Partially encased composite steel and concrete columns: a systematic approach to the literature

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Abstract. Partially encased composite columns emerge as a promising solution in structural engineering, combining steel's versatility with concrete's durability. This article explores, at an introductory level, their characteristics and advantages, highlighting the construction efficiency and resource savings they offer compared to traditional reinforced concrete structures. While steel provides strength and speed in construction, concrete offers protection against fire and compression. The study consisted of two stages: the systematic literature review, in which the most relevant bibliography for the article's objective was selected, and the meta-analysis stage. The studies indicated a decrease in the initial stiffness, maximum load, and ultimate strength of the columns, with an increase in eccentricity, as well as an increase in the peak axial load and final moment of resistance in high-strength concrete, especially in slender columns which present reduced peak axial load due to the increase in the slenderness index. Furthermore, partially encased columns demonstrated superior compressive strength to steel at high temperatures. Therefore, these columns represent a promising option, subject to additional considerations and specific studies.

Keywords: Partially encased composite columns, Structural engineering, steel and concrete, construction efficiency, fire resistance**.**

1 Introduction

Structural engineering is advancing with a focus on performance, efficiency, and resource savings. Composite columns, combining steel profiles and concrete, offer promising solutions. This study emphasizes Partially Encased Composite (PEC) columns, which feature steel "I" or "H" sections with concrete between the flanges. According to Pereira [1], PEC columns provide structural strength, cost reduction, and construction efficiency, eliminating the need for forms and supports and enabling prefabrication to speed up construction.

In his work, Piquer [2] adds that steel offers high strength and rapid construction but requires fire protection, while concrete provides fire resistance and compression strength for durability. Combining these materials enhances savings and performance in pillar design. Integrating steel and concrete is gaining relevance for its unique benefits over single-material structures.

Despite the importance, research on composite columns was limited between 1994 and 2013, with increased interest more recently. Most studies originate from the United Kingdom, indicating the country's adoption of new technologies.

2 Goals

The Systematic Review (RS) seeks to gather valid information on the performance of PEC columns, examining different steel sections with concrete, both with normal and high compressive strength, and various slenderness indices. Thus, this study aims to identify evaluated aspects of these columns at an introductory level. Specific objectives include synthesizing results from selected studies to provide a comprehensive view of pillar performance, assessing the feasibility of using PEC columns in civil construction, and presenting a qualitative analysis of composite column performance with varying eccentricity, slenderness, and concrete strength.

3 Methodology

Once this paper is presented in the context of the research beginner's section, it should be noted that specific details and discussions of the scientific research initiation were synthesized to adhere to authorship guidelines.

3.1 Review Development

Initially, the following research question was defined: "How do Partially Encased Composite Columns, formed by cold-formed profiles, perform?". To carry out the Systematic Review, the Scopus database was used, in which three combinations of words were used to find as many relevant articles as possible for the research: (Steel-concrete AND column* OR composite column* AND concrete AND Partially encase or PEC), (Composite column* AND Partially encase OR PEC AND Fire) and (Composite column* AND Partially encase OR PEC AND Strength OR efficiency OR ductility OR connector). Once the articles were found, exclusion criteria were applied to provide greater reliability of the information. The flowchart summarizes the steps for selecting articles for research, as shown in Figure 1.

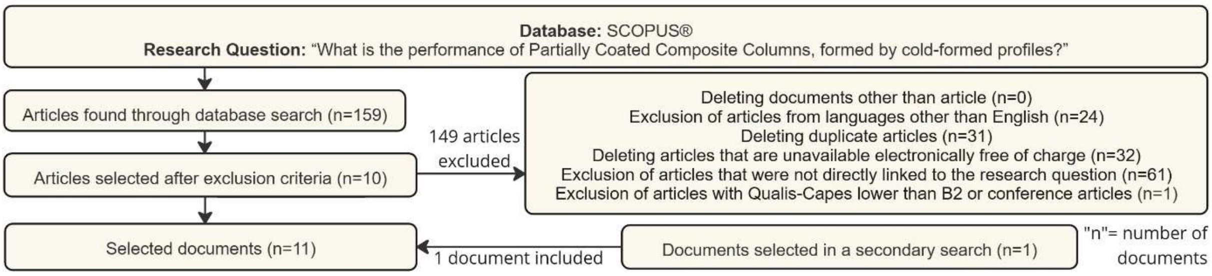

Figure 1. Article selection flowchart

The inclusion of studies in the review is directly aligned with the exclusion criteria and the research question. Therefore, the chosen articles, while not necessarily the most recent, are the ones that most effectively contribute to the systematic review, underscoring their significance and relevance to the current state of the art.

3.2 Correlation analysis

In this work, the Pearson correlation will be used. This statistical measure quantifies the strength and direction of the linear relationship between two variables. Gomes [3] says that the Pearson correlation coefficient varies between -1 and 1: a value of 1 indicates a perfect positive linear correlation (the variables are directly proportional), -1 indicates a perfect negative linear correlation (the variables are inversely proportional), and 0 means no linear correlation.

4 RESULTS AND DISCUSSIONS

Among the works studied, pillars of different sections and lengths were included, and other parameters were analyzed. These include eccentricity, concrete strength, steel strength, slenderness index, load capacity, fire resistance, and width-thickness ratio.

4.1 Eccentricity

As mentioned by Hunaiti and Fattah [4], studies indicate the importance of checking the maximum load, as it is close to it that greater deflections appear and excessive yielding of steel and concrete. In this sense, studies indicate that eccentricity affects the peak axial load or maximum load. Thus, gathering data from Hunaiti and Fattah [4] and Begum [5], a graph shows the influence of increasing eccentricity on decreasing maximum stress, as shown in Figure 2. Furthermore, obtaining the square root of R^2, it is observed that the lowest R-value was 0.9273, demonstrating a strong Pearson correlation.

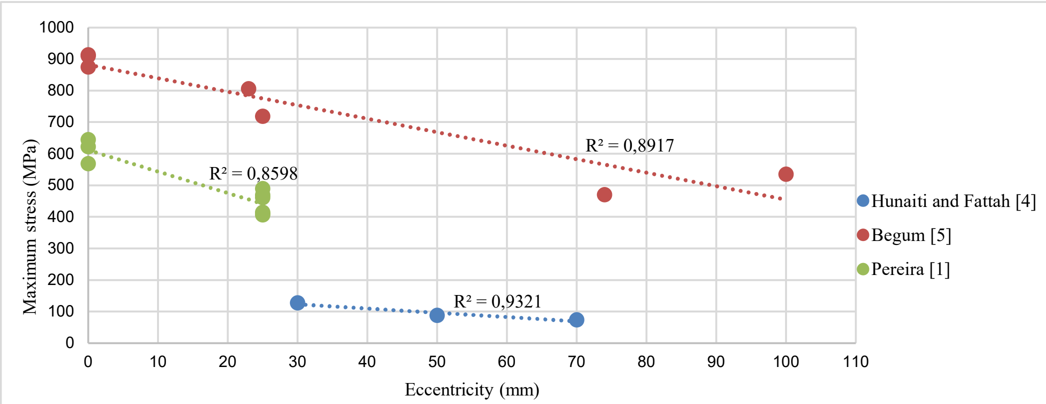

Figure 2. Eccentricity x Maximum stress

4.2 Concrete and Steel Strength

In the words of Hunaiti and Fattah [4], the final moment of resistance increases with the increase in concrete strength. Thus, analyzing the data from Hunaiti and Fattah [4] and Begum [6], an increase in concrete resistance was observed, and the maximum tension increased, as shown in Figure 3. However, this tension peak is higher in short columns, showing that the peak stress is reduced with an increase in the slenderness ratio.

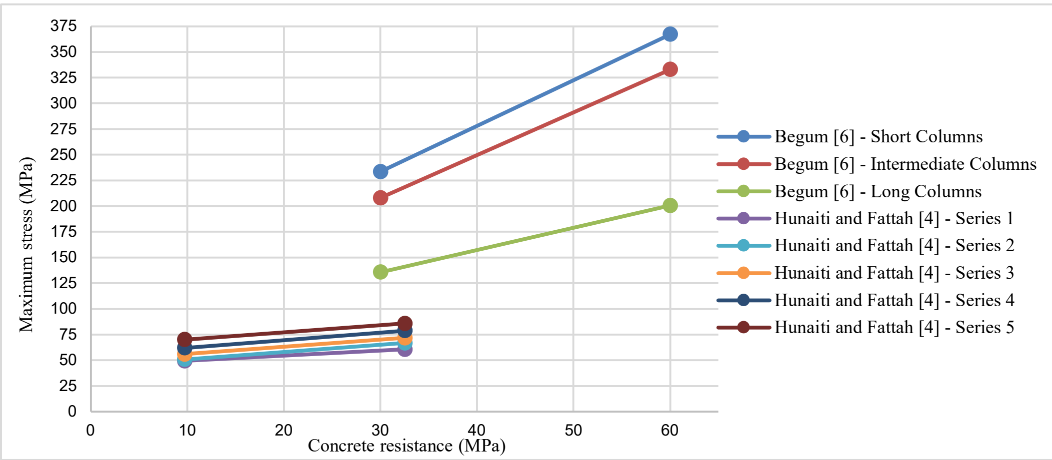

Figure 3. Concrete resistance x Maximum stress

Regarding the steel strength, according to Wang [7], increasing the yield strength of the steel results in greater column strength but can increase local buckling of the flange. By increasing the strength of the steel, the ultimate capacity of eccentrically loaded PEC columns is significantly improved. Column ductility is not compromised by increasing yield strength due to an increasing portion of the load supported by the steel section rather than the concrete. This clearly illustrates the benefit of using higher-strength steels in PEC columns. Furthermore, according to Yin [8], because of concrete, the stiffness of composite columns is greater than that of steel columns

4.3 Slenderness Index

As described by Begum [5] and Yin [8], With an increase in the slenderness index, there is a decrease in the load, stiffness, and support capacity of the columns. Begum [6] indicates that a greater slenderness ratio reduces the axial load capacity and increases moments at peak load and lateral displacement. Local buckling occurs just after the peak load in low and long columns, exactly at the peak in intermediate columns, and after concrete crushing.

In the study by Pereira [1], 0.6m and 2m high pillars and thinner pillars were used to evaluate the behavior during flexion-compression. The maximum strength of the columns under simple compression showed little variation with the increase in the slenderness ratio (0.25 to 0.83): -13% for conventional reinforcement and mesh, and +4% for fiber. In the case of flexure-compression, there was a significant reduction: 30% for conventional reinforcement and mesh and 43% for concrete with steel fibers.

4.4 Load Capacity

In Yin [8], the final load capacity of the column was studied, and it was realized that it is higher in composite columns than in steel-only columns. Furthermore, the load capacity and initial stiffness increased with increasing section width.

Local buckling was observed by Kazemzadeh [9] in several locations along the flanges of section I specimens, in addition to observing an increase in peak load with the enlargement of the section.

In the push-out test in Pereira [1], specimens 1 to 3 had a maximum force value of 66.8 kN, 35.78 kN, and 48.22 kN, while the specimen with a section composed of stirrups fixed to the core of the steel profile had a value of 534.1 kN. This specimen performed much better than the others since these stirrups function as shear connectors.

4.5 Fire Resistance

According to Piquer [2], only 4.9% of steel columns resist fire for up to 60 minutes. However, partially encased composite columns resist high temperatures better, with many lasting up to 2 hours. Composite columns are the most economical, reducing costs by around 50% while maintaining load and fire resistance. Optimal PEC column configurations for fire exposure are HE sections for up to 90 minutes and HP sections for 120 minutes. Thus, the authors concluded that high-strength concrete and low-strength steel are recommended for economical PEC projects.

Fellouh [10] found that partially encased pillars resist fire for around 120 minutes before collapsing, with the concrete covering increasing protection. Using a HEB 220 section, they observed that the temperature decreases towards the center due to the concrete and increases with the time of exposure to the fire. Columns fully encased in high-strength concrete offer better fire protection.

Although structurally superior, high-strength concrete loses strength under fire, equaling the buckling load of normal concrete after 55 minutes. Normal-strength concrete allows for greater deflections, which are beneficial during exposure to fire.

4.6 Width-Thickness Ratio

Song [11] found that ultimate stress in flanges increases with decreasing width-thickness ratio and that flange buckling can occur in both elastic and plastic states. Internal imperfections delay buckling, while external imperfections have a lesser, opposite effect. Plate thickness, yield stress, and link spacing influence post-buckling resistance. Sections with smaller thicknesses, like 450x450x6.35, showed significantly lower maximum compressive stress (20 MPa) than others (70 MPa). Higher peak and residual loads were observed in 600x600 sections compared to 450x450, with thinner sections showing reduced values.

In his studies, Song [12] observed that local buckling and ultimate resistance increase with a higher width-thickness ratio, while yield stress increases decrease these resistances. Reducing the width-to-thickness ratio from 4 to 2 significantly boosts buckling resistance and ultimate strength. However, peak load and moment decrease with a higher b/t ratio. The ductility of composite columns decreases with increased slenderness, and as flange slenderness increases, axial capacity decreases, according to Begum [6].

5 Conclusions

In conclusion, the systematic review effectively met its objectives, providing a comprehensive understanding of partially encased composite columns. Key findings include:

- Partially encased composite columns are promising but require further specific studies.
- Increased eccentricity decreases initial stress, resistance, and maximum load.
- High-strength concrete columns exhibit high peak axial loads but are more brittle compared to normal-strength concrete.
- Higher concrete strength increases the final moment of resistance, especially in slender columns, but peak axial load decreases with higher slenderness, notably in shorter columns.
- Partially encased composite columns show good fire resistance, unlike unprotected steel columns.
- These insights guide future research and practical applications, emphasizing the importance of design and material choices for safe and efficient structural columns.

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Authorship statement. The authors hereby confirm that they are the sole liable persons responsible for the authorship of this work and that all material that has been herein included as part of the present paper is either the property (and authorship) of the authors or has the permission of the owners to be included here.

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