Numerical modeling of cold-formed steel-concrete columns

Lays R. A. da Costa[1], Hidelbrando J. F. Diógenes[1], Maria I. B. Valente[2].

[1]*PPGECAM, Federal University of Paraíba - UFPB*
Campus Universitário, 58.051-900, João Pessoa/PB, Brazil
lays.costa@academico.ufpb.br, hjfd@academico.ufpb.br

[2]*Civil Engineering Department, Institute for Sustainability and Innovation in Structural Engineering University of Minho- ISISE*
Campus de Azurém, 4800-058, Guimarães, Portugal
isabelv@civil.uminho.pt

Abstract. The objective of this study was to perform numerical simulations through the FEM method, using ABAQUS®, to investigate the structural behavior of Cold – formed steel - concrete columns (CFSC). The concrete's influence on the system's efficiency was investigated for systems with different heights between 2.50 and 3.00 meters, since most of the articles with CFSC show results for short columns up to 1 meter. The results showed that the concrete favors the structural behavior, but this resistance's gain is reduced as the systems become higher due to the buckling action: In the columns with 1.5 meters, concrete contributed to a more than 100 % increase in the strength of the columns, while for columns with 3 meters, this gain was only 28%. In columns with 2.5 meters, this gain represents 70%. Even with the loss in strength of the composite systems due to the increase in slenderness, the encased columns with 3 meters in height presented strengths of almost 100 kN, which corresponds to the average values requests in small buildings. In simple steel tubular columns, these values did not reach 60kN.

Keywords: cold-formed structures, steel-concrete columns, composite structures, encased columns.

1 Introduction

Cold-formed steel profiles are those obtained by bending flat steel sheets. According to Pierin [1], the use of these profiles in civil construction has been motivated by the high structural efficiency, expressed by the relationship between the resistance capacity and the weight of this system. In addition, the production's facility, favors the manufacture of elements with different cross-sections.

According to Javaroni [2], this type of profile achieved a prominent place mainly in smaller constructions, which generally have small spans and low-intensity loading. In this type of construction, the use of laminated profiles results, in most cases, in a high cost of the structure to the total required for the work.

Javaroni [2] still mentions that the cold-formed steel profiles most commonly used in structures have shapes very similar to laminated and welded profiles. However, a variety of sections can be achieved by bending shapes for specific applications or by composing profiles.

Despite this advantage, according to Pierin [1], cold-formed profiles are made up of very thin elements, and they have high selenderness, which contributes to their instability. The profiles thus obtained are subject to local buckling of their elements, which in general does not represent the depletion of the resistant capacity of the bar. Thus, the association of these steel elements with concrete through composite systems can favor an increase in stability.

The composite steel-concrete columns are an example of a composite system, with concrete and steel working together to resist the forces. In the group of composite columns, one of the most structural efficient is the Encased columns, which are made up of a concrete core that is surrounded by a protective layer of steel. In the latter case, steel can also act to increase the compressive strength of the columns due to the confinement effect on the concrete core.

According to Hunaiti e Fattah [3], composite columns are generally known for having greater rigidity than steel ones and for presenting greater resistance capacity than reinforced concrete columns. Cortés-puentes et al., [4] conducted studies on Encased columns, consisting of cold-formed steel profiles as a coating and concrete with 30 MPa in its core, and observed that the association of the two materials represented a gain of 33% in strength to axial loads compared to bare steel sections.

Regarding the action of concrete in the performance of composite columns consisting of cold-formed profiles, Cortés-puentes et al.[4] mentions that this has the function of increasing the rigidity of the system, favoring the increase in compressive strength axial and the buckling resistance of the steel components.

The design code NBR 14.762:2010 [5] presents formulations for calculating the resistant axial force for profiles submitted to the axial compression force. This axial solicitation will be evaluated in this article.

The design code NBR 8800:2008 [6], on the other hand, presents formulations for the calculation of steel – concrete composite encased columns, and as expressed in the equations presented, there are some variables that affect the design resistant axial force in these composite columns: concrete, the slenderness of the columns, the cross-section of the profiles and the strength of the steel. In this work, the presence of reinforced concrete and the influence of the slenderness of the profiles on the performance of composite steel-concrete columns formed by cold-formed profiles will be investigated.

Most of the studies about steel-concrete composite columns with cold-formed profiles present results related to the axial compression behavior of the systems and considering short columns, with a height of up to 1 (one) meter. However, as mentioned in previous paragraphs, these columns are used in small works, where, in general, they have heights that vary between 2.5 and 3 meters.

In this work, a numerical analysis will be performed on steel columns and, after, on steel-concrete composite columns. For the same cross-section, the structural behavior on axial compression to steel columns and steel-concrete composite columns at different heights will be investigated.

In this last analysis, the influence of the concrete present in the columns' core will be investigated to attenuate the buckling effect, which tends to affect the structural performance of the structural elements.

First, a numerical model will be built in ABAQUS, whose results will be validated through analytical expressions present in 14.762:2010. Validation will be for a column at 1.5 meter high pillar. Then, a parametric analysis will be performed, and the structural performance will be evaluated for columns with 2.5 and 3 meters.

This paper consists of a preliminary analysis of the composite models' behavior and will provide subsidies for the development of future experimental analyses.

2 Methodology

In this section, the steps to build the numerical model will be presented. It will be presented the numerical simulation techniques and materials properties.

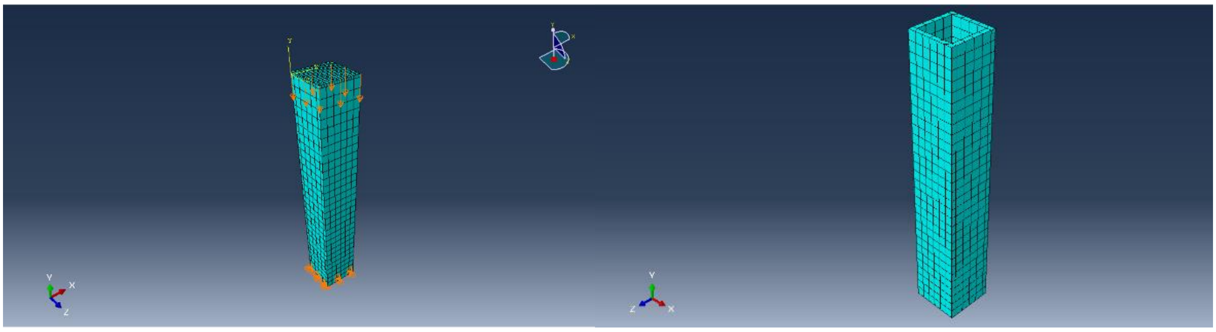
2.1 Model Construction

The model was constructed to simulate the axial compression test in a tubular profile of two welded cold-formed profiles. The profile considered was the Ue250x100x25x2.65 type.

The specimens' geometry was based on the Ue250x100x25x2.65' geometry, a length of 1.5 meters, and was constructed in ABAQUS® using the extrusion technique. For the Finite element choice, it was considered that elements with regular and symmetric shapes, such as square prisms of close dimensions, make the calculation process and interpolations of the model more coherent and less prone to large errors. So, the C3D8R element was used, an 8-node linear brick, ideal for stress and strain analysis.

Related to the boundary conditions, the composite column's model had the displacements restrained in the vertical direction, and it was applied a unitary upward load, increasing continuously to simulate the experimental test conditions. To ensure the application of the axial compression force uniformly in the cross-section, the model considered the presence of a plate in the region of load application. The plate was modeled by a steel plate with the same dimension of the column's cross-section. Initial geometric imperfections were not considered in the analyzed elements.

It was considered a Mesh size of 50 millimeters to the steel profile. Some previous computational simulation was performed to define the mesh size, and bigger mesh element size presented poor results, while smaller, demanded much more simulation time. Figure 1a illustrates the numerical model's geometry, while Fig. 1b shows the finite element mesh obtained.



a) b)

Figure 1. a) Numerical model's geometry; b) Mesh dimension

Tab. 1 presented the materials' properties that was considered.

Table 1. Material properties - steel

Steel	
Density (kg/m³)	7850
Elastic Modulus (GPa)	200
f_y (Mpa)	300

During the numerical simulation, step sizes of 0.1 mm were considered to a number maximum of 1000 increments, and the "Full Newton" technique was applied to the solution. Concerning the convergence strategy, "severe discontinuity iterations" were considered.

3 Results

3.1 Numerical calibration

Fig. 2 presents the vertical reaction value obtained in the numerical simulation, and Fig.3 present the deformed obtained after in the numerical simulation.

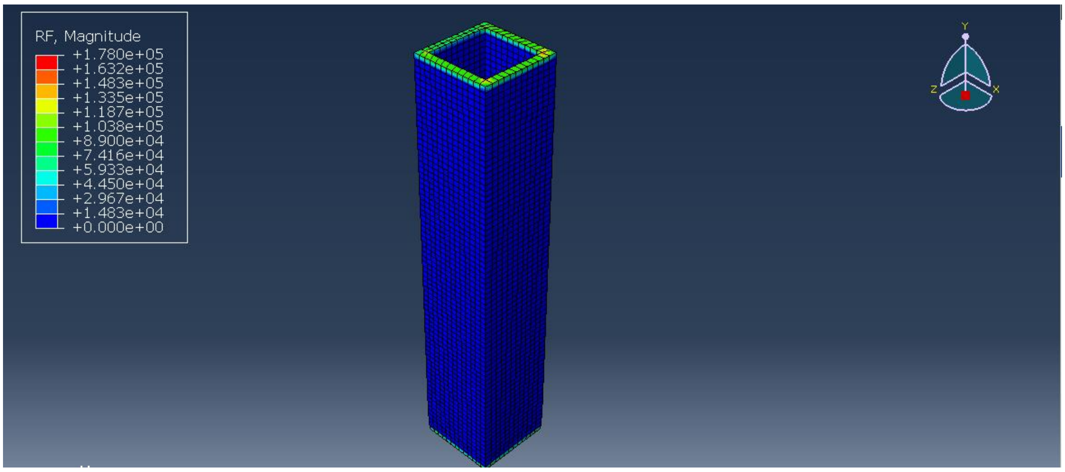


Figure 2. a) Vertical Reaction value from numerical simulation in tubular steel columns

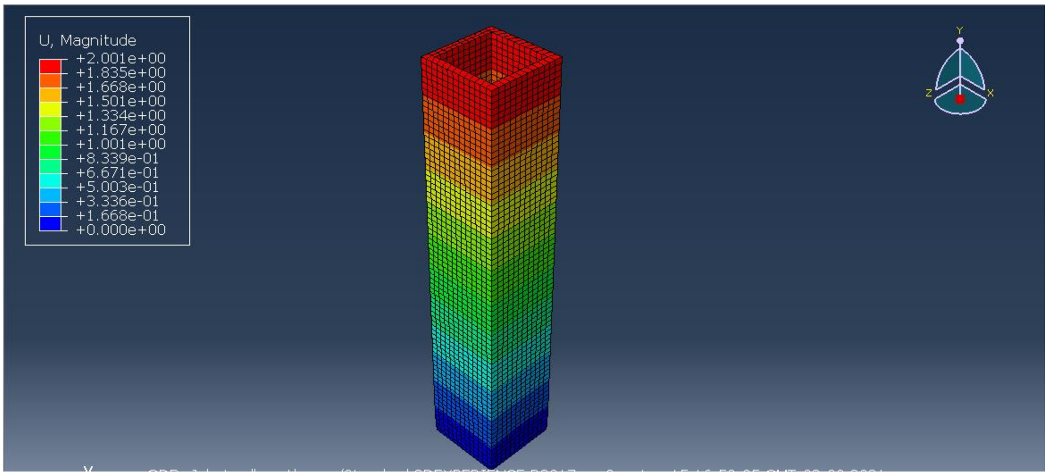


Figure 3. a) Deformed shape from numerical analysis

The resistant capacity obtained in the numerical simulation for the steel tubular column was 178 kN. This resistant capacity was also calculated through the design code NBR 14.762:2010, and it was obtained a value of 162 kN. The comparison between the results obtained through numerical and analytical methods shows a difference of 8.98%, evidencing that the numerical model was coherent and valid for the parametric analysis process. Local buckling is not observed because this first simulation was to a short column.

The next section presents the results obtained after parametric analysis. It was observed the concrete's influence and the height of the columns in the system's performance.

3.2 Parametric analysis

The development of the parametric analysis took place through the variation of the columns' length and was considered heights of 2.5 and 3.00 meters. The simulations were performed first to tubular steel columns, and after, each column was "filled" with concrete to evaluate concretes' influence in the structure performance.

In order to simulate steel-concrete interaction, it was applied a surface contact, and the d*efault* properties from ABAQUS® were considered.

The concrete considered in the numerical analysis presented properties as shown in Tab. 2.

Table 2. Material properties - concrete

Concrete	
Density (kg/m³)	2400
Elastic Modulus (GPa)	28
F_c (Mpa)	30

Figure 4 presents the load x displacements results obtained after numerical simulation.

Six curves are presented: steel tubular column with 1.5, 2.50, and 3.00 meters, and composite encased columns with 1.5, 2.50, and 3.00 meters.

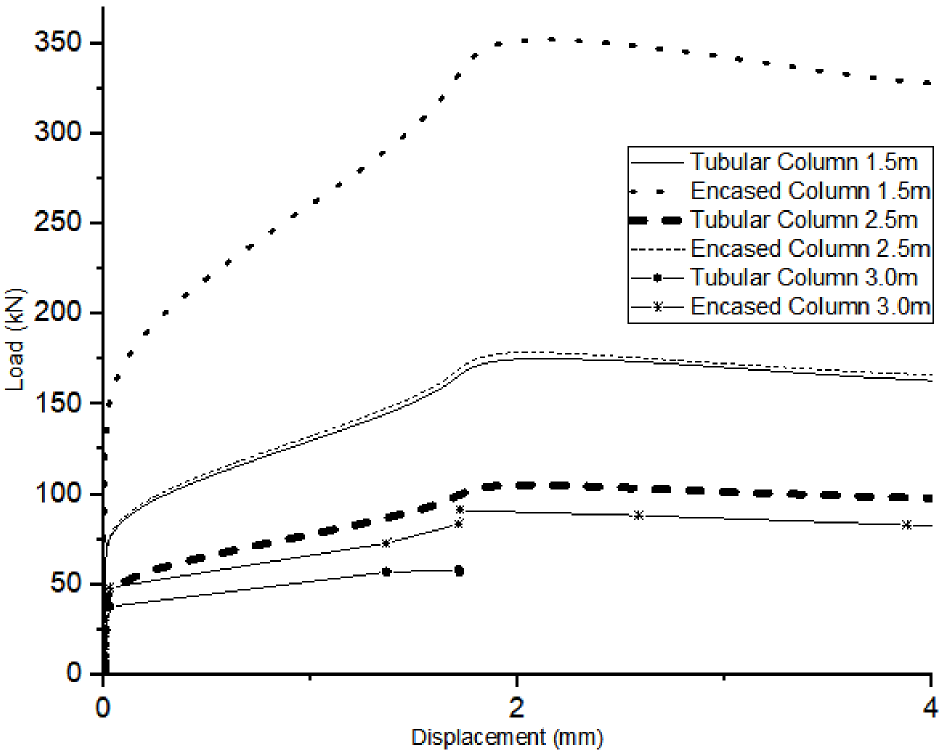


Figure 4. a) Load-displacement results through numerical analysis

From Figure 4, it can be seen that the column's specimens filled with concrete showed best results and structural capacity when compared with tubular columns with the same cross-section. These results confirm the observations from the literature about the concrete's influence in the encased columns' structural performance. This gain in resistance due to concrete, can be related to the confinement as it was also mentioned to Cortés-Puentes et al. [4].

But this concrete's influence decreases as the columns get taller. This behavior can be related to the slenderness of the steel elements and the local buckling in the elements with greater heights.

In the columns with 1.5 meters, concrete contributes to a more than 100 % increase in the strength of the columns, while for columns with 3 meters, this gain was only 28%. In columns with 2.5 meters, this gain represents 70%.

Even with the loss in strength of the composite systems due to the increase in slenderness, the encased columns with 3 meters in height presented strengths of almost 100 kN, which corresponds to the average values requests in small buildings. In simple steel tubular columns, these values did not reach 60kN. According to Cortés-Puentes et al. [4], local buckling controls the strength of the steel section when not restrained by the concrete core.

Thus, it is observed that for small buildings, the use of cold-formed profiles becomes even more viable when it is associated with concrete in composite steel-concrete systems.

This analysis considered only columns height and concrete presence, but different results can be obtained changing cross-sections or materials properties.

4 Conclusions

From Numerical analysis, it was found that a greater maximum load can be obtained for steel columns when associated with concrete by steel-concrete composite structures.

It was observed that even with the loss in strength of the composite systems due to the increase in slenderness, the encased steel-concrete columns with 3 meters in height presented strengths above 100 kN, which corresponds to the average values of requests in small buildings. In simple steel tubular columns, these values did not reach 60kN.

Thus, it is observed that for small buildings, the use of cold-formed profiles becomes even more viable when it is associated with concrete in composite steel-concrete systems.

This analysis considered only columns height and concrete presence, but different results can be obtained changing cross-sections or materials properties.

In addition, an experimental analysis can reinforce the results obtained in this study and bring contributions related to the concrete cracking models' behavior, since this last aspect was not considered in this paper.

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