

## Sensitivity of PSHA in the Region of Peninsular India

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### 1 ABSTRACT

Assessment of the techniques used for estimation of input parameters as well as the approaches followed for calculation is necessary for probabilistic seismic hazard analysis (PSHA) of any location in low seismicity region. Peninsular India poses unique challenges in application of PSHA due to sparse seismicity data, lack of information on seismotectonic characteristics, and non-availability of regional specific attenuation relationships. This paper elaborates the sensitivity analysis of input parameters that are carried out during the estimation of uniform hazard spectra for a site located in peninsular India. The parameters studied include increments in year and magnitude while conducting the completeness check of database using by Stepp's method, source models, and apportionment of earthquake activity estimated for the whole region to individual source areas. De-aggregation of hazard estimated in each stage of sensitivity analysis is also carried out. It is found that use of full database (without completeness check) results in higher hazard. With regard to bin sizes used for completeness check, it is noted that the estimated years of completeness did not vary significantly unless very large sizes for year and magnitude bins are used. The de-aggregated results indicate that the maximum contribution to hazard results from the near earthquakes and relative contribution to hazard remains same irrespective of the shape of sources, provided their characteristics are reasonably represented. It is observed that among the parameters studied, methods followed for rate apportionment play a major role in outcome of PSHA.

### 2 INTRODUCTION

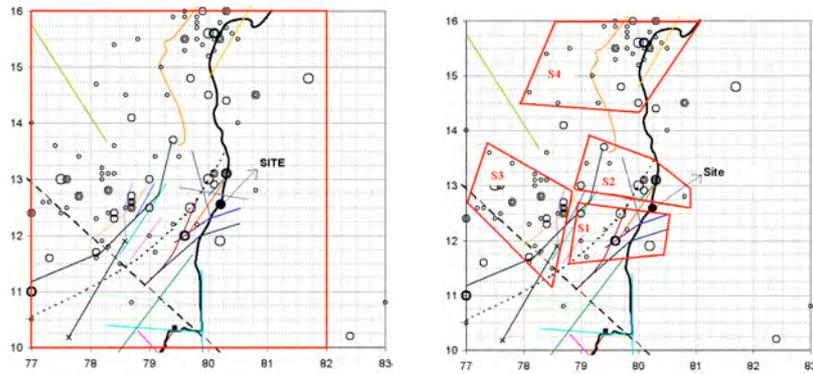
For robust application of probabilistic seismic hazard analysis (PSHA) to a site, data/information on strong motion earthquake, seismotectonic status and site-specific attenuation relation of the region are required. When data inadequacy is substantial, as is the case generally in low seismic region, confidence on the outcome of the PSHA may be low and acceptance of the result may become clouded. To overcome this, impact of data inadequacy needs to be assessed for working out the measures to handle uncertainties arising out of it in the PSHA work. An effective tool for this assessment is the sensitivity analysis of input parameters. The present paper describes application of sensitivity analysis for a site located in low seismic region of peninsular India on the outcome of PSHA.

The site at is located along the coast of Bay of Bengal and lies in the Zone – III of the seismic zoning map of India (IS 1893-2002). A region of about 400km x 400km size around the site is considered for the present work. Faults/lineaments in this region and epicenter of past earthquakes are plotted in Fig. 1. However, the parameters like depth, dip, etc. are not available for identified faults/lineaments.

The past historical earthquake data is collected from AERB/TD/CSE-1 (1993), Rao and Rao (1984), Gupta I.D. (2004), and Chandra U (1977). The duplicate events have been removed from the resulting database. The database includes both historical and instrumentally recorded earthquakes. Very limited data/information is available in the surrounding marine region.

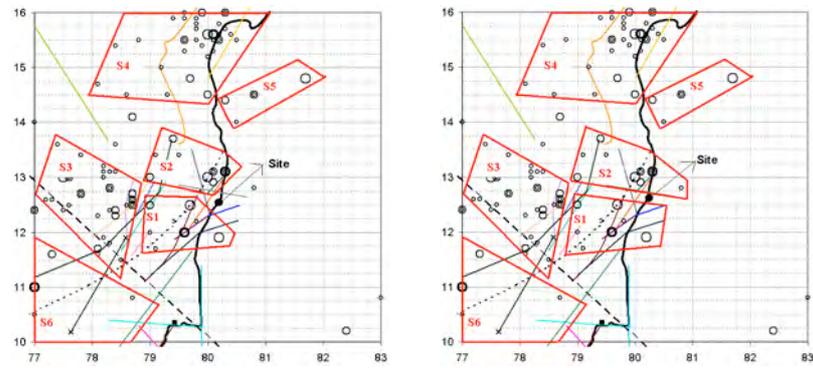
The data spans from 1807 to 2001 and contains approximately 100 records. The largest earthquake that occurred in the region is the Coimbatore earthquake of February 8, 1900, with a magnitude of 6.0 having epicenter around 400 km away from the site. In case of older data, for which earthquake size has been reported in intensity scale, they have been converted to equivalent magnitude. In many cases, even for

instrumentally recorded earthquakes the scale followed for magnitude measurement is not reported. However, the magnitude values being less than 6.0, the effect due this difference is considered minimal.



(a) Source configuration SM1

(b) Source configuration SM2



(c) Source configuration SM3

(d) Source configuration SM4

**Figure 1.** Alternative source models of the region around the site

- Note: 1. Distribution of earthquake epicenters and lineaments around site are taken from published literature  
 2. The magnitude of earthquake is indicated by proportional size of circle  
 3. The seismic events that are not falling inside any of the source are considered as the background seismicity in the corresponding source model.

In the recent years, efforts have been made by researchers to estimate probabilistically the seismic hazard in peninsular India (Ghosh, 2006, Jaiswal and Sinha, 2007). The uniform hazard spectrum at Tarapore located in peninsular India was developed by Ghosh (2006) using the spectral attenuation relationships derived for rock sites and line source model and following Cornell's (1968) approach. He carried out a sensitivity analysis considering variation in maximum magnitude, parameters 'a' and 'b' of magnitude frequency relation, depth of focus, distance to earthquake source (lineament) and length of lineament. As part of PSHA of France, Beauval and Scotti (2004) studied the sensitivity of results to earthquake catalogue uncertainties, truncation of ground motion variables and magnitude limits.

### 3 INPUT AND DATA REQUIREMENT

The seismic hazard of the site is derived using the following expression (Cornell, 1968, Esteva 1974, McGuire, 1976):

$$E(Z > z) = \sum_{i=1}^N \alpha_i \int_{m_{\min}}^{m_{\max, i}} \int_{r=0}^{\infty} f_i(m) f_i(r) P(Z > z | m, r) dr dm \quad (1)$$

Left side of equation (1),  $E(Z > z)$ , is the frequency that acceleration  $Z$  being greater than  $z$ . For obtaining the probability, one has to consider the temporal distribution of the earthquake, which is normally taken as a Poisson process.

For PSHA of a site, earthquake sources within a defined region containing the site are considered. These sources, depending on its characteristics are modeled as point, or line, or aerial, or volume sources. Each source is assigned a maximum potential magnitude  $m_{max,i}$  of earthquake. Total number of such sources (N) to be considered in the PSHA study, their geometry and value of  $m_{max,i}$  are derived from the geological and seismological information of the region/area around the site, and past earthquake data. One value of minimum earthquake magnitude,  $m_{min}$  is generally assigned to all sources from practical consideration of hazardous effect of minimum earthquake that can effect the facility under consideration.

Several empirical relationships have been reported in the literature for conversion of epicentral intensity to equivalent magnitude, (McGuire, 2004). A study of the historical data on earthquakes in peninsular India by the authors reveals that the following relationship conservatively estimates earthquake magnitude from epicentral intensity.

$$m = \frac{2}{3}I_0 + 1 \quad (2)$$

Where,  $m$  is the earthquake magnitude and  $I_0$  is the epicentral intensity.

The maximum magnitude,  $m_{max,i}$  corresponding to each source is estimated using the equation (AERB/SG/S-11, 1990)

$$m_{max,i} = m_i + 0.67 \quad (3)$$

Where,  $m_i$  is the maximum earthquake magnitude observed in the  $i^{\text{th}}$  source.

Activity rate of each source,  $\alpha_i$ , is determined from the earthquake recurrence relationship of the region/source/fault based on Gutenberg-Richter relationship. This can be represented in the form

$$\ln(m) = v_0 e^{-\beta m} \quad (4)$$

Where,  $v_0 = 10^a$  and  $\beta = b \ln 10$  and 'a' and 'b' are constants representing the seismic activity of the region/source/fault.

The activity rate is the rate of earthquake corresponding to  $m_{min}$  and is given by,

$$\alpha = v_0 e^{-\beta m_{min}} \quad (5)$$

$\alpha_i$  is calculated from  $\alpha$ .

$f_i(m)$  and  $f_i(r)$  of eqn (1) represents probability distribution of earthquake magnitude and distance measure respectively.  $P(Z > z|m, r)$  is the probability of exceedance of acceleration, due to an earthquake of magnitude 'm' originated in a source at a distance 'r'. This is obtained by integration of underlying probability distribution function, commonly assumed to follow lognormal distribution.

Primary input to evaluate seismic hazard from equation (1) are source configuration,  $m_{max}$ ,  $m_{min}$ , 'a' and 'b' values to determine  $\alpha_i$  and  $\beta$ , attenuation relationships and  $r$ . Sources of major data/information required to develop the input parameters of eqn. (1) are geology and seismology, historical earthquake data, maximum earthquake potential of sources, and attenuation relationship as well as distance. Some of the input parameters like  $m_{min}$ ,  $r$  are selected from data/information directly and some are derived. The techniques of deriving such primary input parameters from the data and certain co-efficients involved have strong bearing on the outcome of PSHA. These techniques are considered as secondary parameters.

The paper discusses the sensitivity of following parameters

- I. Primary input parameters
  - a. Source configuration
- II. Secondary input parameters
  - a. Increments in year and magnitude while conducting the completeness check of database using by Stepp's method,

- b. Techniques for apportionment of earthquake activity estimated for the whole region to individual source areas.

Peak ground acceleration (PGA) is taken as the reference hazard parameter for this purpose. Hazard calculated in each stage of sensitivity analysis are de-aggregated. The software 'EQRISK', with some in-house augmentation, is used in the present work.

#### 4 SENSITIVITY ANALYSIS

The epicentral locations of historical events around the site could not be well correlated to the locations of faults/lineaments, Fig. 1(a). In view of this, the source zones are considered as spatial in nature and the source configurations are modeled as aerial sources. Further, distribution of epicentral locations is not amenable for a single aerial source model that results in more than one source. After examining several options, four different shapes of the sources (SM1, SM2, SM3 and SM4) are identified as possible source configuration for sensitivity analysis, Fig. 1. Possible shapes are postulated and effects of these shapes on hazard are studied.. The modeling of the source configuration, in general, follows the source zonation scheme as suggested by Gupta (2006).

The activity rate,  $\alpha_i$  of each source is estimated principally through three steps from the earthquake data of the region. First the completeness of the data is checked. Database is checked for the completeness by Stepp's method (Das, 2002). This method requires the database to be split into different magnitude and year bins. Bin size is important for completeness check. In the second step, the parameters related to Gutenberg-Richter recurrence relationship, i.e., 'a' and 'b' are calculated. More than one method exist for determining 'a' and 'b' values from the screened data. In the present work, method of least squares and method of maximum likelihood are used. The activity rate  $\alpha$  of the region is determined from 'a' and 'b' using equations (4 and 5). Finally,  $\alpha$  is apportioned to each source as  $\alpha_i$  following suitable approach.

Ideally, in a region of multiple seismotectonic sources, the Gutenberg- Richter relationship is derived for individual sources. Considering the lower number of seismic events associated with each source in the region within which the site lies, Fig. 1, it is felt that the estimation of 'a' and 'b' for each source may add additional uncertainties to the already existing ones due to sparse data. Hence, 'a' and 'b' are derived for the region instead of individual values for each source.

Deriving 'a' and 'b' for the region (encompassing all sources) would result in one value of activity,  $\alpha$ , for the entire region. To reflect a scenario of variable seismicity for different source zones, total activity  $\alpha$  needs to be apportioned to each source. This apportioning could be done based on either the parameters of source configuration, i.e., length/area/volume of sources, or activity potential of the sources. No particular approach can be attributed superior to other based on published literature. Though, the apportionment based on geometrical dimension of sources is easier to implement, it does not seem to reflect activity potential of the sources. Approach like energy apportionment and constant b-value, reflect in a way, the activity potential of sources. These two approaches are adopted for apportionment of activity.

The activity potential of sources is reflected better through the number of events or magnitude of events that have occurred in that source. This is the basis of energy apportioning approach (EAA), in which  $\alpha_i$  of each source is calculated from the following expression.

$$\alpha_i = \alpha \frac{e_i}{\sum_i e_i} \quad (6)$$

Where,  $e_i$  is a measure of the energy released by  $i^{\text{th}}$  source. The ratio of the energy released between two events with a unit magnitude difference is taken as 31. If the  $i^{\text{th}}$  source has  $N_1$  events with magnitudes between 3.0-4.0,  $N_2$  with 4.0-5.0 and  $N_3$  with 5.0-6.0; the total energy potential of the source is proportional to  $e_i$ , which is given by

$$e_i = N_1 \times 31 + N_2 \times 31 \times 31 + N_3 \times 31 \times 31 \times 31 \quad (7)$$

$e_i$  is calculated for each source,  $i$ , and then the activity rate obtained using eqn (5) is apportioned using eqn (7).

In constant b-value approach (CBA), the slope or rate of activity of the sources,  $\beta$  or 'b' is assumed not to change and only the intercept,  $\alpha_i$  or 'a<sub>i</sub>' varies for each source, *i*. Value of 'a<sub>i</sub>' is calculated, keeping 'b' constant by means of a best fit line or least error (least square) with respect to the observed earthquake activity data of the source.  $\alpha_i$ , corresponding to  $m_{\min}$  is calculated using new value of 'a<sub>i</sub>' and 'b'. It can be noted that the total activity from all sources may change in this methodology as sum of 'a<sub>i</sub>' may not be same as that of total 'a' of the region. A correction/normalisation factor is introduced so that sum of activity calculated for all sources ( $\sum_i \alpha_i$ ) by this approach remains equal to the total activity  $\alpha$  calculated using the full database.

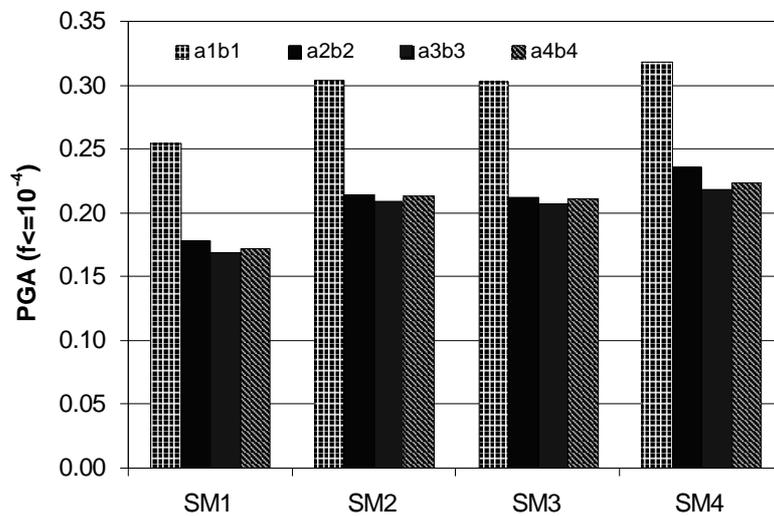
Further, 'a' and 'b' values may depend on splitting of database into different magnitude and year bins required during completeness check. Sizes of year bins are varied from 5 to 20 with increments of 5 and magnitude bins with increments of 0.5 and 1.0. The upper limit for year is chosen based on the total of available data (~200 years duration) so that adequate numbers of points are available while graphical verification of completeness is carried out. 'a' and 'b' values calculated from data set considered in the present work corresponding to different bin sizes used in completeness check evaluated following method of least squares are given in Table 1. 'a' is found to vary from 2.43 to 2.72 and 'b' from 0.67 to 0.825. With regard to bin sizes used for completeness check, it was found that the estimated years of completeness did not vary significantly with respect to bin sizes unless very large sizes for year and magnitude bins are used. The global seismic hazard assessment programme (GSHAP) study has recommended a value of 3.0 and 0.6 respectively for a and b, while Rao and Rao (1984) have reported values of 4.4 and 0.85 respectively for peninsular India.

**Table 1.** Gutenberg – Richter parameters of site

Parameter	<sup>1</sup> Full dataset	<sup>2</sup> 5 yr, 0.5 m	<sup>2</sup> 10yr, 0.5 m	<sup>2</sup> 20yr, 0.5 m
a	2.43	2.72	2.58	2.47
b	-0.67	-0.82	-0.81	-0.78

Note 1: without completeness check

2: Bin sizes considered for completeness check, 'm' denotes magnitude



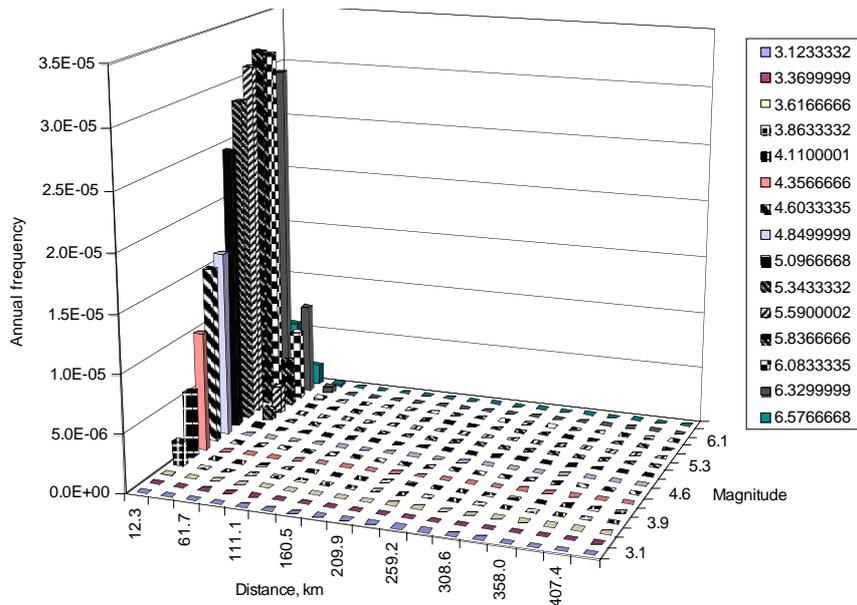
**Figure 2.** Plot of PGA calculated for 16 combination of source characterisation

Four different source configurations, given in Fig. 1, are considered in sensitivity analysis. Hazard from each of these four configuration are further studied with four sets of 'a' and 'b' values obtained from four combinations of bin sizes used for completeness check. Together, these result in sixteen combinations for sensitivity analysis. McGuire (1978) attenuation relation, which is the default attenuation relationship in 'EQRISK' is considered in each case.  $\alpha_i$  of each source is estimated by energy apportioning method of equation (7). The seismicity, which does not part of any source, is considered as background source.

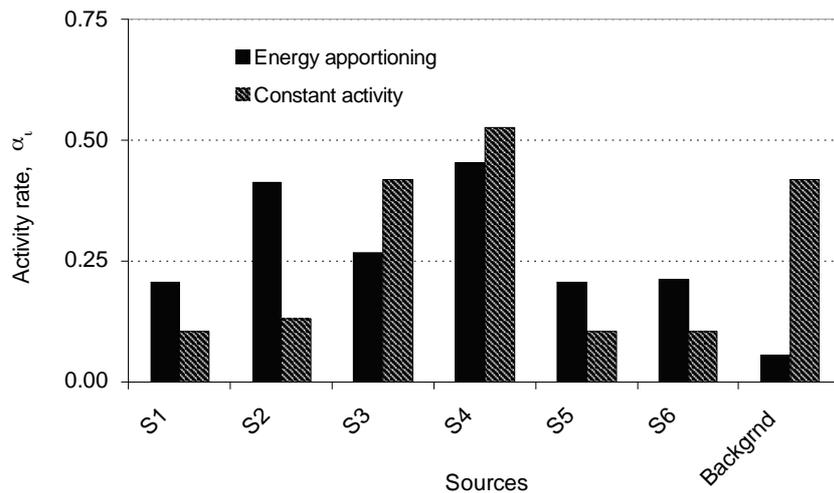
PGA corresponding to annual frequency of  $10^{-4}$  is calculated for each of the combination, and is plotted in Fig. 2. It is noted that source model SM1 predicted the lowest PGA value for all combinations of 'a' and 'b'. This is expected as SM1 has a single source and assumes uniform distribution of seismicity, which is not

actually observed at site. Among remaining three other source models, SM2 and SM3 resulted in almost similar values of PGA, whereas SM4 produced 5-10% higher accelerations compared to SM2 and SM3. Considerable dispersion in results is also noted from hazard curve for PGA of the 16 combinations.

Contribution of distance of source from site and magnitude of earthquake to hazard is examined by means of deaggregation. The results of de-aggregation are extracted for each hazard curve evaluated at different values of acceleration, generated during the sensitivity study. Generally, it is observed from the de-aggregated results of all the cases that the maximum contribution to hazard results from the near earthquakes and relative contribution to hazard remains same irrespective of the shape of sources, excepting the source model SM1. A typical shape of deaggregated hazard corresponding to the case of source model SM4, and ‘a’ and ‘b’ values calculated for bin size of 5 years and 0.5 magnitude is plotted in Fig. 3.



**Figure 3.** De-aggregated results of annual probability of exceedence corresponding to an acceleration of 0.20g. (source model SM4; ‘a’ & ‘b’ corresponds to 5 year and 0.5m.)



**Figure 4.** Activity rate of individual sources corresponding to source model SM4  
 Note :  $\alpha_i$  is calculated for  $m_{\min}=3.0$ , and ‘a’ & ‘b’ corresponds to 5 year and 0.5m.

To study the effect of different approaches used for estimation of  $\alpha_i$ , total activity rate calculated for the region from the ‘a’ and ‘b’ values, given in Table-1, is apportioned to source configurations SM1 through SM4 adopting energy apportionment approach and constant b-value approach as described earlier. The results do not suggest any trend indicating which approach maximizes the hazard. Values of activity rate

derived for source configuration SM4, calculated for bin size of 5 year and 0.5 magnitude, using both the approaches, is plotted in Fig. 4.

## 5 SUMMARY OF RESULTS

Observations made from the sensitivity analysis for the site considered in this work are summarized below.

- a. Use of full database without completeness check results in higher hazard. This could be due to the fact that in a full database, the number of low magnitude events can be on the higher side when completeness is not checked.
- b. Bin size used in completeness check, excepting the extreme cases, has little effect on the outcome of completeness check and finally to 'a' and 'b' values.
- c. No conclusion on the influence of a particular method, EAA or CBA, for apportionment of rate on hazard could be drawn from this study.
- d. The source configuration SM1 predicted least PGA, where as SM4 resulted in highest PGA.
- e. As expected, de-aggregation of hazard indicates that distance of source from site has strong bearing on hazard. However, hazard is relatively insensitive to the shape of source zones provided their characteristics like geometry are reasonably represented.

## 6 CONCLUSION

The work was undertaken as part of estimation of uniform hazard spectra for a site located along east coast of Peninsular India. The sensitivity of some of the input parameters to outcome of PSHA is brought out in the paper. It is found that use of full database (without completeness check) results in higher hazard. With regard to bin sizes used for completeness check, it is noted that the estimated years of completeness did not vary significantly unless very large sizes for year and magnitude bins are used. The de-aggregated results indicate that the maximum contribution to hazard results from the near earthquakes and relative contribution to hazard remains same irrespective of the shape of sources, provided their characteristics are reasonably represented. It is observed that among the parameters studied, methods followed for rate apportionment play a major role in outcome of PSHA.

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