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5º CONGRESSO IBERO-LATINO-AMERICANO EM SEGURANÇA CONTRA INCÊNDIOS

5th IBERIAN-LATIN-AMERICAN CONGRESS ON FIRE SAFETY

15-17 /07/ 2019 - Porto, Portugal

Atas dos Artigos
Proceedings (full papers)

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U.PORTO FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO
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PREFACE

The Iberian-Latin American Congress on Fire Safety (CILASCI) is held once every two years, with the aim of disseminating scientific and technical knowledge in the field of fire safety, integrating different players involved in this area of knowledge. The first edition of the Iberian-Latin American Congress on Fire Safety (CILASCI 1), was held in Natal (Brazil) between 10-12 March 2011. The second congress (CILASCI 2) was held in Coimbra (Portugal), between May 29 and June 1, 2013. The 3rd and 4th editions took place on the South American continent. The third congress (CILASCI 3) was held in Porto Alegre (Brazil) from November 3 to 6, 2015, while the fourth congress (CILASCI 4) was held in Recife (Brazil) from 9 to 11 October 2017. The CILASCI 5 will take place in the city of Porto (Portugal) from 15 to 17 July 2019, and presents 5 invited lectures and 78 manuscripts (full papers) from researchers around the world (Algeria, Australia, Belgium, Brazil, China, Czech Republic, France, Hong Kong, Italy, Mozambique, Portugal, Spain, United Kingdom and United States).

the 5th Iberian-Latin-American congress on fire safety reflects the new developments achieved on active and passive fire protection, on evacuation and human behaviour under fire, on computational modelling of structures and materials under fire, on explosion and risk management, on architectural issues for fire safety in buildings, on fire dynamics, on the experimental analysis of materials and structures under fire, on fires in special buildings and spaces, on fire-fighting operations and equipments, and on the behaviour of structures and materials under fire.

The Fire Safety is reaching new developments as a result of new research, development and innovation around the world, based on the excellence level of the research, the support of new skilled professionals and due to the existence of advanced training programmes in fire science technology. This development will increase the safety level of people, buildings, and products, but also is going to produce an impact in the economy of each country, with a positive impact on society.

The organizing committee believe that this congress will address to our delegates a wide forum of discussion about the recent developments in Fire Safety, promoting the exchange of ideas and international cooperation.

The organizing Committee would like to thanks to all authors and delegates.

On the behalf of the Organizing Committe
Paulo A. G. Piloto

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INDEX

THERMAL BEHAVIOUR OF PARTIALLY ENCASED COLUMN UNDER COMBINED COMPRESSION AND BENDING

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Keywords: Fire, Partially Encased Column, Advanced Method, Annex G, Combined Compression and bending.

ABSTRACT

In this paper, the advanced and simplified calculation methods are used to evaluate the fire resistance of eccentrically loaded partially encased composite columns (PEC). The work consists in developing of an efficient Non-linear 3-D finite element model (ANSYS) to investigate the behaviour of Pin-ended PEC eccentrically loaded at elevated temperature. The columns were tested under standard ISO834 fire. The buckling load is determined for several column heights 3; 4.5 and 6 m, by considering an eccentricity around the minor axis equal to 0,5.B; 1,0.B and 1,5.B (B section base). The numerical method presented here is compared with the simple calculation method Annex G of EN 1994-1-2. The results show that the load capacity of PEC column is reduced more than half in both condition, 50 min of fire exposure or increasing the load eccentricity by 0.5.B. Which is a fair conclusion to take the load eccentricity into consideration in structural fire design. The comparison results show a good agreement between the two methods at high fire ratings (R90 and R120), however at low fire rating (R30), the simple calculation method presents conservative results. It is to be concluded that the reinforcement has an influence on the

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thermal and mechanical behaviour of PEC column especially in combined compression and bending.

1. INTRODUCTION

Fire accident is considered as one of most sever environmental hazard to building construction, which makes people's life and property safety in danger. In order to improve the safety of the structures under fire, investigates have carried out extensive research on composite materials in structures at elevated temperature [1-3]. Partially encased concrete column (PEC) is a structure element used commonly in modern buildings due to their advantages such as, high stiffness, ductility, simple use and in particular excellent fire resistance [4-7]. The composite section in PEC is responsible for increasing the load bearing capacity and the fire resistance compared to the same section of the steel bare profile [8]. In most structures with portal frame, compression load in columns are applied with bending moments (eccentric loading), which may create instability problems, particularly in fire accident. These parameters must be taken into account during the design and the dimensioning of structures.

Some experimental studies are conducted to analyse the behaviour of composite columns under combined compression and bending at elevated temperature [9-12]. It was observed that the steel ratio, slenderness and the load eccentricity have a noticeable influence on the fire resistance of composite columns. Moreover, spalling of the concrete was found to decreases the fire resistance of composite columns. In 1994 a group of researchers [13] studies the fire resistance of concrete filled steel-tube columns, they conclude that the composite columns without reinforcement are sensitive to eccentric loading. In the cases of eccentrically loaded specimens the local buckling of the steel tube directly caused its failure, since the specimens could not resist the bending moment after the local buckling of the steel tube had taken place. For centrally loaded specimens, the column lost its load-bearing capacity by the compressional failure of the inner concrete which was caused by the shift of the load from the steel tube to the concrete after the local buckling of steel tube took place. In the unprotected specimens, the steel tubes were damaged heavily. M.Milanovic and M. Cvetkovska [14] have conducted a comparative study on deferent composite column having the same bearing capacity at ambient temperature. They found that the highest loss of M-N bearing capacity under fire was observed in PEC columns, it could be related to the direct heat exposition of its steel profile. A minimum reduction in the M–N bearing capacity was observed in composite section were the steel profile is totally encased with concrete.

Many numerical studies have been conducted using finite elements (FEA) and analytical method on the thermal and mechanical behaviour of composite columns. [15] Elaborated a FEA model for the full-range analysis of the concrete-encased CFST columns under combined compression and bending. They concluded that the composite columns may suffer from outer concrete failure which decrease its fire resistance. In 2016, N. Mago [16] study the fire behaviour of slender column, highly utilized, eccentrically loaded using concrete filled tubular profile. The results found using the numerical model, confirm that the fire resistance rating (FRR) is significantly reduced as the increase of the bending moment on the column. Also, it was found that for highly utilized columns the FRR was less influenced to changes in the intensity of the bending moments. A. Espinós et al [17] evaluated the fire resistance of eccentrically loaded concrete filled steel tubular columns. The comparison between the results of the different methods demonstrates the unsafety of the current calculation method used in EN1994-1-2 [18]. E. Ellobody and B. Young [19] investigated the concrete encased steel composite columns at elevated temperatures. It has been shown that the finite element model can accurately predict the behaviour of the columns at elevated temperatures. Furthermore, the variables that influence the fire resistance and behaviour of the composite columns comprising different load ratios during fire, different coarse aggregates and different slenderness ratios were investigated in parametric studies. It is also shown that the time–axial displacement relationship is considerably affected by the coarse aggregate.

This work investigates the fire performance of eccentrically loaded concrete partially encased column (PEC), using the advanced calculation method developed by an efficient Non-linear 3-D finite element model (ANSYS) [20]. These analyses are also performed with the simple calculation method in Annex G of EN-1994-1-2 [18]. This paper examines the influence of a range of parameters on fire behaviour of the composite column including: eccentricity loading, slenderness, reinforcement and fire rating.

2. COMPOSITE COLUMNS AND MATERIALS

In this work, a numerical model was developed to simulate the fire behaviour of PEC, HEB300 profile. These columns were tested under fire ISO834 [21] for deferent fire rating class up to R120. The load bearing capacity has been compared for columns with 3, 4.5 and 6m, pinned- pinned ending boundary condition. Properties for steel were assumed from S275 grade and B500 grade for rebars, while C30/37 was assumed for concrete, the non-linear properties of these materials can be found in EN-1994-1-2 [18], and a relative eccentricity about the week axis (*e* function of *b*) tested, *e*=50%**b*; *e*=100%**b* and *e*=150%**b*. Where *e* is the applied load eccentricity, and *b* is the dimension of the section base, see Figure 1.

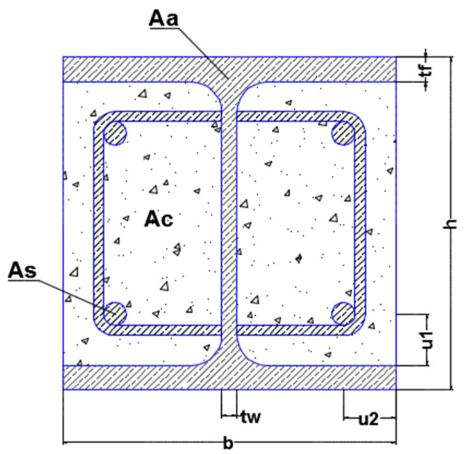


Figure 1: Cross section example of PEC column.

3. SIMPLIFIED CALCULATION METHOD

The fire resistance of partially encased composite columns under eccentricity of loading can be found using the simplified method given in EN-1994-1-2 Annex G [18]. This method leads to determine the load bearing capacity of PEC column, being calculated from the following Eq. 1:

$$N_{fi,Rd,\delta} = N_{fi,Rd}(N_{Rd,\delta} / N_{Rd}) \quad (1)$$

Where: $N_{fi,Rd}$ represents the buckling resistance of PEC at elevated temperature, $N_{Rd,\delta}$ is the buckling resistance of PEC under eccentric loading at ambient temperature and N_{Rd} is the buckling resistance of PEC at ambient temperature.

The different steps to determine the load bearing capacity of PEC are illustrated by the following chart represented in Figure 2.

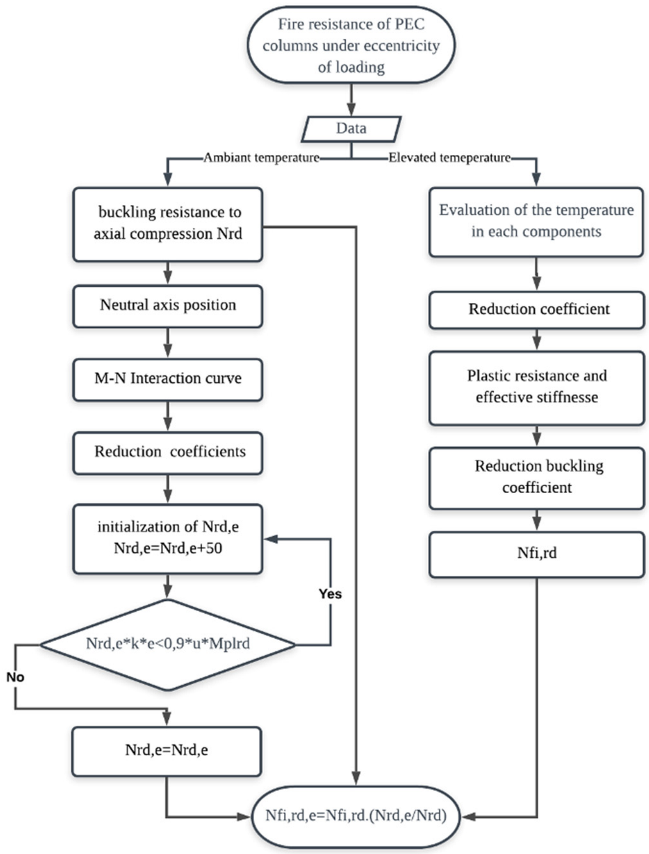


Figure 2: Organogram chart for evaluation of the load bearing capacity of PEC under fire.

This diagram includes three sequentially parts, it begins with the evaluation of the load bearing capacity under axial compression. Then the fire effect is introduced to determine the reduction coefficients for the resistance and stiffness in each component (Steel; Concrete; Rebars). The eccentricity of the load is considered in the last step, in which the applied load is incremented with 50 *N* until to find the resistance moment less than soliciting moment (see Equation 2). The outcome of this chart results in to determine the load bearing capacity of composite column under fire.

$$M_{sd} = N_{Rd,e}.k.e \leq M_{Rd} = 0{,}9.\mu.M_{pl,Rd} \quad (1)$$

M-N interactive curves were developed to present the combined compression-bending resistance of columns in a single Figure. The load (N) versus moment (M) interaction curves for the PEC HEB300 was determined by the simplified method in EN-1994-1-1 [22] and is presented in Figure 3, in comparison with the load bearing capacity for different eccentricities (e0; e150; e450 mm). It can be seen that in general, when the eccentricity of loading is involved, the bearing capacity of the column is decreased.

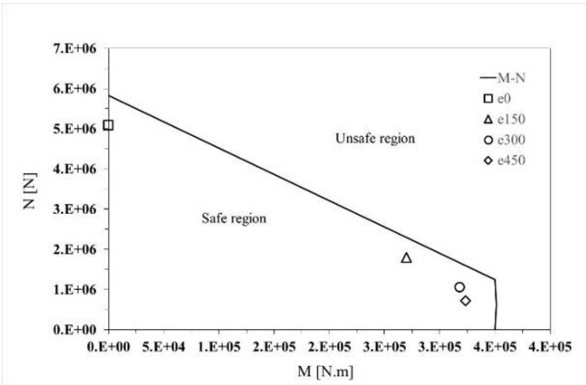
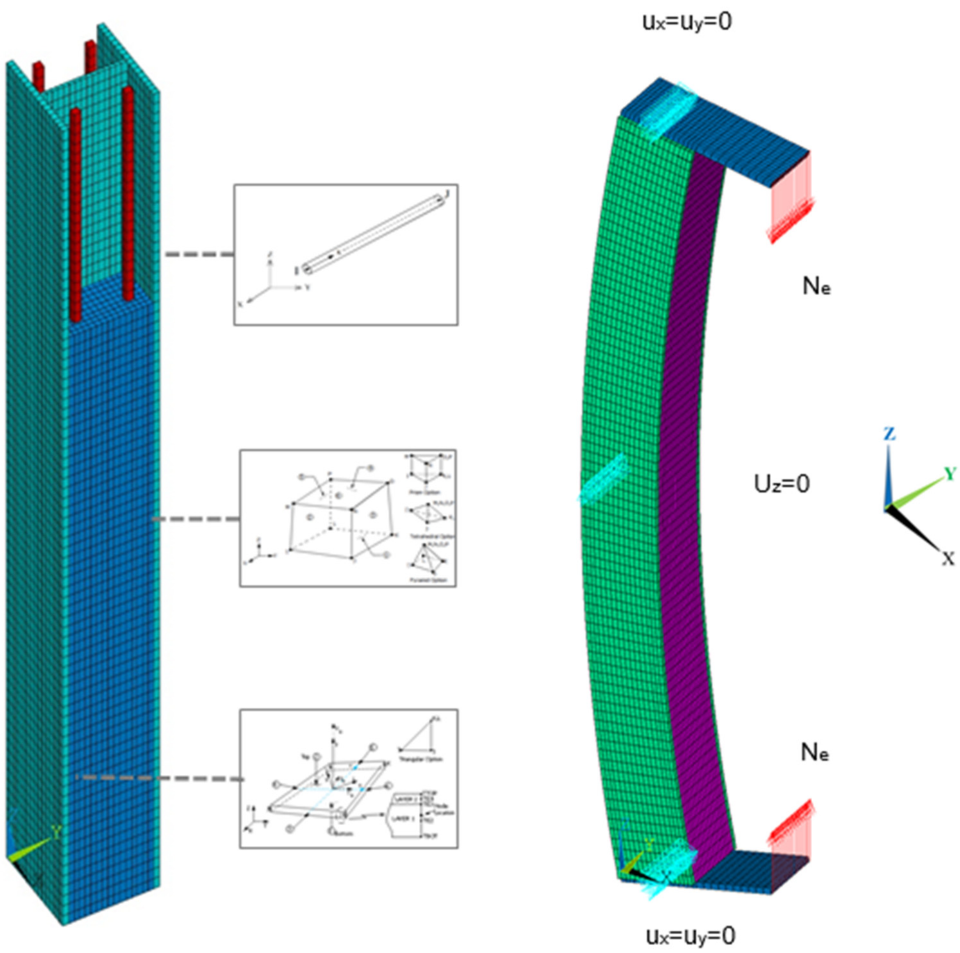


Figure 3: Interaction N-M curve for uniaxial bending PEC HEB300 3m.

As can be seen, when the eccentricity of loading is considered, the method of EC 4 is somewhat relatively complex for an everyday practice and it needs necessarily the computer programming. An advanced calculation method is developed based on finite elements approximation using ANSYS 18.2 [21] to determine the thermal behaviour of PEC under eccentric loading.

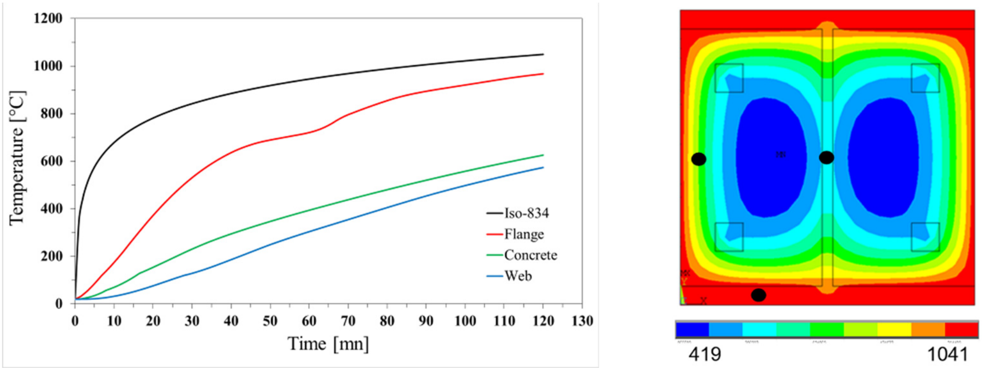
4. ADVANCED CALCULATION METHOD

The thermal behaviour of composite columns under eccentric loading was presented in various finite element studies [15, 16, 23]. In this study, ANSYS 18.2 was used to perform the numerical modelling analysis [20]. After a convergence test, the mesh size used for finite element approximation is defined between 20 mm to 30 mm (see Figure 4 (a)).



(a) (b)
Figure 4: (a) Finite element model; (b) Boundary conditions.

A three-dimensional finite elements type was considered for the thermal analysis: SHELL 131 is used to model the steel profile, SOLID70 is used to model the concrete and LINK33 is used to model the reinforcement see Figure 4 (a). The thermal solution was considered transient and nonlinear, using an incremental procedure with a time step of 60 s up to 7200 s. Four sides of the cross section was heated by the fire source ISO-834 [21], Figure 5 (a) presents the temperature evolution with time of the PEC column. The thermal analysis was considered with radiation and convection heat transfer using standards coefficients from EN-1991-1-2 [18]. Figure 5 (b) Shows the temperature field after 120 minutes of fire. The thermal results are used in the buckling analysis as thermal load.



(a) (b)

Figure 5. (a) Time temperature history for different points in PEC; (b) Temperature in the cross section for a critical time of 120 min.

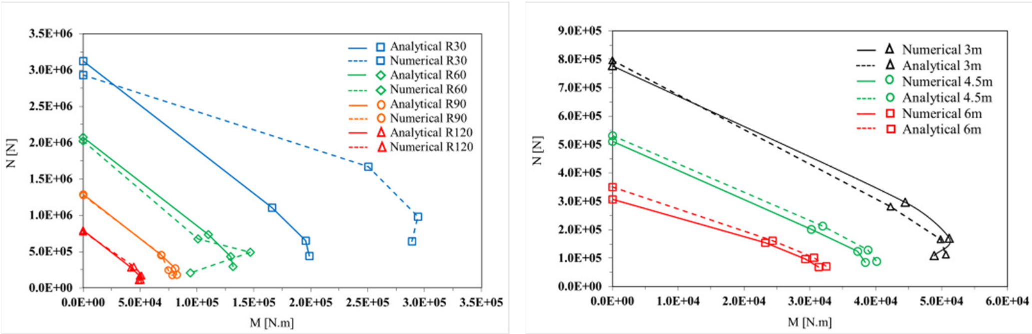
For the non-linear analysis, an imperfection is taken from the Eigen buckling analysis and applied to update the geometry of the column. In this model, an incremental eccentric load (*Ne*) is applied on the top and the bottom of a rigid plate equal to (*Nrd* / 2) / 1000. To model the pin-pin ended boundary condition for the composite column, two mid line nodes of the rigid loading plate are restrained in X and Y direction, and the mid height node of the PEC is restrained in the Z direction to prevent any displacement of the column (displacement controlled) , see the Figure 4-b. Based on a nonlinear material model, the Arc-length solution method is used in this study with a minimum and maximum incremental load of 0.01**Ne* and 10**Ne*, being the convergence criterion based on displacement, with a convergence tolerance of 5%.*N*.

5. RESULTS AND DISCUSSION

5-1 M-N Interaction Diagram

Figure 6 (a) shows the variation of buckling resistance of PEC columns depending on the fire exposure time and eccentricity of the load, using both analytical and numerical method. The buckling load decreases with the increase of fire exposure time and the level of eccentricity. It is known that the high temperatures, caused by fire effect, affects considerably the mechanical properties of the materials component. Consequently, the region limited by the axial force and by the bending moment bearing capacity of the columns is reduced, resulting in a change of the M-N interaction diagrams (load bearing capacity). It is clear from Figure 6 that EN-1994-1-2 results agree fairly with the results of the finite elements model, particularly at higher temperatures (R90-120), however at low temperature (R30) the analytical method presents conservative result of approximately 45% when applying an eccentric loading. A. Silva et al [11] also found that Eurocode 4 provides conservative estimates of the bending capacity of CFST members in comparison with experimental and numerical analysis. The effect of the buckling length on the M-N interaction diagram evaluated with both methods is illustrated in Figure 6 (b). As expected, the

M-N values decreased with the increase of the buckling length of composite column. Especially for the column high with 3m the moment resistance decreases after reaching its maximum value.

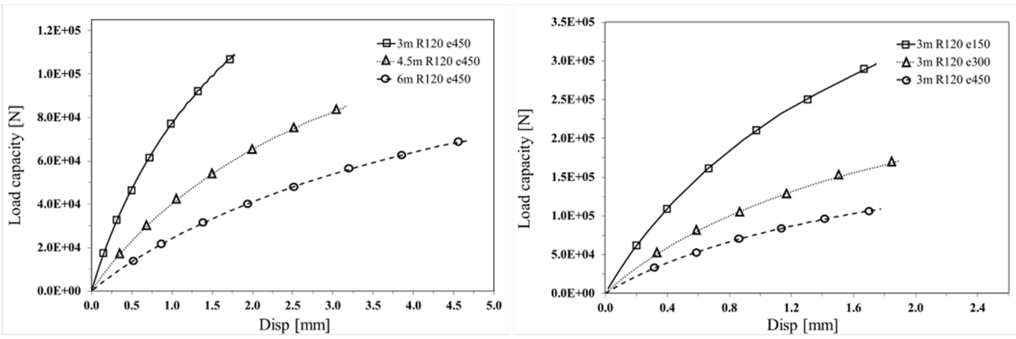


(a) (b)

Figure 6. (a) M-N interaction diagram for different fire rating class; (b) M-N interaction diagram for different column slenderness.

5.2. Compression Load versus Lateral Displacement

The variation of compression load with the lateral displacement in the mid-height of the column is represented in Figure 7 for high fire rating (R120). It is shown in Figure 7 (a) that the lateral displacement increases with the increase of the compression load, for the same buckling length. When increasing the buckling length of the column, the load capacity is reduced and the displacement is decreased. The effect of varying the eccentricity of the load for same high (3m) is plotted in Figure 7 (b). It is to be noted that the variation of eccentricity has a significant influence on the load capacity, however, its effect is less pronounced in the displacement. The comparison of the two Figures indicate that the eccentricity has more influence in the load capacity then the buckling length. In practical design of composite structure, it is more interesting to consider the effect of eccentric loading then the effect the slenderness.

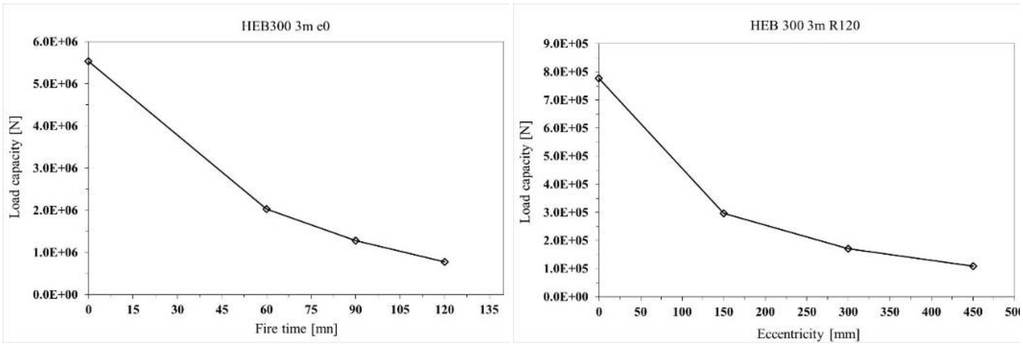


(a) (b)

Figure 7. (a) Displacement versus load capacity with e=450mm; (b) Displacement versus load capacity with column height of 3m.

5.3. Buckling load bearing capacity

Figure 8 (a) shows the variation of the axial compression of the composite column (3m) as a function of fire exposure time. The buckling load decreases with the increase of the fire exposure time as a result of the degradation of the mechanical properties of the materials. The fire effect reduced the load capacity of column with 85% after 120mn. The variation of loading eccentricity versus the load capacity at fire rating class R120 is represented in Figure 8 (b), when calculating the loss of the bearing capacity of the column, the presence of bending moment on the head of the column may have the same effect as the fire.

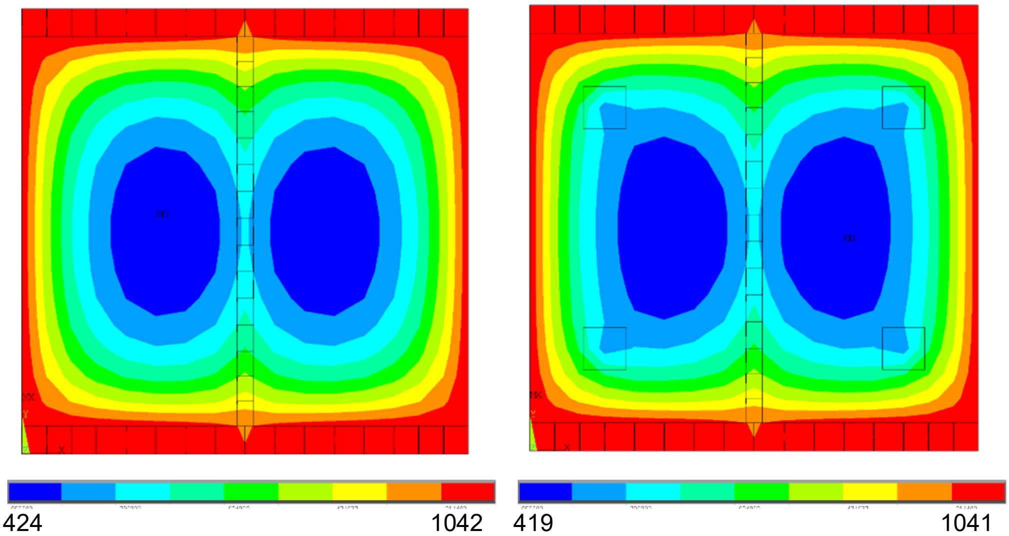


(a) (b)

Figure 8. (a) Fire time versus load capacity in PEC; (b) Eccentricity versus load capacity in PEC.

5.4. Reinforcement Contribution of Composite Column in Fire Resistance

The temperature distribution in PEC composite column with and without rebars is plotted in Figure 9. According to both cross sections, the difference between the minimum temperatures is 5°C after 120 min. The results show that including rebars in composite column increases slightly the level of fire protection as found by K. Ukanwa in 2017 [24]. It is observed that the presence of reinforcement has modified the temperature distribution of the cross section.



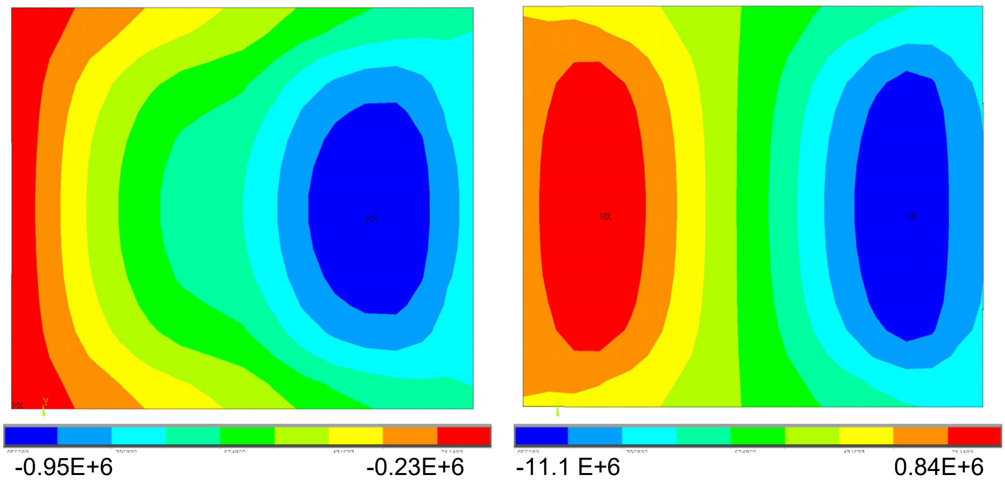
(a) (b)

Figure 9. (a) Temperature distribution in PEC without rabars at R120; (b) Temperature distribution in PEC with rabars ϕ25 at R120.

The effect of the reinforcement on the load capacity for the same geometrical cross section (PEC HEB300) incorporating different rebar's diameter (ϕ0, ϕ10, ϕ25), is illustrated in Table 1. The results found indicate that the load capacity of the PEC column increases with the increase of the amount of reinforcement. So, it is clear that the reinforcement has a greater contribution when the column subjected to eccentric loading than when it is under axial compression as expressed by the difference in percentages (see Table 1) as found elsewhere [25]. This is maybe related to the good compression strength of concrete in case of axial loading, which does not need reinforcement (see Figure 10 (a)). However, in case of combined compression and bending the concrete section may suffer from the tension stress, which explains the importance of the presence of the reinforcement (see Figure 10 (b)). For a given reinforcement the loading eccentricity has a more pronounced effect on plan concrete than the reinforced concrete.

Table 1: Effect of reinforcement on the load bearing capacity of the composite column.

Eccentricity	**Load bearing capacity [N]**			**Difference in [%]**		
e [mm]	**ϕ0**	**ϕ10**	**ϕ25**	**ϕ0/ϕ10**	**ϕ10/ϕ25**	**ϕ0/ϕ25**
0	7.40E+05	7.45E+05	7.77E+05	0.61	4.33	4.96
150	2.47E+05	2.67E+05	2.97E+05	7.78	11.43	20.11
300	1.40E+05	1.51E+05	1.71E+05	8.25	12.96	22.27
450	9.29E+04	9.95E+04	1.09E+05	7.15	9.09	16.89



(a) (b)

Figure 10. (a) Stress in PEC under centric compression load; (b) Stress in PEC under eccentric loading.

6. CONCLUSIONS

The fire resistance of partially encased composite columns under combined compression and bending moment was investigated with analytical and numerical method. The following conclusions can be made:

- The use of a three-dimensional numerical model (ANSYS) allowed to describe easily the thermal behaviour of PEC columns under eccentric loading with the regard to the analytical method, which is based on three complex steps.
- For the fire rating R30, the analytic method presents a conservative result of approximately 45% when applying an eccentric loading.
- There is a good agreement between the two methods particularly at high temperature.
- In this study the presence the load eccentricity has found to have more effect on the loadbearing capacity than the slenderness of the composite column.
- Introducing a bending moment on the top of the column may have the same effect as the fire.
- The reinforcement has a slight influence on the temperature evolution, moreover the reinforcement has a great contribution on the load capacity, especially in combined loading for compression and bending.

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