PROBABILISTIC SEISMIC HAZARD STUDIES OF EAST COAST REGION OF INDIA

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ABSTRACT :

Seismic hazard studies are required for estimating ground motion parameters expected to occur at bedrock levels at a particular site during strong earthquakes. This paper presents probabilistic seismic hazard analysis (PSHA) carried out for Kalpakkam, India, a low seismicity region of the east coromandel coast 80 km south of Chennai. Kalpakkam is known for its nuclear power plants and affiliated research stations. Seismic hazard is characterized by the probability of exceeding a given level of a ground motion parameter (e.g. peak ground acceleration) at least once in a number of years corresponding to the life time of a structure. In a specific sense, seismic hazard is the probability of experiencing a specified intensity at a particular site in some time period of interest. Four appropriate attenuation models have been used for the estimation of peak ground acceleration (PGA) due to poorly known attenuation characteristics of the region. Hazard curves can be used to select the design seismic input at a site and the same can be used in the seismic response analysis of structures.

KEYWORDS: Seismic hazard, Attenuation model, Peak ground acceleration, Seismic input, Uniform hazard spectrum.

1. INTRODUCTION

Estimation of probabilistic seismic hazard in low seismicity regions such as stable continental regions (SCR) has to cope up with the difficulty in identification of active faults and with the low amount of available seismicity data. The recurrence interval of interplate earthquakes is of the order of tens or hundreds of years. The SCR earthquakes may recur only over tens or hundreds of thousands of years. After 1990's, high-magnitude intraplate earthquakes in the peninsular India such as the Killari [moment magnitude (M_w) 6.2, 1993], Jabalpur (M_w 5.8, 1997) and Bhuj (M_w 7.7, 2001) have claimed a lot of human lives, and moderate earthquakes in Kerala (M_w 5.0, 2000), Karnataka (M_w 4.3, 2001) and Tamil Nadu (M_w 5.5, 2001) in the southern peninsular India have created enough concern to understand the rejuvenation of seismic activity along some of the zones of weakness.

Seismic hazard analysis is usually performed to obtain a characterization of the earthquake ground motion, since it causes the largest economic loss in most earthquakes. Seismic hazard is commonly used to describe the severity of ground motion at a particular site without consideration of the consequences (Kramer 1996). In most situations the seismic hazard is uncertain, and is posed by the possible occurrence of earthquakes at more than one location; likewise, the sizes, or magnitudes of potentially damaging earthquakes. The region under study, Kalpakkam falls in the stable continental region of the peninsular India whose latitude and longitude are 12°29′ to 12°34′ N; 80°11′ to 80° 05′ E. Recent seismic history, however, shows that more than eight damaging earthquakes with magnitudes greater than 5.0 have occurred in the peninsular India, highlighting the importance of seismic hazard assessment for the region.

Non-instrumental and instrumental seismicity data for the present study have been retrieved from the published catalogues. The Gutenberg-Richter recurrence law has been used to characterize the seismicity of the Kalpakkam region. Due to poorly known attenuation characteristics of the region, four appropriate attenuation models have been used for the estimation of ground motion parameters. The Cornell-McGuire approach (Cornell 1968, McGuire 1995) has been adopted for the PSHA. Horizontal uniform response spectra have been computed for reference return periods of 72, 224, 475 and 975 years.

2. EARTHQUAKE DATABASE

The seismotectonic details of the region which falls within a distance of 300 km around Kalpakkam have been collected and reviewed. Earthquake catalogue for the period from 1800 to 2001 A.D. have been obtained from various earthquake data centres such as NEIC, India Meteorological Department (IMD), Geological Survey of India (GSI), Gauri Bidanur Array (GBA) (Figure 1) and also from published literature (Chandra 1977, Rao and Rao 1984, Iyengar 1999). The seismicity is based on the compiled catalogues of historical and instrumental seismicity of the region that extends from 77° to 81° E and 9° to 15.5° N. The foreshocks and aftershocks events were removed by windowing criteria and finally a new catalogue of 160 earthquake data was prepared. Seismic events with magnitude greater than 3 are only considered in the preparation of earthquake catalogue. Finally, the catalogue data spanning over a period 1800 – 2001 A.D. (200 years) was used for evaluating the seismicity of the study area.

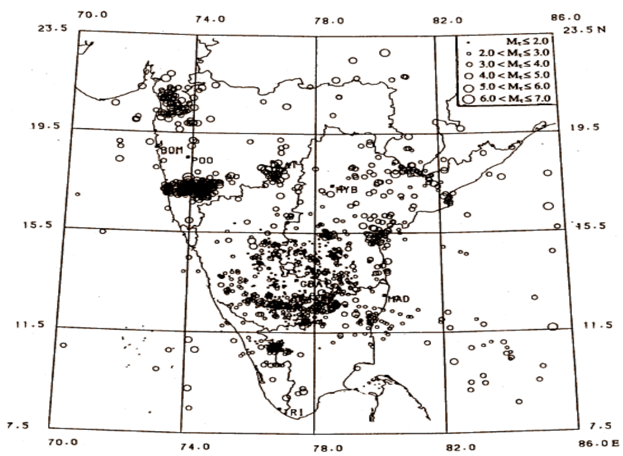

Figure 1 Typical seismicity of peninsular India based on GBA

2.1. Catalogue Completeness

No catalogue can be strictly considered complete for all magnitudes and time period. An analytical method for finding regional recurrence based on incomplete catalogue has been developed notably by Stepp in 1972 (Kijko and Sellevoll 1989a, b). Since availability of data in the Kalpakkam region is very less (only 160 records for 200 years), an alternate method called Visual Cumulative method (CUVI) formulated by Mulargia and Tinti (1985) is adopted in the study to estimate the period of completeness of the catalogue. It is a simple, graphical procedure based on the observation that earthquakes follow a stationary occurrence process, the average rate of occurrence of seismic events must be a constant. Figure 2 illustrates the results of the completeness analysis performed using entire earthquake catalogue. For a given magnitude class, the period of completeness is considered to begin at the earliest time when the slope of the fitting curve can be well approximated by a straight line. The whole catalogue can be considered complete over the entire period 1800 – 2001 A.D. only for magnitudes exceeding 5.5. Table 1 shows the completeness intervals that have been computed for the seismic zone of the study area.

2.2. Fault Characteristics

The fault map was prepared from the Seismotectonics Atlas of India. In the present study, totally 14 faults were demarcated. Most of the faults are located within the radial distance of 300 km from Kalpakkam. From Figure 3 it is seen that the Palar river fault (F) is the nearest and causative fault and it has a low to moderate seismicity, located 22 km away from the Kalpakkam.

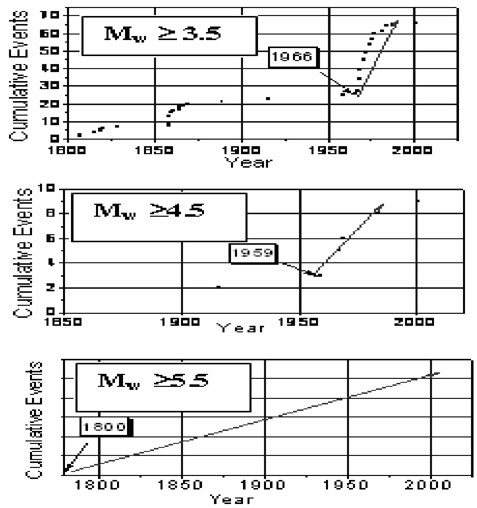

Figure 2 CUVI method for determining catalogue completeness

Table 1 Completeness intervals

Moment magnitude	Completeness interval	Year
$M_W \geq 3.5$	1966 – 2001	36
$M_W \geq 4.5$	1959 – 2001	43
$M_W \geq 5.5$	1800 – 2001	202

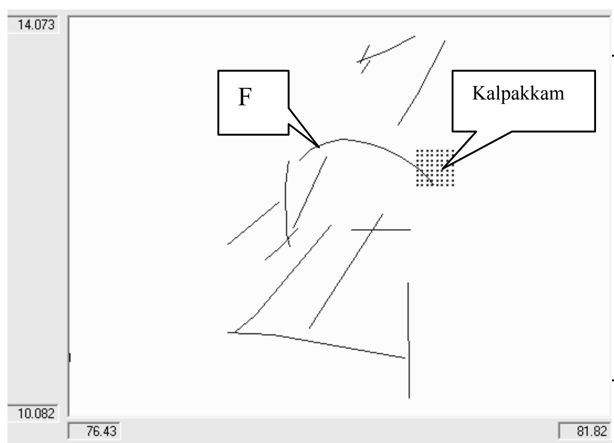

Figure 3 Fault locations around Kalpakkam region (300 km radial distance)

2.3 Frequency-Magnitude Recurrence Relationship

According to Gutenberg-Richter's recurrence relationship, the yearly occurrence rate of earthquakes with magnitude greater than or equal to *M* in a particular source zone can be described by Eqn. 2.1,

$$\log_{10}(\lambda_M) = a - bM \tag{2.1}$$

where λ_M is the mean annual rate of exceedance of magnitude *M*, *a* and *b* are the constants specific to the source zone, and these can be estimated by a least-square regression analysis of the past seismicity data. In the present study, regression analysis has been carried out to obtain *a* and *b* values using DATAFIT software. The cumulative number of events are taken for computation of *a* and *b* values of the frequency-magnitude relationship (Figure 4). Finally these values are compared with the previous values given by the earlier investigators for the Peninsular India. The derived values of *a* and *b* as part of the present investigation are in good agreement with the previously reported values as given in Table 2.

Table 2 Comparison of *a* and *b* values

Sl. No.	Reference	Value of		*a*/*b*	Data for a period
		a	*b*		
1	Avadh Ram and Rathor (1970)	5.30	0.81	6.54	70
2	Kaila et al. (1972)	3.25	0.70	4.64	14
3	Rao and Rao (1984)	4.40	0.85	5.17	170
4	Present study	4.527	1.183	3.827	200

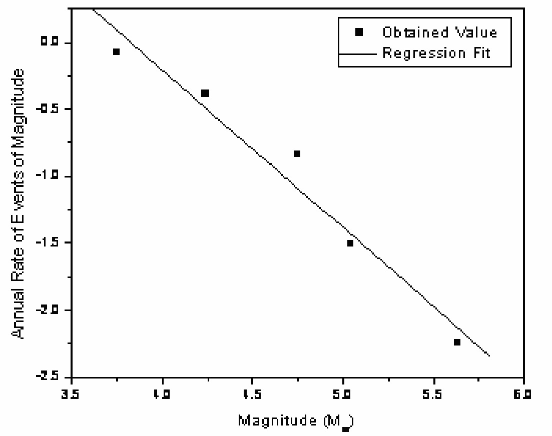

Figure 4 Frequency-magnitude relationship

For the Kalpakkam region, Gutenberg-Richter's recurrence relationship is given by the following expression:

$$\log_{10}(\lambda_M) = 4.527 - 1.183M_w \tag{2.2}$$

The Gutenberg–Richter parameters obtained are: a = 4.527 and b = 1.183. From Eqn. 2.2, the recurrence of earthquakes for Kalpakkam can be established.

2.4 Attenuation Relationship For PGA

Due to unavailability of well-established attenuation relation for the region, four models have been used in the present study and their appropriateness is evaluated. The schemes of expected ground motion parameters for the Kalpakkam were compiled and compared with the corresponding peak PGA values for magnitude 5 as shown in Figure 5. The maximum PGA values obtained from the different attenuation relationship for magnitude 5 are presented in Table 3. It is noted that Iyengar and Raghu Kanth (2004) attenuation relationship predicts the highest value of PGA for the Kalpakkam. The variation of PGA with distance for different magnitudes obtained from the above attenuation relationship is shown in Figure 6.

Table 3 Comparative estimates of maximum PGA

Sl. No.	Author(s)	Max. PGA (g)
1	Sabetta and Pugliese (1996)	0.08
2	Boore et al. (1993)	0.07
3	Sharma (1998)	0.11
4	Iyengar and Raghu Kanth (2004)	0.13

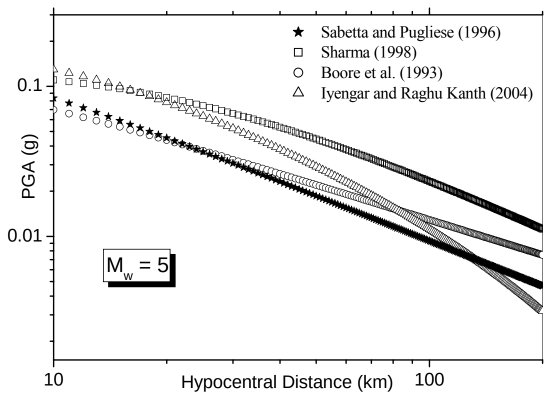

Figure 5 Comparative estimate of PGA for different attenuation relationships

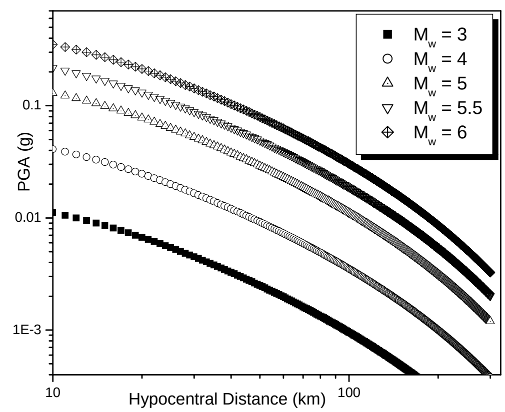

Figure 6 Attenuation of PGA with distance (Iyengar and Raghu Kanth, 2004)

3 PROBABILISTIC SEISMIC HAZARD ANALYSIS FOR KALPAKKAM

In Probabilistic Seismic Hazard Analysis (PSHA) all the parameters associated with the seismic phenomena are considered explicitly and their uncertainties quantified. In low seismicity regions like Kalpakkam, it is extremely difficult to introduce long-term behaviour because active faults cannot be identified in most cases; thus the Poisson process is more or less exclusively used. The Poisson model could be invoked with careful consideration when predicting the ground motion from the seismic sources where seismic gaps prevail and the data on strain release is scarce. The average exceedance rate can be expressed as in Eqn. 3.1 (McGuire, 2004):

$$\lambda_{y^*} = \sum_{i=1}^{N} \alpha_i \int_{M_{\min}}^{M_{\max}} \int_{R=0}^{R=\infty} f_i(M)\, f_i(R) P(Y > y \mid m, r)\; dr\, dm \qquad (3.1)$$

where λ_{y*} is the expected number of exceedance of ground motion level y^*, α_i is the mean rate of occurrence of earthquakes in the i^{th} source, f_i(M) is the probability density distribution of magnitude within source *i*, f_i(R) is the probability density distribution of epicentral distance between the various locations within source *i* and the site for which the hazard being estimated and P(Y > y|m, r) is the probability that a given earthquake of magnitude *m* and epicentral distance *r* will exceed ground motion level *y*.

3.1. Methodology Used for PSHA

A computer program, CRISIS 2003 Version. 3.0.1 (Ordaz et al., 2003) is used in this study to compute seismic hazard. The program uses Poisson and Characteristic earthquake models to consider the occurrence and distribution of earthquakes and the seismicity of the sources along with attenuation relationships to define the ground motion at the site.

The following information is required to run the CRISIS program. Coordinates of the site, the minimal magnitude M_{min} and rate of seismicity associated with each source area i: $\alpha_i = \alpha_i\ (M \geq M_{\min})$, the maximum magnitude M_{max}, slopes of the laws of recurrence β_i, polygons which delimit the source areas, the parameters which control the discretizations in magnitude (Δm) and integration parameters [minimum distance and triangle ratio (F_{min}), minimum triangular size (R_{min}), parameter controlling spatial integration process (D_{max})], coefficients of the attenuation relationship, target accelerations and return period. The CRISIS calculates λ_{y*}: (i) by subdividing each source area in subfields in order to obtain the f_{Ri}, (ii) by calculating the $f_{\mathrm{M}i}$ starting from M_{min} and M_{max}, and (iii) by calculating $P\ [Y > Y^* / m;\ r]$ starting from the relation of attenuation for all the combinations (m, R).

The CRISIS determines target accelerations for which the calculation of the annual rate is carried out using three parameters: minimum acceleration (A_{min}), maximum acceleration (A_{max}) and number of targets. The software evaluates the annual rates of going beyond these targets and interpolates accelerations corresponding to the annual exceedance rates of interest. The targets are distributed in the interval ($A_{min} - A_{max}$) with a step which increases in a logarithmic manner with acceleration. It is important to choose the terminals judiciously, A_{min}, A_{max}, as well as the required number, so that the annual exceedance rates are correctly interpolated. In this study, the annual rates are calculated between 0.01 and 0.2 g. The calculation of the annual exceedance rates on this series of accelerations ensures a very precise interpolation for all the return periods.

3.2. Uniform Hazard Spectrum

The essence of PSHA lies in the uniform hazard spectrum (UHS), which is a convenient tool to compare the hazard representations of different sites. By using the PSHA formulation, the spectral amplitudes of acceleration can be evaluated at all the natural periods for a constant probability of exceedance at a site. The UHS plots are estimated for all the sites defined by the intersection points of the grid. For this purpose, the seismicity which is a function of (M_j, R_i) for the site is evaluated by fitting the Gutenberg-Richter recurrence relation to the past earthquake data within a 300 km radius zone. The attenuation relationship proposed by Raghu Kanth and Iyengar (2007) is used in this study. Figure 7 shows the UHS corresponding to 10% probability of exceedance in 50 years (475) and also for 975, 224 and 72 years return periods. Table 4 presents the peak values of UHS for different return periods.

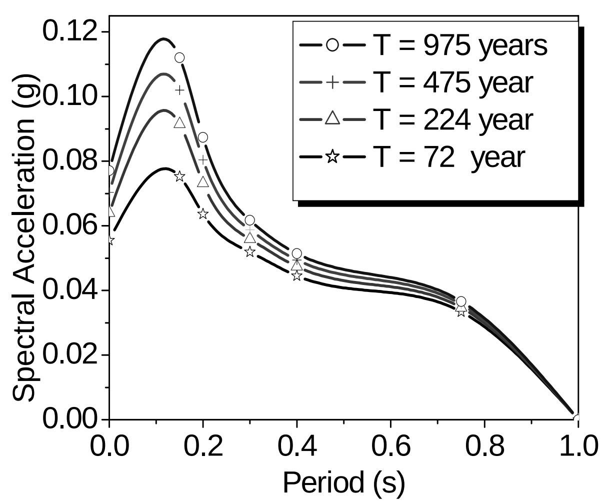

Figure 7 Variation of spectral acceleration for different return periods

The UHS plots obtained for Kalpakkam using Das et al. (2006), Idriss (2002) and Sadigh et al. (1997) attenuation relationships are shown in Figure 8. The UHS plots are constructed for a return period of 475 years (i.e., 10% probability of exceedance in 50 years). It can be concluded from the figure that the uniform hazard spectrum obtained from Das et al. (2006) attenuation relationship gives upper bound values for spectral acceleration whereas Raghu Kanth and Iyengar (2007) attenuation relationship gives lower bound values for the time periods shown in the figure.

Table 4 PGA for different return periods

Probability of exceedance	Return period (years)	Horizontal PGA (g)
50% probability of exceedance in 50 years	72	0.0555
20% probability of exceedance in 50 years	224	0.064
10% probability of exceedance in 50 years	475	0.0704
5% probability of exceedance in 50 years	975	0.0771

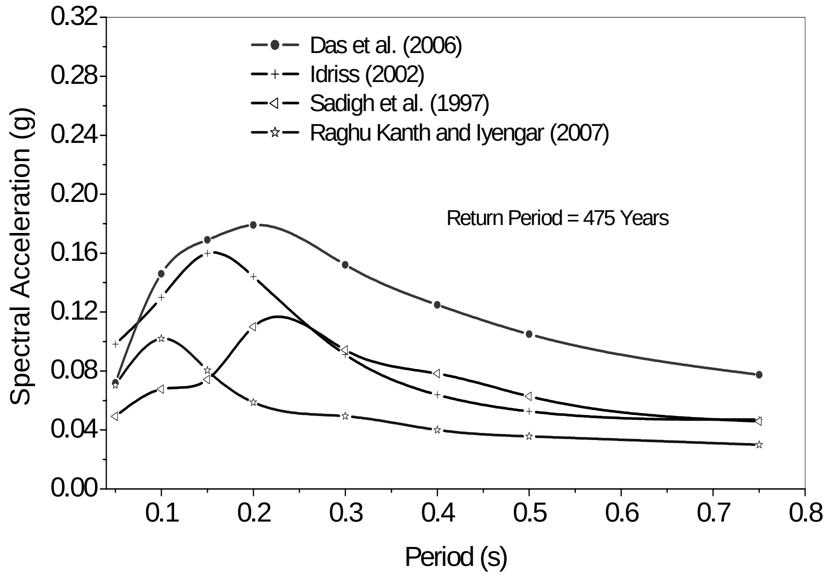

Figure 8 UHS for Kalpakkam using different attenuation relationships

4 CONCLUSIONS

Catalogue completeness has been checked with Visual Cumulative method (CUVI) with magnitude-frequency diagrams. For the Kalpakkam, the estimated values of *a* and *b* are 4.527 and 1.183, respectively. The bounded Gutenberg-Richter recurrence law is found to give an acceptable ground shaking hazard for the Kalpakkam. Results of the analysis are provided in the form of uniform hazard spectra and bed rock level peak ground acceleration (PGA) for various return periods**.** The PGA at Kalpakkam corresponding to 10% probability of exceedance in a life span of 50 years or in other words a PGA corresponding to a return period of 475 years is 0.08g which is indicative of low to moderate seismicity of the region.

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