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Elements for a future brazilian standard for seismic resistance of concrete structures of buildings

Subsídios para uma futura normalização brasileira para resistência anti-Sísmica das estruturas de concreto de edifícios

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Abstract

Due to its low seismicity, the technical tradition in Brazil is to not consider seismic forces in the design of civil structures. Only for some special projects, seismic effects have been considered. Nevertheless, considering the data already available, it can be shown that seismic effects in the structures cannot be disregarded "a priori" in Brazil. Some elements for a future seismic standardization for concrete structures of buildings in Brazil are presented herein. A comparative study between the seismic effects with wind ones, for a typical structure in the Southeast Region is presented, showing that in certain situations, the seismic forces can be the most critical ones. © 2005 IBRACON. All rights reserved.

Keywords: standardization; seismic analysis; concrete structures.

Resumo

Devido à sua baixa sismicidade, a tradição técnica no Brasil, tem sido não incluir forças sísmicas nos projetos de estruturas civis. Somente em alguns projetos especiais estes efeitos têm sido considerados. No entanto, considerando-se os dados hoje disponíveis, constata-se que os efeitos sísmicos nas estruturas não podem ser descartados "a priori" no Brasil. Apresentam-se aqui alguns subsídios para uma futura normalização sísmica de estruturas de concreto de edifícios no Brasil. É feita uma comparação dos efeitos sísmicos com os de vento, para uma estrutura típica na Região Sudeste, mostrando que, em certas situações, as forças sísmicas podem ser as críticas. © 2005 IBRACON. All rights reserved.

Palavras-chave: normalização; análise sísmica; estruturas de concreto.

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1 Introduction

Due its low seismicity, the technical tradition in Brazil, reflected in its design standards, is to not consider seismic forces in the design of civil structures. Only in special projects, of great social and economical importance, such as for the nuclear power plants, these effects have been considered.

Nevertheless, considering the available data and the theoretical studies already done, it can be concluded that the seismic effects in the structures cannot be "a priori" disregarded. It is necessary to define for which structures the seismic effects shall be considered and with what values. It is to be considered also the necessity of integration of Brazil with the neighbour countries, for which the definition of a seismic standard compatible which the ones existent in these countries would be extremely opportune.

Some elements for a future seismic standardization for concrete buildings in Brazil are presented. A comparison between seismic and wind effects in structures in Brazilian Southeast is presented, showing that, in certain situations, the seismic forces can be the critical ones.

2 Seismicity in Brazil

The Brazilian territory presents very low seismicity, typical of an intraplate region. The study of the Brazilian seismicity, in a scientific basis, started in 70's. Since this decade, seismological data have been gathered, from an important seismological net, presently in continuous operation.

Nevertheless, a complete study of the seismicity in the Brazilian territory has not performed up to now. A study of the seismic risk, in a global level, was performed by the GFZ-Potsdam, and presented in the "Global Seismic Hazard Map" [1]. It can be seen in this map that the Brazilian territory presents very low seismicity, with characteristic horizontal accelerations normally inferior to 0.5 m/s^2. Some exceptions can be observed, in some of the North-Eastern Brazilian states, due their position relatively to the Central Atlantic Ridge and in the western part of North and Central-Western regions, due their proximity to the Andes.

A study done by Falconi [2] analyses design standards of six South-American countries (Brazil is not included in this study). From this analysis it can be concluded that, taken into account inclusive the geographic continuity of Brazil with the neighbour countries, an anti-seismic normalization is indispensable today for the country.

Based on the available information, it is presented in Figure 1, a proposal for characteristic horizontal accelerations to be considered in Brazil. These accelerations correspond to a nominal probability of 90% of non-exceedance in 50 years (i.e., to a reference return period of 475 years).

3 Theoretical basis for the definition of the characteristic accelerations

The theoretical basis for the proposal for the horizontal accelerations shown in Figure 1, was presented by the authors [3] for the Brazilian Southeast. It is considered that the conclusions obtained for this region can be extended for the remaining Brazilian regions.

Detailed seismicity studies for the Southeast Regions were summarized by Almeida [4]. The following equation of seismic recurrence, valid for this region, in taken from this reference:

$$\log(\Sigma N) = 4.44 - 1.28\,M \qquad (1)$$

ΣN (annual cumulative frequency) is the total number of earthquakes with magnitude equal or superior to the magnitude M ("body-wave magnitude" m_b), expected in an one year period in the Southeast region.

For the definition of a probabilistic function of accelerations, it is considered that this probabilistic distribution is uniform, and an earthquake with a given magnitude can occur with equal probability in any point in a circumference of equivalent area, with radius equal to 400km, drawn around a site to be analysed in the Southeast Region.

The attenuation function proposed by Toro et al. [5] for the Central and Eastern United States (CEUS) is considered herein. It is supposed that this region presents attenuation conditions similar to the Brazilian Southeast. Obtained results are graphically shown in Figure 2, which express the equation (a_h in g):

$$\log_{10} T_M = 6.654 + 2.02 \log_{10} a_h \qquad (2)$$

T_M is the reference return period (in years) for an earthquake with magnitude at least equal to M, and it is equal to the inverse of the variable (ΣN) defined in equation (1).

For the definition of the characteristic acceleration, the usual consideration of a probability of exceedance of 10% in 50 years, corresponding to T_M equal to 475 years, would lead to a characteristic acceleration of:

$$a_h = 0.011\ g$$

The proposed characteristic value (a_h = 0.05 g), for usual structures in the Brazilian Southeast, is associated to specific characteristic of the seismic excitation, as shown in the Reliability Analysis to be presented in the sequel, and shall be understood as a proposal for discussion.

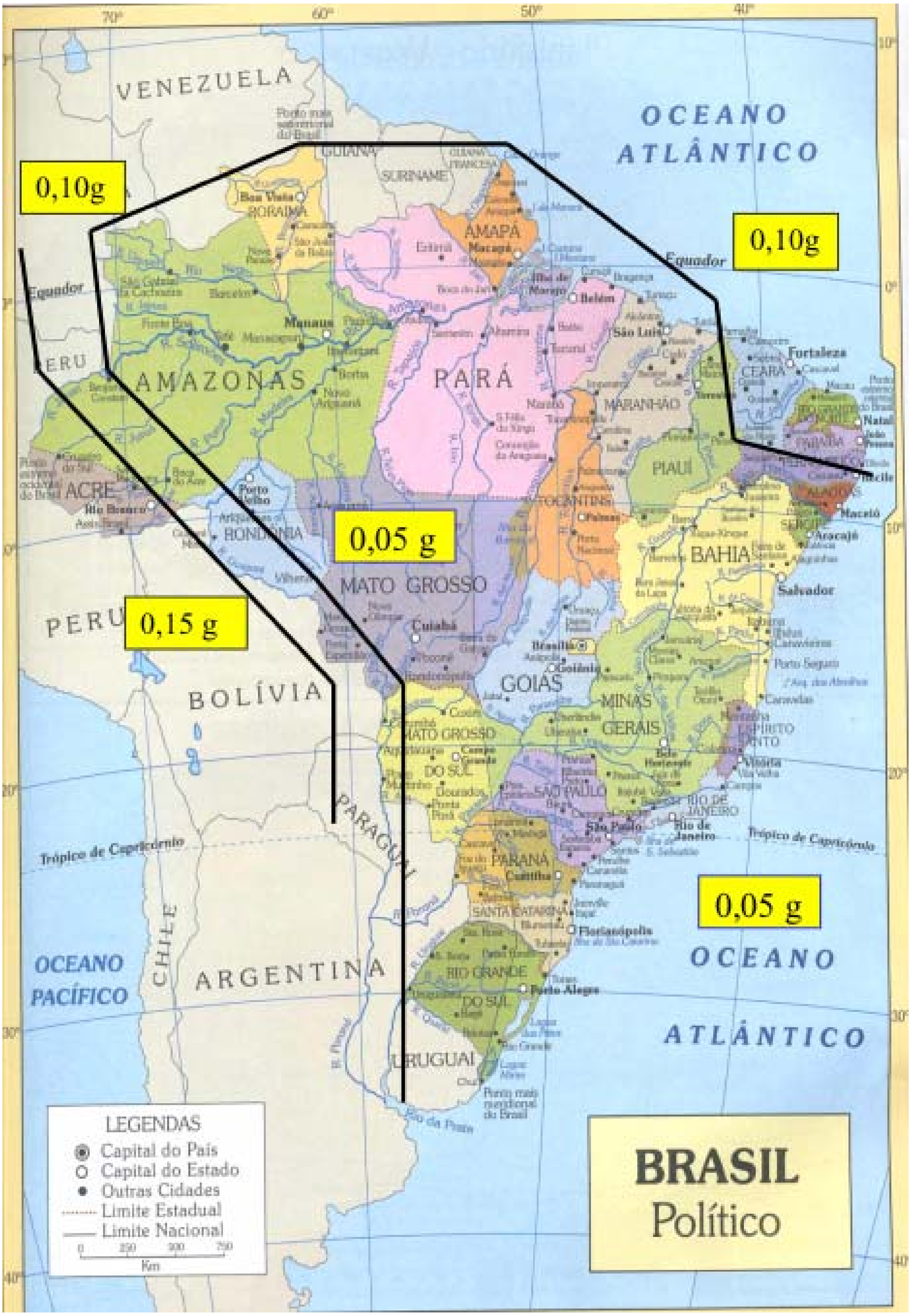

Figure 1 - Characteristic horizontal accelerations.

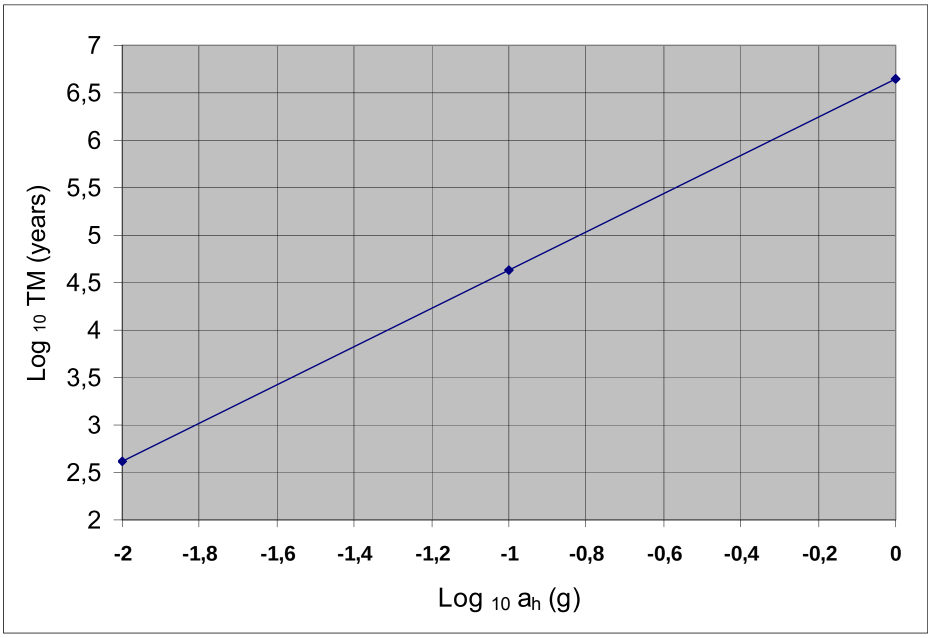

Figure 2 - Recurrence period (T_M) for the horizontal accelerations (ah).

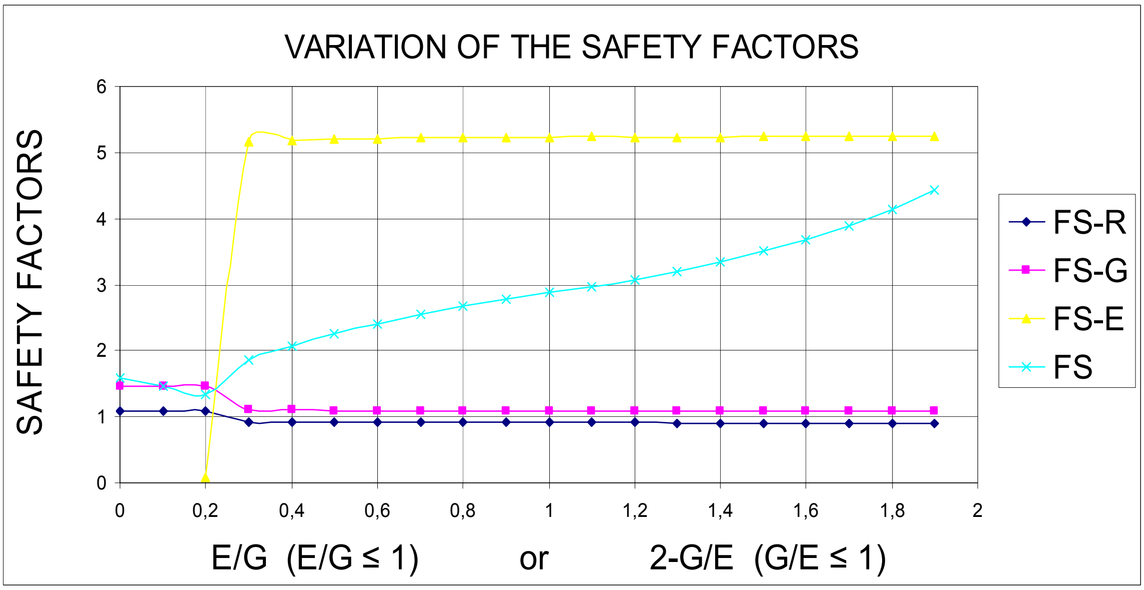

Figure 3 - Variation of the safety factors with the relationship seismic load / permanent load.

4 Analysis of the safety factors

For the definition of the safety factors, a Reliability Analysis is developed. This kind of analysis offers an alternative to the conventional design methods, considering analytically the uncertainties present in the evaluation of the design variables. The basic concepts of Reliability Analysis used herein were summarized in [6].

There is no Brazilian standard defining the verification of the required reliability levels for the structures. Only as a reference parameter for the analyses to be presented, a reliability coefficient of β=3.8, in an annual basis is considered, corresponding to a yearly failure probability of 7.2 x 10-5.

The analysis is developed according to the concepts of the "JCSS 2001" [7], for a standard reinforced concrete section, under flexure. A probabilistic model, considering the statistical distribution of the considered design variables is defined. All the possible relationships between seismic loads and loads of permanent character (predominant in building structures) were analysed. The reliability analyses were done using the computer program COMREL [8].

For each of the relationships between seismic and permanent loads, the situation of the "design point" is studied. In this point, the reliability coefficient is the required one and there is equilibrium among the considered variables, in a situation of ultimate limit state. Then, the corresponding values for the partial safety factors for increasing loads and decreasing the resistances are evaluated.

The Figure 3 presents the variation of these coefficients. The partial factors for the steel resistance (FS-R) and for the permanent loads (FS-G) tend clearly to 1.00, and the factor for the seismic loads (FS-E) tends to 5.25. FS is the global safety factor. It is very clear that the application of partial safety factor for loads (γ_f = 1.0) of NBR8681 [9] on the seismic characteristic loads is insufficient regarding the required reliability conditions.

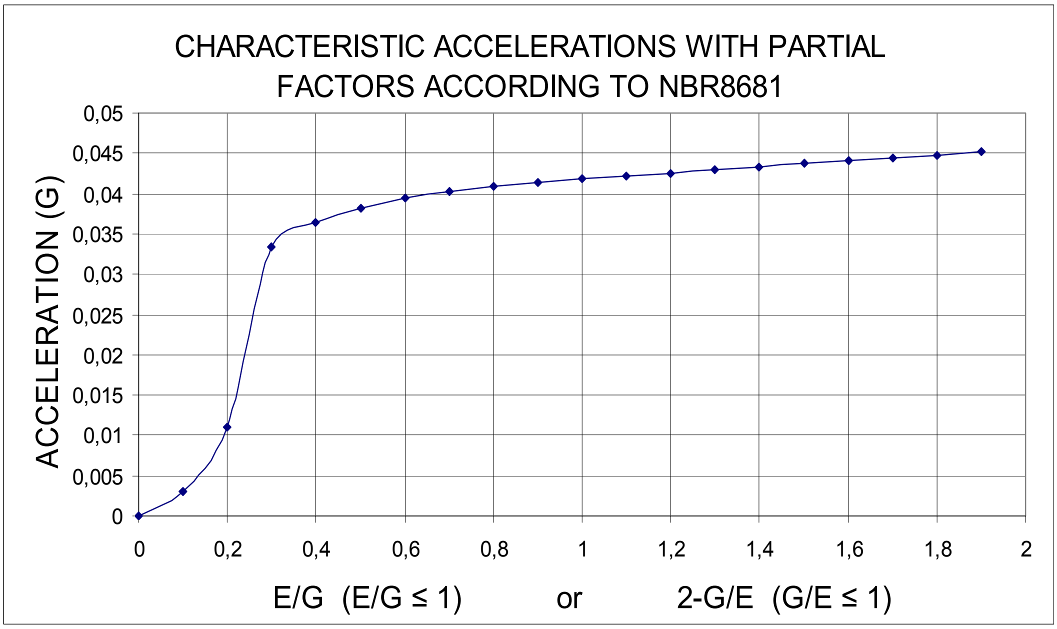

Figure 4 - Variation of the design acceleration to be adopted, considering the remaining safety factors according to NBR8681.

Another analysis is presented in Figure 4, where the coefficients FS-R e FS-G are fixed in 1.15 e 1.20, respectively, according to NBR 8681 [9], and the resulting values of the horizontal accelerations are determined. These values tend to $a_{h\,d}$ = 0.045g.

Analysing Figure 4, it can be concluded that, for the South-Eastern Region, the consideration of the design acceleration of a_h = 0.05g (from Figure 1), leads to an adequate value for the design acceleration:

$$a_g = 0.05g$$

For the comparative study presented in this paper, between horizontal forces caused by wind and earthquakes in buildings, the American standard UBC-97 [10], shortly described in the sequel, will be followed.

5 Dispositions of UBC-97 for the anti-seismic design

A summary of some relevant items of UBC-97 will be presented in the following. This standard can eventually serve as a basis for the future Brazilian anti-seismic standard. Another international standard can eventually be taken as a basis for the Brazilian one, from which will be discussed among the Brazilian engineers.

- The total horizontal force (V) can be evaluated through "Static Force Procedure" (Section 1630.2) of UBC-97:

$$0.11\,Ca\,I\,W \le V = \frac{Cv\,I\,W}{R\,T} \le \frac{2.5\,Ca\,I\,W}{R} \quad (3)$$

Alternatively, or in special situations, the "Dynamic Analysis Procedures", according to Section 1631 of UBC-97, can be applied.

- The "Importance Factor" (I) can be taken as I=1.00 for usual buildings (residential or office buildings). In other cases, Table 6-K of UBC-97 shall be considered.
- The reduction factor of the seismic force (R), defined as a function of the global ductility of the structure, can be taken as R=3.5, coefficient applicable to reinforced concrete ordinary moment-resisting frames (OMRF), i.e., frames detailed usually. For the other cases, Table 16-N of UBC-97 shall be considered.
- In residential and office buildings, W (total seismic weight) corresponds to the dead weight only. For other cases, Item 1630.1.1 of UBC-97 shall be considered.
- The structure period can be evaluated according the expression below, valid for reinforced concrete frames. For other cases, Item 1630.2.2 of UBC-97 shall be considered.

$$T = 0{,}0731\ (h_n)^{0{,}7} \quad (4)$$

h_n = total height of the building (m)

Seismic coefficients Ca e Cv are obtained with the adimensional parameters defined in Table 1 below, according to the respective Soil Profile Type, multiplying them by the basic characteristic acceleration a_g

- Distribution of the total horizontal force V over the height of the structure:

$$F_i = \frac{(V - F_T)\, w_i h_i}{\sum w_i h_i} \quad (5)$$

where F_i is the force to be applied to the level of order *i*, w_i is the part of W assigned to this level, h_i is the height of this level *i* above the base of the building, and F_T is an additional force concentrated at the top of the structure, given by:

$$F_T = 0.07\ T\ V \leq 0.25\ V \quad (6)$$

or

$$F_T = 0 \text{ if } T \leq 0.7\text{s} \quad (7)$$

6 Comparison between the effects of wind and earthquake

A comparative study was presented in [3], between the global effects of wind and earthquake, for typical office buildings, with number of floors varying between 1 and 50, located in the city of Rio de Janeiro.

The considered data were:

- Permanent floor loading: 8 kN/m^2
- Floor area in each level: 20m x 20m = 400m^2
- Floor-to-floor heights = 3m.
- Seismic loads: according to the presented standard proposal, with characteristic accelerations equal to 0,05g and stiff soil (type Sd).
- Wind loads: according to the Brazilian Standard NBR-6123 [11], with basic wind velocity equal to 35 m/s. Standard factors S_1 e S_3 (topographic and probabilistic) taken as equal to a 1,00.

The results of the analyses are shown in Figures 5 to 7.

Table 1 – Definition of the seismic coefficients Ca e Cv.

Soil Profile Type	Description	Vs (measured shear wave velocity)	SPT(average), blows/foot	Ca/a_g	Cv/a_g
Sa	Hard rock	Vs >1500 m/s	-	0,80	0,80
Sb	Rock	760 m/s < Vs < 1500 m/s	-	1,07	1,07
Sc	Soft rock or very dense soil	360 m/s < Vs < 760 m/s	>50	1,20	1,73
Sd	Stiff soil	180 m/s < Vs < 360 m/s	15 a 50	1,60	2,40
Se	Soft soil	Vs < 180 m/s	< 15	2,53	3.45

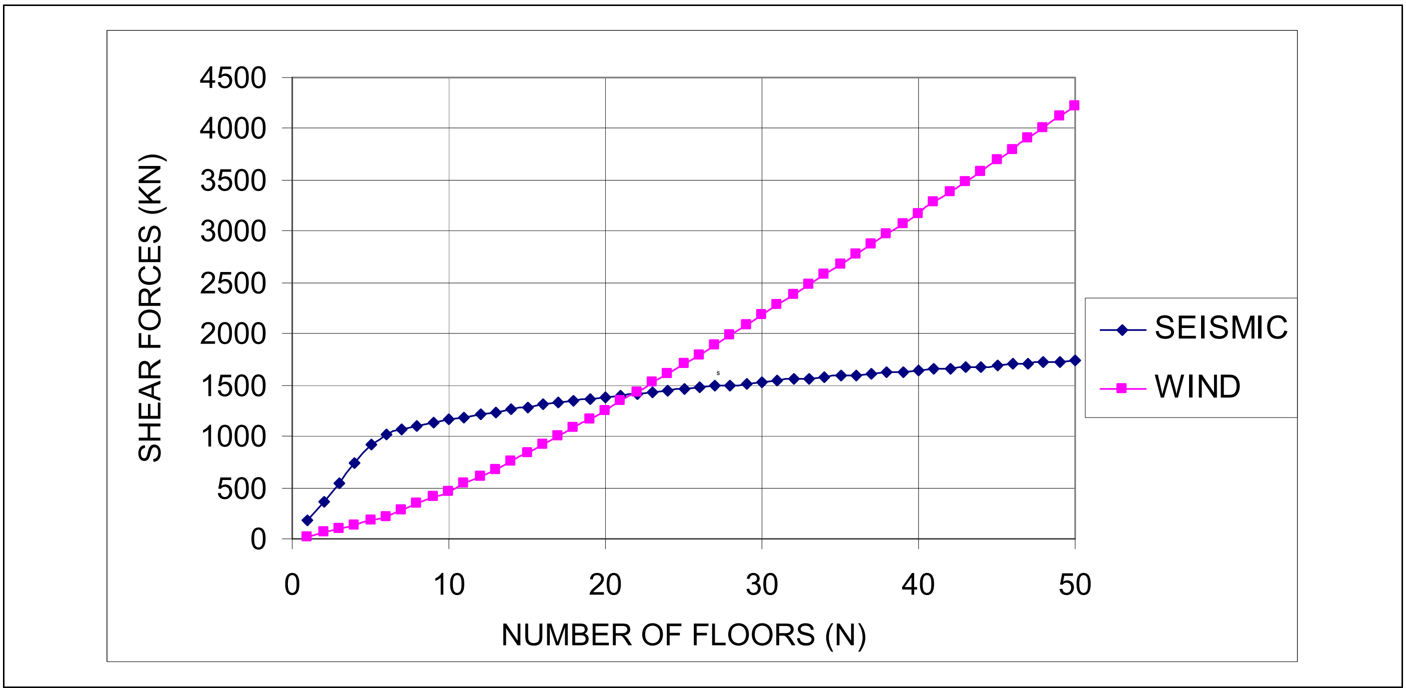

Figure 5 – Comparison between total global design horizontal forces.

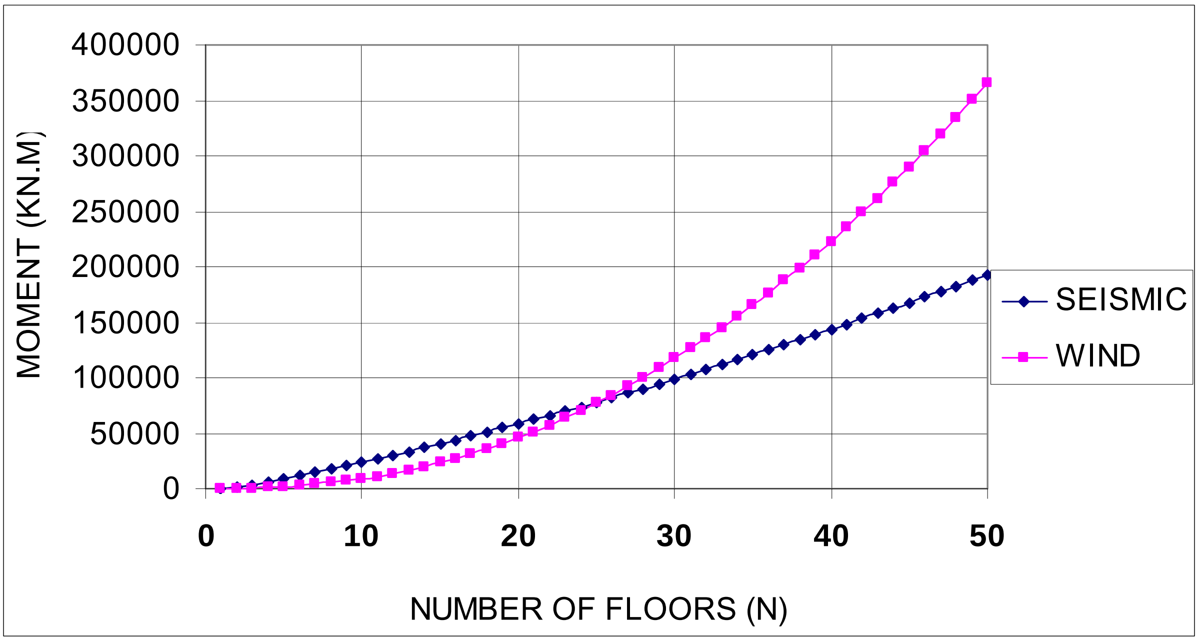

Figure 6 – Comparison between global design moments in the bases.

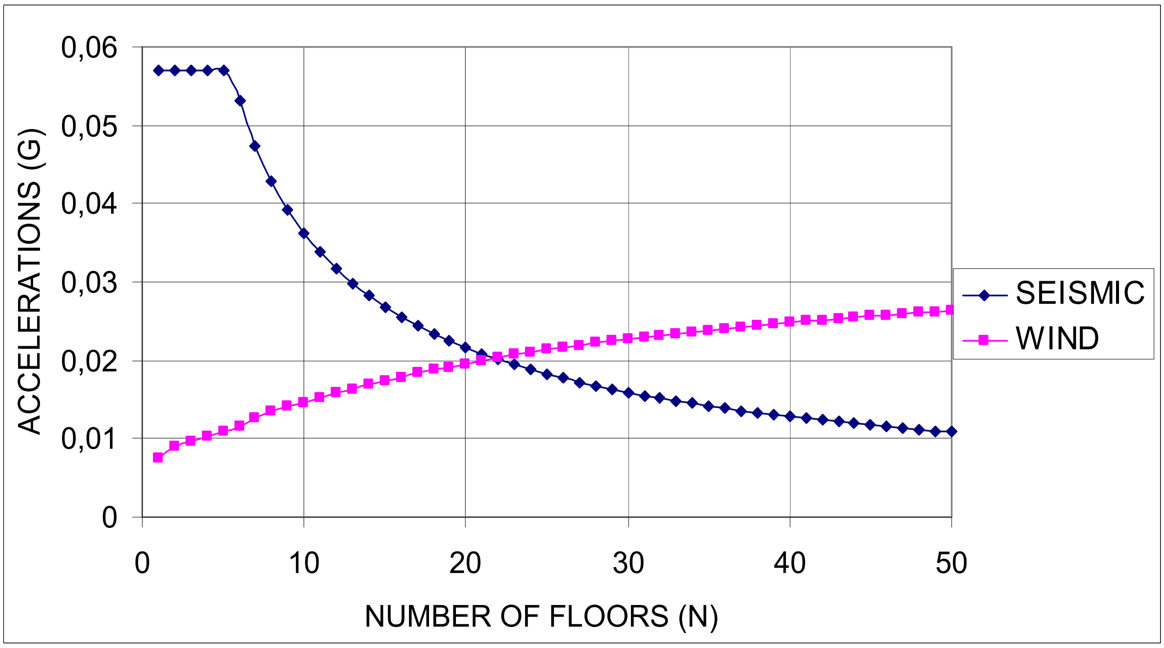

Figure 7 - Comparison between average design horizontal accelerations.

The total design horizontal forces, (i.e., the wind and seismic loads multiplied by the factors γ_f = 1.4 e 1.0 respectively) in the bases of the buildings, are compared in Figure 5. The global design moments relative to the bases are compared in Figure 6. The seismic forces are greater than the wind ones for buildings up to 21 floors, and the seismic moments are the greater ones for buildings up to 25 floors.

A comparison between average horizontal accelerations for the two loading cases is presented in Figure 7. These accelerations are obtained by dividing the total horizontal forces by the total weight of the buildings. The average seismic accelerations are bigger than the wind ones for buildings up to 21 floors.

7 Conclusions and future research

Some elements for a future Brazilian standard for seismic design of reinforced concrete structures were presented in this paper.

The presented comparison between the seismic forces in typical office buildings is only indicative and particular for the considered numerical values, but shows that, in certain cases, the seismic forces can be the critical ones for the design.

It should be noted that the return period to be considered, the respective characteristic values of the design accelerations and the failure probabilities to be accepted in seismic conditions, are points presented for discussion among the Brazilian structural engineers.

A possibility to be analysed is the definition of a "Seismic Zone Zero", where, through a simple comparison with the effects of the wind and with the ones due to the lack of verticality in the structures, according with Item 11.3.3.4.1 of NBR 6118 [12], seismic effects could be neglected.

Other reliability analyses can be performed in the future, considering, for instance, shear forces, bending moment with compressive forces, etc., as well as considering other possible pre-defined reliability coefficients.

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