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PROBABILISTIC SEISMIC HAZARD ANALYSIS OF SGSITS, INDORE

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Abstract
This paper presents the seismic hazard analysis performed for SGSITS Indore by the probabilistic approach where in the peak ground acceleration has been calculated for different frequencies considering the attenuation equation given by Raghukanth and Iyenagar. The intra-plate activity, zone-specific parameters for seismicity and fault map has been used to calculate the seismic hazard. The site lies in the central India which has seen a few major earthquakes over time and hence it is of huge importance to acknowledge the probability in coming years.

Keywords: Seismic Hazard Analysis, Peak Ground Acceleration, Central India.

1. Introduction

Shri G. S. Institute of Technology and Science (SGSITS) Indore is one of the best government engineering institutions in Madhya Pradesh, India. It is located in the peninsular region, which is comparatively less prone to seismic hazard, but past earthquakes justifies the study for this region. Central India covers a major part of the country and approximately half a billion population lives in this region. Instead of doing a comprehensive seismic hazard assessment of the region using either of the deterministic or probabilistic methods, the recent version of India's map showing seismic zones (IS 1893: 2016) is based on limited earthquake catalogue data, iso-seismals of major historical earthquakes, and limited analysis. Several scholars and researchers have raised the topic of upgrading India's present seismic zoning map in the wake of recent earthquake disasters (Koyna 1967, Killari 1993, Jabalpur 1997, Chamoli 1999, Bhuj 2001 and Kashmir 2005), which has resulted in the deaths of over twenty thousand people, the displacement of millions, and a significant impact on the regional and national economies.

2. Study Area and Seismicity

SGSITS (22.7252° N, 75.8713° E) is situated in the city of Indore which lies under the central India

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tectonic zone III as per BIS-1893-2016 Part-I. In terms of seismogenic characteristics, the Indian subcontinent is not uniform. The Andaman-Nicobar Islands, the North East, the Himalayas are much more active than the central India and peninsular India. There's also a map of epicentres and fault lines. The spatial structure of seismic zones and the faults inside these zones must be delineated for PSHA. This activity must be assessed in terms of fault lengths, recurrence relationships and potential maximum magnitude. In peninsular and western central India, there are two types of earthquakes: rift and non-rift. The earthquakes in Koyna (1967) and Killari (1993) were non-rift events, but the earthquakes in Jabalpur (1999) and Kutch (2001) were rift events. The hazard in central and peninsular India is less severe than in the Himalayan region, based on the frequency of earthquakes, but the damages generated by intraplate events are often very substantial. These disasters have a considerably broader impact than the Himalayan earthquakes.

Many active faults have also been identified in this region and have shown their existence since thousands and thousands of years. Some of the most prominent faults from this region are the great boundary fault, Gavilgarh fault, SONATA fault, Tapti North Fault etc.

3. Seismic Hazard Analysis

The quantitative assessment of ground-shaking hazards at a specific location is known as seismic hazard analysis. Two philosophies are involved in seismic hazard analysis. Seismic hazards can be calculated deterministically (when a certain earthquake scenario is assumed) or probabilistically (where uncertainties in earthquake size, location, and occurrence time are explicitly included). Seismic hazard analysis is an important aspect of the ground motion design process, although it is not the only one.

All conceivable sources of seismic activity must be identified and their potential for creating future strong ground motion must be assessed in order to assess seismic hazards for a specific site or region. The geological evidence (fault activity and magnitude indicators), tectonic evidence, historical seismicity and instrumental seismicity are taken into account while identifying and evaluating earthquake sources.

3.1 Methodology for PSHA

The gridded or smoothed seismicity technique is employed in stable continental regions of peninsular and western central India because it is ideal for modelling zone specific seismicity.

The methodology of probabilistic seismic hazard analysis consists of:

(a) Establishing earthquake recurrence activity in each grid cell or source, generating magnitude-frequency connections (Gutenberg-Richter parameters i.e. a and b-values), and estimating the seismicity rates for each grid cell or source using the earthquake catalogue data.
(b) establishing the maximum magnitude potential of a source (grid cell, fault, or area source)
(c) calculating ground shaking at a single site or grid cell from each earthquake source, along with its related rate and growing hazard curve
(d) calculating ground motion at a site or grid cell for predefined exceedance thresholds (e.g., 10% or 2% likelihood of exceedance every 50 years, respectively, equivalent to an average recurrence of 475 or 2500 years)
(e) Using peak ground characteristics (accelerations, velocities) with pseudo-spectral accelerations at varying frequencies to create a seismic hazard map

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3.2 Earthquake Source Characterization

The rate at which earthquakes of a certain magnitude and dimensions (length and width) occur at a specific location is referred to as source characterization. The source characterization creates a set of believable and relevant earthquake scenarios (magnitude, dimension, and location) for each seismic source and calculates the rate at which each scenario occurs.

The first stage in the source characterization process is to create a model of the sources' geometry. There are two basic techniques to model seismic source geometries in hazard studies: sources of areal source zone and faults. After the source geometry has been described, models that characterize the occurrence of earthquakes on the source are constructed. There are models that characterise the distribution of earthquake magnitudes, rupture dimensions for each earthquake magnitude, earthquake locations for each rupture dimension, and the rate at which earthquakes occur on the source (beyond a particular minimum magnitude of interest).

3.3 Catalogue Completeness

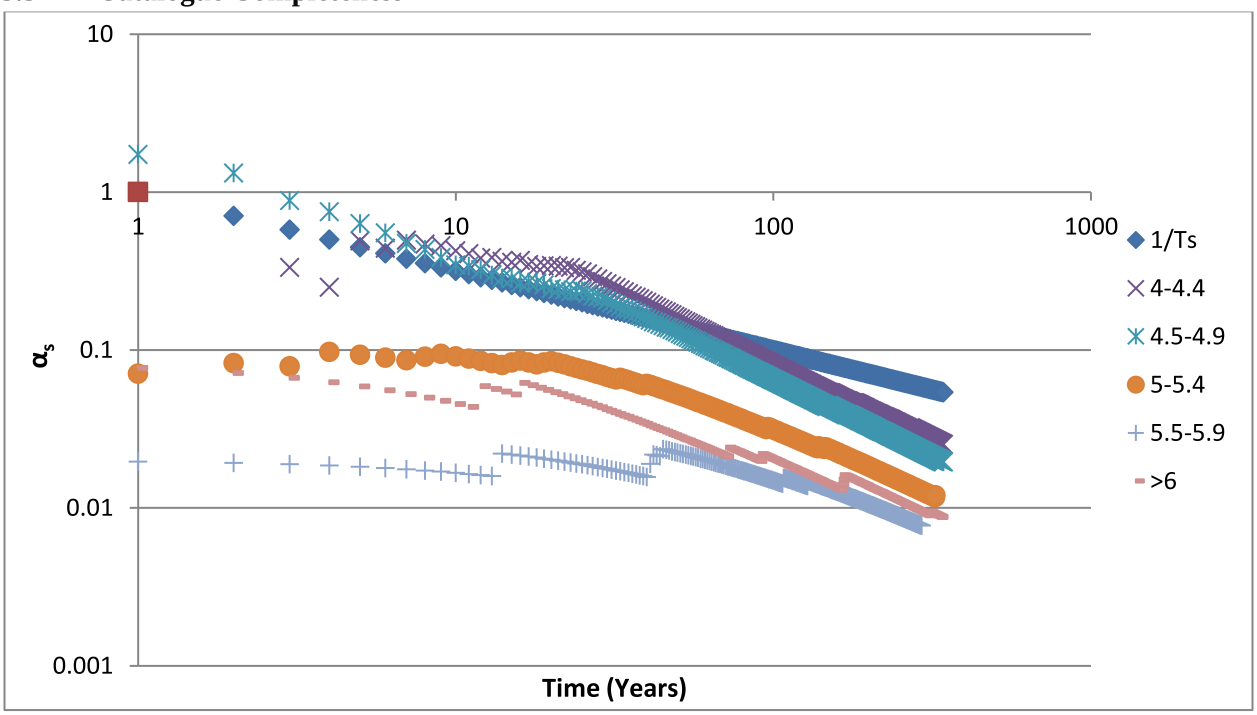

Figure 1 – Completeness of the Catalogue

The sample data series is assumed to be temporally statistically independent for estimating the recurrence parameters. Because aftershocks and foreshocks are inextricably linked to the main shock, they are grouped together in a catalogue. The All India catalogue developed for this project includes the mix of historic, instrumental & prehistoric data. As a result, before moving on, the completeness of magnitudes in time must be established. To calculate the interval in a magnitude class across which the class is complete, the widely used approach given by Stepp (1972) is utilized. The earthquake data is then

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grouped into following five magnitude classes namely, $4 \leq M_w < 4.4$, $4.5 \leq M_w < 4.9$, $5 \leq M_w < 5.4$, $5.5 \leq M_w < 5.9$ and $6 \leq M_w < 7$.

3.4 Gutenberg- Ritcher Recurrence Law

Earthquakes of varied intensities can be caused by tectonic faults (i.e., magnitudes) Gutenberg and Richter (1941) investigated earthquake magnitude observations and discovered that the distribution of these earthquake sizes in a region often follows the below mentioned pattern:

$$\log \lambda_m = a - bm \quad (1)$$

a & b are constants, while λ_m is the rate of earthquakes with magnitudes larger than m. The Gutenberg-Richter recurrence law is the name for this equation.

The "a" and "b" constants are calculated using statistical analysis of historical observations, with additional constraints provided by other types of geological evidence. The "a" value represents the overall rate of earthquakes in a region; whereas the "b" value represents the ratio of small to large magnitude earthquakes (typical b values are approximately equal to 1).

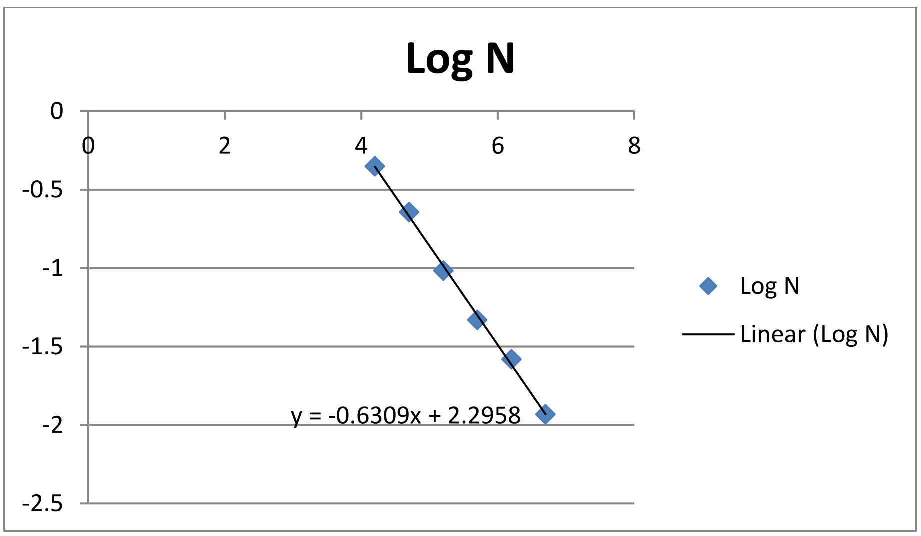

Figure 2 – Gutenberg-Ritcher Reccurrence Parameters

Equation (1) can also be used to calculate a cumulative distribution function (CDF) for earthquakes with magnitudes greater than a certain minimum magnitude M. (This conditioning is employed because earthquakes smaller than M are excluded in subsequent calculations due to their lack of engineering significance.)

$F_M(m)$ denotes cumulative distribution function.

$$F_M(m) = P\,(M \leq m \mid M > m_o)$$

$$= \frac{\textit{Rate of earthquakes with } mo < M \leq m}{\textit{Rate of earthquakes with } mo < M}$$

$$= \frac{\lambda mo - \lambda m}{\lambda mo}$$

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$$= \frac{e^{a-bmo} - e^{a-bm}}{e^{a-bmo}}$$

$$= 1 - e^{-b(m-mo)},\ m > m_o \quad (2)$$

F_M (m) denotes cumulative distribution function for M. Probability distribution function for M can be computed by taking derivative of cumulative distribution function

$$f_M(m) = \frac{d}{dm} F_M(m)$$

$$= \frac{d}{dm}[1-e^{-b(m-mo)}]$$

$$= b\ e^{-b(m-mo)},\ m > m_{min} \quad (3)$$

The PDF in equation (3) is based on the Gutenberg-Richter recurrence law of equation (1), which theoretically predicts magnitudes with no upper limit, but this is impossible due to physical restrictions. Because source defects are finite in size, there is usually an upper limit. The equation (2) becomes as follows if the greatest magnitude can be calculated.

$$F_M(m) = \frac{1-e^{-b(m-mo)}}{1-e^{-b(m(max)-m(min))}},\quad m_o < m < m_{max} \quad (4)$$

Equation (3) becomes as follows

$$f_M(m) = \frac{b\ e^{-b(m-mo)}}{1-e^{-b(m(max)-mo)}},\quad m_o < m < m_{max} \quad (5)$$

The maximum earthquake that a given source may create is denoted by m_{max}. A bounded Gutenberg-Richter recurrence law is a confined magnitude distribution.

Then convert the continuous distribution of magnitudes into a discrete set of magnitudes in order to solve the PSHA problem. The probability of occurrence of these discrete set of magnitudes, assuming that these are the only conceivable magnitudes, are determined in the same way as the cumulative distribution functions:

$$P\ (M=m_j) = F_M(m_{j+1}) - F_M(m_j) \quad (6)$$

Where m_j is a discrete set of magnitudes with the order $m_j < m_{j+1}$. In this procedure, the probabilities corresponding to all magnitudes between m_j and m_{j+1} are ascribed to discrete value m_j. The approximation has no effect on numerical results as the discrete magnitudes are separated.

3.5 Ground Motion Prediction Equation

The ground motion prediction equation (GMPE) is the foundation of a region's seismic hazard analysis. The ground motion parameter at a certain location is predicted by GMPE by linking it to the magnitude of the earthquake, the distance between the site and the source, and other variables such as local soil characteristics. In general, the PGA and PSA at various structural periods are used to describe strong ground motion. In PSHA, choosing a suitable GMPE for a specific location is a crucial responsibility. In any seismic hazard study, it is generally better to use region-specific GMPEs. If region-specific GMPEs are not available, GMPEs produced for other regions with similar seismotectonic features can be used. The GMPEs for shallow crustal earthquakes were selected depending on the geological background of the research region, which has a lot of seismic activity at shallow depths. In the present study, the GMPE given by Raghukanth and Iyenagar (2007) has been selected

$$\ln(PGA) = c_1 + c_2(M-6) + c_3(M-6)^2 - \ln(R) - c_4R + \ln(\varepsilon) \quad (7)$$

where $c_1 = 1.7236$; $c_2 = 0.9453$; $c_3 = -0.0725$; $c_4 = 0.0064$ and $\ln(\varepsilon) = 0.4648$ for western-central India and

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M is the moment magnitude, R is the hypocentral distance.

4. Development of Seismic Hazard Curves

Individual source zone seismic hazard curves can be obtained and blended to express the aggregate danger at a certain location. The underlying premise of the computations needed to generate seismic hazard curves is straightforward. For one conceivable earthquake at one possible source location, the probability of exceeding a given value, y*, of a ground motion parameter, Y, is computed and then multiplied by the probability that that particular magnitude earthquake would occur at that particular place. After that, the process is repeated for all potential magnitudes and locations, with the probability for each being added together.

The entire region is partitioned into smaller grid cells of size 0.1° X 0.1° area for the application of gridded seismicity method. For the hazard estimation, a minimum magnitude of $M_w = 4$ was chosen based on the observation that earthquakes of that size can cause damage to the current sensitive building stock. Ground motion maps were created by taking into account the ground motion distribution from each of the probable earthquakes that could influence the site and have a 2% chance of exceeding in the next 50 years.

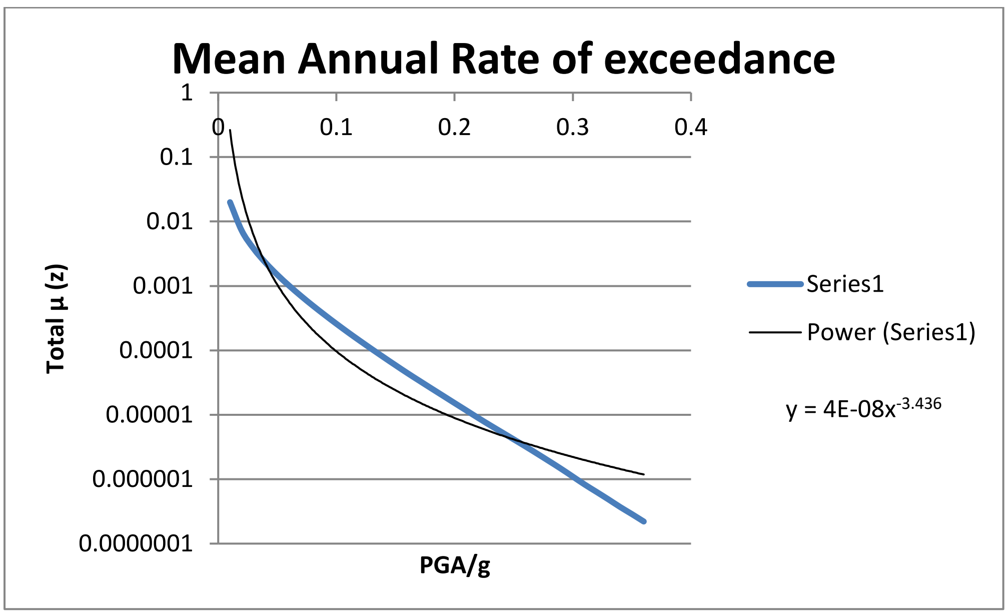

Figure 3 – Seismic Hazard Curve for SGSITS, Indore

The above graph represents the seismic hazard curve developed for SGSITS, Indore.

5. Results Interpretation

Table 1 show the seismic hazard details for a 2% likelihood of exceedance in 50 years, which corresponds to ground motion estimation at a location in terms of peak ground acceleration with an average recurrence of 2500 years, also known as maximum considered earthquake (MCE) ground motion.

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Table 1 – Peak Ground Acceleration for various frequencies

Total μ (z)	Mean Annual rate of Exceedance	PGA
Total μ (z) for 10% probability of exceedance in 50 year	0.00210721	0.041 g
Total μ (z) for 10% probability of exceedance in 100 year	0.001053605	0.051 g
Total μ (z) for 10% probability of exceedance in 500 year	0.000210721	0.086 g
Total μ (z) for 10% probability of exceedance in 1000 year	0.000105361	0.107 g
Total μ (z) for 2% probability of exceedance in 50 year	0.000404054	0.070 g
Total μ (z) for 2% probability of exceedance in 100 year	0.000202027	0.087 g
Total μ (z) for 2% probability of exceedance in 500 year	4.04054E-05	0.146 g
Total μ (z) for 2% probability of exceedance in 1000 year	2.02027E-05	0.182 g

6. Conclusion

In terms of peak ground accelerations at various frequencies, the research gives a probabilistic seismic hazard curve of SGSITS, Indore. Use of several newly developed ground motion prediction equations for hazard assessment, re-assignments of maximum magnitude potentials to zones, re-alignment of zonal boundaries, estimation of zone specific seismicity parameters, and development of hazard curves in terms of spectral acceleration parameters at different frequencies that would be useful for engineering applications are some of the study's key features. Although the study uses more than 300 years of earthquake data and a resemblance hypothesis of seismotectonic characteristics elsewhere to predict future earthquake recurrence characteristics as well as zone-specific peak magnitude potential, more thorough geological and paleoseismic studies are required in this area before such records can be used to confine these parameters for subsequent updates of the eventually results and curves. The newly generated seismic hazard map shows lower design seismic forces than that used in India's IS code earthquake zoning map at the moment. Before a definitive zoning map can be established, the authors believe that further enhancements to the zoning map provided in the paper can be made based on growing multidisciplinary research.

Acknowledgement

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