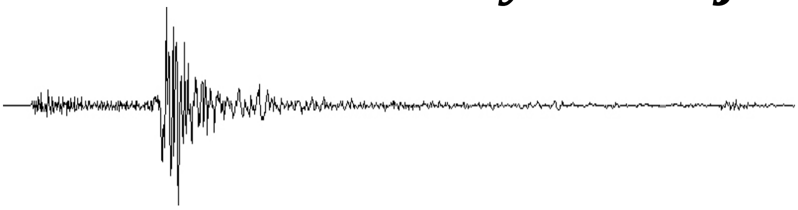
International Institute of Earthquake Engineering and Seismology

Hazard Risk Analysis Project



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Site: Tabriz city

THINK GLOBAL, ACT LOCAL

Spring 2003

1. Project:

Do the seismic hazard analysis for a site in IRAN by PSHA and DSHA methods and define the design spectra for this site.

2. Site Specifications:

Site name: Tabriz City
Geometry: 46.2 E and 38.1 N
Radius of the analysis area: 100+ km

3. Database:

According to the earthquake database, the number if earthquakes bigger than magnitude 4.0 is 49 and the time range is since 1905 until 2002 (97 years).
The number of data is not enough to calculate different Gutenburg-Richter b-line for each source, and then we will use all the data in database to calculate Gutenburg-Richter relation for entire region and then localize it by considering the length and area of sources.
Table 1 include the data in the geometry range of latitude 44.5~47.7 and longitude 36.5~39.6. After positioning the earthquakes on the region map and omitting not used data, we gain *table 2* that contain M_b and M_w.

Table 1: earthquake database

	Year	month	day	hour	min.	sec.	Lattitude	Longitude	Depth	mb
1	1930	5	6	22	34	23	38.15	44.65		7.2
2	1931	4	27	16	50	45	38.7	46.1		6.5
3	1930	5	8	15	35	24	37.3	44.8		6.2
4	1924	2	19	6	59	45	39	47.5		5.7
5	1934	2	22	8	7	20	37.9	45.1		5.7
6	1981	7	23	0	5	30.7	37.141	45.23	33	5.6
7	1905	1	9	6	17		38	46		5.5
8	1930	6	4	7	28	10	37.9	45.1		5.5
9	1970	10	25	11	22	18.2	36.8	45.1	19	5.5
10	1970	3	14	1	51	44.4	38.6	44.7	23	5.3
11	1930	5	8	5	29	30	37.5	45.5		5.2
12	1930	5	23	9	48	20	37.5	45.5		5.2
13	1930	5	29	17	14	55	37.5	45.5		5.2
14	1931	5	12	10	25	10	37.5	45.5		5.2
15	1940	10	18	12	25	44	38.5	45		5.2
16	1949	10	13	10	26	30	36.6	44.5		5.2
17	1950	5	1	8	14	54	38.5	45		5.2
18	1954	10	22	22	47	30	38.9	45.9		5.2
19	1928	3	24	10	53	16	37.8	47.3		5
20	1930	8	3	22	5	51	37.3	44.8		5
21	1930	10	25	23	34	25	37.9	45.1		5
22	1965	2	10	16	9	54.2	37.66	47.09	45	5

	Year	month	day	hour	min.	sec.	Lattitude	Longitude	Depth	mb
23	1968	6	9	0	56	32	39.09	46.1	31	5
24	1968	9	1	5	39	45	39.14	46.2	24	5
25	1996	4	22	14	42	32.3	39.17	47.37	29	5
26	1909	1	26	22	56		39.1	45.5		4.9
27	1949	5	8	9	0		37.3	44.6		4.9
28	1984	8	24	11	31	41.6	38.46	45.943	10 G	4.9
29	1992	3	13	19	30	24.1	36.705	45.207	33 N	4.9
30	1998	11	18	11	37	20.4	38.37	45.3	33	4.9
31	1963	12	21	15	18	7	38.7	45.4		4.8
32	1986	7	12	17	0	53.1	38.438	45.164	36	4.8
33	1988	6	4	3	9	1.8	36.954	45.294	45	4.8
34	1991	7	5	13	52	17.7	36.727	45.219	11 D	4.8
35	1993	3	15	15	32	38.3	38.102	45.807	11 D	4.8
36	1930	5	7	13	47	48	37.5	45.5		4.7
37	1930	5	8	15	5	21	37.5	45.5		4.7
38	1930	5	8	23	36	22	37.3	44.8		4.7
39	1931	7	4	21	0	54	37.5	45.5		4.7
40	1931	7	5	17	57	22	39	47.5		4.7
41	1931	12	24	23	0	5	37.3	44.8		4.7
42	1932	6	16	12	9	31	38.7	46.1		4.7
43	1935	5	2	10	13		37	44.5		4.7
44	1937	3	7	19	10	50	38.5	45		4.7
45	1945	7	21	1	33	21	37.5	45		4.7
46	1958	10	26	12	40	31	37.35	44.5		4.7
47	1969	11	28	1	29	28.1	36.7	45.2	16	4.7
48	1980	3	25	3	57	27.6	38.757	45.445	41	4.7
49	1980	10	10	11	9	52.1	38.315	45.77	33	4.7
50	1981	1	4	7	19	45.6	38.443	44.842	33	4.7
51	1986	7	10	18	57	17.2	38.376	45.114	33	4.7
52	1988	1	7	10	59	38.7	38.346	45.476	33	4.7
53	1989	12	3	7	39	6.6	38.315	45.216	10 G	4.7
54	1996	6	18	8	11	5.7	39.16	45.8	51	4.7
55	1999	8	19	4	33	15.9	38.27	46.51	33	4.7
56	2000	2	26	8	18	34.7	37.3	44.81	10	4.7
57	1953	2	1	18	36	35	38.4	45.4		4.6
58	1979	11	21	15	36	2.1	38.373	47.175	10 G	4.6
59	1980	12	29	21	53	4	38.609	45.019	33	4.6
60	1981	5	24	22	7	6.7	38.44	45.226	33	4.6
61	1981	7	23	14	7	13.9	37.314	45.257	33	4.6
62	1984	6	29	19	55	17.1	38.388	45.167	33	4.6
63	1984	10	28	22	3	59.1	37.017	45.297	33	4.6
64	1986	5	11	7	29	13.7	37.038	45.283	33	4.6
65	1986	8	25	1	21	56	36.98	44.916	10 G	4.6
66	1989	12	2	4	51	56.5	38.64	45.373	10 G	4.6
67	1998	11	23	11	11	37.8	38.31	45.08	21	4.6
68	2002	4	7	22	50	30.7	38.4	45.34	33	4.6
69	1914	11	1	21	52		38.4	45.4		4.5
70	1916	10	11	3	5		39.5	45.5		4.5
71	1929	11	5	10	6	4	37.5	45.5		4.5
72	1930	5	8	14	23	32	37.5	45.5		4.5
73	1932	8	10	17	0	27	38.7	46.1		4.5
74	1940	7	11	1	23	29	39.3	47.5		4.5
75	1963	12	31	15	18	8	38.4	45.3		4.5
76	1969	2	5	20	23	52.1	38.1	45.3	N	4.5
77	1969	5	14	0	44	34.1	39.3	45	36	4.5
78	1980	3	25	4	25	23.7	38.702	45.689	58	4.5
79	1980	5	16	19	50	15.5	38.776	45.945	49	4.5
80	1981	9	14	12	3	45.4	37.067	45.276	43	4.5

	Year	month	day	hour	min.	sec.	Lattitude	Longitude	Depth	mb
81	1984	3	25	2	44	58.1	38.488	45.231	33	4.5
82	1986	5	11	7	50	6.7	37.061	45.255	33	4.5
83	1986	7	17	0	12	1.4	38.444	45.397	33	4.5
84	1988	10	16	23	35	24.5	37.964	44.815	33	4.5
85	1993	3	30	22	25	22.1	38.379	45.047	45 *	4.5
86	1999	2	19	18	0	13.3	38.63	44.52	66	4.5
87	2001	6	12	1	46	49.9	38.98	47.2	33	4.5
88	1930	5	9	8	0		37.5	45		4.4
89	1983	8	3	3	6	0.5	38.923	44.78	29	4.4
90	1986	3	30	20	31	5.3	38.984	44.632	33	4.4
91	1992	3	5	3	30	16.5	38.283	45.037	38	4.4
92	1993	3	17	23	59	15	38.219	44.855	26 D	4.4
93	1999	3	9	9	42	4.7	39.12	44.8	67	4.4
94	1973	1	6	15	39	35.7	37.95	46.67	65	4.3
95	1991	7	21	20	16	50.4	36.882	45.118	33 N	4.3
96	1991	11	12	20	35	59.6	39.306	44.936	33 N	4.3
97	2000	10	6	6	20	17.4	36.75	45.03	33	4.3
98	2001	2	1	2	42	56.9	38.75	44.65	33	4.3
99	1931	2	6	5	20		39.5	46.3		4.2
100	1931	2	6	20	28		39.5	46.3		4.2
101	1931	5	21	12	0		39	44.5		4.2
102	1957	5	29	10	2	55	38	45.5		4.2
103	1962	10	14	14	3	45	37.1	44.5		4.2
104	1968	6	9	11	38	22	39.24	46.23	28	4.2
105	1982	11	4	0	4	49.6	38.5	45.578	33	4.2
106	1987	7	22	18	5	8.7	38.063	46.62	20	4.2
107	1995	5	18	0	52	0.6	38.29	45.7	33	4.2
108	2000	2	26	0	43	46	37.15	44.68	10	4.2
109	2000	9	3	19	2	1	37.4	47	33	4.2
110	2001	6	17	11	22	15.9	39.25	45.85	33	4.2
111	1971	2	11	1	41	29	38.3	46.9	48	4.1
112	1988	7	22	16	31	26.4	38.72	44.9	65	4.1
113	1993	5	25	18	38	25.1	37.557	45.961	33 N	4.1
114	1995	2	22	6	29	48.3	38.6	44.8	50	4.1
115	2000	2	26	10	41	36.8	37.12	44.69	10	4.1
116	1931	6	25	21	41		39.3	46.4		4
117	1952	4	18	5	26	3	38.5	45		4
118	1953	6	21	20	25	9	37.9	47.1		4
119	1963	9	2	4	46	43	38.8	44.5		4
120	1965	2	13	0	57	7.7	38.23	45.74	88	4
121	1973	6	27	22	24	48	38.39	46.7	40	4
122	1988	7	22	16	49	34	38.93	45.42	33	4
123	1992	4	26	13	15	51.3	37.841	47.146	33 N	4
124	1996	6	19	7	7	59.8	39.12	45.94	33	3.9
125	2000	8	17	11	49	12.4	38.15	47.4	33	3.9
126	2002	3	5	6	54	34.3	38.17	45.26	33	3.9
127	1975	7	18	23	44	57.7	39.05	45.45	19	3.8
128	1975	11	19	23	21	20	38.36	45.64	39	3.8
129	2002	3	8	14	29	14.7	36.52	44.66	33	3.8
130	1984	8	11	16	33	42.2	38.44	46.7	10 G	3.7
131	2000	9	7	7	32	41.7	38.51	44.95	33	3.7
132	2002	2	26	0	9	31.2	36.52	45.61	33	3.7
133	1962	1	1	18	18	24	38.3	46.6		3.6
134	1962	10	23	12	17	7	38.5	45.3		3.6
135	1989	6	4	10	39	8	38.759	45.315	33 N	3.6
136	1952	5	1	16	13	50	38.5	45.5		3.5
137	1962	6	20	17	56	15	38.4	45.2		3.5
138	1963	8	11	17	22	47	38.4	46		3.5

	Year	month	day	hour	min.	sec.	Lattitude	Longitude	Depth	mb
139	1968	10	1	18	16	0.3	39.19	46.21	10	3.5
140	2000	11	15	18	16	39.2	39.3	46.2	92	3.5
141	1953	3	14	19	9	55	38.4	45.4		3.2
142	2002	4	10	2	35	0	39.1	44.9	33	3.2
143	1962	11	19	9	27	20	38.9	44.5		2.9
144	1962	12	25	20	55	3	38.6	45		2.5

Table 2: Used data

No.	Mb	Mw
1	6.5	7.3
2	5.7	6.1
3	5.5	5.8
4	5.5	5.8
5	5.2	5.4
6	5.2	5.4
7	5.2	5.4
8	5.2	5.4
9	5.2	5.4
10	5	5.2
11	5	5.2
12	5	5.2
13	4.9	5.1
14	4.9	5.1
15	4.8	4.9
16	4.7	4.8
17	4.7	4.8
18	4.7	4.8
19	4.7	4.8
20	4.7	4.8
21	4.7	4.8
22	4.7	4.8
23	4.7	4.8
24	4.6	4.6
25	4.6	4.6
26	4.6	4.6
27	4.6	4.6
28	4.6	4.6
29	4.5	4.5
30	4.5	4.5
31	4.5	4.5
32	4.5	4.5
33	4.5	4.5
34	4.5	4.5
35	4.5	4.5
36	4.5	4.5
37	4.5	4.5
38	4.5	4.5
39	4.3	4.3
40	4.2	4.2
41	4.2	4.2
42	4.2	4.2
43	4.2	4.2
44	4.1	4.1
45	4.1	4.1
46	4	4
47	4	4
48	4	4
49	4	4

4. Sources:

Four sources include 2 line sources and 2 area sources are defined after positioning the earthquakes from database within the area.

4.1. Line source 1 (S1)

This source is almost according to the Tabriz fault, and 21 earthquakes occurred in this source. This source is divided in 4 segments.

Total Length: L1 = 200 km
Minimum distance from site $R1_{min}$ = 6.25 km
Number of earthquakes: 21

Length of each segment: 50 km
Maximum Magnitude in database= 5.5 (m_b)

Segment 1: L_{11} = 50 km R_{11}=75 km
Segment 2: L_{12} = 50 km R_{12}=27 km
Segment 3: L_{13} = 50 km R_{13}=25 km
Segment 4: L_{14} = 50 km R_{14}=75 km

4.2. Line source 2 (S2)

However there is no specified Fault in the East of Tabriz, but 4 earthquakes occurred on a line that can be a blind fault.

Total Length: L1 = 62.5 km
Minimum Distance from site: $R2_{min}$ = 34 km
Distance from site: R2 = 62.5 km
Maximum Magnitude in database= 4.7 (m_b)
Number of earthquakes: 4

4.3. Area source 1 (S3)

Location: north of Marand.

Position: latitude (45.7 ~ 46.2)
Longitude (38.5~38.9)
Total area: A_1 = 967 km^2
Minimum distance from site $R3_{min}$ = 52 km
Distance from site: R3 = 75 km
Maximum Magnitude in database= 6.5 (m_b)
Number of earthquakes: 7

4.4 Area source 2 (S4)

Located in south of Tabriz and Divided in four sub-areas.
Total area A_2 = 2900 km^2
Minimum distance from site $R4_{min}$ = 55 km
Maximum Magnitude in database= 5.7 (m_b)
Number of earthquakes: 15

Specifications of each sub-area:
Sub-area 1: A_{41} = 725 km^2 R_{41}=73 Km
Sub-area 2: A_{42} = 725 km^2 R_{42}=64 Km
Sub-area 3: A_{43} = 725 km^2 R_{43}=89 Km
Sub-area 4: A_{44} = 725 km^2 R_{44}=81 Km

5. Deterministic Seismic Hazard Analysis

5.1. **Step 1: Identification of sources:** The sources and there specifications were described in previous section, there is a summary in Table 3.

5.2. **Step 2: Selection of the controlling earthquake for each source:** The controlling earthquake is defined as the maximum magnitude earthquake that a given source is capable of generating according to the:

1. Database
2. Historical earthquakes
3. Computing by the equation: (Log L=-4.1+ 0.804M_w) for line sources.

These controlling magnitudes are described in table 3 for each source.

Table 3: Sources and there capacity

Source Name	L_{total} (km)	$L_{effective}$ (km)	Database M_{max}	Calculated M_{max}	Selected M_{max}	R_{min} (Km)
S1	200	50	5.8	7.2	7.2	6.25
S2	62.5	60	4.7	7.3	7.3	34
S3	-	-	7.3	-	7.3	52
S4	-	-	6.1	-	6.1	55

Step 3: Selection of the ground motion relationship: PGA is used to describe the ground motion. The Boore, Joyner and Fumal acceleration attenuation expression is used to determine the resulting site PGA from each source's controlling earthquake.

$$\log PGA = b_1 + b_2(M-6) + b_3(M-6)^2 + b_4\sqrt{R^2+h^2} + b_5.\log(\sqrt{R^2+h^2}) + b_6 G_6 + b_7 G_C$$

5.3. **Step 4: Computation of design ground motion parameter:** The controlling earthquake and associated site-to-source distance determined in *table 3*. These data plugged into the ground motion expressions that explained in step 3 to compute the resulting site PGA.

S1: Line Source 1:

b_1=-0.038	***b_2=0.216***	***b_3=0.0***	***b_4=0.0***	***b_5=-0.777***	***b_6=0.158***
b_7=0.254	***h=5.48***	***G_B=0.0***	***G_C=0.0***	***M_1=7.2***	***R_1=6.25***

$$\log PGA_1 = -0.038 + 0.216(7.2-6) - 0.777.\log(\sqrt{6.25^2 + 5.48^2})$$
$$\log PGA_1 = -0.49$$
$$PGA_1 = 10^{-0.49}$$
$$PGA_1 = 0.32g$$

S2: Line source 2:

b_1=-0.038	***b_2=0.216***	***b_3=0.0***	***b_4=0.0***	***b_5=-0.777***	***b_6=0.158***
b_7=0.254	***h=5.48***	***G_B=0.0***	***G_C=0.0***	***M_1=7.3***	***R_1=34***

$$\log PGA_2 = -0.038 + 0.216(7.3-6) - 0.777.\log(\sqrt{34^2 + 5.48^2})$$
$$\log PGA_2 = -0.95$$
$$PGA_2 = 10^{-0.95}$$
$$PGA_2 = 0.11g$$

S3: Area Source 1

b_1=-0.038	***b_2=0.216***	***b_3=0.0***	***b_4=0.0***	***b_5=-0.777***	***b_6=0.158***
b_7=0.254	***h=5.48***	***G_B=0.0***	***G_C=0.0***	***M_1=7.3***	***R_1=52***

$$\log PGA_3 = -0.038 + 0.216(7.3-6) - 0.777.\log(\sqrt{52^2 + 5.48^2})$$
$$\log PGA_3 = -1.09$$
$$PGA_3 = 10^{-1.09}$$
$$PGA_3 = 0.08g$$

S4: Area Source 2

b_1=-0.038	***b_2=0.216***	***b_3=0.0***	***b_4=0.0***	***b_5=-0.777***	***b_6=0.158***
b_7=0.254	***h=5.48***	***G_B=0.0***	***G_C=0.0***	***M_1=6.1***	***R_1=55***

$$\log PGA_4 = -0.038 + 0.216(6.5-6) - 0.777.\log(\sqrt{55^2 + 5.48^2})$$
$$\log PGA_4 = -1.28$$
$$PGA_4 = 10^{-1.28}$$
$$PGA_4 = 0.05g$$

The largest of the resulting PGA using BJF relationship is from the Line source's controlling earthquake. Therefore the design ground motion parameter is PGA = 0.32g.

6. Probabilistic Seismic Hazard Analysis

For each source we will do the probabilistic hazard analysis. For line source 1 (S1) there is a detailed description.

6.1. LINE SOURCE 1 (S1)

6.1.1 Step 1: Identification of sources: The source and its specifications were described in section 4. A brief description is below.

L=200 km R_{11}=75 km R_{12}=27 km R_{13}=25 km R_{14}=75 km

M_0=4 M_{max}=7.5 Delta (L) =50 km n=4

f(R) delta R = 1/4

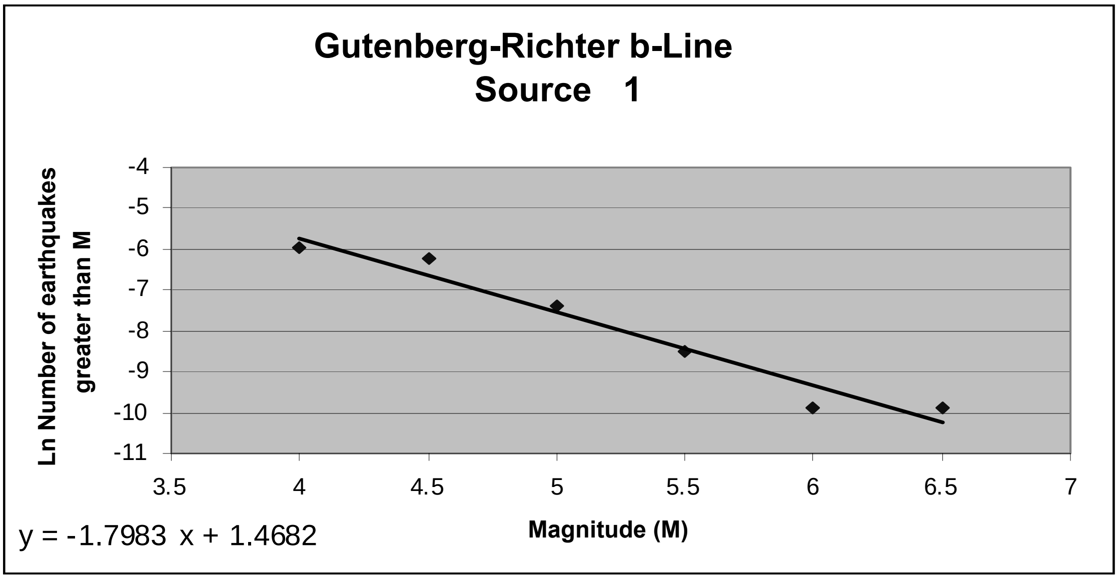
6.1.2 Step 2: Recurrence relationship, Magnitude distribution and average rate of occurrence:

Earthquake recurrence is expressed by Gutenberg-Richter b-line in natural log. Table 4 shows a summary of calculation and chart 1 is the b-line and the result of regression.

Table 4: summary of b-line calculation

Gutenberg-Richter b-line for Source 1 (Line Source)				
Magnitude (mb)	Sum	Sum/Year	Per Length	Ln (N)
M>4.0	49	0.505154639	0.002525773	-5.981208047
M>4.5	38	0.391752577	0.001958763	-6.235442185
M>5.0	12	0.12371134	0.000618557	-7.388121695
M>5.5	4	0.041237113	0.000206186	-8.486733984
M>6.0	1	0.010309278	5.15464E-05	-9.873028345
M>6.5	1	0.010309278	5.15464E-05	-9.873028345

Chart 1: b-line for source 1



Gutenberg-Richter relationship: Ln N = α – β M

Ln N = 1.4682 -1.7983 M

$\alpha_1 = 1.4682$

$\beta_1 = 1.7983$

Magnitude Distribution:

Magnitude limits in evaluating the seismic hazard of the line source:

$m_0 = 4$ $M_{max} = 7.5$

Magnitude probability density function:

$$f_1(M) = c_1.\beta_1.e^{-\beta_1(M-m_0)}$$

$$c_1 = \frac{1}{1-e^{-\beta_1(m_{\max}-m_0)}} = \frac{1}{1-e^{-1.7983(7.5-4)}} = 1.002$$

$$f_1(M) = 1.002 * 1.7983 * e^{-1.7983(M-4)}$$

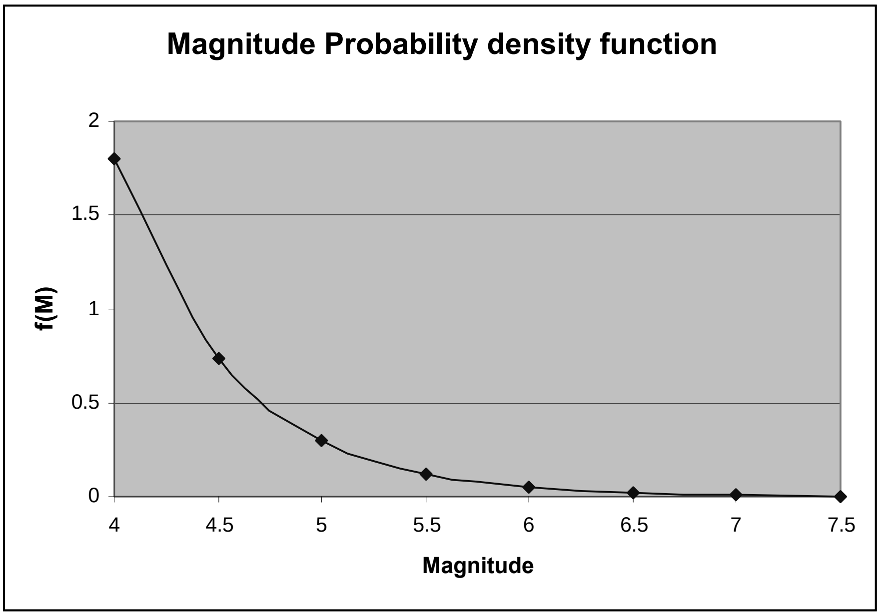
$$f_1(M) = 1.802 * e^{-1.7983(M-4)}$$

Note: because we use unique database to calculate the recurrence relationship, then the β will be general and will be equal in all sources, then this section is uniform and the results (Magnitude probability density function) will be used in other source's hazard calculation.

Table 5: Density function calculation

Magnitude Probability Density function	
M	**f(M)**
4.0	1.802
4.5	0.733261534
5.0	0.298375404
5.5	0.121413544
6.0	0.04940504
6.5	0.020103671
7.0	0.008180493
7.5	0.003328769

Chart 2: MPDS diagram



The magnitude range is divided into subintervals with increments of 0.5 M.

Table 6: Magnitude subinterval ranges

No. of Interval	subinterval range	M_{mid}
1	$4.0 < M < 4.5$	*4.25*
2	$4.5 < M < 5.0$	*4.75*
3	$5.0 < M < 5.5$	*5.25*
4	$5.5 < M < 6.0$	*5.75*
5	$6.0 < M < 6.5$	*6.25*
6	$6.5 < M < 7.0$	*6.75*
7	$7.0 < M < 7.5$	*7.25*

To calculate the probability that magnitude of a given earthquake falls in a given subinterval, we should product the magnitude probability density function at the center value of the subinterval and the interval increment.

$P\,(M_{mid1} - \Delta M/2 < M < M_{mid1} - \Delta M/2) = f1(M_{mid1}).\ \Delta M$

$$P\,(4.0 < M < 4.5 \mid EQ) = f_1(M_{mid\,0}) * \Delta M$$
$$= f_1(4.25) * 0.5$$
$$= 1.802 * e^{-1.7983(4.25-4)} * 0.5$$
$$= 0.575$$

P (4.0 < M < 4.5 | EQ) = 0.575
P (4.5 < M < 5.0 | EQ) = 0.234
P (5.0 < M < 5.5 | EQ) = 0.095
P (5.5 < M < 6.0 | EQ) = 0.039
P (6.0 < M < 6.5 | EQ) = 0.016
P (6.5 < M < 7.0 | EQ) = 0.006
P (7.0 < M < 7.5 | EQ) = 0.003

Average occurrence Rate:

$\nu_1 = N_1(4) - N_1(7.5).L$

➔ $N_1(4) = e^{(1.4682-1.7983*4)} = 0.0033$
$N_1(7.5) = e^{(1.4682-1.7983*7.5)} = 0.000006$
$L = 200$
➔ $\nu_1 = (0.0033 - 0.000006) * 200 = 0.659$
$\nu_1 = 0.659$

6.1.3 Step 3: Ground motion estimation: The peak ground acceleration (PGA) is estimated through the Boore, Joyner and Fumal expression with the coefficients corresponding to the largest horizontal component of the PGA.

Mean/Medial Log(PGA):

$$\log PGA = b_1 + b_2(M-6) + b_3(M-6)^2 + b_4\sqrt{R^2+h^2} + b_5.\log(\sqrt{R^2+h^2}) + b_6G_6 + b_7G_C$$

$$\Rightarrow \log PGA = -0.038 + 0.216(M_{mid} - 6) - 0.777.\log(\sqrt{R^2 + 5.48^2})$$

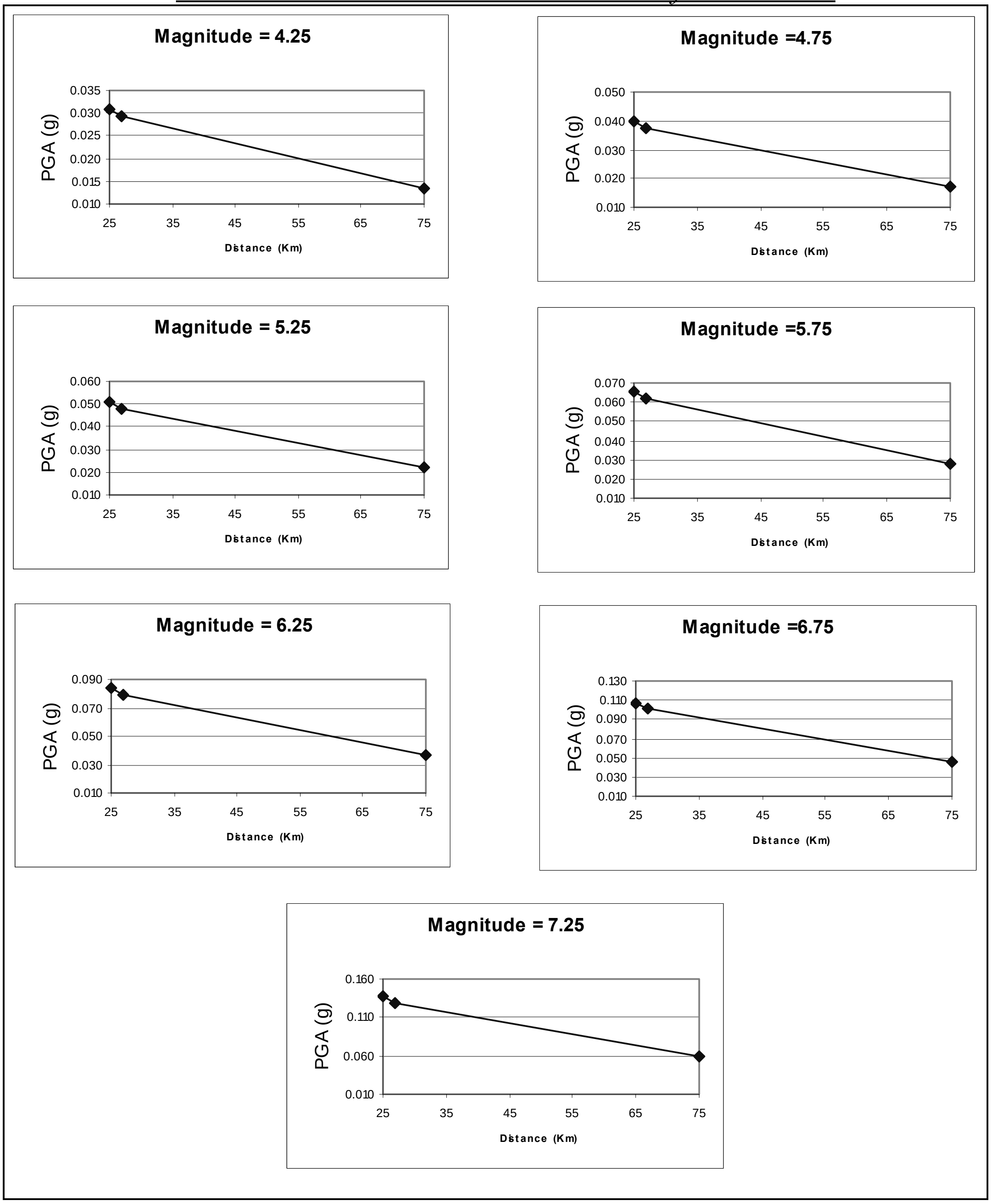
Median PGA:

$$PGA = 10^{\log PGA}$$

Table 7: PGA estimation through attenuation function for S1

M (Mmid)	R = 25 Km		R = 27 Km		R = 75 Km	
	Log (PGA)	PGA (g)	Log (PGA)	PGA (g)	Log (PGA)	PGA (g)
4.25	-1.510	0.031	-1.535	0.029	-1.874	0.013
4.75	-1.402	0.040	-1.427	0.037	-1.766	0.017
5.25	-1.294	0.051	-1.319	0.048	-1.658	0.022
5.75	-1.186	0.065	-1.211	0.062	-1.550	0.028
6.25	-1.078	0.084	-1.103	0.079	-1.442	0.036
6.75	-0.970	0.107	-0.995	0.101	-1.334	0.046
7.25	-0.862	0.137	-0.887	0.130	-1.226	0.059

Chart 3: PGA attenuation estimation for source 1



And now we will examine the accelerations range from 0.05g to 0.65g by an increment of 0.05g:

$$acc_0 = 0.05g$$
$$acc_1 = 0.10g$$
$$acc_2 = 0.15g$$
$$acc_3 = 0.20g$$
.
.
.
$$acc_{12} = 0.65g$$

Standard normal distribution forecasting model will be used in this section to determine the probability that the PGA will exceed an acceleration of interest (acc_i), given the occurrence of an earthquake of magnitude M and at distance R.
The *standard error (σ)* of Boor, Joyner and Fumal attenuation relationship is 0.205 when the constants derived for estimating the peak acceleration for the larger of two horizontal components.

$$P(PGA > acc \mid EQ : R, M) = 1 - \Phi\left(\frac{\log(acc) - \log(PGA)}{\sigma_{\log PGA}}\right)$$

The above equation explains the probability that PGA will exceed an acceleration of interest, given the occurrence of an earthquake of magnitude M and at distance R.
For example:
acc > 0.10g R = 25 Km M=6.25

$$P(PGA > 0.10 \mid EQ : R = 25, M = 6.25) = 1 - \Phi\left(\frac{\log(0.10) - \log(0.084)}{0.205}\right)$$

$$= 1 - \Phi\left(\frac{-1 + 1.0756}{0.205}\right)$$

$$= 1 - \Phi(0.369)$$

$$\Phi(0.369) = 0.6439 \Rightarrow P(PGA > 0.10 \mid EQ : R = 25, M = 6.25) = 0.356$$

The summary of calculations is showed in the following tables. Because of that R=75Km is repeated twice, we will omit the similar calculations but in the SUM column the coefficient of (R=75km) is 2.

Table 8: Probability of Exceeding a given EQ from (acc)

P (PGA > 0.05 | EQ : R,M) acc = 0.05

M (Mmid)	R =	25	R =	27	R =	75
	PGA (g)	P( )	PGA (g)	P ( )	PGA (g)	P ( )
4.25	0.031	1.54E-01	0.029	1.27E-01	0.013	2.60E-03
4.75	0.040	3.11E-01	0.037	2.69E-01	0.017	1.17E-02
5.25	0.051	5.13E-01	0.048	4.65E-01	0.022	4.09E-02
5.75	0.065	7.12E-01	0.062	6.70E-01	0.028	1.12E-01
6.25	0.084	8.62E-01	0.079	8.33E-01	0.036	2.46E-01
6.75	0.107	9.47E-01	0.101	9.32E-01	0.046	4.36E-01
7.25	0.137	9.84E-01	0.130	9.78E-01	0.059	6.43E-01

P (PGA > 0.10 | EQ : R,M) acc = 0.1

M (Mmid)	R =	25	R =	27	R =	75
	PGA (g)	P( )	PGA (g)	P ( )	PGA (g)	P ( )
4.25	0.031	6.42E-03	0.029	4.53E-03	0.013	1.01E-05
4.75	0.040	2.49E-02	0.037	1.86E-02	0.017	9.36E-05
5.25	0.051	7.57E-02	0.048	5.99E-02	0.022	6.66E-04
5.75	0.065	1.82E-01	0.062	1.52E-01	0.028	3.66E-03
6.25	0.084	3.52E-01	0.079	3.08E-01	0.036	1.56E-02
6.75	0.107	5.58E-01	0.101	5.10E-01	0.046	5.17E-02
7.25	0.137	7.49E-01	0.130	7.09E-01	0.059	1.35E-01

P (PGA > 0.15 | EQ : R,M) acc = 0.15

M (Mmid)	R =	25	R =	27	R =	75
	PGA (g)	P( )	PGA (g)	P ( )	PGA (g)	P ( )
4.25	0.031	4.08E-04	0.029	2.62E-04	0.013	1.52E-07
4.75	0.040	2.40E-03	0.037	1.63E-03	0.017	2.17E-06
5.25	0.051	1.09E-02	0.048	7.87E-03	0.022	2.37E-05
5.75	0.065	3.86E-02	0.062	2.95E-02	0.028	1.99E-04
6.25	0.084	1.07E-01	0.079	8.67E-02	0.036	1.29E-03
6.75	0.107	2.38E-01	0.101	2.02E-01	0.046	6.43E-03
7.25	0.137	4.26E-01	0.130	3.79E-01	0.059	2.50E-02

P (PGA > 0.20 | EQ : R,M) acc = 0.2

M (Mmid)	R =	25	R =	27	R =	75
	PGA (g)	P( )	PGA (g)	P ( )	PGA (g)	P ( )
4.25	0.031	3.80E-05	0.029	2.27E-05	0.013	5.01E-09
4.75	0.040	3.02E-04	0.037	1.92E-04	0.017	9.76E-08
5.25	0.051	1.85E-03	0.048	1.25E-03	0.022	1.45E-06
5.75	0.065	8.74E-03	0.062	6.25E-03	0.028	1.66E-05
6.25	0.084	3.22E-02	0.079	2.44E-02	0.036	1.45E-04
6.75	0.107	9.30E-02	0.101	7.44E-02	0.046	9.78E-04
7.25	0.137	2.13E-01	0.130	1.80E-01	0.059	5.08E-03

P (PGA > 0.25 | EQ : R,M) acc = 0.25

M (Mmid)	R =	25	R =	27	R =	75
	PGA (g)	P( )	PGA (g)	P ( )	PGA (g)	P ( )
4.25	0.031	4.73E-06	0.029	2.67E-06	0.013	2.77E-10
4.75	0.040	4.76E-05	0.037	2.86E-05	0.017	6.88E-09
5.25	0.051	3.68E-04	0.048	2.35E-04	0.022	1.30E-07
5.75	0.065	2.19E-03	0.062	1.49E-03	0.028	1.89E-06
6.25	0.084	1.01E-02	0.079	7.27E-03	0.036	2.10E-05
6.75	0.107	3.63E-02	0.101	2.76E-02	0.046	1.79E-04
7.25	0.137	1.02E-01	0.130	8.23E-02	0.059	1.17E-03

P (PGA > 0.30 | EQ : R,M) acc = 0.3

M (Mmid)	R =	25	R =	27	R =	75
	PGA (g)	P( )	PGA (g)	P ( )	PGA (g)	P ( )
4.25	0.031	7.34E-07	0.029	3.97E-07	0.013	2.21E-11
4.75	0.040	8.98E-06	0.037	5.17E-06	0.017	6.70E-10
5.25	0.051	8.43E-05	0.048	5.15E-05	0.022	1.55E-08
5.75	0.065	6.08E-04	0.062	3.95E-04	0.028	2.73E-07
6.25	0.084	3.38E-03	0.079	2.33E-03	0.036	3.69E-06
6.75	0.107	1.46E-02	0.101	1.06E-02	0.046	3.82E-05
7.25	0.137	4.90E-02	0.130	3.79E-02	0.059	3.03E-04

P (PGA > 0.35 | EQ : R,M) acc = 0.35

M (Mmid)	R =	25	R =	27	R =	75
	PGA (g)	P( )	PGA (g)	P ( )	PGA (g)	P ( )
4.25	0.031	1.36E-07	0.029	7.08E-08	0.013	2.33E-12
4.75	0.040	1.96E-06	0.037	1.09E-06	0.017	8.35E-11
5.25	0.051	2.17E-05	0.048	1.28E-05	0.022	2.28E-09
5.75	0.065	1.84E-04	0.062	1.15E-04	0.028	4.76E-08
6.25	0.084	1.20E-03	0.079	7.99E-04	0.036	7.59E-07
6.75	0.107	6.07E-03	0.101	4.28E-03	0.046	9.25E-06
7.25	0.137	2.38E-02	0.130	1.77E-02	0.059	8.65E-05

P (PGA > 0.40 | EQ : R,M) acc = 0.4

M (Mmid)	R =	25	R =	27	R =	75
	PGA (g)	P( )	PGA (g)	P ( )	PGA (g)	P ( )
4.25	0.031	2.90E-08	0.029	1.46E-08	0.013	3.05E-13
4.75	0.040	4.84E-07	0.037	2.59E-07	0.017	1.26E-11
5.25	0.051	6.17E-06	0.048	3.52E-06	0.022	3.99E-10
5.75	0.065	6.04E-05	0.062	3.66E-05	0.028	9.63E-09
6.25	0.084	4.53E-04	0.079	2.92E-04	0.036	1.77E-07
6.75	0.107	2.63E-03	0.101	1.79E-03	0.046	2.50E-06
7.25	0.137	1.18E-02	0.130	8.53E-03	0.059	2.69E-05

P (PGA > 0.45 | EQ : R,M) acc = 0.45

M (Mmid)	R =	25	R =	27	R =	75
	PGA (g)	P( )	PGA (g)	P ( )	PGA (g)	P ( )
4.25	0.031	6.96E-09	0.029	3.40E-09	0.013	4.74E-14
4.75	0.040	1.32E-07	0.037	6.86E-08	0.017	2.24E-12
5.25	0.051	1.91E-06	0.048	1.06E-06	0.022	8.05E-11
5.75	0.065	2.12E-05	0.062	1.25E-05	0.028	2.21E-09
6.25	0.084	1.80E-04	0.079	1.13E-04	0.036	4.62E-08
6.75	0.107	1.18E-03	0.101	7.84E-04	0.046	7.38E-07
7.25	0.137	5.97E-03	0.130	4.21E-03	0.059	9.02E-06

P (PGA > 0.50 | EQ : R,M) acc = 0.5

M (Mmid)	R =	25	R =	27	R =	75
	PGA (g)	P( )	PGA (g)	P ( )	PGA (g)	P ( )
4.25	0.031	1.85E-09	0.029	8.79E-10	0.013	8.55E-15
4.75	0.040	3.92E-08	0.037	1.99E-08	0.017	4.52E-13
5.25	0.051	6.36E-07	0.048	3.43E-07	0.022	1.82E-11
5.75	0.065	7.90E-06	0.062	4.53E-06	0.028	5.61E-10
6.25	0.084	7.51E-05	0.079	4.58E-05	0.036	1.32E-08
6.75	0.107	5.50E-04	0.101	3.56E-04	0.046	2.36E-07
7.25	0.137	3.10E-03	0.130	2.13E-03	0.059	3.23E-06

P (PGA > 0.55 | EQ : R,M) acc = 0.55

M (Mmid)	R =	25	R =	27	R =	75
	PGA (g)	P( )	PGA (g)	P ( )	PGA (g)	P ( )
4.25	0.031	5.33E-10	0.029	2.48E-10	0.013	1.78E-15
4.75	0.040	1.25E-08	0.037	6.21E-09	0.017	1.02E-13
5.25	0.051	2.26E-07	0.048	1.19E-07	0.022	4.57E-12
5.75	0.065	3.10E-06	0.062	1.74E-06	0.028	1.56E-10
6.25	0.084	3.27E-05	0.079	1.95E-05	0.036	4.05E-09
6.75	0.107	2.64E-04	0.101	1.67E-04	0.046	8.05E-08
7.25	0.137	1.65E-03	0.130	1.11E-03	0.059	1.22E-06

P (PGA > 0.60 | EQ : R,M) acc = 0.6

M (Mmid)	R =	25	R =	27	R =	75
	PGA (g)	P( )	PGA (g)	P ( )	PGA (g)	P ( )
4.25	0.031	1.65E-10	0.029	7.53E-11	0.013	0.00E+00
4.75	0.040	4.28E-09	0.037	2.07E-09	0.017	2.53E-14
5.25	0.051	8.47E-08	0.048	4.36E-08	0.022	1.25E-12
5.75	0.065	1.28E-06	0.062	7.01E-07	0.028	4.67E-11
6.25	0.084	1.48E-05	0.079	8.62E-06	0.036	1.34E-09
6.75	0.107	1.31E-04	0.101	8.12E-05	0.046	2.92E-08
7.25	0.137	8.94E-04	0.130	5.88E-04	0.059	4.86E-07

P (PGA > 0.65 | EQ : R,M) acc = 0.65

M (Mmid)	R =	25	R =	27	R =	75
	PGA (g)	P( )	PGA (g)	P ( )	PGA (g)	P ( )
4.25	0.031	5.48E-11	0.029	2.44E-11	0.013	0.00E+00
4.75	0.040	1.55E-09	0.037	7.35E-10	0.017	6.77E-15
5.25	0.051	3.34E-08	0.048	1.69E-08	0.022	3.66E-13
5.75	0.065	5.49E-07	0.062	2.95E-07	0.028	1.50E-11
6.25	0.084	6.92E-06	0.079	3.96E-06	0.036	4.68E-10
6.75	0.107	6.68E-05	0.101	4.06E-05	0.046	1.11E-08
7.25	0.137	4.96E-04	0.130	3.20E-04	0.059	2.02E-07

6.1.4 <u>Step 4:</u> Development of the hazard curve: A Poisson forecasting model is employed to account for the probability that an earthquake occurs.

$$P(PGA > acc \mid EQ) = \sum_R \sum_M P(PGA > acc \mid EQ : M, R).f(M).\Delta M.\Delta R$$

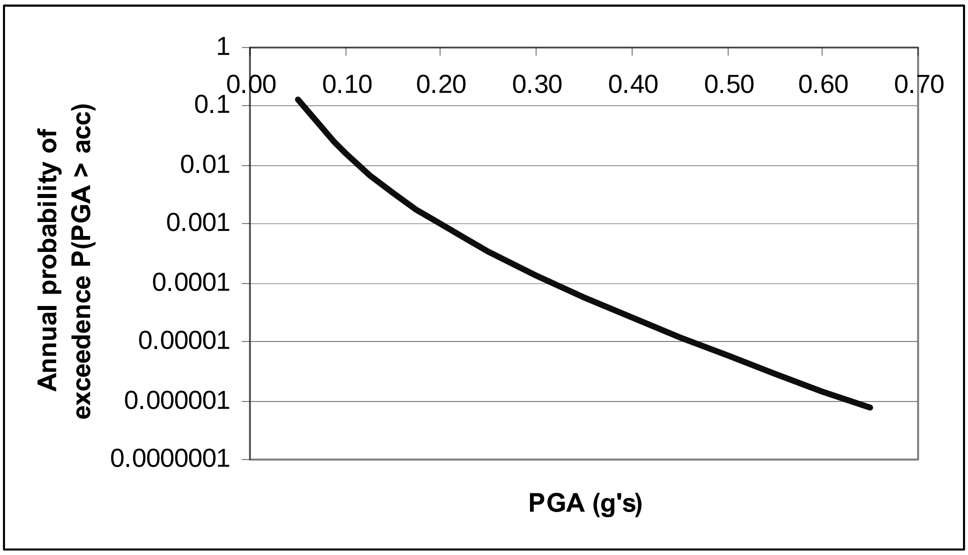
$$P(PGA > acc) = 1 - e^{-\nu P}$$

$$approx : P(PGA > acc) = \nu P$$

Table 9: Probabilities of exceeding

acc	P (PGA > acc | EQ)	P (PGA > acc)	P (PGA > acc) approx
0.05	1.33E-01	1.19E-01	0.1272
0.10	1.65E-02	1.57E-02	0.0158
0.15	3.55E-03	3.40E-03	0.0034
0.20	1.04E-03	9.98E-04	0.0010
0.25	3.62E-04	3.47E-04	0.0003
0.30	1.40E-04	1.35E-04	0.0001
0.35	5.88E-05	5.64E-05	5.64E-05
0.40	2.61E-05	2.50E-05	2.50E-05
0.45	1.22E-05	1.17E-05	1.17E-05
0.50	5.92E-06	5.68E-06	5.68E-06
0.55	2.98E-06	2.86E-06	2.86E-06
0.60	1.55E-06	1.48E-06	1.48E-06
0.65	8.27E-07	7.93E-07	7.93E-07

Chart 4: Hazard curve for Line Source 1 (S1) using Boore, Joyner & Fumal attenuation expression



6.2. LINE SOURCE 2 (S2)

6.2.1 **Step 1:** **Identification of sources:** The source and its specifications were described in section 4. A brief description is below.

L=62.5 km R_2=62.5 km

M_0=4 M_{max}=7 Delta (L) =62.5 km n=1

f(R) delta R = 1

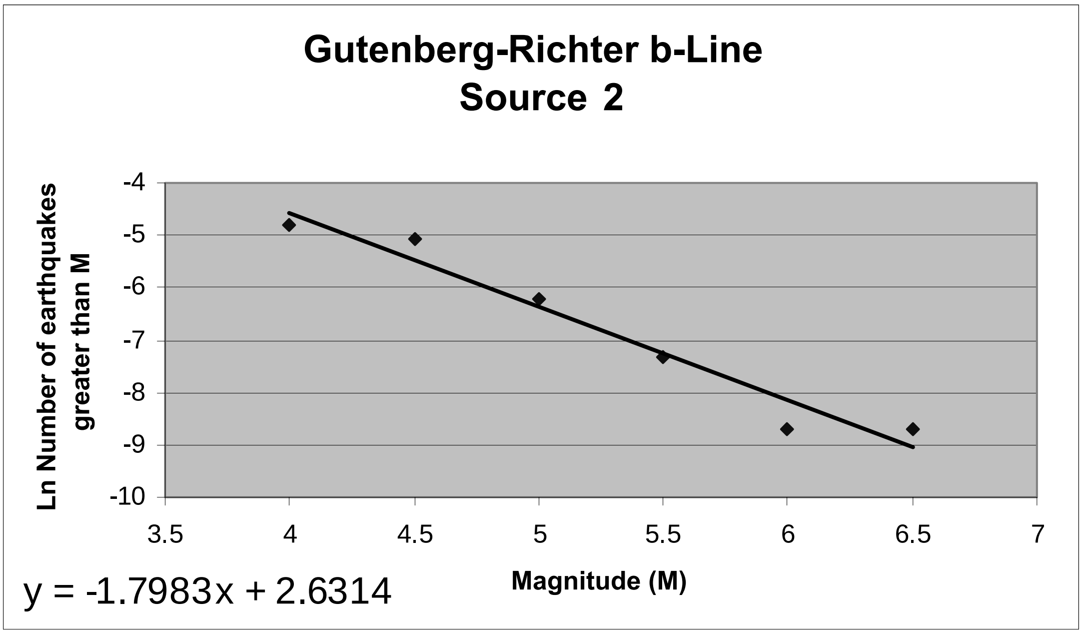
6.2.2 **Step 2:** **Recurrence relationship, Magnitude distribution and average rate of occurrence:**

All the above, calculated in section 6.1 for Line source 1 and just the calculation table and the b-line chart are presented.

Table 10: summary of b-line calculation

Gutenberg-Richter b-line for Source 2 (Line Source)				
Magnitude (mb)	**Sum**	**Sum/Year**	**Per Length**	**Ln (N)**
M>4	49	0.505154639	0.008082474	-4.818057237
M>4.5	38	0.391752577	0.006268041	-5.072291376
M>5	12	0.12371134	0.001979381	-6.224970885
M>5.5	4	0.041237113	0.000659794	-7.323583174
M>6	1	0.010309278	0.000164948	-8.709877535
M>6.5	1	0.010309278	0.000164948	-8.709877535

Chart 5: b-line for source 2



Gutenberg-Richter relationship: Ln N = α – β M

Ln N = 2.6314 -1.7983 M

$\alpha_1 = 2.6314$
$\beta_1 = 1.7983$

Magnitude Distribution:
Magnitude limits in evaluating the seismic hazard of the line source:

$m_0 = 4$ $M_{max} = 7$

Magnitude probability density function:

$$f_2(M) = c_2.\beta.e^{-\beta(M-m_0)}$$

$$c_2 = \frac{1}{1-e^{-\beta(m_{\max}-m_0)}} = \frac{1}{1-e^{-1.7983(7-4)}} = 1.005$$

$$f_2(M) = 1.005 * 1.7983 * e^{-1.7983(M-4)}$$

$$f_2(M) = 1.807 * e^{-1.7983(M-4)}$$

Average occurrence Rate:

$\nu_2 = N_2(4) - N_2(7).L$

➔ $N_1(4) = e^{(2.6314-1.7983*4)} = 0.0104$
$N_1(7) = e^{(2.6314-1.7983*7)} = 0.0000474$
L = 62.5 Km
➔ $\nu_1 = (0.0104 - 0.0000474) * 62.5 = 0.650$
$\nu_1 = 0.650$

6.2.3 Step 3: Ground motion estimation:

Table 11: Probability of Exceeding a given EQ from (acc) for S2

P (PGA > 0.05 | EQ : R,M)

M (Mmid)	f(m).dm	R =		62.5
		Log (PGA)	PGA (g)	P( )
4.25	0.576	-1.813	0.015	6.28E-03
4.75	0.235	-1.705	0.020	2.45E-02
5.25	0.095	-1.597	0.025	7.46E-02
5.75	0.039	-1.489	0.032	1.80E-01
6.25	0.016	-1.381	0.042	3.49E-01
6.75	0.006	-1.273	0.053	5.55E-01

P (PGA > 0.10 | EQ : R,M)

M (Mmid)	f(m).dm	R =		62.5
		Log (PGA)	PGA (g)	P( )
4.25	0.576	-1.813	0.015	3.68E-05
4.75	0.235	-1.705	0.020	2.94E-04
5.25	0.095	-1.597	0.025	1.80E-03
5.75	0.039	-1.489	0.032	8.57E-03
6.25	0.016	-1.381	0.042	3.17E-02
6.75	0.006	-1.273	0.053	9.17E-02

P (PGA > 0.15 | EQ : R,M)

M (Mmid)	f(m).dm	R =		62.5
		Log (PGA)	PGA (g)	P( )
4.25	0.576	-1.813	0.015	7.07E-07
4.75	0.235	-1.705	0.020	8.68E-06
5.25	0.095	-1.597	0.025	8.18E-05
5.75	0.039	-1.489	0.032	5.92E-04
6.25	0.016	-1.381	0.042	3.30E-03
6.75	0.006	-1.273	0.053	1.43E-02

P (PGA > 0.2 | EQ : R,M)

M (Mmid)	f(m).dm	R =		62.5
		Log (PGA)	PGA (g)	P( )
4.25	0.576	-1.813	0.015	2.78E-08
4.75	0.235	-1.705	0.020	4.66E-07
5.25	0.095	-1.597	0.025	5.96E-06
5.75	0.039	-1.489	0.032	5.85E-05
6.25	0.016	-1.381	0.042	4.41E-04
6.75	0.006	-1.273	0.053	2.57E-03

P (PGA > 0.25 | EQ : R,M)

M (Mmid)	f(m).dm	R =		62.5
		Log (PGA)	PGA (g)	P( )
4.25	0.576	-1.813	0.015	1.76E-09
4.75	0.235	-1.705	0.020	3.76E-08
5.25	0.095	-1.597	0.025	6.12E-07
5.75	0.039	-1.489	0.032	7.63E-06
6.25	0.016	-1.381	0.042	7.29E-05
6.75	0.006	-1.273	0.053	5.35E-04

P (PGA > 0.30 | EQ : R,M)

M (Mmid)	f(m).dm	R =		62.5
		Log (PGA)	PGA (g)	P( )
4.25	0.576	-1.813	0.015	1.58E-10
4.75	0.235	-1.705	0.020	4.10E-09
5.25	0.095	-1.597	0.025	8.13E-08
5.75	0.039	-1.489	0.032	1.23E-06
6.25	0.016	-1.381	0.042	1.43E-05
6.75	0.006	-1.273	0.053	1.27E-04

P (PGA > 0.35 | EQ : R,M)

M (Mmid)	f(m).dm	R =		62.5
		Log (PGA)	PGA (g)	P( )
4.25	0.576	-1.813	0.015	1.83E-11
4.75	0.235	-1.705	0.020	5.61E-10
5.25	0.095	-1.597	0.025	1.32E-08
5.75	0.039	-1.489	0.032	2.36E-07
6.25	0.016	-1.381	0.042	3.23E-06
6.75	0.006	-1.273	0.053	3.39E-05

P (PGA > 0.40 | EQ : R,M)

M (Mmid)	f(m).dm	R =		62.5
		Log (PGA)	PGA (g)	P( )
4.25	0.576	-1.813	0.015	2.59E-12
4.75	0.235	-1.705	0.020	9.23E-11
5.25	0.095	-1.597	0.025	2.50E-09
5.75	0.039	-1.489	0.032	5.18E-08
6.25	0.016	-1.381	0.042	8.19E-07
6.75	0.006	-1.273	0.053	9.91E-06

P (PGA > 0.45 | EQ : R,M)

M (Mmid)	f(m).dm	R =		62.5
		Log (PGA)	PGA (g)	P( )
4.25	0.576	-1.813	0.015	4.35E-13
4.75	0.235	-1.705	0.020	1.76E-11
5.25	0.095	-1.597	0.025	5.42E-10
5.75	0.039	-1.489	0.032	1.28E-08
6.25	0.016	-1.381	0.042	2.29E-07
6.75	0.006	-1.273	0.053	3.14E-06

P (PGA > 0.50 | EQ : R,M)

M (Mmid)	f(m).dm	R =		62.5
		Log (PGA)	PGA (g)	P( )
4.25	0.576	-1.813	0.015	8.35E-14
4.75	0.235	-1.705	0.020	3.79E-12
5.25	0.095	-1.597	0.025	1.31E-10
5.75	0.039	-1.489	0.032	3.46E-09
6.25	0.016	-1.381	0.042	6.96E-08
6.75	0.006	-1.273	0.053	1.07E-06

P (PGA > 0.55 | EQ : R,M)

M (Mmid)	f(m).dm	R =		62.5
		Log (PGA)	PGA (g)	P( )
4.25	0.576	-1.813	0.015	1.80E-14
4.75	0.235	-1.705	0.020	9.07E-13
5.25	0.095	-1.597	0.025	3.48E-11
5.75	0.039	-1.489	0.032	1.02E-09
6.25	0.016	-1.381	0.042	2.27E-08
6.75	0.006	-1.273	0.053	3.88E-07

P (PGA > 0.60 | EQ : R,M)

M (Mmid)	f(m).dm	R =		62.5
		Log (PGA)	PGA (g)	P( )
4.25	0.576	-1.813	0.015	4.33E-15
4.75	0.235	-1.705	0.020	2.37E-13
5.25	0.095	-1.597	0.025	1.00E-11
5.75	0.039	-1.489	0.032	3.22E-10
6.25	0.016	-1.381	0.042	7.91E-09
6.75	0.006	-1.273	0.053	1.48E-07

P (PGA > 0.65 | EQ : R,M)

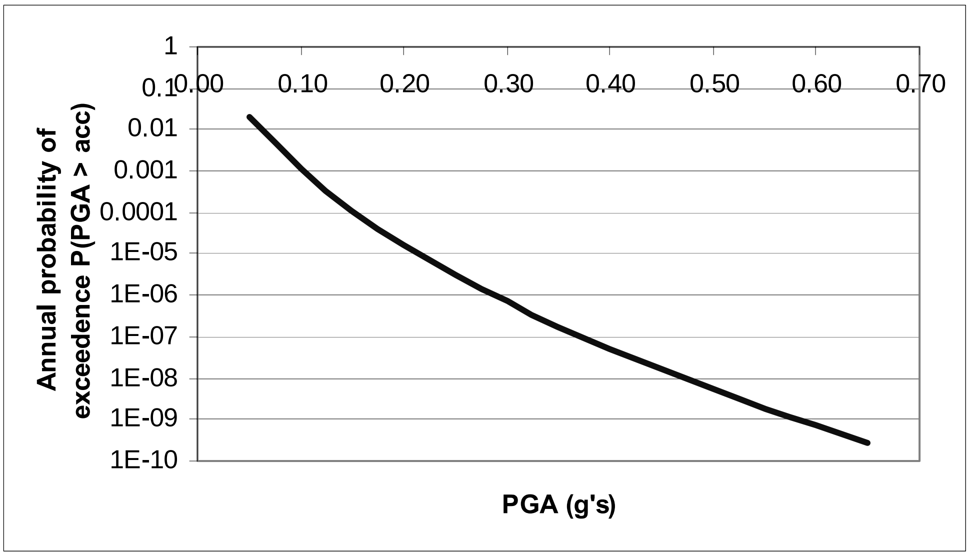
M (Mmid)	f(m).dm	R =		62.5
		Log (PGA)	PGA (g)	P( )
4.25	0.576	-1.813	0.015	0.00E+00
4.75	0.235	-1.705	0.020	6.72E-14
5.25	0.095	-1.597	0.025	3.09E-12
5.75	0.039	-1.489	0.032	1.09E-10
6.25	0.016	-1.381	0.042	2.91E-09
6.75	0.006	-1.273	0.053	5.94E-08

6.2.4 Step 4: Development of the hazard curve:

Table 12: Probabilities of exceeding

acc	P (PGA > acc | EQ)	P (PGA > acc)	P (PGA > acc) approx
0.05	**3.25E-02**	**2.09E-02**	**2.12E-02**
0.10	**1.68E-03**	**1.09E-03**	**1.10E-03**
0.15	**1.77E-04**	**1.15E-04**	**1.15E-04**
0.20	**2.64E-05**	**1.72E-05**	**1.72E-05**
0.25	**4.96E-06**	**3.22E-06**	**3.22E-06**
0.30	**1.10E-06**	**7.16E-07**	**7.16E-07**
0.35	**2.79E-07**	**1.82E-07**	**1.82E-07**
0.40	**7.89E-08**	**5.13E-08**	**5.13E-08**
0.45	**2.44E-08**	**1.59E-08**	**1.59E-08**
0.50	**8.13E-09**	**5.29E-09**	**5.29E-09**
0.55	**2.90E-09**	**1.88E-09**	**1.88E-09**
0.60	**1.09E-09**	**7.09E-10**	**7.09E-10**
0.65	**4.33E-10**	**2.81E-10**	**2.81E-10**

Chart 6: Hazard curve for Line Source 2 (S2) using Boore, Joyner & Fumal attenuation expression



6.3. AREA SOURCE 1 (S3)

6.3.1 **Step 1: Identification of sources:** The source and its specifications were described in section 4. A brief description is below.

A=967 km R_3=75 km

M_0=4 M_{max}=7.5 n=1

f(R) delta R = 1

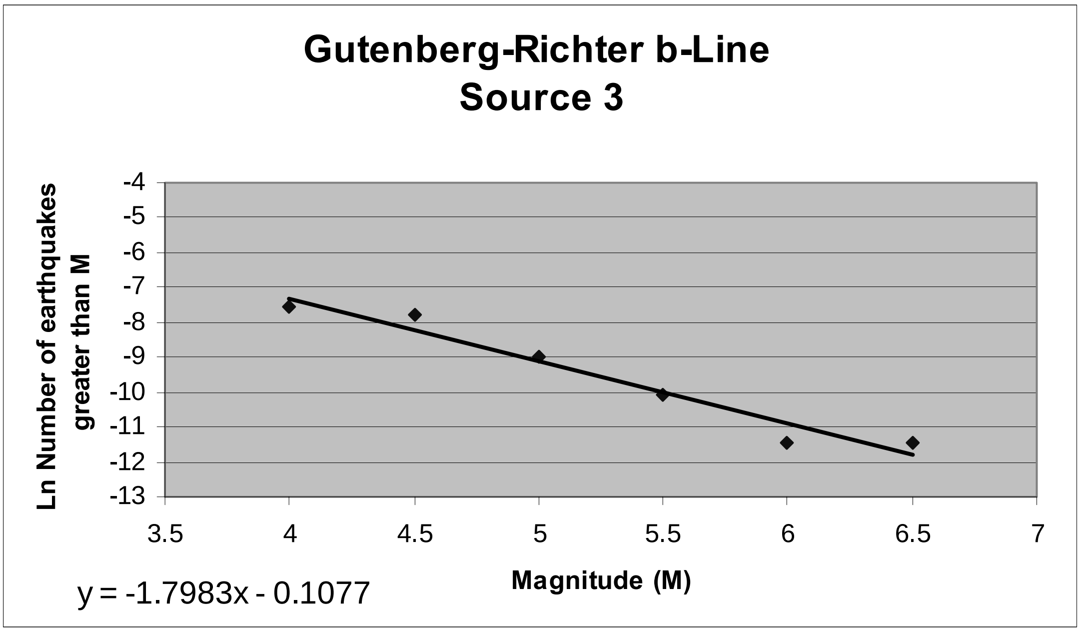
6.3.2 **Step 2: Recurrence relationship, Magnitude distribution and average rate of occurrence:**

All the above, calculated in section 6.1 for Line source 1 and just the calculation table and the b-line chart are presented.

Table 13: summary of b-line calculation

Gutenberg-Richter b-line for Source 3 (Area Source)				
Magnitude (mb)	**Sum**	**Sum/Year**	**Per Area**	**Ln (N)**
M>4	49	0.505154639	0.000522394	-7.557089176
M>4.5	38	0.391752577	0.000405122	-7.811323314
M>5	12	0.12371134	0.000127933	-8.964002824
M>5.5	4	0.041237113	4.26444E-05	-10.06261511
M>6	1	0.010309278	1.06611E-05	-11.44890947
M>6.5	1	0.010309278	1.06611E-05	-11.44890947

Chart 7: b-line for source 3



6.3.3. <u>Step 3:</u> Ground motion estimation:

Table 14: Probability of Exceeding a given EQ from (acc) for S3

P (PGA > 0.05 | EQ : R,M)

M (Mmid)	f(m).dm	R =		25
		Log (PGA)	PGA (g)	P( )
4.25	0.575	-1.510	0.031	1.54E-01
4.75	0.234	-1.402	0.040	3.11E-01
5.25	0.095	-1.294	0.051	5.13E-01
5.75	0.039	-1.186	0.065	7.12E-01
6.25	0.016	-1.078	0.084	8.62E-01
6.75	0.006	-0.970	0.107	9.47E-01
7.25	0.003	-0.862	0.137	9.84E-01

P (PGA > 0.10 | EQ : R,M)

M (Mmid)	f(m).dm	R =		25
		Log (PGA)	PGA (g)	P( )
4.25	0.575	-1.510	0.031	6.42E-03
4.75	0.234	-1.402	0.040	2.49E-02
5.25	0.095	-1.294	0.051	7.57E-02
5.75	0.039	-1.186	0.065	1.82E-01
6.25	0.016	-1.078	0.084	3.52E-01
6.75	0.006	-0.970	0.107	5.58E-01
7.25	0.003	-0.862	0.137	7.49E-01

P (PGA > 0.15 | EQ : R,M)

M (Mmid)	f(m).dm	R =		25
		Log (PGA)	PGA (g)	P( )
4.25	0.575	-1.510	0.031	4.08E-04
4.75	0.234	-1.402	0.040	2.40E-03
5.25	0.095	-1.294	0.051	1.09E-02
5.75	0.039	-1.186	0.065	3.86E-02
6.25	0.016	-1.078	0.084	1.07E-01
6.75	0.006	-0.970	0.107	2.38E-01
7.25	0.003	-0.862	0.137	4.26E-01

P (PGA > 0.20 | EQ : R,M)

M (Mmid)	f(m).dm	R =		25
		Log (PGA)	PGA (g)	P( )
4.25	0.575	-1.510	0.031	3.80E-05
4.75	0.234	-1.402	0.040	3.02E-04
5.25	0.095	-1.294	0.051	1.85E-03
5.75	0.039	-1.186	0.065	8.74E-03
6.25	0.016	-1.078	0.084	3.22E-02
6.75	0.006	-0.970	0.107	9.30E-02
7.25	0.003	-0.862	0.137	2.13E-01

P (PGA > 0.25 | EQ : R,M)

M (Mmid)	f(m).dm	R =		25
		Log (PGA)	PGA (g)	P( )
4.25	0.575	-1.510	0.031	4.73E-06
4.75	0.234	-1.402	0.040	4.76E-05
5.25	0.095	-1.294	0.051	3.68E-04
5.75	0.039	-1.186	0.065	2.19E-03
6.25	0.016	-1.078	0.084	1.01E-02
6.75	0.006	-0.970	0.107	3.63E-02
7.25	0.003	-0.862	0.137	1.02E-01

P (PGA > 0.30 | EQ : R,M)

M (Mmid)	f(m).dm	R =		25
		Log (PGA)	PGA (g)	P( )
4.25	0.575	-1.510	0.031	7.34E-07
4.75	0.234	-1.402	0.040	8.98E-06
5.25	0.095	-1.294	0.051	8.43E-05
5.75	0.039	-1.186	0.065	6.08E-04
6.25	0.016	-1.078	0.084	3.38E-03
6.75	0.006	-0.970	0.107	1.46E-02
7.25	0.003	-0.862	0.137	4.90E-02

P (PGA > 0.35 | EQ : R,M)

M (Mmid)	f(m).dm	R =		25
		Log (PGA)	PGA (g)	P( )
4.25	0.575	-1.510	0.031	1.36E-07
4.75	0.234	-1.402	0.040	1.96E-06
5.25	0.095	-1.294	0.051	2.17E-05
5.75	0.039	-1.186	0.065	1.84E-04
6.25	0.016	-1.078	0.084	1.20E-03
6.75	0.006	-0.970	0.107	6.07E-03
7.25	0.003	-0.862	0.137	2.38E-02

P (PGA > 0.40 | EQ : R,M)

M (Mmid)	f(m).dm	R =		25
		Log (PGA)	PGA (g)	P( )
4.25	0.575	-1.510	0.031	2.90E-08
4.75	0.234	-1.402	0.040	4.84E-07
5.25	0.095	-1.294	0.051	6.17E-06
5.75	0.039	-1.186	0.065	6.04E-05
6.25	0.016	-1.078	0.084	4.53E-04
6.75	0.006	-0.970	0.107	2.63E-03
7.25	0.003	-0.862	0.137	1.18E-02

P (PGA > 0.45 | EQ : R,M)

M (Mmid)	f(m).dm	R =		25
		Log (PGA)	PGA (g)	P( )
4.25	0.575	-1.510	0.031	6.96E-09
4.75	0.234	-1.402	0.040	1.32E-07
5.25	0.095	-1.294	0.051	1.91E-06
5.75	0.039	-1.186	0.065	2.12E-05
6.25	0.016	-1.078	0.084	1.80E-04
6.75	0.006	-0.970	0.107	1.18E-03
7.25	0.003	-0.862	0.137	5.97E-03

P (PGA > 0.50 | EQ : R,M)

M (Mmid)	f(m).dm	R =		25
		Log (PGA)	PGA (g)	P( )
4.25	0.575	-1.510	0.031	1.85E-09
4.75	0.234	-1.402	0.040	3.92E-08
5.25	0.095	-1.294	0.051	6.36E-07
5.75	0.039	-1.186	0.065	7.90E-06
6.25	0.016	-1.078	0.084	7.51E-05
6.75	0.006	-0.970	0.107	5.50E-04
7.25	0.003	-0.862	0.137	3.10E-03

P (PGA > 0.55 | EQ : R,M)

M (Mmid)	f(m).dm	R =		25
		Log (PGA)	PGA (g)	P( )
4.25	0.575	-1.510	0.031	5.33E-10
4.75	0.234	-1.402	0.040	1.25E-08
5.25	0.095	-1.294	0.051	2.26E-07
5.75	0.039	-1.186	0.065	3.10E-06
6.25	0.016	-1.078	0.084	3.27E-05
6.75	0.006	-0.970	0.107	2.64E-04
7.25	0.003	-0.862	0.137	1.65E-03

P (PGA > 0.60 | EQ : R,M)

M (Mmid)	f(m).dm	R =		25
		Log (PGA)	PGA (g)	P( )
4.25	0.575	-1.510	0.031	1.65E-10
4.75	0.234	-1.402	0.040	4.28E-09
5.25	0.095	-1.294	0.051	8.47E-08
5.75	0.039	-1.186	0.065	1.28E-06
6.25	0.016	-1.078	0.084	1.48E-05
6.75	0.006	-0.970	0.107	1.31E-04
7.25	0.003	-0.862	0.137	8.94E-04

P (PGA > 0.65 | EQ : R,M)

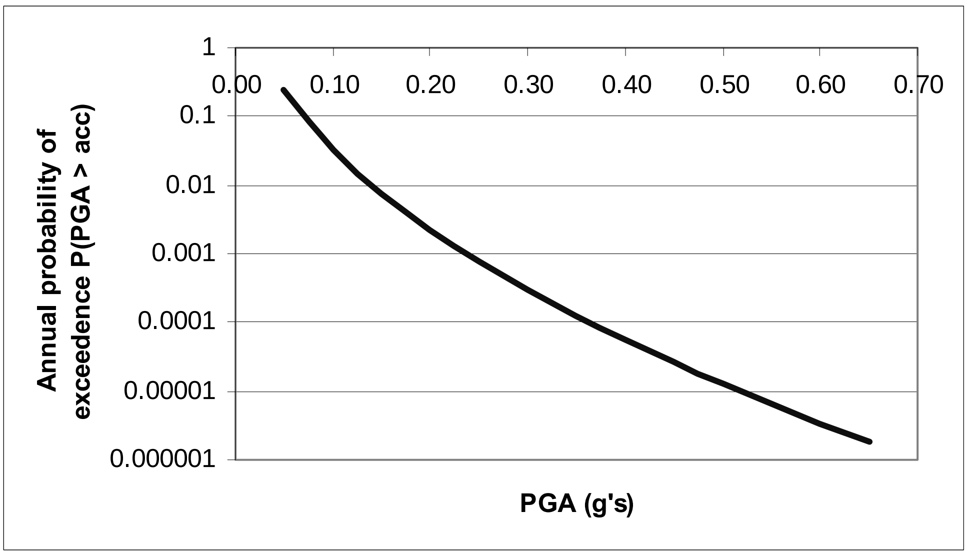
M (Mmid)	f(m).dm	R =		25
		Log (PGA)	PGA (g)	P( )
4.25	0.575	-1.510	0.031	5.48E-11
4.75	0.234	-1.402	0.040	1.55E-09
5.25	0.095	-1.294	0.051	3.34E-08
5.75	0.039	-1.186	0.065	5.49E-07
6.25	0.016	-1.078	0.084	6.92E-06
6.75	0.006	-0.970	0.107	6.68E-05
7.25	0.003	-0.862	0.137	4.96E-04

6.3.4. <u>Step 4:</u> Development of the hazard curve:

Table 15: Probabilities of exceeding

acc	P (PGA > acc | EQ)	P (PGA > acc)	P (PGA > acc) approx
0.05	**2.60E-01**	**2.21E-01**	**0.2492**
0.10	**3.48E-02**	**3.29E-02**	**0.0334**
0.15	**7.66E-03**	**7.32E-03**	**0.0073**
0.20	**2.27E-03**	**2.17E-03**	**0.0022**
0.25	**7.93E-04**	**7.60E-04**	**0.0008**
0.30	**3.09E-04**	**2.96E-04**	**0.0003**
0.35	**1.30E-04**	**1.24E-04**	**1.24E-04**
0.40	**5.78E-05**	**5.54E-05**	**5.54E-05**
0.45	**2.70E-05**	**2.59E-05**	**2.59E-05**
0.50	**1.32E-05**	**1.26E-05**	**1.26E-05**
0.55	**6.65E-06**	**6.38E-06**	**6.38E-06**
0.60	**3.47E-06**	**3.32E-06**	**3.32E-06**
0.65	**1.86E-06**	**1.78E-06**	**1.78E-06**

Chart 8: Hazard curve for Area Source 1 (S3) using Boore, Joyner & Fumal attenuation expression



6.4. AREA SOURCE 2 (S4)

6.4.1. Step 1: Identification of sources: The source and its specifications were described in section 4. A brief description is below.

A_4=2900 km^2

R_{41}=73 km R_{42}=64 km R_{43}=89 km R_{44}=81 km

M_0=4 M_{max}=7.5 Delta(A)=725 km^2 n=4

f(R) delta R = 1/4

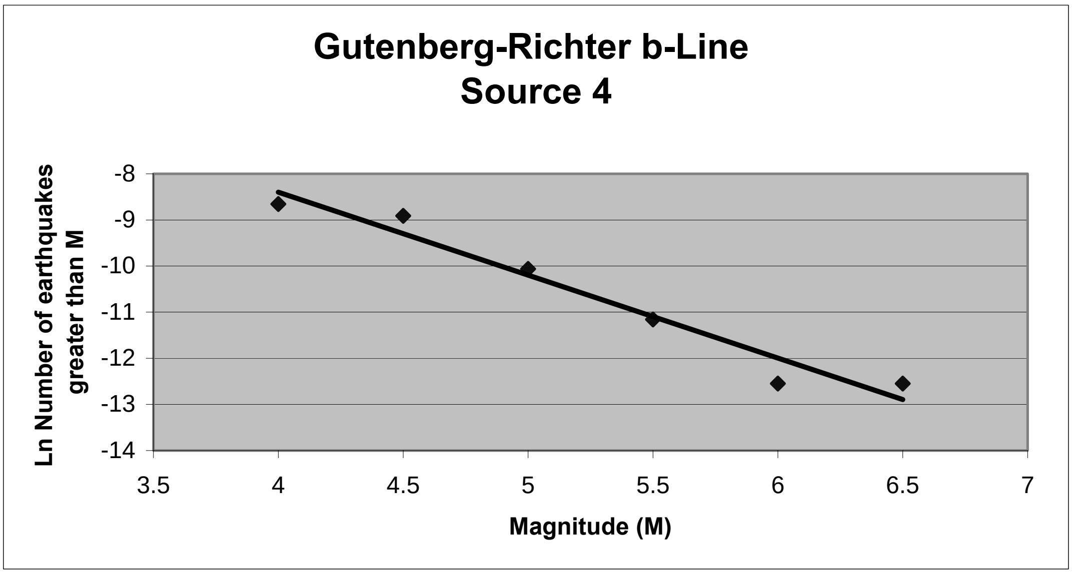
6.4.2. Step 2: Recurrence relationship, Magnitude distribution and average rate of occurrence:

All the above, calculated in section 6.1 for Line source 1 and just the calculation table and the b-line chart are presented.

Table 16: summary of b-line calculation

Gutenberg-Richter b-line for Source 4 (Area Source)				
Magnitude (mb)	Sum	Sum/Year	Per Length	Ln (N)
M>4	49	0.505154639	0.000174191	-8.655356696
M>4.5	38	0.391752577	0.000135087	-8.909590835
M>5	12	0.12371134	4.26591E-05	-10.06227034
M>5.5	4	0.041237113	1.42197E-05	-11.16088263
M>6	1	0.010309278	3.55492E-06	-12.54717699
M>6.5	1	0.010309278	3.55492E-06	-12.54717699

Chart 9: b-line for source 4



6.4.3. Step 3:

Table 17: Probability of Exceeding a given EQ from (acc) for S4

P (PGA > 0.05 | EQ : R,M) **acc =** 0.05 1

M (Mmid)	f(m).dm	R =		64	R =		73	R =		81	R =		89	SUM (P)
		Log (PGA)	PGA (g)	P( )	Log (PGA)	PGA (g)	P ( )	Log (PGA)	PGA (g)	P ( )	Log (PGA)	PGA (g)	P ( )	
4.25	0.575	-1.821	0.015	5.63E-03	-1.865	0.014	2.98E-03	-1.900	0.013	1.75E-03	-1.931	0.012	1.05E-03	1.14E-02
4.75	0.234	-1.713	0.019	2.23E-02	-1.757	0.018	1.31E-02	-1.792	0.016	8.35E-03	-1.823	0.015	5.42E-03	4.92E-02
5.25	0.095	-1.605	0.025	6.93E-02	-1.649	0.022	4.49E-02	-1.684	0.021	3.10E-02	-1.715	0.019	2.16E-02	1.67E-01
5.75	0.039	-1.497	0.032	1.70E-01	-1.541	0.029	1.21E-01	-1.576	0.027	9.02E-02	-1.607	0.025	6.76E-02	4.49E-01
6.25	0.016	-1.389	0.041	3.35E-01	-1.433	0.037	2.60E-01	-1.468	0.034	2.08E-01	-1.499	0.032	1.67E-01	9.70E-01
6.75	0.006	-1.281	0.052	5.40E-01	-1.325	0.047	4.54E-01	-1.360	0.044	3.87E-01	-1.391	0.041	3.30E-01	1.71E+00
7.25	0.003	-1.173	0.067	7.34E-01	-1.217	0.061	6.60E-01	-1.252	0.056	5.95E-01	-1.283	0.052	5.34E-01	2.52E+00

P (PGA > 0.10 | EQ : R,M) **acc =** 0.1 2

M (Mmid)	f(m).dm	R =		64	R =		73	R =		81	R =		89	SUM (P)
		Log (PGA)	PGA (g)	P( )	Log (PGA)	PGA (g)	P ( )	Log (PGA)	PGA (g)	P ( )	Log (PGA)	PGA (g)	P ( )	
4.25	0.575	-1.821	0.015	3.13E-05	-1.865	0.014	1.23E-05	-1.900	0.013	5.71E-06	-1.931	0.012	2.78E-06	5.21E-05
4.75	0.234	-1.713	0.019	2.54E-04	-1.757	0.018	1.12E-04	-1.792	0.016	5.63E-05	-1.823	0.015	2.96E-05	4.52E-04
5.25	0.095	-1.605	0.025	1.59E-03	-1.649	0.022	7.76E-04	-1.684	0.021	4.27E-04	-1.715	0.019	2.42E-04	3.04E-03
5.75	0.039	-1.497	0.032	7.70E-03	-1.541	0.029	4.17E-03	-1.576	0.027	2.49E-03	-1.607	0.025	1.53E-03	1.59E-02
6.25	0.016	-1.389	0.041	2.90E-02	-1.433	0.037	1.74E-02	-1.468	0.034	1.13E-02	-1.499	0.032	7.43E-03	6.51E-02
6.75	0.006	-1.281	0.052	8.55E-02	-1.325	0.047	5.66E-02	-1.360	0.044	3.97E-02	-1.391	0.041	2.81E-02	2.10E-01
7.25	0.003	-1.173	0.067	2.00E-01	-1.217	0.061	1.45E-01	-1.252	0.056	1.10E-01	-1.283	0.052	8.35E-02	5.38E-01

P (PGA > 0.15 | EQ : R,M) **acc =** 0.15 3

M (Mmid)	f(m).dm	R =		64	R =		73	R =		81	R =		89	SUM (P)
		Log (PGA)	PGA (g)	P( )	Log (PGA)	PGA (g)	P ( )	Log (PGA)	PGA (g)	P ( )	Log (PGA)	PGA (g)	P ( )	
4.25	0.575	-1.821	0.015	5.82E-07	-1.865	0.014	1.92E-07	-1.900	0.013	7.72E-08	-1.931	0.012	3.30E-08	8.84E-07
4.75	0.234	-1.713	0.019	7.29E-06	-1.757	0.018	2.68E-06	-1.792	0.016	1.18E-06	-1.823	0.015	5.44E-07	1.17E-05
5.25	0.095	-1.605	0.025	7.00E-05	-1.649	0.022	2.87E-05	-1.684	0.021	1.37E-05	-1.715	0.019	6.86E-06	1.19E-04
5.75	0.039	-1.497	0.032	5.16E-04	-1.541	0.029	2.35E-04	-1.576	0.027	1.23E-04	-1.607	0.025	6.63E-05	9.41E-04
6.25	0.016	-1.389	0.041	2.94E-03	-1.433	0.037	1.49E-03	-1.468	0.034	8.44E-04	-1.499	0.032	4.93E-04	5.76E-03
6.75	0.006	-1.281	0.052	1.29E-02	-1.325	0.047	7.28E-03	-1.360	0.044	4.48E-03	-1.391	0.041	2.82E-03	2.75E-02
7.25	0.003	-1.173	0.067	4.45E-02	-1.217	0.061	2.77E-02	-1.252	0.056	1.85E-02	-1.283	0.052	1.25E-02	1.03E-01

P (PGA > 0.20 | EQ : R,M) **acc =** 0.2 4

M (Mmid)	f(m).dm	R =		64	R =		73	R =		81	R =		89	SUM (P)
		Log (PGA)	PGA (g)	P( )	Log (PGA)	PGA (g)	P ( )	Log (PGA)	PGA (g)	P ( )	Log (PGA)	PGA (g)	P ( )	
4.25	0.575	-1.821	0.015	2.24E-08	-1.865	0.014	6.49E-09	-1.900	0.013	2.36E-09	-1.931	0.012	9.23E-10	3.21E-08
4.75	0.234	-1.713	0.019	3.82E-07	-1.757	0.018	1.24E-07	-1.792	0.016	4.92E-08	-1.823	0.015	2.08E-08	5.76E-07
5.25	0.095	-1.605	0.025	4.99E-06	-1.649	0.022	1.80E-06	-1.684	0.021	7.81E-07	-1.715	0.019	3.57E-07	7.93E-06
5.75	0.039	-1.497	0.032	4.99E-05	-1.541	0.029	2.01E-05	-1.576	0.027	9.50E-06	-1.607	0.025	4.69E-06	8.42E-05
6.25	0.016	-1.389	0.041	3.84E-04	-1.433	0.037	1.72E-04	-1.468	0.034	8.85E-05	-1.499	0.032	4.73E-05	6.92E-04
6.75	0.006	-1.281	0.052	2.27E-03	-1.325	0.047	1.13E-03	-1.360	0.044	6.35E-04	-1.391	0.041	3.66E-04	4.41E-03
7.25	0.003	-1.173	0.067	1.04E-02	-1.217	0.061	5.77E-03	-1.252	0.056	3.51E-03	-1.283	0.052	2.18E-03	2.19E-02

P (PGA > 0.25 | EQ : R,M) **acc =** 0.25 5

M (Mmid)	f(m).dm	R =	64		R =	73		R =	81		R =	89		SUM (P)
		Log (PGA)	PGA (g)	P( )	Log (PGA)	PGA (g)	P ( )	Log (PGA)	PGA (g)	P ( )	Log (PGA)	PGA (g)	P ( )	
4.25	0.575	-1.821	0.015	1.39E-09	-1.865	0.014	3.66E-10	-1.900	0.013	1.23E-10	-1.931	0.012	4.48E-11	1.93E-09
4.75	0.234	-1.713	0.019	3.03E-08	-1.757	0.018	8.90E-09	-1.792	0.016	3.27E-09	-1.823	0.015	1.29E-09	4.38E-08
5.25	0.095	-1.605	0.025	5.03E-07	-1.649	0.022	1.65E-07	-1.684	0.021	6.61E-08	-1.715	0.019	2.82E-08	7.63E-07
5.75	0.039	-1.497	0.032	6.40E-06	-1.541	0.029	2.34E-06	-1.576	0.027	1.02E-06	-1.607	0.025	4.71E-07	1.02E-05
6.25	0.016	-1.389	0.041	6.23E-05	-1.433	0.037	2.54E-05	-1.468	0.034	1.21E-05	-1.499	0.032	6.03E-06	1.06E-04
6.75	0.006	-1.281	0.052	4.66E-04	-1.325	0.047	2.12E-04	-1.360	0.044	1.10E-04	-1.391	0.041	5.91E-05	8.47E-04
7.25	0.003	-1.173	0.067	2.69E-03	-1.217	0.061	1.36E-03	-1.252	0.056	7.65E-04	-1.283	0.052	4.45E-04	5.26E-03

P (PGA > 0.30 | EQ : R,M) **acc =** 0.3 6

M (Mmid)	f(m).dm	R =	64		R =	73		R =	81		R =	89		SUM (P)
		Log (PGA)	PGA (g)	P( )	Log (PGA)	PGA (g)	P ( )	Log (PGA)	PGA (g)	P ( )	Log (PGA)	PGA (g)	P ( )	
4.25	0.575	-1.821	0.015	1.23E-10	-1.865	0.014	2.98E-11	-1.900	0.013	9.39E-12	-1.931	0.012	3.22E-12	1.65E-10
4.75	0.234	-1.713	0.019	3.25E-09	-1.757	0.018	8.81E-10	-1.792	0.016	3.04E-10	-1.823	0.015	1.13E-10	4.55E-09
5.25	0.095	-1.605	0.025	6.58E-08	-1.649	0.022	1.99E-08	-1.684	0.021	7.49E-09	-1.715	0.019	3.01E-09	9.63E-08
5.75	0.039	-1.497	0.032	1.02E-06	-1.541	0.029	3.44E-07	-1.576	0.027	1.41E-07	-1.607	0.025	6.13E-08	1.56E-06
6.25	0.016	-1.389	0.041	1.21E-05	-1.433	0.037	4.54E-06	-1.468	0.034	2.03E-06	-1.499	0.032	9.54E-07	1.96E-05
6.75	0.006	-1.281	0.052	1.09E-04	-1.325	0.047	4.59E-05	-1.360	0.044	2.23E-05	-1.391	0.041	1.14E-05	1.89E-04
7.25	0.003	-1.173	0.067	7.63E-04	-1.217	0.061	3.56E-04	-1.252	0.056	1.89E-04	-1.283	0.052	1.04E-04	1.41E-03

P (PGA > 0.35 | EQ : R,M) **acc =** 0.35 7

M (Mmid)	f(m).dm	R =		64	R =		73	R =		81	R =		89	SUM (P)
		Log (PGA)	PGA (g)	P( )	Log (PGA)	PGA (g)	P ( )	Log (PGA)	PGA (g)	P ( )	Log (PGA)	PGA (g)	P ( )	
4.25	0.575	-1.821	0.015	1.40E-11	-1.865	0.014	3.18E-12	-1.900	0.013	9.50E-13	-1.931	0.012	3.10E-13	1.85E-11
4.75	0.234	-1.713	0.019	4.40E-10	-1.757	0.018	1.11E-10	-1.792	0.016	3.63E-11	-1.823	0.015	1.28E-11	6.01E-10
5.25	0.095	-1.605	0.025	1.05E-08	-1.649	0.022	2.98E-09	-1.684	0.021	1.06E-09	-1.715	0.019	4.06E-10	1.50E-08
5.75	0.039	-1.497	0.032	1.92E-07	-1.541	0.029	6.07E-08	-1.576	0.027	2.36E-08	-1.607	0.025	9.77E-09	2.86E-07
6.25	0.016	-1.389	0.041	2.69E-06	-1.433	0.037	9.46E-07	-1.468	0.034	4.01E-07	-1.499	0.032	1.80E-07	4.21E-06
6.75	0.006	-1.281	0.052	2.88E-05	-1.325	0.047	1.13E-05	-1.360	0.044	5.21E-06	-1.391	0.041	2.53E-06	4.78E-05
7.25	0.003	-1.173	0.067	2.36E-04	-1.217	0.061	1.03E-04	-1.252	0.056	5.19E-05	-1.283	0.052	2.72E-05	4.18E-04

P (PGA > 0.40 | EQ : R,M) **acc =** 0.4 8

M (Mmid)	f(m).dm	R =		64	R =		73	R =		81	R =		89	SUM (P)
		Log (PGA)	PGA (g)	P( )	Log (PGA)	PGA (g)	P ( )	Log (PGA)	PGA (g)	P ( )	Log (PGA)	PGA (g)	P ( )	
4.25	0.575	-1.821	0.015	1.97E-12	-1.865	0.014	4.21E-13	-1.900	0.013	1.20E-13	-1.931	0.012	3.75E-14	2.55E-12
4.75	0.234	-1.713	0.019	7.16E-11	-1.757	0.018	1.71E-11	-1.792	0.016	5.31E-12	-1.823	0.015	1.80E-12	9.58E-11
5.25	0.095	-1.605	0.025	1.98E-09	-1.649	0.022	5.27E-10	-1.684	0.021	1.79E-10	-1.715	0.019	6.57E-11	2.75E-09
5.75	0.039	-1.497	0.032	4.18E-08	-1.541	0.029	1.24E-08	-1.576	0.027	4.61E-09	-1.607	0.025	1.83E-09	6.07E-08
6.25	0.016	-1.389	0.041	6.75E-07	-1.433	0.037	2.24E-07	-1.468	0.034	9.05E-08	-1.499	0.032	3.89E-08	1.03E-06
6.75	0.006	-1.281	0.052	8.32E-06	-1.325	0.047	3.08E-06	-1.360	0.044	1.36E-06	-1.391	0.041	6.32E-07	1.34E-05
7.25	0.003	-1.173	0.067	7.88E-05	-1.217	0.061	3.25E-05	-1.252	0.056	1.56E-05	-1.283	0.052	7.85E-06	1.35E-04

P (PGA > 0.45 | EQ : R,M) **acc =** 0.45 9

M (Mmid)	f(m).dm	R =		64	R =		73	R =		81	R =		89	SUM (P)
		Log (PGA)	PGA (g)	P( )	Log (PGA)	PGA (g)	P ( )	Log (PGA)	PGA (g)	P ( )	Log (PGA)	PGA (g)	P ( )	
4.25	0.575	-1.821	0.015	3.28E-13	-1.865	0.014	6.63E-14	-1.900	0.013	1.81E-14	-1.931	0.012	5.44E-15	4.17E-13
4.75	0.234	-1.713	0.019	1.35E-11	-1.757	0.018	3.06E-12	-1.792	0.016	9.12E-13	-1.823	0.015	2.98E-13	1.78E-11
5.25	0.095	-1.605	0.025	4.25E-10	-1.649	0.022	1.07E-10	-1.684	0.021	3.50E-11	-1.715	0.019	1.24E-11	5.80E-10
5.75	0.039	-1.497	0.032	1.02E-08	-1.541	0.029	2.88E-09	-1.576	0.027	1.02E-09	-1.607	0.025	3.92E-10	1.45E-08
6.25	0.016	-1.389	0.041	1.87E-07	-1.433	0.037	5.89E-08	-1.468	0.034	2.29E-08	-1.499	0.032	9.46E-09	2.78E-07
6.75	0.006	-1.281	0.052	2.62E-06	-1.325	0.047	9.20E-07	-1.360	0.044	3.89E-07	-1.391	0.041	1.74E-07	4.10E-06
7.25	0.003	-1.173	0.067	2.81E-05	-1.217	0.061	1.10E-05	-1.252	0.056	5.08E-06	-1.283	0.052	2.46E-06	4.66E-05

P (PGA > 0.50 | EQ : R,M) **acc =** 0.5 10

M (Mmid)	f(m).dm	R =		64	R =		73	R =		81	R =		89	SUM (P)
		Log (PGA)	PGA (g)	P( )	Log (PGA)	PGA (g)	P ( )	Log (PGA)	PGA (g)	P ( )	Log (PGA)	PGA (g)	P ( )	
4.25	0.575	-1.821	0.015	6.24E-14	-1.865	0.014	1.20E-14	-1.900	0.013	3.22E-15	-1.931	0.012	0.00E+00	7.76E-14
4.75	0.234	-1.713	0.019	2.89E-12	-1.757	0.018	6.23E-13	-1.792	0.016	1.79E-13	-1.823	0.015	5.65E-14	3.75E-12
5.25	0.095	-1.605	0.025	1.02E-10	-1.649	0.022	2.46E-11	-1.684	0.021	7.72E-12	-1.715	0.019	2.64E-12	1.37E-10
5.75	0.039	-1.497	0.032	2.74E-09	-1.541	0.029	7.39E-10	-1.576	0.027	2.53E-10	-1.607	0.025	9.36E-11	3.83E-09
6.25	0.016	-1.389	0.041	5.63E-08	-1.433	0.037	1.69E-08	-1.468	0.034	6.34E-09	-1.499	0.032	2.54E-09	8.21E-08
6.75	0.006	-1.281	0.052	8.84E-07	-1.325	0.047	2.97E-07	-1.360	0.044	1.21E-07	-1.391	0.041	5.24E-08	1.35E-06
7.25	0.003	-1.173	0.067	1.06E-05	-1.217	0.061	3.97E-06	-1.252	0.056	1.77E-06	-1.283	0.052	8.28E-07	1.72E-05

P (PGA > 0.55 | EQ : R,M) **acc =** 0.55 11

M (Mmid)	f(m).dm	R = 64			R = 73			R = 81			R = 89			SUM (P)
		Log (PGA)	PGA (g)	P( )	Log (PGA)	PGA (g)	P ( )	Log (PGA)	PGA (g)	P ( )	Log (PGA)	PGA (g)	P ( )	
4.25	0.575	-1.821	0.015	1.33E-14	-1.865	0.014	2.44E-15	-1.900	0.013	0.00E+00	-1.931	0.012	0.00E+00	1.58E-14
4.75	0.234	-1.713	0.019	6.86E-13	-1.757	0.018	1.42E-13	-1.792	0.016	3.94E-14	-1.823	0.015	1.21E-14	8.79E-13
5.25	0.095	-1.605	0.025	2.69E-11	-1.649	0.022	6.21E-12	-1.684	0.021	1.88E-12	-1.715	0.019	6.24E-13	3.56E-11
5.75	0.039	-1.497	0.032	8.02E-10	-1.541	0.029	2.07E-10	-1.576	0.027	6.86E-11	-1.607	0.025	2.46E-11	1.10E-09
6.25	0.016	-1.389	0.041	1.83E-08	-1.433	0.037	5.26E-09	-1.468	0.034	1.90E-09	-1.499	0.032	7.40E-10	2.62E-08
6.75	0.006	-1.281	0.052	3.18E-07	-1.325	0.047	1.02E-07	-1.360	0.044	4.03E-08	-1.391	0.041	1.70E-08	4.77E-07
7.25	0.003	-1.173	0.067	4.22E-06	-1.217	0.061	1.52E-06	-1.252	0.056	6.53E-07	-1.283	0.052	2.97E-07	6.69E-06

P (PGA > 0.60 | EQ : R,M) **acc =** 0.6 12

M (Mmid)	f(m).dm	R = 64			R = 73			R = 81			R = 89			SUM (P)
		Log (PGA)	PGA (g)	P( )	Log (PGA)	PGA (g)	P ( )	Log (PGA)	PGA (g)	P ( )	Log (PGA)	PGA (g)	P ( )	
4.25	0.575	-1.821	0.015	3.11E-15	-1.865	0.014	0.00E+00	-1.900	0.013	0.00E+00	-1.931	0.012	0.00E+00	3.11E-15
4.75	0.234	-1.713	0.019	1.78E-13	-1.757	0.018	3.54E-14	-1.792	0.016	9.55E-15	-1.823	0.015	2.89E-15	2.26E-13
5.25	0.095	-1.605	0.025	7.68E-12	-1.649	0.022	1.71E-12	-1.684	0.021	5.02E-13	-1.715	0.019	1.62E-13	1.00E-11
5.75	0.039	-1.497	0.032	2.52E-10	-1.541	0.029	6.26E-11	-1.576	0.027	2.01E-11	-1.607	0.025	7.02E-12	3.42E-10
6.25	0.016	-1.389	0.041	6.31E-09	-1.433	0.037	1.75E-09	-1.468	0.034	6.14E-10	-1.499	0.032	2.32E-10	8.90E-09
6.75	0.006	-1.281	0.052	1.21E-07	-1.325	0.047	3.73E-08	-1.360	0.044	1.43E-08	-1.391	0.041	5.84E-09	1.78E-07
7.25	0.003	-1.173	0.067	1.76E-06	-1.217	0.061	6.08E-07	-1.252	0.056	2.54E-07	-1.283	0.052	1.12E-07	2.74E-06

P (PGA > 0.65 | EQ : R,M) **acc =** 0.65 13

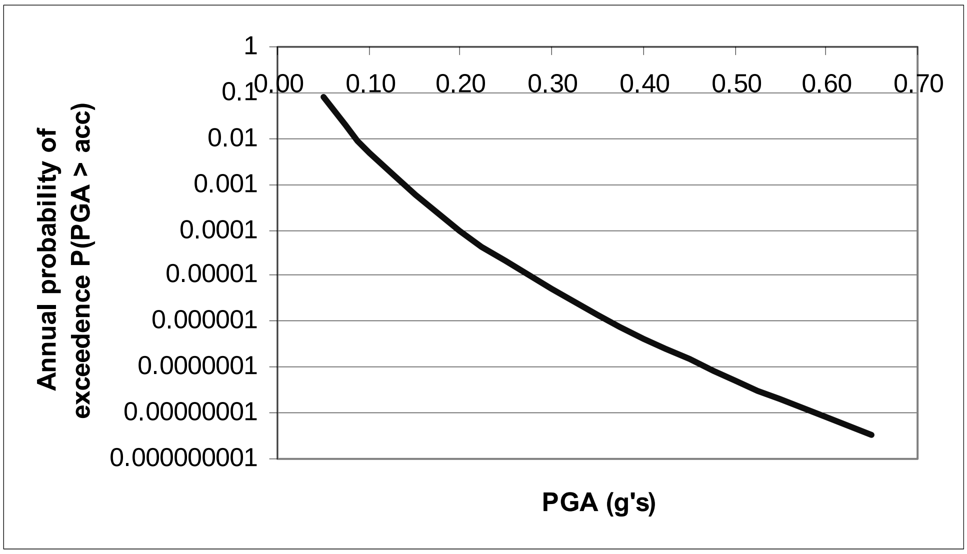
M (Mmid)	f(m).dm	R =		64	R =		73	R =		81	R =		89	SUM (P)
		Log (PGA)	PGA (g)	P( )	Log (PGA)	PGA (g)	P ( )	Log (PGA)	PGA (g)	P ( )	Log (PGA)	PGA (g)	P ( )	
4.25	0.575	-1.821	0.015	0.00E+00	-1.865	0.014	0.00E+00	-1.900	0.013	0.00E+00	-1.931	0.012	0.00E+00	0.00E+00
4.75	0.234	-1.713	0.019	5.01E-14	-1.757	0.018	9.66E-15	-1.792	0.016	2.55E-15	-1.823	0.015	0.00E+00	6.23E-14
5.25	0.095	-1.605	0.025	2.36E-12	-1.649	0.022	5.05E-13	-1.684	0.021	1.45E-13	-1.715	0.019	4.54E-14	3.05E-12
5.75	0.039	-1.497	0.032	8.44E-11	-1.541	0.029	2.02E-11	-1.576	0.027	6.32E-12	-1.607	0.025	2.15E-12	1.13E-10
6.25	0.016	-1.389	0.041	2.31E-09	-1.433	0.037	6.17E-10	-1.468	0.034	2.10E-10	-1.499	0.032	7.75E-11	3.21E-09
6.75	0.006	-1.281	0.052	4.80E-08	-1.325	0.047	1.44E-08	-1.360	0.044	5.35E-09	-1.391	0.041	2.13E-09	6.99E-08
7.25	0.003	-1.173	0.067	7.65E-07	-1.217	0.061	2.55E-07	-1.252	0.056	1.04E-07	-1.283	0.052	4.47E-08	1.17E-06

6.4.4. Step 4: Development of the hazard curve:

Table 18: Probabilities of exceeding

acc	P (PGA > acc | EQ)	P (PGA > acc)	P (PGA > acc) approx
0.05	8.42E-02	7.75E-02	0.0807
0.10	4.82E-03	4.61E-03	0.0046
0.15	5.87E-04	5.63E-04	0.0006
0.20	1.00E-04	9.63E-05	0.0001
0.25	2.13E-05	2.04E-05	0.0000
0.30	5.28E-06	5.06E-06	0.0000
0.35	1.48E-06	1.42E-06	1.42E-06
0.40	4.56E-07	4.37E-07	4.37E-07
0.45	1.53E-07	1.47E-07	1.47E-07
0.50	5.50E-08	5.27E-08	5.27E-08
0.55	2.10E-08	2.01E-08	2.01E-08
0.60	8.43E-09	8.09E-09	8.09E-09
0.65	3.55E-09	3.41E-09	3.41E-09

Chart 10: Hazard curve for Area Source 2 (S4) using Boore, Joyner & Fumal attenuation expression



6.5. Combination of results:

The results of the sources are combined with the following expression:

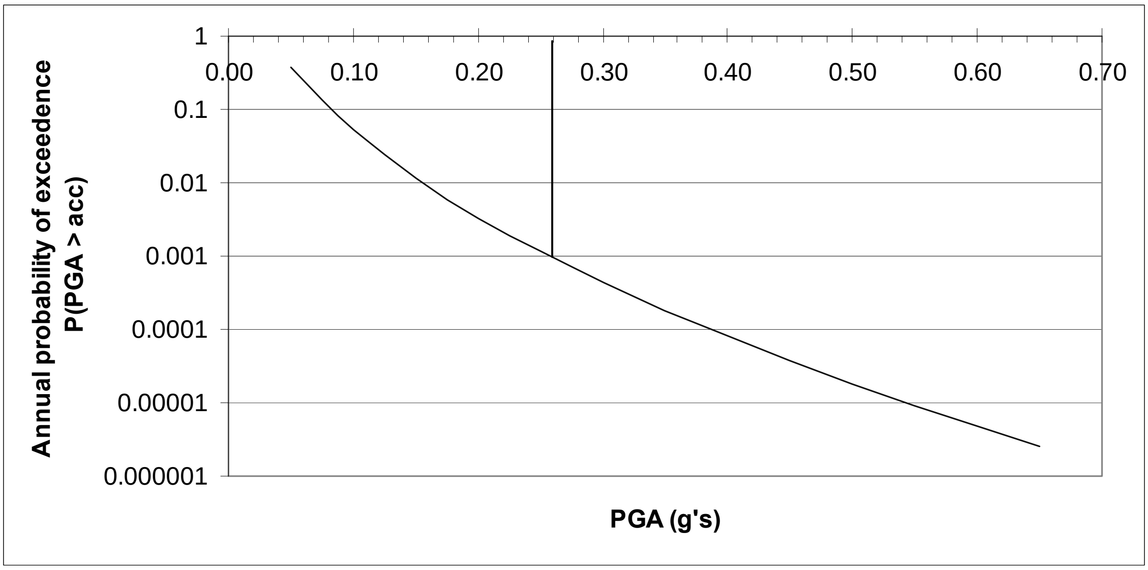
$$P(PGA > acc) = 1 - \prod_{k} \{P(PGA < acc)_K\}$$

$$P(PGA > acc) = 1 - \{1 - P(PGA > acc)_1\} * ... * \{1 - P(PGA > acc)_4\}$$

Table 19: Probabilities of exceeding

acc	Line Source 1 (S1)	Line Source 2 (S2)	Area Source 1 (S3)	Area Source 2 (S4)	Combined
	P (PGA > acc)	P (PGA > acc)	P (PGA > acc)	P (PGA > acc)	P (PGA > acc)
0.05	1.19E-01	2.09E-02	2.21E-01	7.75E-02	3.80E-01
0.10	1.57E-02	1.09E-03	3.29E-02	4.61E-03	5.35E-02
0.15	3.40E-03	1.15E-04	7.32E-03	5.63E-04	1.14E-02
0.20	9.98E-04	1.72E-05	2.17E-03	9.63E-05	3.28E-03
0.25	3.47E-04	3.22E-06	7.60E-04	2.04E-05	1.13E-03
0.30	1.35E-04	7.16E-07	2.96E-04	5.06E-06	4.36E-04
0.35	5.64E-05	1.82E-07	1.24E-04	1.42E-06	1.82E-04
0.40	2.50E-05	5.13E-08	5.54E-05	4.37E-07	8.09E-05
0.45	1.17E-05	1.59E-08	2.59E-05	1.47E-07	3.78E-05
0.50	5.68E-06	5.29E-09	1.26E-05	5.27E-08	1.84E-05
0.55	2.86E-06	1.88E-09	6.38E-06	2.01E-08	9.26E-06
0.60	1.48E-06	7.09E-10	3.32E-06	8.09E-09	4.82E-06
0.65	7.93E-07	2.81E-10	1.78E-06	3.41E-09	2.58E-06

Chart 11: Combined hazard curve for entire SITE



7. PGA for probability and return periods

7.1. PGA for the probability of 2% in 50 years:

P (2% in 50 years) = 0.02 / 50 = 0.0004

➔ P (0.0004) = 0.32 g

7.2. PGA for the probability of 5% in 50 years:

P (5% in 50 years) = 0.05 / 50 = 0.001

➔ P (0.001) = 0.26 g

7.3. PGA for the probability of 10% in 50 years:

P (10% in 50 years) = 0.1 / 50 = 0.002

➔ P (0.002) = 0.22 g

8. Design Response Spectra:

1. Scaled fixed-shape spectra
2. Spectra obtained through spectral attenuation relations

8.1. Scaled fixed-shape spectra:

8.1. Scaled fixed-shape spectra: There are several types of fixed-shape spectra methods that we will gain the Newmark-Hall spectra:

8.1.1. Step 1: Establish the PGA associated with design earthquake: The PGA equals 0.26g from PSHA method (probability of 0.001) and 0.32g in DSHA method.

8.1.2. Step 2: PGV and PGD

$$v = c_1 \frac{a}{g} \qquad d = c_2 \frac{v^2}{a}$$

c_1=36 in/sec
c_2=6
a = PGA v = PGV d = PGD g = gravity acceleration

For DSHA: (PGA = 0.32g)

➔ $a = 0.32 * 386 = 123.5 \, inch/\sec^2$

➔ $v = 36 * \frac{123.5}{386} = 11.5 \, inch/\sec$

➔ $d = 6 * \frac{11.5^2}{123.5} = 6.4 inch$

For PSHA: (PGA = 0.26g)

➔ $a = 0.26 * 386 = 100 \, inch/\sec^2$

➔ $v = 36 * \frac{100}{386} = 9.4 \, inch/\sec$

➔ $d = 6 * \frac{9.4^2}{100} = 5.3 inch$

8.1.3. Step 3: Computing Spectra Values
Computation the 84th percentile amplification factors, these factors are unique in both PSHA and DSHA:
β = percent if critical damping = 5%

$\alpha_a = 4.38 - 1.04\ln(\beta) \rightarrow \alpha_a = 2.706$

$\alpha_V = 3.38 - 0.67\ln(\beta) \rightarrow \alpha_V = 2.302$

$\alpha_d = 2.73 - .45\ln(\beta) \rightarrow \alpha_d = 2.006$

➔Computation the spectral values for DSHA method results:

Pseudo absolute acceleration: $S_{pa} = \alpha_a \frac{a}{g} = 0.87g = 335.8\,{inch}/{\sec^2}$

Pseudo relative velocity: $S_{pv} = \alpha_v v = 26.5\,{inch}/{\sec}$

Maximum relative displacement: $S_d = \alpha_d d = 12.8 inch$

➔Computation the spectral values for PSHA method results:

Pseudo absolute acceleration: $S_{pa} = \alpha_a \frac{a}{g} = 0.70g = 0.7*386 = 270.2\,{inch}/{\sec^2}$

Pseudo relative velocity: $S_{pv} = \alpha_v v = 21.6\,{inch}/{\sec}$

Maximum relative displacement: $S_d = \alpha_d d = 10.6 inch$

8.1.4. <u>Step 4</u>: Determine f1, and 4f1:

After drawing the results on a tripartite paper, we will gain f1:

➔ For DSHA

f_1 = 4 Hz

f_2 = 4f1 = 16 Hz

f_3 = 33 Hz

➔ For PSHA

f_1 = 3 Hz

f_2 = 4f1 = 12 Hz

f_3 = 33 Hz

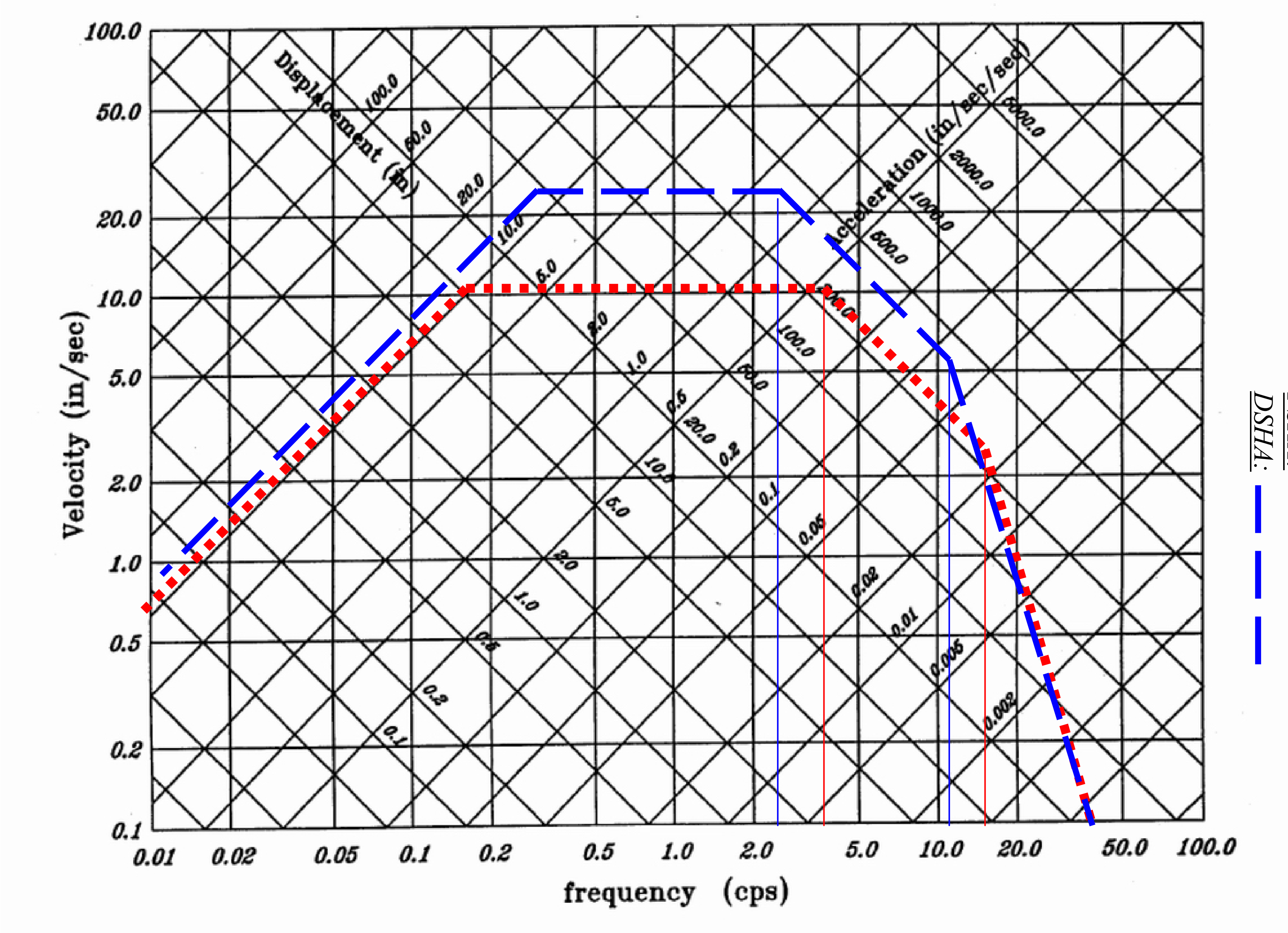


Chart 12: Newmark-Hall design spectra

PSHA: ▪▪▪▪▪

DSHA: — — —

8.2. Attenuation relation design spectra:

8.2.1. Boore, Joyner and Fumal spectral attenuation expression will be used for computation of the 84th percentile design spectrum. The controlling earthquake is the same determined in DSHA method for Line source 1 (S1) (M = 7.2 , R = 6.25 Km).

$$\log(y) = b_1 + b_2(M-6) + b_3(M-6)^2 + b_4\sqrt{R^2+h^2} + b_5.\log(\sqrt{R^2+h^2}) + b_6G_6 + b_7G + \sigma_{\log y}$$

Spv = pseudo relative velocity (cm/sec)

Table 20: BJF calculation

T=0.1

b1	b2	b3	b4	b5	b6	R	Log (Y)
1.7	0.321	-0.104	0	-0.921	0.039	6.25	1.260
b7	**h**	**Gb**	**Gc**	**σ_{logy}**		**M**	**Spv**
0.128	6.18	0	0	0.194		7.2	18.199

T=0.15 s

b1	b2	b3	b4	b5	b6	R	Log (Y)
1.956	0.323	-0.117	0	-0.939	0.137	6.25	1.452
b7	**h**	**Gb**	**Gc**	**σ_{logy}**		**M**	**Spv**
0.217	7.13	0	0	0.194		7.2	28.303

T=0.2 s

b1	b2	b3	b4	b5	b6	R	Log (Y)
2.042	0.332	-0.112	0	-0.931	0.185	6.25	1.573
b7	**h**	**Gb**	**Gc**	**σ_{logy}**		**M**	**Spv**
0.274	6.9	0	0	0.196		7.2	37.414

T=0.3 s

b1	b2	b3	b4	b5	b6	R	Log (Y)
2.063	0.354	-0.092	0	-0.902	0.231	6.25	1.720
b7	**h**	**Gb**	**Gc**	**σ_{logy}**		**M**	**Spv**
0.344	5.79	0	0	0.204		7.2	52.490

T=0.4 s

b1	b2	b3	b4	b5	b6	R	Log (Y)
2.029	0.373	-0.072	0	-0.876	0.252	6.25	1.800
b7	**h**	**Gb**	**Gc**	**σ_{logy}**		**M**	**Spv**
0.388	4.75	0	0	0.211		7.2	63.097

T=0.7

b1	b2	b3	b4	b5	b6	R	Log (Y)
1.917	0.416	-0.033	0	-0.833	0.283	6.25	1.895
b7	**h**	**Gb**	**Gc**	**σ_{logy}**		**M**	**Spv**
0.459	3.08	0	0	0.229		7.2	78.593

T=1 s

b1	b2	b3	b4	b5	b6	R	Log (Y)
1.858	0.444	-0.016	0	-0.825	0.305	6.25	1.922
b7	**h**	**Gb**	**Gc**	**σ_{logy}**		**M**	**Spv**
0.497	2.87	0	0	0.245		7.2	83.538

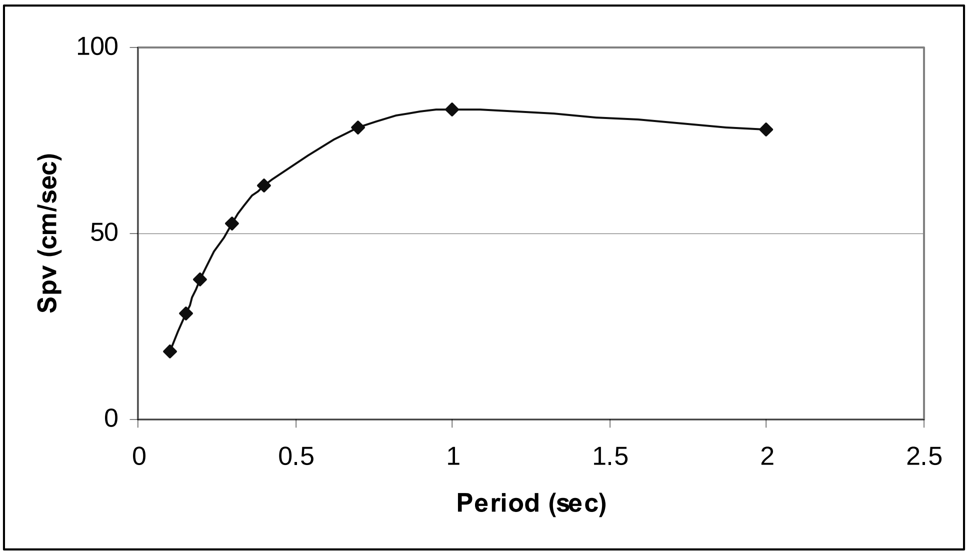
T=2 s

b1	b2	b3	b4	b5	b6	R	Log (Y)
1.905	0.491	-0.028	0	-0.898	0.381	6.25	1.892
b7	**h**	**Gb**	**Gc**	**σ_{logy}**		**M**	**Spv**
0.554	6.21	0	0	0.287		7.2	78.031

Table 21: BJF results

T (sec)	Spv (cm/sec)
0.1	18.199
0.15	28.303
0.2	37.414
0.3	52.490
0.4	63.097
0.7	78.593
1	83.538
2	78.031

Chart 13: BJF result



8.2.2. Crouse spectral attenuation expression with a focal depth of h=5 km.

$$\ln(y) = b_1 + b_2 M + b_3 M^2 + b_4 \ln(R + b_5 \exp(b_6 .M)) + b_7 h + \sigma_{\ln y}$$

Spv = pseudo relative velocity (cm/sec)

Table 22: Crouse attenuation calculation

T=0.1 s

b1	b2	b3	b4	b5	R	Ln (Y)
3.26	1.12	0	-1.93	1.58	6.25	2.665
b6	**b7**	**h**	**σ ln y**		**M**	**Spv**
0.608	0.00566	5	0.738		7.2	14.370

T=0.2 s

b1	b2	b3	b4	b5	R	Ln (Y)
4.44	1.09	0	-1.92	1.58	6.25	3.613
b6	**b7**	**h**	**σ ln y**		**M**	**Spv**
0.608	0.00531	5	0.675		7.2	37.086

T=0.4 s

b1	b2	b3	b4	b5	R	Ln (Y)
3.03	1.18	0	-1.69	1.58	6.25	3.928
b6	**b7**	**h**	**σ ln y**		**M**	**Spv**
0.608	0.00357	5	0.637		7.2	50.792

T=0.6 s

b1	b2	b3	b4	b5	R	Ln (Y)
2.86	1.41	0	-1.93	1.58	6.25	4.291
b6	**b7**	**h**	**σ ln y**		**M**	**Spv**
0.608	0.00257	5	0.691		7.2	73.018

T=0.8 s

b1	b2	b3	b4	b5	R	Ln (Y)
1.82	1.5	0	-1.83	1.58	6.25	4.399
b6	**b7**	**h**	**σ ln y**		**M**	**Spv**
0.608	0.00215	5	0.705		7.2	81.366

T=1 s

b1	b2	b3	b4	b5	R	Ln (Y)
1.43	1.56	0	-1.83	1.58	6.25	4.422
b6	**b7**	**h**	**σ ln y**		**M**	**Spv**
0.608	0.00114	5	0.691		7.2	83.254

T=1.5 s						
b1	b2	b3	b4	b5	R	Ln (Y)
-0.433	1.5	0	-1.45	1.58	6.25	4.026
b6	b7	h	$\sigma_{\ln y}$		M	Spv
0.608	0.000843	5	0.736		7.2	56.044

T=2 s						
b1	b2	b3	b4	b5	R	Ln (Y)
-0.987	1.5	0	-1.38	1.58	6.25	3.782
b6	b7	h	$\sigma_{\ln y}$		M	Spv
0.608	-0.0022	5	0.719		7.2	43.894

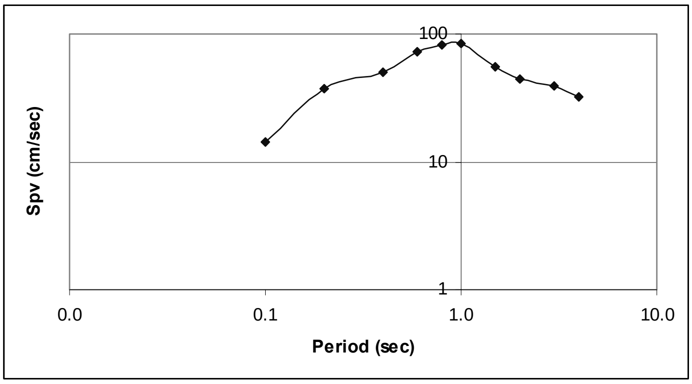
T=3 s						
b1	b2	b3	b4	b5	R	Ln (Y)
-1.67	1.59	0	-1.41	1.58	6.25	3.678
b6	b7	h	$\sigma_{\ln y}$		M	Spv
0.608	-0.00367	5	0.804		7.2	39.564

T=4 s						
b1	b2	b3	b4	b5	R	Ln (Y)
-2.2	1.67	0	-1.46	1.58	6.25	3.482
b6	b7	h	$\sigma_{\ln y}$		M	Spv
0.608	-0.00439	5	0.81		7.2	32.529

Table 23: Crouse spectra attenuation result

T (sec)	Spv (cm/sec)
0.1	14.370
0.2	37.086
0.4	50.792
0.6	73.018
0.8	81.366
1.0	83.254
1.5	56.044
2.0	43.894
3.0	39.564
4.0	32.529

Chart 14: Crouse spectra attenuation result



9. Summary:

This is a summary of the objectives of this project :

Site:	Tabriz city	
Database time period:	97 years	
Number of sources:	4 sources	
DSHA method result:	0.32g	
PSHA method result:	2% in 50 years:	0.32g
	5% in 50 years:	0.26g
	10% in 50 years:	0.22g

The main uncertainty in this project is the attenuation relation selection, because the limitations of Boore, Joyner and Fumal expression are:

1. 5.0 § M § 7.7
2. d § 100 km

There is no problem in second one but we used (4.0 § M) then it may cause some uncertainty in results.

10. References:

1. Russell A. Green, William J. Hall, "An overview of selected seismic hazard analysis methodologies", Civil Engineering Studies, No. 592 August 1994
2. Website of Memphis University, Teaching notes of Dr. S. Pezeshk, http://www.ce.memphis.edu/7119