EVALUATION OF EARTHQUAKE HAZARD POTENTIAL OF ANDAMAN REGION, INDIA

A DISSERTATION

Submitted in the partial fulfilment of the requirements for the award of the degree

of

MASTER OF TECHNOLOGY

in

EARTHQUAKE ENGINEERING

(With specialization in Soil Dynamics)

by

JAGTAP PRITAM PRAKASH

(17525002)

DEPARTMENT OF EARTHQUAKE ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

ROORKEE-247 667 (INDIA)

JUNE, 2019

CANDIDATE'S DECLARATION

I hereby, declare that the work which is being presented in this dissertation entitled, **"EVALUATION OF EARTHQUAKE HAZARD POTENTIAL OF ANDAMAN REGION, INDIA"**, being submitted in partial fulfilment of the requirements for the award of degree of "Master of Technology" in "Earthquake Engineering" with specialization in Soil Dynamics, to the Department of Earthquake Engineering, Indian Institute of Technology Roorkee, under the supervision of Dr. Daya Shanker, Associate Professor, Department of Earthquake Engineering, Indian Institute of Technology Roorkee, is an authentic record of my own work carried out during the period of June 2018 to June 2019

The matter embodied in this thesis has not been submitted by me for the award of any other degree of this or any other institute/University.

Date: June 2019
Place: Roorkee

Jagtap Pritam Prakash
Department of Earthquake Engineering
IIT Roorkee

CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief.

Date: June 2019
Place: Roorkee

Dr. Daya Shanker
Associate Professor
Department of Earthquake Engineering
Indian Institute of Technology Roorkee

ACKNOWLEDGEMENT

I wish to express my deep sense of gratitude and indebtedness to my guide and mentor **Dr. Daya Shanker**, Associate Professor, IIT Roorkee for being helpful and great source of inspiration. I am thankful to him for his persistent interest, constant encouragement, vigilant supervision and critical evaluation. His encouraging attitude has always been a source of inspiration for me. His helping nature, valuable suggestions and scholastic guidance are culminated in the form of the present work.

I would like to record my deep sense of gratitude to my encouraging parents and my loving brother, and my family, without whose blessings and love the thesis would not have seen the daylight. I would also like to thank all my dear friends and classmates for their support.

Place: Roorkee — Jagtap Pritam Prakash

Date: 20-06-2019 — Enrol No.-17525002

ABSTRACT

In the present study, a deterministic seismic hazard assessment of Andaman and Nicobar region is carried out, which is one of the most seismically active regions of India. Which usually need estimate of return period, probabilities of exceedance of specific levels of design load criteria or extreme safety conditions. Region 10°N – 15°N latitude and 91°E – 95°E longitude which exclusively include Andaman Islands have been considered for potential earthquake hazard analysis. Earthquake data from the 1973 – 2018 with magnitude $M_w \geq 4.5$ have been used from the catalogue of USGS. Hazard in the region have been quantified in terms of return periods and probabilities of occurrence of earthquake of any given magnitude. The line of expected extremes (LEE) based on 46 years (1973-2018) of seismicity for the region has been plotted. The medium to large size earthquakes have been predicted. Study indicates that the most probable largest annual earthquakes are close to 5.5 and the most probable earthquake that may occur in an interval of 50 years is estimated to be 7.2.

Seismic hazard analysis involves the quantitative estimation of ground shaking hazard at a particular site or for a particular region. In the present study Deterministic Seismic Hazard Analysis (DSHA) has been carried out for the Andaman region. The study area is one of the most seismically active regions. Fourteen seismotectonic sources are identified in this region. Using appropriate attenuation model the peak horizontal and peak vertical accelerations were find out. The value of peak vertical acceleration vary from 0.01g to 0.25g and peak horizontal accelerations vary from 0.03 to 0.44. The contour map for these PGA value is prepared which shows the larger PGA value present near the area where there is higher density of larger faults and vice versa.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter-1

Introduction

1.1 General

The Andaman Islands and Nicobar Islands are located near the border of the Indian Plate and the Burmese microplate. The Andaman Trench marks this border, located between the Bay of Bengal to the western part of the archipelago. Another prominent feature is the north-south West Andaman fault, which is strike slip in nature and located in the Andaman Sea to the east of the island. The Andaman Sea is like the Atlantic Ocean, is currently being widened by a tectonic process called "sea floor spreading". This happened along the submarine ridge of the seabed. The Indian plate sneaked into the Burmese microplate along the Andaman Trench, in a process known as "subduction". Shallow and occasional mid-depth earthquakes depict the subduction plate under the Andaman-Nicobar Islands, joining the seismicity activity trends of the India-Burman ranges. However, it must be pointed out that the proximity to the fault does not necessarily translate into a higher risk as compared to areas located further away, since the damage caused by the earthquake depends on many factors, such as subsurface geology and building codes comply with.

All Andaman and Nicobar Islands are located in Zone V. The entire island chain is also vulnerable to tsunamis both from local earthquakes and massive distant shocks. There are currently no early warning systems on any of the islands in the chain. As the earthquake database in India is incomplete, particularly before the period (before 1800 AD), these zones offer a rough guide to earthquake hazard in any given area and need to be updated regularly. In this study, a deterministic seismic hazard assessment was conducted for the Andaman and Nicobar regions, one of the regions with the highest seismic activity in India. This usually requires estimating the return period, the probability of exceeding a specific level of design load criteria or extreme safety conditions. Region 10^{o} N – 15^{o} N latitude and 91^{o} E – 95^{o} E longitude which exclusively include Andaman Islands have been considered for potential earthquake hazard analysis. Forty six years of earthquake data from the 1973 – 2018 with magnitude $M_w \geq 4.5$ have been used from the catalogue of USGS

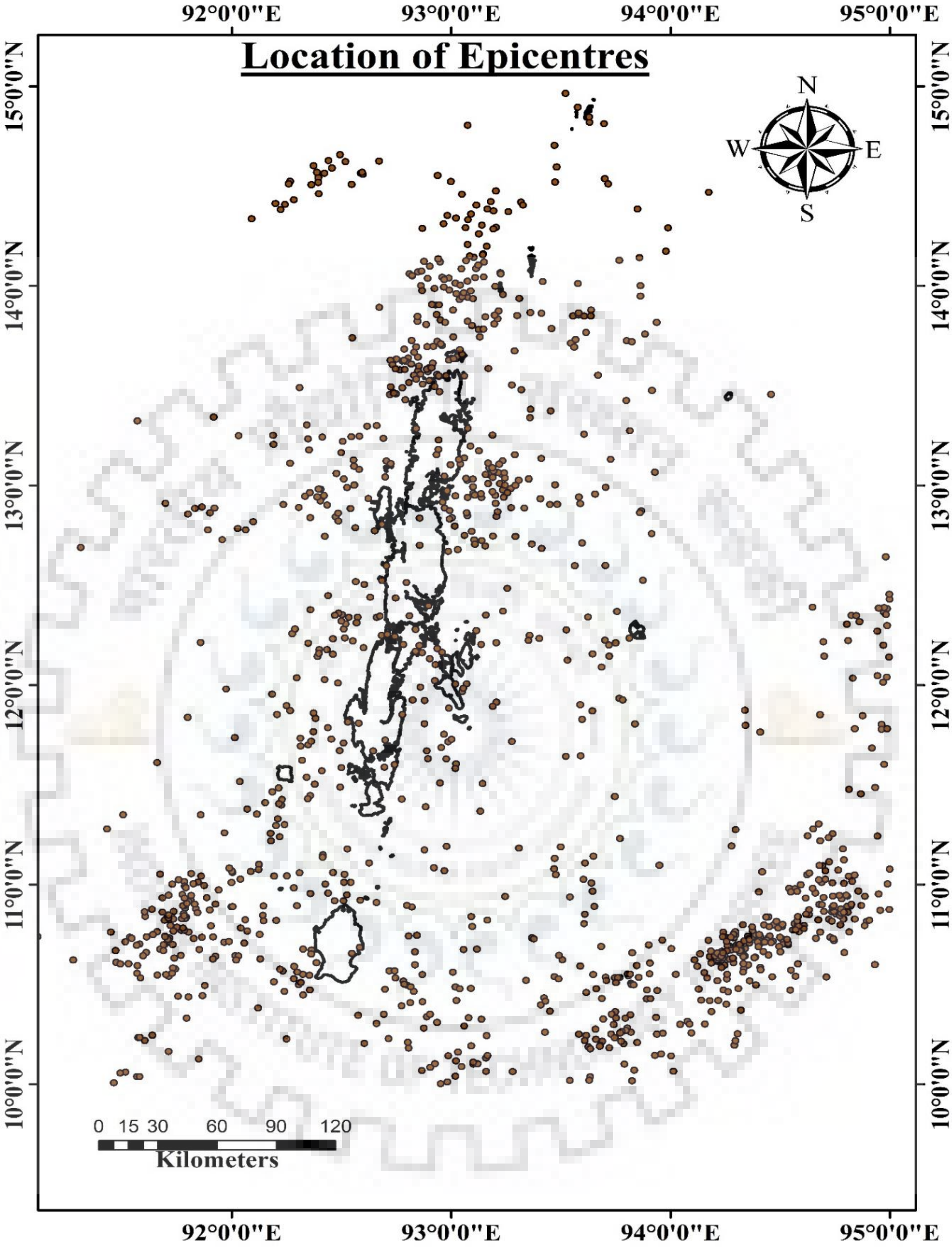

Figure 1.1.1 *Epicentres of all the earthquakes from 1973-2018*

1.2 Seismic hazards

Hazards related to earthquakes are commonly named as seismic hazards. The practice of earthquake engineering involves the classification and improvement of unstable hazards. Hazards connected with earthquakes are (Kramer. 1996): [7]

1.2.1 Ground shaking

Ground shaking is the most familiar effect of earthquakes. It is a result of the passage of seismic waves through the ground, and ranges from quite gentle in small earthquakes to incredibly violent in large earthquakes.

1.2.2 Faulting and Ground rupture

Ground rupture is the visible offset of the ground surface when an earthquake rupture along a fault affects the Earth's surface.

1.2.3 Structural hazards

Most dramatic and unforgettable pictures of earthquake damage are the structural collapse. It is not only restricted to predictable collapse of unreinforced masonry and adobe structures however to the surprising destruction of more modern constructions. Structural harm is the leading reason behind death and economic loss in several earthquakes.

1.2.4 Liquefaction

Liquefaction is the process that occurs in loose, water-saturated sediments due to shaking. In areas underlain by such material, ground vibrations cause the grains to lose contact with the grains, so the material tends to flow.

1.2.5 Tsunami

The tsunami is a secondary impact, a huge wave that can quickly cross the ocean, as discussed in more detail later. Earthquakes that occur below sea level and in coastal areas can cause tsunami, which can cause tsunami on the other side of the ocean thousands of kilometres away.

1.2.6 Landslides

Landslides caused by earthquakes are due to direct rupture and by sustained shaking of unstable slopes. They can easily destroy buildings in the path, or block roads and railway lines, or carry hilltop houses with them as they tumble. They can even stop the river occasionally, just like the Hebgen Lake earthquake on August 17, 1959.

1.2.7 Fire

Fire is the main source of damage after an earthquake. Ground rupture and liquefaction can easily damage natural gas mains and water pipes, both of which can cause fires to ignite and hinder efforts to control them.

Chapter-2

Evaluation of Probability of Earthquake occurrence

2.1 Introduction to Gumbel's Method

Seismic hazard analysis utilizes the total probability theorem associated with extreme the values. This method is called the Gumbel distribution, can be used to determine the peak ground acceleration for various return periods. The effect of each event on any point of interest can be determined by using an attenuation function, assuming each seismic event is independent of the point of interest.[10]

Various statistical models have been proposed to analyse earthquake occurrences and have achieved varying degrees of success. The occurrence of earthquakes in space and time can be explained by a stochastic process, which is a mathematical model that gives changes in physical systems in accordance with the law of probability. These models typically contain Poisson distributions or are extended to event clustering using Markov models of non-independent events. Estimates obtained are often unreliable due to the incompleteness of the data set or the inherent uncertainty of the distributed parameters. However, compared to methods that require the entire data set, the extremum approach has certain significant and significant advantages when it comes to the necessary data, which is rarely completely reported. Gumbel's Type I uses extreme value statistics and only requires partial data (the largest earthquake, i.e. extremes). [10]

2.2 Methodology and Formulas used for analysis

In this study, the Gumbel model based on extremum theory is used for calculations. Nevertheless, the theoretical details given in some steps are given here. The Gumbel distribution is a special case of the Fisher and tippet distributions used to estimate the Gutenberg-Richter parameters a and b. Gumbel's extreme value theory assumes that if the magnitude of the earthquake is unlimited, if the number of earthquakes decreases with increasing size each year, and if individual events are not correlated, then the largest annual earthquake magnitude is distributed by the cumulative distribution function G (m), where

$$G(m;\ \alpha,\beta) \ = \ \exp\left[-\alpha \exp\left(-\beta m\right)\right] \quad m \geq 0 \tag{1}$$

Where α is the average number of earthquakes having magnitude greater than 0 per year, β is the reciprocal of the average magnitude of the earthquake under the considered area, and m is the magnitude of the largest annual earthquake. Probability integral transformation theorem and the manipulation of equation (1) give the relationship

$$-\ln\left[-\ln\left(p_m\right)\right] \ = \ \beta m_i - \ln\left(\alpha\right) \tag{2}$$

where, p_m is the plotting position. The mean frequency of the i^{th} observation in the ordered extreme value set can be expressed as

$$p_m = \frac{i}{N+1} \tag{3}$$

Where, N is the total number of observations. The relationship between the Gumbel parameters α and β and the Gutenberg-Richter parameters *a* and *b* can be given by an expression

$$b = \beta \log_{10} e \tag{4}$$

And

$$a = \log_{10} \alpha \tag{5}$$

The expected number of earthquakes (N_m), with magnitude exceeding M in a given year can be represented by the Gutenberg-Richter seismicity relationship as

$$\log_{10} N_m = a - bM \tag{6}$$

where, *a* and *b* are constants; From above equation (6) we get

$$N_m = 10^{a-bM} \tag{7}$$

Poisson process gives the probability of at least one earthquake of magnitude ≥ M occurring within one year

$$p = 1 - e^{-N_m} = 1 - e^{-10^{a-bM}} = 1 - e^{-e^{\ln 10^{a-bM}}} \tag{8}$$

After simplification of above equation (8) we get,

$$M = \frac{a}{b} - \frac{1}{b \ln 10} \ln\left[-\ln(1-p)\right] \tag{9}$$

where, ‘p’ lies in the interval (0,1).

The probability of occurrence of at least one earthquake of magnitude equal to or greater than M within t years can be represented by the following relationship

$$p = 1 - e^{-Nt} = 1 - e^{-\left(10^{a-bM}\right)*t} \tag{10}$$

The expected number of earthquakes for any period of time which have magnitude ≥ M can be computed using equation given below.

$$\ln N_m = \ln \alpha - \beta m \tag{11}$$

Also, the return period of earthquakes having magnitude ≥ M is given by

$$T_m = \frac{1}{N_m} = \exp(\beta m)/\alpha \tag{12}$$

Several different formulas can be obtained from the model described by equation (1). As an example, the most probable annual maximum magnitude (u) will be estimated using α and

$$\beta u = ln.\alpha/\beta \tag{13}$$

The magnitude of most probable earthquake ‘u_t’ in‘t’ years period can be written as,

$$u_t = ln.\frac{\alpha.t}{\beta} = u + \frac{ln.t}{\beta} \tag{14}$$

By using the above formulas and method in considered region earthquake hazard parameters are estimated in the form of an expected time interval for the reoccurrence of an earthquake, the most probable magnitude of an earthquake in a given duration and the probability of occurrence of an earthquake in the specified time interval(i.e.=46 years).

2.3 Annual maximum earthquake magnitude

This report utilizes the 46 years earthquake data from 1973 to 2018 with M ≥ 4.5 for the considered region to study the return periods, probability of occurrence and earthquake risk.

The annual maximum magnitudes of all earthquakes observed in the region considered from the year 1973 to 2018 are shown in Table below.

Table 2.3.1: *Annual maximum earthquake magnitude for time interval 1973-2018*

Time	Magnitude	Magnitude (type)
1973	5.7	mb
1974	6.1	ms
1975	5.1	mb
1976	5.7	mb
1977	4.7	mb
1978	5.5	mb
1979	5.1	mb
1980	5.1	mb
1981	5.7	mb
1982	5.3	mb
1983	6.8	mw
1984	5.4	mb
1985	5.1	mb
1986	5	mb
1987	4.7	mb
1988	5.2	mb
1989	4.8	mb
1990	5.4	mw
1991	5.5	mw
1992	5.1	mb
1993	4.9	mb
1994	5.5	mw

1995	4.8	mb
1996	5.2	mb
1997	5.1	mb
1998	5	mb
1999	5	mb
2000	5.9	mw
2001	5.9	mw
2002	6.5	mw
2003	6	mw
2004	5.9	mb
2005	6.1	mw
2006	6.2	mw
2007	5.5	mw
2008	6.6	mw
2009	7.5	mw
2010	6.6	mw
2011	5.6	mw
2012	5.2	mb
2013	5.4	mw
2014	5.3	mb
2015	5.3	mb
2016	5.3	mb
2017	5.3	mb
2018	5.5	mb

2.4 Formula used for magnitude conversion

Non-uniform distributions between different magnitude scales require an empirical relationship to convert the magnitude scales of the various reports into Mw. In formulas, the ordinary least squares and total least squares techniques were used to compute the relationship between Mw and other magnitude scales.[3]

$Mw = 1.104mb - 0.194, \quad 3.5 \le mb \le 6.3 \quad (4.1)$

$Mw = 0.571Ms + 2.484, \quad 3.0 \le Ms < 5.5 \quad (4.2)$

$Mw = 0.817Ms + 1.176, \quad 5.5 \le Ms \le 7.7 \quad (4.3)$

Table 2.4.1: *Yearly earthquake maxima by order decreasing size of magnitude (Mw)*

Rank	Year	Magnitude	Magnitude (Type)	Magnitude (Mw)
1	2009	7.5	mw	7.5
2	1983	6.8	mw	6.8
3	2008	6.6	mw	6.6
4	2010	6.6	mw	6.6
5	2002	6.5	mw	6.5
6	2004	5.9	mb	6.3
7	1974	6.1	ms	6.2
8	2006	6.2	mw	6.2
9	1973	5.7	mb	6.1
10	1976	5.7	mb	6.1
11	1981	5.7	mb	6.1
12	2005	6.1	mw	6.1
13	2003	6	mw	6
14	1978	5.5	mb	5.9
15	2000	5.9	mw	5.9
16	2001	5.9	mw	5.9
17	2018	5.5	mb	5.9
18	1984	5.4	mb	5.8

19	1982	5.3	mb	5.7
20	2014	5.3	mb	5.7
21	2015	5.3	mb	5.7
22	2016	5.3	mb	5.7
23	2017	5.3	mb	5.7
24	2011	5.6	mw	5.6
25	1988	5.2	mb	5.5
26	1991	5.5	mw	5.5
27	1994	5.5	mw	5.5
28	1996	5.2	mb	5.5
29	2007	5.5	mw	5.5
30	2012	5.2	mb	5.5
31	1975	5.1	mb	5.4
32	1979	5.1	mb	5.4
33	1980	5.1	mb	5.4
34	1985	5.1	mb	5.4
35	1990	5.4	mw	5.4
36	1992	5.1	mb	5.4
37	1997	5.1	mb	5.4
38	2013	5.4	mw	5.4
39	1986	5	mb	5.3
40	1998	5	mb	5.3
41	1999	5	mb	5.3
42	1993	4.9	mb	5.2
43	1989	4.8	mb	5.1
44	1995	4.8	mb	5.1
45	1977	4.7	mb	5
46	1987	4.7	mb	5

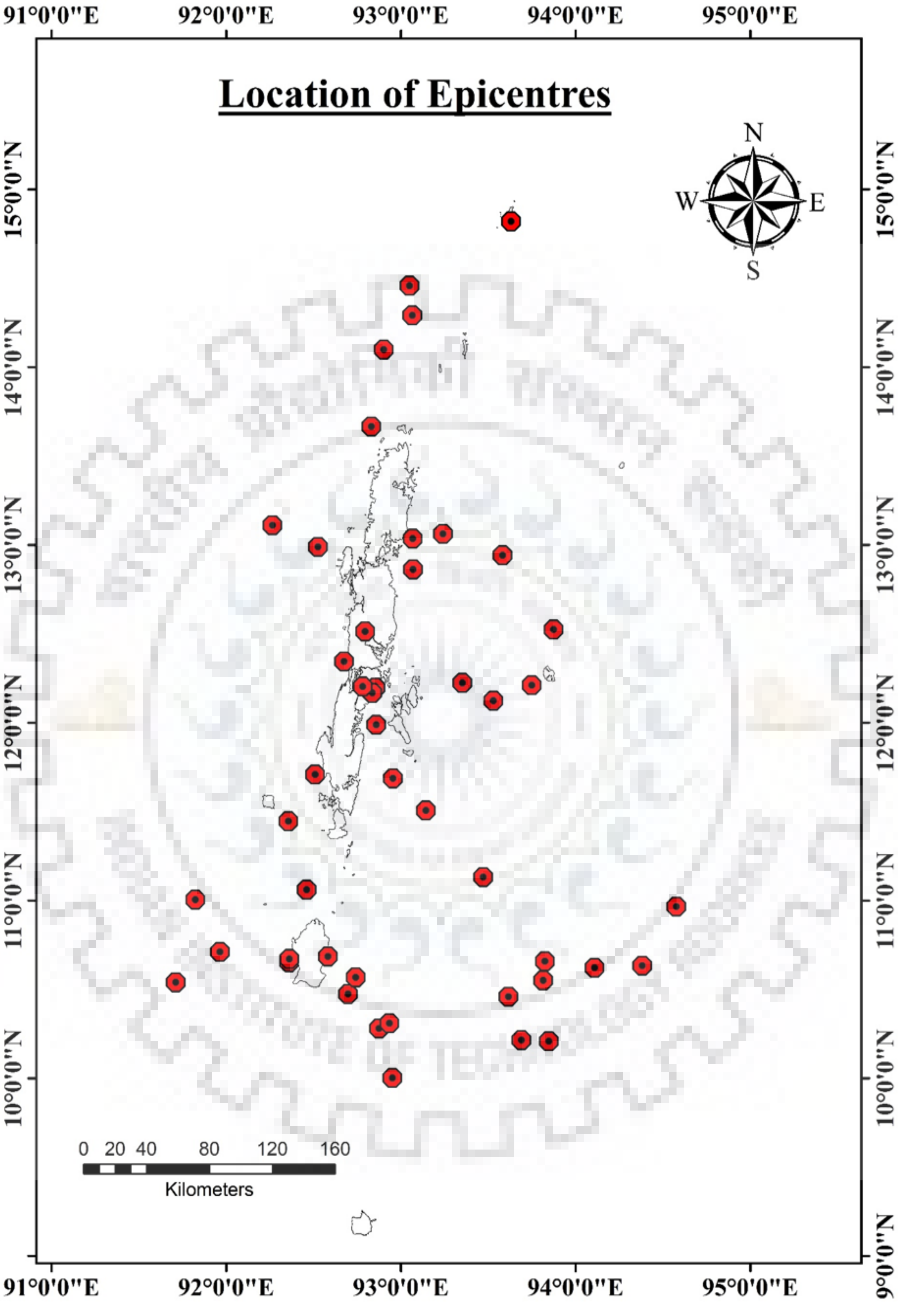

Figure 2.4.1 *Epicenters of all the extreme earthquake from 1973-2018*

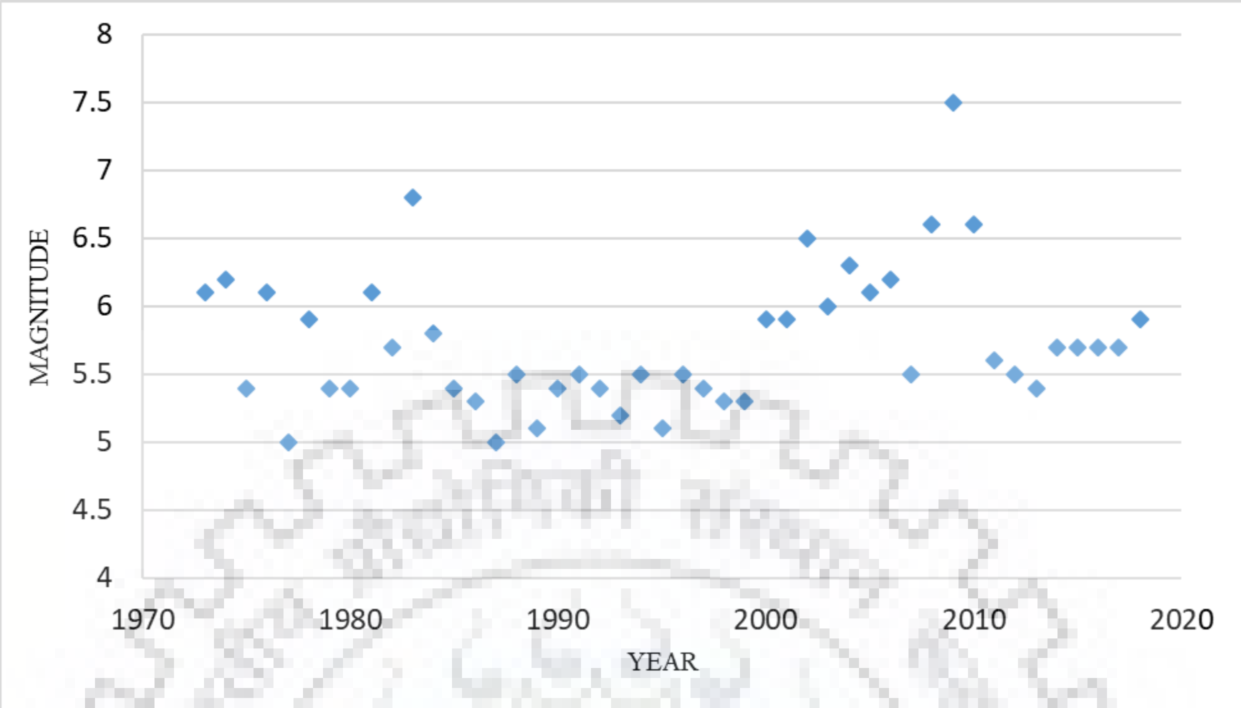

Figure 2.4.2 *Variation of maximum annual earthquake magnitude during time interval 1973-2018*

2.5 Regression constant *a & b* computation by using least square method

Table 2.5.1 *Frequency and reduced variate with increasing earthquake magnitude*

Rank	Magnitude (Mw)	Plotting Position (Pm)	Reduced variate ln [-ln (Pm)]
1	5	0.0213	1.348111486
2	5	0.0426	1.149622343
3	5.1	0.0638	1.012159052
4	5.1	0.0851	0.901726482
5	5.2	0.1064	0.806792641
6	5.3	0.1277	0.721923217
7	5.3	0.1489	0.644081641
8	5.3	0.1702	0.571378371
9	5.4	0.1915	0.502545251
10	5.4	0.2128	0.436681118
11	5.4	0.2340	0.373115682
12	5.4	0.2553	0.311330935

13	5.4	0.2766	0.250912982
14	5.4	0.2979	0.191521005
15	5.4	0.3191	0.132866397
16	5.4	0.3404	0.074698186
17	5.5	0.3617	0.016792472
18	5.5	0.3830	-0.041055518
19	5.5	0.4043	-0.099037633
20	5.5	0.4255	-0.157337871
21	5.5	0.4468	-0.216136702
22	5.5	0.4681	-0.275614976
23	5.6	0.4894	-0.335957629
24	5.7	0.5106	-0.397357407
25	5.7	0.5319	-0.460018801
26	5.7	0.5532	-0.524162392
27	5.7	0.5745	-0.590029855
28	5.7	0.5957	-0.657889905
29	5.8	0.6170	-0.728045563
30	5.9	0.6383	-0.800843266
31	5.9	0.6596	-0.876684523
32	5.9	0.6809	-0.956041168
33	5.9	0.7021	-1.039475719
34	6.0	0.7234	-1.127669149
35	6.1	0.7447	-1.221459678
36	6.1	0.7660	-1.321898363
37	6.1	0.7872	-1.430331146
38	6.1	0.8085	-1.548524194
39	6.2	0.8298	-1.678863258
40	6.2	0.8511	-1.824686786
41	6.3	0.8723	-1.990877447
42	6.5	0.8936	-2.184997779
43	6.6	0.9149	-2.419709128
44	6.6	0.9362	-2.718737591

45	6.8	0.9574	-3.135336654
46	7.5	0.9787	-3.839413771

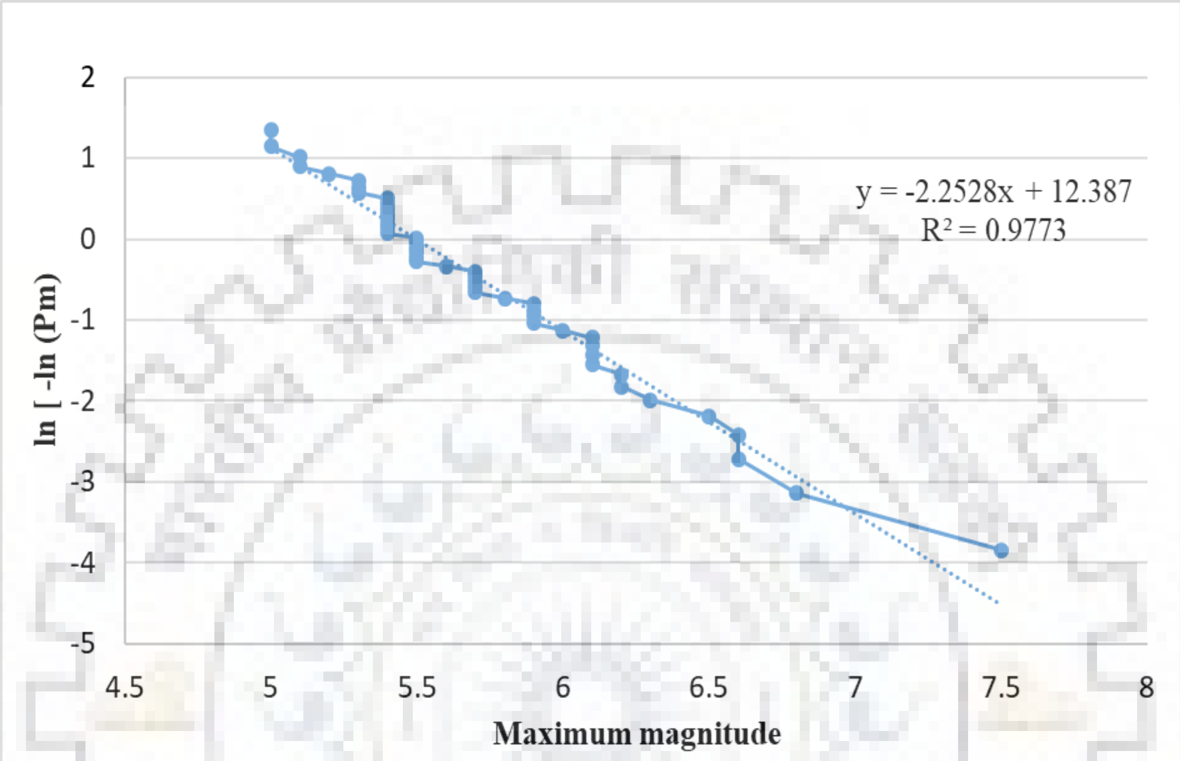

Fig.2.5.1 *Plot of Reduced variate with maximum magnitude to estimate a & b*

From the above graph,

β = 2.2528, $ln\ \alpha$ = 12.387

α = 239665

$a = log_{10}\alpha$ = 5.3796

$b = \beta\ log_{10}e$ =0.9784

2.6 Computation of expected number of earthquakes and it's the return period

The probability of earthquake occurrence for the period of

T=1 yr

T= 50 yrs

T= 100 yrs

is given as follow

Table 2.6.1 *Expected number of earthquake and the return period of an earthquake*

Magnitude (Mw)	**Nm**			**Tr (Year)**
	1 Year	***50 Year***	***100 Year***	
5	3.07	153.66	307.33	0.33
5.1	2.45	122.67	245.34	0.41
5.2	1.96	97.92	195.85	0.51
5.3	1.56	78.17	156.34	0.64
5.4	1.25	62.40	124.81	0.80
5.5	1.00	49.82	99.63	1.00
5.6	0.80	39.77	79.54	1.26
5.7	0.63	31.75	63.49	1.57
5.8	0.51	25.34	50.69	1.97
5.9	0.40	20.23	40.46	2.47
6	0.32	16.15	32.30	3.10
6.1	0.26	12.89	25.78	3.88
6.2	0.21	10.29	20.58	4.86
6.3	0.16	8.22	16.43	6.09
6.4	0.13	6.56	13.12	7.62
6.5	0.10	5.24	10.47	9.55
6.6	0.08	4.18	8.36	11.96
6.7	0.07	3.34	6.67	14.99
6.8	0.05	2.66	5.33	18.77
6.9	0.04	2.13	4.25	23.52
7	0.03	1.70	3.39	29.46

7.1	0.03	1.35	2.71	36.90
7.2	0.02	1.08	2.16	46.23
7.3	0.02	0.86	1.73	57.91
7.4	0.01	0.69	1.38	72.54
7.5	0.01	0.55	1.10	90.87
7.6	0.01	0.44	0.88	113.83
7.7	0.01	0.35	0.70	142.59
7.8	0.01	0.28	0.56	178.62
7.9	0.00	0.22	0.45	223.75
8	0.00	0.18	0.36	280.29

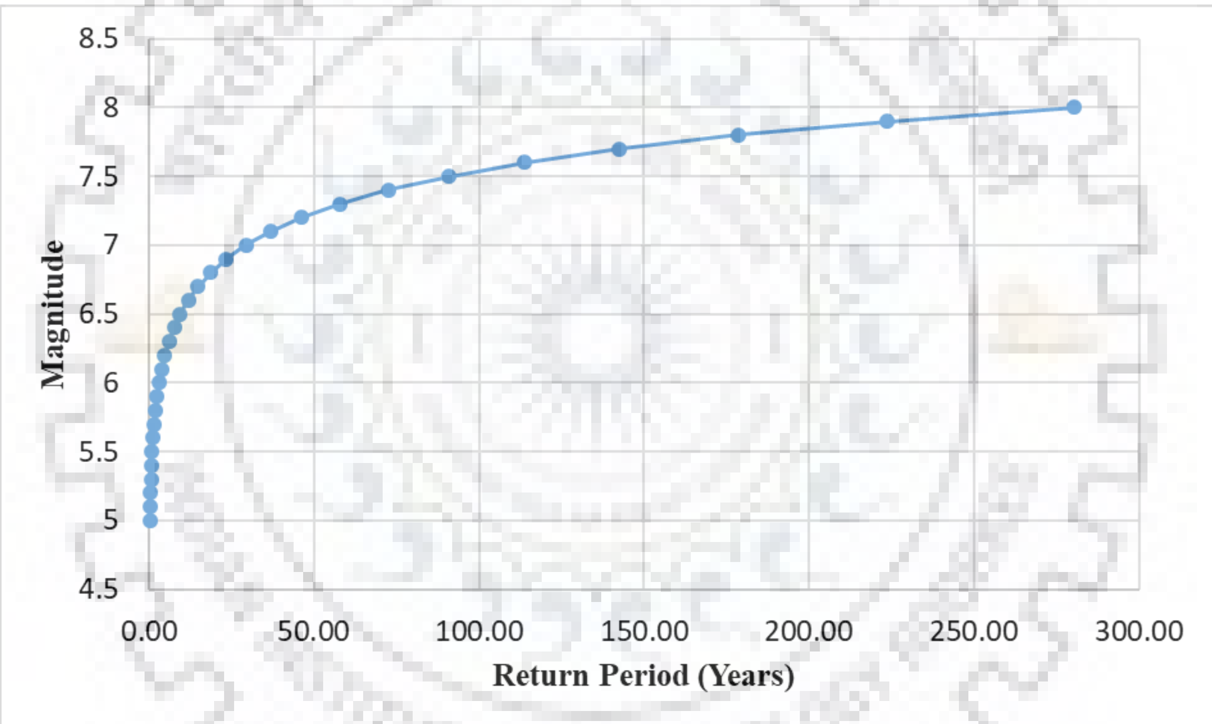

Fig.2.6.1.*Distribution of Magnitude with respect to the return period*

2.7 Probability of occurrence of an earthquake with time interval

Table 2.7.1 *Probability of earthquake with different time interval*

Time (Years)	P5.0	P5.5	P6.0	P6.5	P7.0	P7.5
1	0.95373	0.630765	0.276025	0.099417	0.033377	0.010945
2	0.997859	0.863666	0.47586	0.18895	0.06564	0.02177
3	0.999901	0.949661	0.620535	0.269582	0.096826	0.032477
4	0.999995	0.981413	0.725277	0.342198	0.126972	0.043066
5	1	0.993137	0.801107	0.407595	0.156111	0.05354
6	1	0.997466	0.856007	0.46649	0.184278	0.063899
7	1	0.999064	0.895752	0.51953	0.211504	0.074144
8	1	0.999655	0.924527	0.567296	0.237822	0.084278
9	1	0.999872	0.94536	0.610314	0.263261	0.0943
10	1	0.999953	0.960442	0.649056	0.287851	0.104213
11	1	0.999983	0.971361	0.683946	0.311621	0.114017
12	1	0.999994	0.979266	0.715367	0.334597	0.123714
13	1	0.999998	0.984989	0.743664	0.356806	0.133305
14	1	0.999999	0.989132	0.769148	0.378274	0.142791
15	1	1	0.992132	0.792099	0.399026	0.152173
16	1	1	0.994304	0.812768	0.419084	0.161452
17	1	1	0.995876	0.831382	0.438474	0.17063
18	1	1	0.997014	0.848145	0.457216	0.179708
19	1	1	0.997839	0.863242	0.475332	0.188686
20	1	1	0.998435	0.876838	0.492844	0.197565
21	1	1	0.998867	0.889082	0.509772	0.206348
22	1	1	0.99918	0.90011	0.526134	0.215034
23	1	1	0.999406	0.91004	0.54195	0.223626
24	1	1	0.99957	0.918984	0.557239	0.232123
25	1	1	0.999689	0.927038	0.572017	0.240527
26	1	1	0.999775	0.934292	0.586302	0.24884
27	1	1	0.999837	0.940824	0.60011	0.257061

28	1	1	0.999882	0.946707	0.613457	0.265193
29	1	1	0.999914	0.952006	0.626359	0.273235
30	1	1	0.999938	0.956777	0.63883	0.281189
31	1	1	0.999955	0.961074	0.650885	0.289057
32	1	1	0.999968	0.964944	0.662537	0.296838
33	1	1	0.999977	0.968429	0.673801	0.304534
34	1	1	0.999983	0.971568	0.684688	0.312146
35	1	1	0.999988	0.974394	0.695212	0.319674
36	1	1	0.999991	0.97694	0.705385	0.32712
37	1	1	0.999994	0.979233	0.715219	0.334485
38	1	1	0.999995	0.981297	0.724724	0.341769
39	1	1	0.999997	0.983157	0.733912	0.348973
40	1	1	0.999998	0.984831	0.742793	0.356099
41	1	1	0.999998	0.986339	0.751378	0.363146
42	1	1	0.999999	0.987697	0.759676	0.370116
43	1	1	0.999999	0.98892	0.767698	0.37701
44	1	1	0.999999	0.990022	0.775451	0.383829
45	1	1	1	0.991014	0.782946	0.390573
46	1	1	1	0.991907	0.790191	0.397243
47	1	1	1	0.992712	0.797193	0.40384
48	1	1	1	0.993436	0.803963	0.410365
49	1	1	1	0.994089	0.810506	0.416819
50	1	1	1	0.994677	0.816831	0.423201
51	1	1	1	0.995206	0.822944	0.429514
52	1	1	1	0.995682	0.828854	0.435758
53	1	1	1	0.996112	0.834566	0.441934
54	1	1	1	0.996498	0.840088	0.448042
55	1	1	1	0.996846	0.845425	0.454083
56	1	1	1	0.99716	0.850585	0.460058
57	1	1	1	0.997442	0.855572	0.465968
58	1	1	1	0.997697	0.860392	0.471813
59	1	1	1	0.997926	0.865052	0.477594

60	1	1	1	0.998132	0.869556	0.483311
61	1	1	1	0.998318	0.87391	0.488966
62	1	1	1	0.998485	0.878118	0.49456
63	1	1	1	0.998635	0.882187	0.500092
64	1	1	1	0.998771	0.886119	0.505563
65	1	1	1	0.998893	0.88992	0.510975
66	1	1	1	0.999003	0.893594	0.516327
67	1	1	1	0.999102	0.897146	0.521621
68	1	1	1	0.999192	0.900579	0.526857
69	1	1	1	0.999272	0.903897	0.532035
70	1	1	1	0.999344	0.907105	0.537157
71	1	1	1	0.99941	0.910205	0.542223
72	1	1	1	0.999468	0.913202	0.547233
73	1	1	1	0.999521	0.916099	0.552188
74	1	1	1	0.999569	0.9189	0.55709
75	1	1	1	0.999612	0.921607	0.561937
76	1	1	1	0.99965	0.924223	0.566732
77	1	1	1	0.999685	0.926752	0.571474
78	1	1	1	0.999716	0.929197	0.576164
79	1	1	1	0.999745	0.93156	0.580803
80	1	1	1	0.99977	0.933845	0.585391
81	1	1	1	0.999793	0.936053	0.589929
82	1	1	1	0.999813	0.938187	0.594417
83	1	1	1	0.999832	0.94025	0.598856
84	1	1	1	0.999849	0.942245	0.603247
85	1	1	1	0.999864	0.944172	0.607589
86	1	1	1	0.999877	0.946036	0.611884
87	1	1	1	0.999889	0.947837	0.616132
88	1	1	1	0.9999	0.949578	0.620333
89	1	1	1	0.99991	0.951261	0.624489
90	1	1	1	0.999919	0.952888	0.628599
91	1	1	1	0.999927	0.95446	0.632664

92	1	1	1	0.999935	0.95598	0.636684
93	1	1	1	0.999941	0.957449	0.640661
94	1	1	1	0.999947	0.95887	0.644593
95	1	1	1	0.999952	0.960242	0.648483
96	1	1	1	0.999957	0.961569	0.652331
97	1	1	1	0.999961	0.962852	0.656136
98	1	1	1	0.999965	0.964092	0.659899
99	1	1	1	0.999969	0.96529	0.663622
100	1	1	1	0.999972	0.966449	0.667303

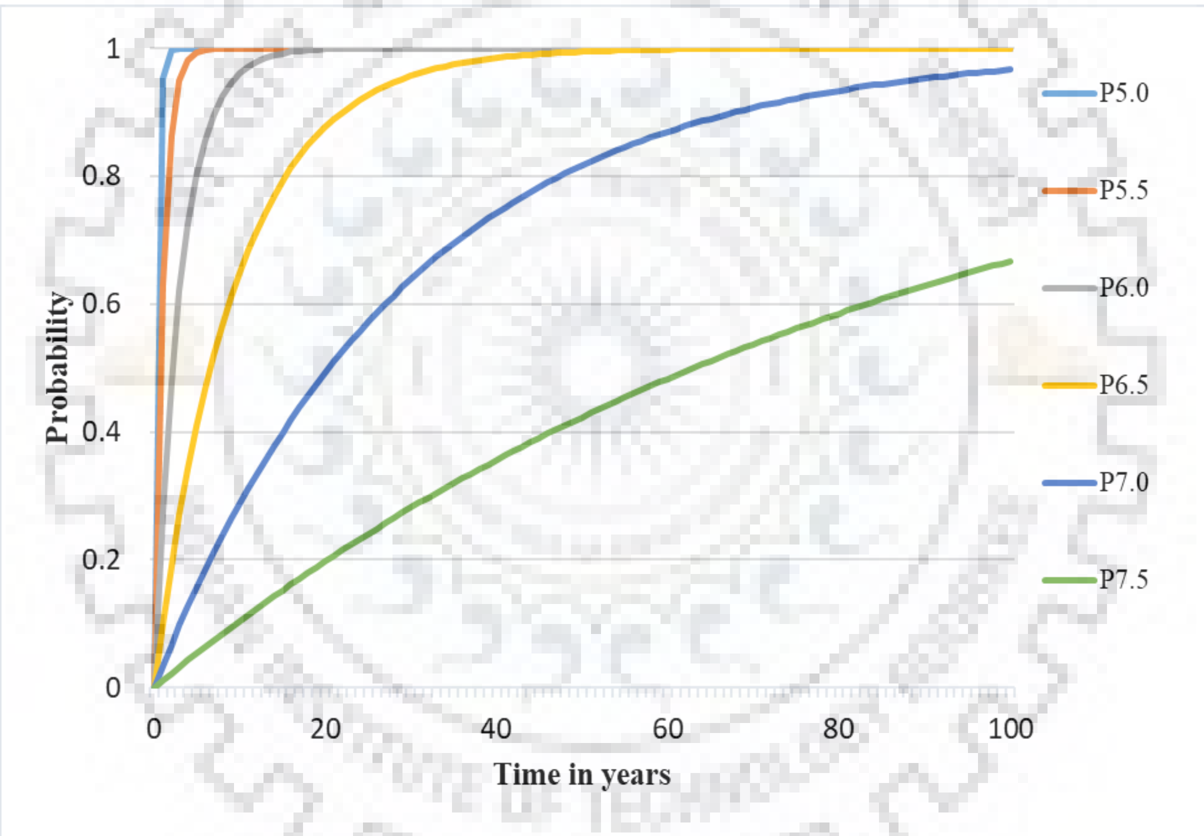

Fig.2.7.1 *Probability of occurrence of various magnitude earthquake over varying time*

Chapter-3

Seismic hazard assessment

3.1 General

India is viewed as a standout amongst the most seismically active nations. As indicated by seriousness of earthquake, Indian zones are partitioned in to five earthquake zones. To do seismic risk examination for a specific area one should consider the fault earthquake information first. Earthquake data has been created by considering some region around that specific locale. By thinking about the faults, shear zones, and lineaments in the region having the past earthquake events, a seismotectonic map can be made. Seismic earthquake catalogue has been utilized to determine the peak ground acceleration (PGA). By utilizing simple mathematical equation shortest distance between site to source has been determined causing seismic activities. Peak ground acceleration (PGA) model is provided for the basic design parameters of that region.

Seismic hazard describes the potentially damaging natural phenomena associated with earthquakes, such as ground shaking, surface fault rupture, soil liquefaction, landslides, fissures and tsunami. Seismic hazard could result to confrontational outcomes in the general public and society, for example, destruction of built environment and death toll. Seismic hazard assessment includes quantitative estimation of ground shaking. Seismic hazard can be surveyed deterministically as and when a particular earthquake scenario is assumed, or probabilistically, in which vulnerabilities in earthquake size, location, and time of event are explicitly considered. [7]

Seismic hazard examination involves quantitative estimation of ground motion hazards in specific areas. The ground motion can be described by various ground motion parameters. The earthquake resistant design of the main structures and engineering systems at site (e.g. dams, long-span bridges, nuclear power plants, high-rise buildings) found these descriptions to be an important requirement. A significant utilization of seismic hazard analysis is the preparation of seismic zoning map. The zoning map is based on estimating the magnitude of ground motion parameters (e.g., peak ground acceleration), which describes the risk of ground vibration covering a larger area. These maps can be used for seismic design of common types of structures.

There are two ways to analyse seismic hazard, first by a deterministic approach to the hazard estimation for a particular earthquake scenario, or secondly by using a probabilistic approach of hazard estimation, where the uncertainty of the magnitude, location, and timing of the earthquake is explicitly considered. (Kramer, 1996). A key part of seismic hazard analysis is the determination of Peak Ground Acceleration (PGA) and response acceleration (spectral acceleration) for a region/site. Spectral acceleration (Sa) is the important factor for civil engineering structural design. For different types of basic materials, such as rock, hard soil and weak soil, the development of design response spectra is a recognized trend in engineering practice. Analysis of tectonic features such as thrust, and faults helps to understand regional seismotectonic activity in the area. [7]

There are two methods of earthquake hazard analysis deterministic and probabilistic. The former is based on the estimation of the ground motion of a single large event whose size, and the shortest distance to the site is known. The probabilistic approach takes into account the full range of ground motion that may occur at different types of seismotectonic sources found around the site. Attenuation models are used to estimate strong motion parameters in a deterministic and probabilistic methodologies which correlates earthquake magnitude, distance, soil, geological conditions and seismic motion parameters of seismic motion.

Probabilistic and deterministic seismic hazard assessments are often expressed as discordant and different approaches to the problem of calculating seismic ground motion for design. Which approach to choose for each study depend on the nature of the project, and is adjusted for the amount and quality of seismic activity available in the area under study, i.e., available data to characterize seismic activity.

3.2 Deterministic Seismic Hazard Analysis (DSHA)

Deterministic seismic hazard analysis targets to find the largest possible ground motion at the site by considering the different types of seismotectonic records on the site. To do this, we need to assign the largest magnitude for each identified seismic seismotectonic source ((also termed as maximum credible earthquake or maximum considered earthquake). Typically, an area of 300 kilometres radius around the location is considered to identify the seismotectonic sources. The seismotectonic sources of an earthquake are idealized as a line, area, and volume sources. Point sources may be used if the epicentre is concentrated in a very small area away from the target location. Deterministic seismic hazard analysis assumes that the maximum magnitude earthquake in each source zone will occur at the closest possible distance from the site.

Deterministic Seismic Hazard Analysis (DSHA) uses seismic history and geology to identify seismic source and all hypotheses are used to interpret the strongest earthquakes that can occur over time.

The largest earthquake that can reasonably be expected at this particular location is called the Maximum Credible Earthquakes (MCEs). Assuming that such an earthquake can occur at any time during the use of the structure, an important structure is always designed for the MCEs. The Maximum Credible Earthquake (MCE) affecting the site is determined by performing a deterministic seismic hazard assessment. MCE is the largest earthquake that can occur along a recognized fault, which has the most severe impact on the site under currently known or assumed tectonic activity. The DSHA methodology can be described as a four-step process as given bellow.

Step 1: Identify all sources that can generate significant amounts of ground motion in the field, such as large sources over long distances and small sources over short distances. Definition of source geometry and establishment of seismic potential is included in characterization. [7]

Step 2: Selection of source-site distance parameter must be consistent with predictive relationship and should include finite fault effect. [7]

Step 3: The choice of controlling earthquake is based on ground motion parameters. Consider all sources, assuming Mmax appears at Rmin for each source Based on Mmax and Rmin calculated ground motion parameters and determine the critical values of ground motion parameters. [7]

Step 4: The definition of hazard at the site by using controlling earthquake involves ground motion M and source to site distance R to determine the parameters like Peak Ground Acceleration (PGA) and spectral acceleration (Sa). [7]

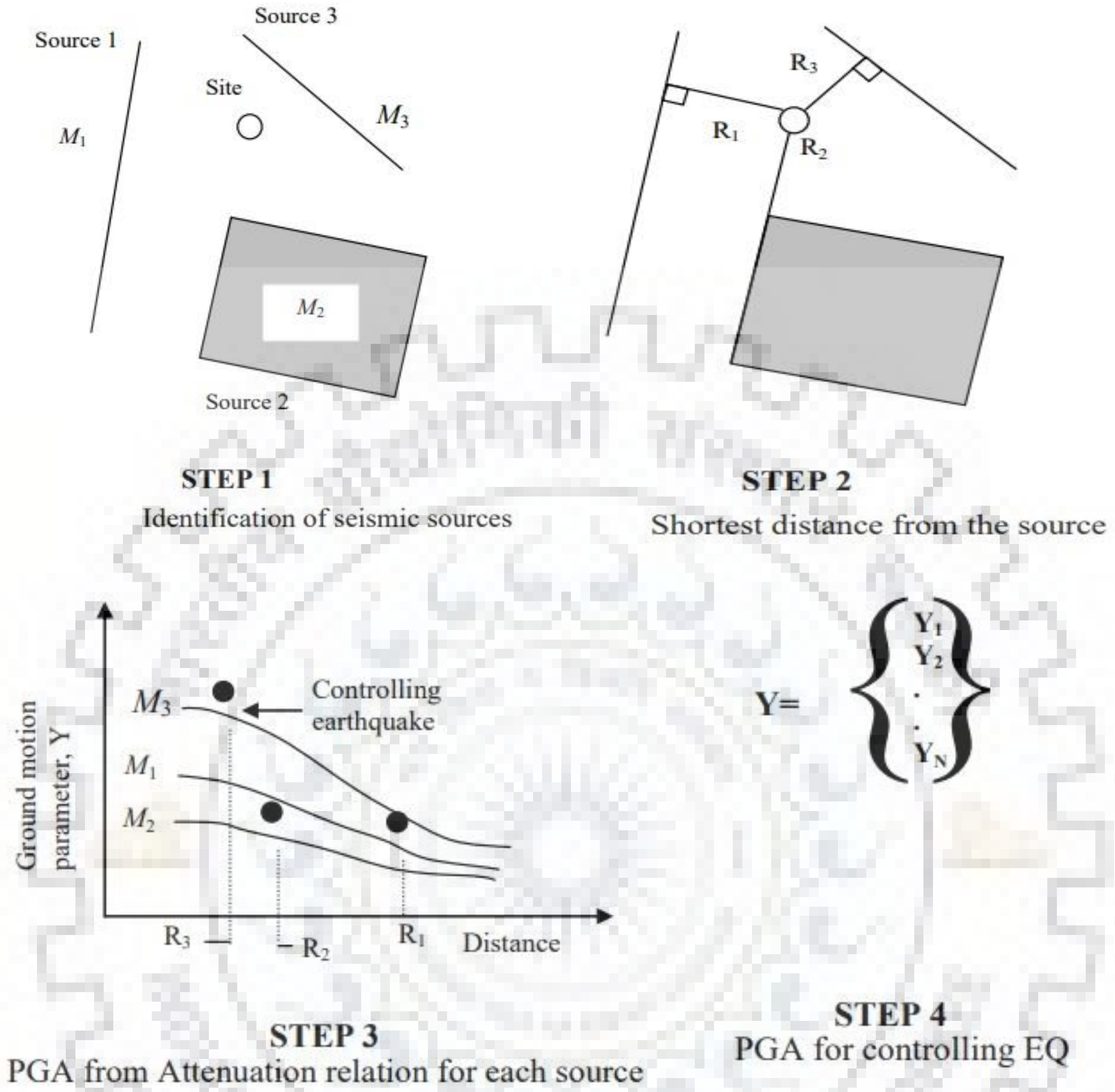

Figure 3.2.1 *Steps involved in Deterministic Seismic hazard analysis.* [7]

The seismic activity catalogue is the basic database used to determine the location, size and frequency of earthquakes. However, seismic activity statistics are usually based on a geologically short catalogue. Thus, information from seismic monitoring, history, geodetic monitoring, and geological records are combined to characterize the seismic sources. Understanding seismotectonic sources requires understanding of regional and local tectonic, geological and seismic activities. As mentioned earlier, earthquake sources are roughly divided into three types

i) Faults

ii) Geological structures and

iii) Hypothetical seismotectonic provinces.

In seismic hazard analysis, faults are often modelled as line sources or area sources. Seismic tectonic structures can have dimensions of tens to hundreds of kilometres and are often modelled as area sources. The seismotectonic province is modelled as a volume source. Figure 3.2.1, given below, shows the various types of source geometry.

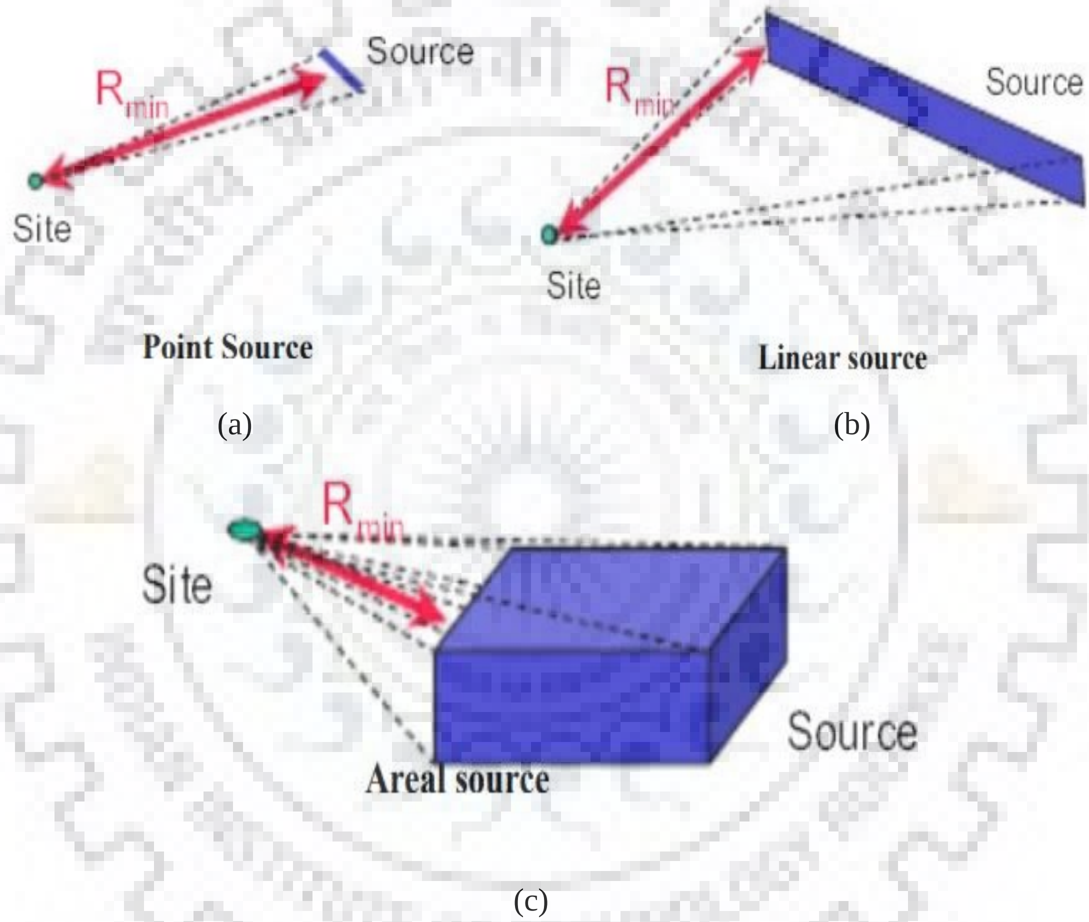

Figure 3.2.2 *Examples of different source zone geometries (a) short fault that can be modelled as a point source (b) shallow faults that can be modelled as a linear source (c) Three dimensional source zone. (source:nptel)*

3.3 Attenuation relation for estimation of strong ground motion

For a particular ground motion parameter, the relationship between the distance away from the fault rupture and the magnitude of the earthquake is called the attenuation relationship. In engineering practice, attenuation relationships are needed to estimate ground motion at the site. The attenuation relationship (also known as the attenuation model) is a mathematical expression that relates a particular strong ground motion parameter to one or more seismic parameters of the earthquake. This relationship should be simple. Physical models should be used to describe seismic energy attenuation with few parameters, such as earthquake magnitude, source distance, and sometimes geological conditions. The attenuation relationship can also be used as a predictive relationship of parameters, which decreases as the distance increases. In this study, the attenuation relationship was used. [l] Use the peak vertical accelerations recorded from 585 ground motion records, from 76 global earthquakes and fit them to the attenuation model. Vertical attenuation is the result of hybrid regression of regression described by [2]:

$$log_{10}a_v(g) = -1.15 + 0.245M - 1.096log_{10}(r + e^{0.256M}) + 0.096F - 0.011Er$$

Where r is the closest distance to the energy release zone in kilometres, M is the magnitude, F is the dummy variable, has a value equal to 1 for the reverse or reverse oblique event, otherwise O, and E is a dummy variable .The value of E is equal to 1 for interplate events, and the value is equal to 0 for intraplate events. When the ratio of vertical acceleration to horizontal acceleration is also sought, the same regression procedure is used to obtain the horizontal attenuation relationship from the same record. The resulting horizontal attenuation relationship is:

$$log_{10}a_h(g) = -0.62 + 0.177M - 0.982log_{10}(r + e^{0.284M}) + 0.132F - 0.00008Er$$

Where $a_h(g)$ represents the peak horizontal acceleration.

Chapter-4

Deterministic Seismic Hazard Assessment of considered region

4.1 Listing of seismotectonic sources

Using the SEISAT of India and regional seismic activities in the study region, 14 seismotectonic sources with linear characteristics were identified. These sources are listed in Table 4.1.1 and drawn using ArcGIS 10.5

Table 4.1.1 *List of the seismotectonic sources in the considered region*

Sr. no.	Source Name	Type of source
1	Eastern Boundary thrust (T-1)	Trust Fault
2	T-3	Trust Fault
3	T-4	Trust Fault
4	T-5	Trust Fault
5	T-6	Trust Fault
6	T-7	Trust Fault
7	T-8	Trust Fault
8	T-9	Trust Fault
9	T-10	Trust Fault
10	T-11	Trust Fault
11	T-12	Trust Fault
12	FC-1	Fault Involving Cover
13	FC-2	Fault Involving Cover
14	West Andaman Fault	Strike slip Fault

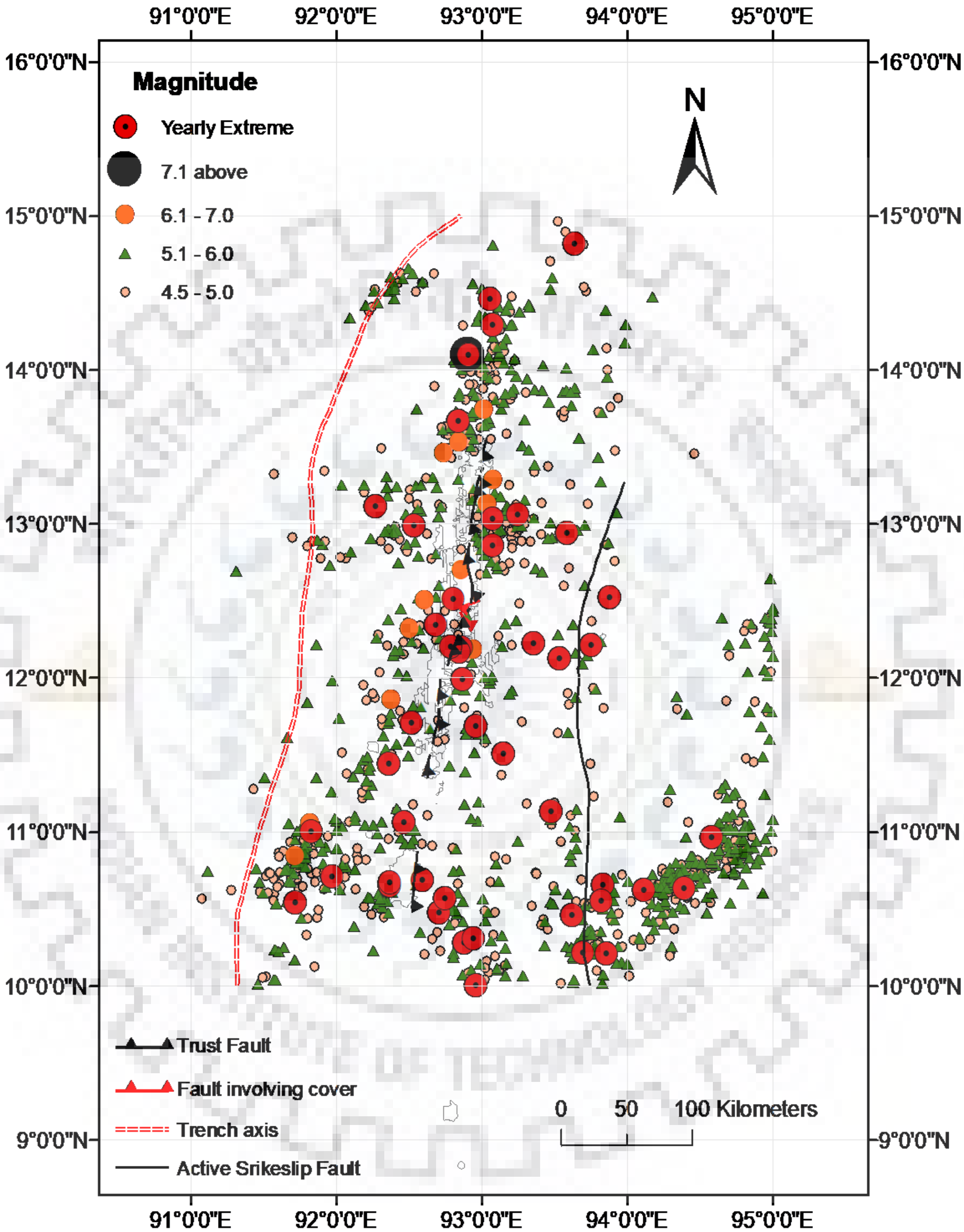

Fig 4.1.1 *All Seismotectonic sources of the study area.*

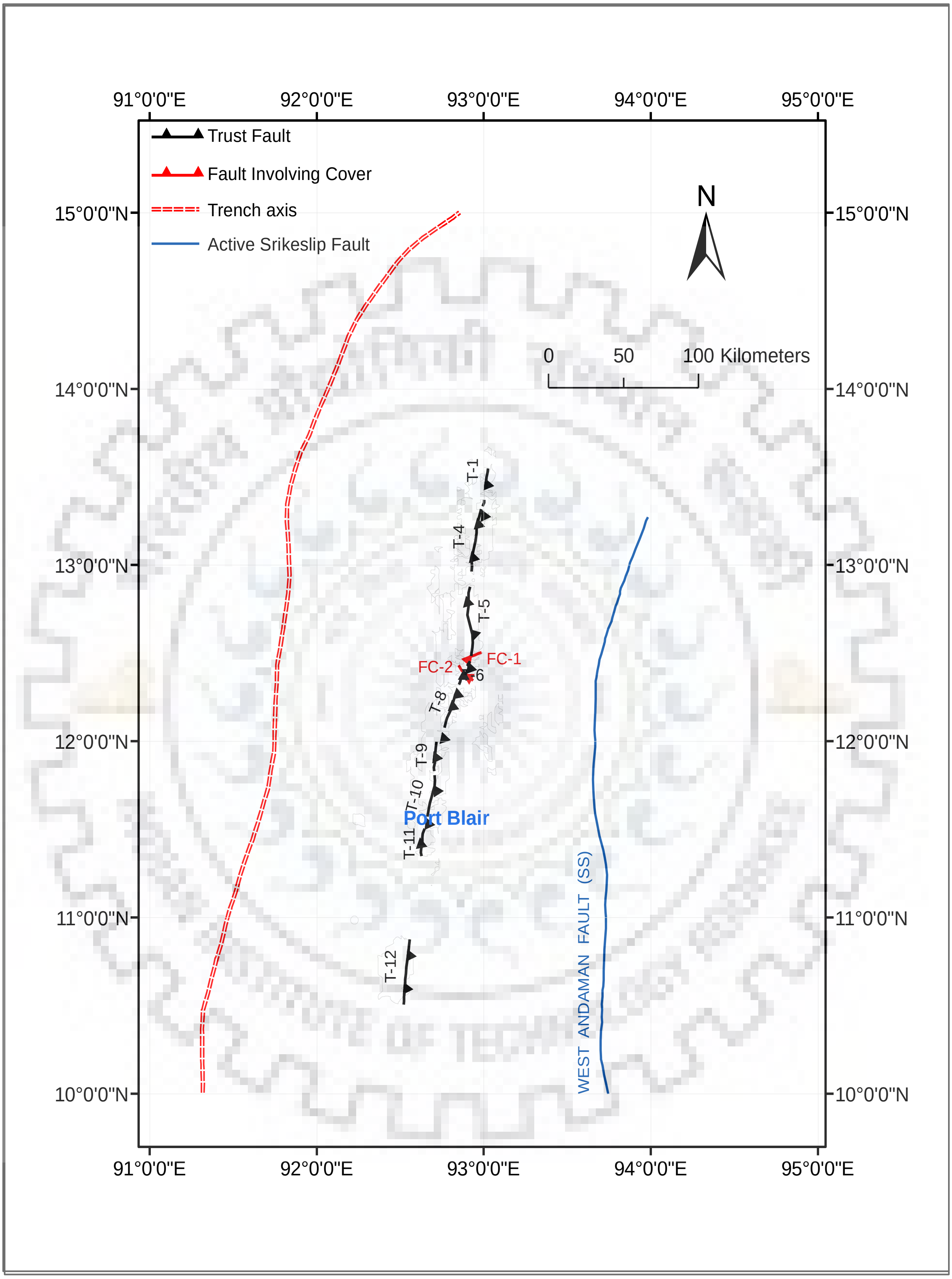

Fig 4.1.2 Names of major faults and lineaments

4.2 Estimation of maximum magnitude of sources and depth or energy release

There are two ways to calculate the expected magnitude or to assign the maximum magnitude for any fault.

a) Depending on the past seismicity records: This method uses the maximum magnitude observed in the seismic zone in the earthquake catalog. This is not an effective method because there are some faults without any obvious earthquakes, which are responsible for ground motion. This does not mean that they will not trigger any future earthquakes.

b) Depending on dimensions of rupture: Using the general assumption based on global data, that 1/3 to 1/2 of the total length of the fault will rupture to produce the largest earthquake. And using the following relationship between the surface rupture length (L) and the earthquake magnitude for reverse, strike slip, and normal faults the moment value (Mw) of each seismic source is computed. [10]

$$Mw = 5.16 + 1.12 logL \quad \text{(Srike slip fault)}$$

$$Mw = 5.00 + 1.22 logL \quad \text{(Reverse fault)}$$

$$Mw = 4.86 + 1.32 logL \quad \text{(Normal Fault)}$$

Using the above relationship, the maximum magnitude and rupture width of various seismotectonic sources were calculated and listed in Table 4.2.1.

4.3 Steps for computation

Maximum horizontal ground accelerations and maximum vertical ground acceleration for a given point were calculated using four softwares Arc View GIS 10.5, Arc Info GIS 10.5, MS Excel and Surfur 13. The steps used for the computation of maximum horizontal ground accelerations and maximum vertical ground acceleration are given bellow:

- All the earthquake epicenters and tectonic features laying between latitude $10°N$ to $15°N$ and longitude $91°E$ to $95°E$ were identified and digitized in Arc View GIS 10.5.To do this, SEISAT 36, 37, 40 and 41 of the Seismotectonic atlas of

India (GSI, 2000) were scanned and seismic tectonic maps were prepared. Using these digitized seismotectonic maps, composite seismotectonic maps were generated to indicate seismic sources such as faults, lineaments and other geological formations. To calculate the maximum magnitude of the various sources, estimate their length.

- The study area is located between latitude 10°N to 15°N and longitude 91°E to 95°E. The area is divided into small grids, each grid has a dimension of 0.5° Longitude 0.5° longitude. The center of each grid is the site used to calculate ground motion parameters.
- For every site following computational steps were used
    1. The shortest distance to all seismic sources (faults) were measured by using Arc Info GIS 10. 5
    2. These shortest distances were combined with the vertical distances gives the depth of energy release to calculate the distance to the zone of energy release. By using these distances of the zone of energy release and maximum magnitudes assigned to various seismotectonic sources, the peak vertical ground accelerations and horizontal accelerations for the site were calculated by using the specified attenuation relationship.
    3. The largest value among the all accelerations were taken to represent the acceleration of the considered site

The above mentioned steps were repeated for all the grid points (i.e. sites) and the highest acceleration value at the centre of each grid was taken and the contour maps showing the variation of PGA is prepared. For the preparation of contour map Surfer13 software was used.

Table 4.3.1 *Seismotectonic source and corresponding fault length, rupture length, maximum magnitude, shortest distance to site*

Sr. no.	Seismotectonic Source Name	Fault Type	Fault Length (km)	Rupture Length (km)	Magnitude (Mw)	Shortest Distance to site (km)
1	Eastern Boundary Thrust (T-1)	RF	11.377	3.792	5.71	232.28
2	T-3	RF	4.331	1.444	5.19	242.16
3	T-4	RF	39.7	13.233	6.37	244.44
4	T-5	RF	44.106	14.702	6.42	273.58
5	T-6	RF	3.789	1.263	5.12	310.56
6	T-7	RF	3.955	1.318	5.15	316.47
7	T-8	RF	24.201	8.067	6.11	321.62
8	T-9	RF	18.822	6.274	5.97	342.53
9	T-10	RF	26.644	8.881	6.16	360.98
10	T-11	RF	17.712	5.904	5.94	388.83
11	T-12	RF	41.276	13.759	6.39	450.75
12	FC-1	RF	8.535	2.845	5.55	308.11
13	FC-2	RF	13.451	4.484	5.79	308.57
14	West Andaman Fault	SS	369.541	123.180	7.50	336.38

By using the Mw value from above table, the rupture width (Rw) of each source is computed using the following relationship. [10]

$$\text{Log (Rw)} = -1.01 + 0.32\text{Mw}$$

For the calculation of the depth of energy release (Dz), the General Focal Depth (GFD) was set to 40 km because the earthquake depth reported in this area is generally in the range of 20 to 60 kilometre. The non seismogenic depth (NSD) is considered as 3 km (Campbell, 2003). The dip angle (α) is 15 ° for thrust type fault source and 90 ° for normal and strike slip type faults. [10]

The depth of energy release (Dz) has been computed using the following relationships

$$Dz = NSD + GFD - (Rw/2)\sin\alpha \quad \text{when } Rw < GFD$$

$$Dz = NSD + (Rw/2)\sin\alpha \quad \text{when } Rw \geq GFD$$

Table 4.3.2 *Seismotectonic sources and corresponding rupture length, maximum magnitude, rupture width (Rw), Depth to the zone of energy release (Dz)*

Sr. no.	Source Name	Fault Type	Fault Length (km)	Rupture Length (km)	Magnitude (Mw)	Rupture Width Rw (km)	Dz (km)
1	Eastern Boundary thrust (T-1)	RF	11.377	3.792	5.71	6.546	42.153
2	T-3	RF	4.331	1.444	5.19	4.490	42.419
3	T-4	RF	39.7	13.233	6.37	10.663	41.621
4	T-5	RF	44.106	14.702	6.42	11.111	41.563
5	T-6	RF	3.789	1.263	5.12	4.262	42.449
6	T-7	RF	3.955	1.318	5.15	4.334	42.439
7	T-8	RF	24.201	8.067	6.11	8.790	41.863

8	T-9	RF	18.822	6.274	5.97	7.968	41.969
9	T-10	RF	26.644	8.881	6.16	9.126	41.820
10	T-11	RF	17.712	5.904	5.94	7.781	41.994
11	T-12	RF	41.276	13.759	6.39	10.827	41.600
12	FC-1	RF	8.535	2.845	5.55	5.852	42.243
13	FC-2	RF	13.451	4.484	5.79	6.989	42.096
14	West Andaman fault	SS	369.541	123.180	7.50	24.547	30.726

The distance to the zone of energy release (De) is estimated using the depth to the zone of energy release (Dz) and the epicentral distance (Ep) as:

$$De = (Ep^2 + Dz^2)^{0.5}$$

The attenuation relationship developed by Abrahamson and Lithehiser (1989) has been used to compute both peak horizontal acceleration (a_h) and peak vertical acceleration (a_v). [1]

$$log_{10}a_v(g) = -1.15 + 0.245M - 1.096log_{10}(r + e^{0.256M}) + 0.096F - 0.011Er$$

$$log_{10}a_h(g) = -0.62 + 0.177M - 0.982log_{10}(r + e^{0.284M}) + 0.132F - 0.00008Er$$

The results of ground motion of Shimla using the above relationship with respect to different sources are listed in table 4.2.3

Table 4.3.3 *Calculation of PGA using attenuation relationship of Abrahamson and Lithehiser*

S.No.	**Source Name**	**Fault Type**	**Mmax**	**De (km)**	**E**	**F**	**PGA-Ah (g)**	**PGA-Av (g)**
1	T-1	RF	5.706	236.074	1	1	0.010	0.003
2	T-3	RF	5.195	245.847	1	1	0.008	0.002
3	**T-4**	**RF**	**6.368**	**247.958**	**1**	**1**	**0.018**	**0.006**
4	T-5	RF	6.424	276.719	1	1	0.010	0.003
5	T-6	RF	5.124	313.448	1	1	0.005	0.001
6	T-7	RF	5.146	319.303	1	1	0.005	0.001
7	T-8	RF	6.106	324.333	1	1	0.007	0.002
8	T-9	RF	5.973	345.092	1	1	0.006	0.002
9	T-10	RF	6.157	363.394	1	1	0.006	0.002
10	T-11	RF	5.941	391.091	1	1	0.005	0.001
11	T-12	RF	6.389	452.666	1	1	0.005	0.001
12	FC-1	RF	5.554	310.992	1	1	0.006	0.002
13	FC-2	RF	5.795	311.428	1	1	0.007	0.002
14	WAF	SS	7.500	337.78	1	0	0.009	0.004

PGA calculation in above table shows that for site considered (i.e. 14.75^{o}N, 91.25^{o}E) peak horizontal acceleration (a_h) of 0.018g and peak vertical acceleration (a_v) of 0.006g is produced by thrust (T-4).

Chapter-5

Result and Discussion

5.1 General

The study present the Deterministic Seismic Hazard Assessment (DSHA) of Andaman region in India The study area lies within latitude 10°N to 15°N and longitude 91°E to 95°E

The area is divided into small grids, each grid has a dimension of 0.5° Longitude 0.5° longitude. The centre of each grid is the site used to calculate ground motion parameters. The ratios of peak vertical acceleration to peak horizontal acceleration is also calculated and tabulated bellow.

The maximum value of peak vertical acceleration and peak horizontal acceleration at the centre of each grid (i.e. site) point is calculated. And the source which is making the maximum contribution to it is tabulated in table given bellow.

The contour map showing the variation of peak vertical acceleration and peak horizontal acceleration is drawn using Surfer software.

Table5.1.1 *computed peak horizontal accelerations (Ah), peak vertical accelerations (Av)*

Sr.No.	Latitude (°N)	Longitude (°E)	PGA-Ah (g)	PGA-Av (g)	Av/Ah	Source
1	14.75	91.25	0.018	0.006	0.30	T4
2	14.25	91.25	0.035	0.011	0.31	T4
3	13.75	91.25	0.049	0.017	0.35	T4
4	13.25	91.25	0.052	0.019	0.36	T4
5	12.75	91.25	0.055	0.020	0.36	T5
6	12.25	91.25	0.053	0.019	0.35	T8
7	11.75	91.25	0.059	0.021	0.36	T10
8	11.25	91.25	0.057	0.020	0.35	T11
9	10.75	91.25	0.060	0.021	0.35	T11
10	10.25	91.25	0.060	0.021	0.35	T11

11	14.75	91.75	0.038	0.012	0.32	T1
12	14.25	91.75	0.048	0.016	0.33	T1
13	13.75	91.75	0.071	0.027	0.38	T4
14	13.25	91.75	0.077	0.030	0.38	T4
15	12.75	91.75	0.083	0.032	0.39	T5
16	12.25	91.75	0.079	0.031	0.39	T5
17	11.75	91.75	0.093	0.036	0.39	T10
18	11.25	91.75	0.089	0.034	0.39	T10
19	10.75	91.75	0.118	0.049	0.41	T12
20	10.25	91.75	0.115	0.047	0.41	T12
21	14.75	92.25	0.055	0.020	0.36	T4
22	14.25	92.25	0.078	0.030	0.38	T4
23	13.75	92.25	0.110	0.045	0.41	T4
24	13.25	92.25	0.225	0.094	0.42	T4
25	12.75	92.25	0.280	0.119	0.43	T5
26	12.25	92.25	0.215	0.059	0.28	T8
27	11.75	92.25	0.166	0.106	0.64	T10
28	11.25	92.25	0.244	0.101	0.42	T11
29	10.75	92.25	0.332	0.152	0.46	T12
30	10.25	92.25	0.198	0.089	0.45	T12
31	14.75	92.75	0.057	0.020	0.34	T1
32	14.25	92.75	0.093	0.035	0.37	T1
33	13.75	92.75	0.158	0.064	0.41	T1
34	13.25	92.75	0.360	0.167	0.46	T4
35	12.75	92.75	0.444	0.214	0.48	T5
36	12.25	92.75	0.363	0.163	0.45	T8
37	11.75	92.75	0.249	0.113	0.45	T10
38	11.25	92.75	0.320	0.139	0.43	T11
39	10.75	92.75	0.364	0.169	0.46	T12
40	10.25	92.75	0.205	0.093	0.45	T12
41	14.75	93.25	0.062	0.029	0.47	SS

42	14.25	93.25	0.095	0.035	0.37	T1
43	13.75	93.25	0.166	0.068	0.41	T1
44	13.25	93.25	0.223	0.102	0.46	T4
45	12.75	93.25	0.206	0.093	0.45	T5
46	12.25	93.25	0.236	0.139	0.59	SS
47	11.75	93.25	0.240	0.142	0.59	SS
48	11.25	93.25	0.211	0.122	0.58	SS
49	10.75	93.25	0.217	0.126	0.58	SS
50	10.25	93.25	0.223	0.130	0.58	SS
51	14.75	93.75	0.070	0.033	0.48	SS
52	14.25	93.75	0.109	0.056	0.52	SS
53	13.75	93.75	0.196	0.112	0.57	SS
54	13.25	93.75	0.329	0.205	0.62	SS
55	12.75	93.75	0.393	0.253	0.64	SS
56	12.25	93.75	0.381	0.244	0.64	SS
57	11.75	93.75	0.377	0.241	0.64	SS
58	11.25	93.75	0.394	0.254	0.64	SS
59	10.75	93.75	0.392	0.252	0.64	SS
60	10.25	93.75	0.390	0.251	0.64	SS
61	14.75	94.25	0.069	0.033	0.48	SS
62	14.25	94.25	0.108	0.056	0.52	SS
63	13.75	94.25	0.192	0.109	0.57	SS
64	13.25	94.25	0.301	0.185	0.61	SS
65	12.75	94.25	0.225	0.132	0.58	SS
66	12.25	94.25	0.184	0.104	0.57	SS
67	11.75	94.25	0.181	0.102	0.56	SS
68	11.25	94.25	0.203	0.117	0.57	SS
69	10.75	94.25	0.197	0.113	0.57	SS
70	10.25	94.25	0.192	0.110	0.57	SS
71	14.75	94.75	0.061	0.029	0.46	SS
72	14.25	94.75	0.087	0.043	0.50	SS

73	13.75	94.75	0.123	0.065	0.53	SS
74	13.25	94.75	0.145	0.079	0.54	SS
75	12.75	94.75	0.123	0.065	0.53	SS
76	12.25	94.75	0.103	0.053	0.51	SS
77	11.75	94.75	0.101	0.051	0.51	SS
78	11.25	94.75	0.110	0.057	0.52	SS
79	10.75	94.75	0.107	0.055	0.51	SS
80	10.25	94.75	0.105	0.054	0.51	SS

5.2 Contour map of vertical and horizontal ground motion

Observation made from Table 5.1.1 shows that the computed PGA values for peak vertical acceleration varies in the range of 0.01g to 0.25g .These values are plotted to draw the contour as shown in Fig 5.2.2.The respective peak horizontal acceleration falls in the range of 0.03g to 0.44g and the contour of peak horizontal acceleration is shown in Fig5.2.1.

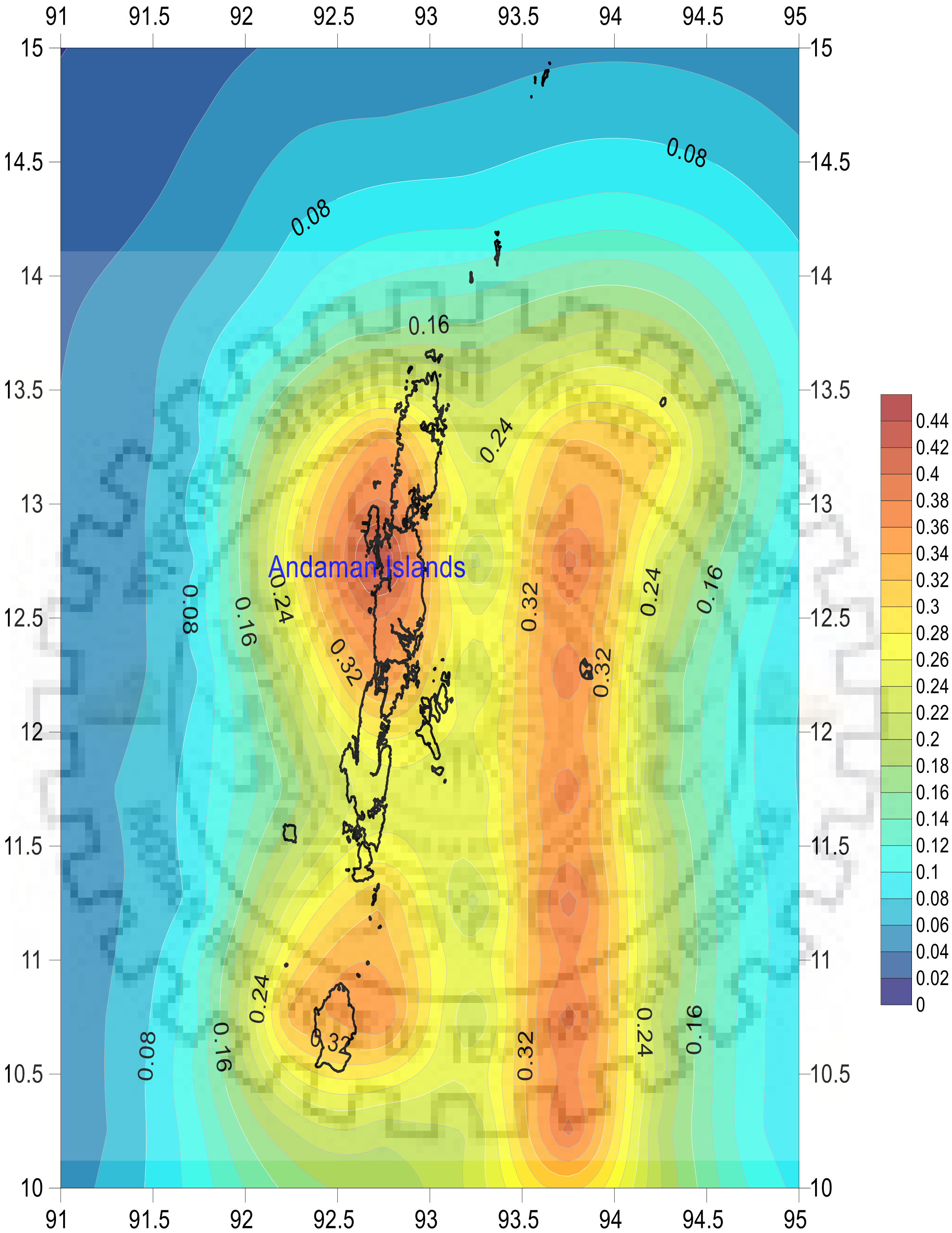

Fig 5.2.1 *Contour map showing variation of peak horizontal acceleration in the study region*

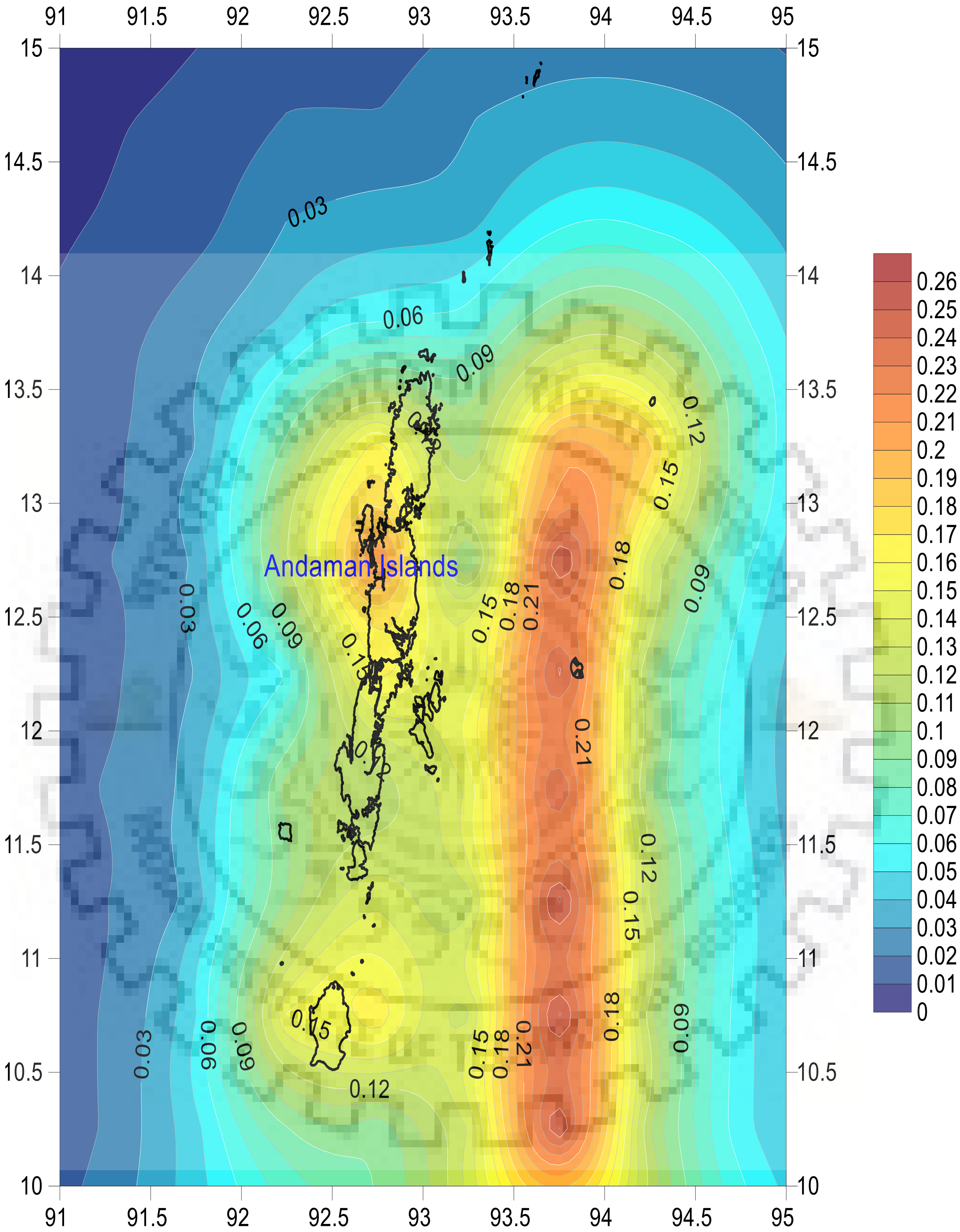

Fig 5.2.1 *Contour map showing variation of peak vertical acceleration in the study region*

5.3 Conclusion

From the above DSHA work the following major conclusions can be made:

- The estimated peak vertical acceleration varies from 0.01g to 0.25g and the respective peak horizontal acceleration falls in the range of 0.03g to 0.44g. These accelerations seems to be more realistic as this area comes in zone V whose PGA value is 0.36g.

- The contour map prepared by using these PGA values shows that the value is higher at the location where the fault density is high and faults of large length are present and vice versa

From the Gumbel's method following conclusion can be made:

- Study indicates that the most probable largest annual earthquakes are close to 5.5 and the most probable earthquake that may occur in an interval of 50 years is estimated to be 7.2.
- The most probable earthquake that may occur in an interval of 100 years is estimated to be 7.5.
- With increase in magnitude of earthquake, the value of probability of occurrence decreases.

References

[1] Abrahamson, N.A., Lithehiser, J. J. (1989), "Attenuation of vertical peak acceleration". Bulletin of seismological society of America; vol.79, no.3: 549-567.

[2] Boore, D.M., Joyner, W.B. (1978), "Estimation of ground motion parameters". U.S.G.S; vol. 795, no.43.

[3] Yenier, E., Erdogan, O., Akkar, S. (2008), "Empirical relationships for magnitude and source-to-site distance conversions using recently compiled Turkish strong-ground motion database", The 14th World Conference on Earthquake Engineering; Beijing, China.

[4] Gumbel, E. J. (1958), "Statistics of Extremes". Columbia University Press; New York, no. 375.

[5] Gutenberg, B., Richter, C. F. (1944), "Frequency of earthquakes in California". Bulletin of seismological society of America; 34, no. 185-188.

[6] IS: 1893-Part 1 (2016), "Criteria for earthquake resistant design of structure". General provisions for building (Sixth revision), Bureau of Indian standards; New Delhi.

[7] Kramer, S.L., (1996), "Geotechnical earthquake engineering". Prentice Hall international series, Pearson education, Low price edition; Delhi.

[8] Shanker, D., Singh, V. P. (2010), "Seismic risk analysis for the occurrence of medium size earthquakes in Kangra region of Himachal Pradesh". India. Proc. Indian Natl. Sci. Acad. Part A, 1997; no. 63, 197–202.

[9] Shanker, D., Sherif M. Ali., Manisha. Singh. (2017), "Earthquake Hazard and Engineering Determinations for Indonesian Region Using IMS Network Data", Geosciences, 7(5), 150-155.

[10] Shubham.,Shanker, D. (2018). "Earthquake hazard update in central Himalaya". Geosciences, 8(1), 1-6.

[11] Shanker, D., Yadav, R.B.S., H.N. Singh (2007), "On the seismic risk in the Hindukush-Pamir-Himalaya and their vicinity", Current Sciences, 92 (1), 1625-1630.