# Deterministic Seismic Hazard Analysis For Shallow Earthquakes For Ballar Dam of Chhattisgarh State (India)

**Ashish K. Parashar, S. Atmapoojya, S.S. Rathore**

*Abstract*— **Seismic vulnerability analysis, an approach to get an estimate of the strong ground-motions at any particular site, is mainly intended for earthquake resistant designs or for seismic safety assessments. The hazard study usually attempts to analyze two different kinds of anticipated ground motions, "The Probablistic Seismic Hazard Analysis" (PSHA) and "The Detemininstic Seismic Hazard Analysis" (DSHA). A sincere effort is made herein to do seismic hazard analysis for Ballar Dam of Chattisgarh state . An attempt was made to compile the occurrence of past and recent seismic activities within 300 km radius, around the Dam site. Further the seismic hazard analysis was carried out at substratum level in terms of PGA using (DSHA), deterministic seismic hazard analysis technique The main benchmark and indicator involved in carrying out the hazard analysis is the correctness and completeness of the data which needs to be attained. The knowledge presented in this paper helps in evaluating the seismicity of the region around, Ballar Dam Site after statistical analysis of the database. Finally the results are furnished in the form of peak ground acceleration (PGA) for 50 Percentile & 84 Percentile with 100 years of Recurrence Period which can be used directly by engineers as fundamental considerations, for generating earthquake-resistant design of structures in and around Ballar Dam.**

***Index Terms***— **Seismic hazard; Ballar Dam; DSHA; Fault Map; Recurrence Period; PGA.**

## I. INTRODUCTION

In the recent years, the attention of the scientific community regarding seismology and seismotectonic study has enhanced significantly in Peninsular India (PI), especially in the field related to seismic hazard assessment, of seismic areas and its possible reduction measures. The hazard in this part of India is considered to be less critical than in the Himalayan plate boundary region. The fact that the Earthquakes in various parts of India as compared to the Himalayan Plates are less severe, is totally based on the relative occurrence of past tremors in the various regions. However, intra-plate earthquakes are rarer than plate boundary events but usually tend to be more harmful. Paucity of recorded ground motion data introduces uncertainties in predicting the nature of occurrence of future ground motions and the dynamic forces, which needs to be considered in the designing of manmade structures. The behavior of a building, dam or a power plant depends primarily on the local ground motion at the foundation level. A fairly accurate knowledge of such motions, pertaining to all possible sources in the influenced zone of about 300 km radius around the construction site, is the most sought information in engineering practices. The existing Indian code IS-1893 does not furnish any quantification of seismic hazard. Seismic hazard analysis plays an important role in generating earthquake-resistant design of structures by providing a rational value of input hazard parameters, like peak ground acceleration (PGA). Traditionally, PGA has been a popular hazard parameter, but it is often found to be poorly correlated with the damage potential of ground motion. All the existing researches, related to seismicity in India, have been made simply in terms of the peak ground acceleration or by using the attenuation relations for some or the other parts of the world.

Table 1.Salient Features of Dam Site

| | |
|---|---|
| Name of the Dam | Ballar Dam |
| Basin Name | Mahanadi |
| River | Balar Nalla |
| Dam Type | Earthen |
| Purpose | Irrigation |
| Length of Dam (m) | 945.12 |
| Dam Height (m) | 19.7 |
| Design flood (cumec) | 603.5 |
| Crest Level of spillway | 314.58 |
| Spillway capacity (cumec) | 606.64 |
| Seismic Zone | Seismic Zone-II |

## II. SEISMICITY OF THE REGION

The present study uses a Deterministic method for the Hazard Analysis of Ballar Dam taking into consideration the location of Chhattisgarh, it is found to be located in the zone where the occurrence of seismic activity is found to be very low. In recent past, tremors from earthquakes have been felt, in neighbouring states, most notably in 1969 not forgetting

**Ashish K. Parashar,** Ph. D. Research Scholar, MIT, Gondia, Department of Civil Engineering, IT, GGV, Central University, Bilaspur, Chhattisgarh, India, Mobile No.09425502572.

**S. Atmapoojya**, Professor Department of Civil Engineering, K.I.T.S. Ramtek, Maharashtra, India Mobile No.09765496850.

**S.S. Rathore,** Principal, M.I.E.T. Kudwa, Gondia, Maharashtra, India

minor seismic activities that have been recorded in the vicinity of Chiraikund and Muirpur along the border of Madhya Pradesh. Many faults have been identified further, for eg. few faults form the eastern section of the Narmada-Son Fault Zone which have shown movements during the Holocene epoch. Another active fault identified is the Tatapani Fault which trends in an east-west direction in the vicinity of Manpura in Sarguja district. In the southern part, the Godavari fault, flanking the northern part of the Godavari Graben run, through the southern part of the state and is also found to be active. The known earthquakes in this region had either observed intensities of V or higher (historical events) or had known magnitudes of M 4.5 or more (instrumented events).

## III. Identification and Characterization of Sources

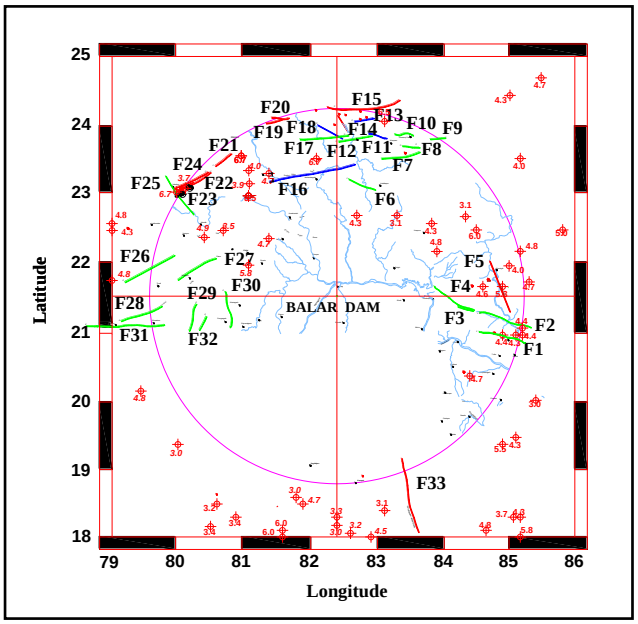


Figure 1: Seismotectonic map of Ballar Dam

Now coming back to the present study after a general introduction to the state, because Ballar Dam is selected as the target, including a control region of radius 300 km around the District Headquarter, having centre at 21° 32' N, 82° 30' E, was considered for further investigation. The fault map of this circular region which was prepared in reference with the Seismo-tectonic Atlas of India, is as shown in Figure 3.1. From Figure 1, it is obvious that in recent years seismic activity appears to be concentrated along Bamhni-Chilpa fault (F16-140 km in Length) and Parvatipuram- Bobbili Fault (F33-121 km in Length) . A total of thirty-three major faults, which influence seismic hazard at Ballar Dam , were identified in the above map. Fault details are tabulated in Table 2.

Table 2. Faults Considered for Hazard Analysis around the Ballar Dam

| Fault no. | Length in km | Hypo. Distance | Weightage | Moment Magnitude ($M_W$) |
|---|---|---|---|---|
| F1 | 75 | 235.57 | 0.0379 | 4.9 |
| F2 | 86 | 230.66 | 0.0435 | 4.9 |
| F3 | 26 | 195.33 | 0.0132 | 5.1 |
| F4 | 75 | 157.56 | 0.0379 | 5.1 |
| F5 | 87 | 251.85 | 0.044 | 5.8 |
| F6 | 46 | 180.55 | 0.0233 | 4.8 |
| F7 | 62 | 230.78 | 0.0314 | 7.0 |
| F8 | 28 | 261.62 | 0.0142 | 7.0 |
| F9 | 25 | 292.00 | 0.0127 | 7.0 |
| F10 | 30 | 274.73 | 0.0152 | 7.0 |
| F11 | 30 | 264.39 | 0.0152 | 7.0 |
| F12 | 55 | 246.40 | 0.0278 | 7.0 |
| F13 | 32 | 279.98 | 0.0162 | 7.0 |
| F14 | 30 | 263.55 | 0.0152 | 7.0 |
| F15 | 117 | 302.45 | 0.0592 | 7.0 |
| F16 | 140 | 211.60 | 0.0708 | 7.2 |
| F17 | 78 | 256.85 | 0.0395 | 7.2 |
| F18 | 45 | 251.60 | 0.0228 | 7.2 |
| F19 | 28 | 295.17 | 0.0142 | 7.2 |
| F20 | 28 | 294.59 | 0.0142 | 7.2 |
| F21 | 33 | 282.80 | 0.0167 | 7.2 |
| F22 | 51 | 281.30 | 0.0258 | 7.2 |
| F23 | 31 | 292.77 | 0.0157 | 7.2 |
| F24 | 60 | 285.30 | 0.0304 | 7.2 |
| F25 | 76 | 263.55 | 0.0385 | 7.2 |
| F26 | 91 | 267.44 | 0.046 | 5.3 |
| F27 | 70 | 202.00 | 0.0354 | 6.3 |
| F28 | 70 | 280.35 | 0.0354 | 6.3 |
| F29 | 45 | 225.09 | 0.0228 | 6.3 |
| F30 | 58 | 178.93 | 0.0294 | 6.3 |
| F31 | 125 | 280.08 | 0.0632 | 6.3 |
| F32 | 25 | 211.15 | 0.0127 | 6.3 |
| F33 | 121 | 280.34 | 0.0612 | 3.6 |

After going through various available literatures and sources such as (USGS, NIC), 78 Nos. of Earthquakes in the magnitude range 3< Mw <6.7 for Ballar Dam, occurring over the period from 1837 to 2012 were identified in the present study. In places where the magnitude of any event was not available in the previous reports, they were derived using the approximate empirical relation [m = (2/3) I0 + 1] using the reported maximum MMI number. To avoid further confusion associated with different magnitude scales, all magnitudes were converted to moment magnitude $M_w$. Based on the nearness of epicenters to a particular fault, the maximum potential magnitude mu of each fault was fixed, which were kept 0.5 units higher than the magnitude reported in the past as observed from Figure 1 and value of moment magnitude $M_w$ is given in Table 2.

## IV. Regional Recurrence

Seismic activity of a region, is usually characterized in terms of the Gutenberg–Richter frequency–magnitude recurrence relationship

$$\log10\ (N) = a - b*M_w$$

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 may lead to erroneous results. Kijko and Sellevoll have proposed a reliable statistical method to address the issue of incompleteness of earthquake catalogues. They classified the database into two groups, called the extreme part and the complete part. The extreme part consists of a long time period where information related to only large historical events is consistently available. The complete part further represents the data related to the recent decades during which information on both large and small magnitude earthquakes is available. As it is very clear that, 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 it may be difficult to know the actual precision of the faults from the catalogues, thus the above stated method, suited to engineering requirements, which can easily estimate such doubly truncated Gutenberg–Richter relationship with statistical errors in values of the magnitude that have occurred in the past. The present study, incorporates the earthquake data of the samples, of past 176 years around Ballar Dam , was first evaluated for its degree of completeness.

Table 2. Activity Rate and Completeness for Ballar Dam

The analysis is shown in (Table 2), that data are complete, in a statistical sense, in the following fashion: ($3.0 \leq Mw < 4$) is complete in 40 years; ($4.0 \leq Mw < 5$) is complete in 70 years;

($5.0 \leq Mw < 6$) is complete in 100 years; and ($6.0 \leq Mw < 7$) is complete in 130 years. Regional Recurrence Relationship Ballar Dam is given by

| Magnitude Mw | No. of Events ≥ Mw | Complete in interval (year) | No. of Events per year ≥ Mw |
|---|---|---|---|
| 3.0 | 78 | 40 | 1.950 |
| 4.0 | 55 | 70 | 0.785 |
| 5.0 | 20 | 100 | 0.200 |
| 6.0 | 8 | 130 | 0.061 |

$$\text{Ballar Dam Log 10 (N)} = 3.5624 - 0.6252M_w$$

Norm of residuals R2= 0.51387

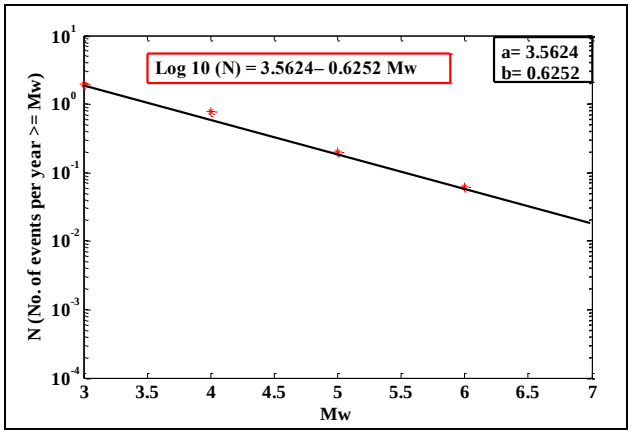


Figure 4.30: Regional Recurrence Relationship at Ballar Dam

## V. Ground Motion Attenuation

Attenuation relationship developed by Iyenger and Raghukanth (2004) was considered for the analysis and PGA was calculated. Maximum value of PGA has been taken amongst the PGA calculated by various source at each point.

$$\ln (PGA/g) = C1+C2\ (M-6)+C3\ (M-6)\ 2-\ln(R)-C4(R) +\ln \varepsilon$$

Where, C1= 1.6858, C2= 0.9241, C3= 0.0760,

C4= 0.0057, R= Hypo central distance, M= magnitude = M100, $\ln \varepsilon = 0$ (for DSHA) for 50 Percentile, $\varepsilon = 0.4648$ for Percentile

## VI. Deterministic Estimation of PGA

Finally the Deterministic Seismic Hazard Analysis (DHSA) was carried out for Ballar Dam 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.

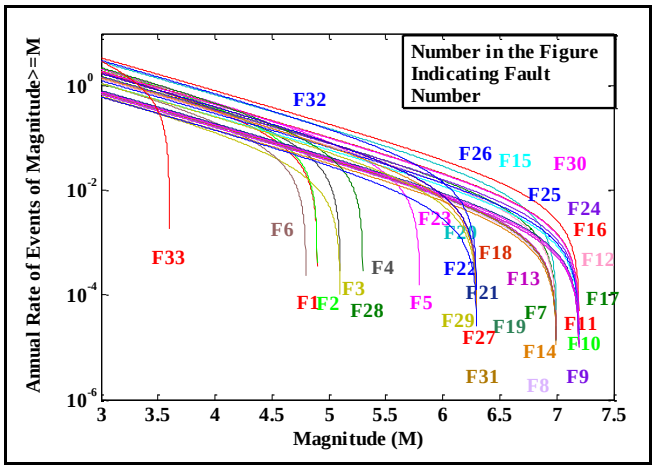


Figure 4.3: Deaggregation of Seismic Sources Near Ballar Dam

Shortest distance to each source and site of interest was evaluated and taken as major input for performing DHSA. In the present investigation truncated exponential recurrence

model developed by Mcguire and Arabasz (1990) was used and is given by following expression;

$$\lambda_m = (m_0) * \upsilon * \frac{\exp[-\beta(m-m_0)]-\exp[-\beta(m_{max}-m_0)]}{1-\exp[-\beta(m_{max}-m_0)]}$$

Where υ=exp(α-β*m0), α=2.303*a, β=2.303*b and Ni(m0) is the weightage factor for a particular source based on recurrence. The threshold value having a magnitude 3.0, was adopted in the study.

Table 3:PGA For $M_{100}$ Earthquakes at Ballar Dam

| Fault No. | Fault Length | Hypo Central Distance R in Km | Magnitude $M_{100}$ [100 years Recurrence Period] | PGA Values (g) (100Years) | |
|---|---|---|---|---|---|
| | | | | 50 Percentile | 84 Percentile |
| F1 | 75 | 235.575 | 4.849 | 0.00187 | 0.00297 |
| F2 | 86 | 230.667 | 4.853 | 0.00197 | 0.00314 |
| F3 | 26 | 195.337 | 4.915 | 0.00304 | 0.00485 |
| F4 | 75 | 157.568 | 5.621 | 0.00972 | 0.01547 |
| F5 | 87 | 251.851 | 5.64 | 0.00362 | 0.00576 |
| F6 | 46 | 180.551 | 4.728 | 0.00292 | 0.00464 |
| F7 | 62 | 230.787 | 6.228 | 0.00772 | 0.01228 |
| F8 | 28 | 261.622 | 5.804 | 0.00386 | 0.00615 |
| F9 | 25 | 292.004 | 5.74 | 0.00274 | 0.00436 |
| F10 | 30 | 274.73 | 5.846 | 0.00355 | 0.00565 |
| F11 | 30 | 264.393 | 5.831 | 0.00386 | 0.00614 |
| F12 | 55 | 246.405 | 6.176 | 0.00631 | 0.01005 |
| F13 | 32 | 279.986 | 5.876 | 0.00348 | 0.00554 |
| F14 | 30 | 263.555 | 5.848 | 0.00395 | 0.00629 |
| F15 | 117 | 302.458 | 6.504 | 0.00497 | 0.00792 |
| F16 | 140 | 211.608 | 4.846 | 0.00238 | 0.00378 |
| F17 | 78 | 256.851 | 6.402 | 0.00696 | 0.01108 |
| F18 | 45 | 251.607 | 6.133 | 0.00577 | 0.00919 |
| F19 | 28 | 295.177 | 5.843 | 0.00293 | 0.00467 |
| F20 | 28 | 294.59 | 5.848 | 0.00296 | 0.00472 |
| F21 | 33 | 282.802 | 5.923 | 0.00354 | 0.00564 |
| F22 | 51 | 281.302 | 6.179 | 0.00454 | 0.00723 |
| F23 | 31 | 292.773 | 5.89 | 0.00314 | 0.00499 |
| F24 | 60 | 285.306 | 6.272 | 0.00476 | 0.00757 |
| F25 | 76 | 263.555 | 6.377 | 0.00639 | 0.01017 |
| F26 | 91 | 267.441 | 5.222 | 0.00204 | 0.00325 |
| F27 | 70 | 202.002 | 5.954 | 0.00809 | 0.01288 |
| F28 | 70 | 280.353 | 5.954 | 0.00373 | 0.00594 |
| F29 | 45 | 225.095 | 5.821 | 0.00562 | 0.00894 |
| F30 | 58 | 178.932 | 5.894 | 0.00985 | 0.01568 |
| F31 | 125 | 280.081 | 6.076 | 0.00419 | 0.00666 |
| F32 | 25 | 211.159 | 5.577 | 0.00512 | 0.00815 |
| F33 | 121 | 280.346 | 3.597 | 0.00027 | 0.00043 |

## VII. Result And Discussion

The present research, the seismic hazard analysis carried out, for the establishment of PGA at substratum level for Ballar Dam, was based on deterministic approach. An attempt has also been made to evaluate the seismic hazard in terms of PGA at the same level. The Regional Recurrence Relationship obtained for Ballar Dam as depicted in Equation 1 shows the obtained "b" value as 0.6252. The Values of P.G.A. for $M_{100}$ Earthquakes have been shown in Table No.3. The Maximum value of Peak Ground Acceleration (P.G.A.) for recurrence period of 100 years for Ballar Dam was found to be due to the fault No. 30 (Fault length 58 km, Min. Map Distance 178.932 km) which came out to be equal to 0.00985g for 50 Percentile and 0.01568g for 84 Percentile. The study results outlined in this paper can be directly be implemented for designing of earthquake-resistant structures, in and around Ballar Dam.

## References


[1] Anbazhagan P. and Sitharam T. G., Seismic Microzonation of Bangalore, India. Journal of Earth Systems Science 117 (S2), 833–852. 2008

[2] Acharyya S K, Mitra N D and Nandy D R 1986 Regional geology and tectonic setting of northeast India and adjoining region Geol. Surv. India Mem. 119 61–72

[3] Ambraseys N and Jackson D 2003 A note on early earthquakes in northern India and southern Tibet Curr. Sci. 84 570–82

[4] Baranowski J, Armbruster J, Seeber L and Molnar P 1984 Focal depths and fault plane solutions of earthquakes and active tectonics of the Himalaya J. Geophys. Res. 89 6918–28

[5] Bhatia S C, Kumar R and Gupta H K 1999 A probabilistic seismic hazard map of India and adjoining regions (GSHAP) Curr. Sci. 77 447–50

[6] Chandra, U., Earthquakes of Peninsular India – A seismotectonic study. Bull. Seismol. Soc. Am.,1977, 67, 1387–1413.

[7] Fitech T J 1970 Earthquake mechanisms in the Himalaya, Burmese and Andaman regions and continental tectonics in Cental Asia J. Geophys. Res. 75 2699–709

[8] Guha, S. K. and Basu, P. C., Catalogue of earthquakes (M 3.0) in Peninsular India. Atomic Energy Regulatory Board, Tech. Document No. TD/CSE-1, 1993, pp. 1–70.

[9] IS-1893, Indian Standard Criteria for Earthquake Resistant Design of Structures, Fifth Revision, Part-1, Bureau of Indian Standard, New Delhi,
2002.

[10] Iyengar R N, Sharma D and Siddiqui J M 1999 Earthquake history of India in Medieval times Indian J. Hist. Sci. 34

[11] Iyenger R N and Raghukant S T G, Attenuation of Strong Ground Motion in Peninsular India. Seismological Research Letters. Volume 75, Number 4, July/August 2004, pp530-539.

[12] Iyengar R. N. and Raghu Kanth S. T. G., Seismic Hazard Estimation for Mumbai city. Current Science 91 (11, 10), 1486-1494. 2006

[13] Iyenger R N and Ghose S, Microzonation of Earthquake Hazard in Greater Delhi Area.. Current Science. Vol. 87, No. 9, 10, November 2004, pp 1193-1201.

[14] Kennedy, R.P. "Ground motion parameters useful in structural design," presented at the Conference on Evaluation of Regional Seismic Hazards and Risk, Santa Fe, New Mexico (1980).

[15] Kijko, A. and Sellevoll, M. A., Estimation of earthquake hazard parameters from incomplete data files. Part I. Bull. Seismol. Soc. Am., 1989, 79, 645–654.

[16] Nuttli, O.W. "The relation of sustained maximum ground acceleration and velocity to earthquake intensity and magnitude," Miscellaneous Paper S-73-1, Report 16, U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi, 74 pp. (1979).

[17] Rao, B. R. and Rao, P. S., Historical seismicity of Peninsular India. Bull. Seismol. Soc. Am., 1984, 74, 2519–2533.

[18] Raghu Kanth, S. T. G., Engineering seismic source models and strong ground motion. Ph D thesis, Indian Institute of Science, Bangalore, 2005.