of case 2 boundary condition.so effective length 1l was recommended for better results. 3) Flange thickness has a greater influence on load carrying capacity of the composite columns. The contribution of the steel profile in the load capacity of the composite column increases with the thickness of flanges. 3) Stress and strain induced are found to be within the yielding limit of the corresponding material. 4) Structural steel ISMB 400 was performed better than other steel sections.

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