Seismic Hazard Analysis for Raipur Region

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ABSTRACT

The paper presents seismic hazard assessment for Raipur, the capital city of the newly born Chhattisgarh State. The historical data for past 167 years for the Raipur city has been taken into consideration. The methods of Deterministic Seismic Hazard Assessment (DSHA) and Probabilistic Seismic Hazard Assessment (PSHA) has been applied to the city, to assess the maximum Peak Ground Acceleration (PGA), at the site. A fairly accurate knowledge of such motion, due to all possible sources in the influence zone of about 300 km radius around the construction site, is the most sought after information, in engineering practice. This result is further used, to compute the probability of ground motion that can be induced by each of the twenty-three known faults that exist around the city.

Keywords  
Fault Map; Earthquakes; Deterministic Seismic Hazard Assessment; Probabilistic Seismic Hazard Assessment, Peak Ground Acceleration

INTRODUCTION

The existing Indian code IS-1893 does not provide quantified seismic hazard in the fashion, but lumps large parts of the country into unstructured regions of equal hazard, of doubtful accuracy. In contrast, the international building code IBC-2000, which can be used as a design code anywhere in the world, requires the hazard to be specified in a more scientific manner, after factoring in all possible future events influencing the construction site on a probabilistic basis. Engineering design and construction cannot be viewed in isolation, disjointed from socio-economic considerations. Since the economic lifetime of a structure can be envisioned at the planning stage, the uncertain seismic scenario can be tailored to match the expected life of the structure.

This way a normal building with a shorter life period of about 100 years may be designed for a shorter return period spectrum, whereas a hospital or a monumental structure which has a longer social life could be...
designed for a longer return period scenario. Specification of seismic hazard in terms of response spectra valid for different local soil condition is the information that a structural engineer can use in earthquake-resistant design. Seismic hazards may be analyzed deterministically as and when a particular earthquake scenario is assumed, or probabilistically, in which uncertainties in earthquake size, location, and time of occurrence are explicitly considered (Kramer 1996). In practice, DSHAs often assume that earthquakes of the largest possible magnitude occur at the shortest possible distance to the site within each source zone. The earthquake that produces the most severe site motion is then used to compute site-specific ground motion parameters. Deterministic seismic hazard analyses involve the assumption of some scenario, viz (i) the occurrence of an earthquake of a particular size at a particular location, (ii) for which ground motion characteristics are determined. For assessment of PGA, of District Headquarter Raipur has been considered for this study.

METHODOLOGY
2.1 Deterministic Seismic Hazard Assessment (DSHA)

In the early years of geotechnical earthquake engineering, the use of DSHA was prevalent. DSHA involves the development of a particular seismic scenario upon which a ground motion hazard evaluation is based. A typical DSHA can be described as a four-step process consisting of (Fig. 3):

- Identification and characterization of all earthquake sources capable of producing significant ground motion at the site. Source characterization includes definition of each source’s geometry (the source zone) and earthquake potential.
- Selection of a source-to-site distance parameter for each source zone. In most DSHAs, the shortest distance between the source zone and the site of interest is selected.
- Selection of the controlling earthquake (i.e., the earthquake that is expected to produce the strongest level of shaking), generally expressed in terms of some ground motion parameter, at the site.
- The hazard at the site is formally defined, usually in terms of the ground motions produced at the site by the controlling earthquake.

![Fig. 3: Steps for Deterministic Seismic Hazard Analysis (DSHA)](image)

2.2 Probabilistic Seismic Hazard Assessment (PSHA)

Probabilistic Seismic Hazard Assessment (PSHA) incorporates uncertainty and the probability of earthquake occurrences, delivering the hazard in probability of exceedance for a specified return period (Cornell, 1968; Reiter, 1990). The conventionally followed steps in the PSHA are as mention below:

- Characterization of spatial uncertainty of the seismic sources: In addition to the identification of the seismic sources, PSHA needs to characterize the uncertainty in the spatial description of each source.
- Characterization of magnitude uncertainty: The distribution of the rate of occurrence of future earthquakes for each source has to be described as a function of magnitude.
Determination of uncertainty in ground motion attenuation: For the controlling region around the site, determination of the relation that expresses how the amplitudes of ground motion parameter varies with earthquake magnitude and source-to-site distance, associated with certain probability of exceedance is an essential step in PSHA.
Calculation of the seismic hazard using the mathematical model and presentation of results: The results are presented as seismic hazard curves, which show the annual probability of exceedance of a given hazard (PGA) value at the site.

APPLICATION OF DSHA FOR DISTRICT HEADQUARTER

DSHA has been applied to Raipur city using the following steps:

3.1 Seismic Sources - Fault map

In seismic hazard estimation, the first step is to identify the source zones. Seeber et al. (unpublished) have divided PI into nine broad seismic zones based on seismotectonic regimes and geology. In the present study, since Raipur city is selected as the target, a control region of radius 300 km around the city with centre at 21° 15‘ N, 81° 41’ E is considered for further investigation.

![Seismotectonic Map of District Headquarter Raipur and Surroundings](image)

The fault map of this circular region prepared from the Seismo-tectonic Atlas of India is shown in Figure 4, superimposed with known epicentres. Since earthquakes occurring at epicentral distances greater than 300 km do not generally cause structural damage, the current practice is to include only sources lying within this radius from the site in estimating hazard. From Fig.5, it is observed that in recent years seismic activity appears to be concentrated along Son Narmada South fault and Gavilgarh Fault. All the faults having fault length \( \geq 25.00 \) km has been marked. A total of twenty-three major faults, which influence seismic hazard at Raipur, can be identified from the above map. Some details of these faults are given in Appendix-1.

3.2 Regional Recurrence

Seismic activity of a region is characterized in terms of the Gutenberg–Richter frequency–magnitude recurrence relationship \( \log_{10} N = a - b M_w \), where \( N \) stands for the number of earthquakes greater than or equal to a particular magnitude \( M_w \). Parameters \( (a, b) \) characterize the seismicity of the region. The simplest way to obtain \( (a, b) \) is through least square regression, but due to the incompleteness of the database, such an approach leads to erroneous results. It is generally known that, large damage causing events are rare, but would not have gone unnoticed in past centuries. On the other hand, small events have been catalogued in
recent decades owing to modern instrumentation and advances in seismology. In hazard analysis, one would not be interested in events below a threshold level say, \( m_0 = 3 \). Again, there will be an upper limit on the potential of a fault, but this may not be precisely known from the catalogue.

Table 1. Activity Rate and Interval of Completeness for District Headquarter Raipur

<table>
<thead>
<tr>
<th>Magnitude Mw</th>
<th>No. of Events ( \geq Mw )</th>
<th>Complete in interval (year)</th>
<th>No. of Events per year ( \geq Mw )</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>67</td>
<td>40</td>
<td>1.6750</td>
</tr>
<tr>
<td>4</td>
<td>45</td>
<td>60</td>
<td>0.7500</td>
</tr>
<tr>
<td>5</td>
<td>18</td>
<td>90</td>
<td>0.2000</td>
</tr>
<tr>
<td>6</td>
<td>8</td>
<td>140</td>
<td>0.0572</td>
</tr>
</tbody>
</table>

The above method, suited to engineering requirements, can estimate such doubly truncated Gutenberg–Richter relationship, with statistical errors in past magnitude values. In the present study, the sample of earthquake data for the past 167 years around Raipur, was first evaluated for its degree. From the Table 3.2(a) it becomes clear that a earthquake magnitude of 3.0 will be completed in 40 years time interval, while 6.0 earthquake magnitude will complete in 140 years. With the help of different websites and literatures available, 66 nos. of Earthquakes in the magnitude range of 3 < \( m \) < 6.7 for the site of Raipur, over the period from, 1846 to 2012, has been collected. For obtaining “b” value of region. Completeness analysis has been performed on these data to have a fair idea about the seismicity of the region.

![Graph](image)

Fig.6: Regional Recurrence Relationship for District Headquarter Raipur

Using completeness analysis, Regional Recurrence Relationship has been obtained for:

District Headquarter Raipur

\[
\log_{10} (N) = 3.1021 - 0.5403 M_w
\]

Now, as per the maximum likelihood method of Kijko and Sellevoll, the parameters of the Gutenberg and Richter equation are, \( a = 3.1021 \) and \( b = 0.54034 \). The pooled data and the curve fit of the recurrence relation are shown in Fig.6. Other method that was developed by Utsu (1965), popularly known as Maximum-Likelihood Estimation, is given by

\[
b = \log 10e/(M_{av} - M_{min}) = 0.43/(M_{av} - M_{min})
\]

where \( M_{av} \) is the mean of the observed magnitudes and \( M_{min}=m_0=3.0 \) is the minimum or threshold magnitude in the group of events for complete reporting.
Table 2. “b” value for District Headquarter Raipur

<table>
<thead>
<tr>
<th></th>
<th>Maximum Likelihood Estimation, Utsu. (1965)</th>
<th>From Steep (1972)</th>
<th>Norm of Residuals ($R^2$)</th>
<th>Considered for the Present Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>b Value From</td>
<td>0.2914</td>
<td>0.54034</td>
<td>0.39117</td>
<td>0.54034</td>
</tr>
</tbody>
</table>

3.3 Deaggregation of Seismic Hazard

Finally the Deterministic Seismic Hazard Analysis (DSHA) was carried out for District Headquarter Raipur, considering the seismic events and Seismotectonic sources from the newly developed seismotectonic model for the region, 300 km around the District Headquarter. The maximum possible earthquake magnitude for each of the seismic sources within the area was then estimated. Shortest distance to each source and site of interest was evaluated and taken as major input for performing DSHA. In the present investigation truncated exponential recurrence model developed by McGuire and Arabasz (1990) was used and is given by following expression:

$$\lambda_i = N_i(m_0) \cdot \nu \cdot \frac{\exp[-\beta(m-m_0)] - \exp[-\beta(m_{\text{max}}-m_0)]}{1-\exp[-\beta(m_{\text{max}}-m_0)]}$$

Where $\nu = \exp(a \cdot \beta \cdot m_0)$, $a = 2.303 \cdot a$, $\beta = 2.303 \cdot b$ and $N_i(m_0)$ is the weightage factor for a particular source based on recurrence. The threshold value having a magnitude 3.0 was adopted in the study.

![Fig.7: Deaggregation of Regional Hazards in terms of Fault Recurrence for District Headquarter Raipur](image)

3.4 Ground Motion Attenuation and Peak Ground Acceleration (PGA)

Attenuation may be described as the way in which strong motion parameters decay with distance from the source. This depends on the source properties (M, focal depth, fault type and size), as well as on the regional properties (frequency dependent damping, layering, anisotropy etc.). The property of the site (hard rock, soft soil, valley and mountain) also influences the ground motion attenuation. For the present study attenuation relationship suggested by R N Iyengar & S T G Raghukanth (2004), (Applicable for peninsular India, under bed rock condition) has been used.

$$\ln(\text{PGA}/g) = C_1 + C_2 \cdot (m-6) + C_3 \cdot (m-6)^2 - \ln(R) - C_4 \cdot R + \ln \varepsilon$$

Where, $C_1 = 1.6858$, $C_2 = 0.9241$, $C_3 = 0.0760$, $C_4 = 0.0057$
### Table 3. Deterministic PGA Values at District Headquarter Raipur

<table>
<thead>
<tr>
<th>Fault No.</th>
<th>Fault length Li in km</th>
<th>Magnitude ( M_{100} ) [100 years Recurrence Period]</th>
<th>PGA Values (g) (100 Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>50 Percentile</td>
</tr>
<tr>
<td>F1</td>
<td>26</td>
<td>4.867</td>
<td>0.0013</td>
</tr>
<tr>
<td>F2</td>
<td>75</td>
<td>5.008</td>
<td>0.0020</td>
</tr>
<tr>
<td>F3</td>
<td>140</td>
<td>6.171</td>
<td>0.0085</td>
</tr>
<tr>
<td>F4</td>
<td>33</td>
<td>6.276</td>
<td>0.0059</td>
</tr>
<tr>
<td>F5</td>
<td>51</td>
<td>6.192</td>
<td>0.0058</td>
</tr>
<tr>
<td>F6</td>
<td>60</td>
<td>6.284</td>
<td>0.0062</td>
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<tr>
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<td>70</td>
<td>5.092</td>
<td>0.0018</td>
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<td>F9</td>
<td>76</td>
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<td>0.0105</td>
</tr>
<tr>
<td>F10</td>
<td>47</td>
<td>6.142</td>
<td>0.0053</td>
</tr>
<tr>
<td>F11</td>
<td>38</td>
<td>4.423</td>
<td>0.0008</td>
</tr>
<tr>
<td>F12</td>
<td>477</td>
<td>7.003</td>
<td>0.0102</td>
</tr>
<tr>
<td>F13</td>
<td>182</td>
<td>5.525</td>
<td>0.0036</td>
</tr>
<tr>
<td>F14</td>
<td>38</td>
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<td>0.0028</td>
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<td>F15</td>
<td>90</td>
<td>6.000</td>
<td>0.0089</td>
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<tr>
<td>F16</td>
<td>70</td>
<td>5.924</td>
<td>0.0161</td>
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<tr>
<td>F17</td>
<td>70</td>
<td>5.917</td>
<td>0.0087</td>
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<tr>
<td>F18</td>
<td>125</td>
<td>6.072</td>
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<td>F19</td>
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<td>5.871</td>
<td>0.0158</td>
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<tr>
<td>F20</td>
<td>25</td>
<td>6.175</td>
<td>0.0265</td>
</tr>
<tr>
<td>F21</td>
<td>58</td>
<td>5.864</td>
<td>0.0345</td>
</tr>
<tr>
<td>F22</td>
<td>180</td>
<td>5.527</td>
<td>0.0032</td>
</tr>
<tr>
<td>F23</td>
<td>121</td>
<td>5.229</td>
<td>0.0016</td>
</tr>
</tbody>
</table>

### APPLICATION OF PSHA FOR DISTRICT HEADQUARTER

#### 4.1 Uncertainty in the Sources to Site Distance

In the PSHA, the other uncertainty involved is, the distance of each source to the site. In a seismogenic source, each point/segment of the source can rupture and generate an earthquake. The geometries of seismic sources depend on the tectonic processes involved in their formation. Earthquakes are usually assumed to be uniformly distributed with in a particular fault or lineaments. A uniform distribution of source to site distance is expressed in ground motion parameter in terms of some measure of source to site distance; the uncertainty must be described with respect to the appropriate distance parameter. The uncertainty involved in the source to site distance is described by a probability density function. Thus the relative orientation of each source with...
respect to the site becomes important. The hypocentral distance has been evaluated by considering focal depth of 10km from the ground level, similar to the one used for DSHA. The probability distribution for the hypocenter distance, from any site to earthquake rupture on the source, is computed conditionally for the earthquake magnitude. Generally, the rupture length is a function of magnitude. The conditional probability distribution function of the hypocentral distance \( R \) for an earthquake magnitude \( M = m \) for a ruptured segment, is assumed to be uniformly distributed along a fault.

Since predictive relationships express ground motion parameters in terms of some measure of source-to-site distance, the spatial uncertainty must be described with respect to the appropriate distance parameter. The uncertainty in source-to-site distance can be described by a probability density function.

**Fig. 8: Source-to-Site Distance Uncertainty**

For the linear source of figure 5.1 (a) the probability that an earthquake occurs on the small segment of the fault between \( L = l \) and \( L = l + dl \) is the same as the probability that it occurs between \( R = r \) and \( R = r + dr \); that is,

\[
f_L(dl) = f_R(dr) \quad \text{------------------------4.1(a)}
\]

Where \( f_L \) and \( f_R \) are the probability density functions for variables \( L \) and \( R \), respectively. Consequently,

\[
f_R(dr) = f_L(l) * (dl/dr) \quad \text{------------------------4.1(b)}
\]

If earthquakes are assumed to be uniformly distributed over the length of the fault, since the probability density function of \( R \) is given by

\[
f_L(l) = \frac{l}{L_f} l^2 = \sqrt{r^2 - r_{\text{min}}^2} \quad \text{------------------------4.1(c)}
\]

the probability density function of \( R \) is given by

\[
f_R(r) = \frac{r}{L_f \sqrt{r^2 - r_{\text{min}}^2}} \quad \text{------------------------4.1(d)}
\]
Uncertainty in Magnitude

The source can experience an earthquake of any magnitude within the predicted minimum and maximum range for the particular source. This uncertainty in the magnitude of the earthquake is accounted by the probability of occurrence of a particular magnitude in the given range. All source zones have a maximum earthquake magnitude that cannot be exceeded; in general, the source zone will produce earthquakes of different sizes up to the maximum earthquake, with smaller earthquakes occurring more frequently than larger ones. A basic assumption of PSHA is that the recurrence law obtained from past seismicity is appropriate for the prediction of future seismicity. In most PSHA’s, the lower threshold magnitude is set at values from about 3.0 to 7.0, since magnitudes smaller than that seldom cause significant damage. For each source, the probability of occurrence of an earthquake of a particular magnitude is obtained using the probability density function of the magnitude. The distribution with an upper bound magnitude is given by:

\[
f_M(m) = \frac{\beta e^{-\beta (m-m_{\text{min}})}}{[1-e^{-\beta (m_{\text{max}}-m_{\text{min}})}]} \quad m_{\text{min}} \leq m \leq m_{\text{max}} \quad \text{------ 4.2 (a)}
\]

\[
P(m_1 < m < m_2) = \int_{m_1}^{m_2} f_M(m)dm \approx f_M\left(\frac{m_1 + m_2}{2}\right)x(m_2 - m_1) \quad \text{------ 4.2 (b)}
\]
For realistic cases, PDF’s for M (Magnitude) and R (Source to Site Distance) are too complicated to integrate analytically. Therefore, we do it numerically, dividing the range of possible magnitudes and distances into NM and NR increments, respectively and are given by

\[ \lambda_{y} = \sum_{i} \sum_{j} \sum_{k} v \int f(y|m_i, r_j) f_m(m_i) f_r(r_j) \Delta m \Delta r \]

Where \( \Delta r \) and \( \Delta m \) is given by

\[ \Delta r = \frac{r_{max} - r_{min}}{N_R} \]
\[ \Delta m = \frac{m_{max} - m_{min}}{N_M} \]

Final PSHA Equation is given by

\[ \lambda_{y} = \sum_{i} \sum_{j} \sum_{k} v \int P[Y > y|m_i, r_j] P[M = m_i] P[R = r_j] \]

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Fig. 11: Hazard Curve for District Headquarter Raipur at rock level

Fig. 13: Return Period Curve for District Headquarter Raipur
RESULT & CONCLUSION

Deterministic and probabilistic seismic hazard analyses are carried to determine peak ground accelerations at District Headquarter Raipur at bed rock level. The Regional Recurrence Relationship obtained for District Headquarter Raipur has been presented in Equation No 1. Obtained “b” value is 0.54034. Hence, the site is situated in less seismically active zone. For District Headquarter Raipur, Values of the Peak Ground Acceleration (P.G.A.) for $M_{100}$ Earthquake, has been presented in Table 3. The Maximum values of Peak Ground Acceleration (P.G.A.) for Site, obtained due to fault No. 21 (length 58 km, Distance 84.936 km) are 0.0345g and 0.0549g for 50 Percentile and 84 Percentile respectively. Where Peak Ground Acceleration (P.G.A.) for fault No. 12 (length 477 km, Distance 269.151 km) are 0.0102g and 0.0162g respectively. It is clear that faults situated far away from the site shows, low seismicity even if they are greater in length and fault of shorter length exhibit higher seismicity when they are nearer to the site. The hazardous effect on site structure reduces with increase in the distance of a fault. As far as safety of vital public structures against seismic hazard is considered, it is essential to make sure that construction sites are far away from the active faults. Thus, it can be concluded that the outcome of present study verifies and endorses the IS zone classification. The hazard curve has been prepared for calculation probability for different return periods. Further a return period curve has been prepared calculate PGA value for particular return period.

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### Table 1. District Headquarter Raipur Faults Considered for Hazard Analysis

<table>
<thead>
<tr>
<th>Fault No.</th>
<th>Fault length Li in km</th>
<th>Hypo-central Distance R in Km</th>
<th>$M_{\text{max}}$ Considered for the present study (M)</th>
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<tbody>
<tr>
<td>F1</td>
<td>26</td>
<td>283.181</td>
<td>5.1</td>
</tr>
<tr>
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<td>75</td>
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</tr>
<tr>
<td>F3</td>
<td>140</td>
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</tr>
<tr>
<td>F4</td>
<td>33</td>
<td>263.240</td>
<td>7.2</td>
</tr>
<tr>
<td>F5</td>
<td>51</td>
<td>257.129</td>
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