Int. Journal for Housing Science, Vol.40. No.4 pp. 243-253, 2016
Published in the United States

INFLUENCE OF THE REDUCTION FACTOR AND LOAD LEVEL IN THE FIRE RESISTANCE OF REINFORCED CONCRETE COLUMNS

M. B. Ramalho, M. C. Gonçalves
Building Division, Faculty of Engineering
University of Oporto, Porto
Portugal

ABSTRACT

The fire resistance of reinforced concrete columns can be checked, according to EN 1992-1-2 [1], considering three methods presented in the form of tables: Method A, Method B and Method C (or Method of estimated curvature). In this paper is presented a study developed in order to verify the influence of two parameters required for the application of these methods: the reduction factor, η_{fi}, and the load level at normal temperature conditions, n. The methods referred in the previous paragraph were applied to the 14124 reinforced concrete columns inserted in the structures of 63 buildings, designed for different types of occupations and licensed before 2007, in Portugal. The fire resistance classes, defined for the different occupations, vary from R30 to R180. The reduction factor values were calculated for each project and the load level for each column. As it was observed, the reduction factor values vary between 0.58 and 0.68 ($0.58 \leq \eta fi \leq 0.68$) in ordinary buildings. So, it is recommended the use of values in this interval for the calculation of the axial design load in fire situation, $N_{Ed,fi}$, determined from the design value of the column's resistance, N_{Rd}, namely for the quantification of the initial load to be applied to the columns in experimental tests. Comparing the results, considering the reduction factor, η_{fi}, with design values and with $\eta_{fi}=0.7$, a recommended value in EN 1992-1-2 [1] that can be used as a simplification, it was found that using the second value led to a lower number of columns that satisfied the required fire resistance, corresponding to a percentage between 1,4% and 4,4% of the columns. Regarding the load level, n, calculated for each column, it was found that the most frequent values vary between 0.2 and 0.4 ($0.2<n\leq 0.4$), followed by values between 0.4 and 0.5 ($0.4<n\leq 0.5$). However, 15.8% of the columns presented a load level value exceeding 0.7 ($n> 0.7$), the limit value for the applicability of the Method B and the Method C

0146-6518/04/243-253, 2016

Key words: Fire resistance, Columns, Concrete, Reduction factor, Load level

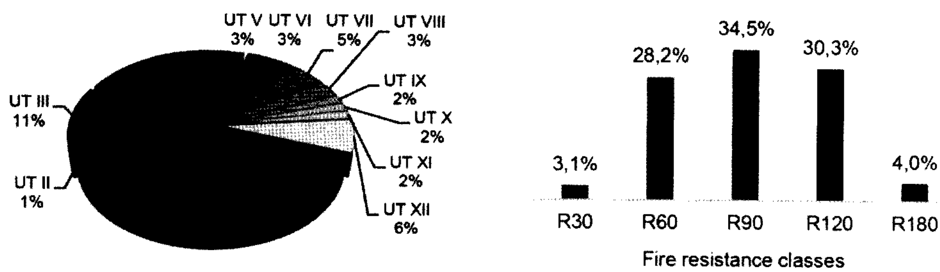
Characteristics of the Analyzed Buildings and Concrete Columns

Sixty-three building designs, licensed in the North of Portugal, were analyzed with the purpose of studying the consequences of using the load level reduction factor, η_{fi}, in the verification of the reinforced concrete columns fire resistance, considering the design values of this parameter, calculated for each type of occupation provided in architecture designs, and the conservative simplified value pointed in EN 1992-1-2 [1], η_{fi}=0.7.

The analyzed buildings were designed for different types of occupations, inserted in the standard-uses (UT) provided in paragraph n.º1 of article 8.º of "Legal Framework for Fire Safety in Buildings", RJ-SCIE [2], Portuguese legislation about buildings fire safety, and are of exclusive or mixed use, as it integrates a single or multiple standard-uses, as specified in paragraph n.º 2 of the mentioned article.

As observed in Graph (a) of Figure 1, considering the 63 studied buildings, 40% are residential (UT I), 22% are schools (UT IV), 11% administrative (UT III) and the remaining 27% are distributed among the other nine standard-uses (UT II - parking, UT V - hospitals and nursing homes, UT VI - entertainment and public meetings, UT VII - hotels and catering, UT VIII – commercial and transport marshalling, UT IX - sports and leisure, UT X - museums and art galleries, UT XI - libraries and archives and UT XII – industrial, workshops and storage).

The structures of these buildings integrate 14124 reinforced concrete columns, 70% having rectangular section, 24% quadrangular section and 6% circular section. The distribution of these columns by fire resistance classes is presented in the Graph (b) of Figure 1.



(a) (b)

Figure 1 : Standard-uses provided in the analyzed projects (a) and studied columns distribution by fire resistance classes (b).

As it turns out the distribution of the columns by R90. R120 and R60 classes is not substantially disparate (about 35%, 30% and 28%, respectively), being substantially lower the number of columns in R180 and R30 classes. The designation of rectangular columns will include, in the following chapters, the columns with rectangular section and square section.

Load Level Reduction Factor, η_{fi}

The load level reduction factor, η_{fi}, is a parameter of significant importance in assessing the fire resistance of structural elements, when the methods presented in the form of tables, in EN 1992-1-2 [1], are applied. The use of η_{fi} corresponds to a conservative simplification specified in this standard, replacing the degree of utilization in the fire situation, μ_{fi}, determined by expression (1). The reduction factor is calculated using expression (3).

$$\mu_{fi} = N_{Ed,fi}/N_{Rd} \tag{1}$$

$$\mu_{fi} = \eta_{fi} \tag{2}$$

$$\eta_{fi} = \frac{G_k + \psi_{fi} Q_{k,1}}{\gamma_G G_k + \gamma_{Q,1} Q_{k,1}} \tag{3}$$

where,

- G_k characteristic value of a permanent action, [kN/m^2];
- $Q_{k,1}$ characteristic value of the principal variable load, [kN/m^2];
- γ_G partial factor for a permanent action;
- $\gamma_{Q,1}$ partial factor for variable action 1;
- ψ_{fi} combination factor for frequent or quasi-permanent values given by $\psi_{1,1}$ or $\psi_{2,1}$ respectively; in this study we considered the frequent values.

The η_{fi} values, determined for each standard-use provided in the analyzed buildings and distributed among the 12 UT established in RJ-SCIE [2], were inserted in the graph of Figure 2.1 pointed in EN 1992-1-2 [1], representing the variation of the reduction factor with the load ratio Q_k/G_k, for each value of $\psi_{1,1}$ (Figure 2). As it can be seen, η_{fi} values are between 0.58 and 0.68.

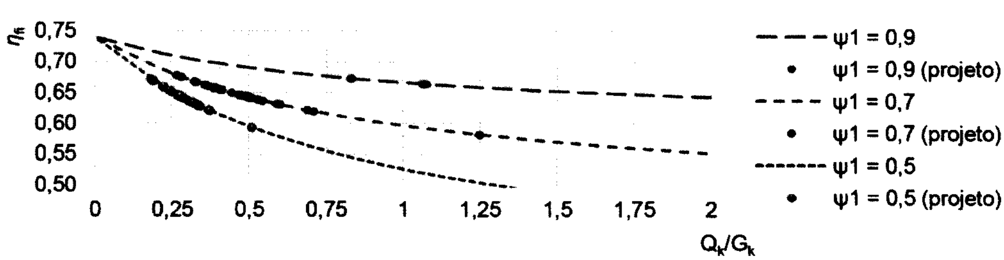


Figure 2 : Variation of the reduction factor η_{fi} with the load ratio Q_k/G_k.

The percentage distribution of the standard-uses by the different values of the reduction factor is shown in Figure 3. It's found that the most frequent values for this parameter are η_{fi}=0.64 (24.9% of the UT), η_{fi}=0.65 (23.0% of the UT), η_{fi}=0.63 (14.4% of the UT) and η_{fi}=0.66 (10.5% of the UT). Then it can be concluded that the most frequent η_{fi} values are between 0.63 and 0.66, with the remaining (ranging between 0.58 and 0.62, 0.67 and 0.68) significantly less frequent. It has been noted that none of the UT present values of reduction factor η_{fi} = 0.69 nor η_{fi} = 0.70.

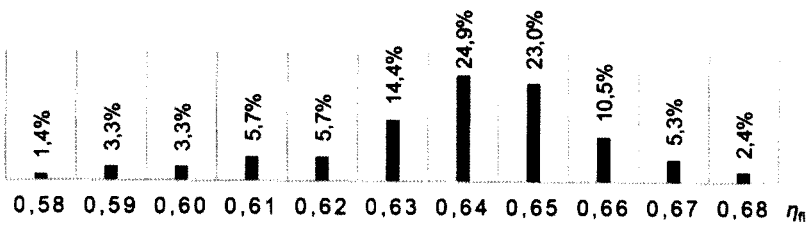


Figure 3 : Percentage distribution of the standard-uses by different values of η_{fi}.

Load Level, *n*

The load level, n, at normal temperature conditions, is given by expression (4), pointed in EN 1992-1-2 [1].

$$n = N_{0Ed,fi}/\left(0.7\left(A_c f_{cd} + A_s f_{yd}\right)\right) \quad (4)$$

where,

- $N_{0Ed,fi}$ axial load under fire conditions, [kN];
- A_c cross sectional area of concrete, [m^2];
- A_s cross sectional area of reinforcement, [m^2];
- f_{cd} design value of concrete compressive strength, [kN/m^2];
- f_{yd} design yield strength of reinforcement, [kN/m^2].

The axial load under fire conditions, $N_{0Ed,fi}$, is determined as shown in expression (5), affecting the axial load (N_{Ed}) indicated in the structure designs for each column, by the load level reduction factor, η_{fi}.

$$N_{0Ed,fi} = \eta_{fi} N_{Ed} \quad (5)$$

The values of the load level, n, were calculated for the 13129 concrete columns constituents of the structures of the 63 analyzed buildings (the 995 columns that, despite being considered as such in the stability designs, have an h/b ratio above the regulatory maximum were not considered). From these, 12243 have rectangular cross-section (94% of the studied columns) and 886 have circular cross-section (6% of the studied columns).

The variation of the load level values is presented in the graphs of Figures 4 and 5, for the columns with rectangular cross-section and in Figures 6 and 7 for the circular cross-section columns.

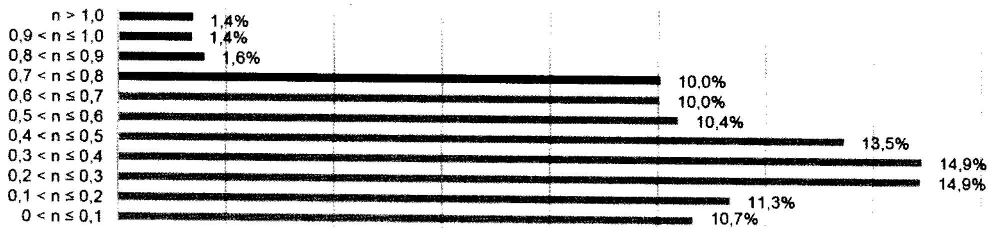


Figure 4 : Percentages of rectangular columns in each range of n values.

As can be seen in the figure above graphic, 14.4% of rectangular cross-section columns have a load level value exceeding 0.7 (red bars), the maximum specified in EN 1992-1-2 [1] for the applicability of Method B and Method C. It can also be observed that the most current values of n are between 0.2 and 0.3 and between 0.3 e 0.4 (14.9% of the columns in each of these ranges) followed by values between 0.4 and 0.5 (13.5%).

In Figure 5 is shown the distribution of rectangular columns by the different intervals of n values, according to cross-section width (b=15cm to b=80cm). It is also indicated, with the broken line, the limit value indicated in the previous paragraph (n=0.7). As observed, the highest percentages of columns that exceeded this limit value have b=20cm, for 0.7<n≤0.8 and b=30cm, for 0.8<n.

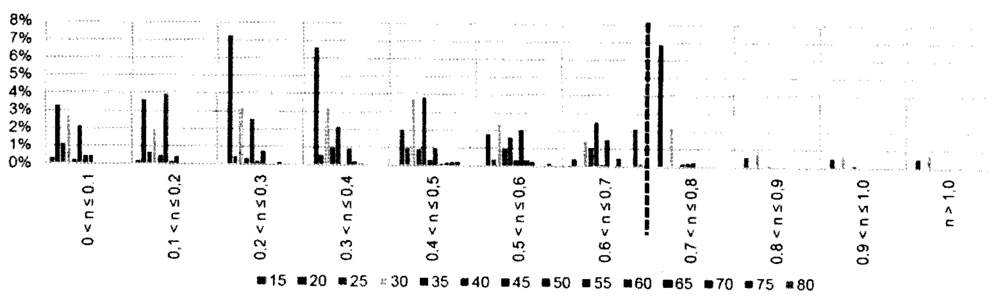


Figure 5 : Percentage distribution of rectangular columns by n intervals, for each value of the cross-section width, b.

The graph of Figure 6 represents the distribution of the circular cross-section columns by the different ranges of n. It can be concluded that 26% of the columns exhibit a value of this parameter higher than 0.7, a percentage substantially higher than that observed in rectangular columns.

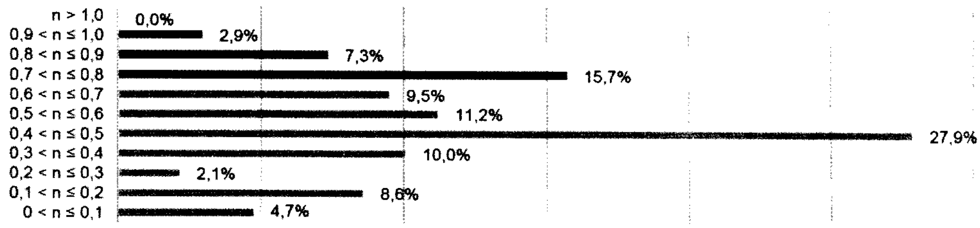


Figure 6 : Percentages of circular columns in each range of n values.

In Figure 7 is shown the distribution of circular columns by the different intervals of n, for each value of the diameter of its cross-section, pointing out, also, the limit value n=0.7. As may be noted, for n>0.7, the columns with Φ50cm diameter present the highest percentage of n values between 0.7 and 0.8, with Φ60cm diameter the highest percentage of n values between 0.8 and 0.9, and the columns with Φ40cm being the only ones with load level values between 0.9 e 1.0. There are no circular columns with load level values higher to 1.0.

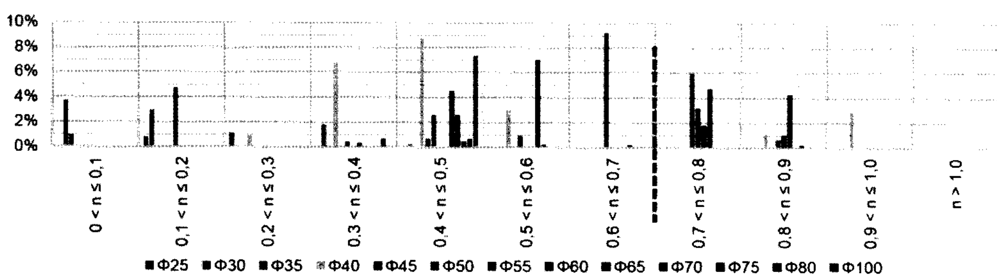


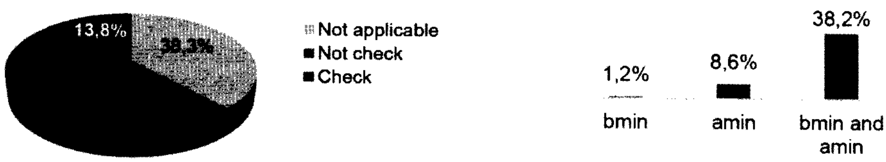
Figure 7 : Percentage distribution of circular columns by n intervals, for each value of the cross section diameter, Φ.

<u>Relevance of η_{fi} and n in the Verification of the Columns Fire Resistance When Using the Methods Presented in the Form of Tables</u>

<u>Influence in the results by applying the Method A</u>

The application of the Method A in the verification of the reinforced concrete columns' fire resistance consists in observing, for each fire resistance class, the minimum values of the cross-section width, b_{min}, and the minimum axis distances to the steel bars from the nearest exposed surface, a_{min}, depending on the degree of utilization in the fire situation, μ_{fi}, being considered $\mu_{fi}=\eta_{fi}$, the conservative simplification specified in EN 1992-1-2 [1], as seen in Chapter 2.

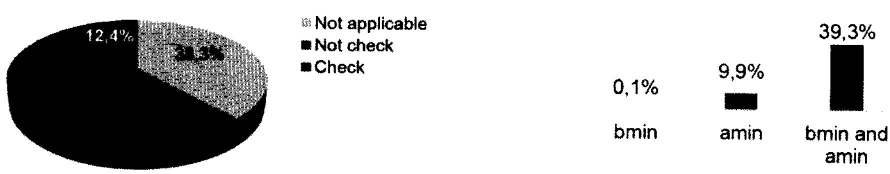
The results of applying this method to the rectangular studied columns is shown in Figure 8, considering the project values of η_{fi}. As it can be seen in Graph (a), 47,9% of the columns do not check the required fire resistance, the method is not applicable to 38,3% and check only 13,8%. The distribution of the columns that do not check by the parameters that lead to nonconformity is presented in Graph (b). Most columns do not check by not observing, simultaneously, of b_{min} and a_{min} (38.2%).



(a) (b)

Figure 8 : Results of applying the Method A to the rectangular analyzed columns, considering the project values of η_{fi}: (a) Percentage of columns that check, that does not check and which the method is not applicable; (b) Parameters that lead to nonconformity.

The results obtained when considering the conservative simplification that predicts the use of η_{fi}=0.7 are shown in Figure 9, noting that verify the fire resistance 12.4% of the columns.



(a) (b)

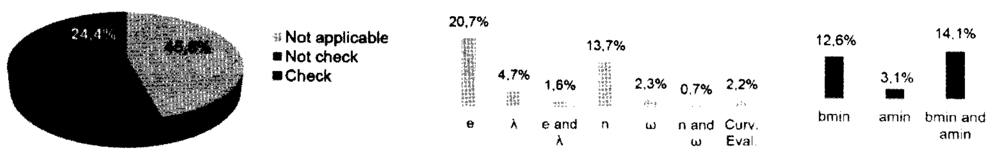
Figure 9 : Results of applying the Method A to the rectangular analyzed columns, considering η_{fi}=0.7: (a) Percentage of columns that check, that does not check and which the method is not applicable; (b) Parameters that lead to nonconformity

Comparing the graphs of Figures 8 and 9 can be conclude that the simplification by adopting η_{fi}=0.7 leads to the decrease of 1,4% in the columns that verify the fire resistance, an increase in the columns that do not verify only a_{min} and a reduction in the columns that do not verify only b_{min}, starting these columns to not check b_{min} and a_{min} simultaneously. The most affected parameter was, therefore, a_{min}.

<u>Influence in the results by applying the Method B</u>

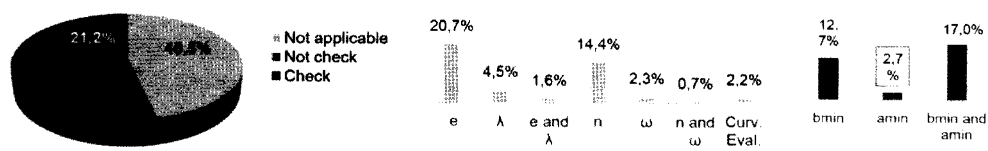
The application of the Method B consists in observing, for each fire resistance class, the minimum values of b and a, depending on the mechanical reinforcement ratio at normal temperature conditions, ω, and the load level, n. As presented in Chapter 3, the value of n, determined by the expression (4), is dependent on the load level reduction factor, η_{fi}, as seen from expression (5).

Adopting the conservative simplification of considering η_{fi}=0.7, it can be note an increase of 0.7% in the number of columns to which the method is not applicable and a decrease of 3,2% in the number of columns that verify the required fire resistance, as seen by comparing the graphs (a) of Figures 10 and 11. As expected, the increase of non-applicability of the method is due, exclusively, to the increased number of columns whose load level values began to exceed 0.7, as seen in Graphs (b) of the same figures. For the parameters that lead to nonconformity, as evidenced in Graphs (c), it is noted a slight increase in the columns that began to not check b_{min} (0.1%), a reduction of 0.4% in the number of columns that do not check a_{min}, but an increase of 2.9% in the number of columns that do not verify simultaneously b_{min} and a_{min}.



(a) (b) (c)

Figure 10 : Results of applying the Method B to the rectangular analyzed columns, considering the project values of η_{fi}: (a) Percentage of columns that check, that does not check and which the method is not applicable; (b) Parameters that lead to the inapplicability; (c) Parameters that lead to nonconformity.



(a) (b) (c)

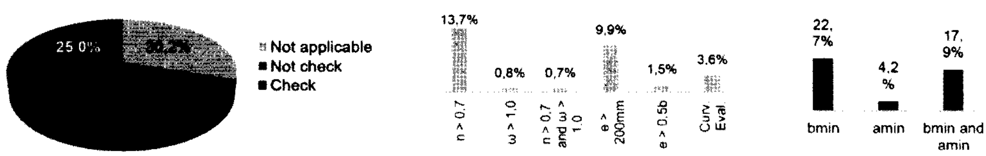
Figure 11 : Results of applying the Method B to the rectangular analyzed columns, considering η_{fi}=0.7. (a) Percentage of columns that check, that does not check and which the method is not applicable; (b) Parameters that lead to the inapplicability; (c) Parameters that lead to nonconformity.

<u>Influence in the results by applying the Method C</u>

The Method C, based on estimation of curvature, allows to define the minimum values of b and a, for each fire resistance class, considering the mechanical reinforcement ratio, ω, the first order eccentricity, e, the slenderness, λ and the load level, n. The value of the latter parameter is determined by the expression (4), being dependent of the load level reduction factor, η_{fi}, as seen from expression (5) presented in Chapter 3.

Comparing the graphs of Figure 12 with those in Figure 13 it appears that the simplification of considering ηfi=0.7 is reflected in the increase of 2,3% in the number of columns to which the method is not applicable and a decrease of 4,4% in the number of columns that verify the required fire resistance.

Considering the parameters that lead to the non-applicability of the method, Graphs (b) of the same figures, it is concluded that there was an increase of 2,0% in the number of columns to which the method is not applicable because n>0.7 and an increase of 0.3% in the number of columns that require a specific evaluation of buckling. For the parameters that lead to nonconformity, Graphs (c), it is noted a decrease of the columns that do not check b_{min} (0.7%), because they start to not check b_{min} and a_{min} simultaneously, the increase of 0.8% in the number of columns that do not verify a_{min} and an increase of 1,9% in the number of columns that does not simultaneously check b_{min} and a_{min}.



(a) (b) (c)

Figure 13 : Results of applying the Method C to the rectangular analyzed columns, considering η_{fi}=0.7. (a) Percentage of columns that check, that does not check and which the method is not applicable; (b) Parameters that lead to the inapplicability; (c) Parameters that lead to nonconformity.

Comparison of Results

The results of the utilization of the three methods, presented in EN 1992-1-2 [1] in the form of tables (Method A, Method B and Method C), in the verification of fire resistance of 12243 rectangular concrete columns are summarized in Figure 14 and compared in Table 1. It have been considered the load level reduction factor, ηfi, with project values, ηfi(proj), and ηfi=0.7, a conservative simplification specified in the same norm.

The impact of adopting the pointed simplification has less significance when Method A is used (decrease of 1.4% in the number of columns that check the fire resistance) and is more significant when using the Method C (decrease of 4.4% in the number of columns that check the fire resistance and the method is not applicable to more 2.3%). A similar study was conducted by the same authors for the circular cross-section concrete columns.

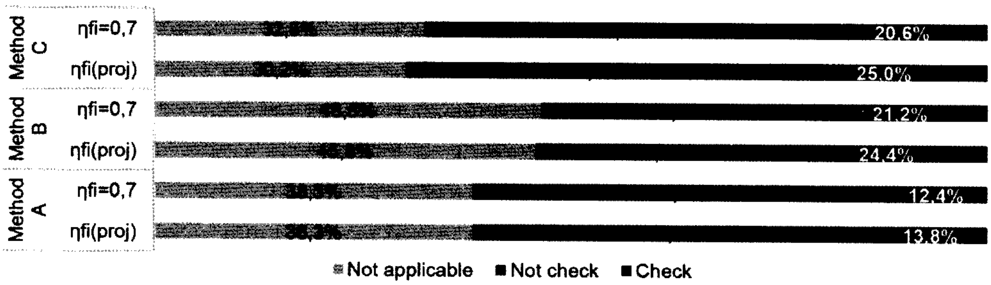


Figure 14 : Results of applying the Method A, the Method B and the Method C to the rectangular analyzed columns, considering the project values of η_{fi} and η_{fi}=0.7.

Table 1 : Results of applying the Method A, the Method B and the Method C to the rectangular analyzed columns, considering the project values of η_{fi} and η_{fi}=0.7.

Method	Check [%]			Not check [%]			Not applicable [%]		
	$\eta_{fi}=0.7$	$\eta_{fi(proj)}$	(1)-(2)	$\eta_{fi}=0.7$	$\eta_{fi(proj)}$	(4)-(5)	$\eta_{fi}=0.7$	$\eta_{fi(proj)}$	(7)-(8)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Method A	12.4	13.8	-1.4	49.3	47.9	1.4	38.3	38.3	0
Method B	21.2	24.4	-3.2	32.3	29.8	2.5	46.5	45.8	0.7
Method C	20.6	25.0	-4.4	46.9	44.8	2.1	32.5	30.2	2.3

Conclusions

The study briefly presented in this article, about the influence of the load level reduction factor, η_{fi}, and the load level at normal temperature, n, in the verification of fire resistance of reinforced concrete columns, allows the following conclusions:

In current buildings, the load level reduction factor, η_{fi}, varies between 0.58 and 0.68 ($0.58 \leq \eta fi \leq 0.68$), so it is recommended the use of values in this range to calculate the initial axial load in fire situation ($N_{Ed,fi} = \eta_{fi}.N_{Rd}$), in experimental fire tests. For rectangular columns, the most frequent values of load level at normal temperature, n, are included in the ranges $0.2<n\leq0.3$ and $0.3<n\leq0.4$ (14.9% of columns at each of these ranges), followed by the values $0.4<n\leq0.5$ (13.5%).

Values of n higher than 0.7 (maximum provided in EN 1992-1-2 [1] for the applicability of Method B and Method C) are observed in 14.4% of the rectangular columns. In the circular columns, the most frequent values of n are included in the range $0.4<n\leq0.5$ (27.9%), followed by $0.7<n\leq0.8$ (15.7%, in a range of values leading to non-applicability). About a quarter (25.9%) of the circular analyzed columns presented values of n greater than 0.7. The conservative simplification of considering η_{fi}=0.7 leads to negligible consequences when using Method A and very significant consequences when using Method C.

The study of the influence of the reduction factor, η_{fi}, and the load level, n, in the behavior of reinforced concrete columns, in experimental fire tests, have been the subject of some works developed by the same authors [3], [4].

References

1. CEN, EN 1992-1-2: "Eurocode 2: Design of concrete structures: Parte 1-2: General rules- Structural fire design", European Standard, December 2004.
2. Decreto-Lei n.º 220/2008: "Legal Framework for Fire Safety in Buildings", RJ-SCIE, Imprensa Nacional Casa da Moeda. Lisboa, Portugal, November 12, 2008.
3. M. Ramalho, M. Gonçalves, "Experimental and numerical analysis of concrete columns under fire", in Proceedings of 8th International Conference on Structures in Fire, SiF'14, Shanghai, China, June 11-13, 2014.
4. M. Ramalho, et al., "Resistance pillars of fire reinforced square and circular section concrete. Experimental and numerical evaluation", in Proceedings of Encontro Nacional de Betão Estrutural - BE2012, Porto, Portugal, October 24-26, 2012.