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Seismic Hazard for Brazilian Northeastern Region

Risco Sísmico na Região Nordeste do Brasil

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Abstract

The Brazilian territory presents low seismicity, typical of a tectonic intra-plates region. Nevertheless, the seismic effects cannot be simply disregarded in the engineering projects. Therefore, a study is presented in this paper, of the seismicity of the Brazilian Northeastern Region, which due to its proximity with the South Atlantic Ridge, presents a seismic activity rate higher than of other Brazilian regions. In this way, the seismic recurrences and the probabilistic distribution functions of spectral accelerations are determined for the region. From the obtained values, the design response spectra are defined for the region, being its values compared, for several periods, with the design spectrum presented by the Brazilian Seismic Standard NBR 15421.

Keywords: seismic hazard, seismic engineering, hazard anaysis.

Resumo

O território brasileiro apresenta baixa atividade sísmica, característica de região tectônica intra-placas. Entretanto, os efeitos dos sismos não podem ser simplesmente desconsiderados em projetos de engenharia. Assim, é apresentado neste trabalho um estudo da sismicidade da região Nordeste do Brasil, que por estar posicionada próxima à falha do Atlântico Central, a leva a apresentar uma taxa de atividade sísmica com continuidade de ocorrência mais alta do que a de outras regiões brasileiras. Dentro deste contexto, são calculadas as recorrências sísmicas e as distribuições probabilísticas de acelerações espectrais para a região. De posse desses valores, são determinados os espectros de resposta de projeto para a região, fazendo as devidas comparações entre os resultados obtidos para cada período de recorrência com o espectro apresentado pela Norma Brasileira de Sismos NBR 15421.

Palavras-chave: risco sísmico, engenharia sísmica, análise de risco.

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1. Introduction

The first scientific studies of seismicity in the Brazilian territory began around the year 1970, from which seismic data began being collected, but these studies have not yet been completed. Initially, it had been considered in Brazil data from the results of seismological studies conducted in other countries. Santos and Souza Lima [1], considering the geographical continuity between the neighboring countries of Brazil, from a study by Falcone [2], who analyzed seismic design standards for six South American countries excluding Brazil, consolidated a seismicity map of Brazil. These studies provided the basis for the proposal of the Brazilian Standard for the Design of Seismic-Resistant Structures, NBR 15421 [3]. This Standard considers that most of Brazil has low seismicity, but in two regions, part of the Northeast and parts of North and Central West (Western Amazonia), the seismic potential is not negligible.

The present paper aims to present a detailed analysis of the seismicity of the Brazilian Northeastern Region and to obtain their nominal horizontal accelerations, according to the periods of recurrence of seismic events and their design response spectra for seismic analysis in order to compare them with the spectrum of NBR 15421. The seismic data available and the studies already done for defining the functions of probability distribution of earthquake magnitudes are used. This same subject has been already presented more briefly by Santos and Souza Lima [4]. The paper summarizes part of Graduation Project of the third author, performed at the Polytechnic School of UFRJ, under the guidance of the first two authors.

2. Seismic data in Brazil and South America

The analysis of the seismicity of the Brazilian territory is not yet completed.. There is, however, a study of seismic risk on a global scale made by the GFZ-Potsdam Institute [5]. This study is considered by the U.S. Geological Survey [6] on its map of global seismicity, which is reproduced in Figure 1 for South America.

The map shows that Brazilian territory has a very low seismicity, with horizontal accelerations usually less than 0.4 m / s ^{2}. It is noteworthy also that in some areas of Brazil, the seismicity is not negligible. Regions with higher seismicity are some Northeastern states, due to its position with respect to the failure of the Central Atlantic Ridge and the western part of the North and Midwest regions, due to its proximity to the Andes.

In a paper presented by Falconi and Baez [7] a study of the seismicity in South America is presented. In a more recent paper, previously cited, Falconi [2] presents a comparative analysis of the standards for seismic design of six South American countries. Brazil was not included in this study, but the actual Brazilian seismic activity, mainly in its Northern areas can be inferred using data from the seismic zoning of neighboring countries.

Considering these studies and taking into account the geographical continuity between neighboring countries, the map of seismic activity in Brazil was consolidated by Santos and Souza Lima [1]. The same analyses were used to define the seismic zones of Brazil in the NBR 15421. Brazilian seismicity zones and their respective nominal values of the horizontal accelerations a_g are shown in Figure 2, where g is the gravity acceleration.

Figure 1 – Seismicity of South America according to U.S. Geological Survey, accelerations in m/s^2

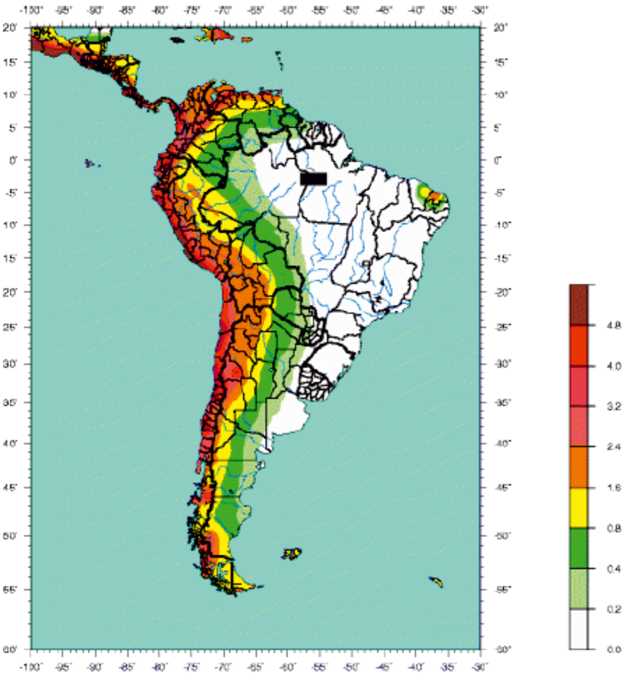


Figure 2 – Map of the seismic nominal horizontal accelerations in Brazil for soil class B (Rock)

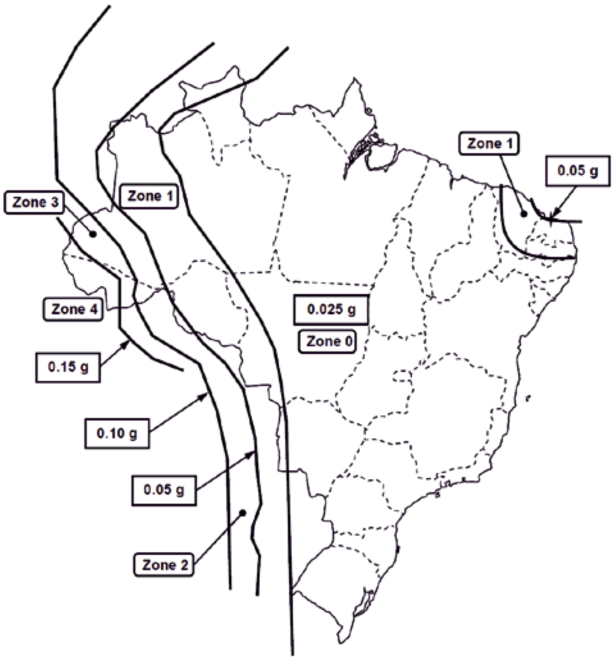
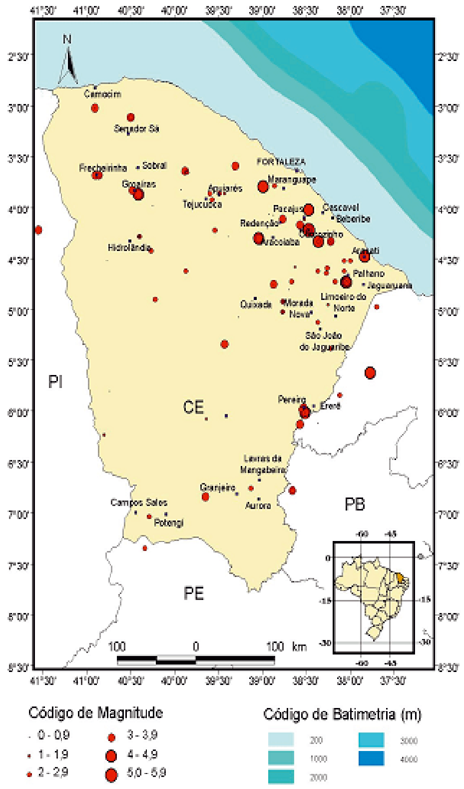


Figure 3 – Map of seismicity in the Ceará state



Most of the Brazilian territory, present an acceleration a_g equal to 0.025 g, characteristic of regions where no significant seismic events occur. However, it is also possible to observe in Figure 3, the existence of two regions, previously described, presenting the higher seismicity of the country. Accelerations defined in this figure correspond to the nominal 10% probability of being exceeded in 50 years, which corresponds to a recurrence period of 475 years.

Figure 4 shows the seismicity map of the state of Ceará, presented by Marza et al [8], containing historical and instrumented earthquakes in the time interval from 1808 to 2000. Only the most significant earthquakes are represented, being the total number of detected events in the region beyond the tens of thousands.

The temporal coverage of the earthquake catalog of the state of Ceara is very uneven, like the majority of seismic catalogs. The time lapse of the catalog is divided into two parts, each one with 96 years. The first part, the interval between 1808 and 1904, covers only 14 events, while the second part, the interval between 1905 and 2000, covers 348 events. This happens because the seismographic monitoring has been improved especially in the last 20 years. According to Table 1, it can be seen that the catalog of Ceará State includes 20 seismic events with magnitude greater than or equal to 4.0, confirming the significant seismicity in the region.

3. Calculation of seismic recurrence

Gutenberg and Richter [9] performed studies of seismic recurrence related to accumulated annual frequency, suggesting the expression below:

$$\log\left(\sum N\right) = a - b \cdot M \qquad (1)$$

In this expression, *a* and *b* are coefficients which depend on the local seismicity, *M* is the magnitude and *ΣN* is the total number of earthquakes with magnitude equal to or greater than *M* in a period of one year.
The expression above can also be written as:

$$\sum N = \frac{1}{T_M} = c.e^{(-d.M)} \qquad (2)$$

where T_M is the period of recurrence of an earthquake with a magnitude of at least equivalent to *M,* where:

Figure 4 – Discretized study areas in Ceará state

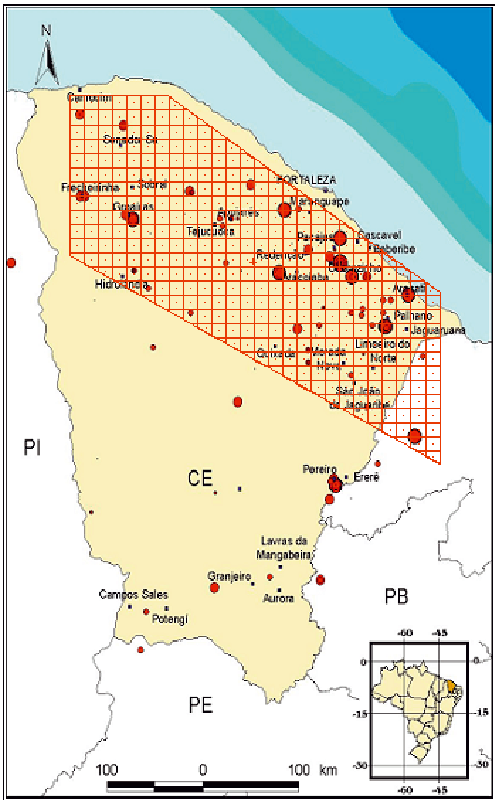


Table 1 – Earthquakes with magnitude $m_b > 4.0$ in the region in question occurred in the period 1808-2000, source (Marza et al. (8)). I_0 represents the intensity (scale Mercalli Modified), Mag is the magnitude

N°	Date AAAA/MM/DD	Lat.(°)	Long.(°)	Error (km)	Local	State	I_0 (MM)	Cat.	Area 10^3 km^2	Mag. m_b
1	1808/08/08	-05,70	-37,70	100	Açú	RN	VI	B	230	4,8
2	1903/02/14	-04,38	-38,97	30	Baturité	CE	VI	C	12	4,1
3	1903/02/15	-04,38	-38,97	30	Baturité	CE	VI	C	12	4,1
4	1903/02/16	-04,38	-38,97	30	Baturité	CE	VI	C	12	4,1
5	1919/11/24	-03,87	-38,92	50	Maranguape	CE	IV	B	70	4,5
6	1928/04/14	-04,56	-37,76		Aracatí	CE	VI	C	10	4,0
7	1968/02/15	-06,99	-38,44	10	Perreiro	CE	VI	B	11	4,1
8	1968/02/23	-06,29	-38,44	5	Perreiro	CE	VII	A	84	4,6
9	1980/11/20	-04,30	-38,40	10	Pacajús	CE	VII	A	1000	5,2
10	1988/03/20	-03,25	-40,34	2	Groaíras	CE	VI-VII	I		4,1
11	1988/10/18	-04,81	-37,98	2	Palhano	CE	VI	I		4,2
12	1988/10/29	-04,81	-37,97	2	Palhano	CE	VI	I		4,1
13	1989/03/25	-04,81	-37,97	5	Palhano	CE		I		4,1
14	1989/03/26	-04,81	-37,97	5	Palhano	CE		I		4,5
15	1989/05/26	-04,81	-37,97	5	Palhano	CE		I		4,1
16	1989/08/28	-04,81	-37,97	5	Palhano	CE		I		4,3
17	1989/10/17	-04,81	-37,97	5	Palhano	CE		I		4,2
18	1991/04/19	-03,90	-39,39	20	Taperuaba	CE	VI-VII	I	196	4,8
19	1998/06/04	-04,41	-38,29	2	Cascavel	CE		I		4,0
20	2000/07/04	-04,10	-38,40		Pitombeiras	CE		I		4,1

$$T_M(M) = \frac{1}{\sum N(M)} \tag{3}$$

Adopting this formula for seismic characterization corresponds to considering the "diffuse seismicity", as defined by McGuire [10]. This means that for this type of intra-plate tectonic region, the seismicity is assumed to have future distributions of properties and release points of energy that do not vary in time and space. The seismic risk is not evaluated taking into account that active faults presenting a potential seismic data, but diffuse sources distributed in the tectonic province considered.

Marza et al. [8] developed a study to characterize the seismicity of Ceará State that can be considered as representative and conservative enough for the region in question.

The statistical analysis of earthquakes occurrence was made, by these authors using the frequency-magnitude relation of Gutenberg and Richter, Equation 1 or Equation 2. The cumulative distribution of the frequencies of earthquakes was represented by the following relationship:

$$\log\left(\sum N\right) = 2{,}92 - 1{,}01 \cdot M \tag{4}$$

The results presented by Marza et al. have shown that the seismic potential of the State of Ceará is not negligible and the probability of occurrence of significant events (magnitude greater than or equal to 4) are quite high, as can be seen graphically in Figure 3.

4. Methodology for analysis of seismic data

The study performed for the Northeastern region is restricted to the state of Ceará, since it is considered the most active area in the condidered seismic region, as previously emphasized. The limits of the seismic area under study, shown in Figure 4, were defined in order to involve the largest number of points of occurrence of earthquakes with larger magnitudes and denser distribution points (in this case, the northern area of Ceará State). The discretized region is an area with 78.729km ^{2} in total, which was divided into 351 sub-regions with 225km^2 each one (perfect squares). Sub-regions positioned on the boundary of the total area, were considered only when presenting with an area greater than or equal to half the area of a perfect square. In this study 8 magnitudes levels have been used: $M_1 \geq 3.5$; $M_2 \geq 4.0$; $M_3 \geq 4.5$; $M_4 \geq 5.0$; $M_5 \geq 5.5$; $M_6 \geq 6.0$; $M_7 \geq 6.5$; $M_8 \geq 7.0$.

Using Equation 4 and considering the above discretization, the number of events that occur in the following ranges can be evaluated: $3.5 \leq M \leq 4.0$, $4.0 \leq M \leq 4.5$, $4.5 \leq M \leq 5.0$, $5.0 \leq M \leq 5.5$, $5.5 \leq M \leq 6.0$, $6.0 \leq M \leq 6.5$, $6.5 \leq M \leq 7.0$. This number is divided

Table 2 – Number of events in the Northeastern Region

	M	$\log(\Sigma^N)=2{,}92-1{,}01M$	Σ^N (em 1 ano)	Σ^N (em 1.000.000 anos)	Intervalos	Σ^N (intervalos)	Cada sub-região (/351)
M≥3,5	3,5	-0,615	0,24266101	242661,0095			
					3,5≤M≤4,0	166803,2520	475,2229
M≥4,0	4,0	-1,12	0,075857758	75857,7575			
					4,0≤M≤4,5	52144,0204	148,5585
M≥4,5	4,5	-1,625	0,023713737	23713,7371			
					4,5≤M≤5,0	16300,6346	46,4406
M≥5,0	5,0	-2,13	0,007413102	7413,1024			
					5,0≤M≤5,5	5095,7078	14,5177
M≥5,5	5,5	-2,635	0,002317395	2317,3946			
					5,5≤M≤6,0	1592,9587	4,5383
M≥6,0	6,0	-3,14	0,000724436	724,4360			
					6,0≤M≤6,5	497,9715	1,4187
M≥6,5	6,5	-3,645	0,000226464	226,4644			
					6,5≤M≤7,0	155,6699	0,4435
M≥7,0	7,0	-4,15	7,07946E-05	70,7946			

among the number of sub-regions that compose the total area. The results are presented in Table 2.

5. Probabilistic distribution of accelerations

There are not yet available studies defining seismic attenuation functions for the Brazilian territory. Then, it is considered that the attenuation functions proposed by Toro et al. [11] for the regions of central and eastern United States, considered areas of low seismicity within the U.S. territory, can be used in the case of Brazil, since it presents similar conditions of low seismicity. The function adopted is the following:

$$\ln(a_g)=C_1+C_2(M-6)+C_3(M-6)^2-C_4\ln R_4)-(C_5-C_4)\max[\ln(R_M/100),0]-C_6R_M \quad (5)$$

Where a_g is the spectral horizontal acceleration in g units; $R_M = (r^2 + C_7^2)^{1/2}$, being *r* the distance to the epicenter (km); *M* is the magnitude of the earthquake; C1, C2, … C7 are constants that are different for different spectral frequency values, being their values reproduced in Table 3.

6. Calculation of periods of recurrence

With values of acceleration spectra calculated for each area element, and each range of magnitudes, it is possible to evaluate how many sub-regions (discretized elements) have accelerations (g's) within the defined ranges. With these values, they are simply multiplied by the number of events that occur in one million years in each sub-region according to the considered magnitude, as presented in Table 2, and summed up for each interval of accelerations. The values of the period of recurrence were obtained by inverting the values of cumulative frequency. The evaluated results were listed according to the considered magnitude and the spectral ranges of accelerations. As examples of the obtained results, the results for the PGA (peak ground acceleration), corresponding to the frequency of 0 hertz, and the frequency of 10 hertz, are presented respectively in Tables 4 and 5.

Table 3 – Coefficients for the attenuation functions

Freq. (Hz)	C1	C2	C3	C4	C5	C6	C7
0,5	-0,97	2,52	-0,47	0,93	0,60	0,0012	7,0
1	-0,12	2,05	-0,34	0,90	0,59	0,0019	6,8
2,5	0,90	1,70	-0,26	0,94	0,65	0,0030	7,2
5	1,60	1,24	0,00	0,98	0,74	0,0039	7,5
10	2,36	1,23	0,00	1,12	1,05	0,0043	8,5
25	3,34	1,19	0,00	1,46	1,84	0,0010	10,5
35	3,87	1,19	0,00	1,58	1,90	0,0005	11,1
PGA	2,07	1,20	0,00	1,28	1,23	0,0018	9,3

Table 4 – Period of recurrence for Peak Ground Acceleration (PGA)

Número de sub-regiões com acelerações espectrais dentro dos intervalos definidos e para cada magnitude adotada - PGA															
Valores de Magnitude	Intervalos de acelerações espectrais (em g's)														
	0,0001-0,0002	0,0002-0,0005	0,0005-0,001	0,001-0,002	0,002-0,005	0,005-0,01	0,01-0,02	0,02-0,03	0,03-0,04	0,04-0,05	0,05-0,06	0,06-0,1	0,1-0,2	0,2-0,5	0,5-1,0	≥1,0
M=4,0		29	120	92	82	19	7	1	1							
M=4,5			44	117	122	43	18	3	2	1	1					
M=5,0				62	143	88	38	9	4	3	0	4				
M=5,5				2	116	100	81	24	10	5	4	5	4			
M=6,0					19	114	99	50	25	12	7	14	7	4		
M=6,5						29	120	55	37	31	21	30	19	7	2	
M=7,0							44	71	45	33	24	65	44	21	3	1
Produto do número de sub-regiões com acelerações espectrais delimitadas acima pelo número de eventos de cada sub-região em 1.000.000 anos de acordo com a magnitude - PGA															
Valores de Magnitude	Intervalos de acelerações espectrais (em g's)														
	0,0001-0,0002	0,0002-0,0005	0,0005-0,001	0,001-0,002	0,002-0,005	0,005-0,01	0,01-0,02	0,02-0,03	0,03-0,04	0,04-0,05	0,05-0,06	0,06-0,1	0,1-0,2	0,2-0,5	0,5-1,0	≥1,0
M=4,0		13781,46	57026,75	43720,51	38968,28	9029,24	3326,56	475,22	475,22							
M=4,5			6536,57	17381,34	18124,14	6388,02	2674,05	445,68	297,12	148,56	148,56					
M=5,0				2879,32	6641,01	4086,77	1764,74	417,97	185,76	139,32	0,00	185,76				
M=5,5				29,04	1684,05	1451,77	1175,93	348,42	145,18	72,59	58,07	72,59	58,07			
M=6,0					86,23	517,37	449,29	226,92	113,46	54,46	31,77	63,54	31,77	18,15		
M=6,5						41,14	170,24	78,03	52,49	43,98	29,79	42,56	26,96	9,93	2,84	
M=7,0							19,51	31,49	19,96	14,64	10,64	28,83	19,51	9,31	1,33	0,44
Somatório	0	13781,46	63563,32	64010,20	65503,70	21514,30	9580,34	2023,72	1289,19	473,54	278,83	393,28	136,31	37,40	4,17	0,44
Resultados - PGA															
Frequência Acumulada	242590,21	242590,21	228808,75	165245,42	101235,22	35731,52	14217,22	4636,88	2613,16	1323,97	850,43	571,59	178,32	42,01	4,61	0,44
Período (anos)	4,12	4,12	4,37	6,05	9,88	27,99	70,34	215,66	382,68	755,30	1175,88	1749,50	5607,98	23804,42	216853,88	2254791,43

7. Nominal horizontal accelerations

According to NBR 15 421 [3], the period of recurrence established as the basic criterion for defining the nominal values of horizontal accelerations is 475 years. ASCE [12] assumes the values of horizontal accelerations equal to two thirds of the values of accelerations corresponding to the period of recurrence of 2475 years.

In the sequel, the graphs of horizontal accelerations (g's) versus period of recurrence (years) calculated for the Northeastern region (Figures 5 and 6) are presented. In these graphs, the intersections of curves corresponding to each of the periods considered in the construction of the spectra, with vertical lines corresponding to the periods of recurrence of 475 years and 2475 years, give the values of the accelerations to be assigned in the spectra of equal probability, remembering that in the latter case, the factor of 2/3 should be applied.

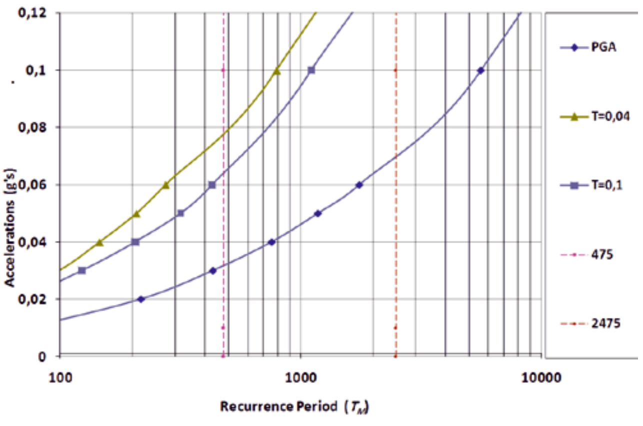
8. Design Spectra

The concept of design spectrum is naturally linked to the concept of response spectrum. Response spectrum may be defined as a graph showing the maximum response, in terms of displacement, velocity or acceleration, depending on the natural period of system with one degree of freedom, considering a certain excitation.

Tabel 5 – Period of recurrence for the frequency of 10 hertz

Número de sub-regiões com acelerações espectrais dentro dos intervalos definidos e para cada magnitude adotada - F=35Hz															
Valores de Magnitude	Intervalos de acelerações espectrais (em g's)														
	0,0001-0,0002	0,0002-0,0005	0,0005-0,001	0,001-0,002	0,002-0,005	0,005-0,01	0,01-0,02	0,02-0,03	0,03-0,04	0,04-0,05	0,05-0,06	0,06-0,1	0,1-0,2	0,2-0,5	0,5-1,0	≥1,0
M=4,0			20	137	124	41	16	7	2	2		2				
M=4,5				36	170	85	34	12	5	2	3	2	2			
M=5,0					106	117	73	23	10	6	3	7	4	2		
M=5,5					4	122	109	46	21	14	6	15	10	4		
M=6,0						12	134	61	41	24	19	29	18	10	3	
M=6,5							23	84	53	39	24	59	41	21	5	2
M=7,0								4	35	52	35	85	82	40	11	7
Produto do número de sub-regiões com acelerações espectrais delimitadas acima pelo número de eventos de cada sub-região em 1.000.000 anos de acordo com a magnitude - F=35Hz															
Valores de Magnitude	Intervalos de acelerações espectrais (em g's)														
	0,0001-0,0002	0,0002-0,0005	0,0005-0,001	0,001-0,002	0,002-0,005	0,005-0,01	0,01-0,02	0,02-0,03	0,03-0,04	0,04-0,05	0,05-0,06	0,06-0,1	0,1-0,2	0,2-0,5	0,5-1,0	≥1,0
M=4,0			9504,46	65105,54	58927,64	19484,14	7603,57	3326,56	950,45	950,45	0,00	950,45				
M=4,5				5348,11	25254,95	12627,47	5050,99	1782,70	742,79	297,12	445,68	297,12	297,12			
M=5,0					4922,70	5433,55	3390,16	1068,13	464,41	278,64	139,32	325,08	185,76	92,88		
M=5,5					58,07	1771,16	1582,43	667,81	304,87	203,25	87,11	217,77	145,18	58,07		
M=6,0						54,46	608,13	276,84	186,07	108,92	86,23	131,61	81,69	45,38	13,61	
M=6,5							32,63	119,17	75,19	55,33	34,05	83,70	58,17	29,79	7,09	2,84
M=7,0								1,77	15,52	23,06	15,52	37,70	36,37	17,74	4,88	3,10
Somatório	0	0,00	9504,46	70453,64	89163,36	39370,78	18267,91	7242,99	2739,30	1916,76	807,90	2043,42	804,28	243,87	25,59	5,94
Resultados - F=35Hz															
Frequência Acumulada	242590,21	242590,21	242590,21	233085,75	162632,11	73468,75	34097,97	15830,06	8587,07	5847,77	3931,00	3123,10	1079,68	275,40	31,53	5,94
Período (anos)	4,12	4,12	4,12	4,29	6,15	13,61	29,33	63,17	116,45	171,01	254,39	320,19	926,20	3631,13	31717,03	168296,34

Figure 5 – Horizontal acceleration (g's) x Recurrence Period (years) for PGA, T = 0.04 and T = 0.1 s



Response spectra for accelerations at the base are important in seismic analysis, because the accelerations produced by an earthquake are the more significant way to characterize its effects on structures. With the response of a system of one degree of freedom subjected to movement in its base, the equations of the displacements, velocities and accelerations of the mass relative to basis of the structure can be obtained. Combining these equations,

$$S_a = \omega^2 . S_d \qquad (6)$$

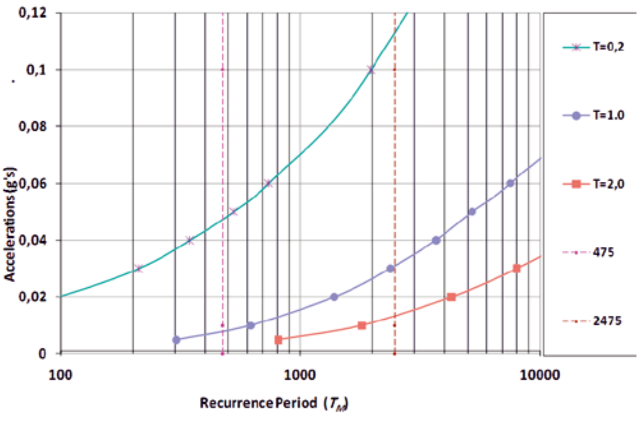
we obtain a differential equation of relative motion whose solution provides the conditions to calculate displacements, velocities, and subsequently the absolute accelerations. For lightly damped systems, the pseudo-acceleration S_a, defined in equation 6 is a good approximation of the absolute acceleration.

Where ω represents the circular frequency and S_d the spectral displacement.

The maximum values of absolute accelerations are called spectral accelerations and the variation of this quantity as a function of natural period is the spectrum of acceleration or response spectrum. Design spectra are made from a set of response spectra for earthquakes that occurred at the site of interest by statistical criteria. Therefore, the response spectrum has no direct application in the design or verification of structures, since it represents a particular earthquake at a certain place and it is not assured that its features recur in future earthquakes. Within this context, from the graphs presented in item 7, the response spectra are obtained. As described above, the intersections of curves corresponding to the periods considered, with the lines for the recurrence periods of 475 years and 2475 years, give the values of the accelerations of the spectra of equal probability. These were, therefore, the values of horizontal accelerations used to define the design spectrum presented in the graph shown in Figure 7.

Table 6 presents the input data to define the spectrum of responses to the Northeastern region. In this table, the first column list all

Figure 6 – Horizontal acceleration (g's) x Recurrence Period (years) for T = 0.2 s, T = 1.0 s and T = 2.0s

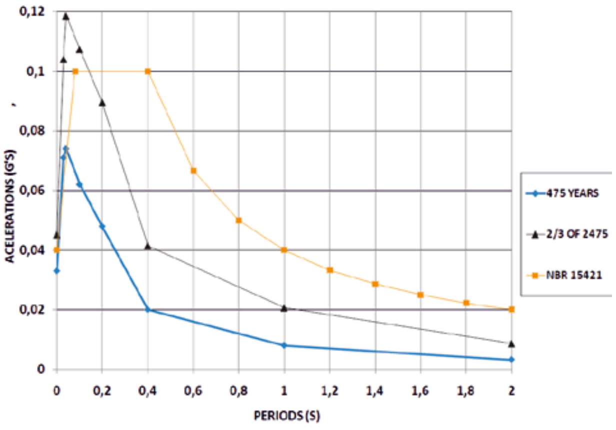


the frequencies under which were made the graphs of horizontal acceleration (g's) x period of recurrence (years) and the second column equals the inverse of the first, representing the periods (in seconds) corresponding to each frequently studied. The third column lists the values of spectral accelerations obtained from the graphs of Figures 5 and 6 for the period of recurrence of 475 years. The fourth column lists the values of spectral accelerations for the period of recurrence of 2475 years. And finally, the fifth column lists the values of spectral accelerations of the fourth column multiplied by 2/3 to meet the criterion of nominal values of horizontal accelerations according to ASCE [12].

9. Final remarks and conclusion

The results presented in the graph in Figure 7 and the spectrum for the region, respectively, show that the design spectrum defined by NBR 15421 [3] (red curve) is conservative enough. It is important

Figure 7 – Design spectra for the Northeastern region



point out that the spectrum defined by the Brazilian Standard takes into account a period of recurrence of 475 years. Considering this, it can be observed in the graphs that the curve on the spectrum of standard exceeds the curve of response spectrum considering a recurrence time of 475 years (blue curve). It is also observed that the curve on the response spectrum obtained according to the ASCE [12] (yellow curve), where it is established that the nominal values of horizontal accelerations are taken as two thirds of the values corresponding to the time of recurrence 2475 years, is also covered by the design spectrum of NBR 15421 [3].

Therefore, NBR 15421 [3] appears to be conservative enough for this region and may be adopted as a standard reference for the design spectrum to be used in seismic analysis of building structures.

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Table 6 – Data for defining the response spectra (Northeast Region)

Frequency (Hz)	Periodo (s)	Horizontal Acceleration (g's)		
		475 years	2475 years	2/3 de 2475 years
PGA	0	0,033	0,070	0,046
35	0,03	0,074	0,174	0,116
25	0,04	0,075	0,182	0,121
10	0,1	0,064	0,148	0,098
5	0,2	0,050	0,116	0,077
2,5	0,4	0,019	0,063	0,042
1	1	0,008	0,031	0,021
0,5	2	0,003	0,013	0,009