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Generation of Uniform Hazard Response Spectrum for a Peninsular Indian site

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Abstract: The present paper describes the details of generation of Uniform Hazard Response Spectrum (UHRS) for a Peninsular Indian site. Probabilistic Seismic Hazard Analysis (PSHA) has been carried out using seismotectonic parameters for the region covering a radius of 300 km around the site. Seismic hazard parameters 'a' and 'b' have been evaluated considering the available earthquake data using Gutenberg-Ritcher (G-R) relationship and Kijko and Sellovell method utilizing extreme and complete catalogues. Epistemic uncertainty is considered by using alternative models and/or parameter values through logic tree approach. The PSHA model is developed by integrating the seismic source characterization models and ground motion characterization models.

Keywords: *Uniform Hazard Response Spectrum (UHRS), Probabilistic Seismic Hazard Assessment (PSHA), Peninsular India*

1. Introduction

The annual frequency of exceedance of a ground motion parameter (e.g. spectral acceleration at a given damping value and frequency) at a site is calculated in a typical probabilistic seismic hazard assessment (PSHA). The outcome of PSHA is hazard curves, which are plots of acceleration vis-a-vis annual frequency of exceedance, from which the uniform hazard response spectrum of the site is derived. The PSHA at a site is associated with two types of uncertainties - aleatory and epistemic. The first type is due to natural variability associated with the physical process of and occurrence of seismic event and resulting hazard(s). Epistemic uncertainty is the scientific uncertainty in the model of the process. It is due to limited data and knowledge. The epistemic uncertainty can, in principle, be eliminated with sufficient study.

Epistemic uncertainty is considered by using alternative models and/or parameter values for the source characterization and ground motion attenuation relation. For each combination of alternative models, the hazard is recomputed resulting in a suite of alternative hazard curves. In seismic hazard analyses, it is common to use logic trees to handle the epistemic uncertainty. A logic tree consists of a series of branches that describe the alternative models and/or parameters such as source model, maximum magnitude, apportionment of activity, focal depth and attenuation relationship etc. At each branch, there is a set of branch tips that represent the alternative credible models or parameter. The weights on the branch tips represent the judgment about the credibility of the alternative models. PSHA has been carried out for Peninsular Indian site and the details are given in this paper.

2. Probabilistic Seismic Hazard Assessment (PSHA)

Ground motion parameters are estimated for selected values of the probability of ground motion exceedance in a design period of the nuclear facility or for selected values of annual frequency or return period for ground motion exceedance. PSHA offers a rational framework for risk management by taking account of the frequency or probability of exceedance of the ground motion against which a nuclear facility is designed.

The probability distribution is defined in terms of the annual rate of exceeding the ground motion parameter z at the site under consideration (*v(z))*, due to all possible pairs of the magnitude, M and epicentral distance, R of the earthquake event expected around the site, considering its random nature. The probability of ground motion parameter, Z at a given site, will exceed a specified level, *z*, during a specified time *T* and it is represented by the expression:

$$P(Z > z) = 1 - e^{-v(z)T} \leq v(z)T \qquad (1)$$

Where, *v(z)* is (mean annual rate of exceedance) the average frequency during time period *T* at which the level of ground motion parameters, *Z*, exceed level z at a given site. Function *v(z)* incorporates the uncertainty in time, size and location of future earthquakes and uncertainty in the level of ground motion they produce at the site. It is given by [1]:

$$\nu(z)=\sum_{i=1}^{N}\upsilon_i(m_0)\int_{m_0}^{m_u}\int_{d}^{r_0} f_M(m)\, f_R(r)\, P[Z>z/m\geq m_0, r]\,dr\,dm$$

or

$$\nu(z)=\sum_{i=1}^{N}\upsilon_i(m_0)\left[\sum_M\sum_R P(M=m_i)P(R=r_j/m_i).P(Z>z/m_i,r_j)\right] \qquad (2)$$

In which

$\upsilon(m_0)$ = the annual frequency of occurrence of earthquakes on seismic source n whose magnitudes are greater than m_0 and below the maximum event size, m_u .

$P(R=r_j|\ m_i) = f_R(r) =$ the probability of an earthquake of magnitude mi on source n occurring at a certain distance r_j from the site

$P(M=m_i) = f_M(m_i)$ = the occurrence probability of an earthquake of magnitude m_i on source n

$P(Z>z \mid m_i,r_j)$ = the probability that ground motion level z will be exceeded, given n earthquake of magnitude m_i at distance of r_j from the site.

PSHA is a technique for estimating the annual rate of exceedance of a specified ground motion at a site due to known and suspected earthquake sources. The relative contributions of the various sources to the total seismic hazard are determined as a function of their occurrence rates and their ground-motion potential.

3. Construction of PSHA Model

Seismic source characterization entails analysis of regional geological, geophysical, and seismological and geotechnical data to identify location and geometry of seismic source that may have hazardous impact at site. Seismic source characterization model for the site [2] is shown in Figure 1.

It contains six areal sources. The earthquake data around the site are also shown in this Figure. This data is obtained from published literature, and IMD earthquake catalogue [3].

Earthquakes with magnitude more than 3 are considered for present study. Ground motion characterization model comprises of seven Ground Motion Prediction Equations (GMPE). They are Atkinson & Boore – ATKB [4], Pezeshk –PEZA [5], Toro [6], RSD-1 & RSD-2 [7], NDMA [8] and Campbell [9].

Complete PSHA model of a site is developed by integrating the alternative Seismic source characterization models and ground motion characterization models. The resulting logic tree for PSHA is shown in Figure 2.

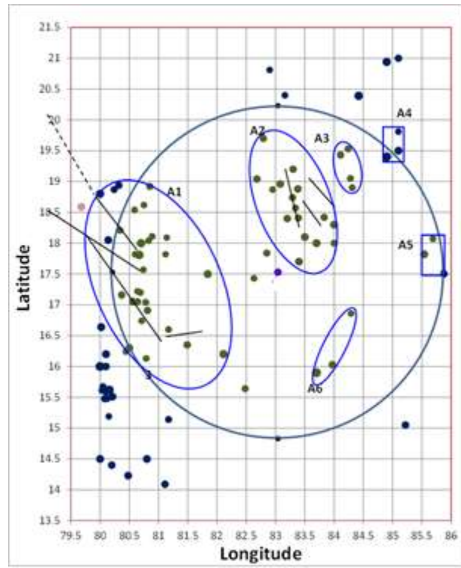

Figure 1 *Seismic source characterization model for a Peninsular Indian site*

It comprises of eight branches and their weightages are given in Figure 2. It comprises of one source model, two methods for evaluation of regional 'a' and 'b'(Kijko-Sellovell method [10] and Regression analysis). Based on the Kijko–Sellovell maximum likelihood estimation method 'a' and b parameters have been estimated as 2.314 and 0.7 respectively. Corresponding values for regression method ar 2.421 and 0.68 respectively for Regression analaysis. Three approaches for estimating m_{max} were proposed and agreed upon after evaluation. These are 1) observed maximum magnitude earthquake plus 0.67; 2) from subsurface rupture length (to be taken as one third of total fault length); and 3) From magnitude-frequency extrapolation of records. Two sets of values for depth of focus are used: 5 Km, 10 Km and 15 Km for earthquake of m $\leq$ 5.5; and 10 Km, 15Km and 20 Km for M > 5.5.

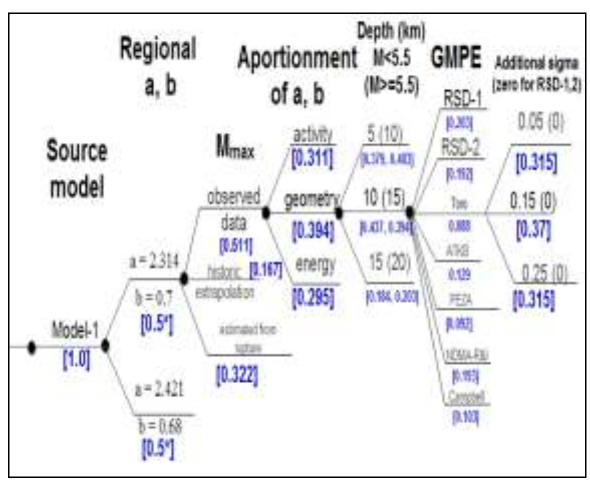

Figure 2 *Logic tree for PSHA*

4. Results and Discussions

The summation of all the probabilities is termed as hazard curve, which is plotted as mean annual rate of exceedance (and its reciprocal is defined as the return period) versus the corresponding ground motion. The mean annual rate of exceedance has been calculated for six seismogenic sources separately and summation of these representing the cumulative hazard curve. The mean annual rate of exceedance versus peak ground acceleration for all the sources at rock level is shown in Figure 3. Hazard curves for individual GMPEs as well as resultant using logic tree weightages are shown in this figure. The resulting Peak Ground Acceleration (PGA) for 10,000 years return period is 0.117g.

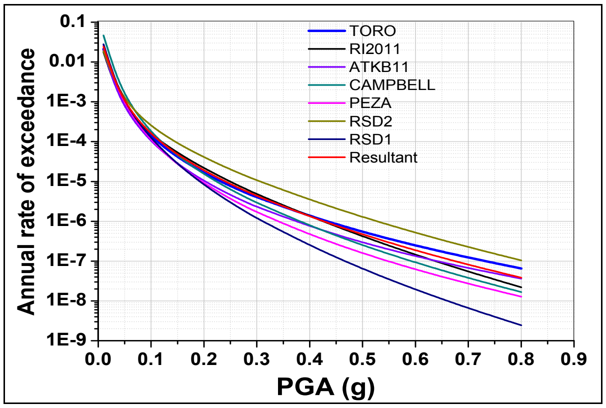

Figure 3 *Hazard curves for various GMPEs*

UHRS is developed from a probabilistic ground motion analysis that has an equal probability of being exceeded at each period of vibration. For finding the UHRS, seismic hazard curves of spectral acceleration are computed for the range of frequencies. From these hazard curves, response spectra for a specified probability of exceedance over the entire frequency range of interest are evaluated. Figure 4 shows the UHRS (with damping of 5%) at bed rock level for various GMPE for 10,000 years return period.

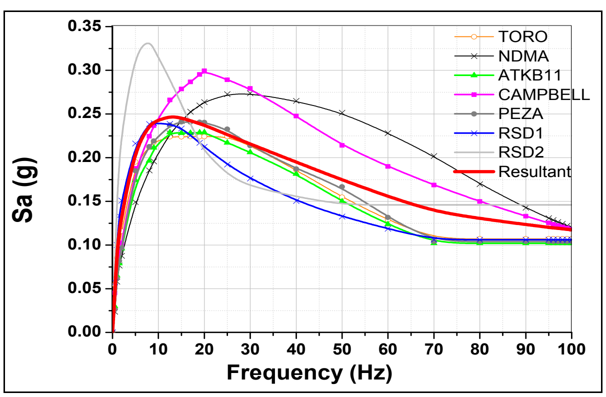

Figure 4 *UHRS for 10,000 years return period (All seven GMPE)*

It can be observed that the significant amplification in the spectra by all GMPEs except NDMA and Campbell occurs in the frequency range of 5- 25 Hz. From the study on few earthquake records of intra plate region [7], it is observed that the predominant frequency of ground motion is less than around 25 Hz. Hence, UHRS from five GMPEs which results in this band of frequency content have been considered for the study and denoted as Option-1. UHRS at bed rock level using five GMPE for 10,000 years return period are given in Figure 5. The resulting PGA for 10,000 years return period is 0.119g for Option-1.

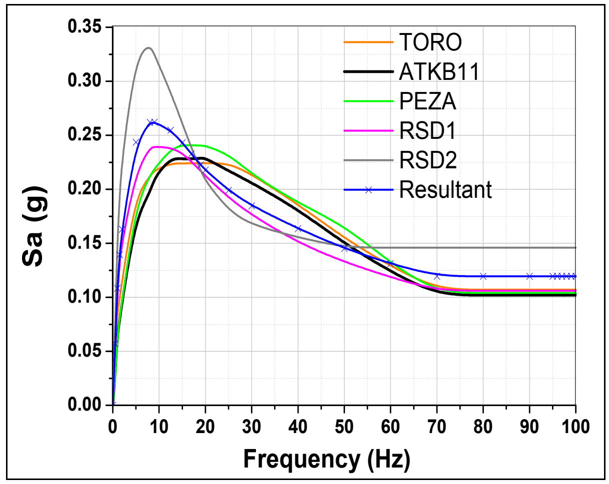

Figure 5 *UHRS for 10,000 years return period (Option-1: Five GMPE)*

Alternatively, UHRS obtained from site specific GMPEs (RSD-1 &2) have been considered and is designated as Option-2. UHRS at bed rock level using these two GMPE for 10,000 years return period are given in Figure 6. The resulting PGA for 10,000 years return period is 0.126g for Option-2.

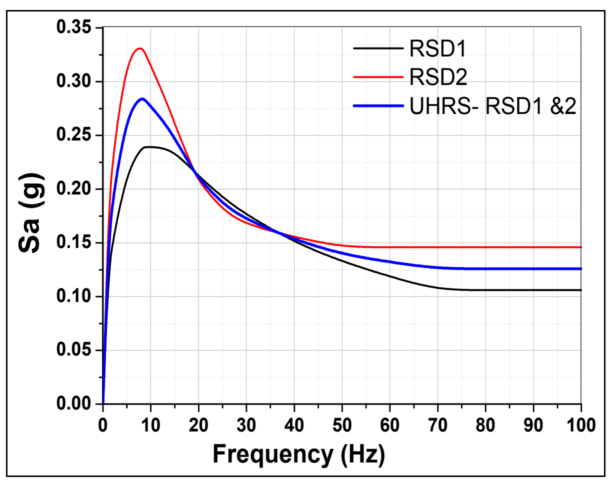

Figure 6 *UHRS for 10,000 years return period (Option-2: Two GMPE)*

5. Conclusion

PSHA has been carried out for a Peninsular Indian site. Alternative models and parameters for PSHA have been considered through logic tree approach. The PGA for the site using seven GMPEs is 0.117g for 10,000 return period. Uniform Hazard Response Spectrum (UHRS) has also been generated. Two alternative options have been worked out for UHRS of the site; first one based on earthquake records of intra plate region and second one based on site specific data. Accordingly, five GMPEs are selected for option-1 and two for option-2. The resulting PGA for these options are 0.119g and 0.126g respectively.

6. Acknowledgement

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