13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 61

AN ENGINEERING APPROACH FOR EVALUATING THE SEISMIC RISK IN BRAZILIAN SOUTHEAST REGION

Sergio HAMPSHIRE SANTOS[1]

SUMMARY

Brazilian Southeast region presents a low seismic activity, typical of an intra-plate region. Since the design of the first Brazilian Nuclear Power Plants, the study of the Brazilian seismicity, in a scientific basis, has begun. An important seismographic network, presently in continuous operation, has been implemented in Brazil.

The objective of this paper is to present an evaluation, considering an "engineering approach", of the seismic risk in Brazilian Southeast region. The work is based upon the already available seismic data in this region and also in the theoretical seismological studies already developed in this subject. The characteristic of the adopted "engineering approach" is, from the restricted amount of the available seismological data, and through a simplified process, to obtain an evaluation of the probabilistic distribution function of the horizontal ground accelerations in the analyzed site, in a reliable and conservative way. The concept of "diffuse seismicity" is used in this evaluation, i. e., the seismic risk is not evaluated from actual geological faults with a given seismic potential, but from sources diffusely distributed on the considered Tectonic Province.

The seismic risk is evaluated, in Brazilian Southeast, for two different types of structures, according to their importance to the public safety: critical structures, such as Nuclear Power Plants and usual structures, such as residential and commercial buildings. The importance of the analyzed structures is reflected in the reference probability levels to be considered in design of each of them.

The importance of the seismic risk analysis in the discussed region is illustrated through a numerical example, of a commercial building in the city of Rio de Janeiro, with height ranging between one and fifty floors, in which horizontal forces due to wind and due to earthquake are applied. The comparison between the effects of these forces shows that, in some cases, seismic forces can be the dominant ones.

[1] Associate Professor, Escola Politécnica, Federal University of Rio de Janeiro (UFRJ), Brazil. Email: sergiohampshire@poli.ufrj.br

INTRODUCTION

The Brazilian territory presents a low seismic activity, typical of an intra-plate region. The study of the seismicity in Brazil, in a scientific basis, has begun in the 1970s. Since this decade, seismological data have been obtained, in order to fulfill the stringent criteria required for the design of the first Brazilian Nuclear Power Plants, located in Angra dos Reis. Since then, an important seismographic network has been implemented in Brazil, and is presently in continuous operation.

Due to the low seismicity in Brazil, our technical tradition is to not include the seismic loads in the current design of the structures. For the nuclear industry, specific requirements have been defined by the Brazilian licensing authority (CNEN – Comissão Nacional de Engenharia Nuclear), not only for commercial Nuclear Power Plants, but also for research plants with important nuclear inventory. For other large plants, such as Thermoelectrical Plants, the seismic design has been done under specific owner's request and following specific design criteria.

On the other hand, from the data gathered since the 1970s, and from the theoretical studies that have been done since then, it became clear that seismic effects in the structures cannot be disregarded "a priori", without more detailed considerations. It is necessary to discuss whether seismic forces are to be considered, for whose structures and with what numerical values. This paper intends to contribute in this discussion, which is pertinent not only for Brazil, but also for other countries with low to moderate seismicity.

For this, numerical data are presented, evaluated for structures to be built in the Brazilian Southeast region, regarding the magnitude of the seismic effects that can be expected during their operational life. At first, an evaluation of the probabilistic distribution function of the horizontal ground accelerations in the analyzed region is performed. These accelerations are applied as input, in the base of a typical commercial building. The numerical values of the obtained seismic forces are compared with the ones caused by usual wind loads. The comparison shows that, under some conditions, the seismic forces are the dominant ones.

SEISMICITY OF BRAZIL

A complete study of the seismicity in the Brazilian territory has not yet been done. Available specific seismic risk studies for Brazilian Southeast will be mentioned in the next item. An overview of the Brazilian seismicity appears on the Global Seismic Hazard Map, by GFZ-Potsdam [1]. It can be seen in this map that most of the Brazilian territory possesses a very low seismicity (Peak Ground Acceleration inferior to 0.4 m/s^2, for a reference return period of 475 years). The remarkable exceptions are some states of Brazilian Northeast, due their positions with respect to the Mid-Atlantic Ridge, and the western part of North and Center-West Brazilian Regions, due their proximity of the Andes Mountains.

The seismicity that can be expected in the Northern Brazil is suggested in the study from Falconi and Báez [2], from extrapolation of the curves valid for North Brazilian neighbor countries. From a recent study from Falconi [3], analyzing the seismicity of six South American countries (Brazil is not included in this study), it is also evident that the seismicity in Brazilian areas closer to the Andes shall not be disregarded.

The Brazilian Standard for the design of concrete structures [4], presently under a final stage of a complete revision, will include an annex with provisions for seismic resistance. The seismic zoning shown in Fig. 1 considers Brazilian seismicity within South America and was presented for analysis of the Brazilian Association for Technical Standards (ABNT). Horizontal accelerations defined in the figure correspond to a nominal probability of 90% on non-exceedance in 50 years (reference return period of 475 years).

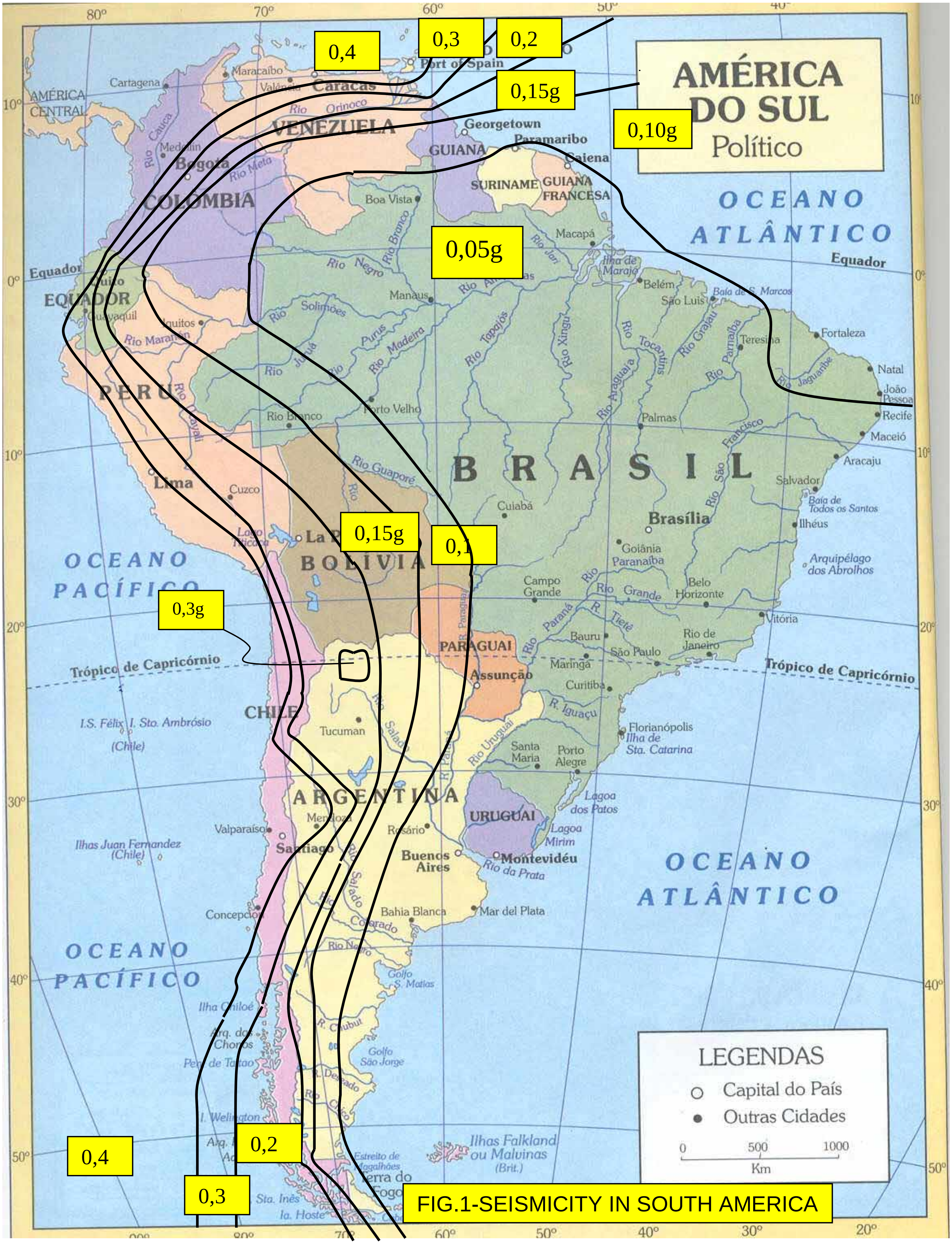

FIG.1-SEISMICITY IN SOUTH AMERICA

SEISMIC RISK IN BRAZILIAN SOUTHEAST

The Southeast region includes four Brazilian states: São Paulo, Rio de Janeiro, Minas Gerais and Espírito Santo. Roughly, the rectangle shown in Fig. 2, encompasses this region. This region is the Brazilian more populated and developed one and possesses Brazilian largest industrial centers and also the nuclear plants and most of the hydroelectric plants. In the figure, a circle of 400km of radius around the city of Rio de Janeiro is also drawn, for being used later on in the paper.

This region is also the Brazilian one with more detailed seismological studies. At least two very active Brazilian research groups have to be cited in the seismological field: IAG/ University of São Paulo (lead by Prof. Berrocal) and University of Brasília (lead by Prof. Assumpção). A complete study of the seismicity in the Brazilian Southeast region was presented by Berrocal et al. [5]. This study was further refined by Almeida [6], considering a more complete set of data.

The following cumulative (Σ N) frequency/magnitude annual seismic recurrence expression for Brazilian Southeast region, will be used in this paper (from Almeida [6]):

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

ΣN is the total number of earthquakes with magnitude equal or greater than M (M = body-wave magnitude m_b) in an one year period, occurring in Southeast Region. The maximum recorded seismic event, occurred up to now in Brazilian Southeast region, presented a magnitude of 6.3 m_b (offshore, in the year of 1955). It is considered that the maximum possible magnitude in the region could be of 7.0 m_b. [5].

The above reproduced equation has been used in the seismic risk assessment of Angra 2 Nuclear Power Plant (see again [6]), and can be considered as the more reliable numerical expression presently available for the Brazilian Southeast region. It should be pointed out that adopting this formula for the seismic characterization corresponds to implicitly accept the concept of “diffuse seismicity” as valid in the analyzed region. This concept is the one used by the U.S. Nuclear Regulatory Commission in its Regulatory Guide 1.165 [7], for application in the CEUS (Central and Eastern United States). This means that in this type of non-active intra-plate region “there is generally no clear association between seismicity and known tectonic structures”, i. e., the seismic risk is not evaluated from actual geological faults with a given seismic potential, but from sources diffusely distributed on the considered Tectonic Province.

The above expression can be further developed and put in the form of a Gumbel distribution:

$$\Sigma N = 1/\ T_M = \alpha\ .\ \exp(-\beta\ .\ M)\ ,\ \text{with}\ \ \alpha = 27530\ \ \text{and}\ \beta = 2.948.$$

T_M is the reference return period (in years) of an earthquake of magnitude at least equal to M, and is the inverse of the variable (ΣN) above defined. Additionally, according to Poisson's formula:

$$R_D\ (M, D) = 1 - \exp[- D\ .\ \alpha\ .\ \exp(-\beta\ .\ M)] = 1 - \exp(-D / T_M) \quad \textit{or} \quad \ln[1 - R_D\ (M)] = -D / T_M$$

R_D is the risk of occurrence of an earthquake of magnitude at least equal to M in the considered time interval D (for instance, D can be put equal to 50 years).

FIG. 2 - BRAZILIAN SOUTHEAST REGION

DEFINITION OF THE ACCELERATION PROBABILITY FUNCTION

As it can be seen in Fig. 1, the nominal design value of 0.05g for the design horizontal accelerations has been considered for Brazilian Southeast region. In the present item, it will be shown that this acceleration corresponds actually to the required probability of 90% on non-exceedance in 50 years (reference return period of 475 years), in the considered region.

For this, the commercial computer program COMREL/ SYSREL [8] has been used. It is considered that the already defined statistical distribution of seismic magnitudes has an equal probability of occurring in any point in a circumference of radius 400km, as depicted in Fig. 2. This is conservative enough, since corresponds to apply the total seismicity of the Southeast region in an area of about 500,000 km^2. For input in the COMREL program, a linear distribution (triangular) probability function is considered, between zero in the center and the maximum value in the external circle. An attenuation function has to be also defined. It is considered that the expression presented by Toro and al. [9] for Central and Eastern North America, can be also applied in Brazilian Southeast conditions:

$$\ln (a_g) = 2.07 + 1.2\,(M-6) - 1.28\,[\ln (R_M)] - 0.05 \,.\, \max [\, \ln (R_M/100), 0.0] - 0.0018\,(R_M) + \varepsilon$$

$$R_M = (r^2 + 86.5)^{1/2}$$

r - epicentral distance in km; M - magnitude m_b

ε - uncertainty parameter, with mean equal to zero and standard deviation equal to σ:

$$\sigma = [(\sigma_M)^2 + (\sigma_R)^2]^{1/2}$$

σ_M (standard deviation of the distribution of the magnitude) = 0.34 + 0.07 (M-6)

σ_R (standard deviation of the distribution of epicentral distance):

$\sigma_R = 0.54$	for $r < 5$km
$\sigma_R = 0.54 - 0.0227\,(r-5)$	for 5km $\leq r \leq$ 20 km
$\sigma_R = 0.20$	for $r > 20$ km

Results obtained with COMREL program are summarized graphically in Figs. 3 and 4. Fig 3 shows the distribution function of the horizontal accelerations a_h against $\log_{10} T_M$, being T_M the corresponding reference return period (in years) for each horizontal acceleration. The following Gumbel distribution, also shown in the figure, is considered, as an approximation for the obtained curve:

$$T_M = 1/ \exp [-40,3\,(a_h + 0.164)] \qquad (a_h \text{ in g's})$$

A much better fit is obtained in Fig. 4, plotting $\log_{10} a_h$ (horizontal accelerations a_h in cm/s^2) against $\log_{10}$ N. The following lognormal equation is considered, as an approximation for the obtained curve:

$$\log_{10} T_M = 0,594 + 2.02 \log_{10} a_h \qquad (a_h \text{ in cm/s}^2) \quad \textit{or}$$

$$\log_{10} T_M = 6.654 + 2.02 \log_{10} a_h \qquad (a_h \text{ in g's})$$

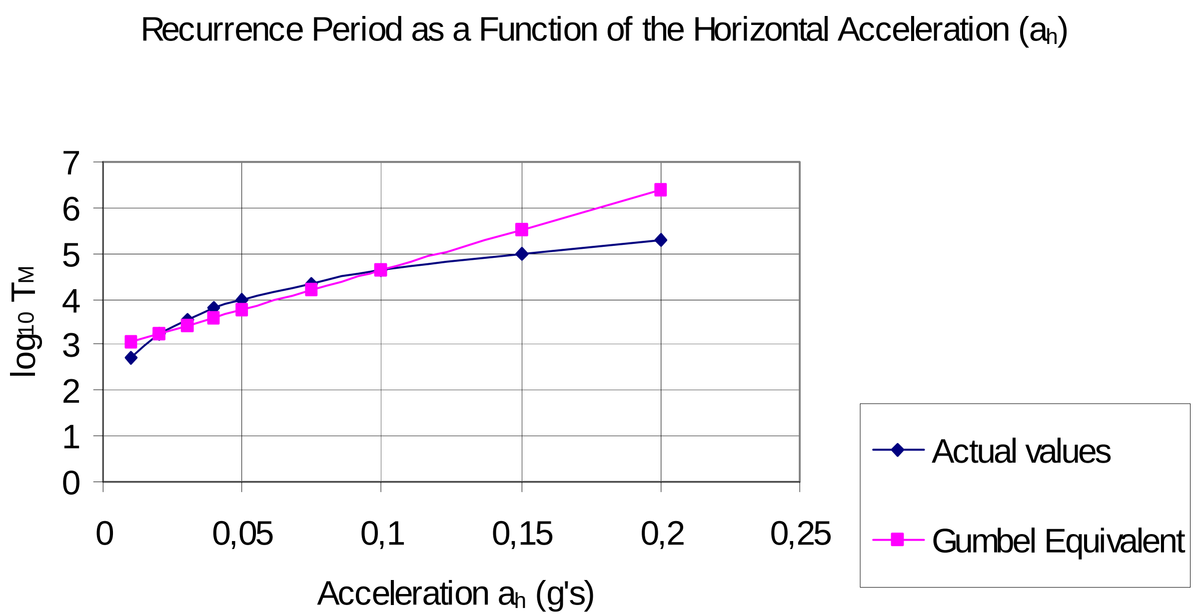

FIGURE 3 - LINEAR GUMBEL DISTRIBUTION OF ACCELERATIONS

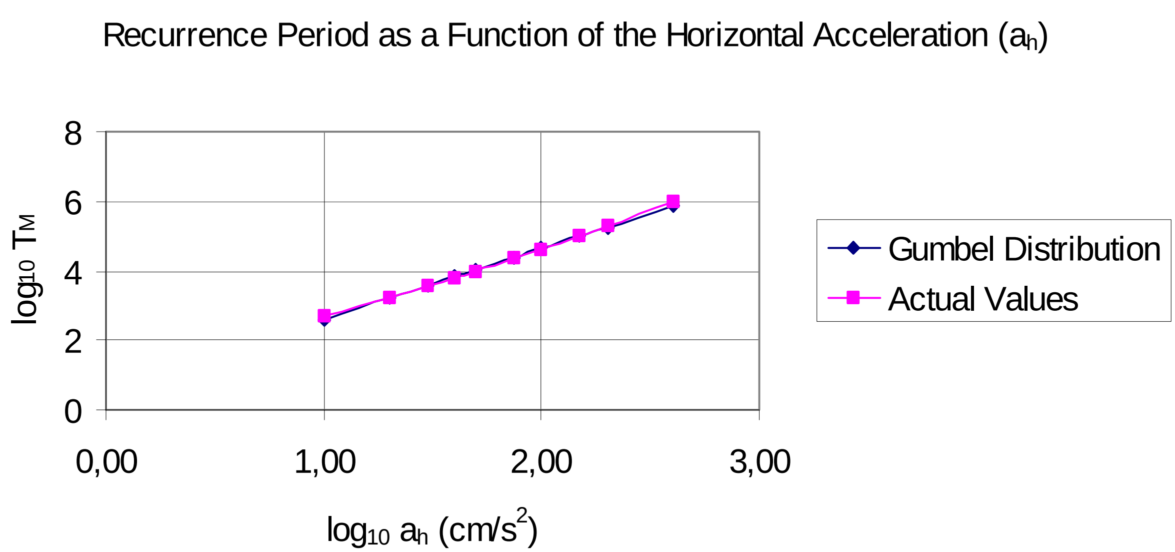

FIGURE 4 - GUMBEL DISTRIBUTION OF LOG OF ACCELERATIONS

EVALUATION OF THE RISK IN NUCLEAR PLANTS

As defined in the USNRC Regulatory Guide 1.165 [7], in its Appendix B – Reference Probability for the Exceedance Level of the Safe Shutdown Earthquake Ground Motion, the reference probability to be considered in the design of Nuclear Power Plants is 1E-5/year. According to the numerical data presented in the previous item, this probability level would correspond to a design horizontal acceleration of:

a_h = 0.152 g's

This value can be considered as non realistic and excessively conservative. It is consequent of the extrapolation of data from weak to strong earthquakes, due to the unavailability of strong motion data in Brazil. Recognizing this, Brazilian Nuclear Regulatory Body (CNEN) has been accepting (see [6]), the less conservative probability level of 1 E-4/ year. This would lead to the design horizontal acceleration:

a_h = 0.049 g's

This value is well covered by the ones actually used in the design of the Brazilian Nuclear Power Plants (a_h = 0.1 g's).

EVALUATION OF THE RISK IN USUAL STRUCTURES

For usual structures, Brazilian Standards [10] require that characteristic values for variable actions shall correspond to a nominal probability level of about 30% of being superseded in 50 years. This correspond to a reference return period of 140 years and to a design horizontal acceleration of:

a_h = 0.006 g's

A more stringent criterion can be followed, according to EUROCODE8 [11], considering a probability level of 10% of the nominal design accelerations being superseded in 50 years This correspond to a reference period of 475 years and a design horizontal acceleration of:

a_h = 0.011 g's

The proposed the design value (a_h = 0.05 g's) for usual structures in the Brazilian Southeast is therefore conservative enough, considering the present uncertainties and the scarcity of data in this region.

NUMERICAL APPLICATION

A comparison between the global effects of seismic loads and wind loads in typical commercial buildings located in Rio de Janeiro is presented in the following. A sensitivity study is done, by comparison of buildings of different heights. Obtained results are then analyzed.

Structure to be analyzed

The global analysis of a typical commercial building, schematically depicted in its transversal section in Fig.5, is presented. The considered area load (permanent plus variable) in each floor is 8 kN/m^2. The plan area of each floor is 20m x 20m = 400m^2. The building is located in the city of Rio de Janeiro.

For the sake of the comparison between the effects of wind and seismic loads, a sensitivity study is done, considering a variation in the numbers of stories between 1 and 50, which corresponds to building heights ranging between 3m and 150m.

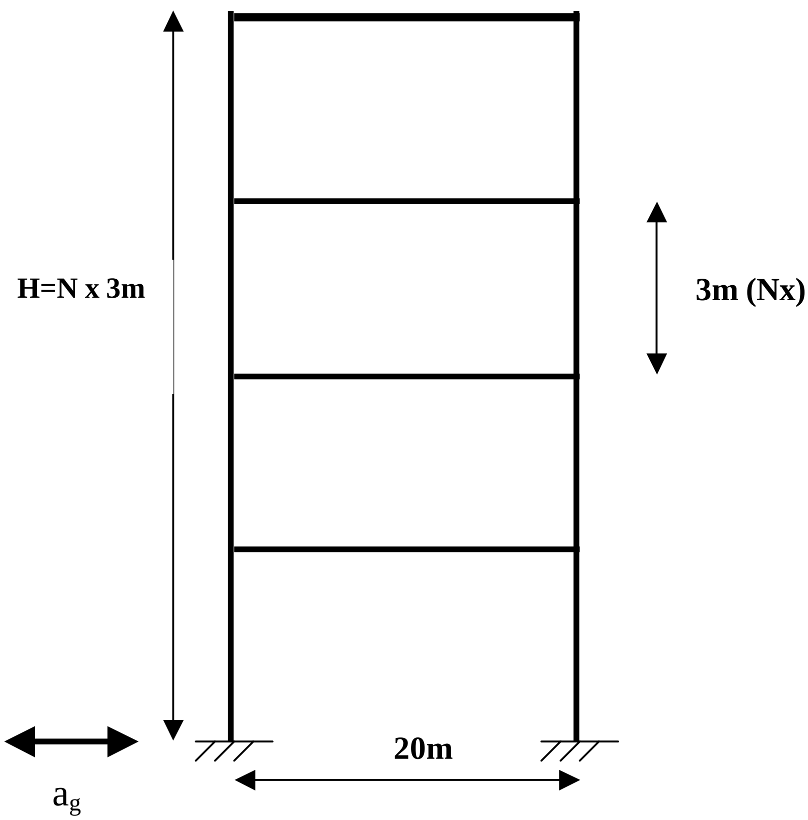

FIG. 5. N-STORY REINFORCED CONCRETE BUILDING

Analysis for seismic loads

There is not a specific Brazilian Standard for the design of seismic resistant usual structures, such as commercial and residential buildings. For this reason, the analysis for seismic loads presented herein follows the UBC97 [12]. As defined before, the basic design accelerations will be taken as equal to 0.05g. Seismic coefficients are taken as for the UBC97 Seismic Zone 1 (Z=0.075), but using a reduction proportionality coefficient of 0.5/0.75 = 0.667.

Total base shear

The Static Lateral Force Procedure, as defined in item 1630.2 of UBC97, is allowed for all structures in Seismic Zone 1. The total design base shear (V) is given by the formulas below:

$$0{,}11\,C_a\,I\,W \leq V = \frac{C_v\,I\,W}{R\,T} \leq \frac{2{,}5\,C_a}{R}\,I\,W$$

In our case, it is adopted:

I = 1.00 (occupancy category, commercial building);

R = 3.5 (ductility reduction factor, corresponding to a ordinary concrete moment-resisting frame);
$T = 0{,}0731\ (h_n)^{0,75}$ (structure period, for a concrete moment-resisting frame in a building of total height equal to h_n in meters).

In this example, a soil type S_D is considered, i.e., a stiff soil profile, with shear wave velocity Vs in the range: 180 m/s < Vs < 360 m/s. Accordingly, the seismic coefficients are taken as:

$C_a = 0.667 \,.\, 0.12 = 0.08$; $C_v = 0.667 \,.\, 0.18 = 0.12$

The total design base shear (V) is given then by:

$$0{,}0088\ W \leq \ V = 0.034 \frac{W}{T} \leq \ 0.0571 \,.\, W$$

Distribution of the total horizontal force V along the height of the building
Additional force to be applied in the top of the building:

$\underline{F_T} = 0{,}07\ T\ V \leq 0{,}25\ V$ or $\underline{F_T} = 0$ if $T \leq 0{,}7s$

Force to be applied in each floor ***i*** :

$$F_i = \frac{(V - F_T)\, w_i\, h_i}{\Sigma\, w_i\, h_i}$$

(F_i , w_i , h_i - force to be applied, weight and height of each floor with respect to the base of the building)

Analysis for wind loads
Wind forces are evaluated according to Brazilian Standard NBR6123 [13]. Characteristic wind velocity V_0 is expressed from the basic wind velocity V_K through the formula:

$$V_0 = V_K \,.\, S_1 \,.\, S_2 \,.\, S_3$$

Where V_K is the basic wind velocity, equal to 35 m/s for the city of Rio de Janeiro. S_1 and S_3 are respectively topographic and probabilistic factors, taken both equal to 1.00 in this example. Factors S_2 depend upon the height above ground, and their adopted numerical values, considering the analyzed situation (center of a big city) are given in Fig. 6. Total (pressure plus suction) effective wind pressures to be considered are given then by the expression:

$$q = (Ce - Ci) \,.\, 0.613\ V_K^{\ 2} = 1.2 \,.\, 0.613 \,.\, 35^{\ 2}\ S_2^{\ 2}\ (Pa) = 0.9\ S_2^{\ 2}\ (kPa)$$

Comparison of results
Obtained results for the analysis with earthquake and wind loads are presented through the figures presented in the following.

Fig. 7 shows the comparison between Global Shear Forces in the bases of the analyzed buildings. Seismic forces are bigger than the wind ones for buildings with up to 30 floors.

The comparison between Global Moments in the bases of the buildings is shown in Fig. 8. Seismic moments are bigger for buildings up to 35 floors. It should be considered that the level arm for seismic forces are higher than for the corresponding wind ones, as will be explained later for Fig. 10.

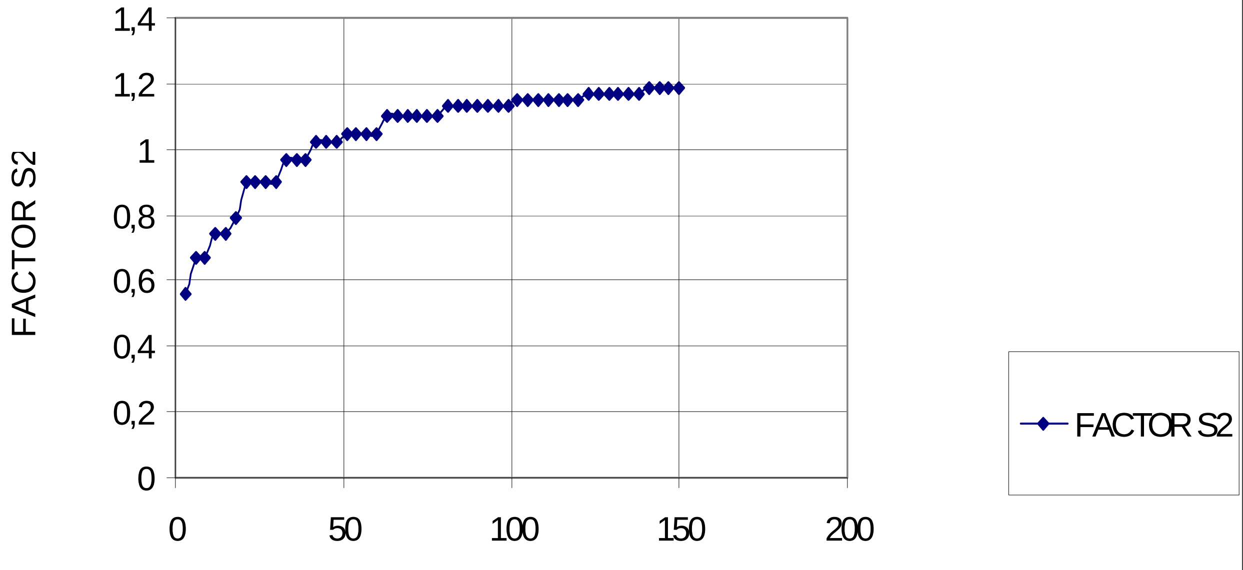

FIGURE 6 - ADOPTED FACTOR S2 ACCORDING TO BRAZILIAN STANDARD NBR6123

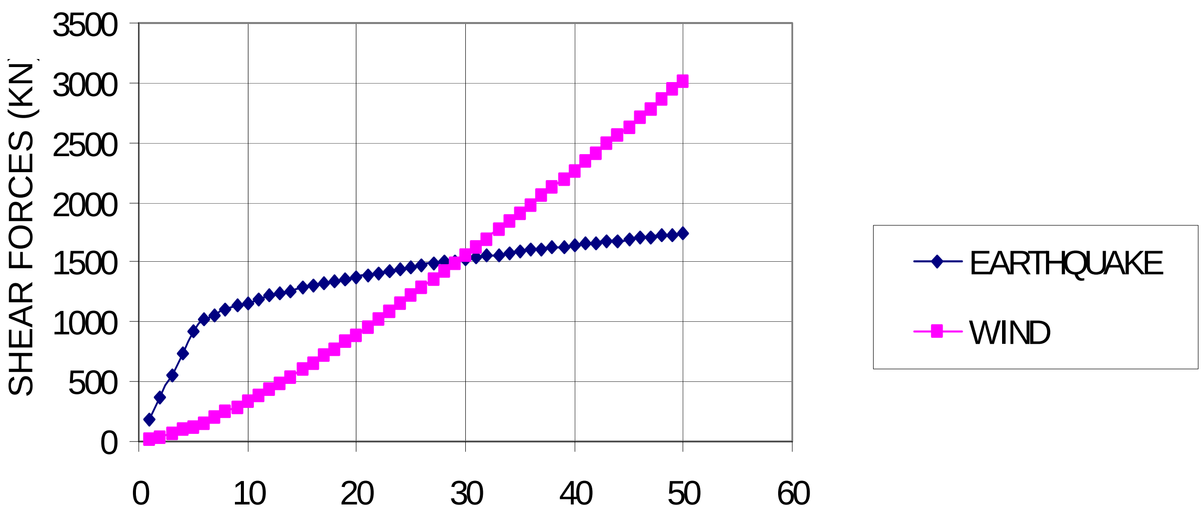

FIGURE. 7 - COMPARISON BETWEEN GLOBAL SHEAR FORCES

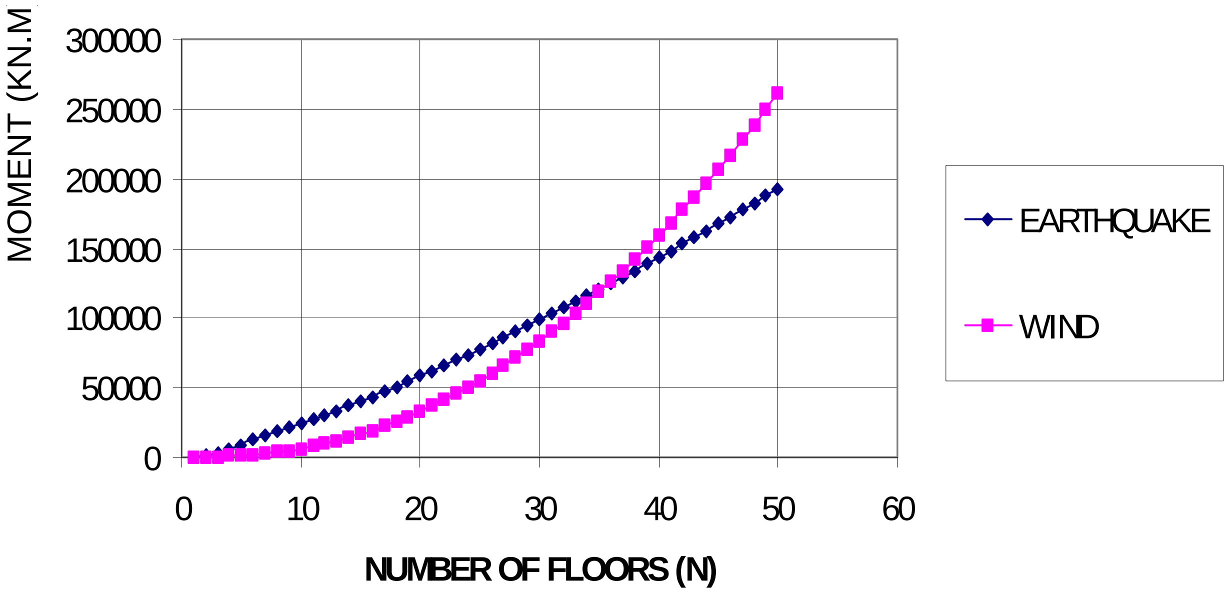

FIGURE 8 - COMPARISON BETWEEN GLOBAL MOMENTS

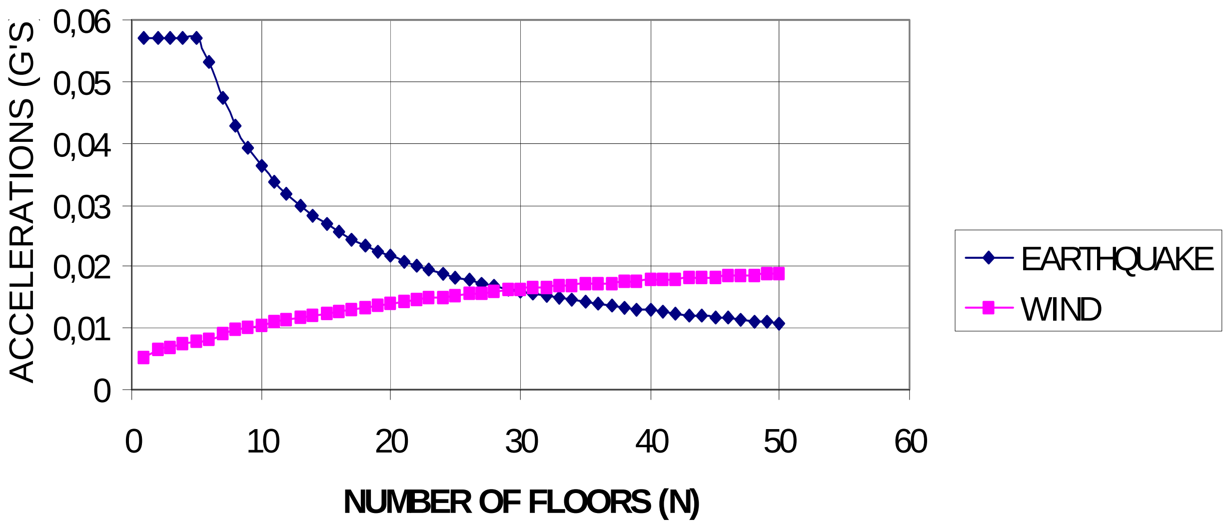

FIGURE 9 - COMPARISON BETWEEN AVERAGE HORIZONTAL ACCELERATIONS

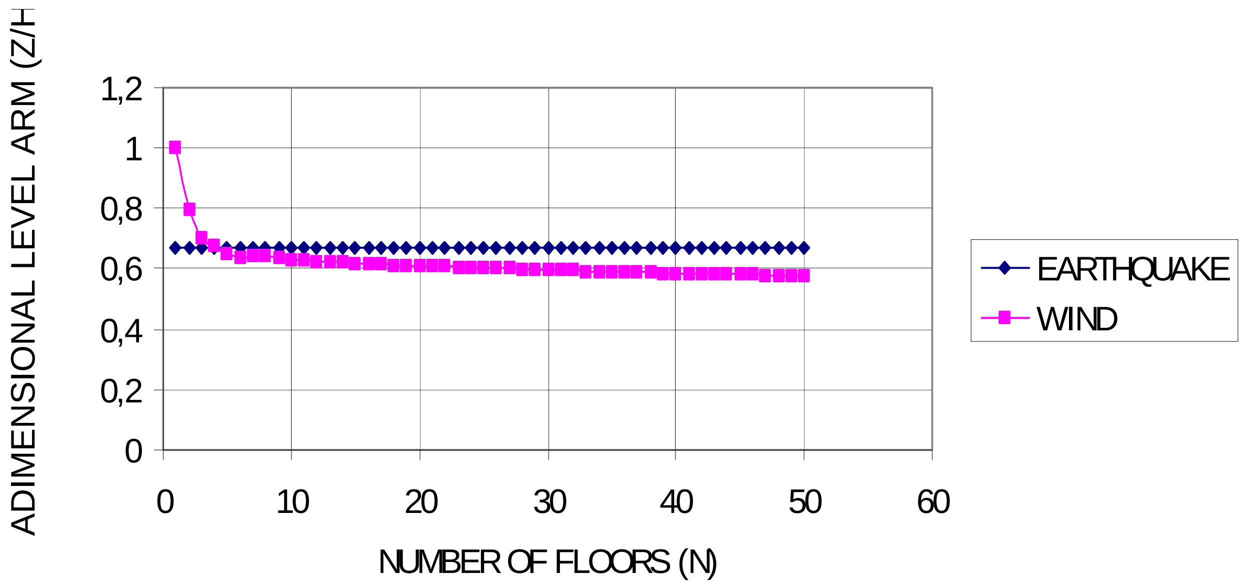

FIGURE 10 - COMPARISON BETWEEN ADOPTED RESULTANT FORCES LEVEL ARM

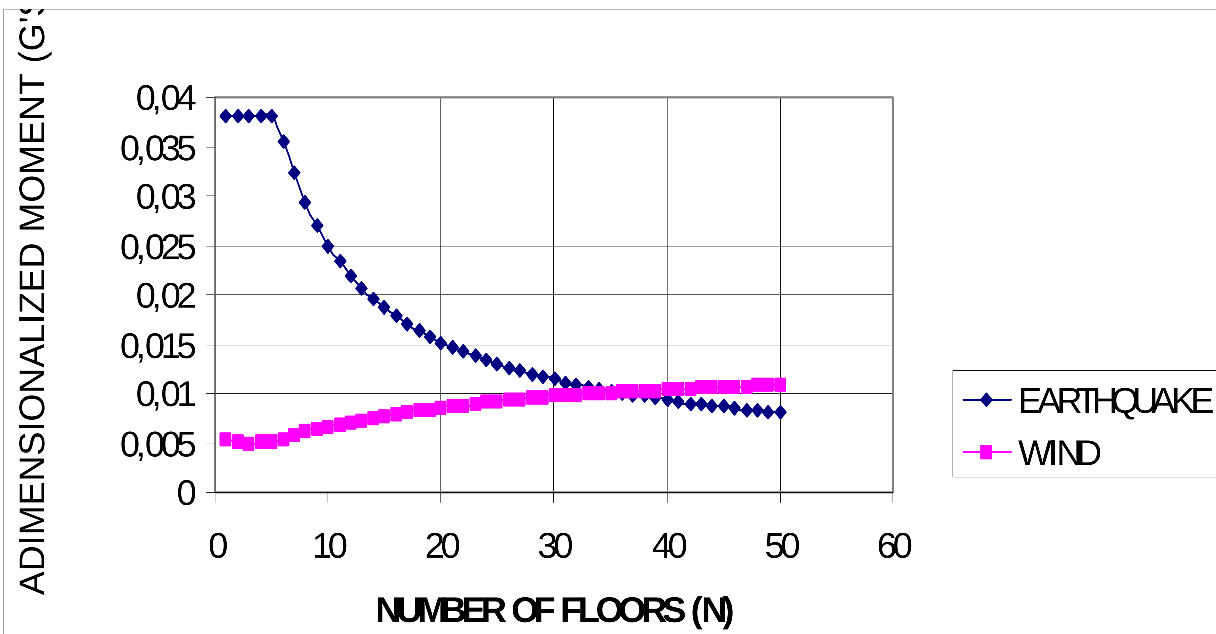

FIGURE11- COMPARISON BETWEEN ADIMENSIONALIZED GLOBAL MOMENTS (AVERAGE ACCEL.*Z/H)

A comparison between average horizontal accelerations is presented in Fig. 9. These accelerations are obtained by dividing the Global Shear Forces by the total weight of the buildings. As in Fig. 7, the seismic average accelerations are bigger than the wind ones for buildings with up to 30 floors. It is interesting to observe the variation of numerical values of the average accelerations compared with the nominal seismic design acceleration value of 0.05 g's. This variation occurs because the UBC's spectral shape is more favorable for higher buildings; it shall be also remembered the reduction due to the consideration of the factor R = 3.5 (ductility reduction factor). For a building with 30 floors, seismic and wind global shear forces are both equal to approximately 1.6% of the total weight of the buildings.

The adimensional values of the resultant level arm for seismic and wind forces are compared in Fig. 10. Dividing Global Moments by Global Shear Forces the absolute vales of the level arm are obtained; the corresponding adimensional values are obtained dividing these results by the height of the buildings. Level arms are relatively higher for seismic forces, justifying that the seismic Global Moments are slightly more unfavorable than seismic Global Shear Forces, when comparing them with the corresponding values for wind. Numerical values range between 0.6 and 0.7, and for higher buildings they approach the value 0.667 (2/3), correspondent to a triangular distribution of forces.

Global moments due to earthquake and wind are again compared in Fig.11, now through adimensional numerical values. The values are obtained by multiplying the adimensional level arms of Fig. 10 times the average accelerations. This figure allows a better understanding of the effects of the seismic forces, which are considerably bigger than the ones due to wind for buildings up to 35 floors.

CONCLUSIONS

Due to its low seismicity, Brazilian technical tradition is to not include seismic loads in the current design of the structures. Only in the design of very special structures, such as Nuclear Power Plants, seismic resistant design has been done, following specific licensing requirements. Nevertheless, considering the already available seismic data and the theoretical studies already done, it is now clear that, in Brazil, seismic effects in the structures cannot be disregarded “a priori”.

An overview of the seismicity in Brazil was presented. It became clear that seismological studies are much more developed in other South American countries than in Brazil. From extrapolation of the data available for the Brazilian neighbors, it is clear that for some of our regions a non-negligible seismic potential is present, and therefore, much more research in seismicity is urgently needed.

Brazilian Southeast is the region with more reliable available data, and the one for which more seismological studies have been done. From the already available data, a seismic risk analysis is presently possible. This analysis was presented, considering an “engineering approach”. This approach proposes to perform an evaluation of the probabilistic distribution function of the horizontal ground accelerations in a reliable and conservative way, considering the scarcity of the available data. A simplified process, using the concept of “diffuse seismicity” has been used. The seismicity of Southeast region was considered as uniformly distributed within a circle defined around the analyzed site. An attenuation function, valid for a region (CEUS) with seismic characteristics similar to the ones of Brazilian Southeast has been used.

Obtained results were applied for two types of structures: for constructions critical to the public safety, such as Nuclear Power Plants and usual structures, such as residential and commercial buildings. It has been shown that the criteria presently adopted for the first group and the ones foreseen to be used for the second one, are in accordance with the results obtained herein.

In order to clarify the application of the proposed seismic criteria, a numerical example was presented, of a commercial building in the city of Rio de Janeiro, in which horizontal forces due to wind and due to earthquake were applied. The comparison between the effects of these forces have shown that under the considered conditions, for buildings up to an average height (30 to 35 floors), seismic forces are predominant. For higher buildings, in the considered conditions, wind loads are the critical ones.

REFERENCES

1. GeoForschungsZentrum-Potsdam, "Global Seismic Hazard Map". In: www.gfz-potsdam.de/pb5/pb53/projects/en/gshap/menue_gshap_e.html. (1999).
2. Falconi RA, Báez AGH, "Zonificacion Sismica en Paises Bolivarianos". Boletin Técnico IMME; Volumen 38, no. 3; 2000; 27-41 (in Spanish).
3. Falconi RA, "Espectros Sísmicos de Riesgo Uniforme para Verificar Desempeño Estructural en Paises Latinoamericanos"; XI Seminario Iberoamericano de Ingenieria Sismica, Mendoza, Argentina; 2004 (to be published, in Spanish).
4. Associação Brasileira de Normas Técnicas (ABNT). "NBR 6118 – Design of Concrete Structures" (in Portuguese); 2003.
5. Berrocal J, Fernandes C, Bassini A, Barbosa JR. "Earthquake hazard assessment in Southeastern Brazil". Geofísica Internacional 35; 1996; 257-72.
6. Almeida AAD. "Análise Probabilística de Segurança Sísmica de Sistemas e Componentes Estruturais". Ph.D. Thesis, PUC/ Rio de Janeiro; 2002; (in Portuguese).
7. U.S. Nuclear Regulatory Commission (USNRC) – "Regulatory Guide 1.165 – Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion"; March, 1997.
8. Reliability Consulting Programs (RCP GmbH). "COMREL & SYSREL Users Manual – DEMO Version"; 1998.
9. Toro GR, Abrahamson NA, Schneider JF, – "Model of Strong Ground Motions from Earthquakes in Central and Eastern North America: Best Estimates and Uncertainties". Seismological Research Letters 68; 1997; 41-57.
10. Associação Brasileira de Normas Técnicas (ABNT). "NBR 8681 – Actions and Safety in Structures" (in Portuguese); 2003.
11. European Committee for Standardization (CEN). "EUROCODE 8 - Design of Structures for Earthquake Resistance – Draft no.1"; May, 2000.
12. International Council of Building Officials (ICBO). "Uniform Building Code (UBC97)"; Whittier; 1997.
13. Associação Brasileira de Normas Técnicas (ABNT). "NBR 6123 – Forces due to Wind in Structures" (in Portuguese); 1988.