Volume 2, Number 1 (March 2006) p. 1-30 ISSN 1809-1121
Revista IBRACON de Estruturas
IBRACON Structural Journal

Directions of the new Brazilian standard NBR 15200:2004 for concrete structures design in fire conditions – a comparative analysis to NBR 6118:2003

Diretrizes da nova norma brasileira NBR 15200:2004 para projeto de estruturas de concreto em situação de incêndio – uma análise comparativa com a NBR 6118:2003

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Abstract

Concrete structures should ensure the support ability in fire conditions, to allow the occupants escape and, if necessary, the fire control operations in safety. Specific standards to concrete structures design in fire conditions are common in Developed countries, where the structural elements are usually designed, based on the known "tabular method". In the last year, the standard NBR 15200:2004 – "Projeto de estruturas de concreto em situação de incêndio – Procedimento" (Design of concrete structures in fire condition – Procedures) was published to complete the standardization of the design of concrete structures in Brazil. This paper presents the basic rules of the design of concrete structures in fire conditions and the standards comparison between the recent NBR 15200:2004, and the current NBR 6118:2003 to design of concrete structures at room temperature.

Keywords: structural concrete, safety, high temperatures, fire.

Resumo

As estruturas de concreto devem assegurar a capacidade de suporte em situação de incêndio, a fim de permitir a fuga dos usuários e, se necessárias, as ações de combate do sinistro em segurança. Recentemente, foi publicada a NBR 15200:2004 – "Projeto de estruturas de concreto em situação de incêndio – Procedimento", complementando a normatização de projeto de estruturas de concreto do Brasil. O entendimento e a aplicação da nova norma requer o conhecimento de novos conceitos de segurança e termos técnicos da Engenharia de estruturas em situação de incêndio.
Neste trabalho, são apresentadas as diretrizes básicas de projeto de estruturas de concreto em situação de incêndio e uma comparação das dimensões mínimas estabelecidas para elementos de concreto, entre a nova NBR 15200:2004 e a NBR 6118:2003 para projeto à temperatura ambiente.

Palavras-chave: concreto estrutural, segurança, altas temperaturas, incêndio.

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1 Introduction

Structural materials undergone to the high temperature suffer the reduction of the strength and elasticity modulus running a risk to failure partial or totally and so the fire safety must be extended to the structures design, similar to the architectonic, hydraulic, and electric designs, contributing to the integration of systems safety of the buildings.
In the developed countries, the fire safety is considered a Science, being researched and applied. In Brazil, the standard NBR 14432:2000 – "Exigências de resistência ao fogo de elementos construtivos de edificações – Procedimento" (Requirements of fire resistance of constructive members of the buildings – Procedure) establishes the minimal fire resistance required to the design of buildings, as a function of their size, occupation, and construction place, non-dependent on the type of used constructive material.
In 2001, the Instrução Técnica do Corpo de Bombeiros do Estado de São Paulo – IT nº 08 (Technical Instruction No. 08 of the of the Fire Department of the State of Sao Paulo) ruled the use of the standard NBR 14432:2000 in the Civil Construction designs in the State of Sao Paulo. Since 1999, there is a standard and a technical instruction to establish the fire resistance required to the buildings; but, only the steel structures had had a specific standard to the fire design – NBR 14323:1999 – "Dimensionamento de estrutura de aço em situação de incêndio – Procedimento" (Design of steel structures in fire situation – Procedures).
The new standard NBR 15200:2004 - "Projeto de estruturas de concreto em situação de incêndio – Procedimento" (Design of concrete structures in fire situation) was elaborated by CE-02:124.15 – Comissão de Estudo de Estruturas de Concreto Simples, Armado e Protendido, no âmbito do CB-02 – Comitê Brasileiro de Construção Civil (Commission of Studies of Plain, Reinforced and Prestressed Concrete Structures into the Brazilian Committee of Civil Construction) to fill the gap existent in the standardization of fire safety in Brazil.
NBR 15200:2004 is based on the Eurocode 2 Part 2 (1995 and 2002 versions) with slight changes, e.g., the allowance to add the thickness of the incombustible finish to the dimensions of the structural members in order to establish the minimal dimensions needed to observe the required time to the fire resistance.
The requirements of fire resistance in buildings supporting the prevention or fire safety beforehand may be "alleviated" by regarding the reduction of the fire risk, the easing of the evacuation of the users, as well as the fire fight; in other words, the performance of the active fire protection can assume, indirectly, a part of the required fire resistance for the structure.
The conception of new designs of the concrete structures requires a previous knowledge of NBR 15200:2004, NBR 14432:2000 and, IT no. 08 in the State of Sao Paulo. This paper aims to present the differences between the designs at room temperature and in fire situation by means a just analysis between the standards NBR 6118:2003 and NBR 15200:2004.

2 Fire safety of the structures

Most of the developed countries have reduced the direct and indirect expenditures due to fire damage. The progress is more evident in the countries victimized by the greatest death rates at the eighties, which invested heavily in the fire safety systems. However, many developing countries have faced difficulties to deal with the fire safety, evidenced by the high death rates over the average of the most of the other countries at the same time (WILMOT, 2003).
Fire safety is obtained by the integration of the all the safety systems, divided in two classes: active and passive fire protection system.
Active fire protection system is constituted by protection means activated mechanically, whether manual or automatically in fire situation, aiming the quick fire detection to warn the users to evacuate the building and to start the fire fights. The examples of active fire protection means are manual alarm system, smoke and heat detectors, automatic fire alarm, fire extinguishers, hydrants, automatic sprinklers, emergency lighting, and smoke exhaust system (ONO, 2004).
Passive fire protection system is constituted by the means of protection built-in to the building construction, not requiring any mechanical activation to work in fire situation, e.g., ease of access to the yard and the building (windows and other openings), means of egress, the establishment of the protection levels to the users, and fire resistance of structural and compartments members (ONO, 2004).
Reliability of the structures is assured by the fire resistance required as a function of the safety level established by the society trough the current regulations and specific standards. During the fire, the building must assure the load-bearing capacity in order to allow the evacuation of the users, the fire rescue and fight actions in safety, and to minimize the flames spraying to the neighboring compartments or buildings.
The main objective of the fire safety is protecting the human life during the sinister; hence the structure must prop the effects of the thermal action during the escape of the users and the fire fight actions in safety.

3 Why should the fire be considered in the design of the concrete structures?

Structural materials react to the heat differently, according the nature of their microstructure. At high temperatures, only the mechanical properties of metals (steel, aluminium, etc.) are reduced (Figure 3.1 and Figure 3.2), whilst the superficial of the hardened concrete and timber are reduced besides their mechanical properties.
The reduction of the cross-section of the timber and concrete members is caused by the reactions to the heat proper of each material. The timber reacts charring the surface exposed to fire, whilst the hardened concrete reacts by spalling or popping out part of the heated surface.
Hardened concrete is an incombustible material with low thermal conductivity without releasing toxic gases during

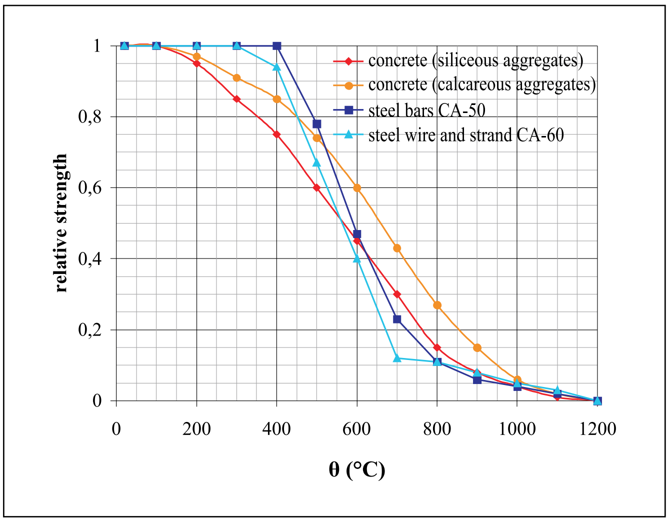

Figure 3.1: Reduction of the materials strength at high temperature (NBR 15200:2004).

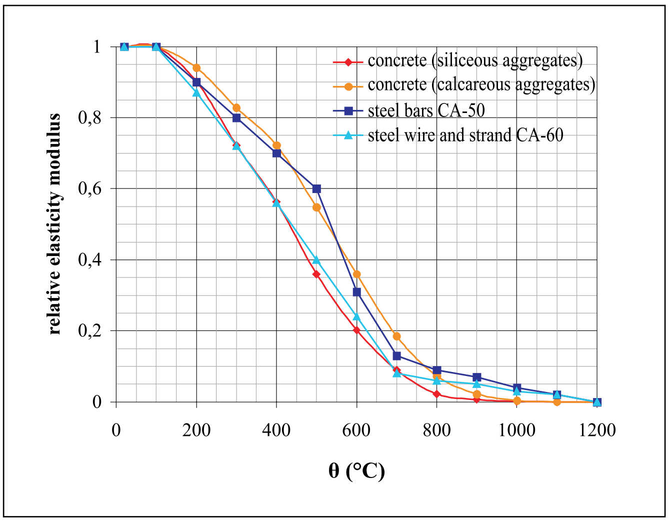

Figure 3.2: Reduction of the elasticity modulus of the materials at high temperature (NBR 15200:2004).

the exposure to the heat. Despite of these appreciated qualities, the concrete reacts to the heat by excessive cracking, and increasing of the porosity and spalling.
The increasing of cracking and the porosity are a typical reaction of the concrete microstructure, guided by its heterogeneity, to the heat. Hardened concrete is a mixture of water, Portland cement, fine and coarse aggregates, and steel; after the concrete curing, all the constituents work as a unique material only at room temperature. At high temperature the constituents of the hardened concrete present differentiated thermal expansions (thermal incompatibility between the aggregates and the mortar, and between the hardened concrete and the steel) and physical-chemical reactions of the cement mortar (dehydratation and water steam).
The spalling is a reaction of the concrete macrostructure to the heat. The concrete pieces spall from the surface, exposing the interior of the member to the thermal action. The spalling can be gradual or can assume an unpredictable behavior during the earlier fire (COSTA et al. 2002).
Steel is chemically stabler than the hardened concrete; however it experiences the creep effects and excessive expansion, besides the reduction of the strength and elasticity modulus due to the elevated temperature.
The reduction of the mechanical properties of the reinforced concrete is took account in the design of concrete members. International codes of North America, Europe, and Oceania present simplified methods for the fire design, according to the fire risk rate of the building.

3.1 Background

Total or partial collapse of the concrete structures of the high rises has been not unusual due to the fire, although structural failure has been enhanced recently by the technical-scientific media after the terrorist attacks on September 11th, 2001.

The partial or total collapse during the fire of many multi-storey reinforced concrete buildings offering danger to the fire rescue and fight has been published by the international technical literature: "Minin works" in Surrey – United Kingdom, 1969; office building "One New York Plaza" in New York – U.S.A., 1970; Linde factory – Germany, 1971; "Military Personnel Record Center", in Overland – U.S.A., 1973; department store "Katrantzos Sport" in Athens – Greece, 1980; CESP's towers I and II in Sao Paulo – Brazil, 1987; storage of Zêlo S.A. stores in Barueri – Brazil, 1995; "Condomínio Edifício Cacique" in Porto Alegre – Brazil, 1996; clothing factory in Alexandria – Egypt, 2000; Linköping library – Sweden, 1996; residential building in Saint Petersburg – Russia, 2002; residential building "Jackson Street Apartment", in Hamilton – Canada, 2002; office building of Eletrobrás in Rio de Janeiro – Brazil, 2004.

4 National standardization

4.1 Background

Brazil had a standard to the design of concrete structures in fire situation – NBR 5627:1980 – "Exigências Particulares das Obras de Concreto Armado e Protendido em Relação à Resistência ao Fogo" (Particular Requirements of the Reinforced and Prestressed Concrete in Relation to the Fire Resistance) – cancelled in 2001 by being outdated. Later, there was an effort to include the guidelines of the fire design to the draft of the NBR 6118:1980 – Projeto e Execução de Obras de Concreto Armado (Design and Execution of Reinforced Concrete), into its Annex B in 2001.
The new NBR 15200:2004 presents certain similarities to the Annex B of the draft of the NBR 6118:2001, prescribing the minimal dimensions for the structural members of any buildings, according to the required fire resistance established by NBR 14432:2000, nondependent of the type of the used materials. Moreover, the technical instruction of de

Fire Department of the State of Sao Paulo IT 08 – "Segurança Estrutural nas Edificações – Resistência ao Fogo dos Elementos de Construção" (Structural Safety of the buildings – Fire resistance of the construction members) give the legal status to the NBR 14432:2000 in this State.
According to the IT 08, the high rises featured by the height and high fire load, should comply with the severe requirements, in order to reduce the damage and loss risks in a fire.

4.2 Fire resistance required by the standardization

Required fire resistance (RFR)[1] is a time deductible by the Engineering (Structures Mechanics, Transport Phenomena, Materials Science, and Fire Dynamics); however, the RFR has been estimated subjectively, in face of the operational difficulty in deducting it for each type of the building. Thus, the RFR has been established by the consensus of the society, and standardized as a function of the fire risk and the consequences of the sinister (Table 4.1).
Required fire resistance for the building members is established by the current regulations, supposing the fire temperature increases according to a time-temperature curve, known as the standard fire or standard curve.
The standard curve does not represent an actual fire and the RFR, associated to it, does not correspond to the time for the users evacuating the buildings or the firemen arriving on time to fight the fire (SILVA, 2004).
For the design at room temperature, the partial safety factors, defined by engineering standards (NBR–ABNT, in Brazil), reflect the likelihood of a failure acceptable to a well-designed building throughout its life-cycle. For the fire design, the RFR reflects the likelihood of a failure acceptable to a well-designed building in a fire throughout its life-cycle.

4.3 Directions of the NBR 15200:2004

Concrete structures in fire design may be optimized by the rational applying of the standard "Projeto de estruturas de concreto em situação de incêndio – Procedimento" (Design of concrete structures in fire situation – Procedure), requiring an integration among the structural and complementary designs.
Standard requirements may be softened when the building designs support the fire prevention or protection, reduction of the sinister risk, and evacuating facilities of the users and the fire fighting; i.e., the requirements may be reduced if some fire protection means used in a risk analysis method, such as sprinklers and any others, have just been defined in any complementary designs (Hydraulic & Electric).
The NBR 14432:2000 allows using the Time Equivalent Method to consider the active fire protection means in the reducing of the requirements of the fire resistance of the structure. Technical Instruction IT 08 of the Fire Department of the State of Sao Paulo presents and details the time equivalent method to be used only in this State.
The Time Equivalent Method associates the standard fire to the natural fire models. Natural fire is a mathematic model of realistic fires, taking into account the impact of the fire load, the geometric features of the fire compartments (horizontal and vertical opening areas, compartment height, and materials), the active protection means (automatic sprinklers and smoke detectors, and fire brigade) and the fire risk of a building as a function of its occupation (museum, library, laboratory, offices, ...) (SILVA *et al*., 2005).
Structural members with non-combustible finishes (cladding, walling and flooring ceramic tiles, natural stones, and mortars) take advantage in the fire design, once that the non-combustible finish may be incorporated in the total thickness of the concrete members to determine the minimal dimensions in function of the RFR.
Although the gypsum plaster is a non-combustible finish, COSTA *et al*. (2005) point out the ordinary gypsum generally used for the finish of walls and ceiling in Brazil is not proper to the thermal protection; only the refractory gypsum finish, assured by the technical statement of the manufacturer, may be included in the total thickness of the member.

Table 4.1: Required fire resistance (min) for main types of the buildings in Brazil (NBR 14432:2000)

Occupation	Building height				
	h ≤ 6m	6m < h ≤ 12m	12m < h ≤ 23m	23m < h ≤ 30m	h > 30m
Residences	30	30	60	90	120
Hotel	30	60	60	90	120
Supermarket	60	60	60	90	120
Office	30	60	60	90	120
Shopping mall	60	60	60	90	120
School	30	30	60	90	120
Hospital	30	60	60	90	120

1 – Translation to the Braziliam technical term "tempo requerido de resistencia ao fogo" – TRRF.

4.4 Tabular method for the design

Tabular method has been widely spread in the international standards of the countries provided by fire safety regulations to the design of concrete structures (COSTA & SILVA, 2003). The simplicity of the method is enhanced by the immediately applying of the minimal dimensions recommended in function of the RFR, organized in tables (Table 4.2 à Table 4.11), for the usual structural members. The minimal tabular values correspond to the dimensions of the cross-section of the element and the minimal axis distance ("c_1") between the centroid of the main reinforcement and the nearest surface exposed to the heat. More distant the reinforcement is from the heated surface, lower is its temperature; i.e., greater value of "c_1", lesser the temperature at the point of the section (Figure 4.1).
The temperature decreases at the regions close to the centroid of the section, due to the thermal inertia of the concrete member; thus, greater cross-section, greater cold concrete nucleus. The reinforcement cover is not so important to protect it, once that the concrete is not a good thermal insulator, being needed a large cover to assure such protection. The temperature of the reinforcement depends on not only the position (indirectly, on the cover) into the member, but also the size of the concrete cross-section (Figure 4.2).
When the reinforcement bars are arranged in several layers, the minimal distance ("$\mathbf{c_1}$") given in the tables of NBR 15200:2004 will be determined by the average axis distance between the centroid of each bar and the nearest heated surface. The average axis "$\mathbf{c_{1m}}$" should be the less value calculated by de equation 4.1.

$$c_{1m} < \left| \begin{array}{c} \dfrac{\sum_{i=1}^{n} c_{1v_i} \cdot A_{s_i}}{\sum_{i=1}^{n} A_{s_i}} \\ \\ \dfrac{\sum_{j=1}^{m} c_{1h_i} \cdot A_{s_i}}{\sum_{j=1}^{m} A_{s_i}} \end{array} \right. \tag{4.1}$$

where:
c1m = average axis distance of steel bar "i" from the nearest surface exposed to the heat;
c1vi = axis distance of steel bar "i" from the bottom of the beam exposed to the heat;
c1hi = axis distance of steel bar "i" from the lateral surface of the beam exposed to the heat;
Asi = cross-section area of the bar "i".

To verify the minimal dimensions, the non-combustible finish applied in a unique or in two surfaces may be added to the total dimensions of the members (Figure 4.3) providing the finish is bonded to the surface. If the finish has refractory properties, the NBR 15200:2004 allows considering its effective thickness by majoring the actual thickness up to 2.5 times to add it to the total width of the structural member, in order to satisfy the minimal values of the following tables (Table 4.2).
Structural members should maintain the stability, assuring the load-bearing capacity to the mechanic actions, in any design situation. In fire situation, some members can have additionally the function of thermal insulation and integrity.
Thermal insulation and integrity assume the fire-barrier function; for this reason, the tabled dimensions of the cross-section should be applied, even though the stability of structural members with reduced dimensions can be attested by refined calculations or physical experiments. Usually, the slabs and load-bearing walls are concrete members with multiple functions: besides supporting the mechanic actions, they should avoid the fire spreading to the neighbouring, by means of the excessive heat transfer (insulation), or flames crossing the member through the excessive concrete cracking (integrity).
The Table 4.11 gives the axis distance "c_1", and a factor, unknown up to earlier by the technical community: the factor "μ_{fi}", for the design of concrete columns in fire situation.
The factor "μ_{fi}" is a ration between the design load in fire situation and the resistant design load in normal situation (equation 4.2).

$$\mu_{fi} = \frac{N_{Sd,fi}}{N_{Rd}} \tag{4.2}$$

where:
μ_{fi} = load level of the column in fire situation;
$\mathbf{N_{Sd,fi}}$ = design axial load for fire situation, calculated by the combination of accidental actions (equation 4.3);
$\mathbf{N_{Rd}}$ = design resistant axial load at room temperature.

where:
$\mathbf{N_{gk}}$ = characteristic value of the axial load due to the permanent actions;
$\mathbf{N_{qk,j}}$ = characteristic value of the axial load due to the direct variable actions "j"; actions from thermal restrain may be neglected;

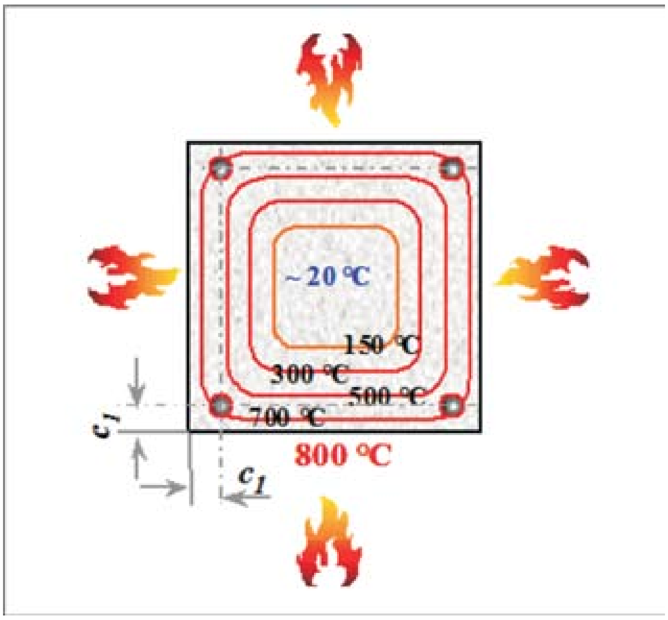

Figure 4.1: Temperature profiles for a concrete cross-section undergone to the heat in all the sides.

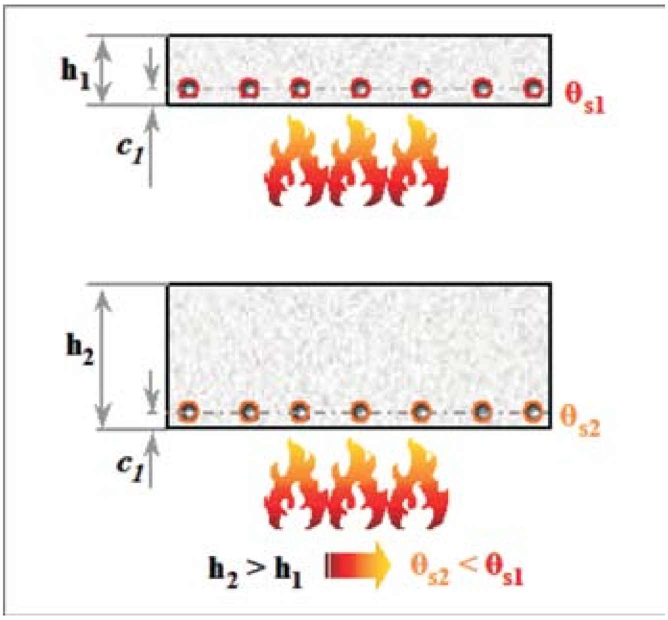

Figure 4.2: Temperature reinforcements with equal cross-section areas and centroid into slabs with different thickness, undergone to the same thermal action.

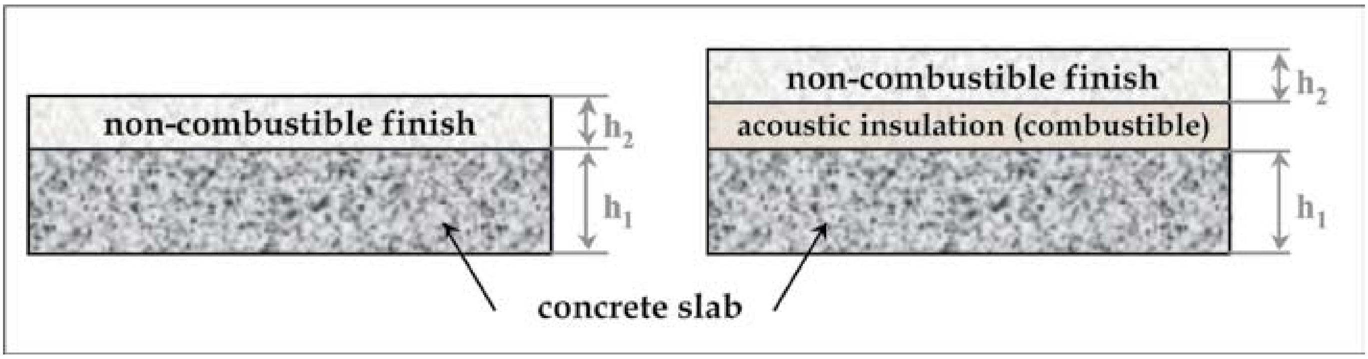

Figure 4.3: Thickness of the concrete slabs with flooring finish regarded in the tabular method (NBR 15200:2004.)

Table 4.2 – Effective thickness of the finish (NBR 15200:2004).

finish	total thickness of the slab
lime & sand mortar	$h_{slab} = h_1 + 0,67 . h_2$
Portland cement & sand mortar	$h_{slab} = h_1 + h_2$
gypsum plaster, sprayed asbestos fibers or vermiculite	$h_{slab} = h_1 + 2,5.h_2$

Table 4.3: Minimal dimensions for tensionedmembers (NBR 15200:2004).

RFR (min)	arrangements between b_{min} and c_1			
	1		2	
	b_{min} (mm)	c_1 (mm)	b_{min} (mm)	c_1 (mm)
30	80	25	200	10
60	120	40	300	25
90	140	55	400	45
120	200	65	500	45

$\gamma_{g,fi}$ = 1.2 and $\gamma_{g,fi}$ = 1.0, respectively, for the favourable and unfavourable permanent actions;
$\gamma_{q,fi}$ = 1.0 and $\gamma_{q,fi}$ = 0, respectively, for the favourable and unfavourable variables actions;
$\psi_{0,j}$ = factor for combination value of the direct variable actions "j" (Table 4.12).
In absence of an accurate calculation, NBR 15200:2004 allows to estimate $N_{d,fi} \cong 0.70 * N_d$. If both applied and resistant design load are equal at room temperature, the factor μ = 0.7 can be used as a conservative simplifying.
Experimental methods conducted by laboratories with international know-how can be used to determine the fire resistance, function of RFR, for member not covered by the new NBR 15200:2004.

4.5 NBR 6118:2003 x NBR 15200:2004

The simply supported solid slabs with $h_{slab} \geq 80$ mm satisfy the RFR ≤ 60 min; the slabs with h_{slab} < 80 mm need the finish to be into this resistance range. For RFR > 60 min, the solid slabs designed according to the NBR 6118:2003 depends on the class of environmental aggressivity and the type of the finish to have the required minimal section dimensions. For RFR = 120 min, the minimal dimensions established by NBR 6118:2003 do not satisfy to the fire resistance criteria.
The flat slabs prescribed by the NBR 6118:2003 do not satisfy to the minimal dimensions necessary for RFR ≥ 60 min, whatever the class of environmental aggressivity or the type of the finish, requiring the increase of their thickness. For RFR = 30 min., only the plate slabs satisfy the minimal dimensions recommended by the NBR 15200:2004.
The minimal dimensions of the ribbed slabs depend on the distances between the ribs axes, established by the designer. In this paper, the minimal values from the NBR 15200:2004 was compared to the minimal relative values from the NBR 6118:2003. Generally, the minimal values given by NBR 6118:2003 for the slab thickness and rib width do not confer the fire resistance for RFR ≥ 30 min, even if taking into account the finish.
For the simply supported beams, the minimal dimensions from NBR 6118:2003 can satisfy the requirements of the NBR 15200:2004 for RFR ≤ 60 min providing the finish thickness is added. For RFR > 60 min., the dimensions from the NBR 6118:2003 depend on the class of environmental aggressivity and the arrangements between the width and the cover, besides the finish to satisfy the required dimensions recommended by NBR 15200:2004.
For the continuous beams, the minimal dimensions from the NBR 6118:2003 are enough to assure the fire resistance for RFR ≤ 60 min. For 60 min < RFR ≤ 90 min., the dimensions for the room temperature satisfy to the requirements from NBR 15200 providing the thickness of the finish is regarded. For RFR > 90 min., the fire resistance of the dimensions from NBR 6118:2003 depend on furthermore the class of the environmental aggressivity and the arrangements between the width and cover.
Columns and the load-bearing walls depend on the load level (μ_{fi}), besides the geometric dimensions and the finish, to assure the fire resistance. The columns with one exposed side to the heat and μ_{fi} **= 0.7** do not need to be verified for RFR ≤ 120 min. For the columns with more than one exposed side, the verifying is unnecessary when: RFR ≤ 90 min and μ_{fi} **= 0.2**; RFR ≤ 60 min and μ_{fi} **= 0.5**; and RFR = 30 min e μ_{fi} **= 0.7**. Otherwise, the fire resistance of columns with the minimal dimensions from the design at room temperature depend on the finish and the class of the environmental aggressivity.
The load-bearing walls with one exposed side to the heat and μ_{fi} ≤ **0.7** satisfy the RFR ≤ 120 min. When two sides are exposed to the heat, the verifying is unnecessary for: RFR ≤ 120 min and μ_{fi} **= 0.35**; RFR ≤ 90 min and μ_{fi} **= 0.7**. For RFR = 120 min and μ_{fi} **= 0.7**, the verifying of the fire resistance depend on the finish to maintain the minimal dimensions from NBR 6118:2003.
The NBR 15200:2004 is applicable to the cast-in-place and precast concrete members. In this paper, only the concrete structural members contemplated by NBR 6118:2003 were evaluated in a just comparative analysis. For the precast concrete members, the minimal dimensions of the cross-section and the cover given by NBR 15200:2004 should be compared to those given by NBR 9062:2001
The Table 4.13 and Table 4.14 summarize the results from the comparison between the minimal dimensions required by NBR 15200:2004 and NBR 6118:2003 for solid slabs, beams, columns, and load-bearing wall.

Table 4.12 – Factors for combination value of the variable actions (NBR 8681:2003).

Occupation	$\psi_{2,j}$
Places with predominance neither of weight of devices staying fixed for long-term, nor high concentration of people (residential building).	0.21
Places with predominance either of weight of devices staying fixed for long-term or high concentration of people (office building).	0.28
Libraries, storages, automotive services and garages.	0.42
Wind loads on structures in general	0

Table 4.4 – Minimal dimensions for simply supported solid slabs reinforced and prestressed concrete (normal density) given by NBR 6118:2003 and NBR 15200:2004.

NBR 6118:2003 minimal thickness of the slab h_{slab}* (mm) – type (occupation) of slab ❶	❷	❸	❹	❺	NBR 6118:2003 class of environmental aggressivity I low c_{min} (mm)	I low c_{1min} † (mm)	II moderate c_{min} (mm)	II moderate c_{1min} † (mm)	III strong c_{min} (mm)	III strong c_{1min} † (mm)	IV very strong c_{min} (mm)	IV very strong c_{1min} † (mm)	NBR 15200:2004 RFR (minutes)	h_{slab}* (mm)	c_1 (mm) two-way spaning $\frac{\ell_y}{\ell_x} \leq 1{,}5$	c_1 (mm) two-way spaning $1{,}5 < \frac{\ell_y}{\ell_x} \leq 2$	c_1 (mm) one-way spaning
50	70	100	120	150	20	25	25	30	35	40	45	50	30	60	10	10	10
													60	80	10	15	20
													90	100	15	20	30
													120	120	20	25	40

Legend:
❶ for non-cantilever roof
❷ for cantilever floor or roof
❸ for supporting vehicles with weight up to 30 kN
❹ for supporting vehicles with weight over to 30 kN
❺ for prestressed slabs

* Minimal dimensions to assure the fire barrier function.

†$c_{1min} \approx c_{min} + 5$ mm (NBR 6118:2003 gives only the minimal covers "c_{min}")

Table 4.5 – Minimal dimensions for flat slabs in reinforced and prestressed concrete (normal density) given by NBR 6118:2003 and NBR 15200:2004.

NBR 6118:2003 minimal thickness of the slab h_{slab}* (mm) – plate	mushroom	NBR 6118:2003 class of environmental aggressivity I low c_{min} (mm)	I low c_{1min} † (mm)	II moderate c_{min} (mm)	II moderate c_{1min} † (mm)	III strong c_{min} (mm)	III strong c_{1min} † (mm)	IV very strong c_{min} (mm)	IV very strong c_{1min} † (mm)	NBR 15200:2004 RFR (min)	h_{slab}* (mm)	c_1 (mm)
160	140	20	25	25	30	35	40	45	50	30	150	10
										60	180	15
										90	200	25
										120	200	35

* Minimal dimensions to assure the fire-barrier function.

†$c_{1min} \approx c_{min} + 5$ mm (NBR 6118:2003 gives only the minimal covers "c_{min}")

Table 4.6: Minimal dimensions for simply supported ribbed slabs reinforced and prestressed concrete (normal density) given by NBR 6118:2003 and NBR 15200:2004.

NBR 6118:2003																			NBR 15200:2004								
rib										b_{min}†† (mm)	rib								RFR (min)	rib						slab*	
h‡ (mm)		class of environmental aggressivity									class of environmental aggressivity									arrangements between b_{min} †† e c_1							
♪ withoud ducts	♫ with embedded ducts	I low		II moderated		III strong		IV very strong			I low		II moderated		III strong		IV very strong			1		2		3		4	
		c_{min} (mm)	c_{1min} † (mm)	c_{min} (mm)	c_{1min} † (mm)	c_{min} (mm)	c_{1min} † (mm)	c_{min} (mm)	c_{1min} † (mm)		c_{min} (mm)	c_{1min} † (mm)	c_{min} (mm)	c_{1min} † (mm)	c_{min} (mm)	c_{1min} † (mm)	c_{min} (mm)	c_{1min} † (mm)	b_{min} (mm)	b_{min} (mm)	c_1 (mm)	b_{min} (mm)	c_1 (mm)	b_{min} (mm)	c_1 (mm)	h‡ (mm)	c_1 (mm)
30	40	20	25	25	30	35	40	45	50	50	20	35	30	40	40	50	50	60	30	80	15	-	-	-	-	80	30
																			60	100	35	120	25	190	15	80	60
										80									90	120	45	160	40	250	30	100	90
																			120	160	60	190	55	300	40	120	120

* Minimal dimensions to assure the fire barrier function.

†$c_{1min} \approx c_{min} + 5$ mm (NBR 6118:2003 gives only the minimal covers "c_{min}")

†† b_{min} is the minimal width of the ribs; ribs with width b < 80 mm should not have compression reinforcement.

‡h is the thickness of the slab.

♪ h should be more then 1/15 of the distances between the ribs.

♫ h ≥ maximum diameter of the embedded ducts should be 12,5 mm.

Table 4.7: Minimal dimensions for ribbed slabs reinforced and prestressed concrete (normal density) with at least one restrained edge given by NBR 6118:2003 and NBR 15200:2004.

NBR 6118:2003											NBR 15200:2004																
rib										b_{min} †† (mm)	rib								RFR (min)	rib						slab*	
h‡ (mm)		class of environmental aggressivity									class of environmental aggressivity									arrangements between b_{min} †† e c_1							
♪ withoud ducts	♫ with embedded ducts	I low		II moderated		III strong		IV very strong			I low		II moderated		III strong		IV very strong			1		2		3		4	
		c_{min} (mm)	c_{1min} † (mm)	c_{min} (mm)	c_{1min} † (mm)	c_{min} (mm)	c_{1min} † (mm)	c_{min} (mm)	c_{1min} † (mm)		c_{min} (mm)	c_{1min} † (mm)	c_{min} (mm)	c_{1min} † (mm)	c_{min} (mm)	c_{1min} † (mm)	c_{min} (mm)	c_{1min} † (mm)	b_{min} (mm)	b_{min} (mm)	c_1 (mm)	b_{min} (mm)	c_1 (mm)	b_{min} (mm)	c_1 (mm)	h‡ (mm)	c_1 (mm)
30	40	20	25	25	30	35	40	45	50	50	20	35	30	40	40	50	50	60	30	80	10	–	–	–	–	80	10
																			60	100	25	120	15	190	10	80	10
										80									90	120	35	160	25	250	15	100	15
																			120	160	45	190	40	300	30	120	20

* Minimal dimensions to assure the fire barrier function.

†$c_{1mín} \approx c_{mín}$ + 5 mm (NBR 6118:2003 gives only the minimal covers "c_{min}")

†† $b_{mín}$ is the minimal width of the ribs; ribs with width b < 80 mm should not have compression reinforcement.

‡h is the thickness of the slab.

♪ h should be more then 1/15 of the distances between the ribs.

♫ h ≥ maximum diameter of the embedded ducts should be 12,5 mm.

Table 4.8: Minimal dimensions for simply supported beams in reinforced and prestressed concrete (normal density, siliceous aggregates) given by NBR 6118:2003 and NBR 15200:2004.

NBR 6118:2003									NBR 15200:2004									
minimal width $b_{mín}$ (mm)	Classes de agressividade ambiental								TRRF (minutos)	possíveis combinações entre $b_{mín}$ e $c_{1mín}$								
	I fraca		II moderada		III forte		IV muito forte			1		2		3		4		$bw_{mín}$ (mm)
	$c_{mín}$ (mm)	$c_{1mín}$ † (mm)	$c_{mín}$ (mm)	$c_{1mín}$ † (mm)	$c_{mín}$ (mm)	$c_{1mín}$ † (mm)	$c_{mín}$ (mm)	$c_{1mín}$ † (mm)		$b_{mín}$ (mm)	$c_{1mín}$ (mm)	$b_{mín}$ (mm)	$c_{1mín}$ (mm)	$b_{mín}$ (mm)	$c_{1mín}$ (mm)	$b_{mín}$ (mm)	$c_{1mín}$ (mm)	
120	25	35	30	40	40	50	50	60	30	80	25	120	20	160	15	190	15	80
									60	120	40	160	35	190	30	300	25	100
100‡									90	190	55	190	45	300	40	400	35	100
									120	200	65	240	60	300	55	500	50	120

‡For the special cases, regarding the established situations by the item 13.2.2 of NBR 6118:2003.

†$c_{1mín} \approx c_{mín}$ + 10 mm (NBR 6118:2003 given only the minimal covers "c_{min}")

Table 4.9: Minimal dimensions for continuous beams in reinforced and prestressed concrete (normal density, siliceous aggregates) given by NBR 6118:2003 and NBR 15200:2004.

NBR 6118:2003										NBR 15200:2004						
minimal width $b_{mín}$ (mm)	class of environmental aggressivity								TRRF (minutos)	possible arrangements between $b_{mín}$ e $c_{1mín}$						
	I low		II moderated		III strong		IV very strong			1		2		3		$bw_{mín}$ (mm)
	$c_{mín}$ (mm)	$c_{1mín}$ † (mm)	$c_{mín}$ (mm)	$c_{1mín}$ † (mm)	$c_{mín}$ (mm)	$c_{1mín}$ † (mm)	$c_{mín}$ (mm)	$c_{1mín}$ † (mm)		$b_{mín}$ (mm)	$c_{1mín}$ (mm)	$b_{mín}$ (mm)	$c_{1mín}$ (mm)	$b_{mín}$ (mm)	$c_{1mín}$ (mm)	
120	25	35	30	40	40	50	50	60	30	80	15	160	12	190	12	80
									60	120	25	190	12	300	12	120
100‡									90	140	35	250	25	400	25	140
									120	200	45	300	35	450	35	200

‡For the special cases, see item 13.2.2 of NBR 6118:2003.

†$c_{1mín} \approx c_{mín}$ + 10 mm (NBR 6118:2003 gives only the minimal covers "$c_{mín}$")

Table 4.10: Minimal dimensions for columns in reinforced concrete (normal density, siliceous aggregates) given by NBR 6118:2003 and NBR 15200:2004.

NBR 6118:2003										NBR 15200:2004							
minimal width $b_{mín}$ (mm)	class of environmental aggressivity								RFR (min)	possible arrangements between $b_{mín}$ e $c_{1mín}$							
	I low		II moderated		III strong		IV very strong			more than 1 exposed side						1 exposed side	
										$\mu_{fi} = 0{,}2$		$\mu_{fi} = 0{,}5$		$\mu_{fi} = 0{,}7$		$\mu_{fi} = 0{,}7$	
	$c_{mín}$ (mm)	$c_{1mín}$ † (mm)	$c_{mín}$ (mm)	$c_{1mín}$ † (mm)	$c_{mín}$ (mm)	$c_{1mín}$ † (mm)	$c_{mín}$ (mm)	$c_{1mín}$ † (mm)		$b_{mín}$ (mm)	$c_{1mín}$ (mm)	$b_{mín}$ (mm)	$c_{1mín}$ (mm)	$b_{mín}$ (mm)	$c_{1mín}$ (mm)	$b_{mín}$ (mm)	$c_{1mín}$ (mm)
190‡	25	35	30	40	40	50	50	60	30	190	25	190	25	190	30	140	25
									60	190	25	190	35	250	45	140	25
									90	190	30	300	45	450	40	155	25
									120	250	40	350	45	450	50	175	35

‡ For the special cases, 120 mm ≤ b < 190 mm (see item 13.2.3 from NBR 6118:2003).

†$c_{1mín} \approx c_{mín}$ + 10 mm (NBR 6118:2003 gives only the minimal covers "$c_{mín}$")

Legend:

$$\mu_{fi} = \frac{N_{Sd,fi}}{N_{Rd}}$$, where:

$N_{Sd,fi}$ = design axial load in fire situation, calculated by the actions arrangement for accidental situations (considering only the axial load and neglecting the bending)

N_{Rdi} = design resistant axial load at room temperature, calculated by actions arrangement for normal services.

Table 4.11: Minimal dimensions for load-bearing wall in reinforced concrete (normal density, siliceous aggregates) given by NBR 6118:2003 and NBR 15200:2004.

NBR 6118:2003									NBR 15200:2004								
minimal width $b_{mín}$ (mm)	Classes de agressividade ambiental								RFR (min)	possible arrangements between $b_{mín}$ e $c_{1mín}$							
	I low		II moderated		III strong		IV very strong			1 exposed side		2 exposed sides		1 exposed side		2 exposed sides	
										μ_{fi} = 0,35				μ_{fi} = 0,7			
	$c_{mín}$ (mm)	$c_{1mín}$ † (mm)	$c_{mín}$ (mm)	$c_{1mín}$ † (mm)	$c_{mín}$ (mm)	$c_{1mín}$ † (mm)	$c_{mín}$ (mm)	$c_{1mín}$ † (mm)		$b_{mín}$ (mm)	$c_{1mín}$ (mm)	$b_{mín}$ (mm)	$c_{1mín}$ (mm)	$b_{mín}$ (mm)	$c_{1mín}$ (mm)	$b_{mín}$ (mm)	$c_{1mín}$ (mm)
190‡	25	35	30	40	40	50	50	60	30	100	10	120	10	120	10	120	10
									60	110	10	120	10	130	10	140	10
									90	120	20	140	10	140	25	170	25
									120	140	25	160	25	160	35	220	35

‡ For the special cases, 120 mm ≤ b < 190 mm (see item 13.2.3 from NBR 6118:2003).
Note: The load-bearing wall is a column, whose the high is equal or superior to 5 times the width.

Legend:

$$\mu_{fi} = \frac{N_{Sd,fi}}{N_{Rd}}$$, where:

$N_{Sd,fi}$ = design axial load in fire situation, calculated by the actions arrangement for accidental situations (considering only the axial load and neglecting the bending)

N_{Rdi} = axial resistant load at room temperature, calculated by actions arrangement for normal services.

5 Concluding remarks

The applying of the standard NBR 15200:2004 is integrated to the NBR 14432:2000, and the IT 08:2004 in the State of Sao Paulo, which rules the minimal required fire resistance of the buildings according to the compartment size and occupation.
The directions of both standards NBR 15200:2004 and NBR 6118:2003 were compared in a just analysis. Most of usual concrete members designed with the minimal dimensions and covers established for the design at room temperature have verified the fire resistance for the RFR ≤ 60 min, excluding only some special cases. For RFR = 90 min., the usual dimensions depend on the finish, the class of environmental aggressivity, and the load level (columns and load-bearing walls).
For the buildings with severe fire risks (RFR = 120 min), the usual dimensions are under to the minimal dimensions required to assure the fire resistance. The Time Equivalent Method may be suitable to these cases, with no structural damage, once that the active (automatic sprinklers, smoke detectors, brigades, etc.) and passive (compartmenting, escape routes, etc.) fire protection can assume part of the required fire resistance indirectly.

6 Acknowledgements

The authors acknowledge the Brazilian foundations CAPES – Coordenadoria de Aperfeiçoamento de Pessoal do Ensino Superior, and CNPq – Conselho Nacional de Desenvolvimento Científico e Tecnológico by supporting this research; and the School of Mechanical, Aerospace and Civil Engineering of The University of Manchester Institute of Science and Technology (UMIST), Manchester – U.K., by availability of the library and equipments necessary to the edition of this paper.

Table 4.13 – Results of the comparison between the NBR 6118:2003 and NBR 15200:2004 for slabs and beams in concrete (normal density and siliceous aggregates).

	Solid slabs					Beams	
RFR (min.)	non-cantilever roof	cantilever floor or roof	supporting vehicles with weight up to 30 kN	supporting vehicles with weight over to 30 kN	prestressed slabs	simply supported	continuous
30	👍	👍	👍	👍	👍	👍	👍
60	👎	f	👍	👍	👍	👍***	👍
90	👎	👎	👍	👍*	👍*	👎	f
120	👎	👎	f	👍**	👍**	👎	👎

Legenda 👍 = satisfy to the minimal dimensions given by NBR 15200:2004, with no finish;

👎 = do not satisfy the minimal dimensions given by NBR 15200:2004, requiring dimensional change dimensional;

f = satisfy to the minimal dimensions given by NBR 15200:2004 providing adding the finish (total in both sides) of mortar of cement and sand or other, with thickness of 2 cm at least (Table 4.3);

* except one-way spanning slabs from the class of environmental aggressivity "I" (NBR 6118:2003);

** except one-way spanning slabs from the class of environmental aggressivity "I" or "II" (NBR 6118:2003);

*** except from the class of environmental aggressivity "I" (NBR 6118:2003).

Table 4.14 – Results from the comparison between NBR 6118:2003 and NBR 15200:2004 for columns and load-bearing walls in concrete of normal density (siliceous aggregate).

RFR (min.)	Pilar				Pilar-parede		
	1 face exposta	mais de 1 face exposta			1 face exposta	mais de 1 face exposta	
	$\mu_{fi} \leq 0{,}7$	$\mu_{fi} \leq 0{,}2$	$\mu_{fi} \leq 0{,}5$	$\mu_{fi} \leq 0{,}7$	$\mu_{fi} \leq 0{,}7$	$\mu_{fi} = 0{,}35$	$\mu_{fi} = 0{,}7$
30	👍	👍	👍	👍	👍	👍	👍
60	👍	👍	👍	👎	👍	👍	👍
90	👍	👍	👎	👎	👍	👍	👍
120	👍	👎	👎	👎	👍	👍	f

Legend: μ_{fi} = level load of the column (equation 7.2);

👍 = satisfy to the minimal dimensions given by NBR 15200:2004, with no finish;

👎 = do not satisfy the minimal dimensions given by NBR 15200:2004, requiring dimensional change dimensional;

f = satisfy to the minimal dimensions given by NBR 15200:2004 providing adding the finish (total in both sides) of mortar of cement and sand or other, with thickness of 2 cm at least (Table 4.3).

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