PROBABILISTIC SEISMIC HAZARD ANALYSIS FOR WARANGAL
CONSIDERING SINGLE SEISMOGENIC ZONING

Nirbhay Narayan Singh¹, Deviprasad B S², Dr. P Hari Krishna³, Dr. G. Kalyan Kumar⁴

ABSTRACT

The estimation of probabilistic seismic hazard in low seismicity regions such as stable continental regions has to copeup with the difficulty in identification of active faults and with the low amount of available seismicity data. In this paper, an attempt is made to carry out comprehensive probabilistic seismic hazard analysis for low seismicity region like Warangal, South India. Warangal is the second-fastest growing city in Telangana state, after Hyderabad. The city is known for its heritage and in late 2014 was included in the Government of India's proposed HRIDAY - Heritage City Development and Augmentation Yojana.

A new earthquake catalogue for Warangal, with unified moment magnitude scale has been prepared. The earthquake catalogue compiled by Rao & Rao (1984), Srivastava & Ramachandran (1985), Jaiswal & Sinha (2007), International Seismological Centre and U.S Geological Survey were used for the analysis. A total of 389 earthquake events of magnitude ($M_w$>=3) spanning from time 1800 A.D. to 2015 A.D. were prepared before declustering. Declustering of earthquake events was performed by Z MAP software using Urhammer method. 111 events out of 389 were identified as dependent events. Catalogue completeness analysis has been carried out by CUVI and Stepp’s method on declustered catalogue.

Seismic Hazard Analysis is carried out by considering the seismotectonic parameters of the study region covering a radius of 350 km with NIT Warangal (17.9808°N, 79.5328°E) as the center. Major faults and lineaments such as Latur Lineament, Kaddam fault, Kinnersasani-Godavari fault, Gundlakamma faults were identified as the sources of occurred earthquake events. The standard Cornell-McGuire method has

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been used for hazard computation considering single seismogenic zoning. Five attenuation relationships suggested by Raghu Kanth and Iyengar (2007), Abrahamson and Silva (1997), Ambraseys et al. (2005), Campbell and Bozorgnia (2003), Hwang and Huo (1997) are selected for calculation of PGA. Annual rate of exceedance of different time periods for Warangal has been evaluated by using the Gutenberg-Richter recurrence relationship. CRISIS 2007 Version 1.1, a computer program for computing seismic hazard, developed by Ordaz et. al., (2007) has been used for seismic hazard analysis. The frequency-intensity curves are generated by computing the annual probability of exceedance for a range of ground motion intensities. The uniform hazard spectra of acceleration and Spectrum-compatible acceleration time-histories have been obtained for different return periods and is compared with the IS 1893 code specified design response spectra.

Keywords: Earthquakes, Probabilistic hazard analysis, Hazard Curves, PGA, Warangal, Uniform hazard spectra, Design spectra.
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ABSTRACT: Probabilistic seismic hazard analysis (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. PSHA is carried considering the seismotectonic parameters of the region covering a radius of 350 km with NIT Warangal (17.98°N and 79.53°E) as the centre. Raw earthquake catalogue is taken and statistical analysis is carried out. About 36% of the events with reported magnitude $M_d \geq 3.0$ in the catalogue are identified and subsequently removed by applying the dynamic window algorithm, and finally a new catalogue of 248 earthquake data were prepared. Using the attenuation relationship, the horizontal PGA expected in NIT Warangal on stiff ground, with a 10% probability of exceedance in 50 years (which corresponds to a return period of 475 years) and that with a 2% probability of exceedance in 50 years (return period = 2475 years) is determined. The uniform hazard spectra (UHS) for different reference return periods ($T = 72$, $475$, $975$ and $2,475$ years) for rock/stiff site conditions have been computed. The mean UHS of the horizontal component of acceleration for different return periods on rock site are plotted and UHS for 475 years return period is compared with the Design Basis Earthquake (DBE) of the BIS (IS 1893: 2002).

1. INTRODUCTION
An earthquake disaster, from the engineering point of view, is a situation in which the intensity of ground shaking produces stresses and strains that exceed the strengths of the structure. The hazards associated with earthquakes are referred to as seismic hazards. Seismic hazard is defined as the potential for earthquake induced natural phenomena such as ground motion, fault rupture, soil liquefaction, landslides and tsunami with adverse consequences to life and built environment at a specific site (Cornell 1968, Reiter 1990).Seismic Hazard Analysis (SHA) is the evaluation of potentially damaging earthquake related phenomena to which a facility may be subjected during its useful lifetime. Seismic hazard studies are required for the preparation of earthquake loadings regulations, for determining the earthquake loadings for projects requiring special study, for areas where no codes exist, or for various earthquake risk management purposes.

This paper outlines the PSHA of Warangal city considering it as single seismogenic zone which would be very useful for the further multi seismogenic analysis and planning of structures accordingly. Tools like ArcGIS, CRISIS2007 and MATLAB has been extensively used for the analysis.

1.1 Seismic Hazard Analysis
Seismic hazard analyses involve the quantitative estimation of ground shaking hazards at a particular site. Seismic hazards may be analyzed deterministically, as when a particular earthquake scenario is assumed, or probabilistically, in which uncertainties in earthquake size, location, and time of occurrence are explicitly considered.

Probabilistic seismic hazard analysis (PSHA) provides a framework in which uncertainties in the size, location, rate of recurrence and effects of earthquakes to be explicitly considered in the evaluation of seismic hazards (Kramer, 1996; McGuire, 2001). All the uncertainties involved in the PSHA is rationally quantified and combined in a consistent manner to provide a more complete picture of the seismic hazard. The products of
PSHA are estimates of ground motion parameters for chosen probabilities of occurrence, for a particular site or a region.

2. METHODOLOGY

2.1 Earthquake Catalogue and Processing

Earthquake catalogues form the backbone of seismic hazard assessment, providing the detailed insight into the seismicity of a region required to develop seismogenic zoning scenarios, in conjunction with seismotectonic and geological information for probabilistic approaches based on classical Cornell-McGuire theory.

2.1.1 Geographical Extent of the Study Area

The earthquake catalogue compiled covers historical and instrumental seismic events in a circular area of 350 km radius, with NIT Warangal at its center. The geographical co-ordinates of NIT Warangal are 17.98° N Latitude and 79.53° E Longitude.

2.1.2 Homogenizing Earthquake Magnitude from Different Sources

Catalogue prepared by Chandra (1977) and Rao and Rao (1984) has been used as sources for the earthquake catalogue along with some internationally recognized internet database like International Seismological Centre (ISC) and United State Geological Survey (USGS). The relationships proposed by Kramer (1996), as provided in equation 1-4, have been used to convert the body wave magnitude (M_b), local magnitude (M_L), and surface wave magnitude (M_s) to the moment magnitude (M_w).

\[
\log[M_o] = 18.28 + 0.679(M_b) + 0.077(M_b^2) \quad (1)
\]

\[
\log[M_o] = 18.31 + 1.017(M_L) \quad (2)
\]

\[
\log[M_o] = 24.66 - 1.083(M_s) + 0.192(M_s^2) \quad (3)
\]

\[
M_w = \frac{2}{3} \log[M_o] - 10.7 \quad (4)
\]

Where M_o is the seismic moment in dyne-cm.

2.1.3 Declustering Earthquake Database

Declustering is the process of removal dependent earthquake events (foreshocks and aftershocks) from an earthquake catalogue. Declustering is done by two approaches namely Static Window method and Dynamic Window method. In static windowing method, removal of those foreshocks and aftershocks are done which fall within a constant time and distance window. While in dynamic windowing method, removal of foreshocks and aftershocks is done based on their temporal and spatial window parameters and magnitude of main events.

2.1.4 Completeness Periods

To define the time window in which the catalogue is presumed to be complete, completeness periods are estimated, as for historical earthquakes the recorded seismicity differs from the true seismicity. Visual Cumulative (CUVI) method, formulated by Mulargia, Gasperini and Tinti (1985) is used for estimation of the period of completeness. Earthquake events are divided into different magnitude classes, as incompleteness is known to be a function of magnitude. Either the subdivisions could be intervals (for instance ΔM = 0.5) or cumulative, containing all the events of magnitude exceeding the lower bound of chosen interval. The catalogue is considered to be complete from the time when the trend of the data stabilizes to approximate a straight line.

2.1.5 Gutenberg-Richter Frequency-Magnitude Recurrence Relationship

The yearly occurrence rate of earthquakes with magnitude greater than or equal to M in a given region can be described by Gutenberg-Richter (1954) recurrence relationship (Eq. 5)

\[
\log_{10}(\lambda_M) = a - bM \quad (5)
\]

Where λ_M is the mean annual rate of exceedance of magnitude M, ‘a’ and ‘b’ are the model constants specific to the source zone.

2.2 Attenuation Relationships

Attenuation relationships are empirical descriptions providing the median and standard deviation of various intensity measures of the strong ground motion, assumed to be log-normally distributed, in terms of earthquake size, distance, source mechanism and site conditions.
2.2.1 Raghu Kanth and Iyengar (2007)
Raghu Kanth and Iyengar (2007) simulated available strong motion records in Peninsular India and suggested an empirical attenuation relationship for estimating 5% damped response spectra which is a function of magnitude and source to site distance by covering bedrock and soil conditions. The attenuation equation is of the form:

$$\ln(y_{br}) = c_1 + c_2(M - 6) + c_3(M - 6)^2 - \ln(r) - c_4r + \ln(\varepsilon_{br})$$

where $y_{br}$ is the spectral acceleration at bedrock level to acceleration due to gravity, $M$ and $r$ refer to moment magnitude and hypocentral distance respectively and $\varepsilon_{br}$ is the error term. The parameters $c_1$, $c_2$, $c_3$ and $c_4$ are functions of the period of the structure and they are defined from 0.0 to 4.0 s.

2.2.2 Abrahamson and Silva (1997)
The functional form of this attenuation relationships, neglecting the style of faulting and the hanging wall effect for rock site is

$$\ln(S_a) = f_1(M, r_{rup})$$

where $S_a$ is the spectral acceleration in g (5% damping), $M$ is moment magnitude, $r_{rup}$ is the closet distance to the rupture plane in km. The function $f_1(M, r_{rup})$ is given by

For $M \leq 6.4$

$$f_1(M, r_{rup}) = a_1 + a_2(M - c_1) + a_12(8.5 - M)^n + [a_3 + a_13(M - c_1)] \ln(R)$$

For $M > 6.4$

$$f_1(M, r_{rup}) = a_1 + a_2(M - c_1) + a_12(8.5 - M)^n + [a_3 + a_13(M - c_1)] \ln(R)$$

Where

$$R = \sqrt{r_{rup}^2 + c^2_4}$$

2.3 Seismic Hazard Curve
The effects of all the earthquakes of different sizes, occurring at different locations in different earthquake sources with different probability of exceeding are integrated into one curve that shows the probability of exceeding different levels of ground motion at the site during a specified period of time. This annual probability of exceedance can be obtained by simply adding the individual annual probabilities of exceedance corresponding to each of the considered seismic sources.

3. RESULTS AND DISCUSSIONS

3.1 Seismicity of the Study Area
A total of 339 earthquakes (Wheeler and Muller, 2001. Rao and Rao, 1984) with moment magnitude ($M_w$) greater than 3 have been identified from different sources in this geographical area. This catalogue spreads over a period of 214 years from 1800-2014 A.D. Then declustering process is carried out by using static and dynamic window methods. Since both declustering algorithms produced essentially comparable results, dynamic window method modified by Urhammer (1986) has been used in this study as shown in fig. 1.
3.2 Seismic Source Zoning
To define the potential seismic sources that affect the site at which hazard is estimated, seismic zoning is done. Seismic source zones have been drawn based on the information provided by the seismotectonics of the study area and historical seismic catalogue. Faults and Lineaments in the study area are and complete area is considered as a single seismic source zone with its associated seismicity parameters as shown in fig. 2

![Seismic Zoning](image)

**Fig. 2 Seismic Zoning**
Completeness analyses is performed by Visual Cumulative (CUVI) method. Completeness interval for the Warangal region for different seismicity scenarios is given in Table 1

<table>
<thead>
<tr>
<th>Magnitude classes (Mw)</th>
<th>Completeness period</th>
<th>Interval (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-3.49</td>
<td>1968-2014</td>
<td>46</td>
</tr>
<tr>
<td>3.5-3.99</td>
<td>1963-2014</td>
<td>51</td>
</tr>
<tr>
<td>4-4.49</td>
<td>1960-2014</td>
<td>54</td>
</tr>
<tr>
<td>4.5-4.99</td>
<td>1954-2014</td>
<td>60</td>
</tr>
<tr>
<td>&gt;5</td>
<td>1800-2014</td>
<td>214</td>
</tr>
</tbody>
</table>

3.3 Seismic Parameters
The basic input for the seismic hazard analysis, Gutenberg-Richter (G-R) activity parameters ‘a’ and ‘b’ for the seismic zone, after sorting out events falling within zone have been carefully evaluated through regression analyses from established earthquake catalogue and compared with various earlier studies in table 2.

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Value of a</th>
<th>Value of b</th>
<th>a/b</th>
<th>Period Considered (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avadh Ram and Rathor (1970)</td>
<td>5.30</td>
<td>0.81</td>
<td>6.54</td>
<td>70</td>
</tr>
<tr>
<td>Kaila et al. (1972)</td>
<td>3.25</td>
<td>0.70</td>
<td>4.64</td>
<td>14</td>
</tr>
<tr>
<td>Rao and Rao (1984)</td>
<td>4.40</td>
<td>0.85</td>
<td>5.17</td>
<td>170</td>
</tr>
<tr>
<td>Anbazhagan et al. (2009)</td>
<td>3.52</td>
<td>0.86</td>
<td>4.09</td>
<td>200</td>
</tr>
<tr>
<td>G Kalyan Kumar (2009)</td>
<td>4.74</td>
<td>1.10</td>
<td>4.31</td>
<td>210</td>
</tr>
<tr>
<td>Present study</td>
<td>3.338</td>
<td>0.783</td>
<td>4.26</td>
<td>214</td>
</tr>
</tbody>
</table>

3.4 Probabilistic Seismic Hazard Analysis
Peak ground acceleration (PGA) values for return periods of 72, 224, 475, 975 and 2475 years are given in Table 3.

<table>
<thead>
<tr>
<th>Annual Probability of Exceedance</th>
<th>Return Period (years)</th>
<th>PGA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raghu Kanth and Iyengar (2007)</td>
<td>0.014 72</td>
<td>0.062</td>
</tr>
<tr>
<td>Abrahamsom and Silva (1997)</td>
<td>0.0045 224</td>
<td>0.105</td>
</tr>
<tr>
<td></td>
<td>0.0021 475</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td>0.0010 975</td>
<td>0.184</td>
</tr>
<tr>
<td></td>
<td>0.0004 2475</td>
<td>0.247</td>
</tr>
</tbody>
</table>
Hazard curves are developed for the rock sites shown in fig. 3 and fig. 4. For any given site, local soil condition will modify the ground motion predicted herein.

Fig. 3 Seismic Hazard Curve (Raghu Kanth and Iyengar, 2007)

Fig. 4 Seismic Hazard Curve (Abrahamson and Silva, 1997)

3.5 Uniform Hazard Spectrum
The spectral amplitudes of acceleration is evaluated at all the natural periods for a constant probability of exceedance at a site and a response spectrum is drawn known as the uniform hazard spectrum (UHS). UHS corresponding to 475 years return period shown in fig. 5 and compared with the response spectra as given in IS 1893 (Part 1) 2002 for rock site, where DBE stands for Design Basis Earthquake.

Fig. 5 UHS for 475 Return Period (Expected and IS code Value)

4. SUMMARY AND CONCLUSIONS
Probabilistic seismic hazard analysis for Warangal is performed through the Cornell-McGuire approach by using a uniform earthquake distribution. Based on the review of seismotectonic set-up and seismic history around Warangal, a controlling region of 350 km radius around the NIT Warangal is considered for the PSHA. Based on the results presented in this study, the following conclusions are drawn:

1. For the Warangal, the estimated values of ‘a’ and ‘b’ are 3.34 and 0.783 respectively. The bounded Gutenberg-Richter recurrence relationship is found to give an acceptable ground shaking hazard for Warangal.
2. The horizontal PGA expected in Warangal on stiff ground, with a 10% probability of exceedance in 50 years (which corresponds to a return period of 475 years) is 0.0836g, whereas, that with a 2% probability of exceedance in 50 years (return period = 2475 years) is 0.153g.
3. The code specified spectra (DBE, IS 1893: 2002) tend to be in accordance with spectral ordinates at low structural periods for the horizontal component of ground motion at Warangal, vis-à-vis the uniform hazard spectra from the PSHA. On the other hand, the spectral ordinates for longer periods from the probabilistic study are significantly lower.
4. The hazard maps developed as part of the study show that the variation of PGA at the bed rock level throughout Warangal is very small.

5. REFERENCES