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Comparing the Behavior of Reinforced Concrete Columns Embedded in Walls and Subjected to Fire

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Abstract: Fire is an exceptional action that may occur during the life of a building. So, it must be considered when designing a building structure. The standards provide several types of design methods for that propose, used for single elements, parts of structure or the structure as a whole. The fire design of columns is important both for new project as for remodel buildings and also for verification of the residual resistance of columns that have suffered a fire accident. In this way, the aim of this work is to analyze numerically different ways of fire exposure to check the compressive strength of the columns when subjected to fire and the influence of the adjacent walls to a column in case of fire. The thermal advanced analysis of the sections columns was performed using the finite element software, Abaqus CAE, where the standard fire curve, ISO 834 (International Organization for Standardization 834), was used, with 4 h of fire duration. It was possible, with the two methods used in this work, to compare them to verify which model is more conservative and which is closer to the advanced numerical model, for calculating temperatures in the column section. It was checked that the walls act as thermal insulators, protecting part of the columns from the convection and radiation of the fire. Consequently, the effects of raising the temperature over the compressive resistance of the reinforced concrete column, were reduced.

Key words: Column, reinforced concrete, thermomechanical analysis, fire.

1. Introduction

Columns are fundamental structural elements to ensure the stability of a building. In case of fire, due to failure of a column, partial collapse or even total collapse of the building may occur. Therefore, it is essential to develop studies related to this structural element in a fire situation.

The design of columns subjected to fire is important both for new buildings, as for buildings that will be remodel and also for verification of the residual loadbearing capacity of columns that have suffered a fire action.

Fire is an exceptional action that may occur during the life of a building, so it must be considered when designing its structure. Eurocode 1 part 1-2 [1] and Eurocode 2 part 1-2 [2] provide several types of design methods for that propose, namely: tabular methods, simplified calculation methods, advanced calculation methods and experimental methods. Also it is considered that the structure of the building can be analyzed by its single elements, parts of the structure or by the structure as a whole.

The methods, provided by Eurocodes and Brazilian standards, consider the columns as isolated elements, that is, without the presence of the walls adjacent to them. They are found different, most of the time, in the buildings.

According to Raut and Kodur [3], the position of columns in a building leads to a different thermomechanical behavior. The position of the neutral axis of the element's cross section can rotate and (or) translate, according to the fire exposure.

Correia et al. [4-6] presented in their studies the behavior of steel columns embedded in walls and

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subjected to fire. They experimentally check the influence of the walls arranged in different ways on the behavior of these columns.

According to Purkiss [7], for the verification of the compressive resistance of columns subjected to fire, the Zone Method was more conservative compared to the 500 °C Isotherm Method, both present in Eurocode 2 part 1-2 [2].

In this way, the aim of this work is to analyze numerically different ways of fire exposure and compare the simplified calculation methods, to check the compressive strength of the columns when subjected to fire and the influence of the adjacent walls to a column in case of fire. The thermal advanced analysis of the sections was performed using the finite element software, Abaqus CAE.

To perform the thermomechanical analysis of the columns subjected to fire, it is necessary first that a thermal analysis of these elements be carried out, in order to determine the temperature gradient in the concrete and the temperature in the steel bars. In this way, the work of Matos et al. [8] was used as a reference, where a thermal analysis of the cross sections of columns was carried out, for several cases of fire exposure. From the results of this work, representative models of possible thermal behavior, through the section of reinforced concrete columns subjected to fire, are obtained.

2. Numerical Simulations

Two simplified calculation methods were considered to obtain the load carrying capacity of square and reinforced concrete columns subjected to fire. They were considered the 500 °C Isotherm Method and the Zone Method.

To calculate the residual load bearing capacity is necessary to obtain the thermal gradient of cross-section of columns. A finite element software, Abaqus CAE, was used for this.

With the temperatures obtained in the concrete and steel reinforcing bars, it was possible to determine the residual load bearing capacity of the columns. The effect of the temperature increasing in the concrete caused a reduction in the area of its cross section. And for the steel rebars a coefficient of reduction of their resistance was applied, according to the temperature reached, as shown in Eurocode 2 part 1-2 [2].

We studied cases of isolated columns, embedded in concrete block walls with a thickness of 15 cm and exposed to different ways of fire, using the two simplified calculation methods to determine the residual load bearing capacity.

The types of columns embedded in walls studied were corner columns and in the middle of the wall. These situations, considering a compartment fire, represent many cases of arrangement of columns and different forms of exposure to fire, depending on thickness of the walls and the position of columns. Thus, it was possible to verify the thermal behavior of the columns, considering the influence of the walls adjacent to it.

Fig. 1 shows the fire curve considered, the ISO 834 (International Organization for Standardization 834) standard fire curve, for a fire duration of 4 h. Using the Abaqus CAE, the 500 °C Isotherm, the temperature in the middle of the zones, used in Zone Method and the temperatures in the steel rebars, were determined. The section of the columns and walls were discretized in square finite elements, type DC2D4: A 4-node linear heat transfer quadrilateral, with dimensions of 1 cm × 1 cm and responsible for obtaining the data referring to the heat transfer (Fig. 1).

The physical and thermal features of concrete and steel, as conductivity, specific heat and density, subject to high temperatures, were considered according to prescriptions of Eurocode 2 part 1-2 [2].

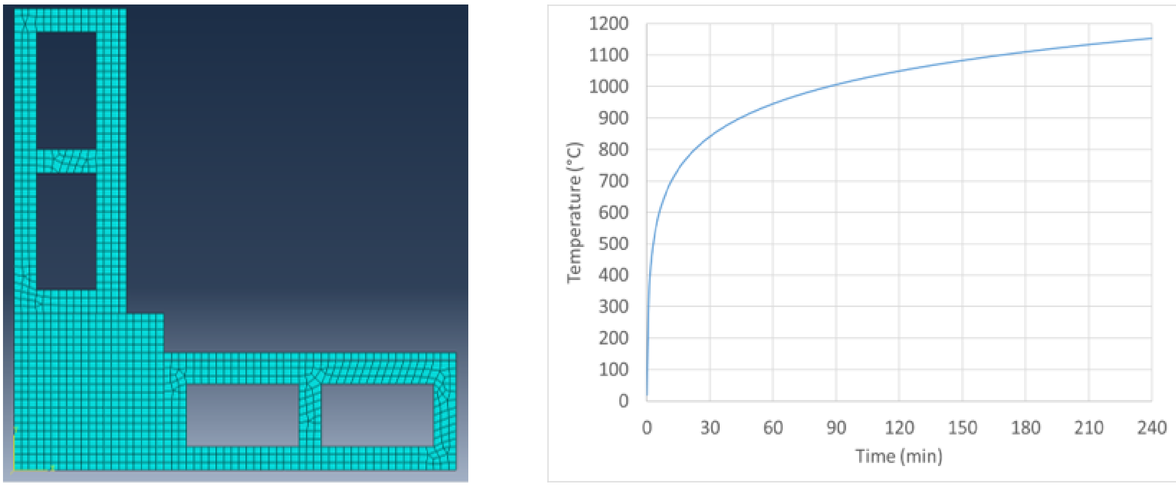

Fig. 1 Discretization used in Abaqus/CAE for the corner column: standard fire curve (ISO 834) case.

3. Analysis of Results

Comparative graphs were obtained between the simplified calculation methods, to determine the residual load bearing capacity of the reinforced concrete columns. Below are the graphs of the residual resistances versus the fire duration time. In Fig. 2, the concrete section of the column was changed between the different simulations and the steel area was kept constant, equal to 4 rebars of 20 mm each in diameter. In Fig. 3, the concrete area remained constant, equal to 20 cm × 20 cm and the steel area was changed between the different simulations. The characteristic strength of concrete into compression was 25 MPa.

Looking to graph of Fig. 2, it is possible to notice that, with the exception of the 20 cm × 20 cm column, the Zone Method showed a loss of resistance, already in the first half hour, more accentuated than the 500 °C Isotherm Method. As well, it presented a lower resistance after 4 h of fire. Therefore, the Zone Method is more conservative in the other cases, like Purkiss [7] presented in his case.

For the case of 20 × 20 column, it was possible to see that the 500 °C Isotherm Method was more conservative. This was due to its small dimensions, making the loss of corners in triangular form and not just rectangular form, as in the Zone Method, more relevant when determining the residual resistance of concrete.

It is also noted that the methods have distanced themselves as the dimensions have been increased.

From this, the worst situation was analyzed, the column with the smallest cross-section, the 20 cm × 20 cm cross-section column with the different steel area inside it.

The result can be seen in Fig. 3, where the 500 °C Isotherm Method was more conservative than the Zone Method, for all the cases analyzed.

Both methods presented similar results. Furthermore, for the columns embedded in walls there is a loss of area of the concrete in a triangular shape, as it can be seen in Figs. 5 and 8. Therefore, the 500 °C Isotherm Method was used to determine the residual load bearing capacity of the corner and middle wall columns.

In the sequence graphs of the residual load bearing capacity of the columns to compression are shown according to the fire exposure time. These graphs are presented varying the rate of steel in the section and the dimensions of the concrete sections, the characteristic strength of the concrete to compression (f_{ck}) was kept equal to C25/30 (25 MPa).

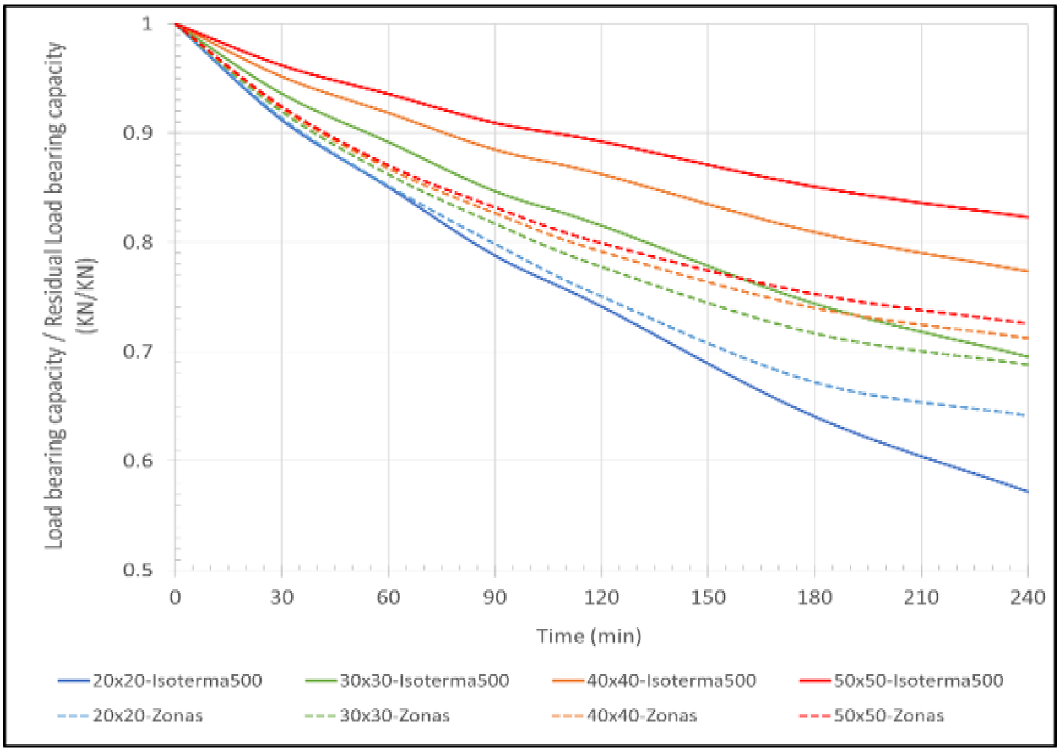

Fig. 2 Comparison between the residual loadbearing capacity of the columns with different cross-section dimensions and constant steel equal to 4 rebars of 20 mm each in diameter, using the 500 °C Isotherm and the Zone Methods.

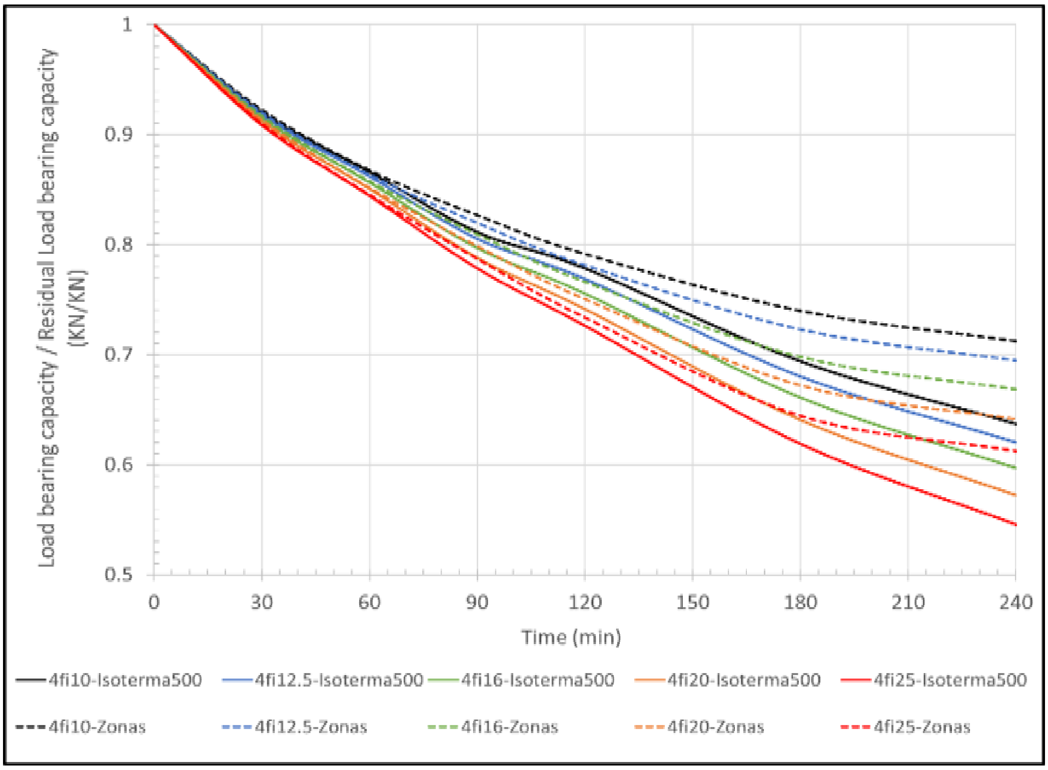

Fig. 3 Comparison between the residual loadbearing capacity of the 20 × 20 cm column with different steel rebar areas, using the 500 °C Isotherm and the Zone Methods.

It is observed that for the corner columns, they can be represented by isolated columns exposed to two adjacent sides, as shown in Fig. 4. The walls had an important function of acting as thermal insulators and with this the loadbearing capacity of the columns to compression was less affected, as shown in Fig. 5.

For the columns in the middle of the wall, there are two possible models to represent these columns isolated and exposed to fire. They can be columns exposed on one face or to three faces, depending on the thickness of the wall.

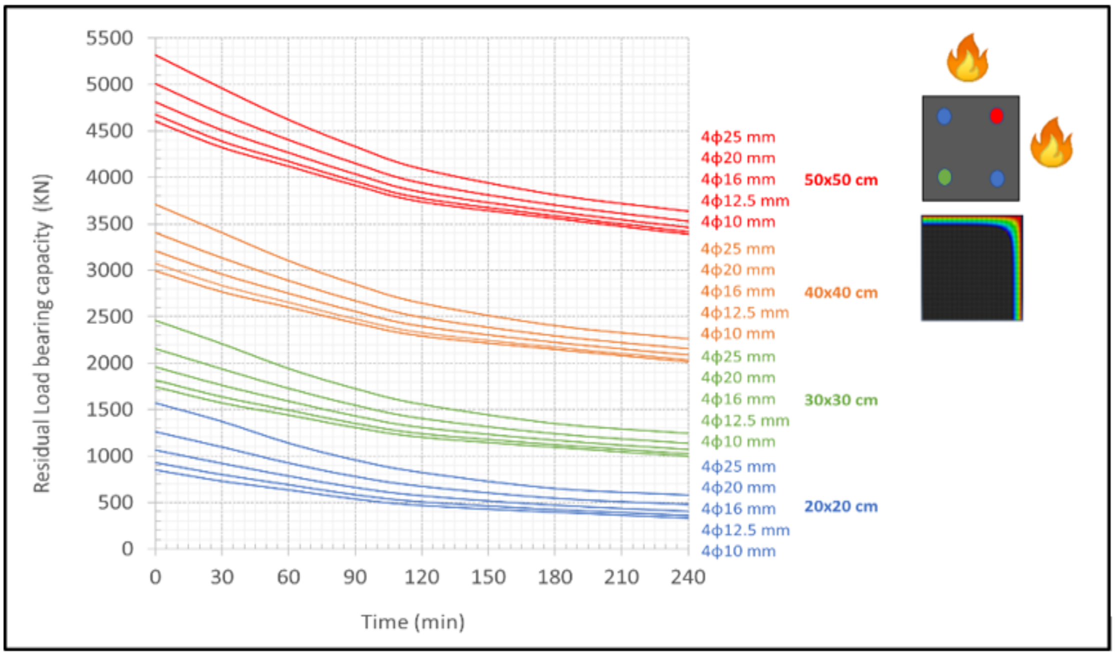

Fig. 4 Residual load bearing capacity of insulated columns with two adjacent faces exposed to fire: 500 °C Isotherm Method.

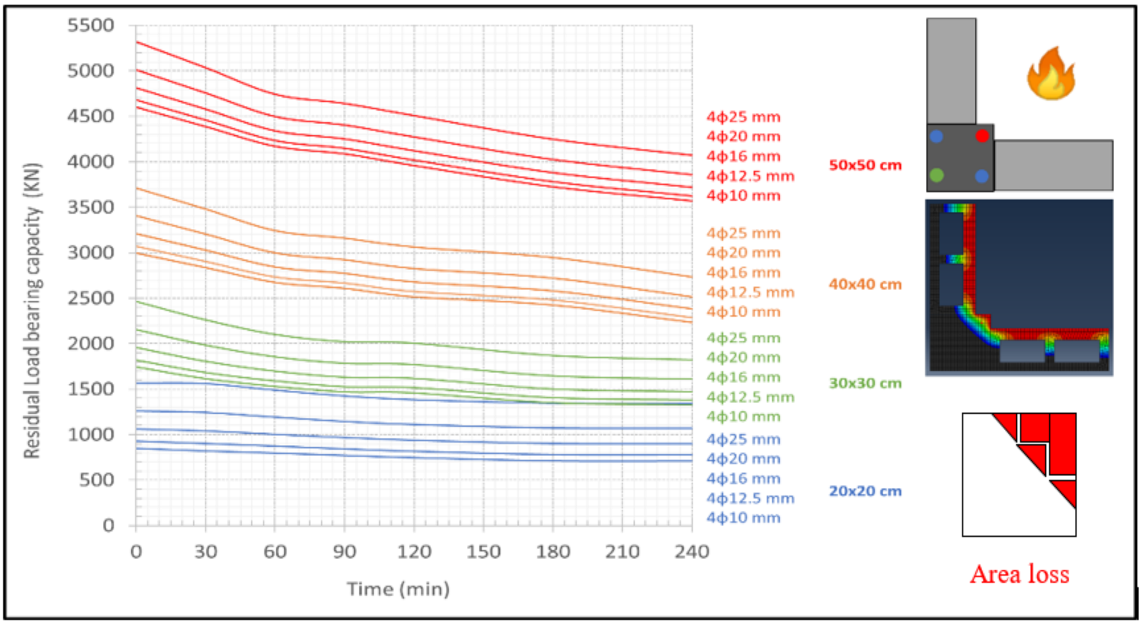

Fig. 5 Residual load bearing capacity for columns embedded in the corner of walls: 500 °C Isotherm Method.

In Fig. 6 it can be observed that the model considers only one side exposed to fire, the column is less seriously affected than in the other two cases (Figs. 7 and 8).

This model does not consider that although the walls act as thermal insulators for the convection and radiation of the fire, the conduction of heat will continue to occur through the walls and towards the column. Thus, adopting this model of isolated column with one exposed face would be against security.

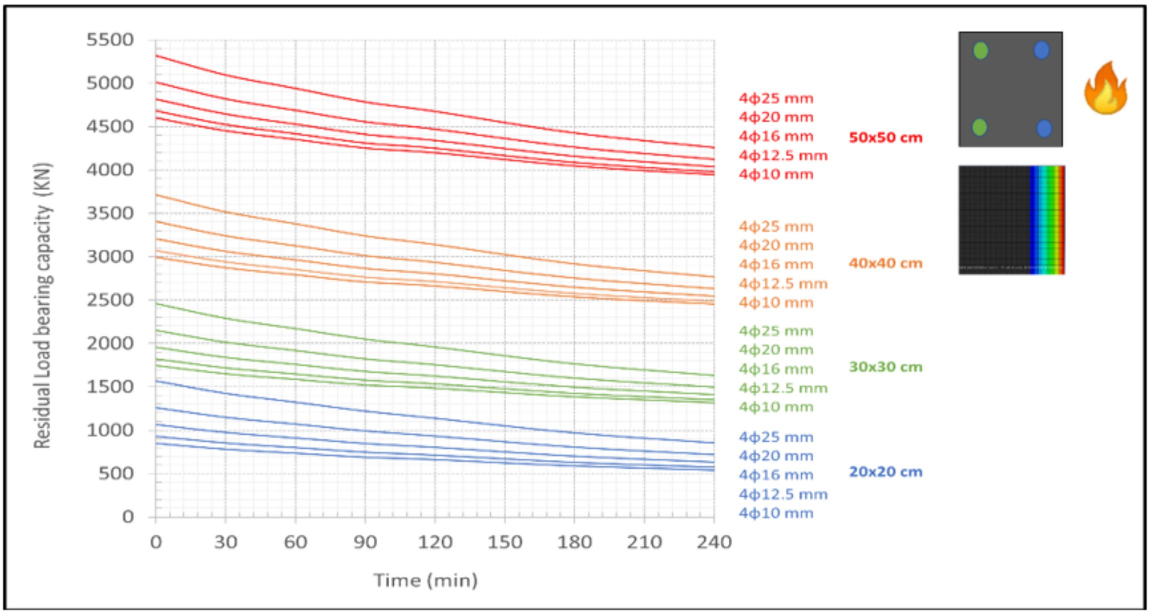

Fig. 6 Residual load bearing capacity for insulated columns with only one face exposed to fire: 500 °C Isotherm Method.

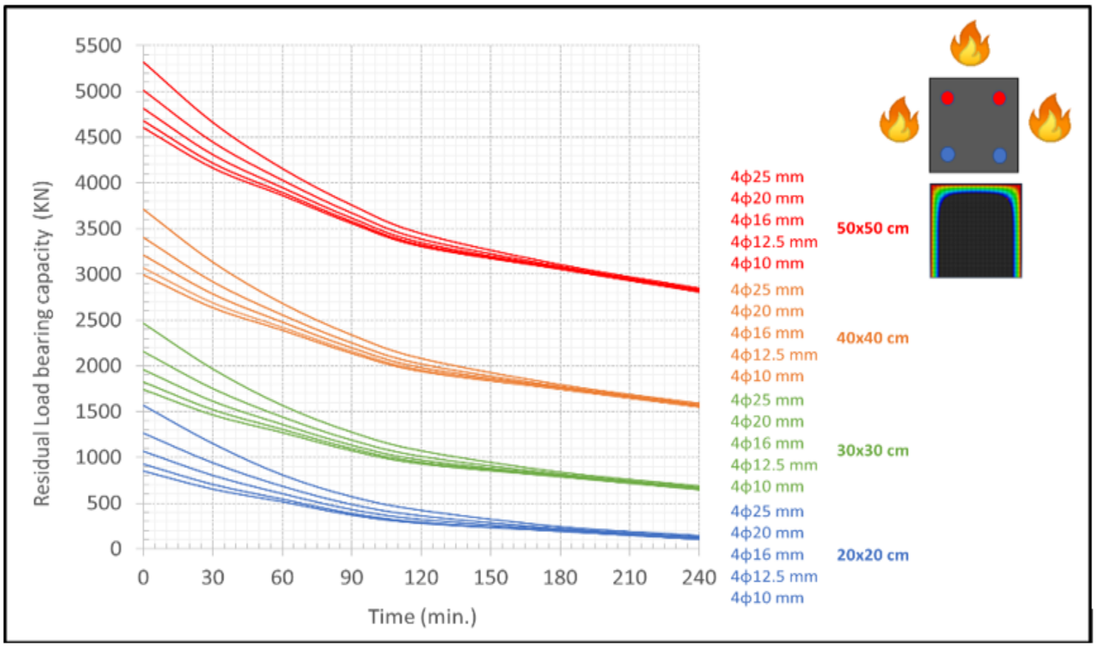

Fig. 7 Residual load bearing capacity for insulated columns with three faces exposed to fire: 500 °C Isotherm Method.

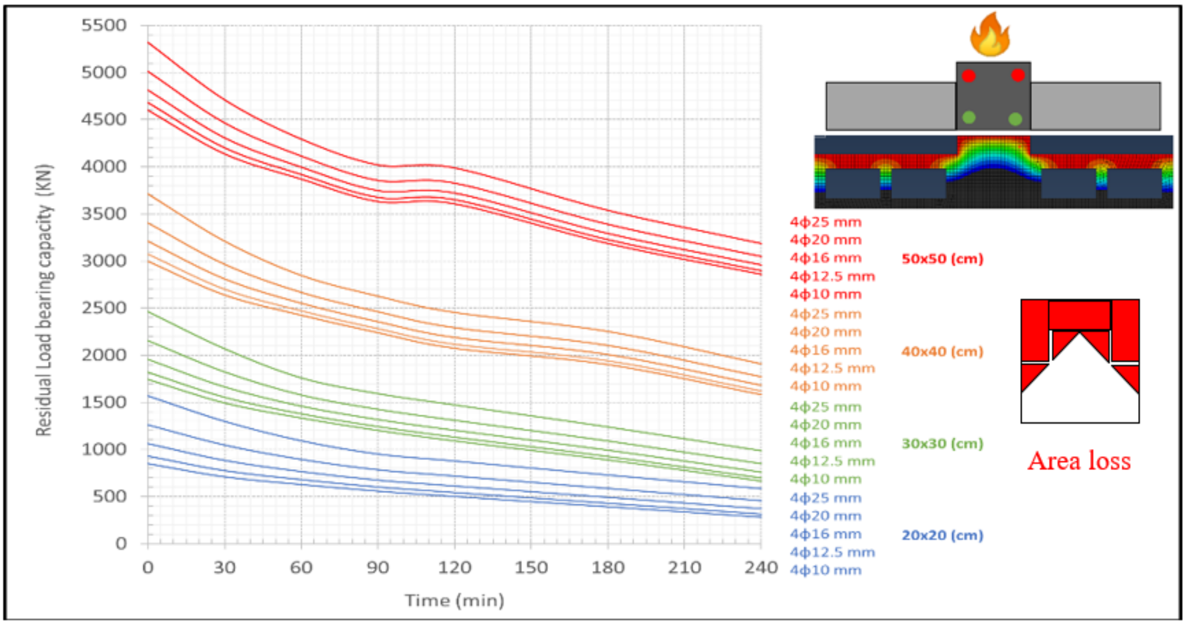

Fig. 8 Residual load bearing capacity for columns embedded in the middle of walls: 500 °C Isotherm Method.

Comparing the model that considers the heating by the three faces of column and the model that considers the walls (Figs. 7 and 8), although the residual load bearing capacity for 4 h of fire is similar, the model that considers the walls shows more gradual loss of resistance in the time, than the model without walls and with three exposed faces.

4. Conclusions

It was possible, with the two methods used in the work, to compared them and verify which model is more conservative and which model is closer to the advanced model for calculating temperatures in the column cross-section.

It was checked the walls act as thermal insulators, protecting part of the columns from the convective and radiation actions of the fire. Consequently, the effect of the raising of temperature over the load bearing capacity of the reinforced concrete column was reduced.

Graphs were presented that can be consulted to know the residual load bearing capacity of columns subjected to fire in a determined time, or from an initial resistance determine the fire resistance time of this column.

In the thermomechanical analyses of the columns, presented in this work, it was considered the worst cross-section removed along the height of the column, subject only to compression and with the thermal gradient through the plane of the columns section. For future works, an analysis in three dimensions should be included, in order to compare the effect of the temperature difference and the physical and geometric non-linearity along the height of the column. Also buckling and the presence of bending moments in these elements are checked.

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