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Seismic Hazard Analysis of Low Seismic Regions, Visakhapatnam: Probabilistic Approach

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ABSTRACT

In this paper an attempt has been made to determine seismic hazard analysis of Visakhapatnam using probabilistic approach. Till 2004, Visakhapatnam is considered as stable region with low intensities. The previous earthquake history of region was considered to generate earthquake recurrence relation. The mean annual rate of exceedance 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, peak ground acceleration.

INTRODUCTION

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

Present study used probabilistic seismic hazard approach 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 are 1) defining earthquake sources, 2) earthquake reoccurrence characteristics for each source, 3) attenuation of ground motion with magnitude and 4) distance and ground motion in specified probability of exceedance.

GEOLOGY OF STUDY AREA

The study area considered here is Visakhapatnam, situated 800 km north east of Chennai (Fig. 1). Major folds are traced in the direction of north east and south west of Eastern Ghat hilly region. The trend is isolated hills in between the main range and coast in NW-SE and E-W (Sriramdas 1963). Major folds are noticed at Mulaga konda in Srikakulam district and Kambala Konda in Visakhapatnam district. Both folds trend towards south east.

The Eastern Ghats are traversed by number of faults. Faults are existing in Sileru River is situated in western border of Eastern Ghats. Kalinga Konda, which 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.

LOCATION OF STUDY AREA

Visakhapatnam is located along the east coast of India between 17 ^{0} 28΄45" to 18 ^{0} 1 ‘0" north latitude and 83^0 59' to 83^0 35' east longitude. The average rainfall of the area is 980 mm with 60 - to 90% relative humidity.

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 from United States Geological survey records and presented in Table 1.

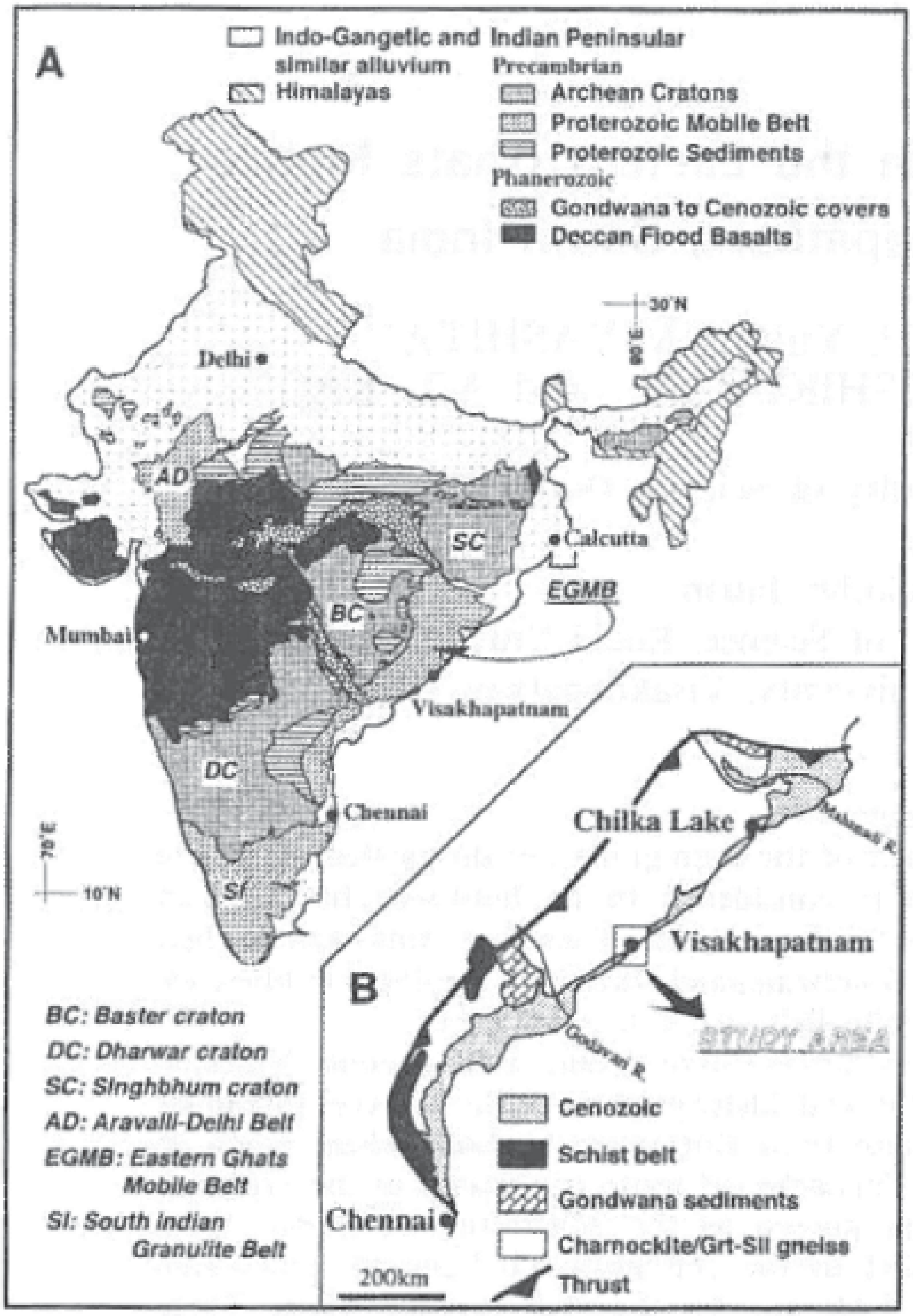

Figure 1: Study Area- Visakhapatnam (Source J. Geosciences, Osaka)

The past records show earthquake magnitudes of 3 to 5 have taken place. Higher values of 7 occurred in Srikakulam and Bhadrachalam regions. The summary list presented decade wise occurrence is shown in Table 2. Based on the summary list a histogram (Figure 5) is prepared and used for further calculations.

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

$$\log N = a - b M \qquad \text{(i)}$$

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)

where N is the number of earthquakes
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 details. 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 ± 0.7. As per Ram and Rathore (1970), a = 4.58 and b = 0.891.

No significant earthquakes of significant magnitudes wise recorded in Visakhapatnam during 1959-72. Gutenberg-Richter relations cannot be used

Figure 2: Satellite villages around Visakhapatnam

Figure 3: Lineaments and faults in and around Visakhapatnam

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	

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

$$N_m = 10^{(a-bm)} = \exp(\alpha - \beta m) \qquad \text{(ii)}$$

Where $\alpha = 2.303$ a and $\beta = 2.303$ b

Equation (ii) can be rewritten eliminating lower earthquake magnitudes

$$N_m = \nu \exp(-\beta(m - m_0)) \; m > m_0 \qquad \text{(iii)}$$

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

Cumulative distribution function CDF is as given below

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

$$\frac{N_{m_0} - N_m}{N_{m_0}} = 1 - e^{-\beta(m-m_0)} \qquad \text{(vi)}$$

And probability density function PDF is given below

$$f_M(m) = \frac{d}{dm} F_M(m) = \beta\, e^{-\beta(m-m_0)} \qquad \text{(vii)}$$

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

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

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

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

$$F_M(m) = P[M < m \mid m_0 \le m \le m_{max}] = \frac{1 - \exp[-\beta(m-m_0)]}{1 - \exp[-\beta(m_{max}-m_0)]} \qquad \text{(ix)}$$

$$f_M(m) = \beta \frac{\exp[-\beta(m-m_0)]}{1 - \exp[m_{max}-m_0]} \qquad \text{(x)}$$

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

Predictive relationships

Considering an earthquake is 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 below

$$P[Y > y^* \mid m,r] = 1 - F_y(y^*) \qquad \text{(xi)}$$

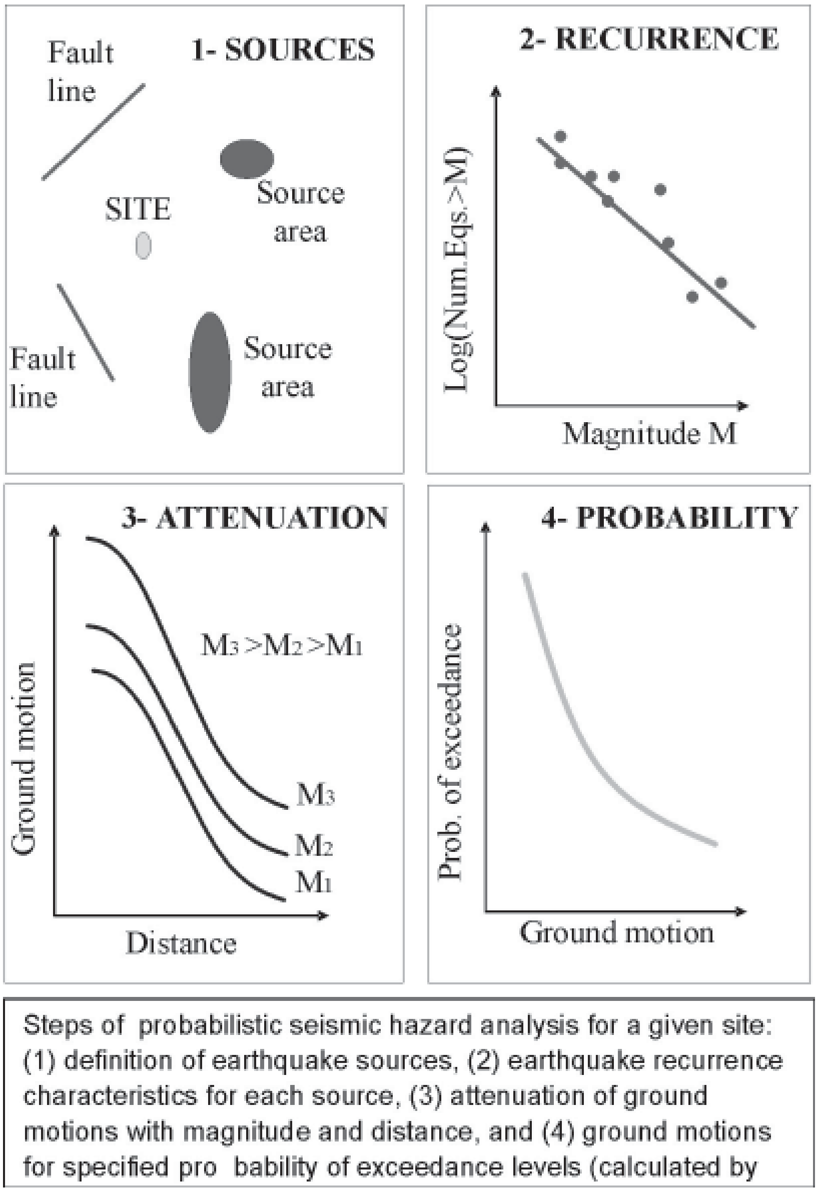

Figure 4: Procedure of probabilistic seismic hazard analysis

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

The standard normal variation is given below

$$Z = \frac{\ln PHA - \ln \overline{PHA}}{\Sigma \ln PHA} \qquad \text{(xii)}$$

where PHA is peak horizontal acceleration

Poisson Model

The occurrence of an earthquake 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 1996).

$$P(Z>z) = 1 - e^{-\nu(z)t} \qquad \text{(xiii)}$$

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

Attenuation relation for present study

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

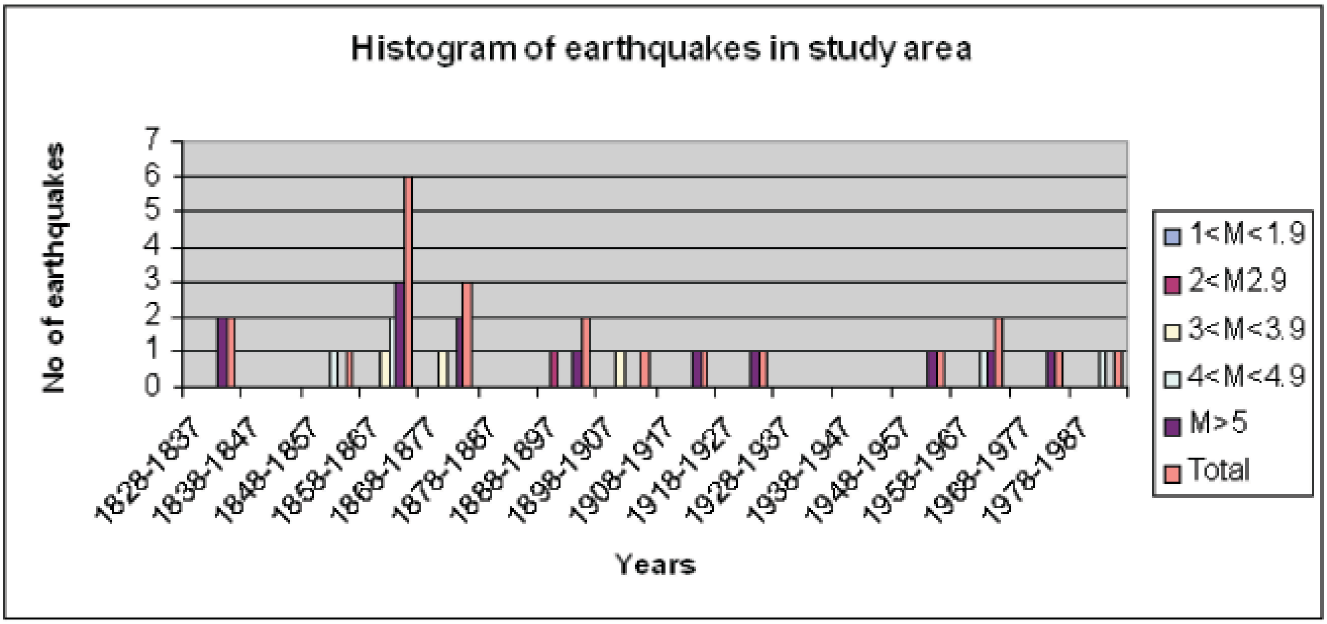

Figure 5: Histogram of earthquake history in study area

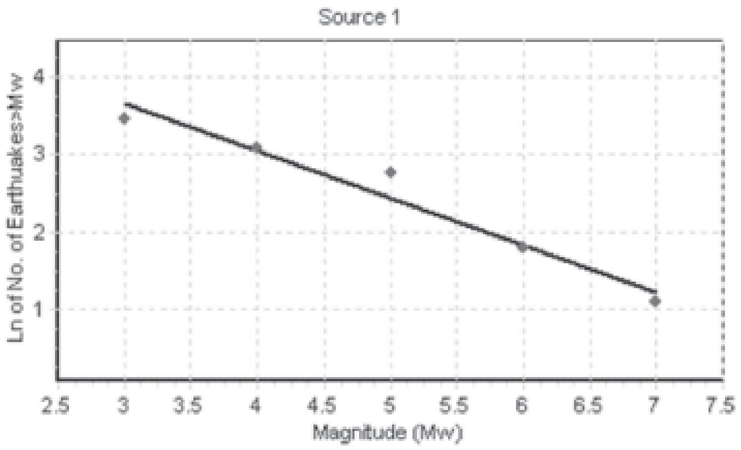

Figure 6: Lognormal events at source 1

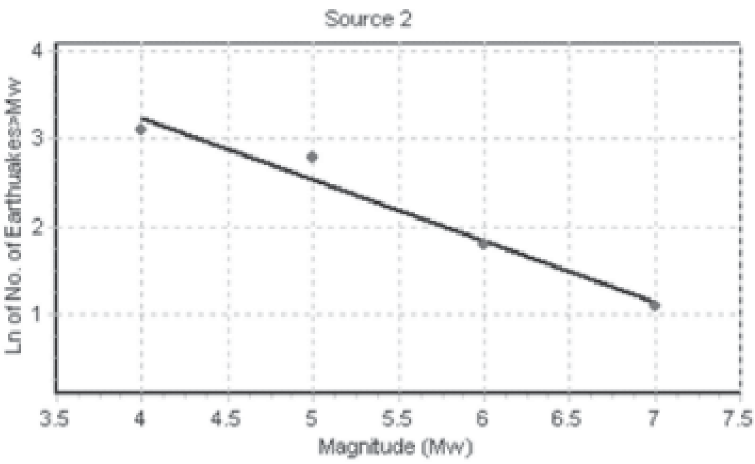

Figure 7: Lognormal events source 2

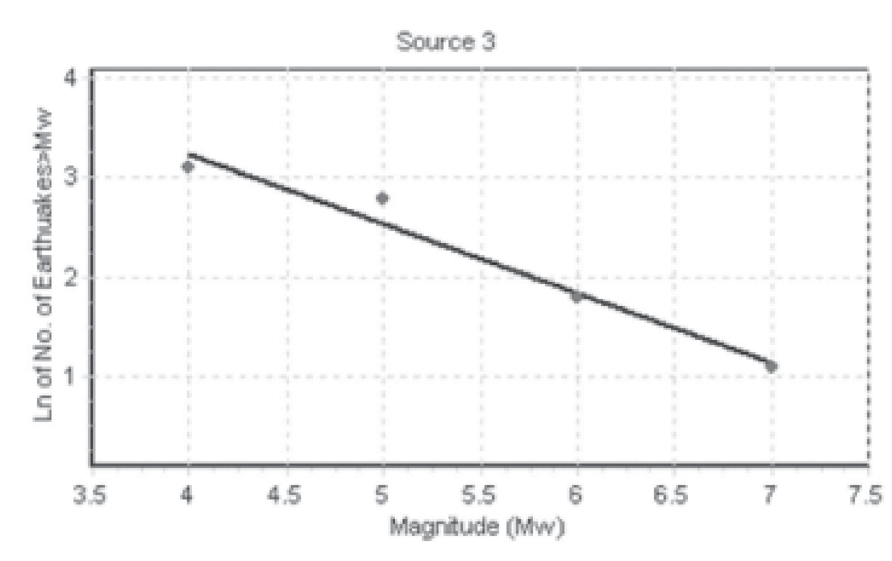

Figure 8: Lognormal events source 3

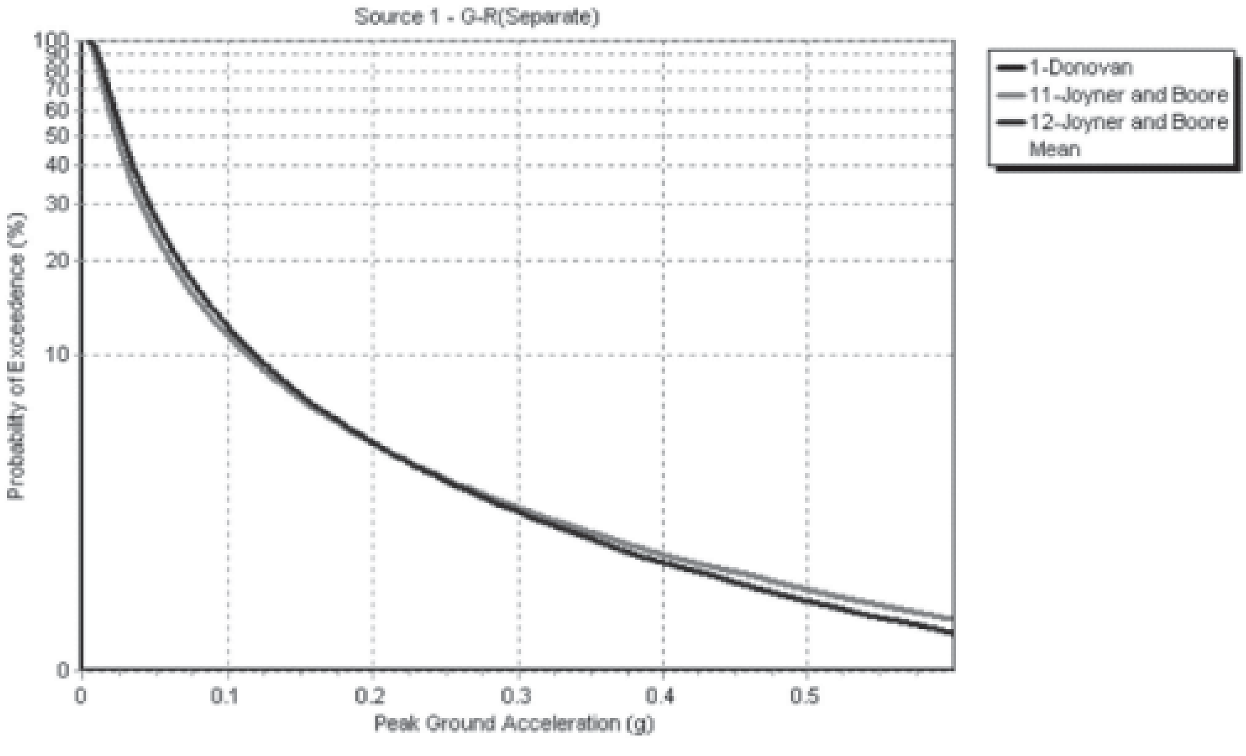

Figure 9: Probability of exceedance vs. peak ground acceleration for source 1

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 show 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. Figures 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.

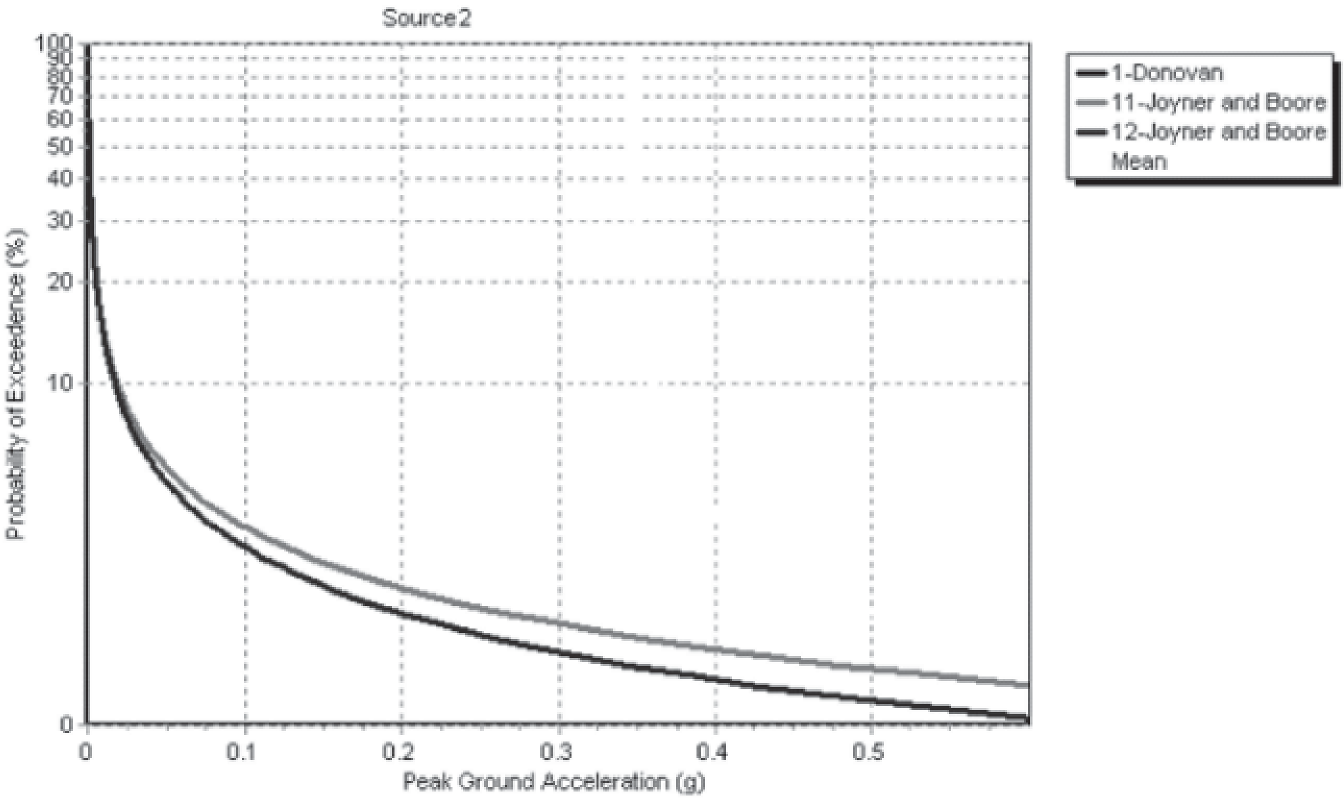

Figure 10: Probability of exceedance vs. peak ground acceleration source 2

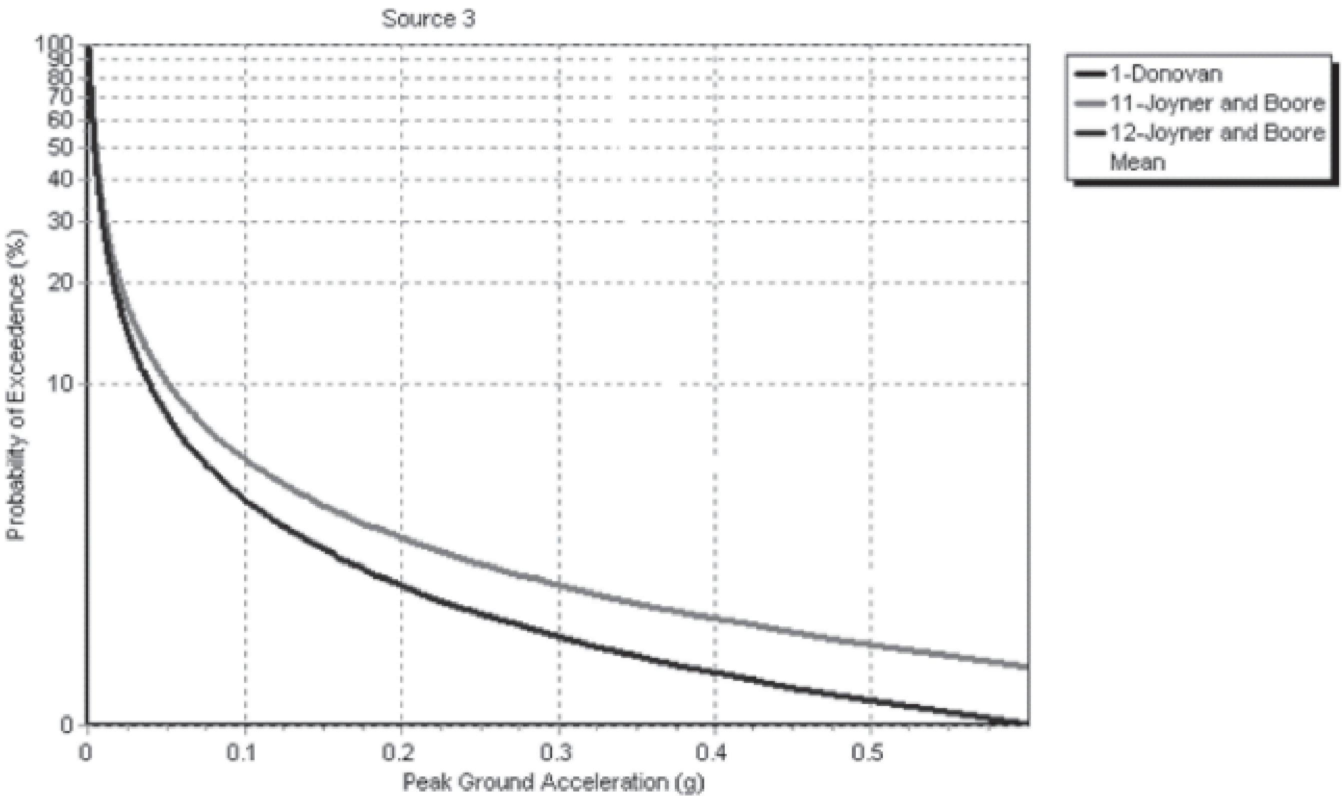

Figure 11: Probability of exceedance vs. peak ground acceleration source 3

ONCLUSIONS

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 take into consideration 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 Lalithkumar 2010).The other significant parameter which is used by designer is spectral acceleration. This has not been considered here.

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