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*Full Length Research Paper*

# Numerical analysis of the load bearing capacity of pin-ended hybrid headed columns under uniaxial loading

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**The behaviour of fully encased composite columns loaded in axial compression through the concrete core and whole cross-section was studied. The primary objective is to develop a complete non-linear finite element model that could represent the behaviour of fully encased composite columns tested under uniaxial compression in the laboratory. A total of 10 models were analyzed using finite element simulations and the results obtained were compared with laboratories' test results. The finite element package LUSAS 14 has been used to carry out non-linear analyses of models in order to study the ultimate load behaviour and ultimate load-carrying capacity of the columns. The effects of parameters such as length of composite columns and loading condition on the ultimate load capacity have been examined. This study implies that load condition has significant influence on the behaviour and strength of the composite columns. Moreover, it is suggested that the finite element models were able to simulate various loading conditions, with very good accuracy.**

**Key words:** Composite column, load-carrying capacity, finite element simulation, column head.

## INTRODUCTION

Steel-concrete composite systems have been on widespread used in recent decades because of the benefits of combining the two construction materials; reinforced concrete is inexpensive, massive, and stiff, while steel members are strong, lightweight, and easy to assemble. One of these systems is the composite column, where steel-concrete structural compression member is used as load-bearing member in a composite framed structure. Composite columns can be an economical solution for cases where additional load capacity is desired over that available with steel columns alone. Composite columns comprise of steel sections with a concrete encasement or core. Steel members have the advantages of high tensile strength and ductility and used for erection of the building and resisting all construction loads, while concrete members are advantageous in compressive strength and stiffness to assist in resisting the service loads. Encased columns usually consist of standard I-beam with a rectangular or square concrete section encasement to form a solid composite section. Fully encased columns are columns with steel section embedded within a minimum cover depth of concrete. Additional reinforcement is placed in the concrete cover around the steel section in order to prevent spalling under axial stress and in fire and to improve the ductility of these columns somewhat under cyclic loading.

In composite columns encasing single steel sections, the steel section provides resistance with its bending rigidity. In the proposed system, the steel section is located at the centroid in the longer dimension and applying a head to the column, making it an efficient load resisting system about the major axis (Ahmed, 2010). This has great advantages when the column is subjected to combined axial loads and large major axis moments by frame action. Many researchers have studied the behaviour of composite columns (EL-Tawil and Deieleinr, 1999; Lachance, 1982; Mirza, 1989; Munoz, 1994; Venugopal et al., 2003). Amongst the problems not studied in great detail is the effect of the introduction of column head on the load bearing capacity of a fully encased composite column. This will be the main focus of this research. Other parameter that will be varied is the column length. Furthermore, the author felt that he is in

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**Table 1.** Convergence study.

| Element size (mm) | Total number of element | Ultimate load (kN) |
|---|---|---|
| 500 | 2248 | 1872.6 |
| 300 | 3195 | 1548.02 |
| 200 | 8022 | 1066.19 |
| 130 | 13240 | 998.46 |
| 60 | 24852 | 989.306 |

need of achieving the ability to conduct a non-linear finite element analysis of such a structure as an important outcome of this study.

The model is to be capable of simulating numerically the full behavioural history including peak capacities and the failure mode caused by local buckling of the steel plates and/or crushing of the concrete. Determination of the composite column strength by varying the column length and introducing column head on the load bearing capacity of the composite column will be studied. The study involves a numerical modelling via non-linear finite element approach employing commercially available software, LUSAS 14 of fully encased composite column under axial static loading. In the present study, non-linear finite element analysis is used to investigate the behaviour of fully encased composite columns. The columns that are subjected to axial loading, through the core and the whole sections require a consideration of cross-section capacity as well as slenderness effects.

## MATERIALS AND METHODS

### Description of the model

This study begins with the attempt to verify a finite element model of fully encased composite column which have been tested in the laboratory. The test was to study the behaviour of fully encased composite column when introducing head to the top of the column on the load carrying resistance. The model test results were published by Szmigiera (2007). Specimens were modelled and analyzed regarding change in column length to study the columns behaviour under static incremental load. This study involved load-displacement relationship, load-strain relationship and ultimate failure load comparison.

In developing the finite element model, an initial verification of the author's LUSAS model was conducted by modelling a test case involving steel I-shape column that was strengthened by concrete casing, that is, a fully encased composite column tested experimentally by Szmigiera (2007). The columns were produced and tested in the Laboratory of Buildings' Construction Institute of Warsaw University of Technology.

Convergence studies have been carried out on the columns in order to determine a suitable finite element model for the analysis. An important step in finite element modelling is the selection of the mesh density. A convergence was carried out and results obtained when an adequate number of elements was used in a model (Table 1). Steel composite columns were modelled as simply supported similar to the one adopted in the experiment by Szmigiera (2007). Yield point of the structural steel HEA160 was 282 MPa and yield point of longitudinal bar steel 317 MPa. Length of models which were simulated are 2500 mm. LUSAS requires input of the Young's modulus, Poisson's ratio and yield stress of steel. Composite columns were modelled using ungraded Mild Steel with Young's Modulus equal to 210 kN/mm$^2$ and Poisson's ratio of 0.3. Young's Modulus and Poisson's ratio of concrete components were 28 kN/mm$^2$ and 0.2, respectively.

In nonlinear analysis of LUSAS software, incremental-iterative solution procedure is used. In this procedure, the total required load is applied in a number of increments. With each increment, a linear prediction of the non-linear response is made, and subsequent iterative corrections are performed in order to restore equilibrium by the elimination of residual forces. The iterative corrections are referred to some form of the convergence criteria that indicate to what extent an equilibrium state has been achieved. The I-beam structural steel section was modelled by using TLS6 3D thin shell element in the LUSAS element library. It has six nodes numbered anticlockwise. Generally, this element can accommodate curved geometry with varying thickness and anisotropic and composite material properties. The element formulation takes account of both membrane and flexural deformations.

The concrete element is simulated by 3-D structural solid continuum element (TH10), with the addition of special cracking and crushing capabilities. It is isoperimetric solid continuum elements with higher order models capable of modelling curved boundaries. The most important aspect of this element is the treatment of non-linear material properties. The concrete is capable of cracking (in three orthogonal directions), crushing, plastic deformation, and creep.

## RESULTS

### Model verification

The goal of the comparison of the finite element models and the columns from Szmigiera (2007) is to ensure that the elements, material properties and convergence criteria are adequate to model the response of the member and make sure that the simulation process is correct. Therefore, in this research, experimental columns tested by Szmigiera (2007) were simulated as verification study. The composite column consists of rolled steel I-shape HEA 160 entirely covered by casing of concrete, four 12 mm diameter longitudinal ribbed bars as well as 6 mm stirrups from plain steel were placed into the section. Length of elements was 2500 mm, while dimensions of cross-section: 260 × 260 mm (Figure 1).

The experimental ultimate load for the columns (P Exp) is presented in Table 2 along with the corresponding finite element values (P FE). The comparison ratio (P Exp/P FE) between the two values in each case is shown in

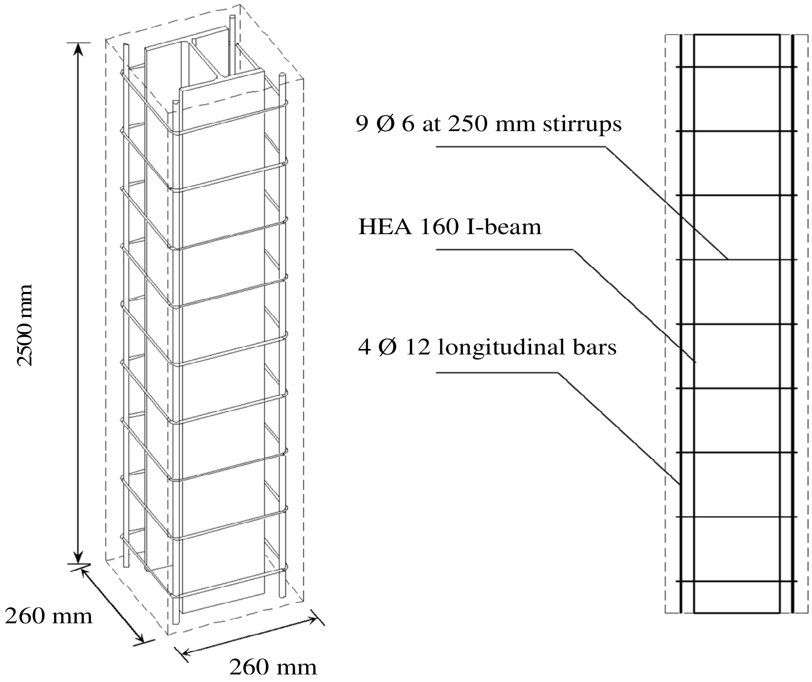

**Figure 1.** Details and elevation of the composite columns.

**Table 2.** Ultimate failure load P for verifying the specimens.

| FE specimen | Experimental failure load [P Exp (kN)] | Finite element failure load [P FE (kN)] | Failure load ratio [P Exp / P FE] |
|---|---|---|---|
| C | 1000 | 1039.885 | 0.96 |
| W | 2190 | 2164.674 | 1.01 |

C, core; W, whole section.

the table. The load-strain relationship of column will be presented later.

The result in Figures 2 and 3 shows close agreement between the experimental and finite element results. The elastic behaviour and ultimate capacity are predicted by the finite element modelling with sufficient accuracy. Therefore, the finite element modelling is used in future analysis of the composite columns.

## Effect of length and column head

The first parameter is the effect of various lengths (2.5, 4, 6, 8 and 10 m) for both group of columns, C (core loaded) and W (whole section loaded) columns. Five different C columns (core loaded) and five coresponding W columns (whole section loaded) having lengths 2.5, 4, 6, 8 and 10 m were considered in the study. These columns were assumed as pin-ended. The results from the analyses are shown in Figures 4 and 5 in the form of load-displacement curves.

As can be seen from Figures 4 and 5, the ultimate load capacity of columns is decreased by the increase of the columns length. Actually, the axial buckling resistance of a real column will be less than the squash resistance because of the effects of slenderness and initial imperfections.

The second parameter of this study is considering the effect of column head, a way of which the load is applied through the core (C) or the whole section (W) for the columns having the same length (Figure 6). Column head was made from fibre concrete in the laboratory, while it was simulated by steel plate (thin shell element) 30 mm thickness for the place, where the load is applied. Such application changes a scheme of applied compressive force, aiming at distribution of load in the whole composite section and prevent the local crushing of concrete just under the loading location.The verification of results show that this assumption is accurate.

The evaluation of ultimate load capacity of columns C

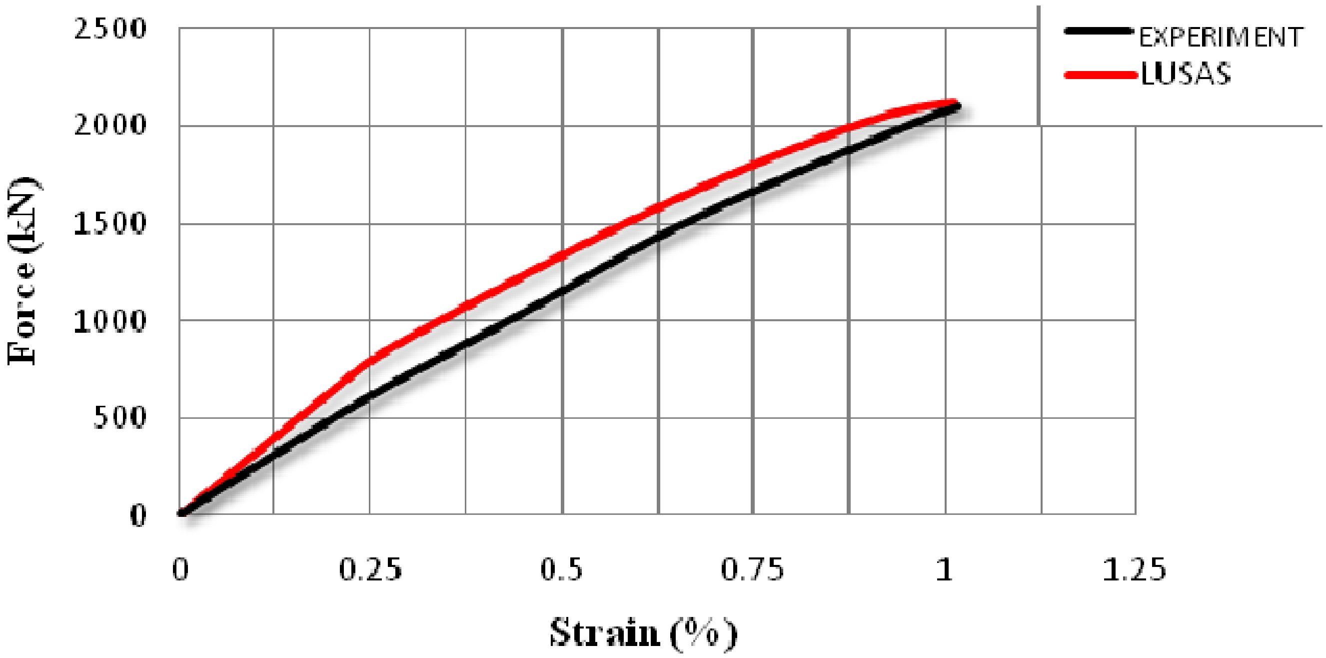

**Figure 2.** Loading through the whole composite section (W) verification result.

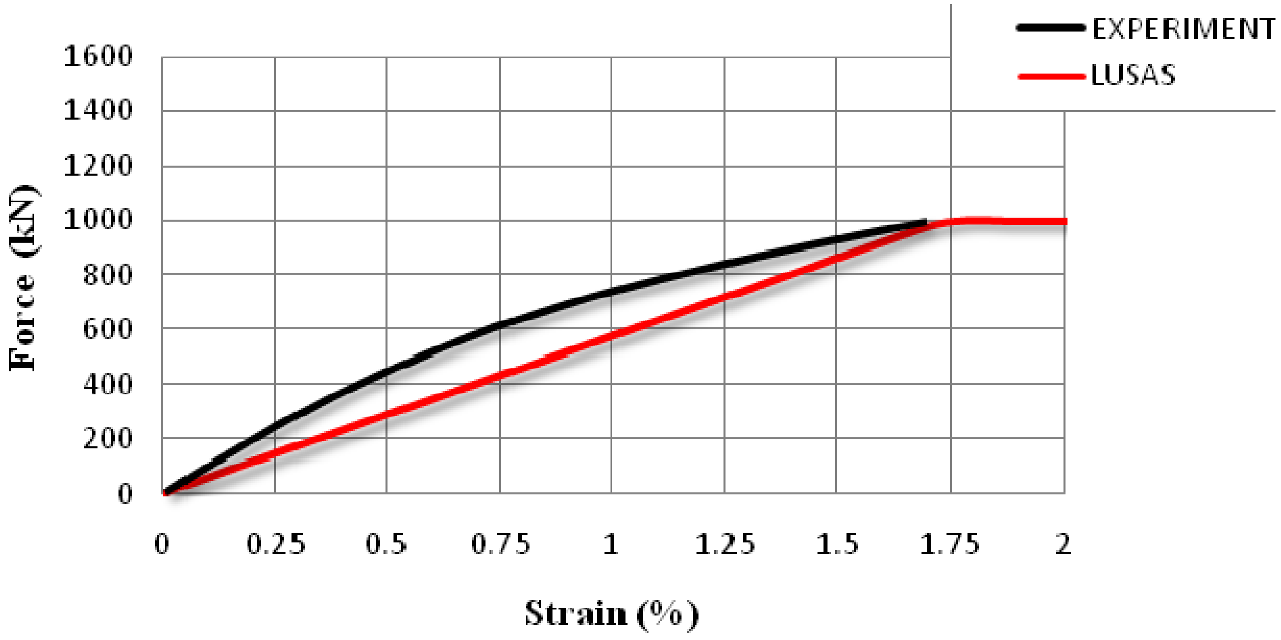

**Figure 3.** Loading through the core (C) verification result.

and W, which have the same length, were considered by (2.5, 4, 6, 8, and 10 m) lengths and the results will compare the ultimate load for each certain length. These results are shown subsequently.

For all the columns with same heights and different loading conditions, the ultimate load for columns W obtained from the software exhibits higher stiffness and ultimate strength compared to the C columns that proves the advantage of the column head, which were able to sustain more bearing capacity. The results are shown in Figures 7 to 11 as a form of load-displacement curves and summarised in Table 3.

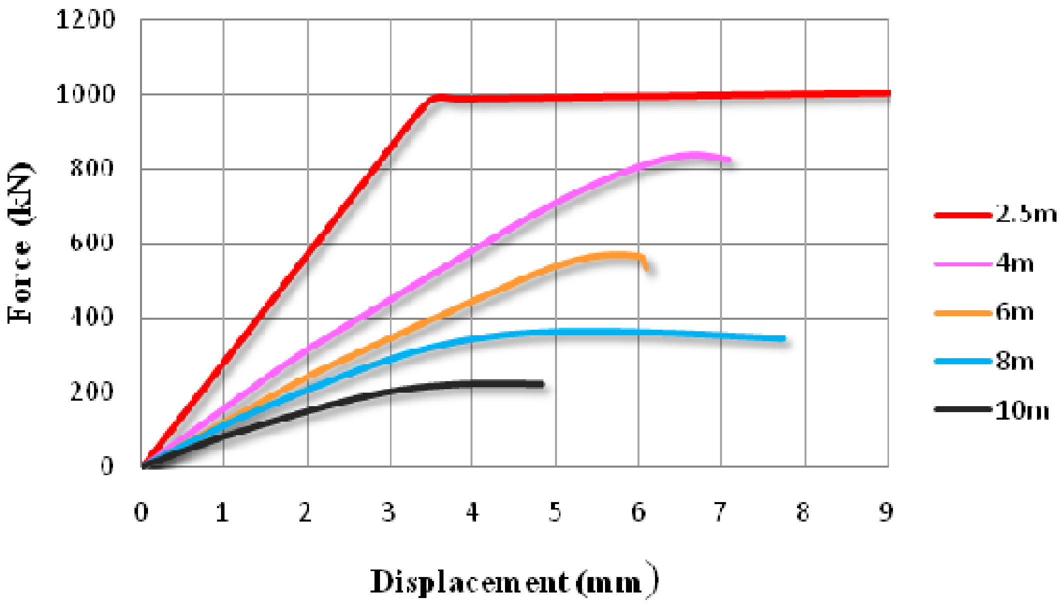

**Figure 4.** Loading the composite columns of various lengths through the core.

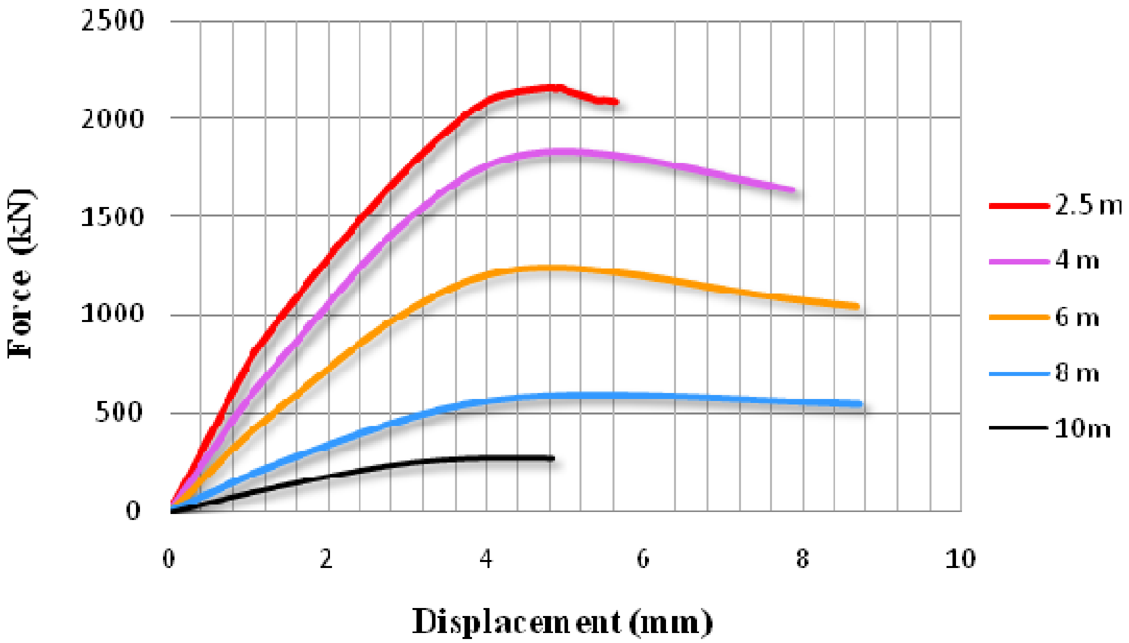

**Figure 5.** Loading the composite columns of various lengths through the whole section.

## DISCUSSION

The interaction between the steel and concrete and their separation at the common interface because of the local instability of the flange was successfully represented in the finite element analysis of the test specimens using full models developed herein. The numerical models also provided good representations of the peak load, axial displacement at the peak load curve, including the post-peak behaviour of the test columns.

Comparison between the ultimate load bearing capacities of W and C columns shows that the effect of column head decrease by increasing the length as shown in the first parameter study (length). The analysis showed

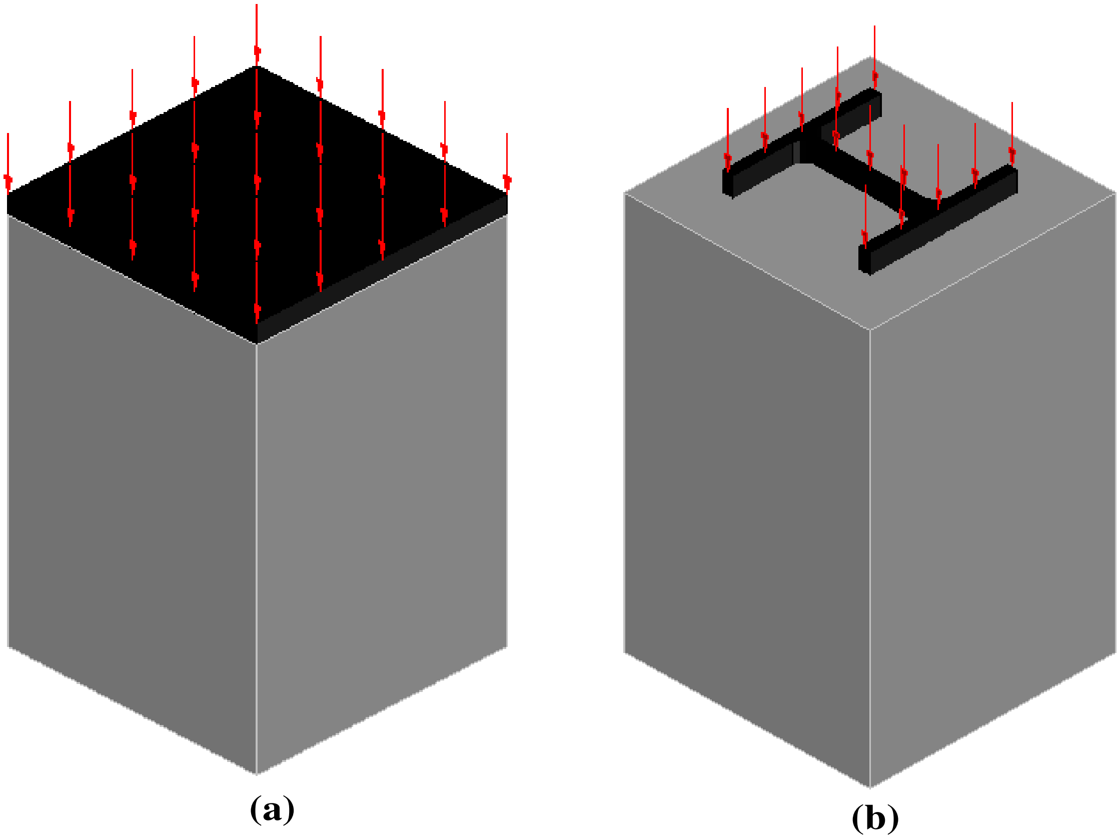

**Figure 6.** Two ways of applying load to the column: (a) Loading through the whole section W, by using column head; (b) Loading through the steel core C, protruded from column section.

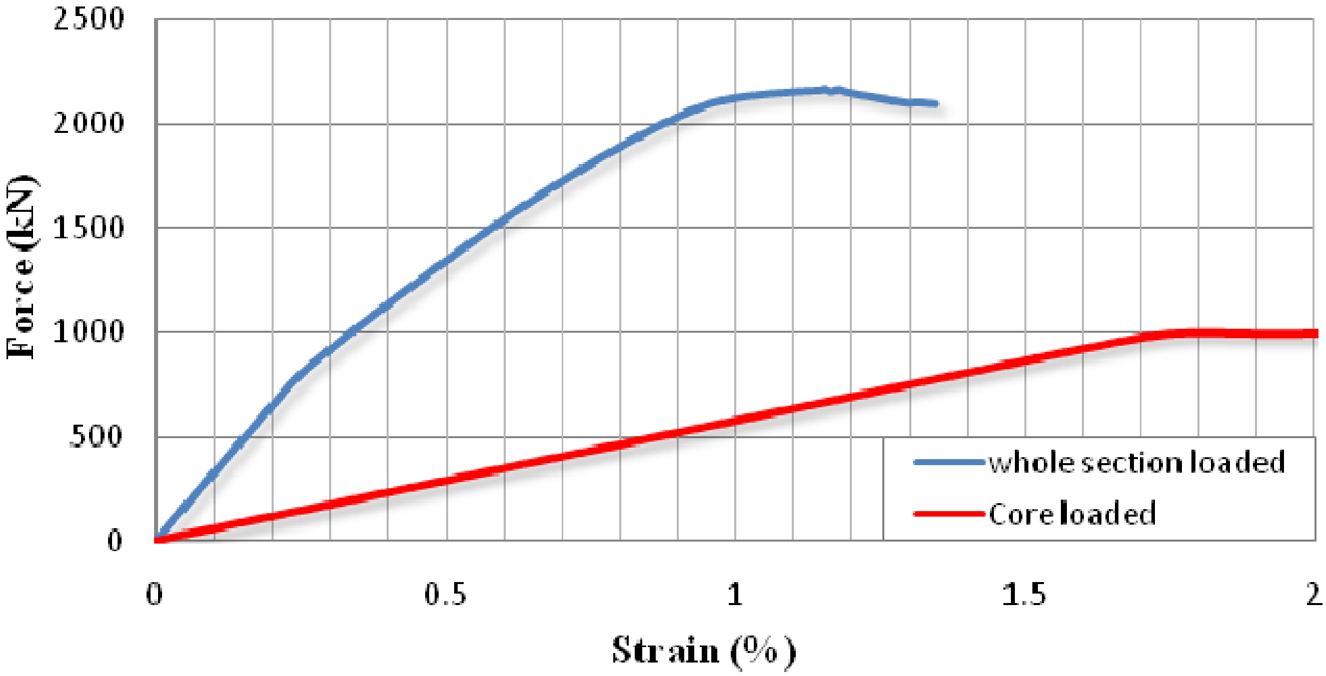

**Figure 7.** Strains of the composite column 2.5 m length in various loading conditions.

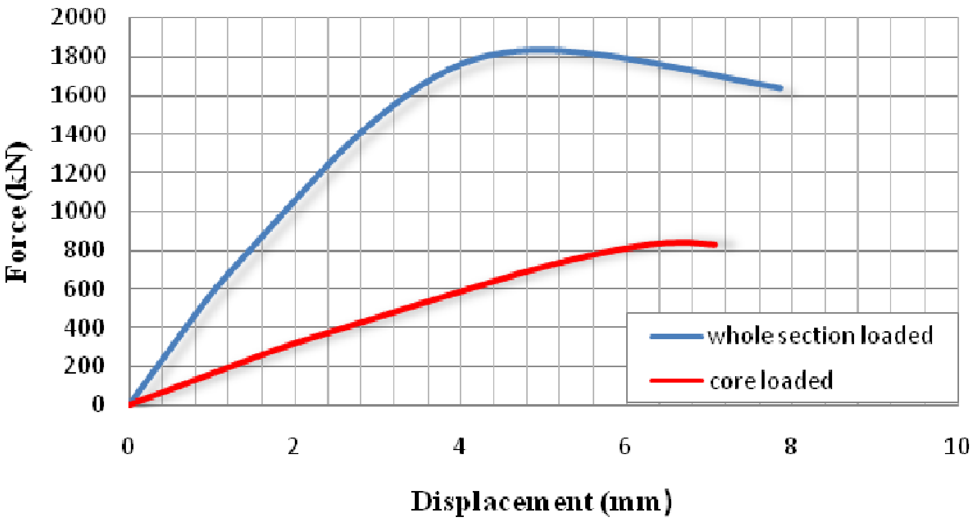

**Figure 8.** Displacement of the composite column 4 m length in various loading conditions.

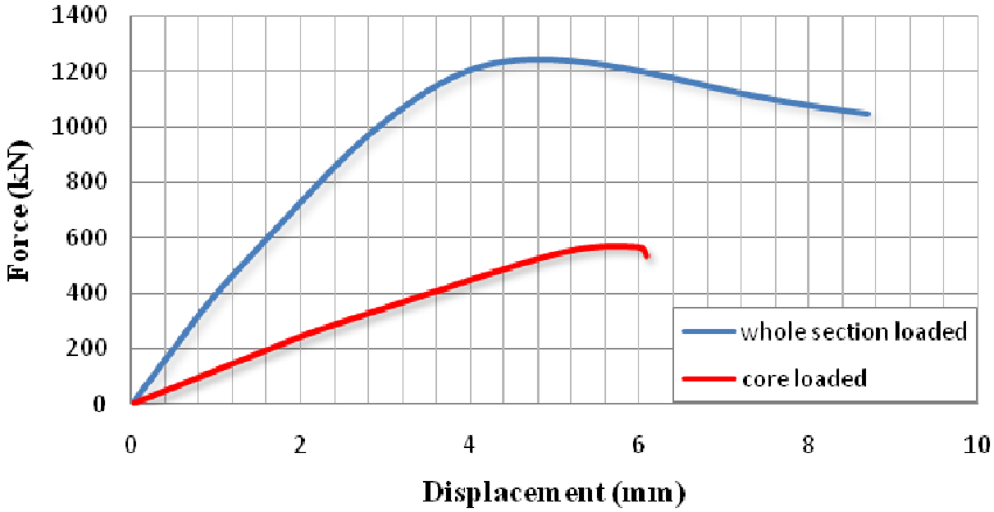

**Figure 9.** Displacement of the composite column 6 m length in various loading conditions.

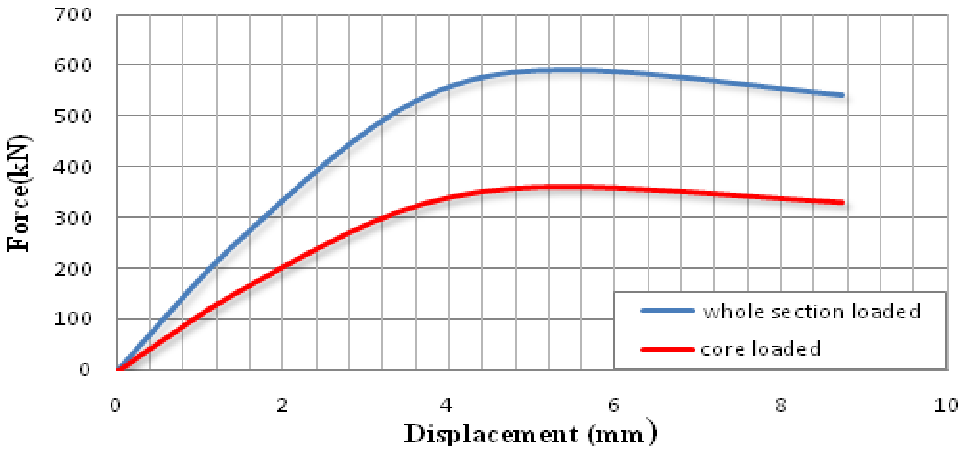

**Figure 10.** Displacement of the composite column 8 m length in various loading conditions.

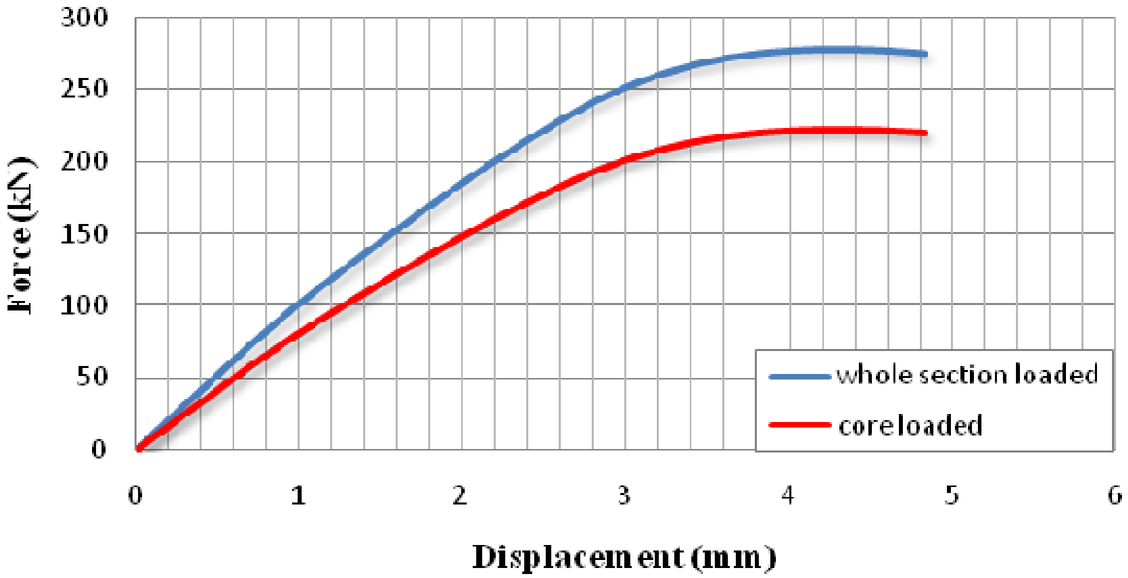

**Figure 11.** Displacement of the composite column 10 m length in various loading conditions.

**Table 3.** Maximum failure load for each group of loaded columns.

| Length (m) | Maximum failure load (kN) | | % |
|---|---|---|---|
| | (W) Column | (C) Column | |
| 2.5 | 2164.647 | 1039.885 | 51.96052751 |
| 4 | 1834.874 | 839.955 | 54.22274227 |
| 6 | 1246.209 | 571.2 | 54.16499159 |
| 8 | 593.4393 | 363.627 | 38.72549391 |
| 10 | 277.92 | 222.336 | 20 |

also that the behaviour and characteristics of failure of such columns are of a very complex kind and they depend on many factors. Not all of them are considered in recommendations of actually valid standards. The increment of the ultimate load bearing capacity for each column length due to column head is as shown in Figure 12. It decreases by increasing the length due to the increase in column slenderness. By observing the columns with length 2.5 to 6 m, it is noticed that the effect of the column head on the ultimate load of column is very significant. This is due to the ultimate load bearing capacity being governed by the strength of material and area of the section. However, by increasing the length of column from 6 to 10 m, it is observed that the effect of the column head dropped because the ultimate load bearing capacity is governed by length.

Comparison between the failure loads of composite columns and that of their respective change in length as it is observed from the load-displacement curves in Figure 12 clearly shows that stiffness, stability and load capacity increases due to the effect of column head in comparison with corresponding column without column head. Observations made after the failure load had been reached by Szmigiera (2007), confirming that the steel component and the concrete encased within the steel act together even after failure and are capable of sustaining considerable loading while maintaining a ductile behaviour.

## Conclusion

In general, the proposed three dimensional numerical models using the software package LUSAS were capable to simulate the mechanical behaviour of the composite columns and predict the ultimate load with relatively high accuracy. The column head has significant influence on the behaviour and strength of these columns and also on the load bearing capacity. An important event observed during the analysis was that the column head is more than adequate for medium length columns in which the bearing resistance reached its ultimate capacity. Future work suggests that LUSAS or other software package may be improved further to improve the accuracy of three

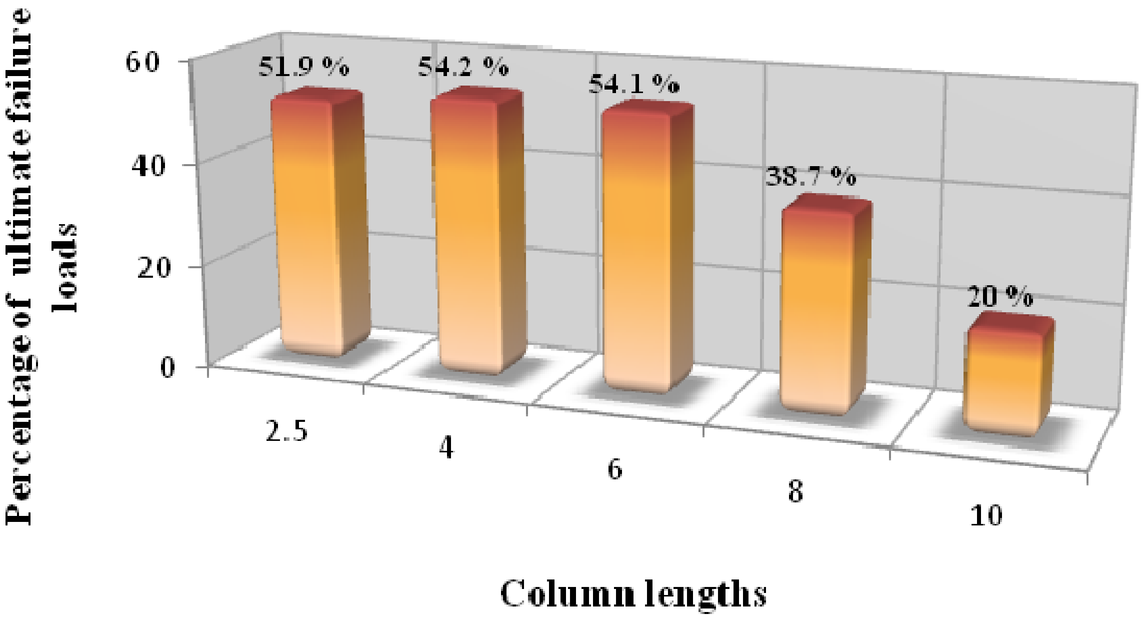

**Figure 12.** Percentage of ultimate failure loads due to the effect of column head in each column length.

dimensional numerical models.

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