A Seismic Hazard Analysis in the Southeast Region of Brazil

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Abstract. This paper presents an overview of the results obtained from a seismic hazard analysis in the Southeast region of Brazil. The results provide seismic parameters and criteria for the Maximum Credible Earthquake (MCE) and design earthquakes considering return periods of 100, 475, 2475, 4975 and 9975 years for a class B (rock) site.

Keywords: seismic hazard, Southeast region of Brazil, design spectra.

1 Introduction

This paper presents a probabilistic and deterministic analysis, specific for Southeast region of Brazil, to estimate the severity of seismic motions and their annual exceedance rate and corresponding return periods that could affect structures near the city of Belo Horizonte - MG. The research scopes includes:

- Selection and processing of seismic catalogs;
- Seismic sources characterization;
- Probabilistic analysis for return periods of 100, 475, 2475, 4975 and 9975 years;
- Development of a logic tree to quantify uncertainties;
- Selection and use of recent ground motion prediction equations;
- Deterministic seismic hazard analysis;
- This paper also includes justifications for the considered parameters, as well as figures and tables containing the results of the study.

2 Seismic Sources

The delimitation of seismic sources is complex, since the information of the intraplate seismicity is diffuse (there are no geological features related to the origin of motions) and different models are discussed in the literature. This study is based on a specific seismotectonic model within a 500 km radius from the site of interest – the city of Belo Horizonte. Four seismic sources (F1, F2, F3 and F4) have been identified within the continental crustal area; although the tectonic settings are similar for all sources, their earthquakes frequencies are different. The geometric forms of the seismic sources are based on those proposed by the South America Risk Assessment (SARA) project [1]. Regional seismicity can produce moderate events, a maximum moment magnitude Mw of 6.0 was registered with an average depth of 10 km. Figure 1 shows a view of the earthquakes and sources considered in this study.

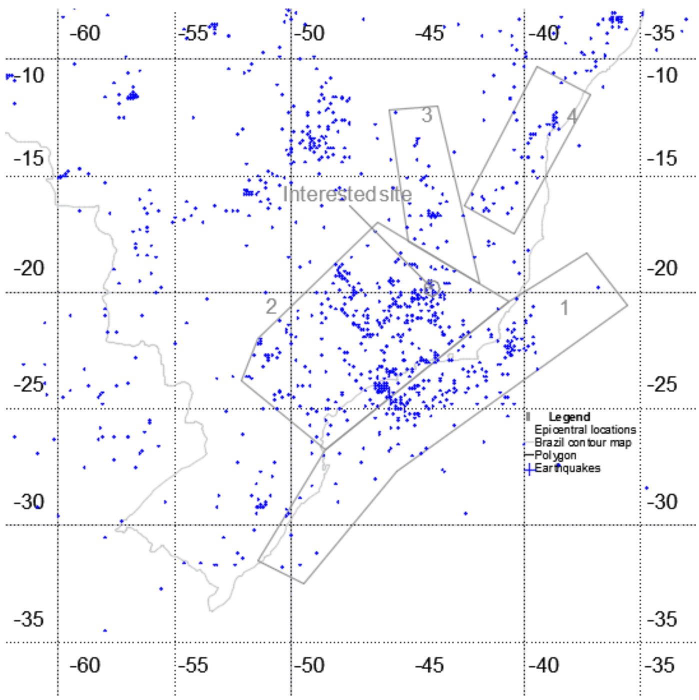

Figure 1. View of the seismic sources

2.1 Seismic Return Periods

In order to determine the seismic parameters for a recurrence model, an instrumental and historical catalog has been compiled, with earthquakes since 1724 to 2020, from several international agencies. Because the magnitudes of seismic events were in different scales, the seismic catalog was standardized to moment magnitude (Mw). Seismic events of unspecified magnitude were assumed to be Mw. Filtering of the seismic catalog consisted of the elimination of duplicate and aftershock events. This process was carried out using the algorithm proposed by Stiphout et al. [2] which establishes a criteria of spatial and temporal filtering to determine main or independent seismic events. The seismic information contained in the catalog is not complete at different time intervals. The completeness of the catalogue was assessed by using the visual cumulative method by which the cumulative number of events for a specific magnitude range in plotted against the years. The catalogue is considered complete for a specific magnitude range when in some time window a straight line can approximate the observed number of events (Fig. 2). Table 1 shows the time intervals with complete periods.

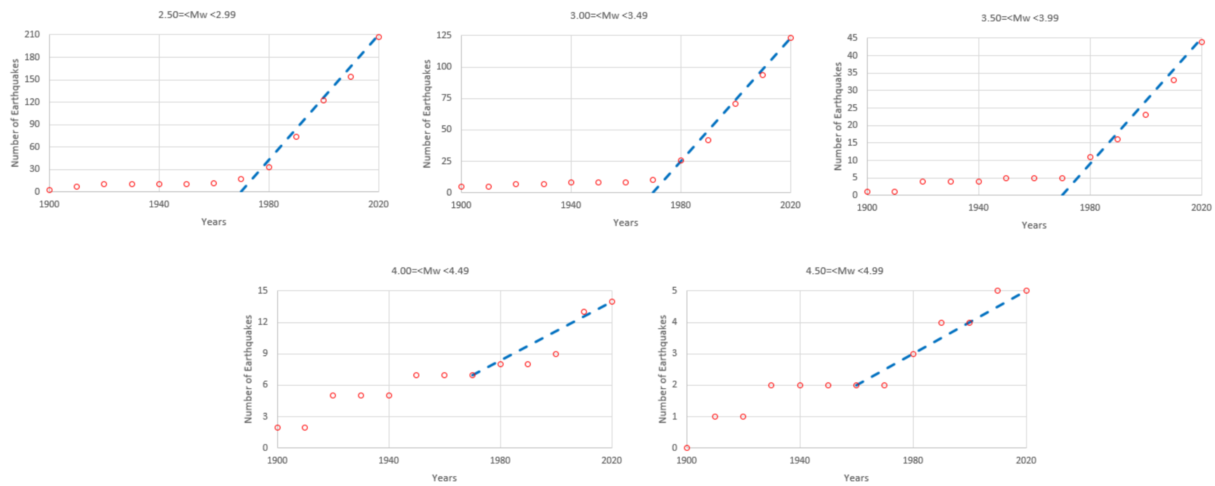

Figure 2. Visual Method for Estimation of Different Magnitude Ranges

Table 1. Time Intervals with Complete Periods

Range of Magnitudes	Year
2.50 – 2.99	1970
3.00 – 3.49	1970
3.50 – 3.99	1970
4.00 – 4.49	1970
4.50 – 4.99	1960

2.2 Seismic Recurrence Parameters

Table 2 shows the seismic recurrence parameters used for each seismic source.

Table 2. Seismic Recurrence Parameters

Source	M_{max}	β	$\lambda_{expected}$	Depth (km)
F1	7.0	1.7	0.8	5
F2	7.0	2.5	0.7	5
F3	6.5	1.6	0.2	5
F4	6.5	2.7	0.5	5

where:

- M_{max}: maximum expected magnitude
- β: β = b ln 10, and b is the slope of the linear logarithmic relationship of earthquake frequency versus magnitudes which controls the frequency of occurrence of earthquakes with different magnitudes.
- λ: is defined as the average annual rate of occurrence of events greater than or equal to the minimum magnitude.
- Depth: based on the depth of occurrence of earthquakes.

2.3 Prediction Relationships of Ground Motions

Seismicity in Brazil is low and the catalog presents limited records (unregistered earthquakes prior 1972). Therefore, the development of specific attenuation relationships to estimate ground motion parameters such as spectral acceleration for Brazil is not available yet. For this reason, it is a common practice to use attenuation laws developed in different regions, if they obey the same tectonic process for earthquake generation as in Brazil (CSR – Continental Stable Region). In the present study, the GMPE (Ground Motion Prediction Equations) developed by Toro et al [3], Atkinson [4] and Pezeshk et al [5] were used, because these equations are developed for areas with similar geologic characteristics. Campbell [6] was referenced in this document, but this ground motion estimation is applicable on hard rock with a shear-wave velocity of 2800 m/sec, and for this study it was assumed a V_{s30} = 1100 m/sec (V_{s30} is the shear wave velocity for the first 30 meters of the stratigraphic profile). Table 3 shows the attenuation laws by seismic source.

Table 3. GMPE by Seismic Source

Source	Type	GMPE
F1 F2 F3 F4	Crustal	Atkinson and Boore (2008), Pezeshk et al (2011) and Toro et al (1997)

3 Seismic Hazard Analysis

The seismic hazard analysis was performed considering the site with coordinates of latitude

-19.80°S and longitude -43.15°W. If structures are built on soils with Vs30 < 1100 m/sec, an amplification of these predicted accelerations would occur but, typically, dams are founded on rock or hard material. In order to consider the epistemic uncertainties for this study a logic tree was used for the seismogenic sources, which is shown in Fig. 3.

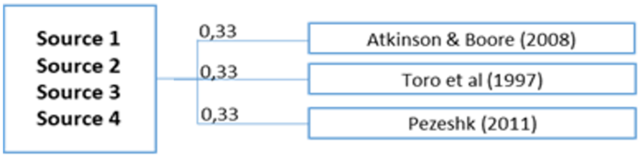

Figure 3. Logic Tree by Seismic Sources

3.1 Probabilistic Seismic Hazard Assessment (PSHA)

Figure 4 presents the seismic hazard curves obtained by the probabilistic method considering 5% of critical damping ratio for Peak Ground Acceleration (PGA) and spectral accelerations at periods of 0.04 sec and 1.0 sec.

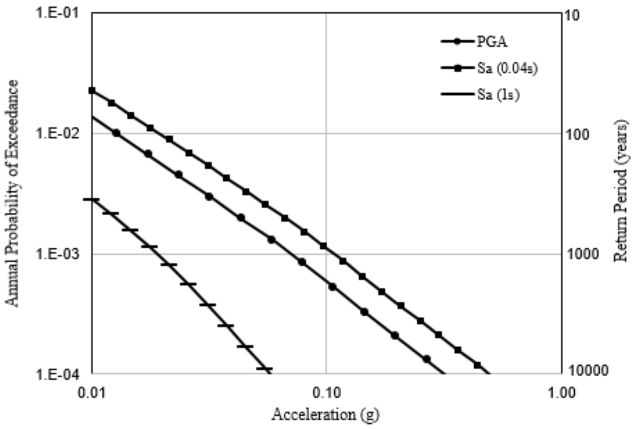

Figure 4. Curves of Probabilistic Seismic Hazard Assessment

The total seismic hazard curves and the contribution for each seismic source considering the PGA are shown in Fig. 5. The analysis of seismic disaggregation shows that F2 source has the greatest influence on the predicted responses and source F4 has a very small contribution to the seismic hazard analysis.

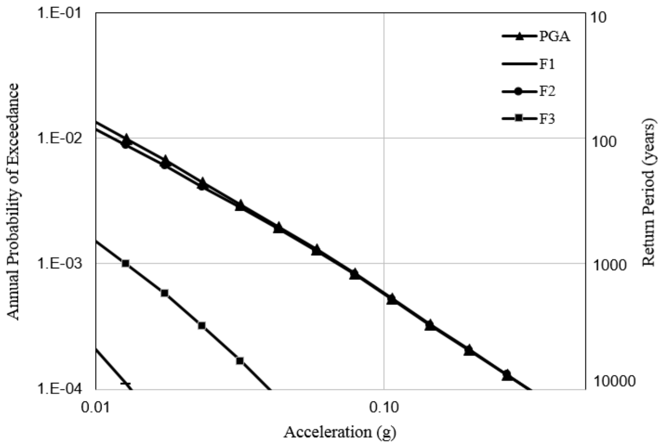

Figure 5. Curves of Seismic Hazard by Seismic Source

PGA values, calculated for different exceedance probabilities in 50 years of exposure to different return periods, are presented in Tab. 4. The spectral accelerations for different periods of vibration for the same return periods are listed in Tab. 5 and Fig. 6 shows the average seismic hazard spectra, for return periods (YRP) of 100, 475, 2475, 4975 and 9975 years.

Table 4. Peak Ground Acceleration (PGA) - PSHA

Return Period (Years)	Exceedance Probability in 50 years	Maximum Expected Acceleration (PGA) g
100	3.93E-01	0.01
475	9.99E-02	0.04
2475	2.00E-02	0.13
4975	1.00E-02	0.20
9975	5.00E-03	0.32

Table 5. Maximum and Spectral Accelerations (Sa)

Return Periods (Years)	PGA	Sa 0.04	Sa 0.1	Sa 0.2	Sa 0.4	Sa 1	Sa 2
100	0.01	0.02	0.02	0.02	0.01	0.00	0.00
475	0.04	0.06	0.06	0.05	0.03	0.01	0.01
2475	0.13	0.19	0.16	0.11	0.07	0.03	0.01
4975	0.20	0.31	0.22	0.16	0.10	0.04	0.02
9975	0.32	0.49	0.32	0.22	0.13	0.06	0.03

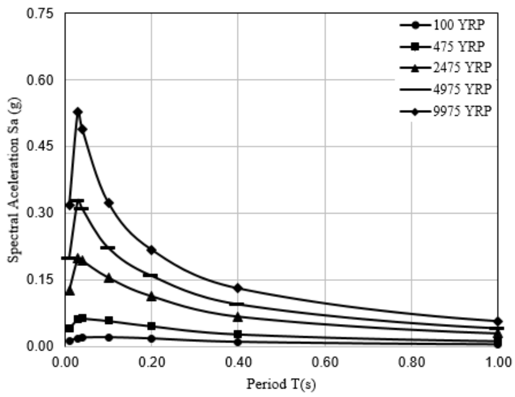

Figure 6. Uniform Spectra - PSHA

Figure 7 presents the results of seismic disaggregation by magnitude and distance for the analyzed site, considering design earthquake with 475, 2475 and 9975 years of return period, from PGA to Sa (0.04sec) or Sa (1.0sec). For return period of 475, 4975 and 9975 and from PGA to Sa (0.04), the events with highest incidence correspond to earthquakes of average magnitude of 4.16 and focal distance of 11 km. For return period of 475 years and Sa (1.0), the main events have an average magnitude of 6.16 and focal distance of 109 km, while for return period of 4975 and 9975 years and Sa (1.0), the events with highest incidence correspond to earthquakes of average magnitude of 5.83 and focal distance of 11 km.

3.2 Results of Deterministic Seismic Hazard Assessment (DSHA)

Results from a deterministic seismic hazard assessment are shown in Tab. 6. Values are given for the mean (50^{th} percentile) and the mean + one standard deviation (84^{th} percentile). The deterministic predictions were obtained from the geometric average of the maximum horizontal acceleration by applying the GMPEs defined by Toro et al. [3], Atkinson [4] and Pezeshk et al. [5] for crustal earthquakes. Values computed from the seismic disaggregation (magnitude 4.16 a focal distance of 11 km), corresponding to F2 source, were used in the DSHA. According to results from the previous analysis, the site is mainly affected by earthquakes generated in source F2. Assuming that an earthquake occurs exactly below the site of interest, the results show a maximum horizontal ground acceleration of 0.32g for the 84^{th} percentile and 0.18g for the 50^{th} percentile.

Figure 8 shows the spectral accelerations from the deterministic analysis and Fig. 9 compares the uniform spectral from PSHA with spectral accelerations from DHSA analysis.

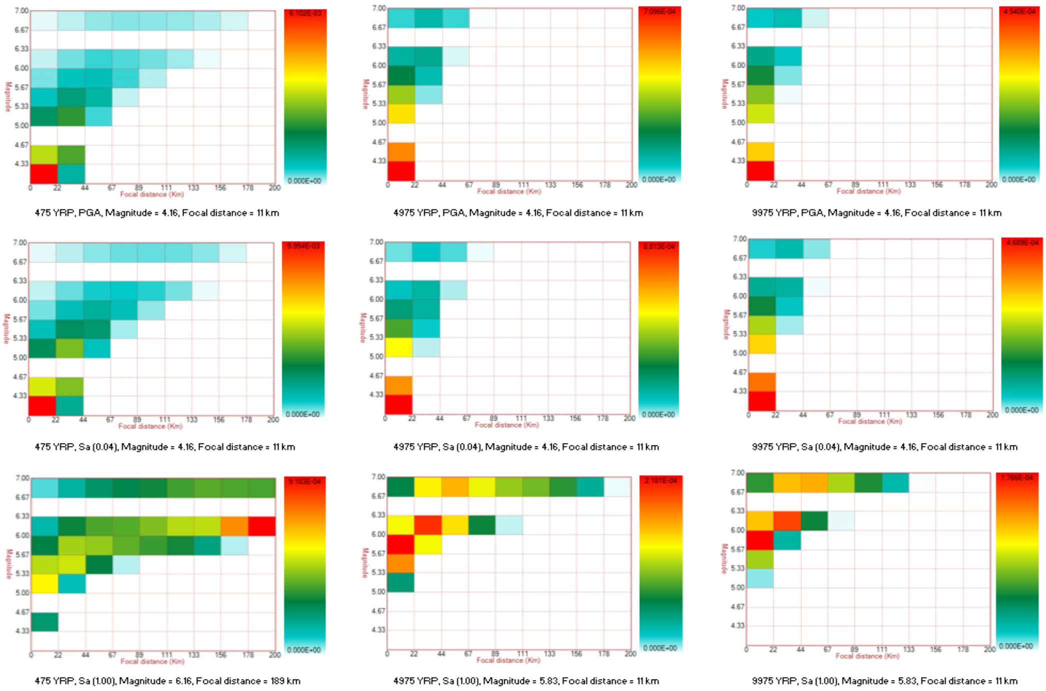

Figure 7. Seismic Disaggregation by Magnitude and Distance

Table 6. Results of the Deterministic Seismic Hazard Assessment

Seismic Scenario	Percentile	Sa						
		PGA	0.04	0.1	0.2	0.4	1	2
M 4.16	P (84)	0.324	0.468	0.391	0.222	0.088	0.014	0.002
Focal distance = 11 km	P (50)	0.177	0.253	0.218	0.123	0.048	0.008	0.001

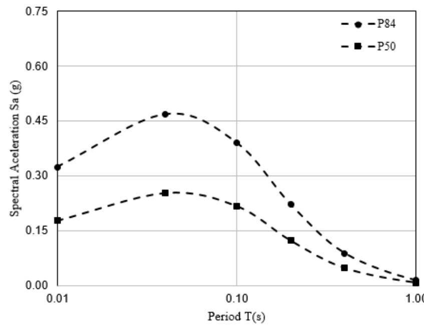

Figure 8. Spectral Acceleration - DSHA

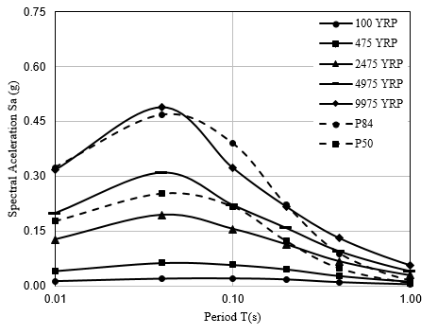

Figure 9. Spectral Acceleration from PSHA and DSHA

The maximum credible earthquake spectrum MCE obtained considering the 84th percentile (P.84) associated with an earthquake of magnitude Mw=4.16, focal distance of 11 km is close to the spectra obtained from the PSHA assessment with return period of 9975 years from PGA to Sa (0.04s). For acceleration higher than Sa (0.04s) it increases until Sa (0.2) and then decreases until Sa (1.0s), as seen in Fig. 9. The spectrum of the maximum credible earthquake obtained for the 50th percentile (P.50) is between the spectra obtained from PSHA of 4975 and 2475 years until an acceleration Sa (0.01s), while for an acceleration higher than Sa (0.01s) it also decreases (Fig. 9).

4 Conclusions

- This study is based on a specific seismotectonic model within a 500 km radius from the city of Belo Horizonte – MG. The seismic activity in this region is characterized by crustal earthquakes of low to moderate magnitudes.
- From the probabilistic seismic hazard assessment (PSHA) maximum accelerations of 0.32g and 0.04g were obtained for return periods of 9975 and 475 years, respectively.
- Based on results from seismic disaggregation, the acceleration corresponding to maximum credible earthquake MCE (P84) is 0.32g and for the maximum credible earthquake (P50) is 0.17g.
- The present study estimated the site-specific seismic hazard for the site of Belo Horizonte, considering a rock foundation with shear velocity of V_{s30} = 1100 m/sec. For other types of soil, it is suggested to measure the shear-wave velocity V_{s30} since it requires a specific response analysis to estimate its amplification.
- The seismic hazard assessment for a local site and studies of seismic site effects (soil amplification) are fields of scientific research and engineering in great evolution. Consequently, standards of practice in this particular area continue to be developed. Therefore, seismic hazard analysis should be reviewed at least every five years, when new seismic information is available or when a more recent scientific theory (GMPE) emerges.

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