PROBABILISTIC SEISMIC HAZARD APPROACH FOR LOW SEISMIC REGIONS, VISAKHAPATNAM, ANDHRA PRADESH, INDIA

B.V.K Lalith Kumar[1], G.V Rama Rao[2] and K Srinivasa Rao[3]

[1]Research Scholar, Department of Civil Engineering, Andhra University College of Engineering, Visakhapatnam, AP, India, Tel +91-99634 28887; correspondence bvklalitkumar@rediffmail.com

[2]Professor, Department of Civil Engineering, Andhra University College of Engineering, Visakhapatnam, AP, India, ramaraogv_2000@yahoo.com

[3]Assocaite Professor, Department of Civil Engineering, Andhra University College of Engineering, Visakhapatnam, AP, India, killamsetti@yahoo.com

Abstract
This paper presents seismic hazard analysis of Visakhapatnam using probabilistic approach. Visakhapatnam is a rapid growing coastal city in India and considered as stable region with low intensities. In this paper previous earthquake history of region was considered to generate earthquake recurrence relation. The mean annual rate of exceedence is generated against peak ground acceleration considering study area site conditions. From the present investigation the values of peak ground acceleration varies from 0.004 g to 0.02 g with rate of exceedance 50% and 0.05 g to 0.12g for 10% rate of exceedance.

Keywords: Probabilistic seismic hazard method, peak ground acceleration, Earthquakes.

1. Introduction

Earthquakes are natural disasters and result in huge loss to mankind and assets. In India, large numbers of earthquakes took place with low to high magnitudes. Some areas earlier considered stable have experienced severe damages caused by earthquakes. Noticeable earthquakes happened in India in various places such as Latur in Maharashtra, Bhuj in Gujarat and Jabalpur in Chhattisgarh.

In this paper probabilistic seismic hazard approach was used to find out peak ground acceleration values with various return periods. Probabilistic seismic hazard analysis (PSHA) has gained popularity ever since it was formulated by Cornell (1968). It is considered as proven tool to estimate hazard analysis considering uncertainties like site, time and period. This tool is widely accepted in regions with poor earthquake data to analyze. Various steps involved in probabilistic seismic hazard approach shown in Figure 4.

2. Objectives and Methodology

Objective of present study is to find out peak ground accelerations of study area against probability rate of exceedance 50%, 10% and 2%. This process involves collecting geological features of study area such as faults lineaments and collection of previous earthquake catalogue. In the present study, a catalogue of past earthquake history was collected from United States geological survey (USGS) web site and the previous earthquake sources were identified. The radial distance search was used to obtain catalogue data; for present study earthquake catalogue around Visakhapatnam was obtained with a radial search of 350 km.

2.1 Geology of study area

The study area considered here is Visakhapatnam situated 800 km north east side of Chennai. Major folds are traced in the direction of north east and south west of Eastern Ghat hilly region. The Eastern Ghats are traversed by number of faults. Faults are existing in Sileru River which is 50 km away and situated in western border of Eastern Ghats. Kalinga Konda is 8 km away from Srikakulam and 90 km away from Visakhapatnam has significant faults. The solidified zone west of Endada hill near Visakhapatnam is also considered as fault zone.Major villages around Visakhapatnam are shown in Figure 2 and major lineaments are shown in Figure 3. The lineaments are of various lengths and close to main city Visakhapatnam.

2.2 Location of study area

Visakhapatnam is located along the east coast of India between 17 ^{0} 28 $^’$45” to 18 ^{0} 1 ’min latitude and 83^0 59’ to 83^0 35’ east longitude.

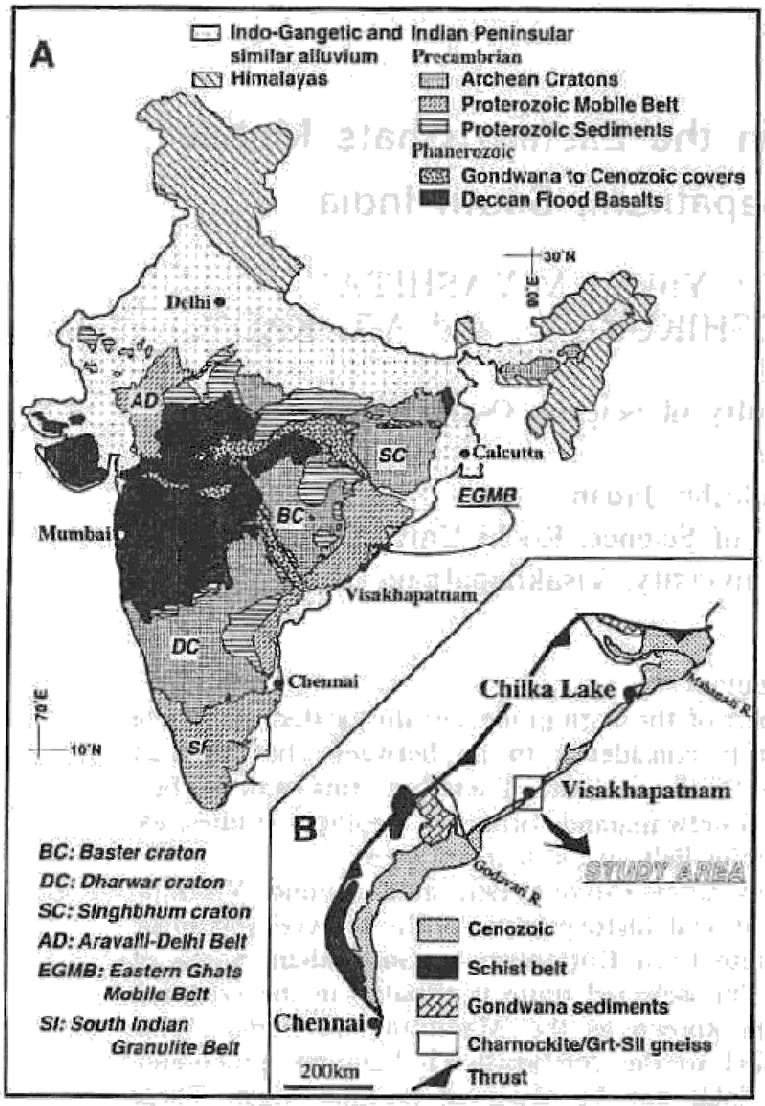


Figure 1: Study Area- Visakhapatnam

2.3 Earthquake History of Study Area

The seismicity of study area is addressed by Kaila et al 1972; Umesh Chandra 1977; as per IS 1893 (2002) seismic intensity is under zone II. The earthquake events were collected with United States Geological survey and presented in Table 1.The past records show earthquake magnitudes of 3 to 5 are available. Higher values 7 occurred in Srikakulam, Bhadrachalam regions. The summary list presented decade wise occurrence shown in Table 2. Based on the list histogram (Figure 4) is prepared and used for further calculations.

3. The Proposed Model

Seismic hazard assessment has been studied by many researchers. In general, the seismic hazard evaluation can be done in two ways first method is deterministic seismic hazard approach and second method is probabilistic seismic hazard approach.

The first method, the deterministic seismic hazard approach can be performed using earthquake epicentral locations, magnitude, rate of occurrence and intensities. The results give highly conservative estimates of seismic hazard.

The second method, the probabilistic seismic hazard approach which takes into account the uncertainties in the level of magnitude of earthquake, its epicentral location, its recurrence relation and its attenuation. This approach gives more realistic values for earthquake hazard parameters.

3.1 Steps in probabilistic model

The steps involved in probabilistic seismic hazard can be summarized as follows: identification of sources; establishment of recurrence relationships, magnitude distribution and average rate of occurrence for each source; selection of attenuation relationship; and finally, the computation of site hazard curve.

3.1.1 Regional recurrence relation

The recurrence relation is the relationship between the cumulative frequency of occurrence of earthquake and its magnitude. Gutenberg-Richter (1944) suggested following relation

$$\log N = a - b\,M \tag{1}$$

where N is the number of earthquakes magnitude greater than M

M is earthquake magnitude

a and b are constants depending upon source area and can be determined by least square method. The constants 'a' and 'b' have great physical meaning. The 'a' value indicates earthquake magnitude above zero and it depends upon source events. The b value is the measure of seismic severity of source region. A higher value of b indicated smaller fraction of a total earthquake count when lower value of b indicates higher earthquake count (Kobe 1994).Various investigators established values of a and b depending upon region specific and some of the equations related to India by Kaila (1971), Sitharam and Anbazhagan (2007) Vipin K.S (2009). Jaiswal and Sinha (2006) have suggested value of b is 0.88 plus or minus 0.7, as per Ram and Rathore (1970) a=4.58 and b= 0.891.

Since there were no significant earthquake magnitudes recorded in Visakhapatnam during the period 1959-72. Gutenberg-Richter relations cannot be used directly. Hence available values of earthquake magnitude are increased from 4 to 4.5 and 5 to 5.5. The output results obtained from PSHA software and results are shown in Figures 6, 7 and 8.

The standard Gutenberg-Richter (GR) equation (i) can be re-written as below

$$N_m = 10^{(a-bm)} = \exp(\alpha - \beta m) \tag{2}$$

Where α =2.303 a and β=2.303 b

Equation (ii) can be rewritten eliminating lower earthquake magnitudes

$$N_m = \nu \exp(-\beta(m - m_0)) \quad m > m_0 \tag{3}$$

where $\nu = \exp(\alpha - \beta m_0)$

(4)

Cumulative distribution function CDF is as given below

$$F_M(m) = P[M < m \mid M > m_0] = \frac{N_{m_0} - N_m}{N_{m_0}} \tag{5}$$

$$\frac{N_{m_0} - N_m}{N_{m_0}} = 1 - e^{-\beta(m - m_0)} \tag{6}$$

And probability density function PDF is given below

$$f_M(m) = \frac{d}{dm} F_M(m) = \beta e^{-\beta(m - m_0)} \tag{7}$$

The mean annual rate of exceedance expressed below (McGuire and Arabasz, 1990)

$$N_m = \nu \frac{\exp[-\beta(m - m_0)] - \exp[-\beta(m_{max} - m_0)]}{1 - \exp[-\beta(m_{max} - m_0)]} \tag{8}$$

$$m_0 < m < m_{max}$$

The CDF and PDF for Gutenberg-Richter law with upper and lower bound expressed as

$$F_M(m) = P[M < m | m_0 \le m \le m_{max}] = \frac{1-\exp[-\beta(m-m_0)]}{1-\exp[-\beta(m_{max}-m_0)]} \quad (9)$$

$$f_M(m) = \beta \frac{\exp[-\beta(m-m_0)]}{1-\exp[m_{max}-m_0]} \quad (10)$$

where m is earthquake magnitude and m_o and m_{max} are minimum and maximum earthquake magnitudes.

3.1.2 Predictive relationships

Considering an earthquake influence due to source at a distance, the probability that a particular ground motion Y exceeds certain value y* for an earthquake magnitude, m, occurring at a distance r is given in below

$$P[Y > y^* | m, r] = 1 - F_y(y^*) \quad (11)$$

Where Fy(y) is the value of CDF of y at m and r. The value if Fy (y) depends on probability distribution used to represent Y.

The standard normal variation is given below equation

$$Z = \frac{\ln PHA - \ln \overline{PHA}}{\sum \ln PHA} \quad (12)$$

where PHA is peak horizontal acceleration

3.1.3 Poisson Model

The occurrence of an earthquake is seismic source is assumed to follow Poisson distribution. The probability of ground motion parameter at a given size, Z, will exceed a specified level, z, during specified time period T by the expression (S.L Krammer).

$$P(Z > z) = 1 - e^{-v(z)t} \quad (13)$$

Where v(z) is the mean annual rate of exceedance. v(z) depends upon time, size and location of future earthquakes.

3.2 Attenuation relation for present study

For the present study ground accelerations are based on attenuation equations given by Donovan (1973) and Joyner Boore (1981).

$$\log PGA = \frac{190}{R^{1.83}} \quad (14)$$

Joyner Boore suggested following equations for western US and worldwide

$$\log PGA = -1.02 + 0.249M - \log\sqrt{R^2 + 7.3^2} - 0.00255 \log\sqrt{R^2 + 7.3^2} \quad (15)$$

$$\log PGA = 0.49 + 0.23(M-6) - \log\sqrt{R^2 + 8^2} - 0.0027\sqrt{R^2 + 8^2} \quad (16)$$

Where M is earthquake magnitude and R is the closest distance to the fault rupture in km

4. Results and Discussions

The probabilistic seismic hazard analysis has been performed using three significant sources having recorded earthquake magnitude. The results show regions close to site shows more hazard than far areas. The computer program PSHA has been developed based on Cornell and Krammer (1996) equations. The peak ground acceleration with 50% probability of exceedance varies from 0.023g to 0.027g and 10% rate exceedance 0.114 g to 0.119 g and 2% exceedance is 0.45g. Figure 9, 10 and 11 show rate of exceedance versus peak ground acceleration with sources 1,2 and 3.For source 1 the values of PGA for 50%,10% and 2% rate of exceedance are 0.004 g,0.061 g and 0.57 g and source 3 which is 250 km away the PGA values for 50%, 10% and 2% rate of exceedance are 0.004 g, 0.05 g and 0.4 g.

5. Conclusions

In this paper probabilistic seismic hazard analysis of Visakhapatnam with local conditions has been presented. The curves of mean rate of exceedance for peak ground acceleration generated at rock level considering local site conditions. The source of occurrence is considered as fault region. Since faults are known as weak zones during earthquakes. The obtained peak ground acceleration is 0.114g with 5% damping for Visakhapatnam for 10% probability of exceedance with return rate of 50 years. The peak ground accelerations generated using local conditions is 0.33g considering one dimensional linear analysis (P.S.N Raju and Lalith kumar 2010).The other significant parameter which is used by designer is spectral acceleration which has not been considered here left for future work.

Acknowledgments

The authors express their sincere thanks to Mr. S. Farid Ghahari, Sheriff University of Technology, Iran on providing software PSHA version 1.0.

References

1. Bhatia S.C., Ravikumar M., Gupta S.K., A probabilistic seismic hazard map of India and adjoining regions, Annali Di Geofisica, Vol. 42, N. 6,1999.
2. Cornell, C.A., Engineering Seismic Risk Analysis. B. Seismological Society of America, 58, 1968, pp 1583-1606.
3. Donovan, N.C., Earthquake hazards for buildings, in Building Practice for Disaster Mitigation, National Bureau of Standards Building Science Series 46, 1973, pp 82-111.
4. Guttenberg, B and Richter, C.F., Frequency of earthquakes in California. B. Seismological Society of America, 34, 1944, pp 185-188.
5. Jaiswal, K and Sinha R., Probabilistic modeling of Earthquake hazard in stable continent shield of Indian peninsula, ISET journal of earthquake technology, 43(3), pp 49-64, 2006.
6. Joyner, W.B and Boore D.M., Peak acceleration and velocity from strong motion records including records from 1979 Imperial Valley, California earthquake. B. Seismological Society of America, 71, 1981, pp 2011-2038.
7. Kaila, K.L et al., Quantitative Seismicity maps of India. B. Seismological Society of America, 62, 1972, pp 1119-1131.
8. Krammer, S.L., Geotechnical Earthquake Engineering, Pearson Education Ptd. Ltd. Reprinted 2003, Delhi, India, 1996.
9. McGuire, R.K and Arbasz, W.J., An introduction to probabilistic seismic hazard analysis: Geotechnical and Environmental geophysics, edited by: Ward S.H, Society of Exploration Geophysicist, Vol. 1, 1990, pp 333-353.
10. Ram, A and Rathore, H. S., on frequency magnitude & energy significant Indian earthquakes, Pure and Applied Geophysics. 79, 1970, pp 26-32.
11. Rao, S.P and Rao R.B., 1979. Estimated earthquake probabilities in North East India and Andaman Nicobar Island, Mausam, 30, 1979, pp 267-273.
12. Sitharam, T.G and Anbazhagan P., 2007. Seismic hazard analysis for Bangalore region, Nat. hazards, 40, 2007, pp 261-278.
13. Umesh Chandra., 1977. Earthquakes of peninsular India- a Seismotectonics study, B. Seismological Society of America, 67, No. 5, 1387-1413.
14. Vipin K.S et al., Estimation of peak ground acceleration and spectral acceleration for south India with local site effects: Probabilistic approach. Nat. Hazard Earth Syst. Sci., 9. 2009, pp 865-879.
15. B.V.K Lalith Kumar and Late P.S.N Raju., A site specific amplification study of Visakhapatnam, the ICFAI University Journal of Structural Engineering, Vol. III, No. 1, 2010, pp 1-12.

About the Authors

1. Research scholar, Department of Civil Engineering, Andhra University College of Engineering, Visakhapatnam. bvklalitkumar@rediffmail.com
2. Professor, G.V Rama Rao, Department of Civil Engineering, Andhra University College of Engineering, Visakhapatnam.
3. Associate Professor, Dr. K. Srinivasa Rao, Department of Civil Engineering, Andhra University College of Engineering, Visakhapatnam.

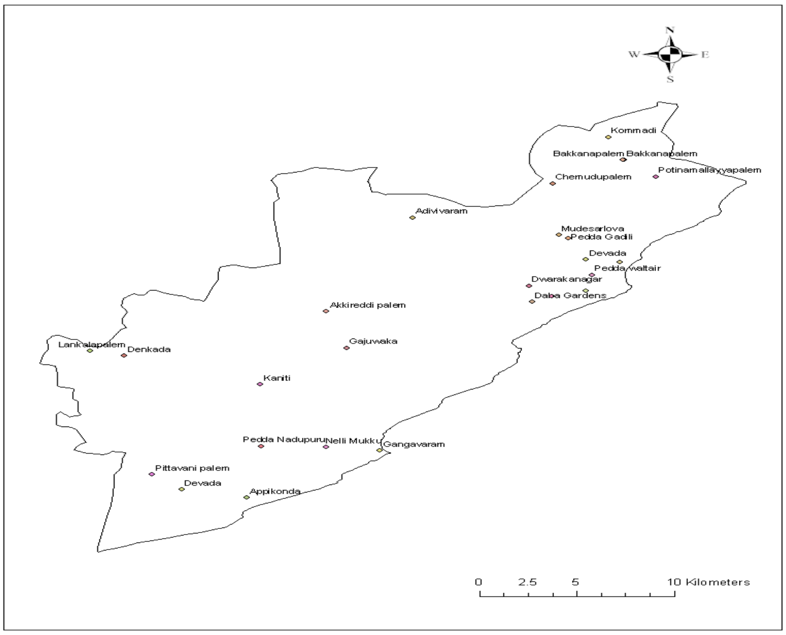


Figure 2: Satellite villages around Visakhapatnam

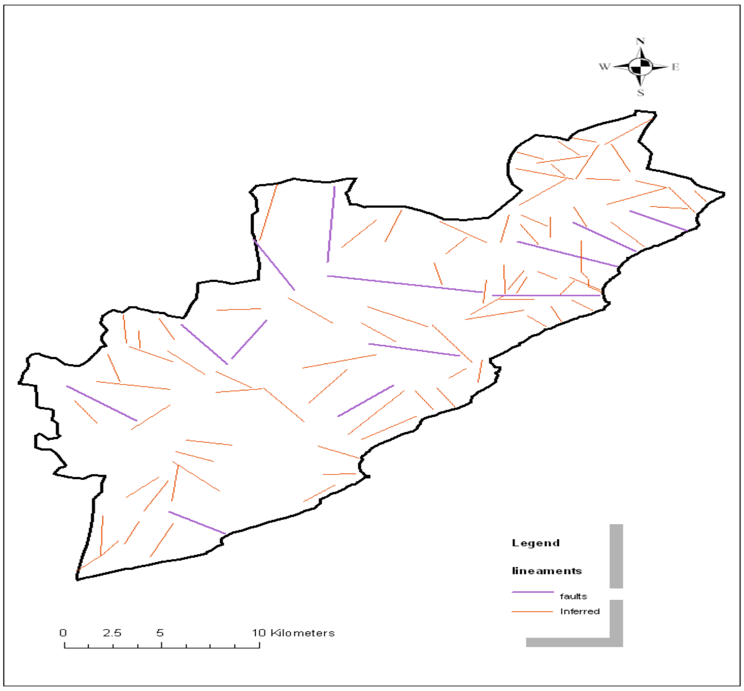


Figure 3: Lineaments and faults in and around Visakhapatnam

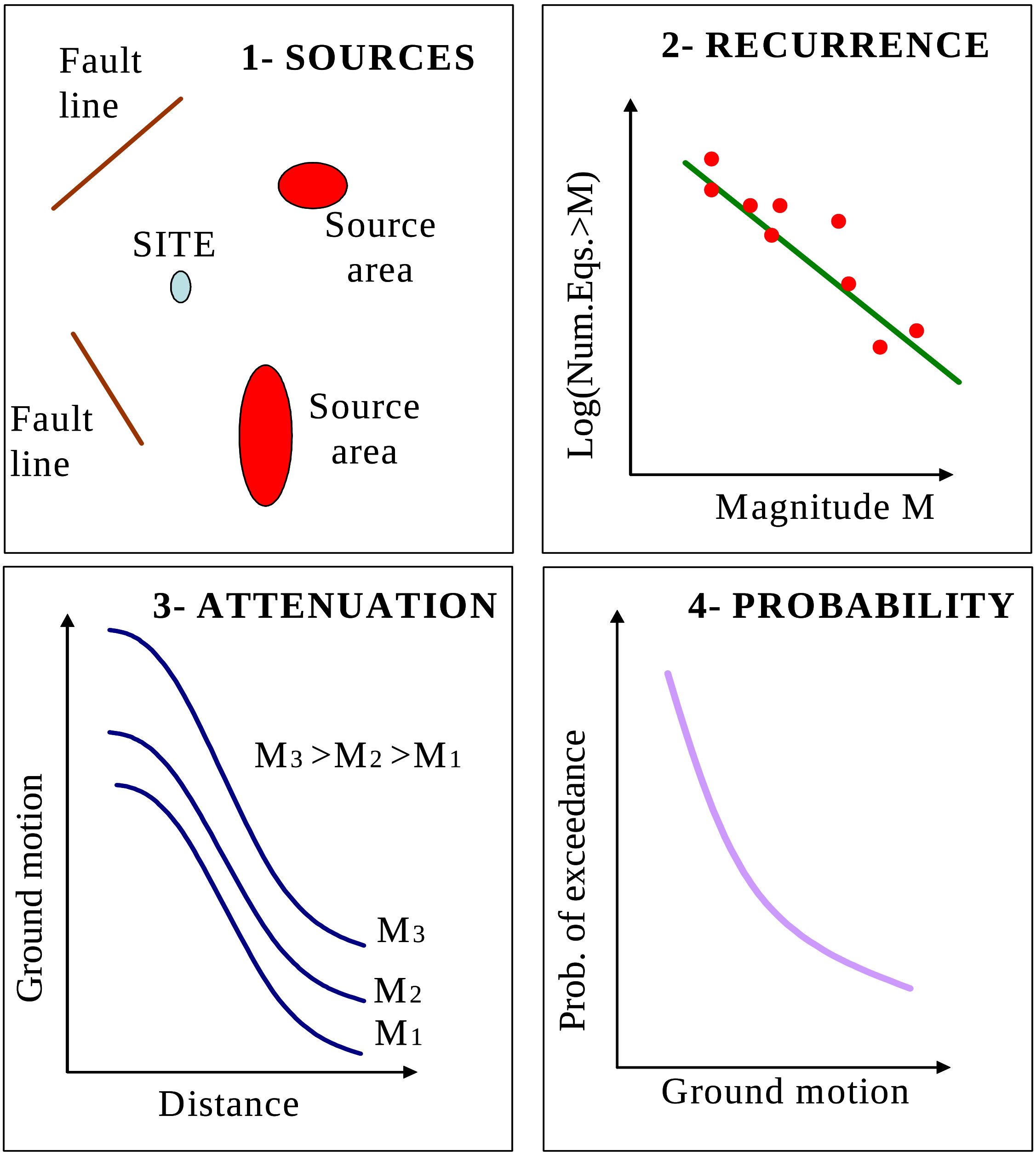
Table 1: Recorded earthquake events, from USGS web site

Number	Year	Month	Day	Latitude N (degrees in decimal)	Longitude E (degrees in decimal)	M_s	M_b	M_w
1	1827	1	6	17.70	83.40	4.8	5.2	5
1	1837	6	15	19.50	85.10	6	5.8	6
1	1853	2	21	17.70	83.40	3.1	4.2	4
1	1858	8	24	17.80	83.40	3.1	4.2	4
1	1858	10	3	19.50	85.10	3.1	4.2	4
1	1858	10	12	18.30	84.00	6	5.8	6
1	1859	7	21	16.29	80.50	6	5.8	6
1	1859	8	2	16.29	80.50	4.8	5.2	5
1	1859	8	9	16.29	80.50	4.8	5.2	5
1	1859	8	24	18.10	83.50	4.8	5.2	5
1	1860	2	25	19.40	84.90	4.8	5.2	5
1	1861	11	13	18.12	83.50	4	2.85	3
1	1869	12	19	17.90	82.30	4.8	5.2	5
1	1870	12	19	17.90	82.30	4.8	5.2	5
1	1871	9	27	18.30	83.90	4	2.85	3
1	1872	11	22	18.86	80.02	3.1	4.2	4
1	1885	7	22	20.06	85.37	4	2.85	3
1	1885	9	1	20.06	85.37	1	2	2
1	1886	5	2	20.06	85.37	4	2.85	3
1	1897	6	12	18.53	83.48	1	2	2
1	1897	6	22	19.00	84.90	7.6	6.6	7
1	1898	6	1	16.98	82.33	4	2.85	3
1	1917	4	17	18.00	81.30	7.6	6.6	7
1	1927	1	1	18.10	83.50	4.8	5.2	5
1	1954	1	5	17.30	80.10	4.8	5.2	5
1	1959	8	9	17.60	80.80	3.1	4.2	4
1	1959	12	23	17.60	80.80	4.8	5.2	5
1	1963	12	5	17.90	80.60	3.1	4.2	4
1	1968	7	27	17.60	80.80	4	2.85	3
1	1968	7	29	17.60	80.80	4	2.85	3
1	1969	4	13	17.90	80.80	7.6	6.6	7
1	1972	6	11	17.60	80.20	4	2.85	3
1	1975	4	24	18.70	80.70	4	2.85	3
1	1981	12	8	16.30	80.50	4	2.85	3

Sources considered in present study are source 1: Lat. 17.7 N, Long. 83.4 E source 2: Lat. 18.1N, Long. 83.50 E and source 3 Lat 19.50N, Long. 85.10 E (http://earthqukes.usgs.gov/regional/neic)

Table 2: Data of Earthquake events based on ten year period

Earthquake Magnitude M						
Duration	1<M<1.9	2<M2.9	3<M<3.9	4<M<4.9	M>5	Total No of Earthquakes
1828-1837					2	2
1838-1847						0
1848-1857				1		1
1858-1867			1	2	3	6
1868-1877			1		2	3
1878-1887						0
1888-1897		1			1	2
1898-1907			1			1
1908-1917					1	1
1918-1927					1	1
1928-1937						0
1938-1947						0
1948-1957					1	1
1958-1967				1	1	2
1968-1977					1	1
1978-1987				1		1
	0	1	3	5	13	



Steps of probabilistic seismic hazard analysis for a given site: (1) definition of earthquake sources, (2) earthquake recurrence characteristics for each source, (3) attenuation of ground motions with magnitude and distance, and (4) ground motions for specified probability of exceedance levels (calculated by summing probabilities over all the sources, magnitudes, and distances).

Figure 4: Procedure of probabilistic seismic hazard analysis

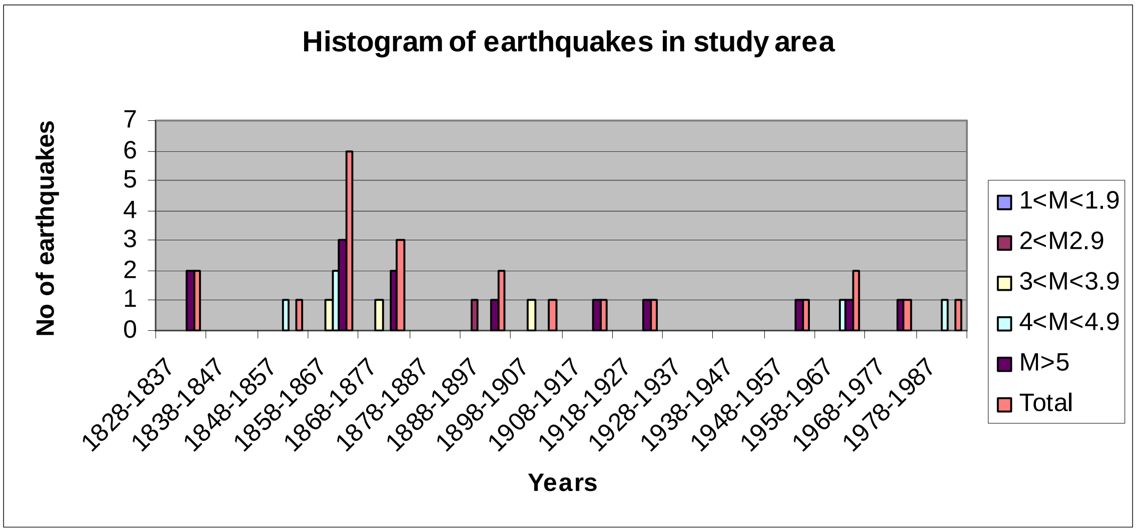


Figure 5: Histogram of earthquake history in study area

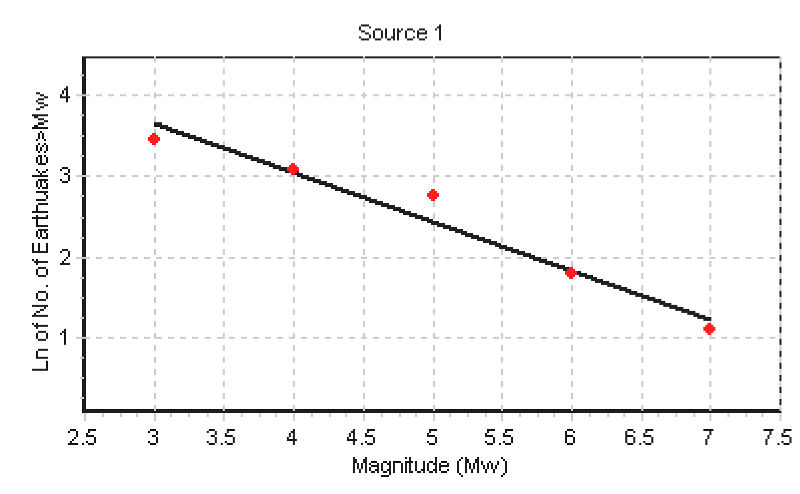


Figure 6: Lognormal events at source 1

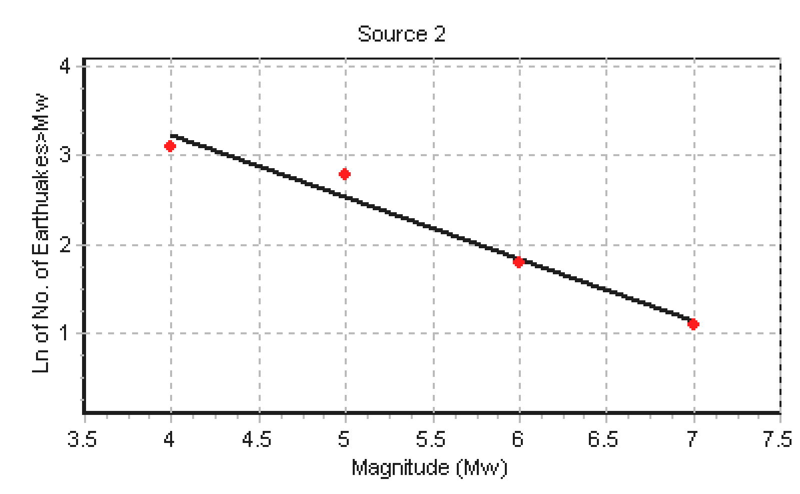


Figure 7: Lognormal events source 2

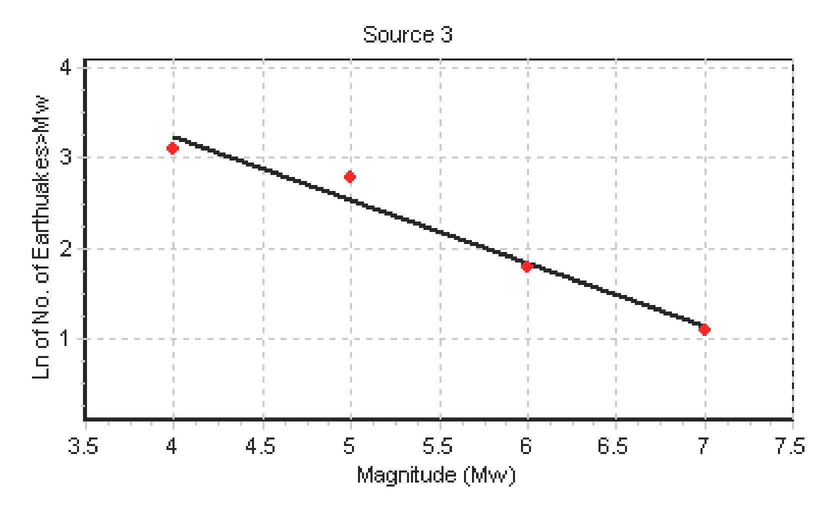


Figure 8: Lognormal events source 3

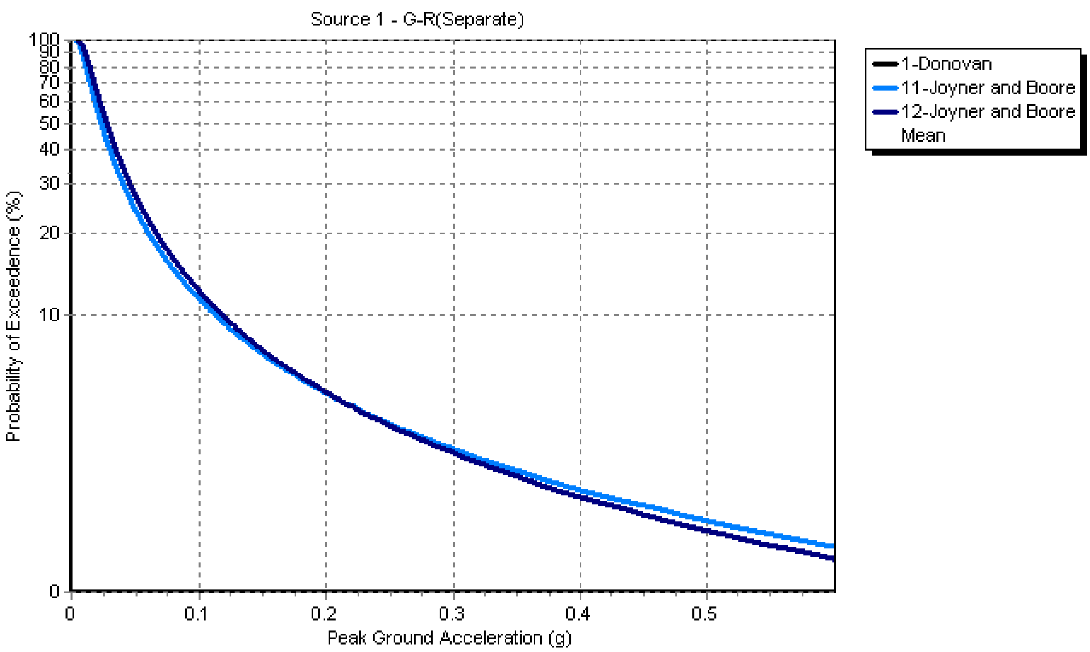


Figure 9: Probability of exceedance vs. peak ground acceleration for source 1

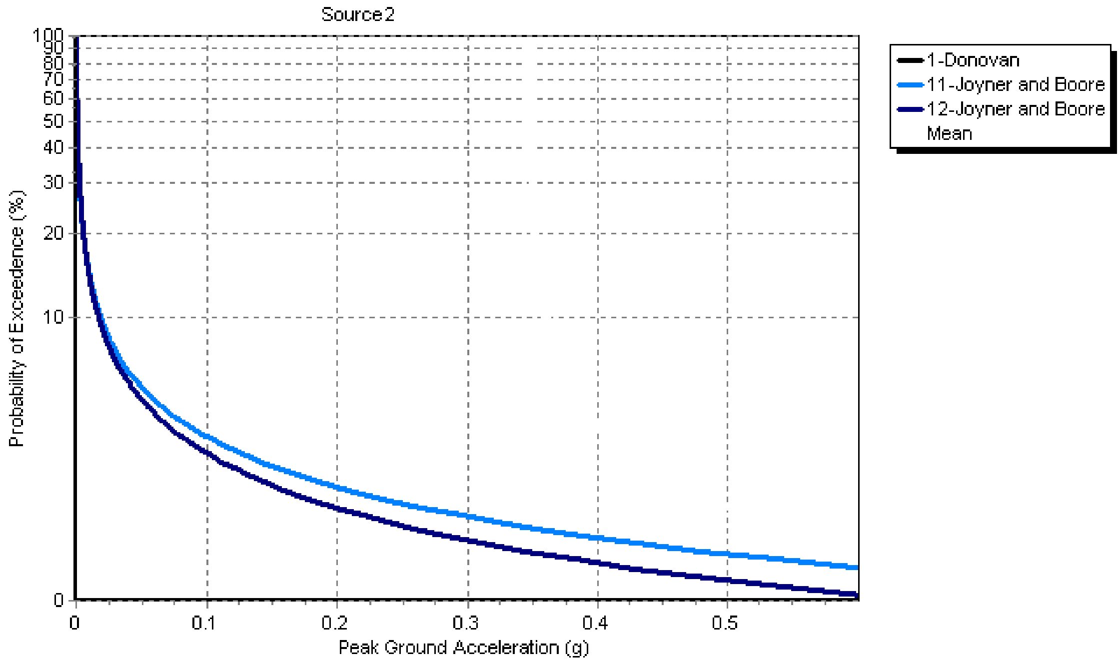


Figure 10: Probability of exceedance vs. peak ground acceleration source 2

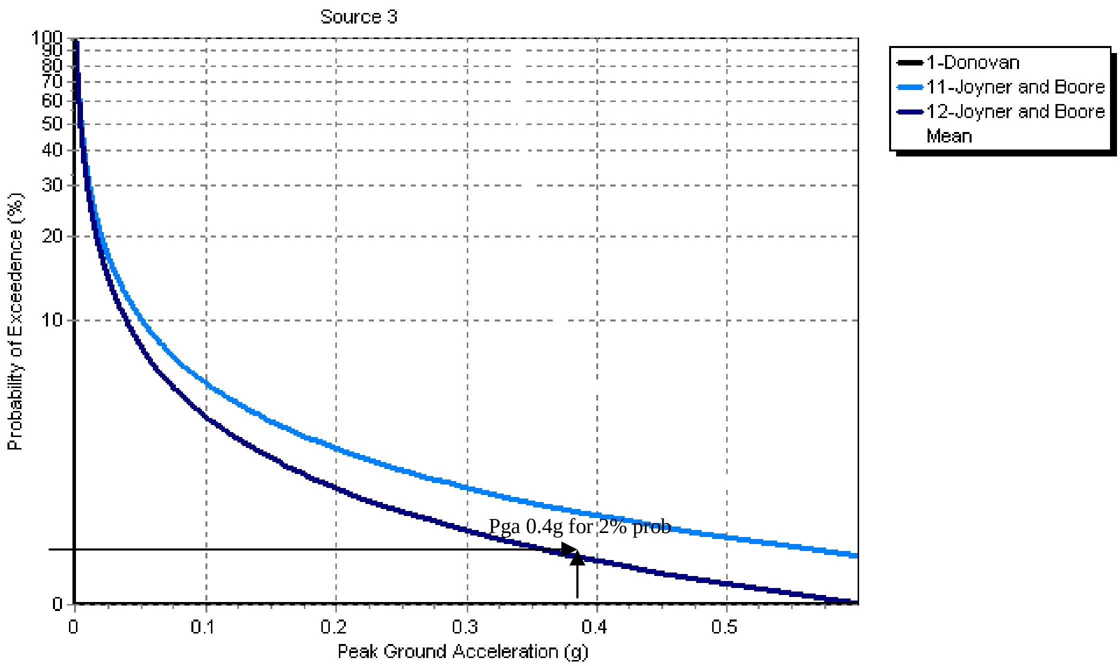


Figure 11: Probability of exceedance vs. peak ground acceleration source 3