Deterministic Seismic Hazard Assessment Of District Headquarters Dantewara And Jagdalpur Sites Of Chhattisgarh State

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ABSTRACT

Seismic Hazard is a regional property. It can neither be prevented nor reduced. The only alternative is to quantify the Hazard and minimize the possible damages to the structures due to possible strong Ground Motion. Dantewara and Jagdalpur sites are two District Headquarters of the state of Chhattisgarh. In the present study the technique of Deterministic Seismic Hazard Assessment (DSHA) has been applied to these District Headquarters to asses the maximum Peak Ground Acceleration (PGA) at these sites. Beauro of Indian Standard has specified these sites in seismic ZoneII. This fact has been established in the present study.

Keywords- Deterministic Seismic Hazard, Earthquake, Peak Ground Acceleration, District Headquarters.

I. INTRODUCTION

A spate of Earthquakes in recent past, causing extensive damage has heightened the sensitivity of Engineers and Planners to the looming seismic risk in densely populated cities, major dams important & historical places. Earthquakes are a universal phenomenon and a global problem. Occurrence of one or more earthquakes at a project site is known as Seismic Hazard. This is a property of the region and hence, can neither be prevented nor reduced. The only alternate is to quantify the hazard and take steps to minimize the vulnerability of the structures to damage arising out of the ensuing strong ground motion.

The Earthquakes in India occur in the plate boundary of the Himalayas region2 as well as in the intra-plate region of peninsular India (P I). Devastating events have occurred in P I in the recent past, which must be considered as a severe warning about the possibility of such Earthquake in the future. Engineering approaches to Earthquake resistant design will be successful to the extent that the forces due to future shocks are accurately estimated at location of a given structure. Earthquakes are low probability events, but with very high levels of risks to the society. Hence, either under estimation or over estimation of seismic hazard will prove dangerous or costly in the end Earthquakes present a threat to people and the facilities they design and build. Seismic hazard analysis (SHA) is the evaluation of potentially damaging earthquake related phenomenon to which a facility may be subjected during its useful lifetime. Seismic hazard analysis is done for some practical purpose, typically seismic-resistant design or retrofitting. Although strong vibratory ground motion is not the only hazardous effect of earthquakes (landslides, fault offsets and liquefaction are others), it is the cause of much wide spread damage and is the measure of earthquake hazard that has been accepted as most significant for hazard resistance planning. Earthquake-resistant design seeks to produce structures that can withstand a certain level of shaking without excessive damage. That level of shaking is described by a design ground motion, which is usually determined with the aid of a seismic hazard analysis. 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.

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 method is the technique in which a single estimate of parameters is used to perform each analysis. To account for uncertainty, several analyses may be conducted with different parameters. For assessment of PGA, of District Headquarters Dantewara and Jagdalpur sites have been considered for this study. The present study details of these District Headquarters sites are as follows:

S. No.	Location	Dantewara	Jagdalpur
1	Latitude	18º 54' N	19º 05' N
	Longitude	81º 21' E	82º 04' E

II DETERMINISTIC SEISMIC HAZARD ASSESSMENT (DSHA)

The DSHA[2] can estimate in the following steps:

- Seismic Sources
- Earthquake- recurrence- frequency.
- Deaggregation of Seismic Hazard.
- Ground motion attenuation.
- Estimation of PGA

2.1 Seismic Sources

- A circular region of 300 km radius has to be assumed around the site.
- Seismicity information has to be collected (i.e Epicenter, Magnitude) inside the 300 km radius.
- Different faults in this 300 Km. radius region have to be identified, length of the fault and their shortest distances from the site have to be worked out.

A historical record of past Earthquake, in the region, is the one of the most important tool. Because, these records are useful to assess the region seismicity. It has been observed that Earthquake of less then 3.0 magnitudes is not posing any serious problems to the civil Engineering structures, and it also very difficult to recognize their occurrence by human beings. Hence, for DSHA is it good enough to collect the information of past Earthquakes ≥ 3 magnitude.

2.2. Earthquake Recurrence Frequency

Earthquake Recurrence relationship has to be worked in the following steps:

- Earthquake information for region has to be collected over a long period from various historical records.
- All the data has to be arranged as per the number of Earthquakes that exceeded various magnitude values (m=0, 1, 2, 3,)
- Suitable Earthquake Recurrence Relation has to be used, which appropriately characterize the seismicity of the region.

2.3. Deaggregation of Seismic Hazard

1. In DSHA, the basic idea is to foreshadow on each of the causative fault, the magnitude of an Earthquake, which may be exceeded in say 100 years or 1000 years.
2. M_{100} has to be worked out for each fault.
3. Using the Regional Recurrence Relation, it is easy to find the above magnitudes for the region, but not for individual faults.
4. The potential of a fault to produce an Earthquake of a particular magnitude would depend on the length of the fault itself.
5. Ni (m_0) on any individual fault may be to be proportional to the length of the fault itself. Weightage Wi=Li / Σ Li.
6. The 'b' value of any fault is to be same as the regional 'b' value.
7. The value of m_{max} for each fault is to be fixed up by finding the most probable magnitude of the largest past event that can be associated with the fault. This value is increased by 0.5 and taken as m_{max}. In case, only the highest intensity value is known, the event magnitude is taken as m=2/3(I_0)+1.

2.4. Ground Motion Attenuation

- Attenuation5 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 relationship5 suggested by R N Iyengar & S T G Raghukant, (Applicable for peninsular India, under bed rock condition) has been used.

In (PGA/g) = C1+C2 (m-6)+C3 (m-6) 2-ln(R)-C4(R) +ln ε

Where,
C1= 1.6858,
C2= 0.9241,
C3= 0.0760,
C4= 0.0057,
R= Hypo central distance, m= magnitude,
ln ε = 0(for DSHA).

2.5. Estimation of Peak Ground Acceleration (PGA).

The PGA, which can be exceeded with 50 % probability, is to be calculated from the attenuation equation.

In DSHA, the maximum among these values is to be taken as the design basis acceleration depending on the acceptability of this value based on other seismological considerations.

This PGA value could be a reference value for further work.

III APPLICATION OF DSHA

Deterministic seismic hazard analysis (DSHA) has been applied to Dantewara and Jagdalpur sites using the following steps:

A region of 300 km radius around both Dantewara and Jagdalpur sites were considered and all the faults having ≥ 25 km length has been marked. This region is shown in Figure 3.1 and Figure 3.2 respectively.

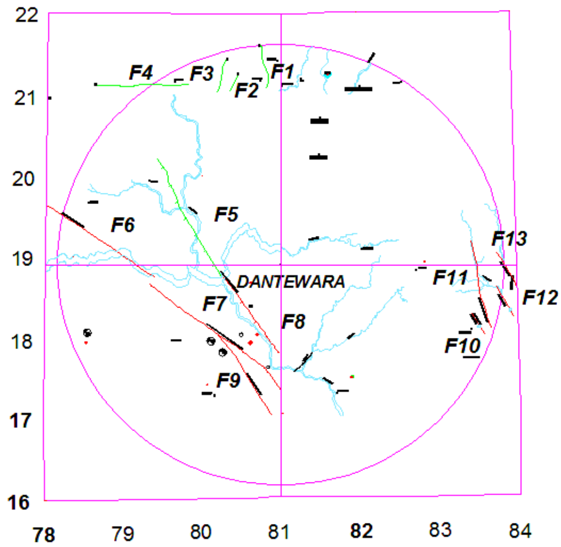

Figure 3.1 Fault considered for Deterministic Seismic Hazard Analysis of District Headquarter Dantewada

With the help of different literature available and websites 79 and 69 Nos. of Earthquakes in the magnitude range 3< Mw <6.5 for Dantewara and Jagdalpur sites over the period from 1827 to 2012 (185) years have been collected.

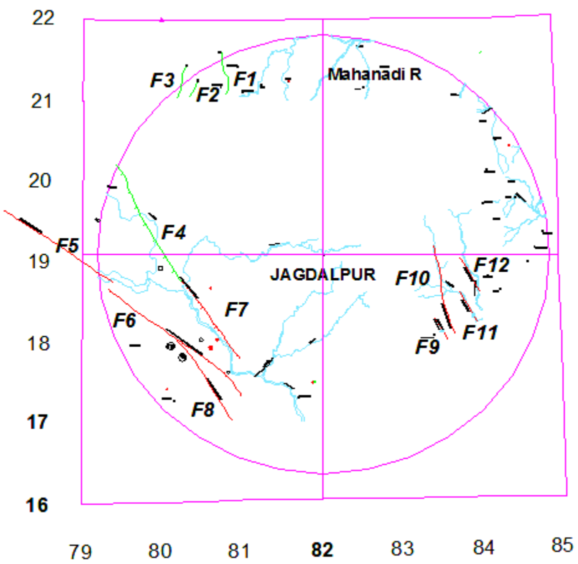

Figure 3.2 Fault considered for Deterministic Seismic Hazard Analysis of District Headquart Jagdalpur

The same is presented at Appendix I and Appendix II respectively. From these collected 79 and 69 numbers data of Earthquakes with magnitude 3 < Mw < 6.5 for Dantewara and Jagdalpur sites over the period from 1827 to 2012 (185) years has been arranged as per the number of Earthquakes that exceeded various magnitude values. Magnitude-frequency data for Dantewara and Jagdalpur sites have been presented in Table 3.1 and Table 3.2 (Appendix III) respectively. From the data of magnitude and frequency, construct a recurrence relation between magnitude and frequency of Earthquakes for a seismic source and obtained the values of "a and b".

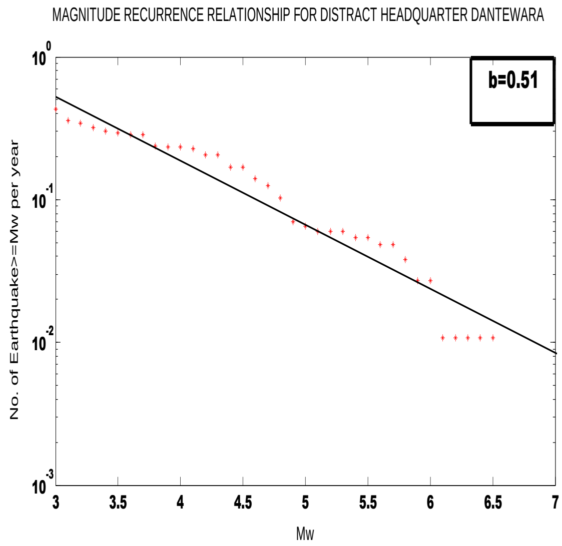

Figure 3.3 Magnitude-Recurrence Relationship for District Headquarter Dantewara site

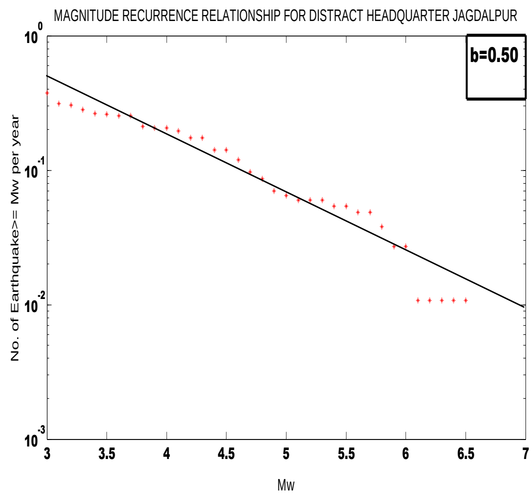

Figure 3.4 Magnitude-Recurrence Relationship for District Headquarter Jagdalpur site

The above relationship for Dantewara and Jagdalpur sites have been shown in Figure 3.3 and Figure 3.4 respectively. In the Figure, the values of 'b' are showing steep slopes, therefore 'completeness analysis' have been performed.

Earthquakes data for completeness test for Dantewara and Jagdalpur sites have been presented in Table 3.2 and Table 3.3 (Appendix III) respectively.

Completeness test of Earthquakes data for Dantewara and Jagdalpur sites has been shown in Figure 3.5 and Figure 3.6 respectively.

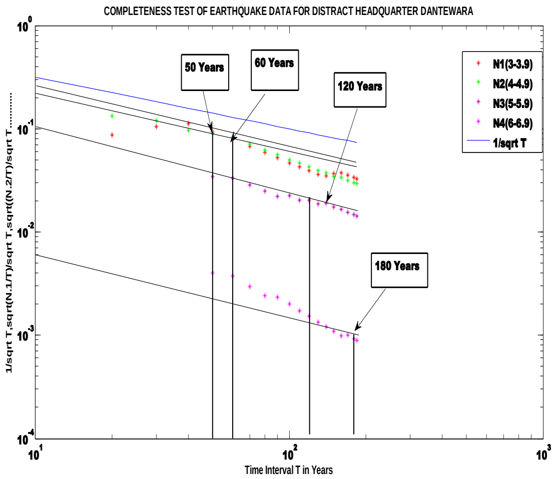

Figure 3.5 Completeness Test of Earthquake data for District Headquarter Dantewara

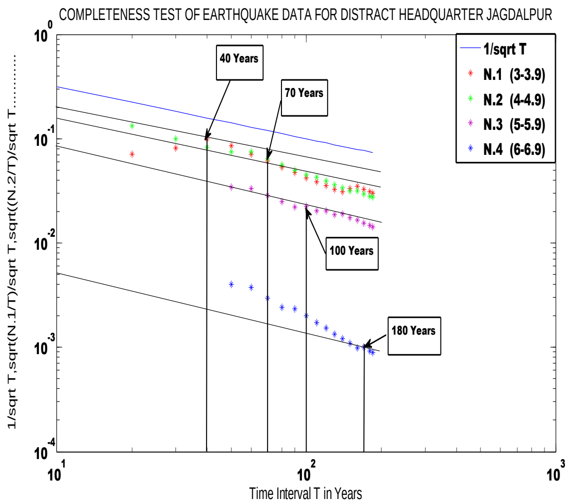

Figure 3.6 Completeness Test of Earthquake Data for District Headquarter Jagdalpur

It has been observed for Dantewara (from the Table 3.1 below) that 3.0 magnitude will be completed in 50 years time interval while 6.5 magnitude will complete in 180 years, and for Jagdalpur, it has been observed (from the Table 3.2 below) that 3.0 magnitude will be completed in 40 years time interval while 6.5 magnitude will complete in 180 years.

Table 3.1 Activity Rate and Interval of Completeness at District Headquarter Dantewara

Magnitude Mw	No. of Events ≥ Mw	Complete in interval (year)	No. of Events per year ≥ Mw
3.0	79	50	1.5800
4.0	43	60	0.717
5.0	12	120	0.1000
6.5	2	180	0.0112

Table 3.2 Activity Rate and Interval of Completeness at District Headquarter Jagdalpur

Magnitude Mw	No. of Events ≥ Mw	Complete in interval (year)	No. of Events per year ≥ Mw
3.0	69	40	1.7250
4.0	38	70	0.5428
5.0	12	100	0.1200
6.5	2	180	0.0112

Using completeness analysis, Regional Recurrence Relationship has been obtained as for:
District Headquarter Dantewara

$\text{Log}_{10}(N) = 1.9800 - 0.6483\ M_w$…(3.1)

District Headquarter Jagdalpur

$\text{Log}_{10}(N) = 1.7250 - 0.5800\ M_w$.…(3.2)

The same is shown in Figure 3.7 and Figure 3.8 for District Headquarter Dantewara and Jagdalpur respectively.

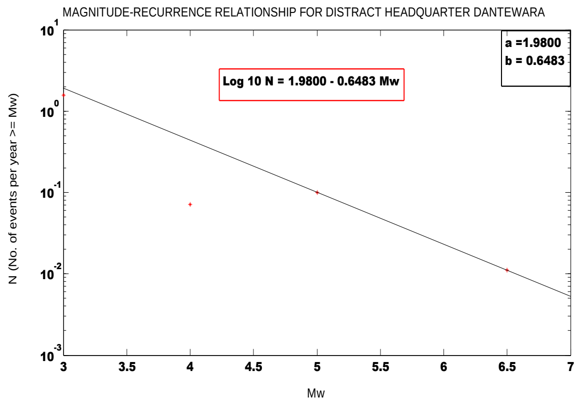

Figure 3.7 Regional Recurrence Relationship for District Headquarter Dantewara

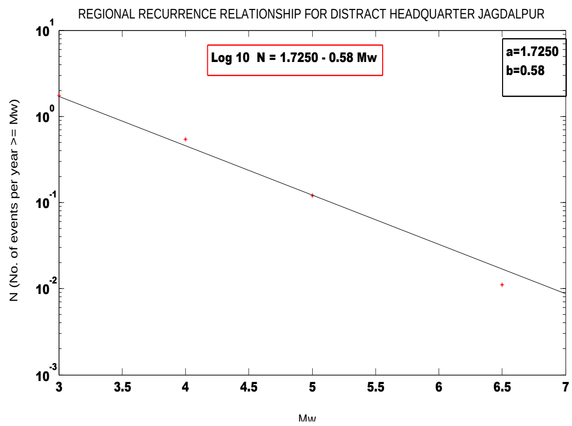

Figure 3.8 Regional Recurrence Relationship for District Headquarter Jagdalpur

Lengths of all the 13 numbers faults, around the Dantewara and 12 numbers around the Jagdalpur having length of 25 km or more are considered for Deterministic Seismic Hazard Analysis (DSHA), were measured. Hypo-central distance (by considering the focal depth as 10 km), weightage and maximum potential magnitude (M_u) is obtained for each fault and has been presented in Table 3.7 for Dantewara and in Table 3.8 (Appendix III) for Jagdalpur respectively.

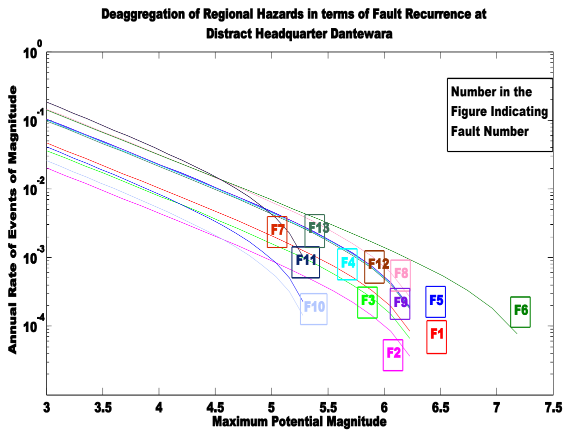

Figure 3.9 Deaggregation of Regional Hazards in terms of Fault Recurrence at Distract Headquarter Dantewara

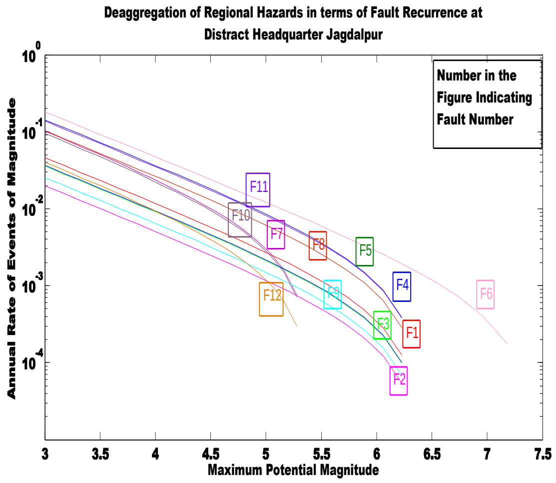

Figure 3.10 Deaggregation of Regional Hazards in terms of Fault Recurrence at District Headquarter Jagdalpur

M_{100} has been obtained by generating the fault deaggregation record. In this study all the faults having ≥ 25 km lengths are considered. Fault deaggregation for Dantewara and Jagdalpur have been shown in Figure 3.9 and Figure 3.10 respectively.

IV RESULT & CONCLUSION

Regional Recurrence Relationship obtained for Dantewara and Jagdalpur sites have been presented in Equation No 3.1 & 3.2 Obtained "b" values are 0.6483 and 0.58 respectively. Hence, the both the sites are situated in less seismic active zone.

Deterministic Seismic Hazard Analysis has been applied to the District Headquarters Dantewara and Jagdalpur sites, Values of P.G.A. for M_{100} Earthquakes have been presented in Table No.3,9 & Table No.3.10 (Appendix III) respectively.

Maximum values of Peak Ground Acceleration (P.G.A.) for Dantewara Site has been obtained due to fault No. 5 (length 180 km, Distance 81.831 km) is equal to 0.01145g. As per IS 1893:2002(Part-1) Maximum value of Peak Ground Acceleration (P. G. A.) for Jagdalpur Site has been obtained due to fault No. 10 (length 121 km, Distance 147.031 km) is equal to 0.0033g. As per IS 1893:2002(Part-1) the District Headquarters region have been categorized as zone II and corresponding P.G.A. is equal to 0.1g. Hence, this fact has also been verified from the present study.

REFERENCES

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

[2] AERB Technical Document, Catalogue of Earthquakes (≥ M 3.0) in Peninsular India, Atomic Energy Regulatory Board, Government of India-1993.

[3] Benjamin J.R. and Associates "A criterion for determining exceedance of the Operating Basis Earthquake," EPRI Report NP-5930, Electric Power Research Institute, Palo Alto, California (1988).

[4] Catalogue of Earthquakes in India and Neighborhood, (From Historical period up to 1979) Indian Society of Earthquake Technology, Roorkee-1993.

[5] Criteria for Earthquake Resistant Design of Structures (Part, General Provisions and Buildings, IS-1893:2002.

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

[6] Newmark, N.M. and Hall, W.J. Earthquake Spectra and Design, EERI Monograph, Earthquake Engineering research Institute Berkeley, California, 103 pp (1982).

[7] 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).

[8] Steven L. Kramer. Geotechnical Earthquake Engineering, Pearson Education (Singapore) Ltd. 1996.
[9] Seismic Tectonic Atlas of India and its Environs. Geological Survey of India 2000.
[10] Ruff, L. and Kanamori, H. "Seismicity and subduction processes," Physics of the Earth and Planetary Interiors, Vol.23, pp.240-252 (1980).
[11] U. S. Geological Survey Earthquake Database (Website).

Appendix I
Listing of Earthquake Events around District Headquarter Dantewada Site
(Latitude - 16º 0' - 22º 0' Longitude - 78º 0' - 84º 0')

S No.	Year	Month	Date	Latitude	Long	Int	Ms	Mb	Mw	Depth	Source
1.	1827	1	6	17.7	83.4				4.3		OLD, NEIC
2.	1843	3	12	17.5	78.5				3.7		OLD, NEIC
3.	1846	5	27	23.5	79.3				6.5		IMD
4.	1853	2	21	17.7	83.4				3.7		OLD, NEIC
5.	1858	8	24	17.8	83.4				3.0		OLD, NEIC
6.	1858	10	12	18.3	84	V			4.3		OLD, NEIC
7.	1859	7	21	16.3	80.5				4.3		RAO, UKRAO
8.	1859	8	02	16.3	80.5				3.7		OLD, NEIC
9.	1859	8	09	16.3	80.5				3.7		OLD, NEIC
10.	1859	8	24	18.1	83.5	V			3.7		OLD, NEIC,UKGSI
11.	1861	11	13	18.11	83.5	Iii			3		UGS
12.	1867	1	03	16.1	79.6				3.0		OLD, NEIC
13.	1867	1	06	16.1	79.8				3.0		OLD, NEIC
14.	1867	03	11	16.0	80.3				3.7		OLD, NEIC
15.	1869	12	19	17.9	82.3				3.7		OLD
16.	1870	12	19	17.7	83.4				3.7		GSI
17.	1871	9	27	18.3	83.9	Iii			3		UGS
18.	1872	11	22	18.86	80	Vi			5		UGS
19.	1876	11	1	17.5	78.5				4.7		RAO, UKRAO
20.	1878	12	10	18.3	83.9	Iv			3.7		UGS
21.	1903	5	17	23	80				4.1		RAO, UKRAO
22.	1905	4	2	16	80.1				4.1		RAO, UKRAO
23.	1917	4	17	18	84		5.5		5.8		ISS, NEIC, UKIMD
24.	1927	6	2	23.5	81				6.5		ISC
25.	1954	1	5	18	81.8		4		4.5		IMD
26.	1954	1	5	18	81.3				4		NEIC, UKIMD
27.	1957	8	25	22	80		5.5	5.5	5.8		SHL, NEIC, UKSHL
28.	1959	8	9	18.1	83.5		4.1		4.7		RAO, UKRAO
29.	1959	10	12	16.0	80				6.0		TS, NEIC
30.	1959	12	23	18.1	83.5		4.3		4.8		RAO, UKRAO
31.	1960	10	08	16.0	80.3				4.3		GUB, NEIC
32.	1968	6	20	16.0	79.6				3.2		GBA, NEIC
33.	1968	7	27	17.6	80.8				4.5		GUB, NEIC
34.	1968	7	29	17.6	80.8				4.5		GUP , NEIC
35.	1968	11	14	21.8	78		4.2		4.8		IMD, NEIC, UKHYB
36.	1969	3	26	22.6	78.1		4.2		4.8		IMD
37.	1969	4	13	17.9	80.6				5.7		TS
38.	1969	4	14	18	80.5			5.2	5.3		IMD
39.	1969	4	14	18.1	80.5				6		UKTS

40.	1969	4	14	18	80.5				6		USC
41.	1969	4	14	18	80.5	Vi			5.7	33	USC
42.	1969	4	15	18	80.7			4.6	4.6	33	ISC
43.	1969	9	15	17.6	80.5				3.8		IMD
44.	1975	4	24	18.7	80.7		3		3		INR, NEIC, UKHYB
45.	1975	7	3	18	79.5		3.2		3.2		INR
46.	1975	9	15	18.4	79.2		3.2		3.2		INR, NEIC, UKHYB
47.	1975	7	3	18.5	79.5				3.2		UKHYB
48.	1977	9	30	18.08	81.5		3.3		3.3		GBA
49.	1979	8	29	18.24	81.3		3		3		GBA
50.	1979	4	22	18.5	80.8		3.5		4.7		INR
51.	1980	3	30	17.16	81.9				4.5	33	MBGS
52.	1981	3	21	16.0	79.6				3.0		UKHYB
53.	1981	12	4	18.16	81.4		3		3		GBA
54.	1981	12	08	16.3	80.5				3.0		UKHYB
55.	1981	12	16	18.57	80.7		3.3		3.3		GBA
56.	1982	1	14	17.5	78.6				3.1		UKHYB
57.	1983	4	8	18.17	81.3		3		3		GBA
58.	1983	6	30	17.6	78.5				4.5		UKHYB
59.	1984	4	24	18.27	78.8		3.4		3.4		GBA
60.	1984	4	27	18.16	79.4		3.4		3.4		GBA
61.	1984	6	20	20.4	78.5		3.7		4.3		GBA
62.	1984	6	27	16.0	79.6				3.3		UKHYB
63.	1985	1	6	20.22	78.4		4.2		4.8		GBA
64.	1985	9	27	19.39	78.9		3		3		GBA
65.	1986	4	9	18.34	82		3.1		3.1		GBA
66.	1987	4	18	22.53	79.2			4.8	4.8	20	ISC
67.	1987	4	18	22.35	79.3			4.9	4.9	33	GSPDE, UKHYB
68.	1990	6	9	18.1	80.5		4		4.6		CVR
69.	1995	5	24	16.52	79.7				4.6	33	MBGS, NEIC
70.	1996	2	12	22.62	82.7				4.3	33	MLDMIV, UKHYB
71.	1996	8	4	16.01	79.8				4.1	10	MBGS, NEIC
72.	1998	3	9	22.49	78			4.3	4.3	10	GSPDE, NEIC
73.	1998	4	9	16.54	78.34				5.5		IMD
74.	1998	6	29	18.59	79.68				4.1	15	IMD
75.	2000	6	19	18.17	76.62				4.7		ISC
76.	2001	6	12	22.22	83.9			4.8	4.8	33	GSPDE, NEIC
77.	2007	4	13	22.7	83.2				3.1	10	RAIG., IMD
78.	2010	1	25	21.5	76.9				3.0	10	AMRA., MAH.,IMD
79.	2011	2	8	22.5	79.6				3.5	12	SEONI,MP,IMD

Appendix II
Listing of Earthquake Events around District Headquarter Jagdalpur
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8.	1859	8	09	16.3	80.5				3.7		OLD, NEIC
9.	1859	8	24	18.1	83.5	V			3.7		OLD, NEIC,UKGSI
10.	1860	02	25	19.40	84.90				4.3		OLD, NEIC
11.	1861	11	13	18.11	83.5	Iii			3		UGS
12.	1867	1	03	16.1	79.6				3.0		OLD, NEIC
13.	1867	1	06	16.1	79.8				3.0		OLD, NEIC
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17.	1871	9	27	18.3	83.9	Iii			3		UGS
18.	1872	11	22	18.86	80	Vi			5		UGS
19.	1878	12	10	18.3	83.9	Iv			3.7		UGS
20.	1897	6	22	19.40	84.9				5.5		JAISWAL, SINHA, NIC
21.	1903	5	17	23	80				4.1		RAO, UKRAO
22.	1905	4	2	16	80.1				4.1		RAO, UKRAO
23.	1917	4	17	18	84		5.5		5.8		ISS, NEIC, UKIMD
24.	1927	6	2	23.5	81				6.5		ISC
25.	1954	1	5	18	81.8		4		4.5		IMD
26.	1954	1	5	18	81.3				4		NEIC, UKIMD
27.	1957	8	25	22	80		5.5	5.5	5.8		SHL, NEIC, UKSHL
28.	1958	11	1	22	85				4.0		IMD
29.	1959	8	9	18.1	83.5		4.1		4.7		RAO, UKRAO
30.	1959	10	12	16.0	80				6.0		TS, NEIC
31.	1959	12	23	18.1	83.5		4.3		4.8		RAO, UKRAO
32.	1960	10	08	16.0	80.3				4.3		GUB, NEIC
33.	1968	6	20	16.0	79.6				3.2		GBA, NEIC
34.	1968	7	27	17.6	80.8				4.5		GUB, NEIC
35.	1968	7	29	17.6	80.8				4.5		GUP , NEIC
36.	1969	4	13	17.9	80.6				5.7		TS
37.	1969	4	14	18	80.5			5.2	5.3		IMD
38.	1969	4	14	18.1	80.5				6		UKTS
39.	1969	4	14	18	80.5				6		USC
40.	1969	4	14	18	80.5	Vi			5.7	33	USC
41.	1969	4	15	18	80.7			4.6	4.6	33	ISC
42.	1969	9	15	17.6	80.5				3.8		IMD
43.	1975	4	24	18.7	80.7		3		3		INR, NEIC, UKHYB
44.	1975	7	3	18	79.5		3.2		3.2		INR
45.	1975	9	15	18.4	79.2		3.2		3.2		INR, NEIC, UKHYB
46.	1975	7	3	18.5	79.5				3.2		UKHYB
47.	1977	9	30	18.08	81.5		3.3		3.3		GBA
48.	1979	8	29	18.24	81.3		3		3		GBA
49.	1979	4	22	18.5	80.8		3.5		4.7		INR
50.	1980	3	30	17.16	81.9				4.5	33	MBGS
51.	1981	3	21	16.0	79.6				3.0		UKHYB

52.	1981	12	4	18.16	81.4		3		3		GBA
53.	1981	12	8	16.3	80.5				3.0		UKHYB
54.	1981	12	16	18.57	80.7		3.3		3.3		GBA
55.	1983	4	8	18.17	81.3		3		3		GBA
56.	1984	4	27	18.16	79.4		3.4		3.4		GBA
57.	1984	6	27	16.0	79.6				3.3		UKHYB
58.	1986	4	9	18.34	82		3.1		3.1		GBA
59.	1987	4	18	22.53	79.2			4.8	4.8	20	ISC
60.	1987	4	18	22.35	79.3			4.9	4.9	33	GSPDE, UKHYB
61.	1990	6	9	18.1	80.5		4		4.6		CVR
62.	1995	3	27	21.67	84.57				4.6	10	MBGS, NEIC
63.	1995	5	24	16.52	79.7				4.6	33	MBGS, NEIC
64.	1996	2	12	22.62	82.7				4.3	33	MLDMIV, UKHYB
65.	1996	8	4	16.01	79.8				4.1	10	MBGS, NEIC
66.	1998	6	29	18.59	79.68				4.1	15	IMD
67.	2001	6	12	22.22	83.9			4.8	4.8	33	GSPDE, NEIC
68.	2007	4	13	22.7	83.2				3.1	10	RAIG., IMD
69.	2011	2	8	22.5	79.6				3.5	12	SEONI,MP,IMD

Appendix III

Table 3.1 Magnitude-Frequency Data of District Headquarter Dantewara

Observation Period – 185 years

S.No.	Moment Magnitude M_w	No. of Earthquake $\geq M_w$	No. of Earthquake $\geq M_w$ per year
1	3.0	79	0.427027
2	3.1	66	0.356756
3	3.2	63	0.340540
4	3.3	59	0.318919
5	3.4	56	0.302702
6	3.5	54	0.291892
7	3.6	53	0.286486
8	3.7	53	0.286486
9	3.8	44	0.237838
10	3.9	43	0.232432
11	4.0	43	0.232432
12	4.1	42	0.227027
13	4.2	38	0.205405
14	4.3	38	0.205405
15	4.4	31	0.167567
16	4.5	31	0.167567
17	4.6	26	0.140540
18	4.7	23	0.124324
19	4.8	19	0.102703
20	4.9	13	0.070270
21	5.0	12	0.064865
22	5.1	11	0.059459
23	5.2	11	0.059459
24	5.3	11	0.059459
25	5.4	10	0.054054
26	5.5	10	0.054054
27	5.6	9	0.048649
28	5.7	9	0.048649
29	5.8	7	0.037838
30	5.9	5	0.027027
31	6.0	5	0.027027

32	6.1	2	0.010811
33	6.2	2	0.010811
34	6.3	2	0.010811
35	6.4	2	0.010811
36	6.5	2	0.010811

Table 3.2
Magnitude - Frequency of District Headquarter Jagdalpur
Observation Period – 185 years

S.No.	Moment Magnitude M_w	No. of Earthquake $\geq M_w$	No. of Earthquake $\geq M_w$ per year
1	3.0	69	0.372945
2	3.1	58	0.313490
3	3.2	56	0.302680
4	3.3	52	0.281060
5	3.4	49	0.264845
6	3.5	48	0.259440
7	3.6	47	0.254035
8	3.7	47	0.254035
9	3.8	39	0.210795
10	3.9	38	0.205390
11	4.0	38	0.205390
12	4.1	36	0.194580
13	4.2	32	0.172960
14	4.3	32	0.172960
15	4.4	26	0.140530
16	4.5	26	0.140530
17	4.6	22	0.118910
18	4.7	18	0.097290
19	4.8	16	0.086480
20	4.9	13	0.070265
21	5.0	12	0.064860
22	5.1	11	0.059455
23	5.2	11	0.059455
24	5.3	11	0.059455
25	5.4	10	0.054050
26	5.5	10	0.054050
27	5.6	9	0.048645
28	5.7	9	0.048645
29	5.8	7	0.037835
30	5.9	5	0.027025
31	6.0	5	0.027025
32	6.1	2	0.010810
33	6.2	2	0.010810
34	6.3	2	0.010810
35	6.4	2	0.010810
36	6.5	2	0.010810

Table 3.3 Earthquake Distribution by Time and Magnitude for District Headquarter Dantewara

Time	Time Interval T in year	No. of Cumulative Earthquakes occurred in the time interval T				Rate of occurrence of Earthquake /year for the Magnitude			
		3-3.9 M_w	4-4.9 M_w	5-5.9 M_w	6-6.9 M_w	3-3.9 M_w(N1)	4-4.9 M_w(N2)	5-5.9 M_w(N3)	6-6.9 M_w(N4)
2002-2012	10	3	0	0	0	0.300	0	0	0
1992-2012	20	3	7	1	0	0.150	0.350	0.050	0
1982-2012	30	10	13	1	0	0.334	0.434	0.034	0
1972-2012	40	20	15	1	0	0.500	0.375	0.025	0
1962-2012	50	22	20	6	0	0.440	0.400	0.120	0
1952-2012	60	22	25	8	0	0.367	0.417	0.134	0
1942-2012	70	22	25	8	0	0.314	0.357	0.114	0
1932-2012	80	22	25	8	0	0.275	0.3125	0.100	0
1922-2012	90	22	25	8	1	0.245	0.278	0.089	0.012
1912-2012	100	22	25	9	1	0.220	0.250	0.090	0.010
1902-2012	110	22	26	9	1	0.200	0.236	0.081	0.009
1892-2012	120	22	26	9	1	0.184	0.217	0.075	0.008
1882-2012	130	22	26	9	1	0.169	0.200	0.069	0.007
1872-2012	140	24	27	10	1	0.171	0.192	0.071	0.007
1862-2012	150	30	27	10	1	0.200	0.180	0.067	0.007
1852-2012	160	36	29	10	1	0.225	0.181	0.062	0.006
1842-2012	170	37	29	10	2	0.217	0.170	0.059	0.011
1832-2012	180	37	29	10	2	0.205	0.161	0.056	0.011
1827-2012	185	37	30	10	2	0.200	0.162	0.054	0.010

Table 3.4 Earthquake Distribution by Time and Magnitude for District Headquarter Dantewara

Time	Time Interval T in year	No. of cumulative Earthquakes occurred in the time interval T				Rate of occurrence of Earthquake /year for the Magnitude			
		3-3.9 M_w	4-4.9 M_w	5-5.9 M_w	6-6.9 M_w	3-3.9 M_w(N1)	4-4.9 M_w(N2)	5-5.9 M_w(N3)	6-6.9 M_w(N4)
2002-2012	10	2	0	0	0	0.200	0	0	0
1992-2012	20	2	7	0	0	0.100	0.350	0	0
1982-2012	30	6	9	0	0	0.200	0.300	0	0
1972-2012	40	16	11	0	0	0.400	0.275	0	0
1962-2012	50	18	14	3	2	0.360	0.280	0.060	0.040
1952-2012	60	18	20	4	3	0.300	0.334	0.067	0.050
1942-2012	70	18	20	4	3	0.257	0.285	0.057	0.043
1932-2012	80	18	20	4	3	0.225	0.250	0.050	0.037
1922-2012	90	18	20	4	4	0.200	0.222	0.045	0.045
1912-2012	100	18	20	5	4	0.180	0.200	0.050	0.040
1902-2012	110	18	22	5	4	0.164	0.200	0.045	0.036
1892-2012	120	18	22	6	4	0.150	0.183	0.050	0.033
1882-2012	130	18	22	6	4	0.138	0.169	0.046	0.030
1872-2012	140	19	22	7	4	0.136	0.157	0.050	0.028
1862-2012	150	25	22	7	4	0.167	0.147	0.047	0.027
1852-2012	160	31	25	7	4	0.194	0.156	0.044	0.025
1842-2012	170	31	25	7	5	0.182	0.147	0.041	0.029
1832-2012	180	31	25	7	5	0.172	0.139	0.039	0.028
1827-2012	185	31	26	7	5	0.167	0.140	0.038	0.027

Table 3.5 Rate of Occurrence of Magnitude of District Headquarter Dantewara

Time Interval T in year	$\frac{1}{\sqrt{T}}$	$\frac{\sqrt{(N_1/T)}}{\sqrt{T}}$	$\frac{\sqrt{(N_2/T)}}{\sqrt{T}}$	$\frac{\sqrt{(N_3/T)}}{\sqrt{T}}$	$\frac{\sqrt{(N_4/T)}}{\sqrt{T}}$
10	0.3162	0.1732	0.0000	0.0000	0
20	0.2236	0.0866	0.1323	0.0500	0
30	0.1826	0.1054	0.1202	0.0333	0
40	0.1581	0.1118	0.0968	0.0250	0
50	0.1414	0.0938	0.0894	0.0490	0
60	0.1291	0.0782	0.0833	0.0471	0
70	0.1195	0.0670	0.0714	0.0404	0
80	0.1118	0.0586	0.0625	0.0354	0
90	0.1054	0.0521	0.0556	0.0314	0.001171
100	0.1000	0.0469	0.0500	0.0300	0.001
110	0.0953	0.0426	0.0464	0.0273	0.000867
120	0.0913	0.0391	0.0425	0.0250	0.000761
130	0.0877	0.0361	0.0392	0.0231	0.000675
140	0.0845	0.0350	0.0371	0.0226	0.000604
150	0.0816	0.0365	0.0346	0.0211	0.000544
160	0.0791	0.0375	0.0337	0.0198	0.000494
170	0.0767	0.0358	0.0317	0.0186	0.000638
180	0.0745	0.0338	0.0299	0.0176	0.000586
185	0.0735	0.0329	0.0296	0.0171	0.000562

Table 3.6 Rate of Occurrence of Magnitude of District Headquarter Jagdalpur

Time Interval T in year	$\frac{1}{\sqrt{T}}$	$\frac{\sqrt{(N_1/T)}}{\sqrt{T}}$	$\frac{\sqrt{(N_2/T)}}{\sqrt{T}}$	$\frac{\sqrt{(N_3/T)}}{\sqrt{T}}$	$\frac{\sqrt{(N_4T)}}{\sqrt{T}}$
10	0.3162	0.1414	0.0000	0.0000	0
20	0.2236	0.0707	0.1323	0.0000	0
30	0.1826	0.0816	0.1000	0.0000	0
40	0.1581	0.1000	0.0829	0.0000	0
50	0.1414	0.0849	0.0748	0.0346	0.004
60	0.1291	0.0707	0.0745	0.0333	0.003727
70	0.1195	0.0606	0.0639	0.0286	0.002957
80	0.1118	0.0530	0.0559	0.0250	0.002421
90	0.1054	0.0471	0.0497	0.0222	0.002342
100	0.1000	0.0424	0.0447	0.0224	0.002
110	0.0953	0.0386	0.0426	0.0203	0.001734
120	0.0913	0.0354	0.0391	0.0204	0.001521
130	0.0877	0.0326	0.0361	0.0188	0.001349
140	0.0845	0.0311	0.0335	0.0189	0.001207
150	0.0816	0.0333	0.0313	0.0176	0.001089
160	0.0791	0.0348	0.0313	0.0165	0.000988
170	0.0767	0.0328	0.0294	0.0156	0.001009
180	0.0745	0.0309	0.0278	0.0147	0.000926
185	0.0735	0.0301	0.0276	0.0143	0.000889

Table 3.7 Faults Considered for Hazard Analysis around the District Headquarter Dantewara

Fault No.	Fault length Li in km	Minimum map distance to the site D in km	Focal depth F in km	Hypo-central Distance R in km	Weightage of fault W_i	Maximum potential magnitude M_u
F1	58	242.902	10	243.11	0.0431	6.4
F2	25	247.537	10	247.74	0.0186	6.4
F3	45	251.168	10	251.37	0.0334	6.4
F4	125	275.917	10	276.1	0.0930	6.4
F5	180	81.831	10	82.44	0.1339	6.4
F6	174	170.930	10	171.23	0.1294	7.4
F7	228	170.725	10	171.02	0.1696	5.4
F8	130	204.843	10	205.09	0.0967	6.4
F9	129	80.540	10	81.16	0.0959	6.4
F10	32	265.137	10	265.33	0.0238	5.4
F11	121	257.837	10	258.04	0.0900	6.4
F12	46	291.190	10	291.37	0.0342	5.4
F13	51	290.698	10	290.87	0.0379	5.4
	1344					

Table 3.8 Faults Considered for Hazard Analysis around the District Headquarter Jagdalpur

Fault No.	Fault Length L in km	Minimum map distance to the site D in km	Focal depth F in km	Hypo-central distance R	Weightage of fault W_i	Maximum potential magnitude M_u
F1	58	255.303	10	255.5	0.0476	6.4
F2	25	279.778	10	279.96	0.0206	6.4
F3	45	289.365	10	289.54	0.0370	6.4
F4	180	193.089	10	193.35	0.1477	6.4
F5	174	281.809	10	281.99	0.1428	6.4
F6	228	221.100	10	221.33	0.1871	7.4
F7	129	179.975	10	180.26	0.1059	5.4
F8	130	246.804	10	247.01	0.1067	6.4
F9	32	171.603	10	171.9	0.0263	6.4
F10	121	147.031	10	147.38	0.0993	5.4
F11	46	187.611	10	187.88	0.0378	6.4
F12	51	181.202	10	181.48	0.0419	5.4
Total =	1219					

Table 3.9 PGA for M_{100} Earthquakes at District Headquarter Dantewara

Fault No.	Fault length L_i in km	Minimum map distance to the site D in km	Focal depth F in km	Hypo central distance R in km	100 years Recurrence M_{100}	PGA * of Site
F1	58	242.902	10	243.11	4.0	0.00065
F2	25	247.537	10	247.74	3.5	0.00033
F3	45	251.168	10	251.37	3.75	0.00044
F4	125	275.917	10	276.1	4.50	0.00085
F5	180	81.831	10	82.44	4.75	0.01145
F6	174	170.930	10	171.23	4.75	0.00332

F7	228	170.725	10	171.02	4.65	0.00298
F8	130	204.843	10	205.09	4.55	0.00182
F9	129	80.540	10	81.16	4.55	0.00934
F10	32	265.137	10	265.33	3.65	0.00034
F11	121	257.837	10	258.04	4.50	0.00101
F12	46	291.190	10	291.37	3.85	0.00034
F13	51	290.698	10	290.87	3.80	0.00032

Table 3.10 PGA for M_{100} Earthquakes at District Headquarter Jagdalpur

Fault No.	Fault length L_i in km	Minimum map distance to the site D in km	Focal depth F in km	Hypo central distance R in km	100 years recurrence M_{100}	PGA* of Site
F1	58	255.303	10	255.5	4.10	0.00065
F2	25	279.778	10	279.96	3.51	0.00024
F3	45	289.365	10	289.54	3.95	0.00039
F4	180	193.089	10	193.35	4.90	0.00306
F5	174	281.809	10	281.99	4.88	0.00124
F6	228	221.100	10	221.33	5.2	0.00314
F7	129	179.975	10	180.26	4.5	0.00226
F8	130	246.804	10	247.01	4.7	0.00141
F9	32	171.603	10	171.9	3.68	0.00092
F10	121	147.031	10	147.38	4.50	0.00333
F11	46	187.611	10	187.88	4.82	0.00298
F12	51	181.202	10	181.48	3.96	0.00117