

Concrete beams fire design. Enhancement of some recommendations of the Eurocode

Dimensionamento de vigas de concreto armado em situação de incêndio. Aprimoramento de algumas recomendações do Eurocode



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Abstract

The Brazilian standard ABNT NBR 15200 is in revision. Some omissions on the design of beams in the 2004 version of the standard will be included now. Possibility of reduction of c_1 in situations of safety reserves, different design for unidirectional ribbed slab and lateral increase in c_1 in some cases are the cases of interest in this work. The Eurocode provides recommendations on these items, however, they are not considered adequate to Brazilian design. The objective of this article is to perform thermal or structural analyzes of reinforced concrete beams and propose alternatives to the recommendations of Eurocode in order to standardize them at this stage of revision of the Brazilian standard.

Keywords: fire, design, beam, fire safety.

Resumo

A norma brasileira ABNT NBR 15200 está em fase de revisão. Algumas omissões sobre o dimensionamento de vigas, na versão de 2004 da norma, serão incluídas agora. Possibilidade de redução do c_1 em casos em que haja reserva de segurança, dimensionamento distinto para laje nervurada unidirecional e aumento de c_1 lateral em algumas situações são os casos de interesse neste trabalho. O Eurocode fornece recomendações a respeito desses itens, no entanto, não são consideradas adequadas aos costumes brasileiros de projeto. O objetivo deste trabalho é, por meio de análise térmica ou estrutural de vigas de concreto armado, propor alternativas às recomendações do Eurocode, visando normatizá-las, já nesta fase de revisão da norma brasileira.

Palavras-chave: incêndio, dimensionamento, vigas, segurança contra incêndio.

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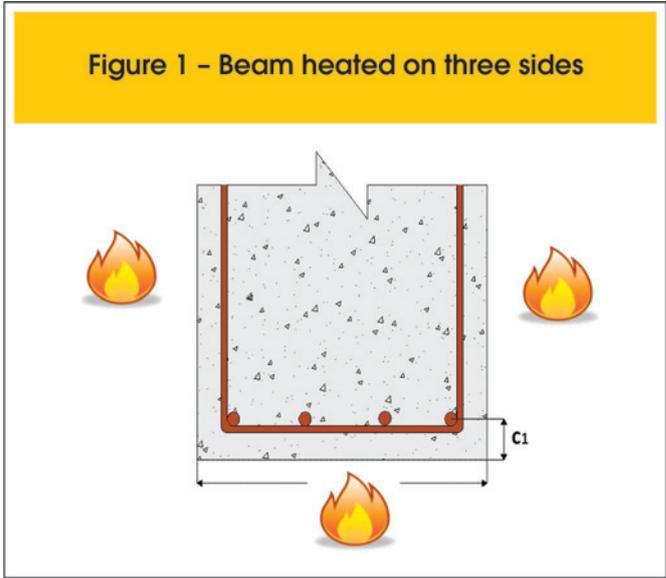
1. Introduction

The Brazilian standard ABNT NBR 15200:2004 [1] is under revision and the European standard Eurocode [2] is the main reference standard. Since some omissions from the 2004 version of ABNT NBR 15200 will now be included, the aim is to improve the Eurocode recommendations related to such additions, suggesting more expeditious procedures for the Brazilian standard.

The Eurocode [2] allows the design of reinforced concrete beams in fire situation using the tabular method (tables 1 and 2), which is associated with the time required for fire resistance (TRRF), the smallest dimension of the beam (b_{min}) and the distance between the centroid of the reinforced steel and the face exposed to fire (c_1). The tables of the simplified method are constructed assuming the following hypotheses:

- Beams under slabs
- Heating on the sides and bottom of the beam (figure 1)
- Maximum temperature in the reinforced steel at the soffit of the beam equal to 500 °C (θ_{cr})
- Redistribution of bending moments in the case of continuous beams

ABNT NBR 15200:2004 [1] presents the same tables as the Eurocode [2] up to TRRF = 120 min, and the review will include information concerning TRRF = 180 min. Three recommendations in [2] should be aggregated to the revision of ABNT NBR 15200:2004 [1]. They are detailed in sections 1.1 to 1.3.



1.1 Reduction of the values of c_1
 The values of c_1 in the tables were determined assuming $S_{d,fi}/S_d = 0.7$ and $A_{s,calc}/A_{s,ef} = 1$ where $S_{d,fi}$ e S_d are the design values of the

effect of actions in fire situation and at room temperature, respectively, and $A_{s,calc}$ and $A_{s,ef}$ at room temperature, respectively, and $A_{s,calc}$ and $A_{s,ef}$ are the values of the areas of the reinforcement required for ultimate limit state at room temperature and the reinforcement provided, respectively. If these values are lower, c_1 can be reduced by Δc_1 , as in Equation 1, where θ_{cr} in °C is given by Equation 2, where, f_{yk} and $\sigma_{s,fi}$ are the yield strength of steel at room temperature and steel stress in fire, respectively.

$$\Delta c_1 = 0.1 (500 - \theta_{cr}) \text{ (mm)} \tag{1}$$

$$k_{s,fi}(\theta_{cr}) = \frac{\sigma_{s,fi}}{f_{yk}} \tag{2}$$

The value of $\sigma_{s,fi}$ is determined by Equation 3, where γ_s is the partial safety factor for reinforcing steel at room temperature.

$$\sigma_{s,fi} = \frac{S_{d,fi}}{S_d} \times \frac{f_{yk}}{\gamma_s} \times \frac{A_{s,calc}}{A_{s,ef}} \tag{3}$$

Table 1 – Minimum dimensions for simply supported beams

TRRF min	Combinations of b_{min}/c_1 mm/mm			
	1	2	3	4
30	80/25	120/20	160/15	190/15
60	120/40	160/35	190/30	300/25
90	140/55	190/45	300/40	400/35
120	190/65	240/60	300/55	500/50
180	240/80	300/70	400/65	600/60

Table 2 – Minimum dimensions for continuous beams

TRRF min	Combinations of b_{min}/c_1 mm/mm			
	1	2	3	4
30	80/15	160/12	190/12	-
60	120/25	190/12	300/12	-
90	140/35	250/25	400/25	-
120	190/45	300/35	450/35	500/30

The reduction factor $k_s(q)$ is determined by means of Equations 4.

$$\begin{aligned}
 k_s(\theta) &= 1.0 \text{ for } 20^\circ\text{C} = \theta = 350^\circ\text{C} \\
 k_s(\theta) &= 1.0 - 0.4 \cdot (\theta - 350)/150 \text{ for } 350^\circ\text{C} < \theta = 500^\circ\text{C} \\
 k_s(\theta) &= 0.61 - 0.5 \cdot (\theta - 500)/200 \text{ for } 500^\circ\text{C} < \theta = 700^\circ\text{C} \\
 k_s(\theta) &= 0.1 - 0.1 \cdot (\theta - 700)/500 \text{ for } 700^\circ\text{C} < \theta = 1200^\circ\text{C}
 \end{aligned}
 \tag{4}$$

1.2 Minimum dimensions for one-way reinforced ribbed slab

In the case of ribbed slabs simply supported, the tabular method leads to Table 3 where “h” is the minimum thickness of the slab when compartmentalization is required.

Table 3, however, applies only to slabs reinforced in two directions. For one-way ribbed slabs, table 1 is applied to the ribs and table 4 to the flange.

Thus, for one-layer reinforced steel ribs, table 1 becomes table 5, where c_{1t} is defined in section 1.3.

1.3 Increase of the lateral c_1 in some situations

There is concentration of temperature at the corners of the beams. For this reason, in beams with only one layer of reinforcement and width not exceeding the b_{min} indicated in column 2 of tables 1 and

Table 5 - Minimum dimensions for one-way spanning, simply supported ribbed slabs

TRRF min	b_{min} mm	c_1 mm	c_{1t} mm
30	80	25	35
60	120	40	50
90	140	55	65
120	190	65	75
180	240	80	90

2, the distance c_{1t} (Figure 2) at the bottom of the beams should be 10 mm larger than the c_1 given by those tables.

2. Analysis

The Eurocode is an internationally recognized standard and the most up-to-date with regard to structures in fire, thus unsuspecting in its recommendations. However, the three recommendations mentioned in paragraph 1 herein can be adapted to be better understood and used by practicing engineers. This being our purpose, the results with the demonstrations are presented in the following items.

2.1 Reduction of c_1

The reduction factor $k_s(q)$ recommended for simplified or advanced analytical methods is presented in [1]. However, for the tabular method, an old factor $k_s(q)$ was used according to Equations 4. Graphically, both factors can be seen in Figure 3.

Given the difficulty that this procedure could cause to the user of the standard, a simpler alternative was sought without changing the security level required. The procedure is detailed below.

Table 3 - Minimum dimensions for two-way spanning, simply supported ribbed slabs

TRRF min	Ribs Combinations of b_{min}/c_1^* mm/mm			Slab h/c_1 mm/mm
	1	2	3	
	30	80/15	-	
60	100/35	120/25	190/15	80/10
90	120/45	160/40	250/30	100/15
120	160/60	190/55	300/40	120/20
180	220/75	260/70	410/60	150/30

Table 4 - Minimum dimensions for simply supported slabs

TRRF min	h mm	c_1 for $l_y/l_x > 2$ mm
30	60	10
60	80	20
90	100	30
120	120	40
180	150	55

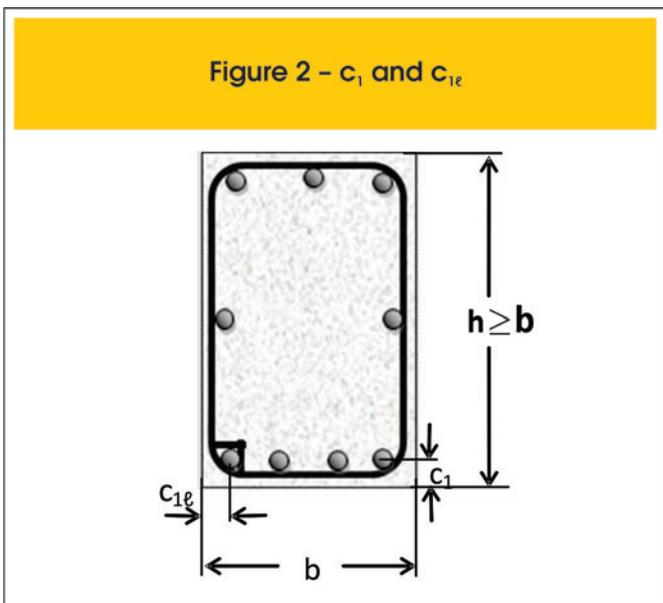
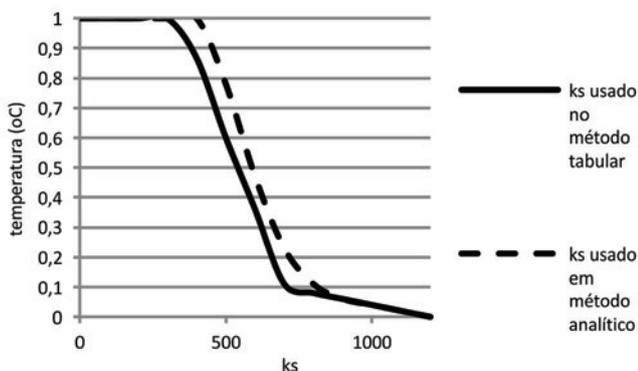


Figure 3 - Two versions of the strength reduction factor for the steel



From Equation 3, it is possible to determine $k_s(\theta_{cr})$ in function of $\frac{S_{d,fi}}{S_d}$ and $\frac{A_{s,calc}}{A_{s,ef}}$ (Equation 5) with $\gamma_s = 1.15$, as recommended

by ABNT NBR 6118:2003.

$$k_s(\theta_{cr}) = \frac{S_{d,fi}}{S_d} \times \frac{1}{1,15} \times \frac{A_{s,calc}}{A_{s,ef}} \quad (5)$$

Within of the ranges $0.7 \leq \frac{A_{s,calc}}{A_{s,ef}} \leq 1.0$ and $0.4 \leq \frac{S_{d,f}}{S_d} \leq 0.7$, the values of k_s are presented in table 6.

No values $\frac{S_{d,f}}{S_d} > 0.7$ were studied because NBR 15200 [1]

Table 6 - Values of k_s

$\frac{S_{d,fi}}{S_d}$	$\frac{A_{s,calc}}{A_{s,ef}}$						
	1	0.95	0.9	0.85	0.8	0.75	0.7
0.7	0.61	0.58	0.55	0.52	0.49	0.46	0.43
0.65	0.57	0.54	0.51	0.48	0.45	0.42	0.40
0.6	0.52	0.50	0.47	0.44	0.42	0.39	0.37
0.55	0.48	0.45	0.43	0.41	0.38	0.36	0.33
0.5	0.43	0.41	0.39	0.37	0.35	0.33	0.30
0.45	0.39	0.37	0.35	0.33	0.31	0.29	0.27
0.4	0.35	0.33	0.31	0.30	0.28	0.26	0.24

Table 7 - Values of θ_{cr} (°C)

$\frac{S_{d,fi}}{S_d}$	$\frac{A_{s,calc}}{A_{s,ef}}$						
	1	0.95	0.9	0.85	0.8	0.75	0.7
0.7	501	513	525	537	549	561	574
0.65	518	529	541	552	563	574	586
0.6	535	546	556	567	577	587	598
0.55	553	562	572	581	591	601	610
0.5	570	579	587	596	605	614	622
0.45	587	595	603	611	619	627	634
0.4	605	612	619	626	633	640	647

Figure 4 - Strength reduction factor of the steel

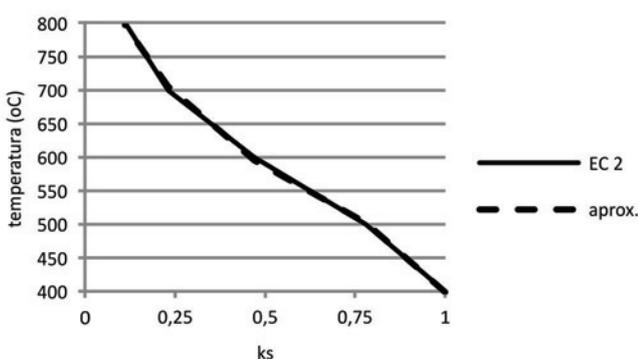


Table 8 - Values of Δ_{c1} (mm) for passive reinforcement

$\frac{S_{d,fi}}{S_d}$	$\frac{A_{s,calc}}{A_{s,ef}}$						
	1	0.95	0.9	0.85	0.8	0.75	0.7
0.7	0	1	2	4	5	6	7
0.65	2	3	4	5	6	7	9
0.6	4	5	6	7	8	9	10
0.55	5	6	7	8	9	10	11
0.5	7	8	9	10	10	11	12
0.45	9	10	10	11	12	13	13
0.4	10	11	12	13	13	14	15

allows adopting $S_{d,fi}/S_d = 0.7$, as an alternative to the exact calculation.

θ_{cr} is determined by Equation 6, the polynomial regression of Equations 4 for the range 400 to 800°C. A good approximation can be found in figure 4.

$$\theta_{cr} = - 810 k_s^3 + 1495.5 k_s^2 - 1199 k_s + 912 \quad (6)$$

Thus, at the same previous intervals, it is possible to build table 7. Finally, Δc_1 is determined by Equation 1. This procedure results in Table 8. Equation 7 very well represents Table 8 in the intervals

$$0.7 \leq A_{s,calc}/A_{s,ef} \leq 1.0 \text{ and } 0.4 \leq S_{d,fi}/S_d \leq 0.7.$$

$$\Delta c_1 = 24.5 - 35 \times \frac{S_{d,fi}}{S_d} \times \frac{A_{s,calc}}{A_{s,ef}} \quad (7)$$

The difference between Δc_1 given by Equation 7 and by Table 8 can be seen in Table 9. Values are in mm and negatives mean unsafety. In practice, the differences were insignificant.

2.2 Minimum dimensions for one-way ribbed slab

Since the first column of Table 2 is used, the widths become standards for manufacturers of plastic formwork for ribbed slabs. However, the widths of the first column of Table 3 are not the same given in column 1 of Table 2. This reason justifies this work. Based on the simplified method recommended by the Eurocode, searched values of c_1 that match the widths of 8 cm, 10 cm, 12 cm, 16 cm and 22 cm and the temperature in the reinforcement concrete? does not exceed 500°C in the TRRF.

Table 9 – Difference between Δc_1 in mm determined by Equation 7 and Table 8

$S_{d,fi}/S_d$	$A_{s,calc}/A_{s,ef}$						
	1	0.95	0.9	0.85	0.8	0.75	0.7
0.7	-0.05	-0.04	-0.04	-0.03	-0.02	-0.01	-0.01
0.65	-0.04	-0.03	-0.03	-0.02	-0.01	-0.01	0.00
0.6	-0.03	-0.02	-0.02	-0.01	0.00	0.00	0.01
0.55	-0.02	-0.01	-0.01	0.00	0.00	0.01	0.02
0.5	-0.01	0.00	0.00	0.01	0.01	0.02	0.02
0.45	0.00	0.01	0.01	0.02	0.02	0.03	0.03
0.4	0.01	0.02	0.02	0.03	0.03	0.03	0.04

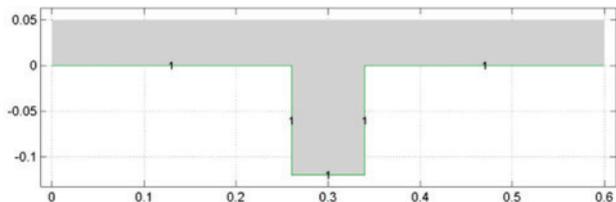
2.2.1 Geometry and discretization of the models

For simplicity, rectangular ribs were adopted. For safety reasons, the rib height is admitted to be equal to 1.5 times the width and it is overlaid with a 5 cm thick and 60 cm wide slab. The widths adopted were 8 cm, 10 cm, 12 cm, 16 cm and 22 cm. The Swedish software Super Tempcalc was employed for thermal analysis [3].

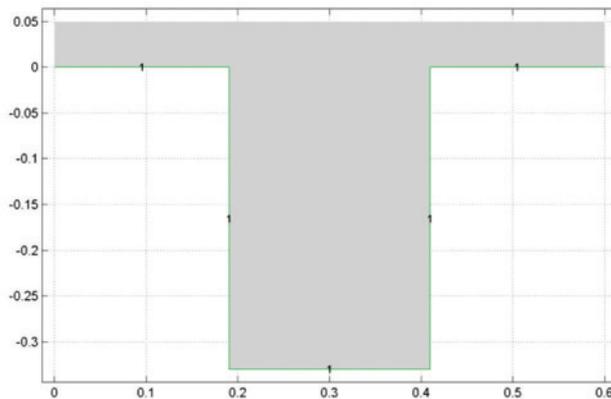
An example of the geometry provided for the software can be seen in Figure 5. In it, the symbol “1” next to the edge of the concrete elements means the heated faces, i.e., the heat flux was provided through the lower boundary of the model. The upper face of the slab was, on the side of safety, admitted to be adiabatic, i.e., there is no heat exchange with the environment.

The models were discretized in square mesh of 5 mm in side for the ribs and rectangle mesh of 10 cm x 1 cm for the slabs (Figure 6). In view of the considerable difference in width between the finite element chosen for the slab and rib, another mesh was tested (Figure 6b). With both meshes, the temperatures in

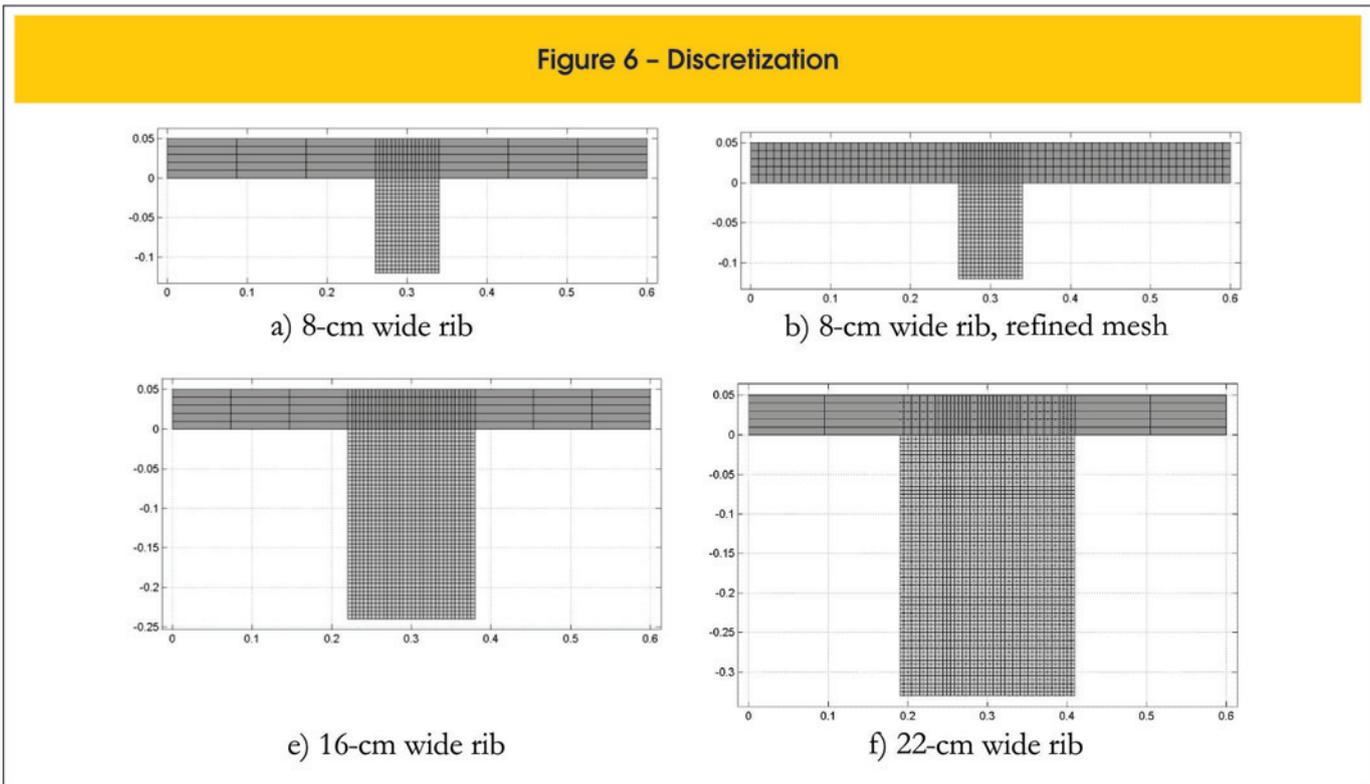
Figure 5 – Geometry and heated region adopted for the analysis



8 cm-wide rib



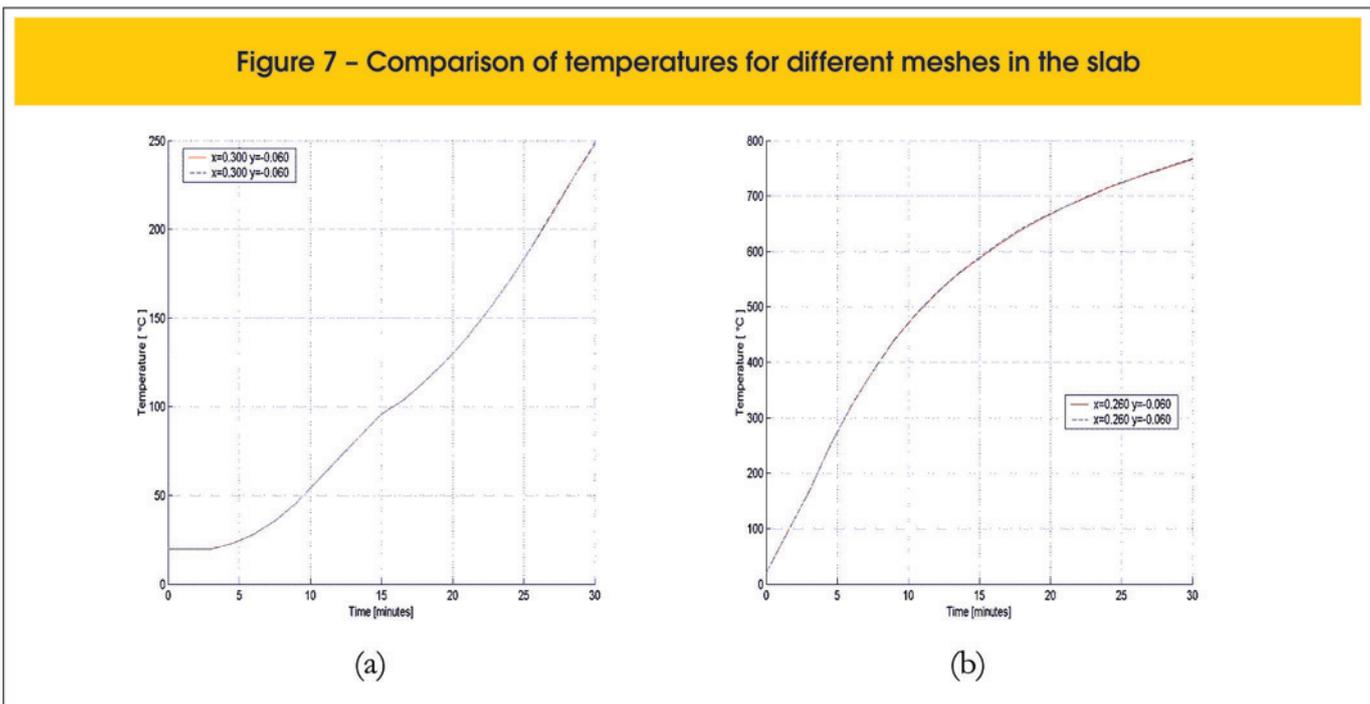
22-cm wide rib



the middle of the rib (Figure 7a, at relatively low temperatures) and CG level in rib were determined, near the face (Figure 7b, high temperatures). The conclusion is that for the thermal analysis in the lower region of the ribs, both discretizations lead to similar responses. Next, the simplest mesh was used.

2.2.2 Parameters used

The physical and thermal properties of the materials to be used in the thermal and structural analysis are given in [2], consistent with the proposed revision of ISO 15200 and presented as follows. The variation of thermal conductivity for concrete with silica nor-



mal density is expressed by equation 8, where λ_c is the thermal conductivity of concrete in W/m °C and q is the temperature in °C.

$$\lambda = 2 - 0.2451 \left(\frac{\theta}{100} \right) + 0.0107 \left(\frac{\theta}{100} \right)^2 \quad (8)$$

Equation 8 is valid for temperatures between 20°C and 1200°C and is plotted in Figure 8.

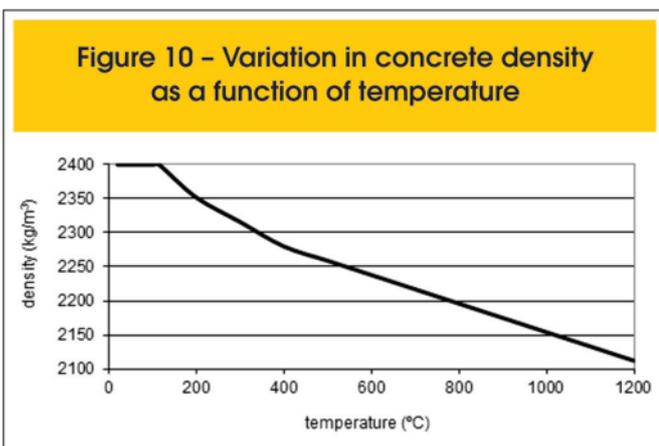
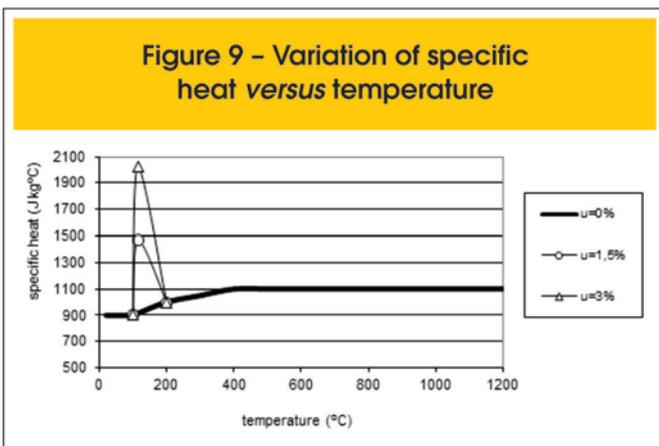
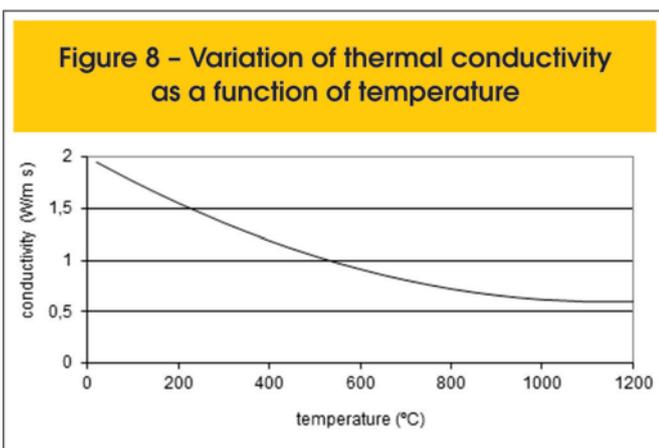


Table 10 - Peak values as a function of moisture content	
Moisture content	$c_{p,peak}$ (J/kg °C)
0%	900
1.5%	1470
3.0%	2020

The variation of specific heat as a function of temperature, $c_{p,q}$, concrete to dry silica is represented by equation 9, where q is the temperature in °C.

$$\begin{aligned} c_{p,\theta} &= 900 \text{ for } 20^\circ\text{C} = \theta = 100^\circ\text{C} \\ c_{p,\theta} &= 900 + (\theta - 100) \text{ for } 100^\circ\text{C} < \theta = 200^\circ\text{C} \\ c_{p,\theta} &= 1000 + (\theta - 200)/2 \text{ for } 200^\circ\text{C} < \theta = 400^\circ\text{C} \\ c_{p,\theta} &= 1100 \text{ for } 400^\circ\text{C} < \theta = 1200^\circ\text{C} \end{aligned} \quad (9)$$

Due to the evaporation of free water present in the hardened concrete, the value of specific heat is constant for temperatures between 100°C and 115°C. The value of $c_{p,peak}$ depends on the moisture content of concrete, as shown in Table 10.

Figure 9 shows the variation of specific heat as a function of temperature. In this study, moisture equal to 1.5% was adopted.

The variation in concrete density with temperature, ρ_q , is influenced by loss of water and can be determined according to equations 10, where q is the temperature in °C and $r(20^\circ\text{C})$ is the density of plain concrete at room temperature (20 °C).

$$\begin{aligned} \rho(\theta) &= \rho(20^\circ\text{C}) \text{ for } 20^\circ\text{C} = \theta = 115^\circ\text{C} \\ \rho(\theta) &= \rho(20^\circ\text{C}) \times (1 - 0.02(\theta - 115)/85) \text{ for } 115^\circ\text{C} < \theta = 200^\circ\text{C} \\ \rho(\theta) &= \rho(20^\circ\text{C}) \times (0.98 - 0.03(\theta - 200)/200) \text{ for } 200^\circ\text{C} < \theta = 400^\circ\text{C} \\ \rho(\theta) &= \rho(20^\circ\text{C}) \times (0.95 - 0.07(\theta - 400)/800) \text{ for } 400^\circ\text{C} < \theta = 1200^\circ\text{C} \end{aligned} \quad (10)$$

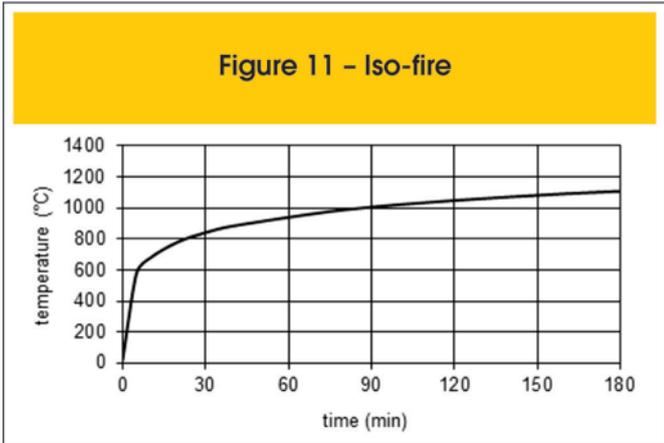
Figure 10 illustrates the variation in concrete density as a function of temperature, considering the concrete density at room temperature equal to 2400 kg/m³, as recommended by the ABNT NBR 6118:2003. The mathematical fire model used was the ISO-fire [4] as in Equation 11 and illustrated in Figure 11.

$$\theta_g = 20 + 345 (8 t + 1) \quad (11)$$

The emissivity factor was 0.7 and the heat transfer coefficient by convection in the face exposed to fire was 25 W/m² °C.

2.2.3 Thermal analysis results

With the parameters described in 2.2.2, the thermal fields were



determined as exemplified in Figures 12 and 13. From the temperatures fields and based on the simplified method proposed by the Eurocode [2], the minimum values for c_1 and width of the ribs for several TRRF's were determined. These values are presented below.

According to Figure 14, for the rib width equal to 8 cm, c_1 must be 25 mm for TRRF equal to 30 min, with no need to impose c_{1t} . According to Figure 15, for the rib width of 10 cm, c_1 must be 20 mm for TRRF equal to 30 min, then an alternative to the constant value of Table 5.

In figure 16, for the rib width of 10 cm, c_1 is 45 mm. Noting that one-way slabs can use just a rib for reinforcement, these dimensions will be considered. For the case of using up to two bars, an alternative was studied for the 12-cm width. According to Figure 17 for the rib width equal to 12 cm, c_1 must be 40 mm for TRRF equal to 60 min, with no need to impose c_{1t} .

Figure 18 proves that there is not c_1 that fits the 12-cm width for TRRF equal to 90 min. In figure 19, for the rib width equal to 16 cm, c_1 must be 50 mm for TRRF equal to 90 minutes, an alternative to table 5.

In spite of the differing widths standard, cases of width 13 cm, 14 cm and 15 cm were studied, and the results can be seen in figures 20 to 22. Respectively, the values of c_1 are 60 mm, 55 mm and 50 mm.

According to Figures 23 and 24, for rib widths equal to 16 cm and 22 cm, c_1 must be 65 mm and 50 mm, respectively, for TRRF equal to 120 min, an alternative to table 5.

According to Figure 25, for the rib width equal to 22 cm, c_1 must be 80 mm for TRRF equal to 180 min, an alternative to table 5. In short, the results are presented in table 11.

2.3 Increasing the lateral c_1 in some cases

Given the difficulty of specifying two different covers for the same beam, an alternative is presented here to the recommendation of the EC (2004), employing the procedure presented below.

Just as in 2.2, with the aid of the Super Tempcalc software, models were built for widths: 8 cm, 12 cm, 14 cm, 16 cm, 19 cm, 24 cm, 25 cm, 30 cm and 40 cm. Temperature fields were determined for each of these models. In figure 26, an example for the 19 cm width. From tables 1 and 2, columns 1 and 2 for each TRRF (30 to 180 min), the following temperatures and, respectively, k_s were determined:

- θ_1 in a place distant c_1 from the lower horizontal face of the beam and $(c_1 + 10)$ mm from the lateral face
- θ_2 in a place distant c_1 from both the lower horizontal face of the beam and the lateral face

Figure 27 shows examples of temperature-time curve of rib with a width of 19 cm at points $c_1 - c_1$ and $c_{1t} - c_1$ for TRRF equal to 120

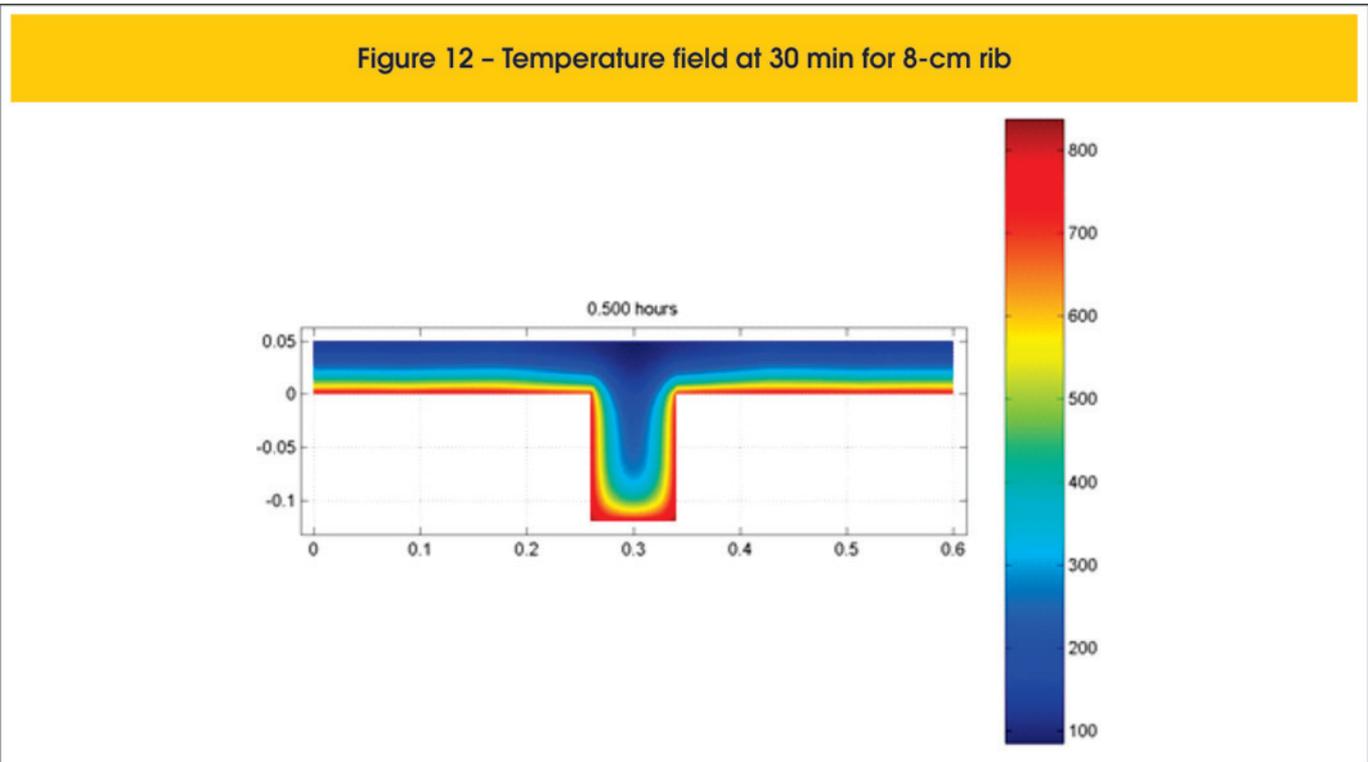


Figure 13 – Temperature field at 120 min for 16-cm ribs

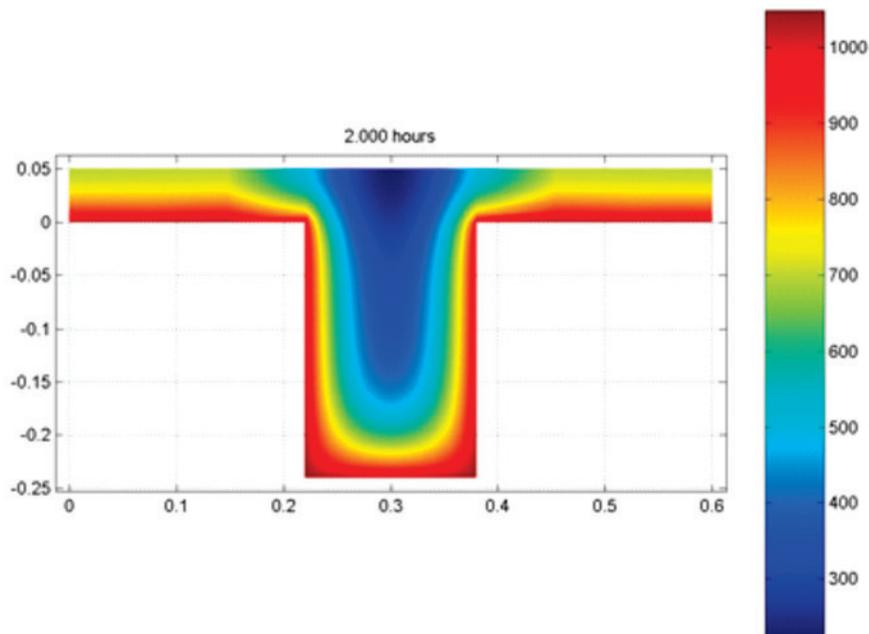
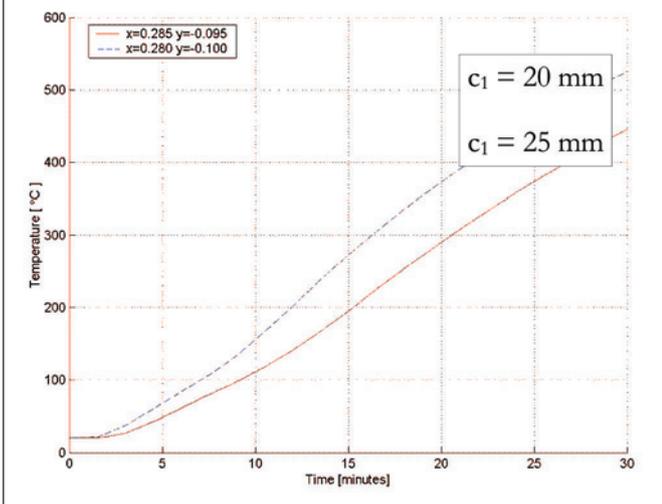


Figure 14 – Temperature rise in 8-cm wide ribs



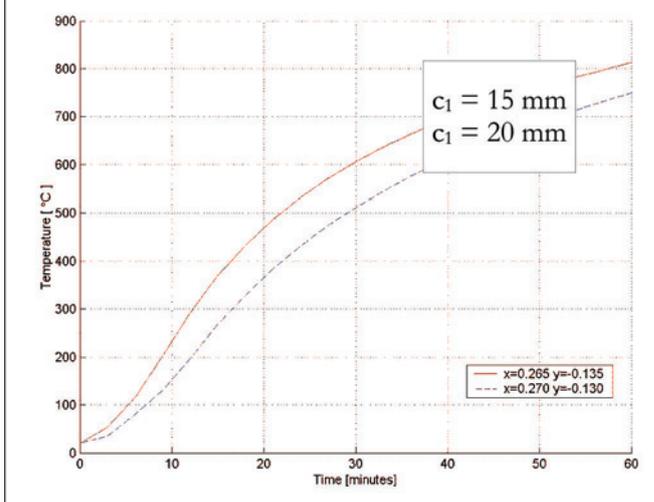
min for simple supported beam and continuous beam. In cases of Figure 26, we have:

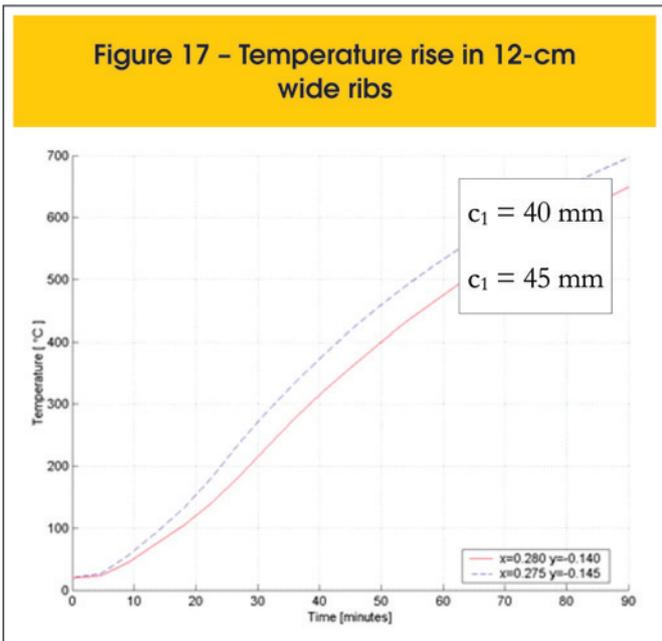
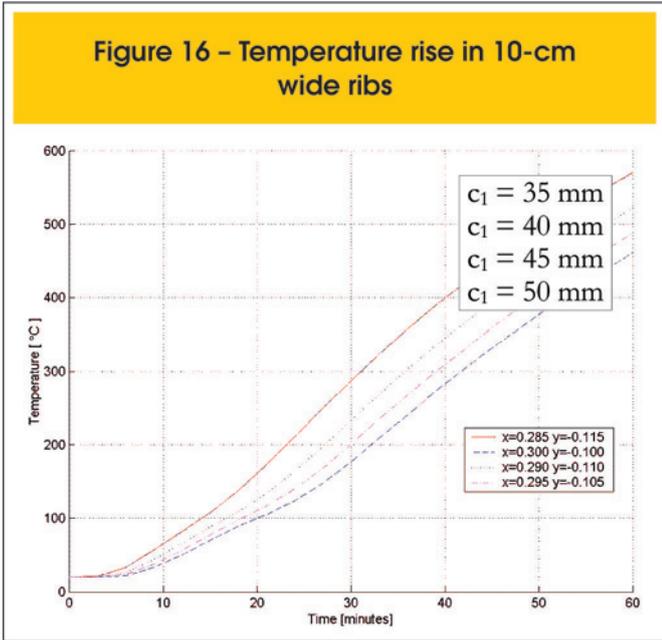
- simple supported beam, $\theta_2 = 508.32 \text{ }^\circ\text{C}$, $k_s(\theta_2) = 0.76$ and $\theta_1 = 484 \text{ }^\circ\text{C}$, $k_s(\theta_1) = 0.815$
- continuous beam, $\theta_2 = 675.86 \text{ }^\circ\text{C}$, $k_s(\theta_2) = 0.288$ and $\theta_1 = 634.32 \text{ }^\circ\text{C}$, $k_s(\theta_1) = 0.388$

Then, relationship $k_s(\theta_2)/k_s(\theta_1)$ was determined. For example, in cases of figure 26, $k_s(\theta_2)/k_s(\theta_1) = 0.9$ for the case of simple sup-

ported beam and 0.74 for the continuous beam. Also regarded were cases in which the set cover (at least 25 mm), stirrup (at least 5 mm diameter) and longitudinal bar diameter require a value of c_1 greater than that recommended by [1] or [2]. Considering this, tables 12 and 13 show all values of $k_s(\theta_2)/k_s(\theta_1)$. As shown in Tables 12 and 13, the reduction of the strength is always above 0.7 if the c_1 has not been increased by 10 mm. According to table 14, the relationship between areas of cross sec-

Figure 15 – Temperature rise in 10-cm wide ribs





tion of a reinforced bar with a certain diameter is always less than 70% of the diameter of a section immediately above, as in ABNT NBR 7480:2007 [5]. Therefore, if instead of c₁ the diameter is increased, safety will be strengthened.

3. Conclusions

A structural and thermal analysis was performed for proposing alternatives to the recommendations of Eurocode 2, part 1.2, which is the model for the ABNT NBR 15200:2004 review. After this analysis, the following proposals for the revision of the Brazilian standards are presented:

The values of c₁ given in tables 1 and 2 herein may be reduced of the Δc₁ as shown in the equation below, valid in the ranges:

$$0.7 \leq \frac{A_{s,calc}}{A_{s,ef}} \leq 1.0 \quad \text{and} \quad 0.4 \leq \frac{S_{d,fi}}{S_d} \leq 0.7$$

$$\Delta c_1 = 24.5 - 35 \times \frac{S_{d,fi}}{S_d} \times \frac{A_{s,calc}}{A_{s,ef}}$$

Table 3 is only for two-way ribbed slabs. For unidirectional slabs, the table presented below should be applied to the ribs. In beams with only one layer of reinforced bar and not greater than

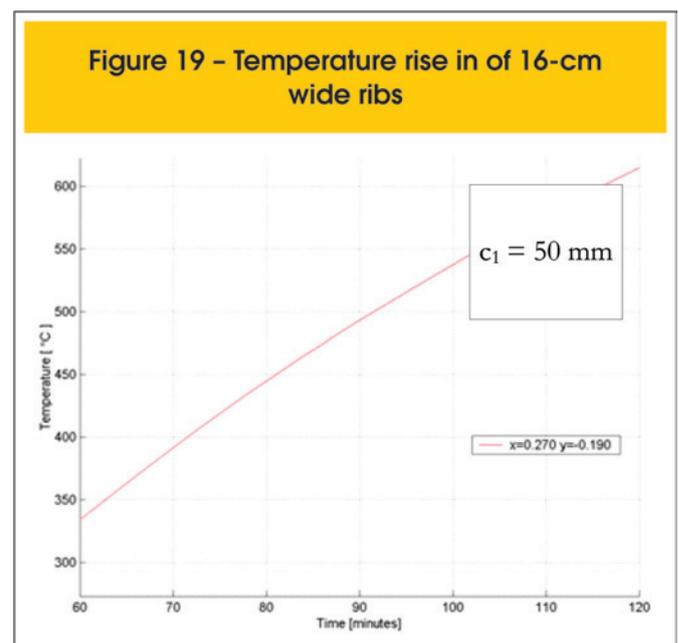
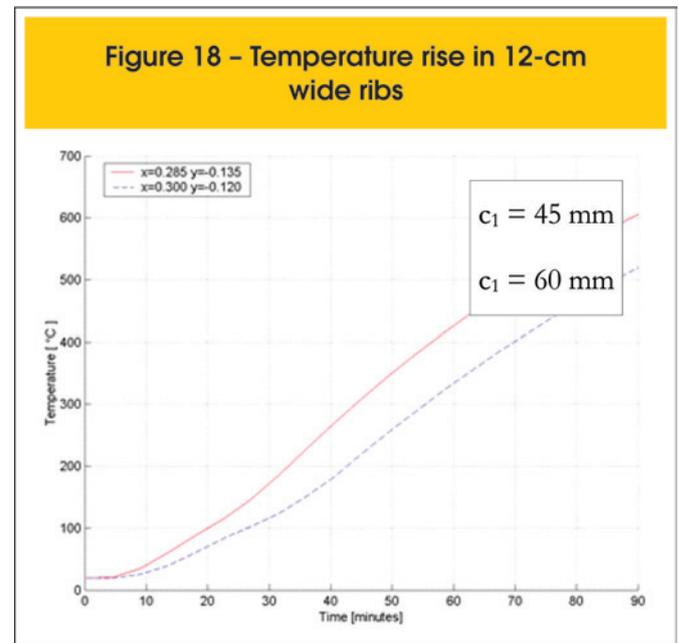


Figure 20 – Temperature rise in 13-cm wide ribs

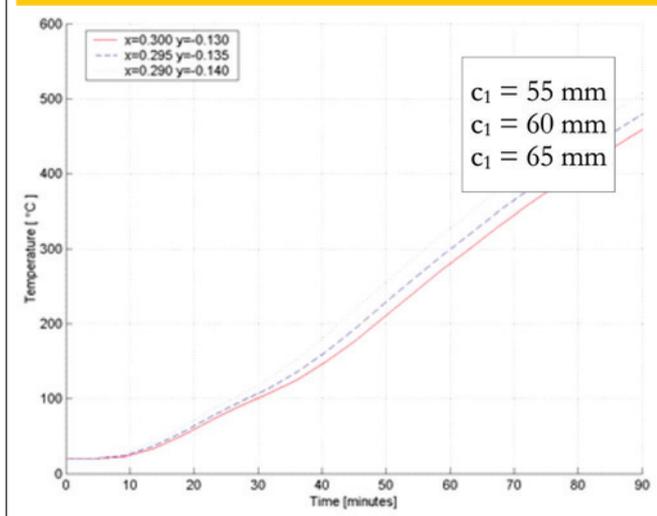


Figure 22 – Temperature rise in 15-cm wide ribs

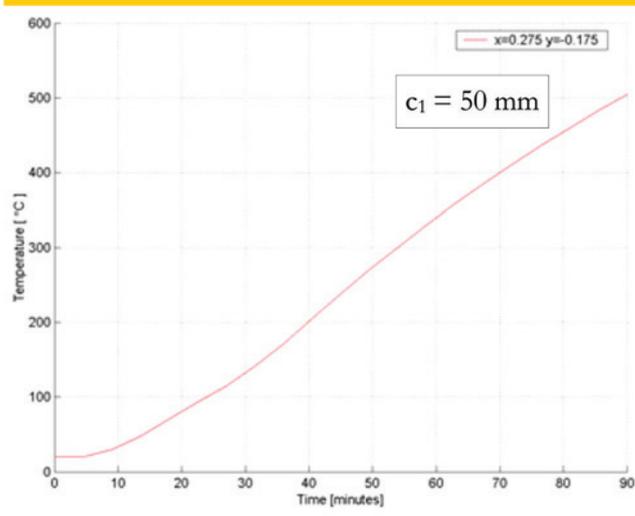


Figure 21 – Temperature rise in 14-cm wide ribs

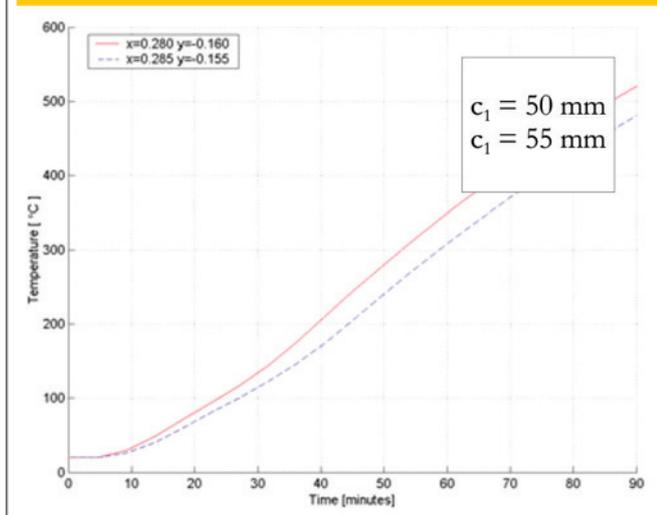
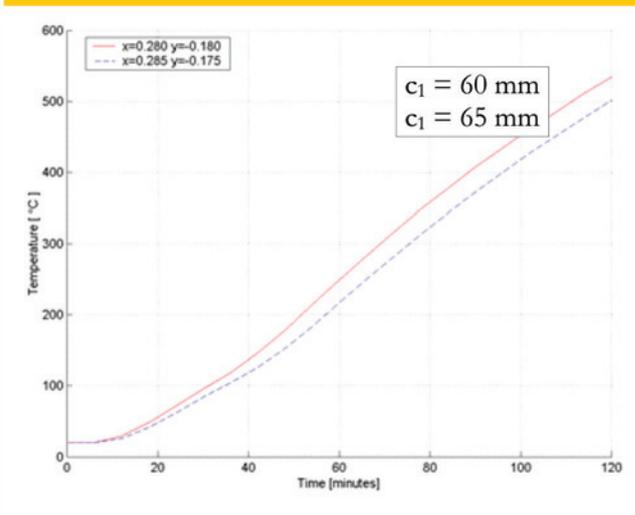


Figure 23 – Temperature rise in 16-cm wide ribs



the width b_{min} indicated in column 2 of tables 1 and 2, the distance between the CG of the reinforcement in the corner and the face exposed to fire should be 10 mm larger than those c_1 tabled. Alternatively, if this increase does not apply, the corner reinforcement has to be specified with a diameter immediately above that designed, according to ABNT NBR 7480.

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Development, and FAPESP - the State of São Paulo Research Foundation.

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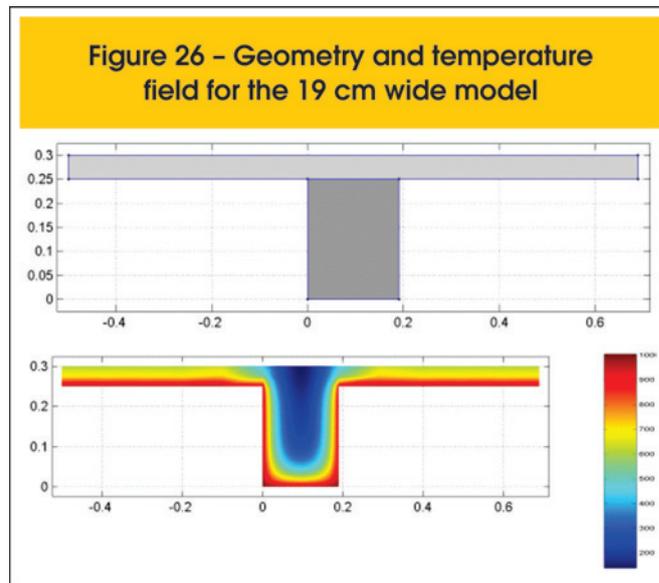
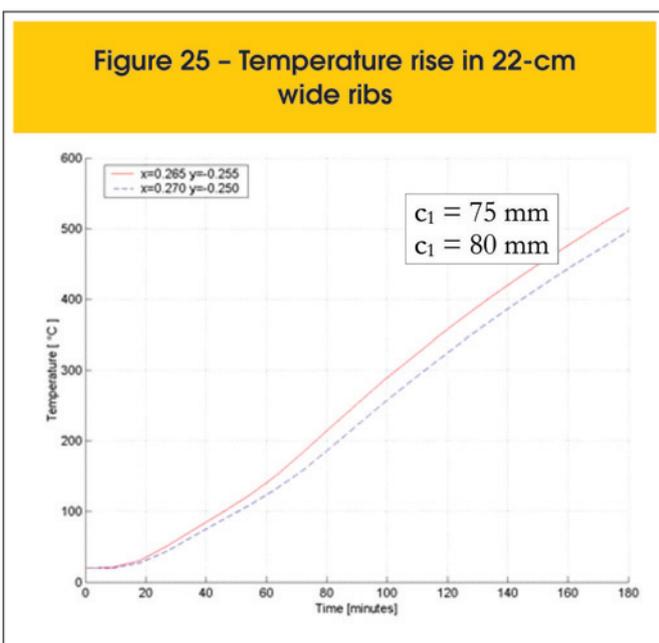
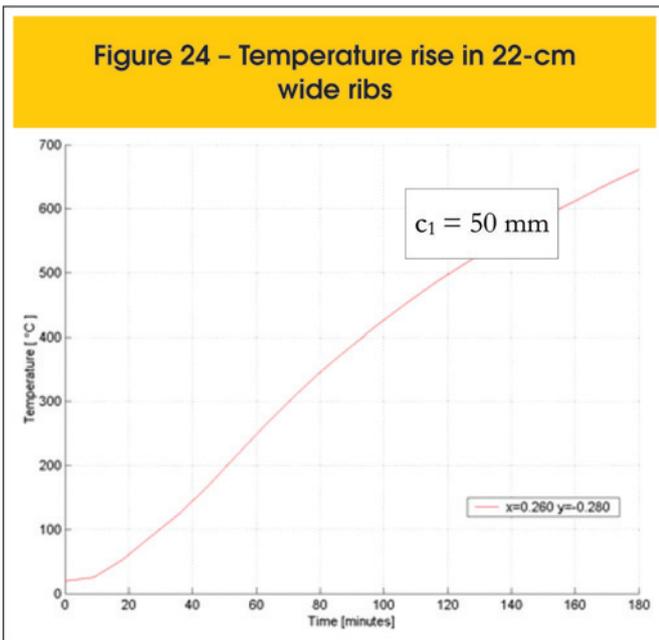


Table 11 - Minimum values of width (b) and c₁ (mm)

TRRF	Ribbed slabs simply supported, one-way
(min)	b _{min} /c ₁ (mm)
30	80/25; 100/20
60	100/45; 120/40
90	130/60; 140/55; 150/50
120	160/65; 220/50
180	220/80

Table 12 - Relation k_s (Θ₂) / k_s (Θ₁) for the dimensions of column 1 in tables 1 and 2

isostatica								
TRRF	width	6.3	8	10	12.5	16	20	25
30	8	1	1	1	1	1	1	1
60	12	0.9	0.9	0.9	0.9	0.9	0.9	0.98
90	14	0.9	0.9	0.9	0.9	0.9	0.9	0.9
120	19	0.9	0.9	0.9	0.9	0.9	0.9	0.9
180	24	0.9	0.9	0.9	0.9	0.9	0.9	0.9
continua								
TRRF	width	6.3	8	10	12.5	16	20	25
30	8	1	1	1	1	1	1	1
60	12	1	1	1	1	1	1	1
90	14	0.7	0.7	0.7	0.75	0.9	1	1
120	19	0.74	0.74	0.74	0.74	0.74	0.74	0.74
180	24	0.76	0.76	0.76	0.76	0.76	0.76	0.76

Figure 27 – Temperature-time curves of rib with a width of 19 cm at points $c_1 - c1$ e $c_{1c} - c_1$ for TRRF =120 min simple supported beam (left) and continuous beam (right)

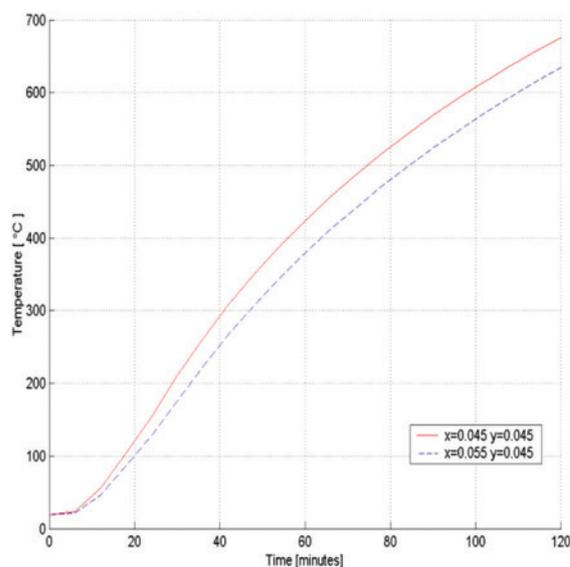
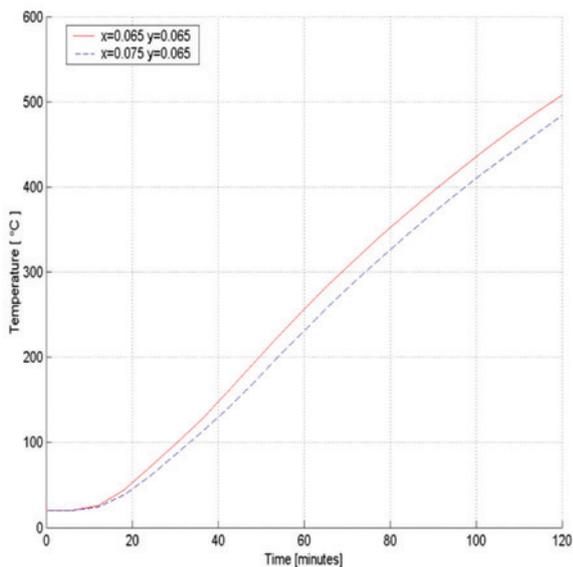


Table 13 – Values of $k_s(\Theta_2) / k_s(\Theta_1)$ for dimensions of column 2 of the tables 1 e 2

Simple supported beam								
TRRF	width	6.3	8	10	12.5	16	20	25
30	12	1	1	1	1	1	1	1
60	16	0.8	0.8	0.8	0.86	0.98	1	1
90	19	0.8	0.8	0.8	0.8	0.8	0.8	0.8
120	24	0.88	0.88	0.88	0.88	0.88	0.88	0.88
180	30	0.83	0.83	0.83	0.83	0.83	0.83	0.83
Continuous beam								
TRRF	width	6.3	8	10	12.5	16	20	25
30	16	1	1	1	1	1	1	1
60	19	1	1	1	1	1	1	1
90	25	1	1	1	1	1	1	1
120	30	0.7	0.7	0.7	0.8	0.9	1	1
180	40	0.8	0.8	0.8	0.8	0.8	0.8	0.8

Table 14 – Relationship between areas of the sequentially commercial diameters of the reinforced bars

diameter	area (mm ²)	Relationship between areas
6.3	31.16	0.62
8	50.24	0.64
10	78.50	0.64
12.5	122.65	0.61
16	200.96	0.64
20	314.00	0.64
25	490.63	-