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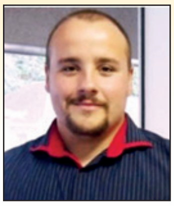
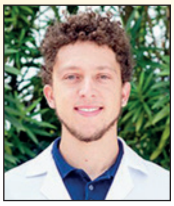
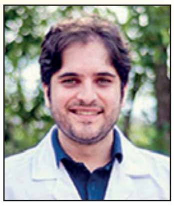
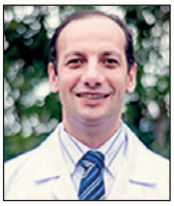
Case study: influence of performance levels of ABNT NBR 15575 without consumption of materials used in reinforced concrete structures

Estudo de caso: influência dos níveis de desempenho da ABNT NBR 15575 no consumo de materiais utilizados em estruturas de concreto armado

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Abstract

The Brazilian construction industry still discusses the consequence of the Performance Standard on housing developments. According to ABNT NBR 15575 [1], the systems that compose residential buildings need to meet minimum performance requirements. Among the systems, the structural must reach a minimum Service Life (SL) of 50 years, or intermediate or higher that corresponds to 63 and 75 years, respectively. The industry also debates the impact and viability of increasing the SL of reinforced concrete structures. Therefore, this article aimed to analyze a single reinforced concrete building designed for the 3 SL specified by ABNT NBR 15575 [1]. The study focused on the total consumption of steel and concrete. The structure's designed conditions of exposure were varied for each performance level, based on the 4 environmental exposure classes (EEC) of ABNT NBR 6118 [3] and ABNT NBR 12655 [11], totalizing 12 situations. It was noted that the increased performance level increases consumption of materials, and the designs made for EEC IV consumed 12.3% and 16.2% more steel and concrete at the intermediate and superior performance levels respectively, when compared to the minimum performance level.

Keywords: brazilian performance standard, concrete strcuture, service life.

Resumo

O setor da construção civil ainda discute a consequência da Norma de Desempenho nas edificações habitacionais. Segundo a ABNT NBR 15575 [1], os sistemas que compõem edificações residenciais necessitam atingir os requisitos mínimos de desempenho. Dentre os sistemas, o estrutural deve atender a uma Vida Útil de Projeto (VUP) mínima de 50 anos, ou intermediária ou superior, correspondendo à 63 e 75 anos, respectivamente. É debatido no setor o impacto e a viabilidade do incremento da VUP nas estruturas de concreto armado. Diante disso, esse artigo objetivou analisar uma mesma edificação em concreto armado projetada para as 3 VUPs contempladas pela ABNT NBR 15575 [1]. O estudo concentrou-se no consumo total de aço e concreto. Para cada nível de desempenho, variaram-se as condições de exposição da estrutura para o dimensionamento, com base nas 4 classes de agressividade ambiental (CAA) da ABNT NBR 6118 [3] e ABNT NBR 12655 [11], totalizando 12 situações. Verificou-se que o incremento do nível de desempenho aumenta o consumo dos materiais, sendo que os projetos elaborados para a CAA IV tiveram um consumo de 12,3% e 16,2% de aço e concreto superior para os níveis intermediário e superior de desempenho, respectivamente, comparando com o nível mínimo de desempenho.

Palavras-chave: norma de desempenho, estruturas de concreto armado, vida útil de projeto.

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1. Introduction

The Brazilian construction industry has shown notorious reactions to the implementation of ABNT NBR 15575 [1]. The standard determines minimum performance requisites that must be applied to systems that make up housing developments to meet requirements of habitability, safety and sustainability [2]. For each requirement, the standard defines minimum, intermediate and superior performance levels, with direct consequences to their stages of use. Among these concepts is the SL, the minimum timespan that systems must remain meeting the performance of design. For reinforced concrete structures, the SL that the system must achieve is related to the performance level sought, which is presented in the performance standard [1].
Since ABNT NBR 15575 is not prescriptive, the performance requirements must be satisfied based on the design standards to which the structure is subjected. The standards adopted for reinforced concrete are ABNT NBR 6118 [3], ABNT NBR 6120 [4], ABNT NBR 8681 [5], ABNT NBR 6123 [6], and others. Except for ABNT NBR 6123 [6], the other standards prescribe requirements for a SL of 50 years [7]. To that end, foreign standards or technical studies with fundament must be consulted to reach intermediate and superior levels as they allow the adoption of consistent design criteria. Hence studies such as Bolina *et al*. [7] and Bolina and Tutikian [8,9] serve as starting point for more sophisticated analyses that strive for SL values above the minimum that have not been defined by Brazilian standards yet.
Concerning durability, the design parameters must contemplate external environmental agents. According to Tutikian and Helene [10], the durability of concrete structures depends on extrinsic factors such as the presence of salts, sea sprays, acid rain, and intrinsic factors, among which are the cement type, water-cement ratio, additions and admixtures. As presented by ABNT NBR 12655 [11] and, if the criteria set by ABNT NBR 6118 [3] have been met, the structures' durability depends directly on the characteristics of concrete and its surroundings. Due to correlations between the structure's characteristics and the concrete used, ABNT NBR 6118 [3] recommends the adoption of specific requirements to achieve the minimum durability prescribed. Bolina and Tutikian [8] assume that the recommendations of this standard regard a SL of 50 years. This assumption is based on ABNT NBR 8681 [5], which proposes increase factors for the combination of loads admitted for the period of 50 years. Thus, designs that seek to surpass the minimum performance level require an analysis of the design parameters of ABNT NBR 6118 [3].
Pertaining the loads admitted in the structural design, permanent loads do not change over time, so they do not change with respect to the SL sought [12]. On the other hand, accidental loads, or imposed loads, vary during service life and must be analyzed for performances levels that surpass the minimum. Because these loads vary over time, the Brazilian standard, ABNT NBR 8681 [5], suggests characteristic values that have from 25 to 35% of probability of occurring over a period of 50 years, disregarding any consideration for response times of 63 and 75 years to these actions [7].
As for wind action, ABNT NBR 6123 [6] states that it is necessary to use zones proposed when defining the wind speeds of each region. The values of the zones consider wind blasts of 3 seconds with 63% of probability of occurring once every 50 years. When a structure is designed to surpass the minimum performance levels, specific equations to determine the base wind speed must be used, as show in Attachment B of that standard.
It is then noted that the Brazilian system of standards applied to structural design still cannot deplete the requirements of ABNT NBR 15575 [1] for a SL of over 50 years. Regarding the costs, next to 40% of the total resources of the industry and 35% of construction works are directed towards repair of structures in an attempt to increase their SL [13, 14]. However, the structural design does not hold information on the additional cost to reach performance levels above the minimum, that is, to increase SL. Therefore, this study

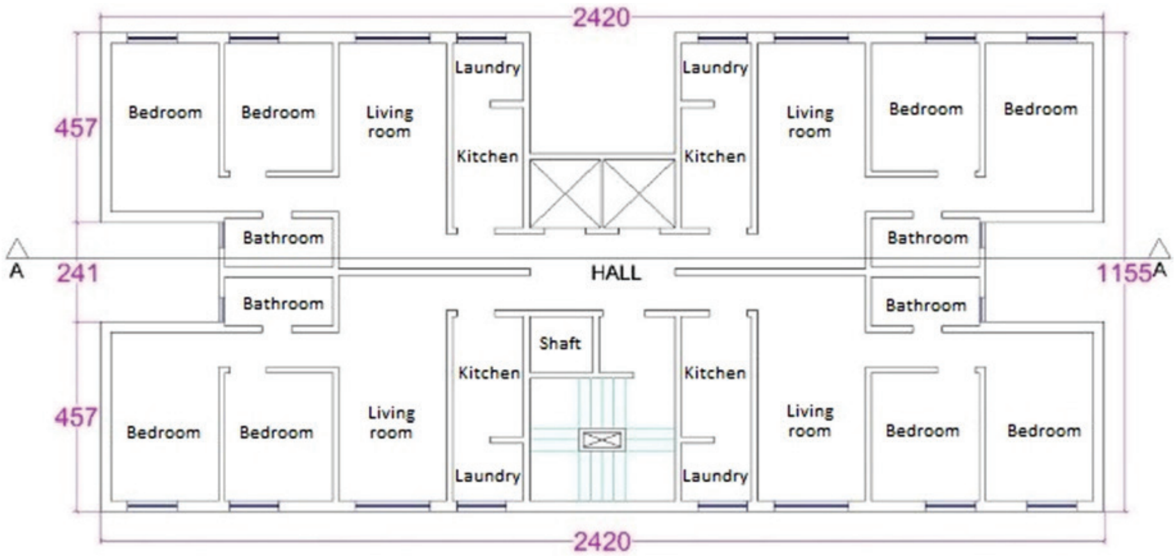

Figure 1
Plan view of the architectural design of the typical floor

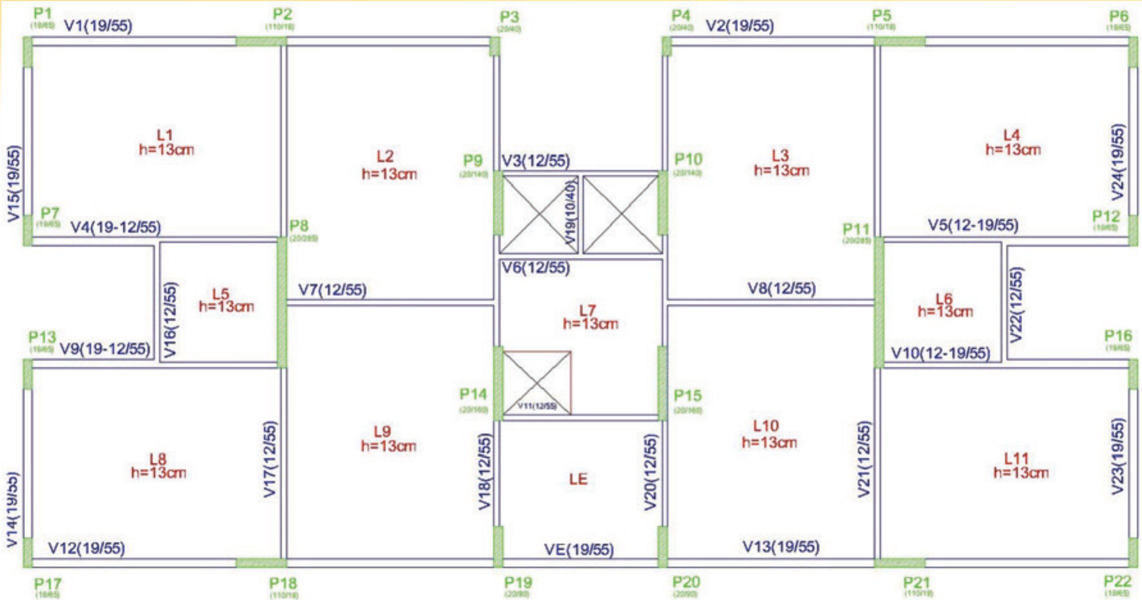

Figure 2
Plan view of the formwork of the typical floor

aims to dimension a single structure, namely a single hypothetical building, for the 3 performance levels prescribed in standard, using the 4 environmental exposure classes (EEC) of NBR 6118 [3], totalizing 12 designs, to assess the additional amount of materials incorporated to the system. The impact the performance level has on the amount materials of design of reinforced concrete structures was based on the concrete volume analysis and the total consumption of steel from reinforcements.

The variables considered for each project were: reinforcement cover thickness and compressive strength of concrete as durability parameters; and the magnitude of variable actions – including the wind – and their respective weighting coefficients as parameters of safety and structural dimensioning.

2. Experimental procedures

The criteria and parameters adopted for the 12 structural designs developed are presented as follows.

2.1 Design

The object of study is an architectural design of a residential building with nine floors. In total, 8 floors are leveled and one is the ground floor. Each leveled floor had area of 255.62 m², with 4 apartments with two bedrooms, living room, kitchen, laundry and bathroom, depicted in Figure 1. On the ground floor stood the halls, corridors and commercial spaces, with the same area as the other floors.

The reinforced concrete structure is made of solid slabs, rectangular beams with spans of two to six meters, with ceiling height of 2.95 m between floors. The column placement was analyzed and determined as to contribute to the stiffness of the building. The beams bore loads from masonry walls, with sealing function and thickness of 12 cm and 14 cm for exterior and interior walls respectively. The structure was calculated with the computer-aided simulation software, Eberick® version 10, which informed the amount of materials of each project.

During the dimensioning of structural elements, a degree of utilization next to 100% was sought. For the main reinforcements, type CA-50 steel was used, whereas the stirrups were made of type CA-60 steel. The 12 structural designs followed the same architectural design, keeping the placement of structural element and the preset areas of utilization, as per Figure 2. The simulation models remained unchanged.

2.2 Procedure

In order to reach the goal of this study, the baseline design was dimensioned for each one of 4 EECs defined by ABNT NBR 6118 [3]

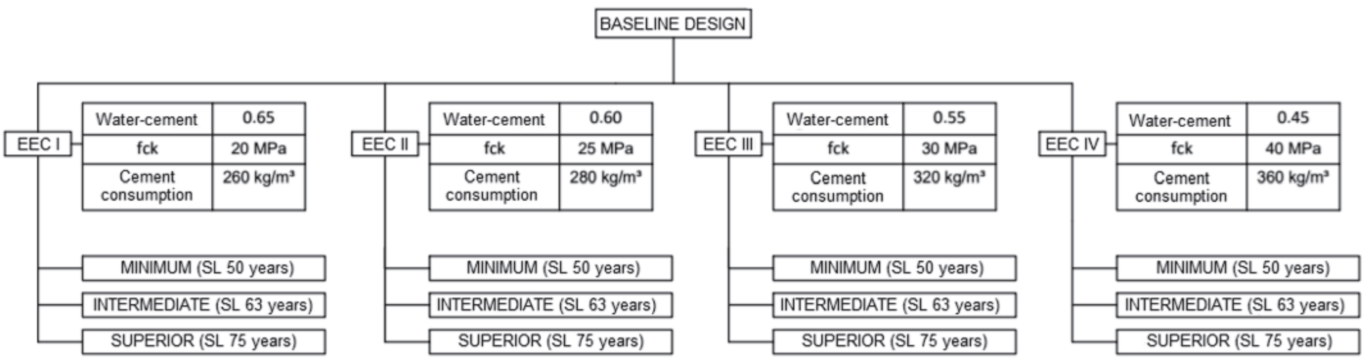

Figure 3
Project flow chart

Table 1
Load values proposed for minimum, intermediate and superior performance of service life of durability for residential buildings

Type	Description	Load (kN/m²) SL (years) 50	63	75
Residential buildings	Bedrooms, living room, pantry, kitchen e bathroom	1.50	1.55	1.57
	Larder, service area and laundry	2.00	2.05	2.09
Stairs	With public access	3.00	3.08	3.10
	No public access	2.50	2.26	2.61
Balconies	No public access	2.00	2.06	2.09
	With public access	3.00	3.08	3.13
	Inaccessible to people	0.50	0.51	0.52

and ABNT NBR 12655 [11]. The design variables were compressive strength, reinforcement cover and the magnitude of imposed loads and wind. Each EEC was subjected to dimensioning to the three performance levels of ABNT NBR 15575 [1], being them minimum, intermediate and superior. The flowchart of Figure 3 depicts the procedure undertaken.

2.3 Loads considered

Presuming that the building does not change, it was assumed that the weight of the structure itself does not change over time. The base for imposed loads was provided by Bolina and Tutikian [8], who had determined increase factors for accidental loads of a building when the intended service life is 63 and 75 years, that is, the intermediate and superior performance levels. Table 1 shows the values of variable actions for each SL mentioned in ABNT NBR 15575 [1].
The reference wind speed of design was defined in accordance with ABNT NBR 6123 [6]. For the topographic factor S1, a building on a flat terrain was considered, whose factor is equals 1. For factor S2, which contemplates terrain roughness and building size, the structure was graded class B as it presented the highest and lowest front dimension of wind action between 20 m and 50 m, and category V, which regards terrains covered by several big, tall obstacles with little space in-between, with factor equals 0.95. Lastly, statistical factor S3, minding that the building has residential use, was assumed to be equals 1. For periods that surpass 50 years, ABNT 6123 [6] presents in its Attachment B a statistical method that corrects factor S3 with respect to the 3-seconds return period of wind blasts, consequently changing the reference wind speed extracted from the zones, which is valid for a return period of 50 years. Applying the standard to SL of 63 and 73 years yielded S3 factors of 1.04 and 1.06 respectively. Therefore, considering the reference wind speed of 45 m/s (Region V) as the zones of the standard depict, Table 2 presents the design corrections proper to intermediate and superior performance levels.

Table 2
Reference wind speed for each SL

SL (years)	Base wind speed (v_0) 50	63	75
S1	1.00	1.00	1.00
S2	0.95	0.95	0.95
S3	1.00	1.04	1.06
v_0 (m/s)	45.00	46.80	47.70

2.4 Durability parameters

The durability parameters for ages higher than 50 years were defined after Bolina and Tutikian [8], who had used theoretical SL prediction models adjusted by the parameters of ABNT NBR 6118 [3], and foreign standards to extrapolate the service lives of 63 and 75 years, as per Table 3. It should be noted that, for the sake of the structural designs of this article, only reinforcement cover thickness and class of concrete strength were influential.

Table 3
Structural dimensioning parameters for durability for SL of 50, 63 and 75 years

EEC		I			II			III			IV		
SL (years)		50	63	75	50	63	75	50	63	75	50	63	75
Slab	C	20	25	30	25	35	40	35	45	50	45	55	65
	CR	C20	C25	C30	C20	C35	C40	C30	C40	C40	C40	C50	C50
	AC	0.65	0.60	0.60	0.60	0.50	0.50	0.55	0.45	0.40	0.45	0.40	0.40
	CC	260	280	280	280	300	340	320	340	360	360	360	380
Beam/Column	C	25	30	35	30	40	45	40	50	55	50	60	70
	CS	C20	C25	C30	C25	C35	C40	C30	C40	C40	C40	C50	C50
	WC	0.65	0.60	0.60	0.60	0.50	0.5	0.55	0.45	0.40	0.45	0.40	0.35
	CC	260	280	280	280	300	340	320	340	360	360	360	380
Elements in contact with the ground	C	30	30	40	30	40	45	40	50	55	50	60	70
	CS	C20	C25	C30	C25	C35	C40	C30	C40	C40	C40	C50	C50
	WC	0.65	0.60	0.60	0.60	0.50	0.45	0.55	0.45	0.40	0.45	0.35	0.35
	CC	260	280	280	280	300	340	320	340	360	360	360	380

C = cover (mm); CS = class of concrete strength; WC = water-cement ratio; CC= cement consumption (kg/m³)

Table 4
Comparison of material consumption for slabs

EEC		I			II			III			IV		
SL (years)		50	63	75	50	63	75	50	63	75	50	63	75
Steel consumption (kg)	CA50	8570	8216	9950	8570	10196	11589	10259	11592	12660	11529	12259	14027
	CA60	817	1119	47	817	30	45	29	404	44	413	642	39
	Total	9387	9335	9997	9387	10227	11633	10337	11996	12704	11942	12900	14066
Change in consumption (%)		0	-1	6.5	0	8.9	23.9	0	16.0	22.9	0	8.0	17.8
Class of concrete strength		C20	C25	C30	C25	C35	C40	C35	C40	C40	C40	C50	C50
Concrete volume (m³)		279	279.1	278.6	279	278.2	277.7	277	277.2	276.9	277.6	318.7	337.6
Change in consumption (%)		0	0	-0.2	0	-0.3	-0.5	0	0.1	0.0	0	14.8	21.6
Steel consumption (kgf/m³)		33,6	33.4	35.9	33.6	36.8	41.9	37.1	43.3	45.9	43	40.5	41.7

3. Results and discussions

3.1 Slabs

Table 4 presents, for the 4 EECs of ABNT NBR 6118 [3], a comparison of consumption of steel and concrete for slabs under different performance levels.

The increased reinforcement cover thickness, which is required to increase the performance level of the piece, did not provoke the remodeling of its geometry except for EEC IV. Since the areas of slabs were higher than those of beams and columns, these elements, when remodeling was needed, presented considerable increases of concrete consumption, reaching over 20% for the superior performance level of EEC IV.

When concrete consumption is stable, the loads generated by the increase of its own weight do not change and do not impact steel consumption. Therefore, the same initial thickness of the element (13 cm) was preserved. A slab with SL 75 years to EEC III loses about 15.8% of its usable height when compared to the minimum performance, hence influencing the increase of area of steel required.

Slabs are subjected to bending moments and have longitudinal fibers in their rigid body that bear tensile and compressive stresses whose magnitudes vary according the circumstances of load and the element itself. Due to the low tensile strength of concrete, increasing compressive strength to comply with the durability parameter did not cause considerable effects to the stiffening of the piece on the stressed fibers.

Due to their slenderness and the type of stress borne, the slabs were sensitive to load changes. Hence, the increase of load related to SL, enhanced by the approximation of the reinforcement to the neutral axis in view of the increased cover thickness, causes the area of steel of the pieces to increase. For EEC III, increasing SL to 63 years changed steel consumption by 16.0%. Comparing the least and most intense situations, EEC I and SL 50 years versus EEC IV and SL 75 years, steel consumption was 50% higher in the worse condition. The choice of performance level of reinforced concrete structures can then be decisive to the costs of the structure.

When EEC I is analyzed separately, though, it demonstrates that the increased steel consumption did not occur proportionately. Seeing that the load increased along with SL, no matter the EEC, and that cement consumption did not vary for EEC I, EEC II and EEC III, the disparity of the increased steel consumption took place from the usable height of the piece.

3.2 Beams

Table 5 compares the consumption of materials for beams among the multitude of performance levels and EEC.

Aiming to preserve the minimum bar spacing dictated by ABNT NBR 6118 [3], the elements had to be remodeled due to the variation of usable thicknesses. It is clear that, as SL and EEC increased, the requirements became stricter and pieces demanded an increase of material consumption. Comparing the most and least favorable conditions, namely EEC I and SL 50 years versus EEC IV and SL 75 years, the differences reached 33.0% for

Table 5
Comparison of material consumption for beams

EEC		I			II			III			IV		
SL (years)		50	63	75	50	63	75	50	63	75	50	63	75
Steel consumption (kg)	CA50	8217	8358	8368	8111	8001	8262	7878	8355	8522	8038	8738	9510
	CA60	1508	1503	1660	1505	1829	1878	1979	1863	1949	1841	2143	2389
	Total	9725	9862	10028	9616	9830	10140	9857	10218	10471	9879	10881	11899
Change in consumption (%)		0	1.4	3.1	0	2.2	5.4	0	3.7	6.2	0	10.1	20.4
Class of concrete strength		C20	C25	C30	C25	C40	C40	C40	C40	C40	C40	C50	C50
Concrete volume (m³)		148.1	148.1	154.9	148.1	157.9	164.8	159.7	168.3	174.6	165.5	179.5	197
Change in consumption (%)		0	0	4.6	0	6.6	11.3	0	5.4	9.3	0	8.5	19.0
Steel consumption (kgf/m³)		65.7	66.6	64.7	64.9	62.2	61.5	58.3	60.7	60	59.7	60.6	60.4

Table 6
Comparativo de consumo de materiais nos pilares

EEC		I			II			III			IV		
SL (years)		50	63	75	50	63	75	50	63	75	50	63	75
Steel consumption (kg)	CA50	6730	6934	6253	6595	6026	6016	6027	6023	6013	6023	5938	5930
	CA60	3402	3240	3220	3429	3067	3002	3061	2920	2854	2917	2773	2650
	Total	10132	10174	9473	10024	9093	9018	9137	8943	8867	8939	8712	8580
Change in consumption (%)		0	0.4	-6.5	0	-9.3	-10.0	0	-2.1	-3.0	0	-2.5	-4.0
Class of concrete strength		C20	C25	C30	C25	C40	C40	C40	C40	C40	C40	C50	C50
Concrete volume (m³)		138.2	138.2	138.2	138.2	138.2	138.2	138.2	138.2	138.2	138.2	138.2	141.0
Change in consumption (%)		0	0	0	0	0	0	0	0	0	0	0	2.0
Steel consumption (kgf/m³)		73.3	73.6	68.6	72.5	65.8	65.3	65.8	64.7	64.2	64.7	63.0	60.8

concrete. The slabs turned out to be more sensitive than the beams under harsher conditions, even if both elements were subjected to tensile stresses.
The dimensions of the piece were increased on the base of their cross-section without changing their stiffness for tensile stresses, as in the increase of usable height. Still, considering the increased characteristic strength of concrete, the bigger dimension made the piece stiffer. In the end, the rate of steel per cubic meter was lower as the SL of EEC I and II increased, whereas the rate of reinforcements of EEC III and IV increased.
Nevertheless, the reduction at EEC I and II was a consequence of the increased concrete volume. When analyzed alone, steel consumption grew as the EEC and SL increased because the weight of slabs and beams and the imposed loads grew as well. Added to the reinforcement displacement and the reduction of usable height, steel consumption achieved an increase of up to 20.4% for EEC IV for SL 75 years.

3.3 Columns

Table 6 compares the consumption of materials for the columns with varying performance levels for the 4 EECs.
As the service life of columns increased, the reinforcement covers within a same EEC increased between 10% and 33%. Concrete consumption did not vary, but the area of reinforcements did, suggesting that remodeling the section was not required, expect for EEC IV, as the section area of the column had to be increased by 2.0% due to the increased reinforcement cover that reached 50 mm. The stabilization of concrete consumption was made possible by the increased compressive strength of concrete, attributable to the durability parameters. Whereas the minimum cover, another criterion, reduced the usable area of the piece, the increased moment capacity of the columns led to a reduction of the steel area needed, despite the increase of loads for a SL of 63 and 75 years, except for EEC II, whose durability parameters did not achieve the minimum level required for the increased concrete strength to be enough to resist the increased load. Figure 4 depicts the loss of usable area with respect to a total area equals X, along with the increased compressive strength, for a section of the regular design column with dimensions of 20x90 cm. As a result, for intermediate and superior performance, the minimum cover and strength parameters got equalized, stabilizing concrete consumption. However, the durability parameters led to higher cement consumption,

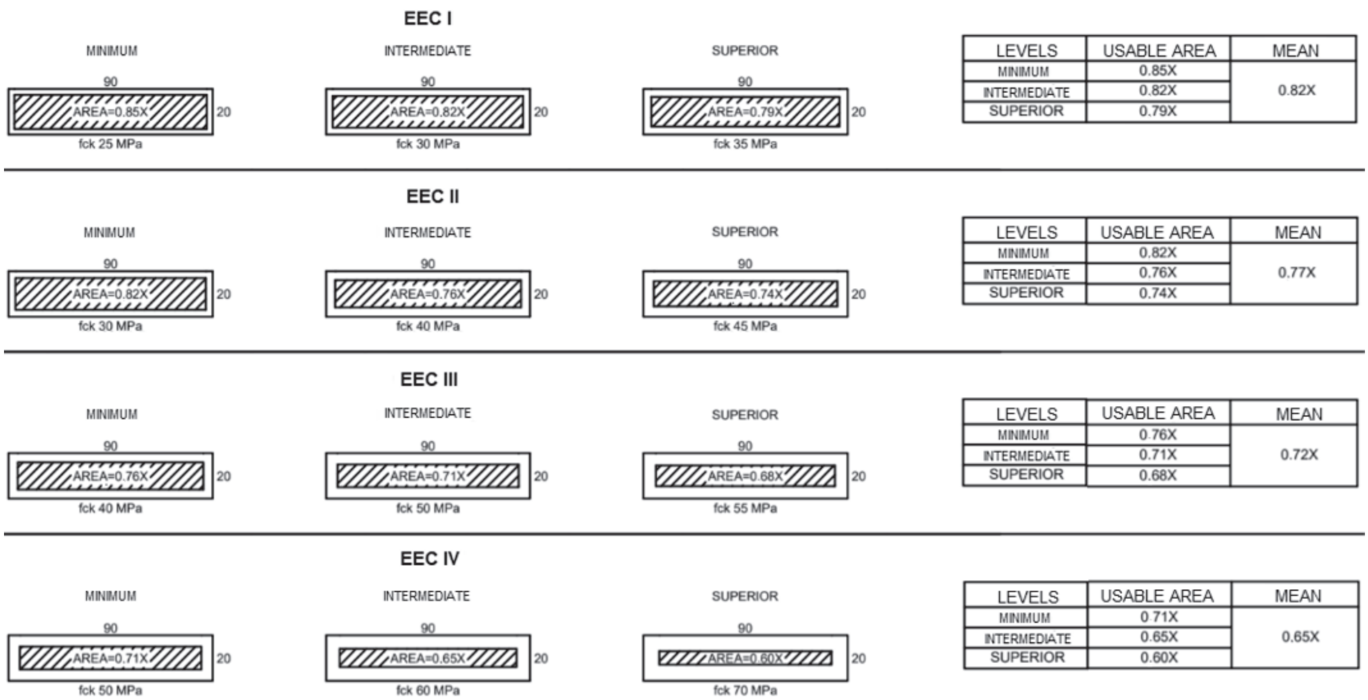

Figure 4
Comparison of the influence of durability parameters on usable area and strength of a column

Table 7
Comparison of material consumption for the structure

EEC	I			II			III			IV		
SL (years)	**50**	**63**	**75**	**50**	**63**	**75**	**50**	**63**	**75**	**50**	**63**	**75**
Steel consumption (kg)	29244	29371	29498	29027	29149	30792	29382	31157	32043	30760	32492	34545
Change in consumption (%)	0	0.4	0.9	0	0.4	6.1	0	6.0	9.1	0	5.6	12.3
Concrete volume (m³)	565.4	565.4	571.7	565.4	574.3	580.6	574.9	583.7	589.7	581.3	631.4	675.6
Change in consumption (%)	0	0	1.1	0	1.6	2.7	0	1.5	2.6	0	8.6	16.2

which causes more environmental impact. Still, the energy spent producing the steel and its environmental impact were lowered by the smaller consumption of the material.

Comparing the extreme cases, EEC I and SL 50 years versus EEC IV and SL 75 years, concrete consumption was 2.0% higher while steel consumption reduced 17.1%. Such phenomenon demonstrates that the increase of concrete strength caused by the durability prescribed to reach service life ended up absorbing the increase of variable actions, resulting in the reduction of the necessary steel area.

3.4 Structure

Table 7 compares total material consumption for the structure among the multitude of performance levels and EEC.

The increased disparity of material consumption as EEC increases along performance levels. For EEC I, the increases of steel and concrete consumption necessary to reach the superior level were 0.9% and 1.1% respectively, whereas such increases were 16.2% and 12.3% for EEC IV. Thus, the higher the performance level sought, the higher the costs of implementation involved. The cost-benefit of the structural system should still be analyzed, because SL can be increased by 50% keeping material consumption around 15% with the possibility of increasing system maintenance periods, reducing the utilization costs of the structure.

4. Conclusions

The main conclusions drawn from this study were:

- The Brazilian structural design standards are in need of compatibility regarding the new performance requirements of ABNT NBR 15575 [1], mainly the ones applied to SL for intermediate and superior performance levels;
- The increased structural performance level increased the dimensions of the pieces in some cases, considering the increased durability requirements, mainly with regards to reinforcement cover thickness;
- There were occasional reductions of the area of reinforcements used for dimensioning the sections. This comes from the fact that, although the acting loads grew along with the increases of the performance level sought due to the need to increase SL, the compressive strength of concrete was increased to meet the durability requirements;
- For SL higher than the minimum, an increase of up to 16% of concrete consumption was noted. Moreover, it was necessary to use with concretes of up to 50 MPa of compressive strength, which increased overall costs;
- The higher the EEC applied to the design of the structure, the higher the impact of the performance level sought. For EEC I, changing from the minimum to the superior performance level increased steel consumption by 0.9% and the volume of concrete by 1.1%. As for EEC IV, the respective increases were 12.3% and 16.2%;
- With the increase of performance level, the minimum dimensions recommended by ABNT NBR 6118 [3] could no longer be applied to the structural projects, in view of the increase of reinforcement cover thickness. For the study of structures with performance levels above the minimum, no significant increases to the dimensions of structural elements were observed.
- It should be verified that this paper did not take into account the fire safety requirements of reinforced concrete structures, as these are requirements that do not vary with the required Service Life, which could alter the results of the objectives established for this work. It is noteworthy that the analysis of concrete structures to fire is mandatory and must be done according to NBR 15200.

5. References

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