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Seismic Hazard Analysis of District Headquarters Dhamtari and Kanker of Chhattisgarh State, India: Deterministic Method

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Abstract- Seismic Hazard analysis is a method of quantifying the area in terms of topographical and seismological data. In the present paper seismic hazard analysis has been presented using deterministic method. Method is good enough for measuring dynamic ground motion parameters which will help in design process. Dhamtari and Kanker are two District Headquarters of the state of Chhattisgarh. In the present study DSHA has been applied to these District Headquarters sites to assess the maximum Peak Ground Acceleration (PGA). The observed values of peak ground acceleration for Dhamtari and Kanker sites are 0.01305g & 0.00313 g. Bureau of Indian Standard has specified these sites in seismic Zone II. This fact has been verified in the present study.

Index Terms- Earthquakes, Fault Map, Deterministic seismic hazard analysis, Peak Ground Acceleration

I. INTRODUCTION

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. The Earthquakes in India occur in the plate boundary of the Himalayas region 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. The 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 the occurrence of an earthquake of a particular size at a particular location, 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 Dhamtari and Kanker sites have been considered for this study. The present study details of these District Headquarters sites are as follows:

1.1 Location of Study Area

Dhamtari and Kanker are two major district headquarters of Chhattisgarh State and can be located 20º 42' latitude, 81º 34' longitude and 20° 15' latitude, 81° 32' longitude(as shown in Figure 1.2). It is identified as the rapid developing cities in, Chhattisgarh State with infrastructure facilities and thick population density.

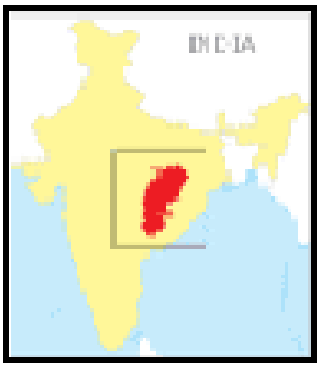

Figure1.1 (a) Chhattisgarh State

Figure1.1 (b) District Headquarters Dhamtari and Kanker

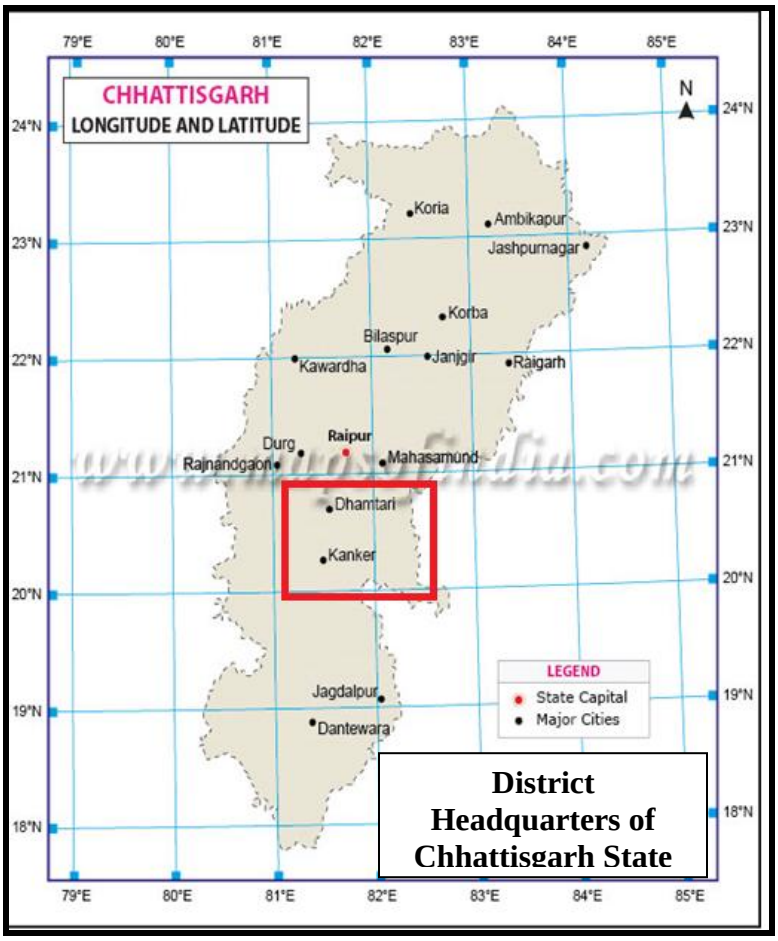

Figure 1.2 Chhattisgarh State District Headquarters Latitude & Longitude

II DETERMINISTIC SEISMIC HAZARD ASSESSMENT (DSHA)

The DSHA 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.
-

2.1.1 Earthquake History of Study Area

Most of the earthquakes occurred in India are in northern part of Indian sub continent. These occurred due to the upward movement of Himalayan region. The earthquake data prior to 1827 is not available. The available data is from 1847- 2011. And earthquake data is available for mostly active regions of India. Damages caused due to Latur 1993 and Bhuj earthquake 2001 highlighted the importance of seismic mitigation and preparedness. However, due to non availability of earthquake data United States Geological survey was collected with radial search of 300 Km. The collected earthquake data is as shown in Appendix I and Appendix II for Dhamtari and Kanker district headquarters. As per the past records the earthquake magnitudes Mw of 3 to 6.7 are available. A historical record of past Earthquakes, in a 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 than 3.0 magnitudes does not pose any serious problems to the civil Engineering structures, and it also very difficult to recognize their occurrence by human beings. Hence, for DSHA it was adequate to collect the information of past Earthquakes $\geq$ 3 magnitude only.

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

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

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

Where,
C1= 1.6858,
C2= 0.9241,
C3= 0.0760,
C4= 0.0057,

R= Hypo central distance,
m= magnitude,
ln ε = 0 (for DSHA).

2.5. Estimation of Peak Ground Acceleration (PGA)

The PGA, which exceeds 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 Dhamtari and Kanker sites using the following steps: A region of 300 km radius around both Dhamtari and Kanker sites were considered and all the faults having ≥ 25 km length were marked. These regions are shown in Figure 3.1 and Figure 3.2 respectively.

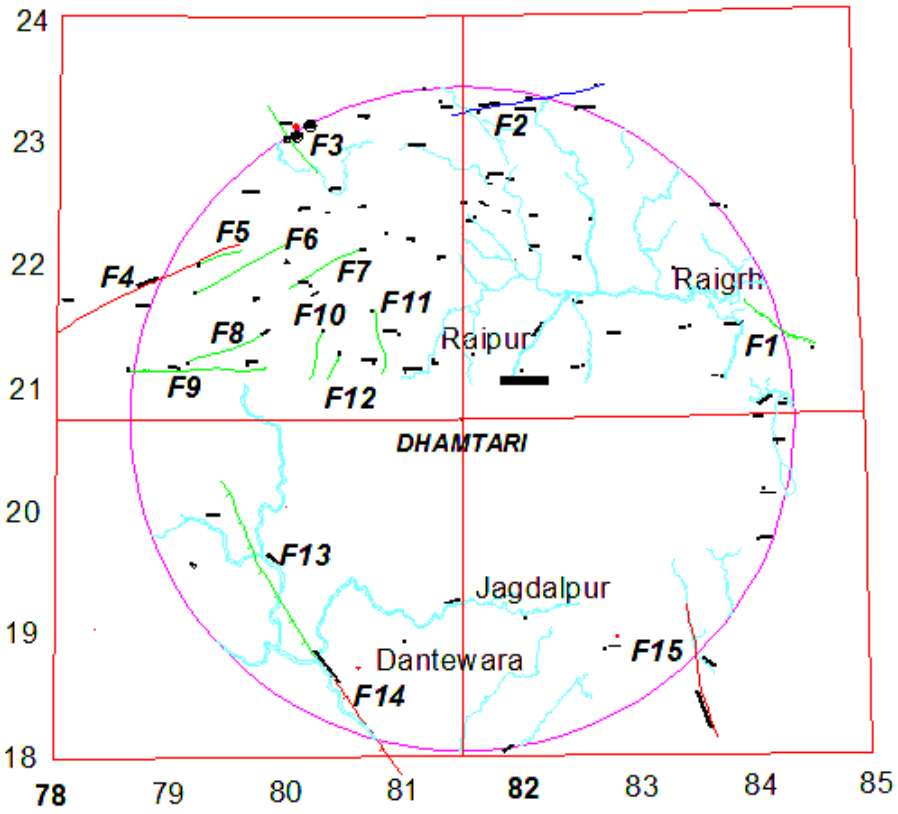

Figure 3.1 Fault considered for Deterministic Seismic Hazard Analysis of District Headquarter Dhamtari

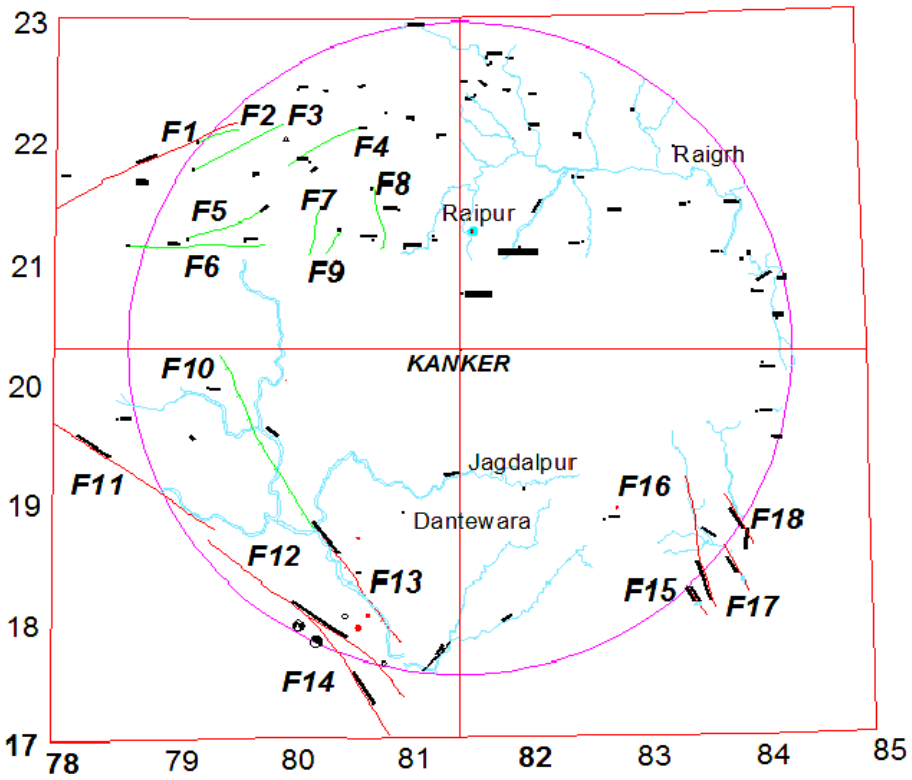

Figure 3.2 Fault considered for Deterministic Seismic Hazard Analysis of District Headquarter Kanker

With the help of different literature available and websites 67 and 101 Nos. of Earthquakes in the magnitude range 3<= Mw <=6.7 for Dhamtari and Kanker sites over the period from 1846 to 2012 (166) years and 1827 to 2012 (185) years have been collected. The same is presented at Appendix I and Appendix II respectively.

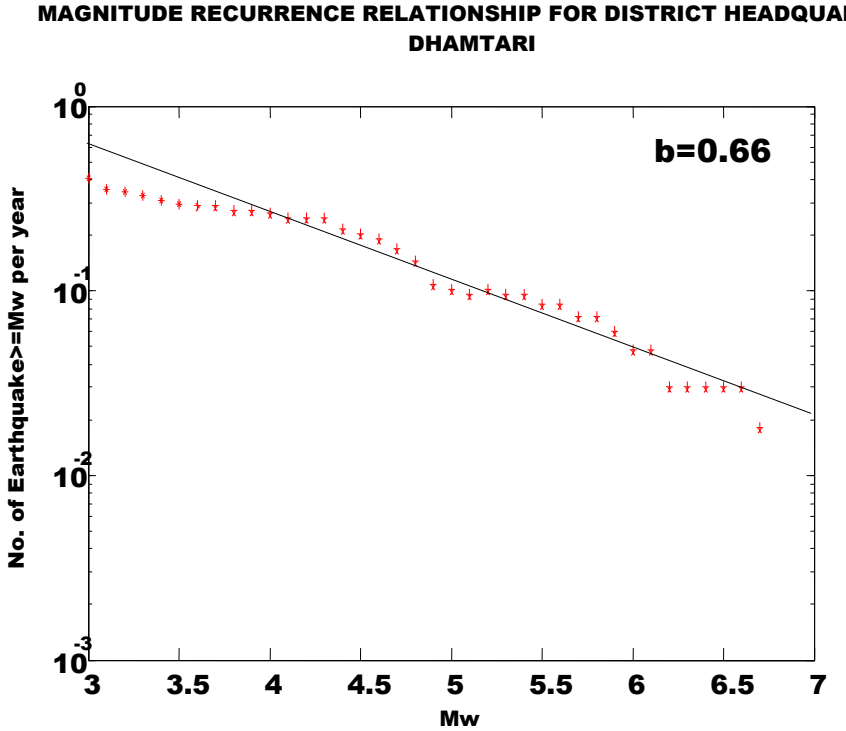

Figure 3.3 Magnitude-Recurrence Relationship for District Headquarter Dhamtari

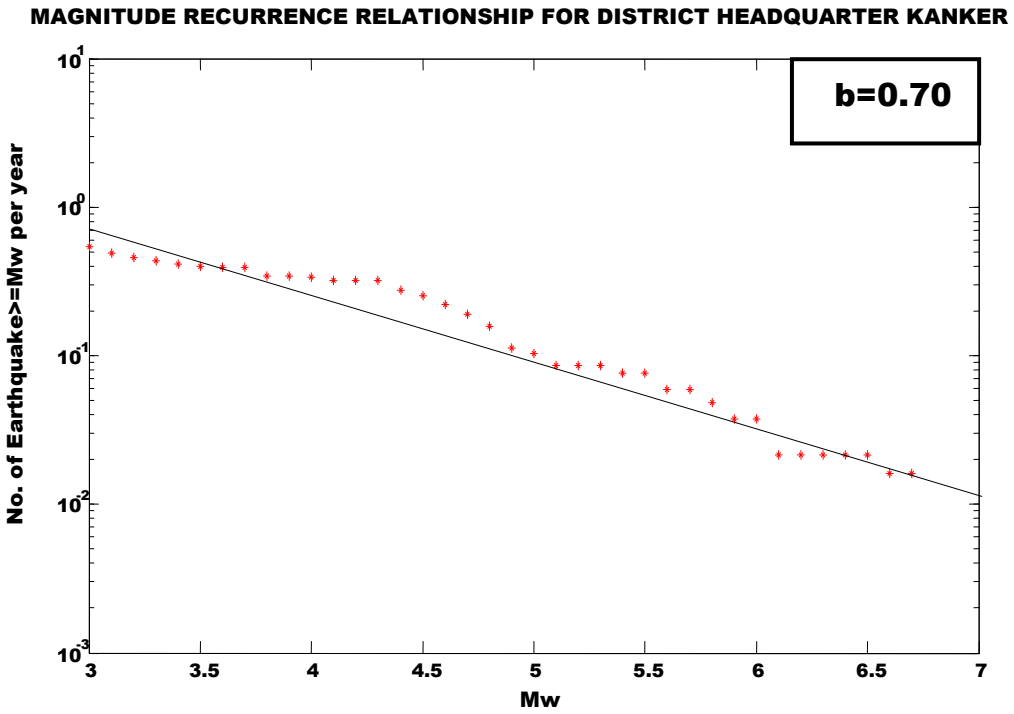

Figure 3.4 Magnitude-Recurrence Relationship for District Headquarter Kanker

With the help of different literature available and websites 67 and 100 Nos. of Earthquakes in the magnitude range $3 \geq Mw \leq 6.7$ for Dhamtari and Kanker sites over the period from 1846 to 2012 (166) years and 1827 to 2012 (185) years have been collected. It is presented in Appendix I and Appendix II respectively. From these collected 67 and 100 numbers data of Earthquakes with magnitude $3 \geq Mw \leq 6.7$ for Dhamtari and Kanker sites over the periods 166 years and 185 years has been arranged as per the number of Earthquakes that exceeded various magnitude values. Magnitude-frequency data for Dhamtari and Kanker 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" for regional seismicity.

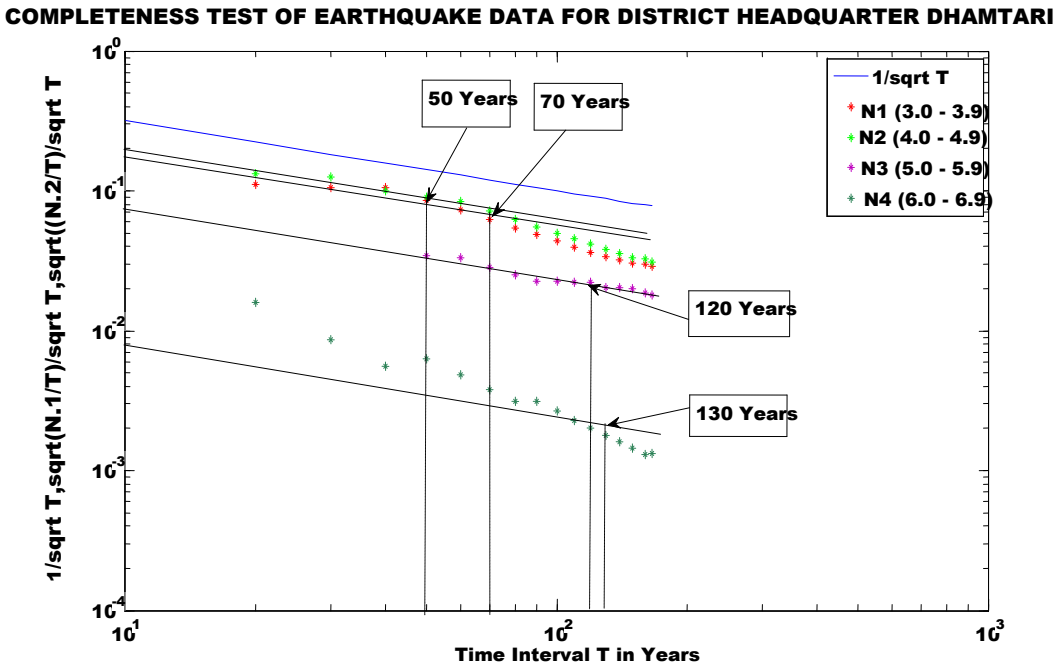

Figure 3.5 Completeness test of earthquake data for District Headquarter Dhamtari

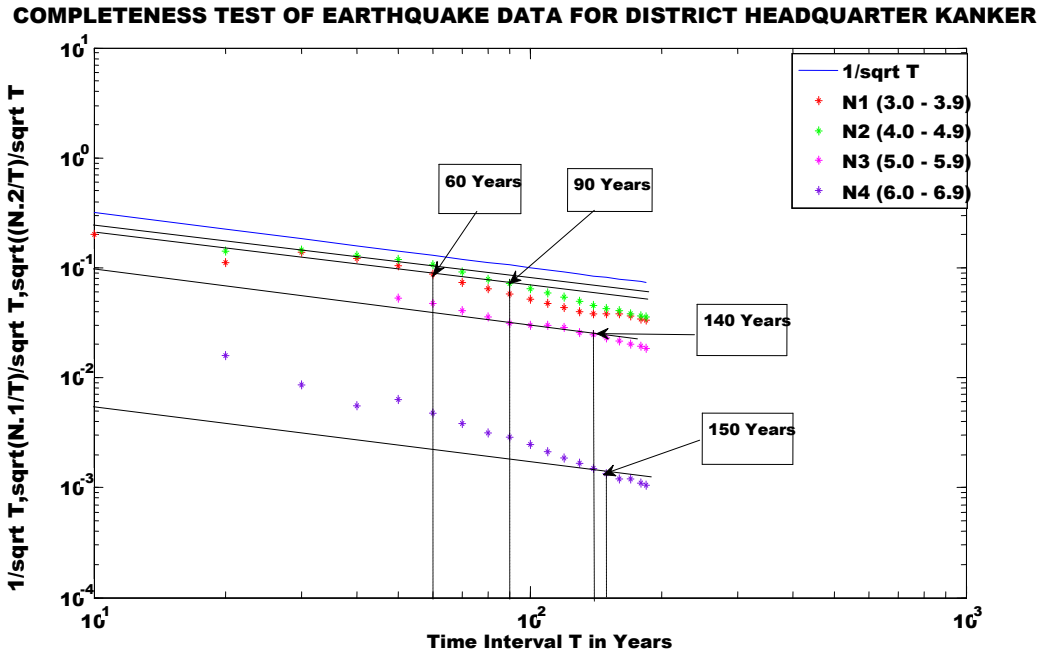

Figure 3.6 Completeness Test of Earthquake Data for District Headquarter Kanker

The above relationship for Dhamtari and Kanker 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 Dhamtari and Kanker sites have been presented in Table 3.2 and Table 3.3 (Appendix III) respectively.

Completeness test of Earthquakes data for Dhamtari and Kanker sites has been shown in Figure 3.5 and Figure 3.6 respectively. It has been observed for Dhamtari (from the Table 3.1 below) that 3.0 magnitude will be completed in 50 years time interval while 6.7

magnitude will complete in 130 years, and for Kanker it has been observed (from the Table 3.2 below) that 3.0 magnitude will be completed in 60 years time interval while 6.7 magnitude will complete in 150 years.

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

Magnitude Mw	No. of Events ≥ Mw	Complete in interval (year)	No. of Events per year ≥ Mw
3.0	67	50	1.3400
4.0	44	70	0.6285
5.0	17	120	0.1417
6.7	3	130	0.0230

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

Magnitude Mw	No. of Events ≥ Mw	Complete in interval (year)	No. of Events per year ≥ Mw
3.0	101	60	1.6834
4.0	63	90	0.7000
5.0	19	140	0.1357
6.7	3	150	0.0200

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

District Headquarter Dhamtari Log 10 (N) = 2.1000 - 0.5288 Mw…(3.1)

District Headquarter Kanker Log 10 (N) = 1.6830- 0.5200 Mw.…(3.2)

The same is shown in Figure 3.7 and Figure 3.8 for District Headquarter Dhamtari and Kanker respectively.

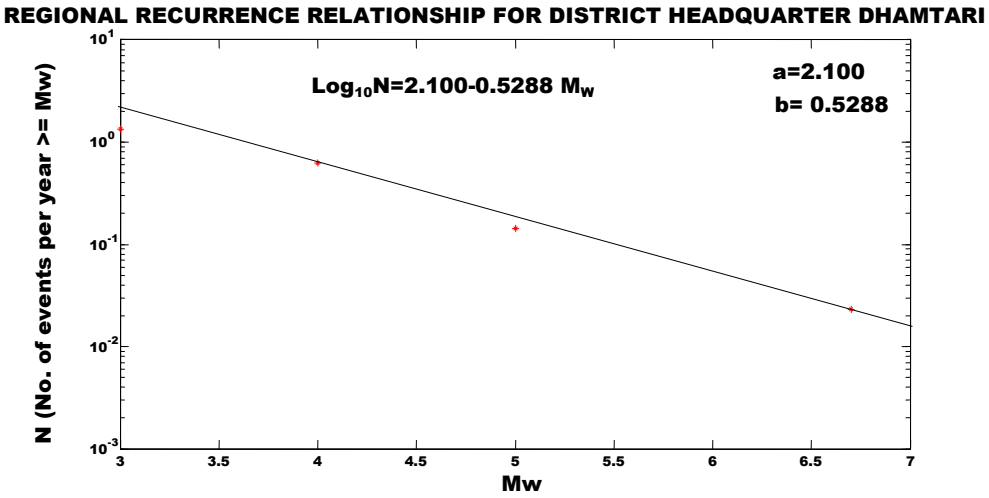

Figure 3.7 Regional Recurrence Relationship for District Headquarter Dhamtari

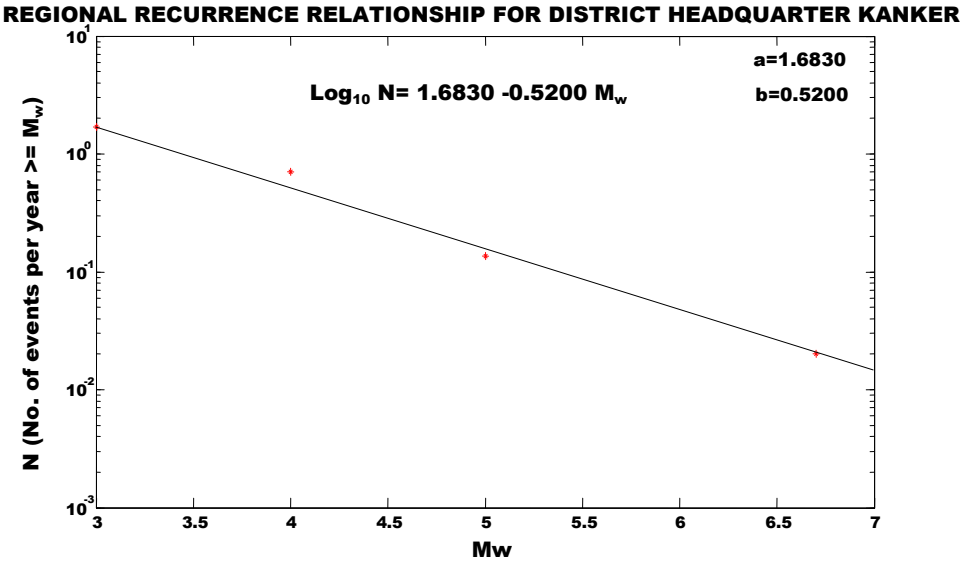

Figure 3.8 Regional Recurrence Relationship for District Headquarter Kanker

Lengths of all the 15 numbers faults, around the Dhamtari and 18 numbers around the Kanker marked having length of 25 km or more are considered for Deterministic Seismic Hazard Analysis (DSHA). 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 Dhamtari and in Table 3.8 (Appendix III) for Kanker respectively.

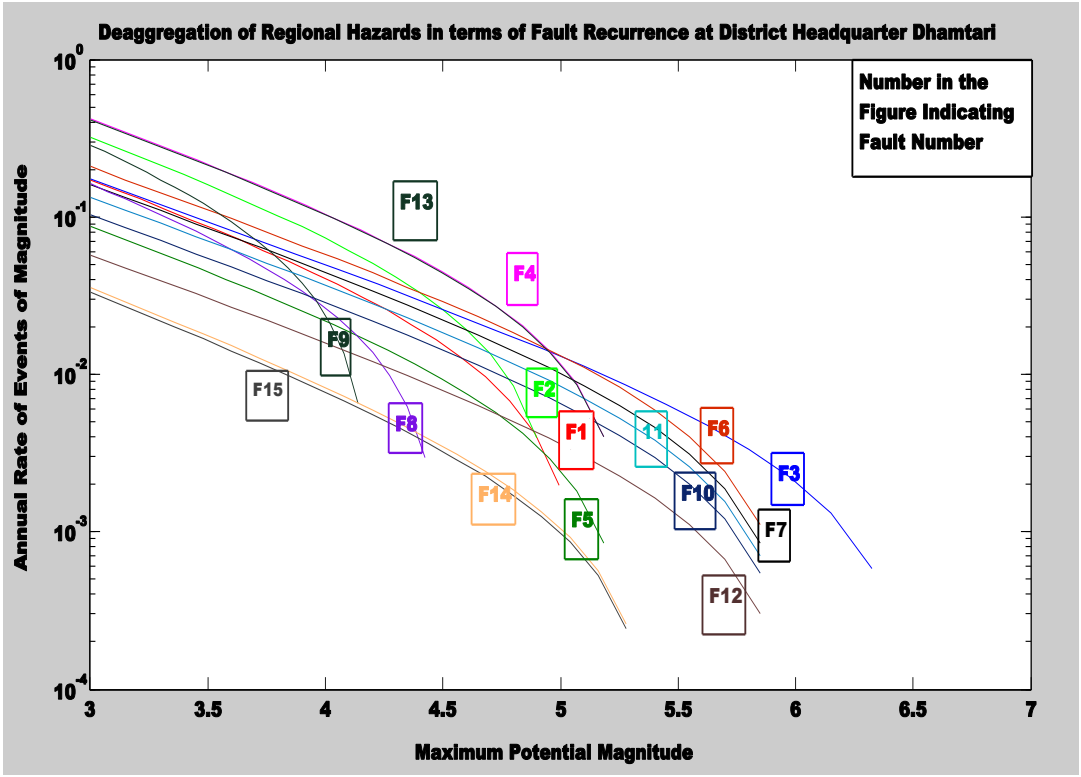

Figure 5.9 Deaggregation of Regional Hazards in terms of Fault Recurrence at District Headquarter Dhamtari

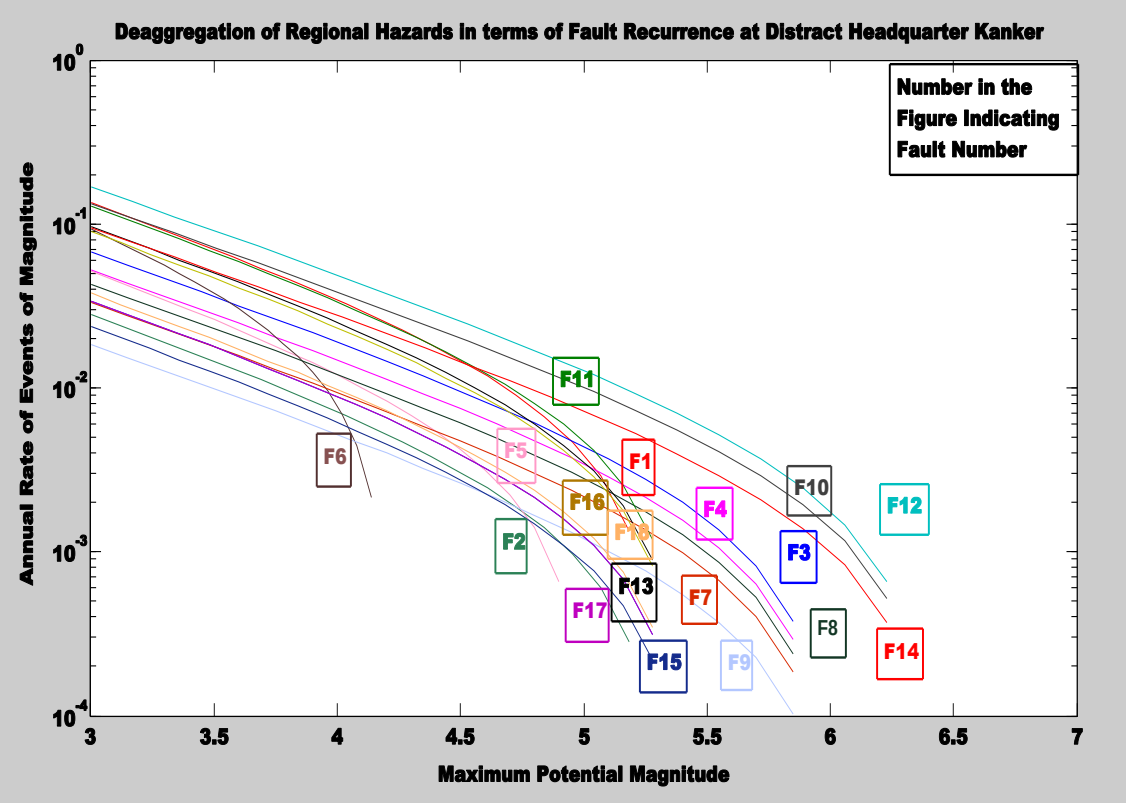

Figure 5.10 Deaggregaton of regional hazards in terms of fault recurrence at District Headquarter Kanker

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 Dhamtari and Kanker have been shown in Figure 3.9 and Figure 3.10 respectively.

IV RESULT & CONCLUSION

Regional Recurrence Relationship obtained for Dhamtari and Kanker sites have been presented in Equation No 3.1 & 3.2 Obtained "b" values are 0.5288 and 0.52 respectively. Hence, both the sites are situated in less seismic active zone. Deterministic Seismic Hazard Analysis has been applied to the District Headquarters Dhamtari and Kanker 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 Dhamtari Site has been obtained due to fault No. 11 (length 58 km, Distance 83.799 km) is equal to 0.01305g. Maximum value of Peak Ground Acceleration (P. G. A.) for Kanker Site has been obtained due to fault No. 8 (length 58 km, Distance 116.039 km) is equal to 0.00313g. 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.

APPENDIX-I

Listing of Earthquake Events around Distract Head Quarter Dhamtari

(Latitude 18º 0'-24º 0', Longitude 78º 0'-85º 0')

S No.	Year	Month	Date	Latitude	Longitude	Int	Ms	Mb	Mw	Depth	Source
1	1846	5	27	23	80	Vi			6.5		OLD, NEIC, UKOLD
2	1858	10	12	18.3	84	V			4.3		OLD, NEIC
3	1859	8	24	18.1	83.5	V			3.7		OLD, NEIC, UKGSI

4	1860	2	25	19.4	84.9	V			4.3		OLD, NEIC
5	1861	11	13	18.11	83.5	Iii			3		UGS
6	1868	9	30	24	85	Vii			5.7		OLD, NEIC, UKOLD
7	1871	9	27	18.3	83.9	Iii			3		UGS
8	1872	11	22	18.86	80	Vi			5		UGS
9	1878	12	10	18.3	83.9	Iv			3.7		UGS
10	1897	6	22	19.4	84.9	Vii			5.5		HNS, NEIC, UKSTA
11	1903	5	17	23	80		5		5.5		TRI, NEIC, UKTRI
12	1917	4	17	18	84		5.5		5.8		ISS, NEIC, UKIMD
13	1927	6	2	23.5	81		6.5	6	6.7		GR
14	1927	6	2	24	82				6.5		NEIC, UKCH
15	1954	1	5	18	81.8		4		4.5		IMD
16	1954	1	5	18	81.3				4		NEIC, UKIMD
17	1957	8	25	22	80		5.5	5.5	5.8		SHL, NEIC, UKSHL
18	1958	11	1	22	85				4		SHL, NEIC, UKIMD
19	1959	8	9	18.1	83.5		4.1		4.7		RAO, UKRAO
20	1959	12	23	18.1	83.5		4.3		4.8		RAO, UKRAO
21	1963	5	8	21.7	84.9			5.2	5.3	33	CGS
22	1963	5	8	22.5	84.5				6		NEIC, UKRR
23	1965	4	29	23.5	84				4		NEIC
24	1968	11	14	21.8	78		4.2		4.8		IMD, NEIC, UKHYB
25	1969	4	14	18	80.5			5.2	5.3		IMD
26	1969	4	15	18	80.7			4.6	4.6	33	ISC
27	1969	4	14	18.1	80.5				6		UKTS
28	1969	3	26	22.6	78.1		4.2		4.8		IMD
29	1969	4	14	18	80.5				6		USC
30	1969	4	14	18	80.5	Vi			5.7	33	USC
31	1973	7	12	23.2	80		4		4.6		IMD
32	1973	7	12	23.1	79				3.7		NEIC, UKHYB
33	1975	4	24	18.7	80.7		3		3		INR, NEIC, UKHYB
34	1975	7	3	18	79.5		3.2		3.2		INR
35	1975	9	15	18.4	79.2		3.2		3.2		INR, NEIC, UKHYB
36	1975	7	3	18.5	79.5				3.2		UKHYB
37	1977	9	30	18.08	81.5		3.3		3.3		GBA
38	1979	8	29	18.24	81.3		3		3		GBA
39	1979	4	22	18.5	80.8		3.5		4.7		INR
40	1981	12	4	18.16	81.4		3		3		GBA
41	1981	12	16	18.57	80.7		3.3		3.3		GBA
42	1982	10	14	20.39	84.4			4.7	4.7		ISC
43	1983	4	8	18.17	81.3		3		3		GBA
44	1984	4	24	18.27	78.8		3.4		3.4		GBA
45	1984	4	27	18.16	79.4		3.4		3.4		GBA
46	1984	6	20	20.4	78.5		3.7		4.3		GBA
47	1985	1	6	20.22	78.4		4.2		4.8		GBA
48	1985	9	27	19.39	78.9		3		3		GBA
49	1986	4	9	18.34	82		3.1		3.1		GBA
50	1986	1	19	20.94	84.9			4.4	4.4	33	ISC
51	1987	4	18	22.53	79.2			4.8	4.8	20	ISC
52	1987	4	18	22.35	79.3			4.9	4.9	33	GSPDE, UKHYB
53	1990	6	9	18.1	80.5		4		4.6		CVR

54	1995	3	27	21.66	84.6			4.4	4.4	21	ISC
55	1995	3	27	21.67	84.6			4.6	4.6	10	GSPDE
56	1996	2	12	22.62	82.7				4.3	33	MLDMIV, UKHYB
57	1997	5	21	23.07	80			6	6.7	36	CGS
58	1997	5	21	23.08	80			6	6.7	36	NEIC, GS
59	1997	6	4	23.14	80				3.9	33	MDHYR, PDE, NEIC
60	1998	3	9	22.49	78			4.3	4.3	10	GSPDE, NEIC
61	2000	10	10	23.8	82.7			4.5	4.5	33	GSPDE, NEIC
62	2000	10	16	23.28	80.3			4.7	4.7	33	GSPDE, NEIC
63	2001	6	12	22.22	83.9			4.8	4.8	33	GSPDE, NEIC
64	2007	3	21	23.9	84.8				3.3	39	JHAR., IMD
65	2007	4	13	22.70	83.2				3.1	10	RAIG., IMD
66	2010	1	25	21.5	76.9				3.0	10	AMRA., MAH.,IMD
67	2011	2	8	22.5	79.6				3.5	12	SEONI,MP,IMD

Appendix -II
Listing of Earthquake Events around Distract Head Quarter Kanker

(Latitude $17^0\ 0^{"}$ - $23^0\ 0^{"}$ Longitude -$78^0\ 0^{"}$ - $85^0\ 0^{"}$)

S No.	Year	Month	Date	Latitude	Longitude	Int	Ms	Mb	Mw	Depth	Source
1	1827	1	6	17.7	83.4	V			4.3		OLD, NEIC, UKOLD
2	1843	3	12	17.5	78.5	Iv			3.7		OLD, NEIC, UKOLD
3	1846	5	27	23	80	Vi			6.5		OLD, NEIC, UKOLD
4	1853	2	21	17.7	83.3	Iv			3.7		UGS, NEIC
5	1853	2	21	17.7	83.4	Iv			3.7		UKOLD
6	1858	8	24	17.8	83.4	Iv			3		0LD,NEIC
7	1858	10	12	18.3	84	V			4.3		OLD, NEIC
8	1859	8	24	18.1	83.5	V			3.7		OLD, NEIC, UKGSI
9	1860	2	25	19.4	84.9	V			4.3		OLD, NEIC
10	1861	11	13	18.11	83.5	Iii			3		UGS
11	1869	12	19	17	82.3	V			3.7		OLD, UKOLD
12	1869	12	19	17.9	82.3	V			3.7		UKOLD
13	1870	12	19	17.7	83.4	V			3.7		OLD, UKGSI
14	1871	9	27	18.3	83.9	Iii			3		UGS
15	1872	11	22	18.86	80	Vi			5		UGS
16	1878	12	10	18.3	83.9	Iv			3.7		UGS
17	1897	6	22	19.4	84.9	Vii			5.5		HNS, NEIC, UKSTA
18	1903	5	17	23	80		5		5.5		TRI, NEIC, UKTRI
19	1917	4	17	18	84		5.5		5.8		ISS, NEIC, UKIMD
20	1927	6	2	23.5	81		6.5	6	6.7		GR
21	1954	1	5	18	81.8		4		4.5		IMD
22	1954	1	5	18	81.3				4		NEIC, UKIMD
23	1957	8	25	22	80		5.5	5.5	5.8		SHL, NEIC, UKSHL
24	1958	11	1	22	85				4		SHL, NEIC, UKIMD
25	1959	8	9	18.1	83.5		4.1		4.7		RAO, UKRAO
26	1959	12	23	18.1	83.5		4.3		4.8		RAO, UKRAO
27	1963	12	5	17.3	80.1		3.7		4.3	33	CGS/IMD
28	1963	5	8	21.7	84.9			5.2	5.3	33	CGS
29	1963	5	8	22.5	84.5				6		NEIC, UKRR
30	1965	4	29	23.5	84				4		NEIC
31	1968	7	29	17.6	80.8		4.5		5		GUB, NEIC,UKGUB

32	1968	7	27	17.6	80.8				4.5		NEIC, UKGUB
33	1968	11	14	21.8	78		4.2		4.8		IMD, NEIC, UKHYB
34	1969	4	13	17.81	80.7			5.3	5.5	25	ISC
35	1969	4	14	18	80.5			5.2	5.3		IMD
36	1969	4	15	18	80.7			4.6	4.6	33	ISC
37	1969	4	18	17.9	80.6		4.1		4.7		INR
38	1969	4	19	17.9	80.6		4.3		4.8		INR
39	1969	7	26	17.9	80.6		4		4.6		INR
40	1969	8	30	17.9	80.6		4.5		5		INR
41	1969	9	15	17.6	80.5		3.8		4.4		IMD, NEIC, UKIMD
42	1969	4	13	17.9	80.6				5.7		NEIC, UKTS
43	1969	4	14	18.1	80.5				6		UKTS
44	1969	3	26	22.6	78.1		4.2		4.8		IMD
45	1969	4	14	18	80.5				6		USC
46	1969	4	14	18	80.5	Vi			5.7	33	USC
47	1970	7	28	17.9	80.6		4		4.6		INR
48	1973	7	12	23.2	80		4		4.6		IMD
49	1973	7	12	23.1	79				3.7		NEIC, UKHYB
50	1975	4	24	18.7	80.7		3		3		INR, NEIC, UKHYB
51	1975	7	3	18	79.5		3.2		3.2		INR
52	1975	9	15	18.4	79.2		3.2		3.2		INR, NEIC, UKHYB
53	1975	7	3	18.5	79.5				3.2		UKHYB
54	1977	9	30	18.08	81.5		3.3		3.3		GBA
55	1978	5	1	17.45	80.6		3.1		3.1		GBA
56	1979	8	29	18.24	81.3		3		3		GBA
57	1979	4	22	18.5	80.8		3.5		4.7		INR
58	1980	3	30	17.5	81.8	V		4.4	4.4	54	ISC
59	1980	3	31	17.46	81.8				4.5	33	ISC
60	1980	3	30	17.16	82			4.5	4.5	33	GSPDE, CAT, NEIC
61	1981	12	4	18.16	81.4		3		3		GBA
62	1981	12	16	18.57	80.7		3.3		3.3		GBA
63	1982	10	14	20.39	84.4			4.7	4.7		ISC
64	1982	1	14	17.43	78.4		3.5		4.7	2	RAS
65	1982	2	24	17	80.4		3.1		3.1		CVR
66	1982	1	14	17.5	78.6				3.1		UKHYB
67	1983	4	8	18.17	81.3		3		3		GBA
68	1983	6	30	17.9	78.5			4.9	4.9	33	ISC
69	1983	6	30	17.6	78.5				4.5		UKHYB
70	1984	3	28	17.27	83.3		4.2		4.8		GBA
71	1984	8	23	17.16	82.6		3.4		3.4		GBA
72	1984	4	24	18.27	78.8		3.4		3.4		GBA
73	1984	4	27	18.16	79.4		3.4		3.4		GBA
74	1984	6	20	20.4	78.5		3.7		4.3		GBA
75	1985	9	7	17.82	81.7		3.2		3.2		GBA
76	1985	1	6	20.22	78.4		4.2		4.8		GBA
77	1985	9	27	19.39	78.9		3		3		GBA
78	1986	1	10	17.26	81		3.2		3.2		GBA
79	1986	4	9	18.34	82		3.1		3.1		GBA
80	1986	6	2	17.96	81.8		3		3		GBA
81	1986	1	19	20.94	84.9			4.4	4.4	33	ISC

82	1987	2	16	17.48	83.1		3.1		3.1		GBA
83	1987	4	18	22.53	79.2			4.8	4.8	20	ISC
84	1987	4	18	22.35	79.3			4.9	4.9	33	GSPDE, UKHYB
85	1990	6	9	18.1	80.5		4		4.6		CVR
86	1995	12	18	17.94	82.8			4.3	4.3		ISC
87	1995	3	27	21.66	84.6			4.4	4.4	21	ISC
88	1995	3	27	21.67	84.6			4.6	4.6	10	GSPDE
89	1996	2	12	22.62	82.7				4.3	33	MLDMIV, UKHYB
90	1997	5	21	23.07	80			6	6.7	36	CGS
91	1997	5	21	23.08	80			6	6.7	36	NEIC, GS
92	1997	6	4	23.14	80				3.9	33	MDHYR, PDE, NEIC
93	1998	3	9	22.49	78			4.3	4.3	10	GSPDE, NEIC
94	2000	10	10	23.8	82.7			4.5	4.5	33	GSPDE, NEIC
95	2000	10	16	23.28	80.3			4.7	4.7	33	GSPDE, NEIC
96	2001	6	12	22.22	83.9			4.8	4.8	33	GSPDE, NEIC
97	2007	3	21	23.9	84.8				3.3	39	JHAR., IMD
98	2007	4	13	22.70	83.2				3.1	10	RAIG., IMD
99	2008	5	29	17.7	82.6				3.7	5.0	VISHA., IMD
100	2011	2	8	22.5	79.6				3.5	12	SEONI,MP,IMD

Appendix-III
Table 3.1
Magnitude-Frequency Data of District Headquarters Dhamtari
Observation Period– 166 years [1846-2012]

S.No.	Moment Magnitude M_w	No. of Earthquake $\geq M_w$	No. of Earthquake $\geq M_w$ per year
1	3.0	67	0.403608
2	3.1	59	0.355416
3	3.2	57	0.343368
4	3.3	54	0.325296
5	3.4	51	0.307224
6	3.5	49	0.295176
7	3.6	48	0.289152
8	3.7	48	0.289152
9	3.8	45	0.271080
10	3.9	45	0.271080
11	4.0	44	0.265056
12	4.1	41	0.246984
13	4.2	41	0.246984
14	4.3	41	0.246984
15	4.4	36	0.216864
16	4.5	34	0.204816
17	4.6	32	0.192768
18	4.7	28	0.168672
19	4.8	24	0.144576
20	4.9	18	0.108432
21	5.0	17	0.102408
22	5.1	16	0.096384
23	5.2	16	0.102408

24	5.3	16	0.096384
25	5.4	14	0.096384
26	5.5	14	0.084336
27	5.6	12	0.084336
28	5.7	12	0.072288
29	5.8	10	0.072288
30	5.9	8	0.060240
31	6.0	8	0.048192
32	6.1	5	0.048192
33	6.2	5	0.030120
34	6.3	5	0.030120
35	6.4	5	0.030120
36	6.5	5	0.030120
37	6.6	3	0.030120
38	6.7	3	0.018072

Table 3.2

Magnitude - Frequency of District Headquarter Kanker

Observation Period– 185 years [1827-2012]

S.No.	Moment Magnitude M_w	No. of Earthquake $\geq M_w$	No. of Earthquake $\geq M_w$ per year
1	3.0	100	0.54054
2	3.1	91	0.491891
3	3.2	85	0.459459
4	3.3	80	0.432432
5	3.4	77	0.416216
6	3.5	74	0.40000
7	3.6	73	0.394594
8	3.7	73	0.394594
9	3.8	63	0.34054
10	3.9	63	0.34054
11	4.0	62	0.335135
12	4.1	59	0.318919
13	4.2	59	0.318919
14	4.3	59	0.318919
15	4.4	51	0.275675
16	4.5	47	0.254054
17	4.6	41	0.221621
18	4.7	35	0.189189
19	4.8	29	0.156757
20	4.9	21	0.113513
21	5.0	19	0.102703
22	5.1	16	0.086486
23	5.2	16	0.086486
24	5.3	16	0.086486

25	5.4	14	0.075676
26	5.5	14	0.075676
27	5.6	11	0.059459
28	5.7	11	0.059459
29	5.8	9	0.048649
30	5.9	7	0.037838
31	6.0	7	0.037838
32	6.1	4	0.021622
33	6.2	4	0.021622
34	6.3	4	0.021622
35	6.4	4	0.021622
36	6.5	4	0.021622
37	6.6	3	0.016216
38	6.7	3	0.016216

Table 3.3

Earthquake Distribution by Time and Magnitude for District Headquarter Dhamtari

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(N	6-6.9 M_w(N4)
2002-2012	10	4	1	0	0	0.40	0.10	0	0
1992-2012	20	5	7	0	2	0.25	0.35	0	0.10
1982-2012	30	10	14	0	2	0.334	0.467	0	0.067
1972-2012	40	18	16	0	2	0.450	0.400	0	0.050
1962-2012	50	18	20	3	5	0.360	0.400	0.060	0.100
1952-2012	60	19	25	4	5	0.317	0.417	0.067	0.084
1942-2012	70	19	25	4	5	0.271	0.357	0.057	0.071
1932-2012	80	19	25	4	5	0.237	0.312	0.050	0.062
1922-2012	90	19	25	4	7	0.211	0.278	0.045	0.078
1912-2012	100	19	25	5	7	0.190	0.250	0.050	0.070
1902-2012	110	19	25	6	7	0.173	0.227	0.054	0.063
1892-2012	120	19	25	7	7	0.158	0.208	0.058	0.058
1882-2012	130	19	25	7	7	0.146	0.192	0.053	0.053
1872-2012	140	20	25	8	7	0.143	0.178	0.057	0.050

1862-2012	150	21	25	9	7	0.140	0.167	0.060	0.047
1852-2012	160	23	27	9	7	0.144	0.168	0.056	0.044
1846-2012	166	23	27	9	8	0.138	0.162	0.054	0.048

Table 3.4

Earthquake Distribution by Time and Magnitude for District Headquarter Kanker

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	4	0	0	0	0.400	0	0	0
1992-2012	20	5	8	0	2	0.250	0.400	0	0.100
1982-2012	30	17	19	0	2	0.567	0.634	0	0.067
1972-2012	40	24	27	0	2	0.600	0.675	0	0.050
1962-2012	50	27	35	7	5	0.540	0.700	0.140	0.100
1952-2012	60	27	40	8	5	0.450	0.667	0.134	0.083
1942-2012	70	27	40	8	5	0.384	0.579	0.116	0.071
1932-2012	80	27	40	8	5	0.337	0.500	0.100	0.062

1922-2012	90	27	41	8	6	0.300	0.456	0.089	0.067
1912-2012	100	27	41	9	6	0.27	0.41	0.09	0.06
1902-2012	110	27	41	10	6	0.245	0.377	0.099	0.055
1892-2012	120	27	41	11	6	0.225	0.347	0.097	0.05
1882-2012	130	27	41	11	6	0.208	0.315	0.085	0.046
1872-2012	140	28	41	12	6	0.200	0.293	0.086	0.043
1862-2012	150	32	41	12	6	0.213	0.273	0.080	0.040
1852-2012	160	37	43	12	6	0.231	0.268	0.075	0.037
1842-2012	170	38	43	12	7	0.223	0.252	0.070	0.041
1832-2012	180	38	43	12	7	0.211	0.239	0.067	0.039
1827-2012	185	38	44	12	7	0.205	0.238	0.065	0.038

Table 3.5

Rate of Occurrence of Magnitude of District Headquarter Dhamtari

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	0.2000	0.1000	0.0000	0
20	0.2236	0.1118	0.1323	0.0000	0.015811
30	0.1826	0.1055	0.1248	0.0000	0.008628
40	0.1581	0.1061	0.1000	0.0000	0.00559
50	0.1414	0.0849	0.0894	0.0346	0.006325
60	0.1291	0.0727	0.0834	0.0334	0.00483
70	0.1195	0.0622	0.0714	0.0285	0.003807
80	0.1118	0.0544	0.0624	0.0250	0.003112
90	0.1054	0.0484	0.0556	0.0224	0.003103

100	0.1000	0.0436	0.0500	0.0224	0.002646
110	0.0953	0.0397	0.0454	0.0222	0.002282
120	0.0913	0.0363	0.0416	0.0220	0.002007
130	0.0877	0.0335	0.0384	0.0202	0.001771
140	0.0845	0.0320	0.0357	0.0202	0.001597
150	0.0816	0.0306	0.0334	0.0200	0.001445
160	0.0791	0.0300	0.0324	0.0187	0.001311
166	0.0776	0.0288	0.0312	0.0180	0.00132

Table 3.6

Rate of Occurrence of Magnitude of District Headquarter Kanker

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	0.2000	0.0000	0.0000	0.0000
20	0.2236	0.1118	0.1414	0.0000	0.015811
30	0.1826	0.1375	0.1454	0.0000	0.008628
40	0.1581	0.1225	0.1299	0.0000	0.00559
50	0.1414	0.1039	0.1183	0.0529	0.006325
60	0.1291	0.0866	0.1054	0.0473	0.004802
70	0.1195	0.0741	0.0909	0.0407	0.003807
80	0.1118	0.0649	0.0791	0.0354	0.003112
90	0.1054	0.0577	0.0712	0.0314	0.002876
100	0.1000	0.0520	0.0640	0.0300	0.002449
110	0.0953	0.0472	0.0585	0.0300	0.002132
120	0.0913	0.0433	0.0538	0.0284	0.001863
130	0.0877	0.0400	0.0492	0.0256	0.00165
140	0.0845	0.0378	0.0457	0.0248	0.001481
150	0.0816	0.0377	0.0427	0.0231	0.001333
160	0.0791	0.0380	0.0409	0.0217	0.001202

170	0.0767	0.0362	0.0385	0.0203	0.001191
180	0.0745	0.0342	0.0364	0.0193	0.001097
185	0.0735	0.0333	0.0359	0.0187	0.001054

Table 3.7

Faults Considered for Hazard Analysis around the District Headquarter Dhamtari

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	75	276.311	10	276.5	0.0525	5.1
F2	140	273.686	10	273.87	0.0981	5.0
F3	76	257.749	10	257.95	0.0532	6.5
F4	182	256.68	10	256.88	0.1275	5.3
F5	38	251.866	10	252.07	0.0266	5.3
F6	91	224.959	10	225.19	0.0637	6.0
F7	71	178.889	10	179.17	0.0490	6.0
F8	70	196.69	10	196.95	0.0497	4.5
F9	125	183.544	10	183.82	0.0875	4.2
F10	45	149.074	10	149.41	0.0315	6.0
F11	58	83.799	10	84.40	0.0406	6.0
F12	25	125.114	10	125.52	0.0175	6.0
F13	180	225.942	10	226.17	0.1261	5.3
F14	130	253.116	10	253.32	0.0911	5.4
F15	121	263.061	10	263.26	0.0847	5.4
Total= 1427						

Table 3.8

Faults Considered for Hazard Analysis around the District Headquarter Kanker

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 in km	Weightage of fault Wi	Maximum potential magnitude Mu
F1	182	289.122	10	289.3	0.1013	5.3
F2	38	283.721	10	283.9	0.0211	5.3
F3	91	261.459	10	261.66	0.0506	6.0
F4	71	222.399	10	222.63	0.0395	6.0
F5	70	291.522	10	291.7	0.0389	5.0
F6	125	200.507	10	200.76	0.0696	4.2
F7	45	161.198	10	161.51	0.0250	6.0
F8	58	116.039	10	116.47	0.0323	6.0
F9	25	148.451	10	148.79	0.0139	6.0
F10	180	217.247	10	217.48	0.1002	6.4

F11	174	277.406	10	277.59	0.0969	5.4
F12	228	288.384	10	288.56	0.1269	6.4
F13	130	210.941	10	211.18	0.0724	5.4
F14	129	282.015	10	282.2	0.0718	6.4
F15	32	298.074	10	298.25	0.0178	5.4
F16	121	235.618	10	235.84	0.0673	5.4
F17	46	298.307	10	298.48	0.0256	5.4
F18	51	273.877	10	274.06	0.0284	5.4
Total=1796						

Table 3.9

PGA for M_{100} Earthquakes at District Headquarter Dhamtari

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	75	276.311	10	276.5	4.68	0.00104
F2	140	273.686	10	273.87	4.78	0.00120
F3	76	257.749	10	257.95	5.25	0.00230
F4	182	256.68	10	256.88	5.05	0.00189
F5	38	251.866	10	252.07	4.49	0.00106
F6	91	224.959	10	225.19	5.15	0.00287
F7	71	178.889	10	179.17	5.0	0.00399
F8	70	196.69	10	196.95	4.25	0.00140
F9	125	183.544	10	183.82	4.10	0.00135
F10	45	149.074	10	149.41	4.75	0.00431
F11	58	83.799	10	84.4	4.90	0.01305*
F12	25	125.114	10	125.52	4.35	0.00372
F13	180	225.942	10	226.17	5.05	0.00255
F14	130	253.116	10	253.32	3.90	0.00052
F15	121	263.061	10	263.26	3.85	0.00044

Table 3.10

PGA for M_{100} Earthquakes at Kanker Dam site

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	182	289.122	10	289.3	3.80	0.00033
F2	38	283.721	10	283.9	4.70	0.00100
F3	91	261.459	10	261.66	4.50	0.00098
F4	71	222.399	10	222.63	4.30	0.00114
F5	70	291.522	10	291.7	4.10	0.00046
F6	125	200.507	10	200.76	3.95	0.00094
F7	45	161.198	10	161.51	3.95	0.00145

F8	58	116.039	10	116.47	4.10	0.00313
F9	25	148.451	10	148.79	3.50	0.00096
F10	180	217.247	10	217.48	5.00	0.00264
F11	174	277.406	10	277.59	4.70	0.00106
F12	228	288.384	10	288.56	5.20	0.00164
F13	130	210.941	10	211.18	4.60	0.00181
F14	129	282.015	10	282.2	4.80	0.00113
F15	32	298.074	10	298.25	3.70	0.00026
F16	121	235.618	10	235.84	4.50	0.00126
F17	46	298.307	10	298.48	3.90	0.00034
F18	51	273.877	10	274.06	4.00	0.00048

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