P: ISSN No. 0976-8602 RNI No.UPENG/2012/426228 VOL.-IV, ISSUE-I, January-2015
E: ISSN No. 2349 - 9443
Asian Resonance

Seismic Hazard Analysis for Sikaser Dam of Chhattisgarh State (India)

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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 hazards associated with earthquakes are referred to as seismic hazards. The hazard study usually attempts to analyze two different kinds of anticipated ground motions, “the Probabilistic Seismic Hazard Analysis” (PSHA) and “the Deterministic Seismic Hazard Analysis” (DSHA). An effort has been made herein to do seismic hazard analysis for Sikaser Dam (20° 31′ 30″ N, Long. 82° 19′ 0″ E) 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, Sikaser 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 Sikaser Dam.

Keywords: DSHA, Sikaser Dam, seismic hazard, fault map, recurrence period, PGA.

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 man-made 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.

Figure 1: Sikaser Dam

Table 1.Salient Features of Dam Site

Name of the Dam	Sikasar
River	Pairi river Basin
Dam Type	Earthen + Gravity
Purpose	Irrigation
Catchment Area	3563 sq.km.
Length of Dam	1540 m
Dam Height	31.70 m
Design flood	5984 cumec
Full Reservoir Level	335 m
Number of Spillway Gates 22	22
Seismic Zone	Seismic Zone-II

Seismicity of the Region

The present study uses a Deterministic method for the Hazard Analysis of Sikaser 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 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, *e.g.* 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).

Identification and Characterization of Sources

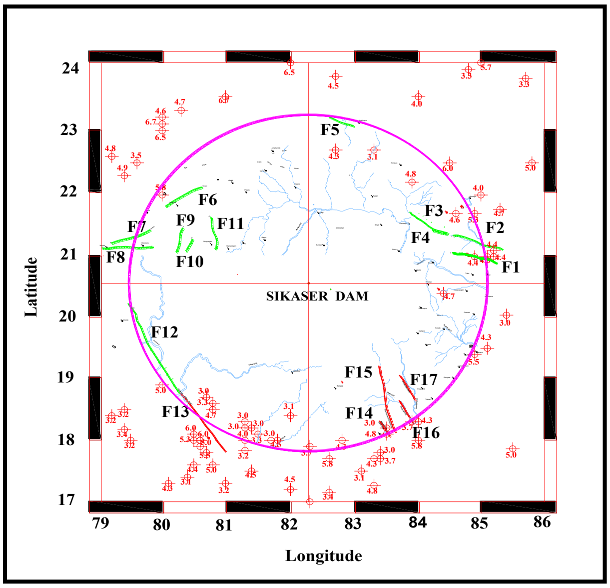

Figure 2: Seismotectonic map of Sikaser Dam

Now coming back to the present study after a general introduction to the state, because Sikaser Dam is selected as the target, including a control region of radius 300 km around the District Headquarter, having centre at 20° 31′ 30″ N, 82° 19′ 0″ 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 2, it is obvious that in recent years seismic activity appears to be concentrated along Godavari Valley Fault (F13-130 km in length) and Parvatipuram- Bobbili Fault (F15-121 km in length). A total of seventeen major faults, which influence seismic hazard at Sikaser Dam, were identified in the above map. Fault details are tabulated in table 2. 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 Sikaser 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.

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

Fault no.	Length in km	Hypo. Distance	Weightage	Moment Magnitude (M_W)
F1	76	249.158	0.0622	4.9
F2	86	258.066	0.0704	4.9
F3	75	213.148	0.0614	5.1
F4	26	229.204	0.0213	5.1
F5	46	290.421	0.0377	4.8
F6	70	246.36	0.0573	6.3
F7	70	281.036	0.0573	6.3
F8	85	268.763	0.0696	6.3
F9	45	227.8	0.0369	6.3
F10	25	208.553	0.0205	6.3
F11	58	167.309	0.0475	6.3
F12	180	293.063	0.1473	5.5
F13	130	292.185	0.1064	6.5
F14	32	275.781	0.0262	4.2
F15	121	191.536	0.0991	3.5
F16	46	261.404	0.0377	4.2
F17	51	226.706	0.0418	4.8

Regional recurrence

Seismic activity of a region, is usually 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 may lead to erroneous results. Steep (1972) proposed a reliable statistical method to address the issue of incompleteness of earthquake catalogues and 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 186 years around Sikaser Dam that was first evaluated for its degree of completeness.

Table 3. Activity Rate and Completeness for Sikaser Dam

Magnitude M_w	No. of Events ≥ M_w	Complete in interval (year)	No. of Events per year ≥ M_w
3.0	106	50	2.120
4.0	69	80	0.862
5.0	24	100	0.240
6.0	8	120	0.067

The analysis is shown in table 3, revealed that data are complete, in a statistical sense, in the following fashion: ($3.0 \le M_w < 4$) is complete in 50 years; ($4.0 \le M_w < 5$) is complete in 80 years; ($5.0 \le M_w < 6$) is complete in 100 years; and ($6.0 \le M_w < 7$) is complete in 120 years. Regional Recurrence Relationship Sikaser Dam is given by

$$\text{Log}_{10}\ (N) = 3.8737 - 0.6781M_w$$

Norm of residuals (R2)= 0.54411

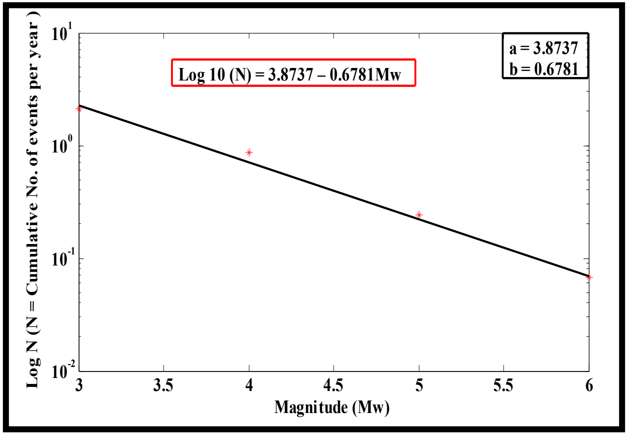

Figure 3: Regional Recurrence Relationship at Sikaser Dam

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 = M_{100}, $\ln\varepsilon = 0$ (for DSHA) for 50 Percentile, $\varepsilon = 0.4648$ for 84 Percentile

Deterministic Estimation of PGA

Finally the Deterministic Seismic Hazard Analysis (DHSA) was carried out for Sikaser Dam considering the seismic events and Seismotectonic sources from the newly developed seismotectonic model for the region, 300 km around the Dam site. The maximum possible earthquake magnitude for each of the seismic sources within the area was then estimated.

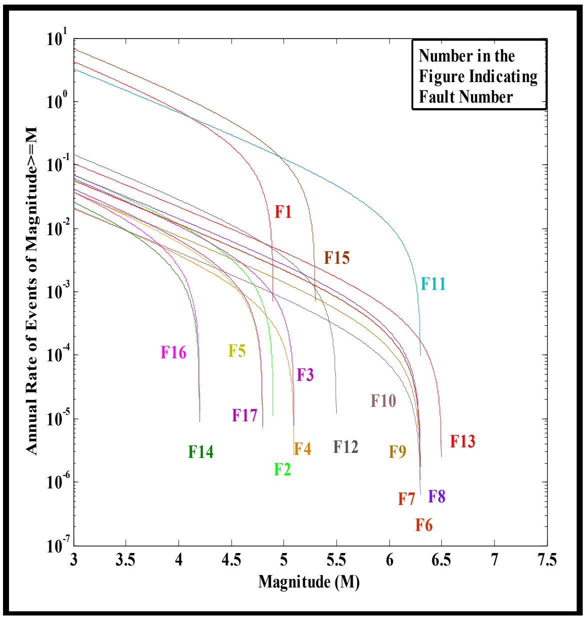

Figure 4: Deaggregation of Seismic Sources Near Sikaser Dam

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 4:PGA For M_{100} Earthquakes At Sikaser Dam

Fault No.	Fault Length	Hypo Central Distance R in Km	Magnitude M100 [100 years Recurrence Period]	PGA Values (g)	
				50 Percentile	84 Percentile
F1	76	249.157	4.873	0.00168	0.00267
F2	86	258.065	4.075	0.00061	0.00097
F3	75	213.147	4.048	0.00093	0.00147
F4	26	229.203	3.46	0.00037	0.00059
F5	46	291.286	3.774	0.00031	0.00049
F6	70	244.361	4.112	0.00073	0.00116
F7	70	281.034	4.109	0.00051	0.00082
F8	85	268.761	4.224	0.00066	0.00105
F9	45	227.799	3.841	0.00062	0.00098
F10	25	208.552	3.459	0.00046	0.00073
F11	58	167.308	6.029	0.01277	0.02032
F12	180	293.062	4.572	0.00079	0.00126
F13	130	292.183	4.498	0.00073	0.00117
F14	32	275.78	3.487	0.00025	0.00039
F15	121	191.535	5.268	0.00462	0.00735
F16	46	261.403	3.625	0.00034	0.00054
F17	51	226.705	3.803	0.00059	0.00095

Result And Discussion

The present research, the seismic hazard analysis carried out, for the establishment of PGA at substratum level for Sikaser 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 Sikaser Dam as depicted in Equation 1 shows the obtained "b" value as 0.6781. The Values of P.G.A. for M_{100} Earthquakes have been shown in Table No.4. The Maximum value of Peak Ground Acceleration (P.G.A.) for recurrence period of 100 years for Sikaser Dam was found to be due to the fault No. 11 (Fault length 58 km, Min. Map Distance 167.308 km) which came out to be equal to 0.01277g for 50 Percentile and 0.02032g for 84 Percentile. The study results outlined in this paper can be directly be implemented for designing of earthquake-resistant structures, in and around Sikaser Dam.

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