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Developments and Applications

PROCEEDINGS

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April, 2019

1 – Introduction

The Organizing Committee of SYMCOMP2019 – 4th International Conference on Numerical and Symbolic Computation: Developments and Applications, welcomes all the participants and acknowledge the contribution of the authors to the success of this event.

This fourth International Conference on Numerical and Symbolic Computation, is promoted by APMTAC - Associação Portuguesa de Mecânica Teórica, Aplicada e Computacional and it was organized in the context of IDMEC - Instituto de Engenharia Mecânica, Instituto Superior Técnico, Universidade de Lisboa. With this ECCOMAS Thematic Conference it is intended to bring together academic and scientific communities that are involved with Numerical and Symbolic Computation in the most various scientific areas

SYMCOMP 2019 elects as main goals:

To establish the state of the art and point out innovative applications and guidelines on the use of Numerical and Symbolic Computation in the numerous fields of Knowledge, such as Engineering, Physics, Mathematics, Economy and Management, Architecture, ...

To promote the exchange of experiences and ideas and the dissemination of works developed within the wide scope of Numerical and Symbolic Computation.

To encourage the participation of young researchers in scientific conferences.

To facilitate the meeting of APMTAC members (Portuguese Society for Theoretical, Applied and Computational Mechanics) and other scientific organizations members dedicated to computation, and to encourage new memberships.

We invite all participants to keep a proactive attitude and dialoguing, exchanging and promoting ideas, discussing research topics presented and looking for new ways and possible partnerships to work to develop in the future.

The Executive Committee of SYMCOMP2019 wishes to express his gratitude for the cooperation of all colleagues involved in various committees, the Scientific Committee, the Programm Committee, Organizing Committee and the Secretariat. We hope everyone has enjoyed helping to consolidate this project, which we are sure will continue in the future. Our thanks to you all.

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FIRE PERFORMANCES OF PARTIALLY ENCASED COLUMN SUBJECTED TO ECCENTRIC LOADING

Abdelkadir Fellouh[1*], Abdelkader Bougara[1], Paulo A. G. Piloto[2] and Noureddine Benlakehal[1]

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Keywords: Fire, Composite column, Simulation Method, Analytic Method, Eccentric loading.

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 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 base). The numerical method presented here is compared with the simple calculation method Annex G of EN 1994-1-2. The results show that after 50 min of fire exposure, the axial load capacity of PEC is reduced to more than half, which is a fair conclusion to take 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 eccentricity of loading reduces the loadbearing capacity of the composite column. The shortest column (3m) presents the higher reduction in load bearing.*

1. INTRODUCTION

Composite columns made with partially encased concrete column (PEC) are among the most commonly used composite members in modern buildings due to their high stiffness, ductility, simple use and in particular excellent fire performance. 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 [1]. There have been some studies of composite columns investigating the behaviour of eccentrically loaded. Yu-Feng and Lin-Hai Han [2] studied the performance of concrete-encased CFST column under combined compression and bending, using a finite element analysis (FEA) model, and they found that the composite columns may suffer the outer concrete failure. Ana Espinós [3] present a simplified design method for evaluating the fire resistance of eccentrically loaded concrete filled steel tubular (CFST) columns. In 2015 Milivoje Milanović et al [4] analysed the cross-section load-bearing capacity of three types of fire exposed steel-concrete composite columns. The highest loss of the M–N bearing capacity was observed in the cross sections where the steel profile is directly exposed to heating, as in PES - Partially Encased Sections. A minimum reduction in the M–N bearing capacity was observed in sections where the steel profile is protected with concrete lining (FES section). In 2010 Xiaoyong Mao, V.K.R. Kodura [5] present results from seven fire resistance experiments on concrete encased steel (CES) columns under standard fire exposure conditions. The test parameters include column size, 3- and 4-side fire exposure, load intensity and load eccentricity. Test results show that CES columns have higher fire resistance under 3-side fire exposure than that under 4-side fire exposure. Also, load ratio and load eccentricity have a noticeable influence on the fire resistance of CES columns. In addition, spalling of the concrete decreases the fire resistance of CES columns. A comparison of measured fire resistance of CES columns with those predicted using current code provisions indicate that the current provisions may not be conservative in some situations.

The main objective of this study is to develop an efficient Non-linear 3-D finite element model to investigate the behaviour of eccentric loaded partially encased column PEC and compared with the simple calculation method from Annex G of EN-1994-1-2 [6]. The model was developed using the software ANSYS [7]. This numerical analysis enables to assess the effect of eccentricity in the mechanical behaviour of composite columns under fire.

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 [8] 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, 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 flange, see figure 1.

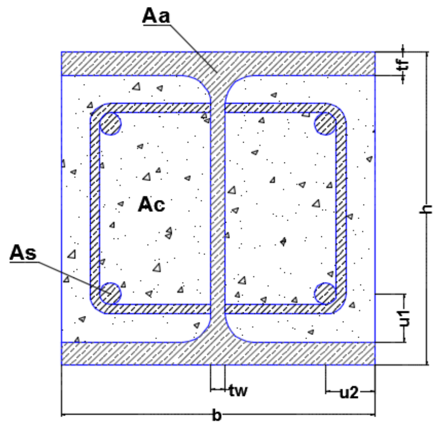

Figure 1. Cross section example of PEC column.

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 Annex G [6]. This method leads to determine the load bearing capacity of PEC column, being calculated from the following expression:

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

Where:

$N_{fi,Rd}$ Buckling resistance of PEC at elevated temperature;

$NN_{Rd,\delta}$ Buckling resistance of PEC under eccentric loading at ambient temperature;

N_{Rd} 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.

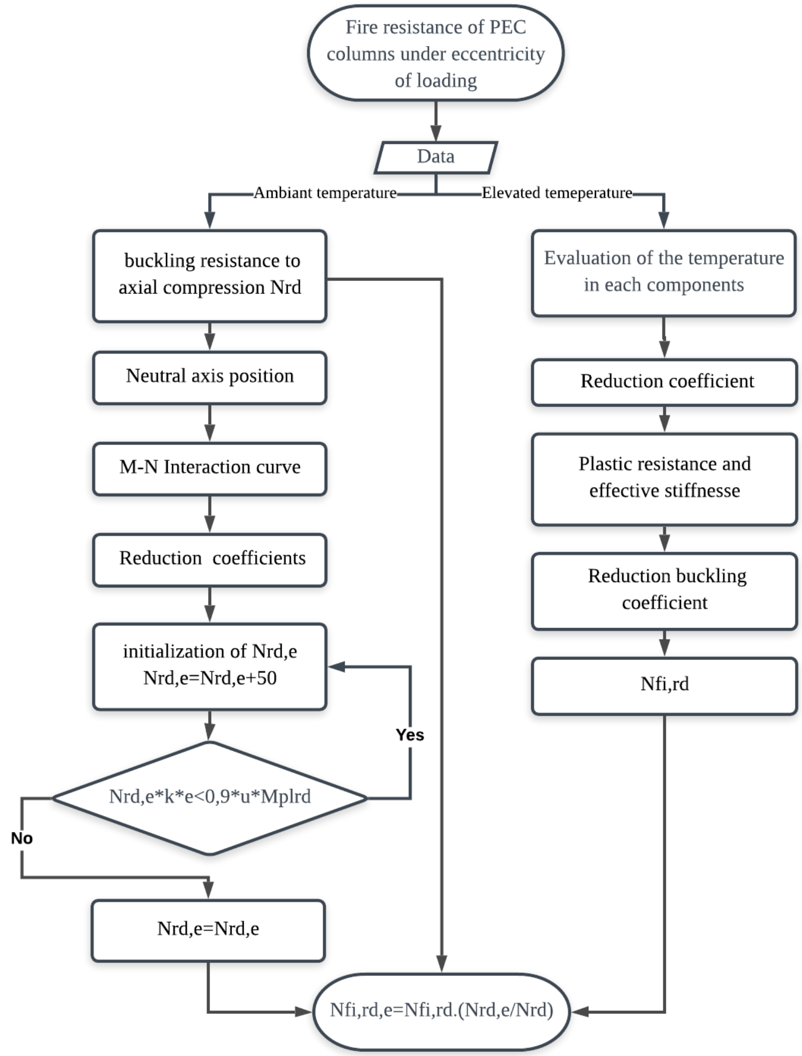

Figure 2. Organogram chart for evaluation of load bearing capacity of PEC under fire.

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.

$$M_{sd} = N_{Rd,e}.k.e \leq M_{Rd} = 0{,}9.\mu.M_{pl,Rd} \quad (2)$$

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 [9] 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.

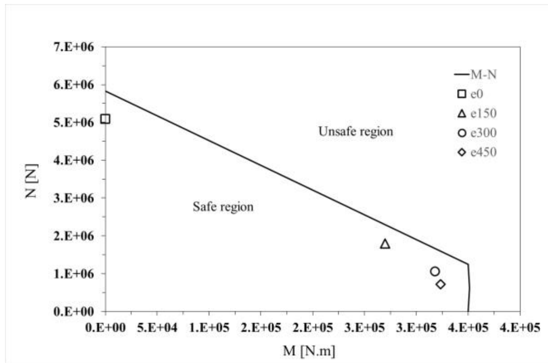

Figure 3. Interaction N-M curve for uniaxial bending PEC HEB300 3m.

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 [7] 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 [10-11-12]. In this study, ANSYS 18.2 was used to perform the numerical modelling analysis [6] [6]. The mesh size used for finite element approximation is defined between 20 mm to 30 mm (see figure 4-a). The standard fire ISO 834 [8] was used as a fire source.

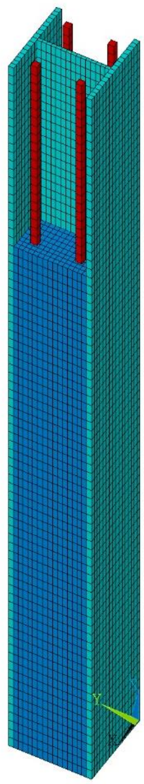

Figure 4-a. Finite element model.

Figure 5-b. Non-linear analysis discretization.

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. The thermal solution was considered transient and nonlinear, using an incremental procedure with a time step of 60 s up to 7200 s. Figure 5 shows the temperature field for the critical time of the PEC. The thermal results are used in the buckling analysis as thermal load.

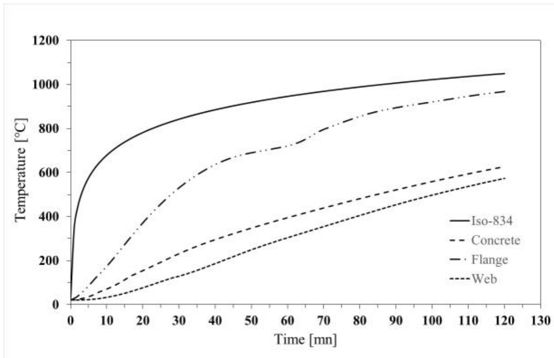

Figure 6-a. Time temperature history for different points in PEC.

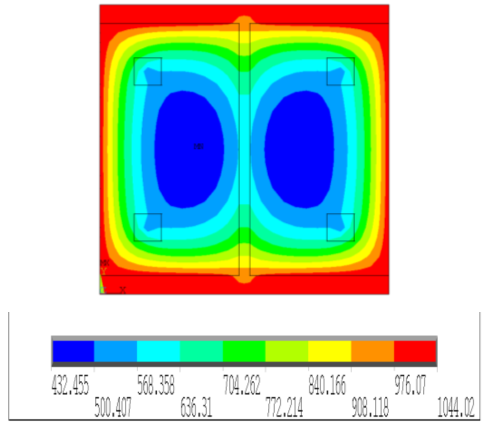

Figure 7-b. Temperature in the cross section for a critical time of 120 min.

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 is applied on the top and the bottom of a rigid plate equal to (N_{rd} / 2) / 1000, as shown in figure 4-b. 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). 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*N and 10*N, being the convergence criterion based on displacement, with a convergence tolerance of 5%.N

5. RESULTS AND DISCUSSION

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. 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 analytic method presents conservative result of approximately 45% when applying an eccentric loading.
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.

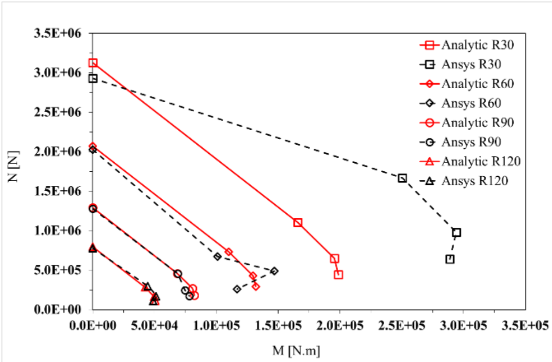

Figure 8-a M-N interaction diagram for different fire rating class.

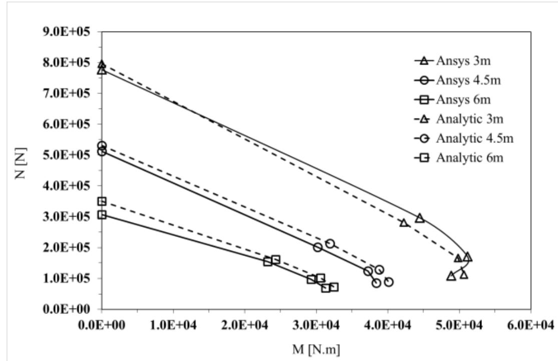

Figure 9-b M-N interaction diagram for different column slenderness.

The variation of compression load with the lateral displacement in the mid-height of the column is represented in figure 7-a and b 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, it's 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.

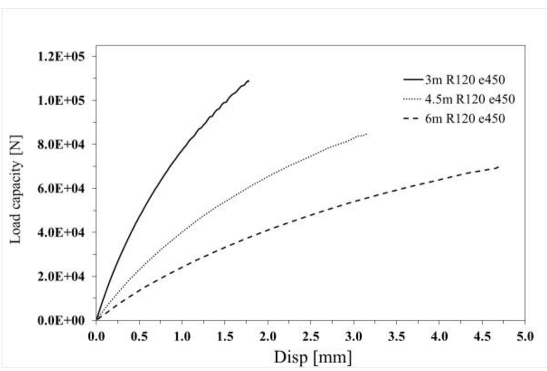

Figure 10-a. Disp versus load capacity with e=450mm

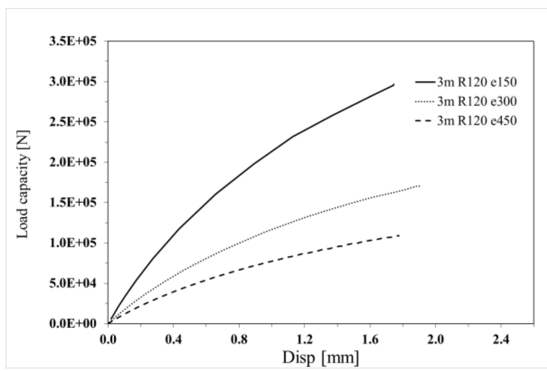

Figure 11. b- Disp versus load capacity with column height of 3m

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.

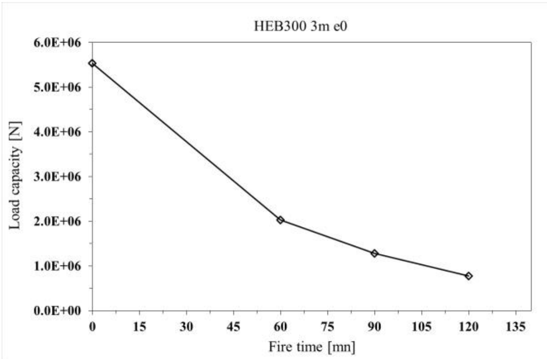

Figure 12-a. Fire time versus load capacity in PEC.

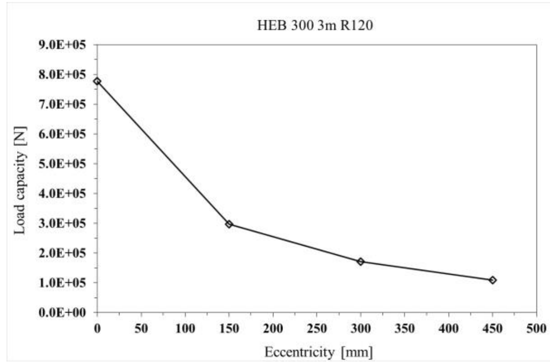

Figure 13-b. Eccentricity versus load capacity in PEC.

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.

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