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Influence in the budget of a building structure due to alterations in the standard ABNT NBR 6118:2014

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ABSTRACT. Knowledge obtained in research and project practice contributed to upgrade the Brazilian standard regarding the dimensioning of concrete structures in 2014. The objective of the study is to evaluate the influence in the budget on the structure of an edifice due to changes in the standard ABNT NBR 6118:2014: use of different aggregates and of high-strength concrete. A building structure of reinforced concrete sized according to standards ABNT NBR 6118:2007 and ABNT NBR 6118:2014, considering different hypotheses. The simulations were performed with the software AltoQi Eberick (2014). The quantitative materials (steel, concrete, forms and expanded polystyrene to slabs) and inputs budget for structure were performed for each simulation. The type of aggregate influenced up to 4.60% of cost of the structure and up to 0.82% in overall cost in comparison with previous version of the standard. The use of C60 concrete compared with to C25 increased the budget of the structure (For the same aggregate type, the increase was, in average, of 14%). Although the use of steel and molds reduced (averaged 5%), it was not sufficient to eliminate the difference in the cost of concrete for edifice analyzed.

Keywords: structural design, dimensioning, standardization, elasticity modulus, aggregates, high-strength concrete.

Influência no orçamento da estrutura de um edifício devido às alterações na norma ABNT NBR 6118: 2014

RESUMO. O conhecimento obtido por meio de pesquisas e prática de projetos permitiu a atualização da norma brasileira referente ao dimensionamento de estruturas de concreto em 2014. O objetivo deste trabalho é avaliar a influência no orçamento da estrutura de um edifício pelas alterações na norma ABNT NBR 6118:2014: o uso de diferentes agregados e de concreto de alta resistência. A estrutura de um edifício em concreto armado é dimensionada conforme as normas ABNT NBR 6118:2007 e ABNT NBR 6118:2014, considerando diferentes hipóteses. As simulações são feitas com a ferramenta computacional AltoQi Eberick (2014). Para cada simulação são feitos quantitativos de materiais (aço, concreto, formas e poliestireno expandido para as lajes) e orçamento de insumos para a estrutura. O tipo de agregado influenciou em até 4,60% no custo da estrutura e em até 0,82% no custo global, em comparação com a versão anterior da norma. O uso de concreto C60, em comparação ao C25, elevou o orçamento da estrutura da obra (para o mesmo tipo de agregado, o incremento foi, em média, 14%). Apesar do consumo de aço e fôrmas serem reduzidos (em média, 5%), não foi suficiente para eliminar a diferença do custo do concreto para o edifício analisado.

Palavras-chave: projeto estrutural, dimensionamento, normalização, módulo de elasticidade, agregados, concreto de alta resistência.

Introduction

The structure of a building must be able to resist the actions and transmit to the soil, through the foundations. Reinforced concrete is the most popular structural material in the world. The high capacity and employability of the material allow it to be used in different situations. Knowledge obtained by means of research works and projects practice enable innovation and updating of normative concepts. The ABNT NBR 6118:2014 (Associação Brasileira de Normas Técnicas [ABNT], 2014) was launched in May 2014 to update the standardization of concrete use in Brazil. This version was corrected in August 2014 and brings updates and new procedures, compared to ABNT NBR 6118: 2007 (Associação Brasileira de Normas Técnicas [ABNT], 2007), that will influence the development of a structural project of reinforced concrete.

The new specifications include the class II resistance concretes (with a compressive strength and characteristic resistance values between 55 to 90MPa) and criteria for calculating the elastic modulus as a function of the mineral species in the aggregate. Cerutti and Santos (2015) declare that the version 2014 puts the standard at the level of upgrade of the most prestigious international standards. This is reflecting the effort of ABNT and Brazilian technical community to achieve a high level of quality in the design and construction of concrete structures (Cerutti & Santos, 2015).

The increasing of the use of high-strength concrete (HSC) contributed to the update of the standard ABNT NBR 6118:2007. According to Tutikian, Isaia, and Helene (2011), the incorporation of other elements into the concrete, as additives, mineral addition, pigments and fibers, and the use of different implementation techniques, such as curing at high temperatures and pressures, allowed to obtain the latest generation of concrete. Theoretically, these concrete could meet any project request, allowing the execution of slender structures, durable and safe for the end user (Tutikian et al., 2011).

Besides that, many studies showed that the origin of aggregate influences in the modulus of elasticity of the concrete, as will be further discussed. Due to this, the type of aggregate can affect the budget and dimensioning of a structural project.

If compared with a structure dimensioned according to the last version of standard, structural analysis with the current standardization will present variations in the design of a structure. Thus, the comparison between budgets of sized structures by the two versions of the standard (2007 and 2014) is important to estipulate the economic impact of structural design in the total amount of edification due to the revision of the standard, and it should be considered the ultimate limit state and serviceability limit state.

Therefore, the objective of this study is to evaluate the influence in the budget on the structure of a building due to changes in the standard ABNT NBR 6118:2014. The present study evaluates the economic impact caused by the use of different aggregates in the concrete and the use of resistance class II concrete.

Influence of the aggregate type on the modulus of elasticity

According to Cerutti and Santos (2015), the advance in knowledge of concrete properties enabled a more precise definition of the concrete elastic modulus when not carried out specific tests for its determination. According to ABNT NBR 6118:2014, when are not carried out tests for its determination; the initial modulus of elasticity (Eci) versus compression strength (f_{ck}) can be estimated using Equation 1 and 2.

$$Eci = 5600\alpha_E\sqrt{f_{ck}} \text{ , for fck 20 MPa to 50 MPa} \qquad (1)$$

$$Eci = 21.5x10^3 x\alpha_E\left(\frac{f_{ck}}{10}+1.25\right)^{1/3} \text{, for fck 55 MPa to 90 MPa} \qquad (2)$$

In which α_E depends on the source of the aggregate, and f_{ck} and Eci in megapascals (MPa): α_E = 1.2 for basalt and diabase; α_E = 1.0 for granite and gneiss; α_E = 0.9 for limestone; α_E = 0.7 for sandstone.

Using Equation 3 can be estimated the secant modulus of elasticity (Ecs).

$$Ecs = \alpha_i.Eci \qquad (3)$$

In which Equation 4:

$$\alpha_i = 0.8 + 0.2\frac{f_{ck}}{80} \leq 1.0 \qquad (4)$$

In which f_{ck} is the compression strength, in megapascals.

Is verified by Neville (2016) the aggregate and the cement paste have almost linear stress strain relationship, while the concrete does not have this relation, but a curvature. The author explains that this nonlinearity is due the composition and presence of the transition zone between aggregate and cement paste, which has empty, concentration of calcium hydroxide crystals and micro cracks, affecting the modulus of elasticity.

Yildrim and Sengul (2011) verified the modulus of elasticity of the concretes produced using dolomite, basalt e quartz were higher than concretes produced using limestone aggregate. Ahmad and Alghamdi (2012) noted that for any combination of mixture, the modulus of elasticity in concrete using aggregates of calcareous limestone is higher than that of the concrete using basalt of volcanic origin. Beushausen and Dittmer (2015) observed the influence of aggregate is highly evident in the 28-day elastic modulus results. For concretes with compressive strengths 30, 60, 90 and 120 MPa, there were obtained a higher elastic modulus using andesite basalt when compared to granite aggregate (Beushausen & Dittmer, 2015). Alexander and Mindess (2005) verified concretes using coarse aggregates granites presented slightly higher elastic modulus values than limestone. Besides of these, the influence of the type of aggregate on the elasticity modulus is approached by Özturan and Çeçen (1997), Shi, Mo, and Dhonde (2008), Neto, Oliveira, and Ramos (2011), Uysal (2012), and others.

The effect of the aggregate type is higher at low water/cement ratios (Ahmad & Alghamdi, 2012). Besides that, the effect of aggregate characteristic on the high strength concrete is more important (Yildrim & Sengul, 2011). Neville (2016) highlights the type of aggregate used also influences the tensile and compressive strengths of the concrete.

High strength concretes

By using thinner structural elements, the development of more resistant concrete is necessary. According to Beushausen and Dittmer (2015), the use of high strength concrete allows much smaller cross sections for elements, resulting in lower volumes of concrete. It is important mentioning the further benefits of structural members with significantly reduced self-weights and occupying less space (Beushausen & Dittmer, 2015).

Caldarone (2009) declare that the definition of ‘high strength’ in terms of a universally applicable numerical value is not possible. In Brazil, according to Tutikian et al. (2011), those concrete having compressive strength varying from 55 to 80 MPa are considered high-strength. The strength is dependent on many things, such as the quality of locally available concrete materials and construction practices (Caldarone, 2009).

The “[…] principles governing high-strength concrete can be so different from those governing concrete of a more conventional strength” (Caldarone, 2009, p. XV). One example is the change in the deformation limits above 50 MPa, altering the stress-strain diagram. For conventional concretes is common to adopt the specified strain of shortening of concrete at the beginning of plastic level (ε_{c2}) is 2 per thousand and the specified strain of shortening of rupture (ε_{cu}) is 3.5 per thousand. However, when the concrete strength increases, the strain at rupture decreases. The high-strength concrete can break on reaching a specified strain of less than 3.5 per thousand. According to Caldarone (2009), as strength increases, the slope of both of portions of the stress-strain diagram becomes steeper. A more brittleness is noticeable when increases the strength (Cerutti & Santos, 2015). The Equations for ε_{c2} e ε_{cu} in concrete class C55 and C90 are presents in the ABNT NBR 6118:2014.

The update of the standard is a factor that enables the increase HSC application in Brazil. This is because the NBR 6118:2007 restricted compressive strength to a maximum of 50 MPa. Before the new standard, an alternative to encompass the high-strength concrete was the use of international standards.

Although the HSC has higher cost than conventional concretes, it must be analyzed the overall cost of the project because with the use of this type of concrete, there may be a significant reduction of steel and molds.

Material and methods

The analysis of the influence of elastic modulus and concrete strength class in the cost of an edification was performed by comparing the costs of a dimensioned structure according to ABNT NBR 6118:2007 and ABNT NBR 6118:2014. The simulations were performed with the software AltoQi Eberick (2014), varying the aggregate type and concrete strength class. The structural elements beams, columns, pre-molded slabs and foundations (piles and blocks) were considered in the simulations. The dimensioning hypotheses are present in Table 1.

Table 1. Hypotheses of simulations.

Hypotheses	Abbreviation	f_{ck} (MPa)	Aggregate	Version NBR 6118
1	H1	25	-	2007
2	H2	60	-	2007
3	H3	25	Sandstone	2014
4	H4	25	Granite	2014
5	H5	25	Basalt	2014
6	H6	60	Sandstone	2014
7	H7	60	Granite	2014
8	H8	60	Basalt	2014

The building is a residential of four floors, with a total height of 15 meters, located in Valparaíso de Goiás, Goiás, Brazil. It has precast slabs lattice with expanded polystyrene (EPS) filling, masonry walls of 15 cm tick and total area of 1046.26 square meters. Figure 1 is a representation of the three-dimensional model of the structure.

For each simulation, it was made quantitative analysis of materials and budgets. The budgets were prepared through of Table Sinapi - *Sistema Nacional de Pesquisa e Custos da Construção Civil* (http://www.caixa.gov.br/) related of the state of Goiás in September (Caixa Econômica Federal [Caixa], 2015. It was considered that the amounts relating to services would be the same for the execution of all projects.

The initial and secant modulus of elasticity in cases related to the ABNT NBR 6118:2014 were estimated according Equation 1, 2, 3 and 4, as described earlier. In cases concerning to ABNT NBR 6118:2007, the modulus were estimated according to Equation 5 and 6. The modulus of elasticity was used for verification of deflection of beams and slabs, and for consideration of the overall effects of second order.

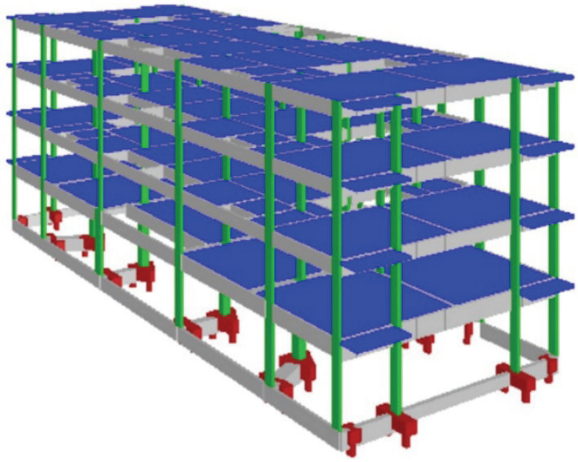


Figure 1. Three-dimensional model of the structure.

$$Eci = 5600 f_{ck}^{1/2} \quad (5)$$

$$Ecs = 0,85 Eci \quad (6)$$

In which f_{ck} is the compression strength, in megapascals; Eci is the initial modulus of elasticity, in megapascals; and Ecs is the secant modulus of elasticity, in megapascals.

For structural launching, the standard ABNT NBR 6118:2007 provides that Equation 7 obtain the average tensile strength.

$$f_{ct,m} = 0.3 f_{ck}^{2/3} \quad (7)$$

In which $f_{ct,m}$ is the average tensile strength and f_{ck} is the characteristic compression strength of concrete.

In turn, the ABNT NBR 6118:2014 provides that in concrete up to C50 class, Equation 7 also estimate the average tensile strength. Equation 8 is present for C55 class until C90.

$$f_{ct,m} = 2.12 ln(1 + 0.11 f_{ck}) \quad (8)$$

In which $f_{ct,m}$ is the average tensile strength and f_{ck} is the characteristic strength compression of concrete.

It is important to highlight that, in the hypothesis 2, due to lack of standardization for group II strength in the standard of 2007, the same class I for specific sizing methods of calculating resistance was used to simulate the use of specific C60.

The possible situations more critical to the ultimate limit state and service limit state were considered for the simulation of the structures. The dimensions of elements have changed where necessary or possible, according to the concrete strength and modulus of elasticity.

The behavior of the structure as a whole was kept in the simulations, always respecting the displacement proportions of L 300^{-1}. Figure 2 contains a schematic of the displacements of the beams and columns of the whole structure.

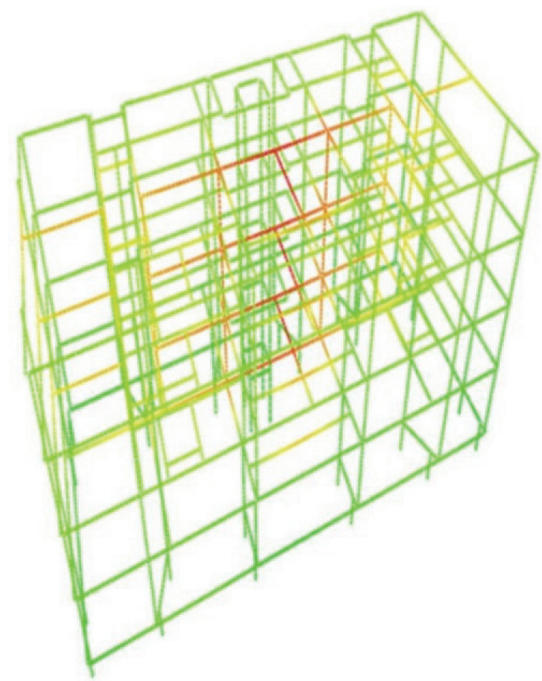


Figure 2. Displacements of the structural elements.

For each hypothesis was verified the need to consider or not the effects of second order. The modulus values were used in these analyses. The horizontal displacements in the x and y directions were analyzed in order to prevent damage to the structure. The geometric imperfections of the axis of elements in charged and discharged structure are considered.

Results and discussion

The initial and secant modulus of elasticity and average tensile strength for each hypothesis, in megapascals (MPa), are presented in Table 2. For hypothesis 4, the concrete C25 produced with granite, did not happen any significant changes that interfere with the preparation of structural design in relation to ABNT NBR 6118:2007. This fact is explained by α_E factor granite is 1. With this, the dimensioning regarding the hypothesis 4 is considered equal to the dimensioning of the hypothesis 1.

Table 2. Summary of elastic modulus and medium tensile strengths.

Hyphotesis	Abbreviation	Eci (MPa)	Ecs (MPa)	$f_{ct,m}$ (MPa)
1	H1	28,000.00	23,800.00	2.56
2	H2	43,377.41	36,870.80	4.60
3	H3	19,600.00	16,905.00	2.56
4	H4	28,000.00	24,150.00	2.56
5	H5	33,600.00	28,980.00	2.56
6	H6	29,128.35	27,671.93	4.30
7	H7	41,611.92	39,531.32	4.30
8	H8	49,934.31	47,437.59	4.30

Table 3 is a summary of the budget obtained for simulations considering the month of September 2015. The values were obtained from the quantitative materials used for each hypothesis. In the steel, concrete and molds costs are included beams, columns, slabs and foundations. In the cost of slabs are included the steel of trusses and the expanded polystyrene (EPS) filling. The values are shown in Brazilian currency (Real) and the total cost of the structure is presented also in US dollars. For this, it was used the US dollar exchange rate to the end of September 2015 (US$ 1 is R$ 3,966).

Table 3. Comparative simulations of costs.

Hyphotesis	Steel cost (R$)	Concrete cost (R$)	Molds cost (R$)	Cost of slabs (R$)	Total cost of structure (R$)	Total cost of structure (US$)
H1 e H4	65.428,52	67.357,33	65.654,55	42.966,64	241.407,04	60,869.15
H2	61.217,01	115.540,46	61.934,96	38.700,32	277.392,75	69,942.70
H3	65.419,60	69.584,76	68.045,95	49.454,95	252.505,25	63,667.49
H5	67.577,38	66.109,97	64.306,24	42.473,24	240.466,83	60,632.08
H6	65.573,42	116.783,43	62.867,38	38.700,32	283.924,55	71,589.65
H7	62.367,54	116.444,44	62.552,10	38.700,32	280.064,40	70,616.34
H8	63.340,40	111.811,52	59.409,40	38.236,19	272.797,51	68,784.04

It is found that, when simulated the structure of the building with C25 concrete by the standard ABNT NBR 6118:2007, it was found a material cost equal to R$ 241.407,04. Considering the ABNT NBR 6118:2014, it was obtained an increase of 4.60% using sandstone, the same cost whit the use of granite and a decrease of 0.40% whit the use of basalt in the cost of the structure observed by adopting other standard. In relation to C60 concrete, it can be noticed an increase of 2.35% with the use of sandstone, an increase of 0.96% for granite and a decrease of 1.60% for basalt.

Considering the basic unit costs of construction available from Table (Pini, 2015), the cost for the construction of popular buildings of four floors in normal pattern in the state of Goiás (Brazil) is R$ 1.293,77 per square meter, and considering this value, it is possible to make a comparison between the budget simulations. Since the building has 1,046.26 square meters, its overall value is estimated at R$ 1.353.619,80. Thus, the influence of the structure in the overall price of the building on each hypothesis is presented in Figure 3. For all cases, the total cost of structural materials is very close to 20% of the total cost.

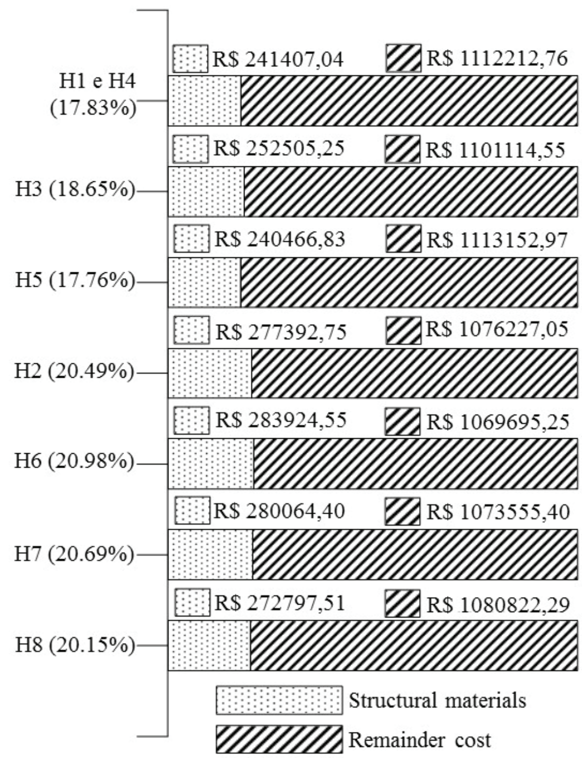
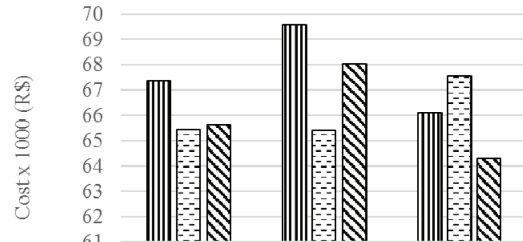


Figure 3. Graphic comparative analysis of budget hypotheses.

For the same strength, the aggregate type showed little influence on the overall cost when compared to the values obtained in dimensioning by ABNT NBR 6118:2007 and ABNT NBR 6118:2014. The largest difference was noted when using C25 concrete and sandstone aggregate (Hypothesis 3). In this case, the difference from the budget obtained using the standard of 2007 was 0.82%.

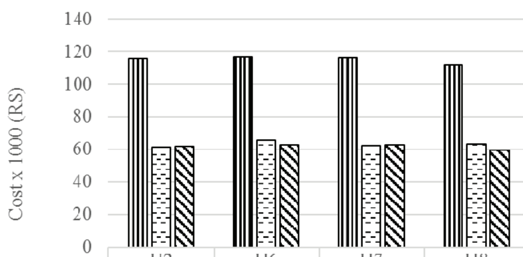
To check the influence of each item in the cost of the building structure simulated with use of C25 concrete, Figure 4 contains the costs of concrete, steel and molds for each case analyzed. The same check for C60 concrete simulations are shown in Figure 5.

The difference of concrete cost can be noted when comparing C25 and C60 classes. The use of concrete C60, compared to C25, elevated the building budget (averaged 14%, for an aggregate type). Regarding the C60 concrete, the consumption of steel and molds were reduced, but not enough to eliminate the difference in the cost of concrete.



	H1 e H4	H3	H5
Cost of concrete	67,35733	69,58476	66,10997
Cost of steel	65,42852	65,4196	67,57738
Cost of molds	65,65455	68,04595	64,30624

Figure 4. Comparative of simulations costs for C25 concrete.



	H2	H6	H7	H8
Cost of concrete	115,54046	116,78343	116,44444	111,81152
Cost of steel	61,21701	65,57342	62,36754	63,3404
Cost of molds	61,93496	62,86738	62,55210	59,40940

Figure 5. Comparative of simulations costs for C60 concrete.

Conclusion

The change in the type of aggregate from rocks with a lower modulus of elasticity (sandstone) to rocks with a higher modulus (basalt) caused an increase in the elastic modulus of concrete. The alteration to concrete with higher modulus caused change in the dimensions of structural elements and, consequently, caused a decrease in the cost of structure. For the analyzed building, the use of high strength concrete (C60) affected negatively in the final budget of the structure. This is because there is an increase in the cost of structure despite the smaller amount of steel and wood for molds.

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