SEISMIC HAZARD ASSESMENT AND RAPID VISUAL SURVEY OF HOSPITAL BUILDINGS

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When Rām was preparing for launching his campaign for the rescue of Sitā from the captivity of Rāvan, there was a terrific noise like the clap of thunder, the mountains shook and rocks fell down violently, and the waters

प्रतिचुक्षुभिरे चाशु सरांसि सरितस्तथा ॥ 7 ॥

आरुजंश्चैव शैलाग्रशिखराणि बभञ्ज च ॥ 10 ॥

सह भूतैः सतोयोर्मिः सनागः सहराक्षसः ॥ 14 ॥

Apparently, an earthquake had hit the Rāmeshwaram coast and a tsunami brought waves of sea water deep into the land. The coming out of snakes in dazed condition and other burrowing animals and fleeing away of toads from the coasts confirms the occurrence of an earthquake

wave-cut notches and staircase-like platform (Pant and Juyal, 1993). The faulting must have been accompanied by a major earthquake.

The Kachchh-Saurāshtra domain is prone to repeated earthquakes (Fig. 10.5). Some very large or major earthquakes have hit the terrain in the present time stretching back to the middle Holocene time. Soft-sediment

KS Valdiya

Geography Peoples and Geodynamics of India in Puranas and Epics

An earthquake in Srinagar, 24th September, 1501 AD

The *Tarikh-e-Hasan* mentions about an earthquake which is not mentioned in the contemporary Sanskrit source, namely the *Rājataraṅginī* by Suka. Pir Hasan Shah records:

> "During the reign of Sultan Fath Shah on 12th of Asvach Pasi of 970 H. (September, 24th 1501 AD) a severe earthquake occurred in the previous night. A large number of creatures of God lost their lives and houses were razed to ground. The earth and sky remained in tumult for a period of three months. Then after three months normalcy was restored."

(Tarikh-e-Hasan, ff. 170a)[5]

An earthquake at Garhgaon, 1548 AD

The *Ahom-Buranji* (Tr. and Ed. Barua, 1930) states:

> "In Lakani Tao-Shinga (i.e. in 1548 AD) a violent earthquake took place, pebbles, sand and ashes came out bursting the surface of earth..."

(Ahom Buranji, pp. 81-82, para 61)[21]

This earthquake was during the reign of the king Suklemung who made his capital at Garhgaon and therefore known as Garhgaya Raja. Gait (1905) also mentions this earthquake. The intensity of this earthquake might be IX. Garhgaon is south east of Sibsagar and its location is approximately 26°45' N, 94°50'E.

VARAHAMIHIRA (5TH Cent. A.D).

ADBHUTA SAGARA OF BALLALA SENA(10TH Cent. A.D)

Lokopakarakam of Chamunda Raya (11th Cent. A.D.)

Earthquakes are classified into four groups, in decreasing order of distress. Felt distances and affected regions are mentioned.

Name	Distance (Yojana)	Region
Vayu	200	Kuru, Yavana, Sourastra, Vanga, Trigarta, Magadha
Varuna	90 (180) *	Gonarda, Cedi ,Kukura, Videha, Sindhu
Agni	80 (110) *	Ashmaka, Dravida, Madhyadesha, Kuru, Yavana, Sourastra, Vanga, Trigarta, Magadha
Indra	70 (160) *	Kashi, Dravida, Kashmir

* 1Yojana=9.6 Kms.(approx.) **Prof. RN Iyengar** ***Current science***

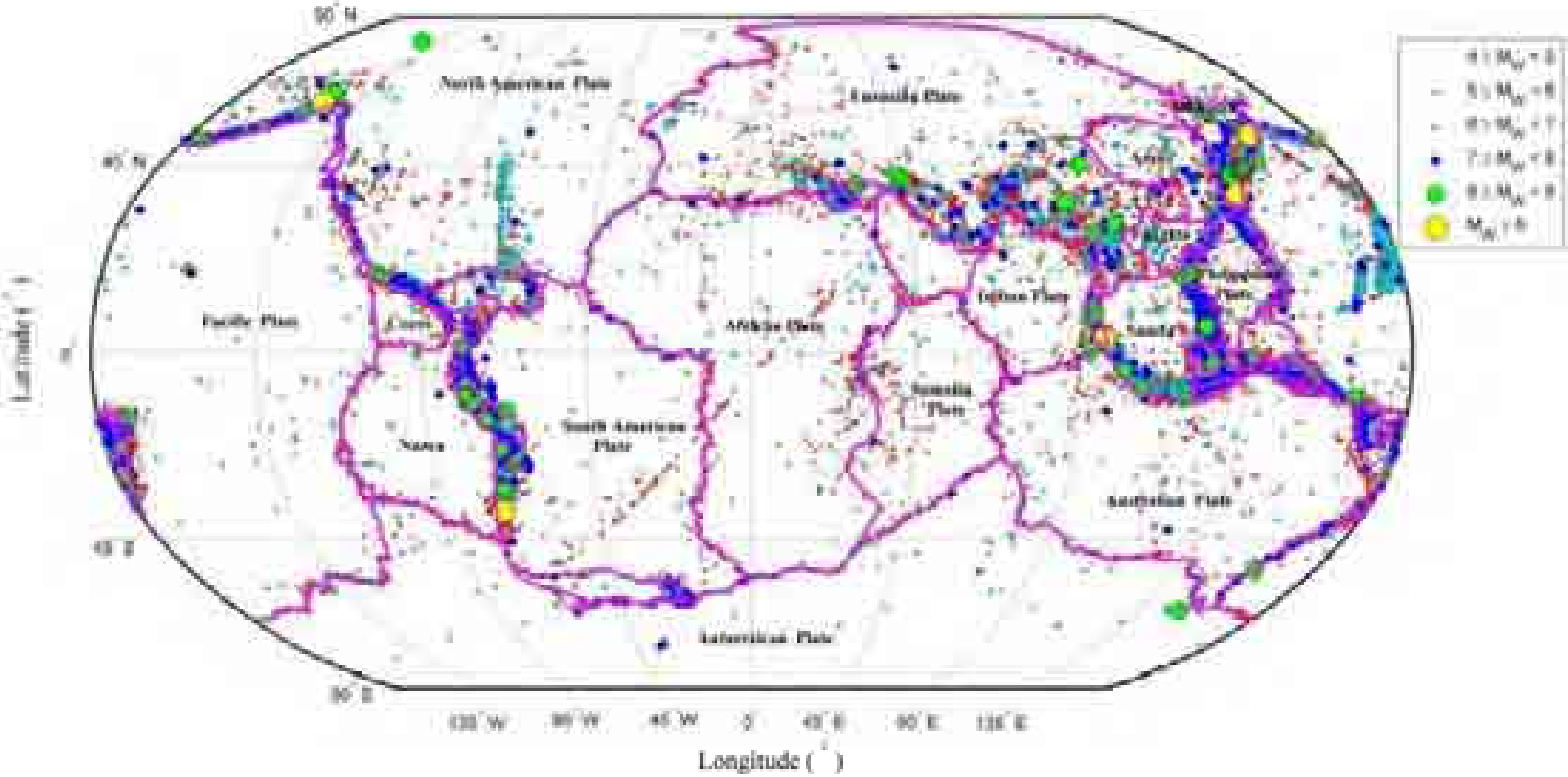
NAMES OF REGIONS WHICH HAVE EXPERIENCE EARTHQUAKES IN ANCIENT TIMES AS PER BRIHAT-SAMHITA OF VARAHA MIHIRA 5-6TH CENT. A.D.

RED COLOUR INDICATES THE SEVEREST TYPE (VAYU).

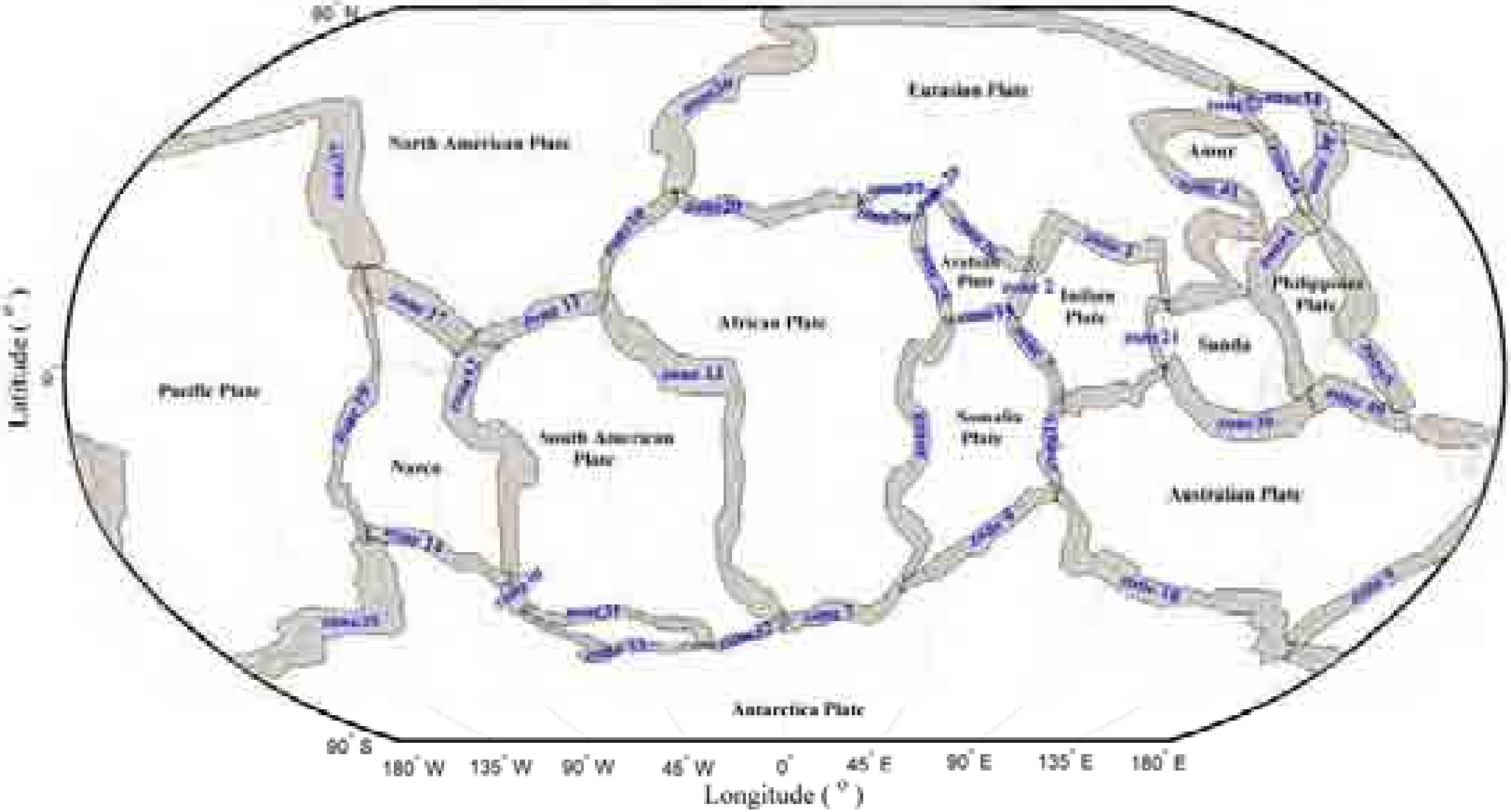
Kedarnath temple 2nd century
National centre for Heritage structures
IIT Madras

M.Tech and PhD Heritage structures
Reconstructing the past Natural disasters

Dhankar monsatery 2000 yrs old



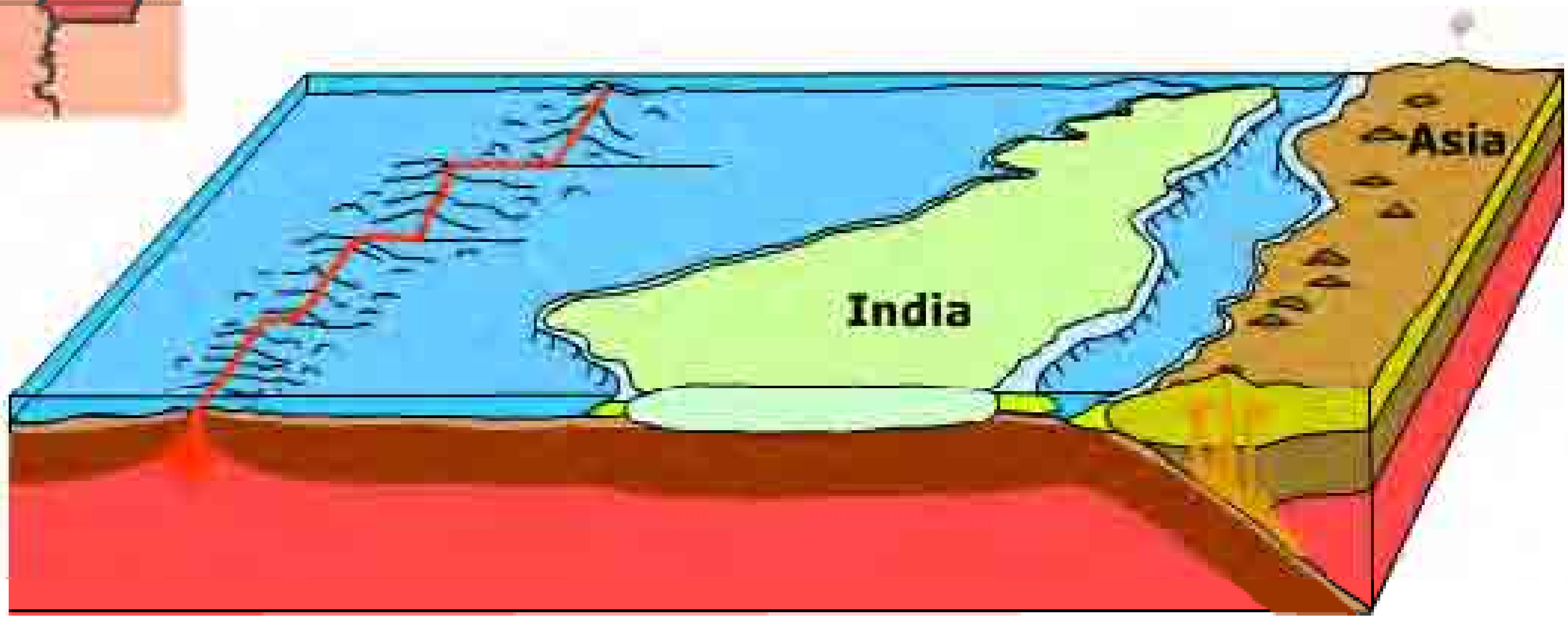
North American Plate
Eurasia Plate
Pacific Plate
African Plate
South American Plate
Nazca
Indian Plate
Somalia Plate
Australian Plate
90° N
45° N
90° S
135° W
90° W
45° W
0
45° E
90° E
135° E
Longitude (°)
Latitude (°)



90° N
Eurasian Plate
North American Plate
Amur
Arabian Plate
Indian Plate
Philippine Plate
African Plate
Sunda
Pacific Plate
Somalia Plate
South American Plate
Nazca
Australian Plate
Antarctica Plate
90° S
180° W
135° W
90° W
45° W
0°
45° E
90° E
135° E
180° E
Longitude (°)
Latitude (°)

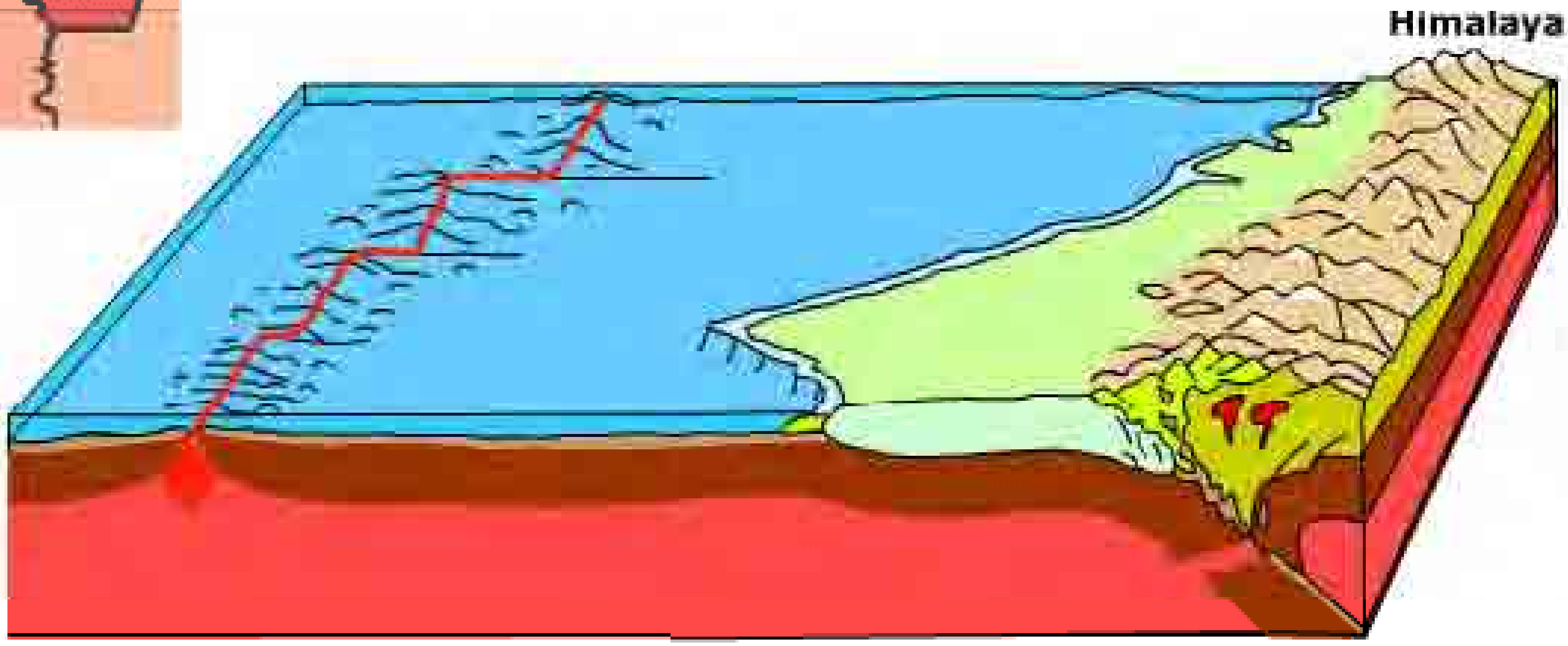
NORTHWARD MOVEMENT OF INDIA

Converging plates - continetal plate vs. continental plate



About 225 million years ago, India was a large island situated off the coast of Australia. The Tethys Sea, a large ocean, separated India from the Asian continent. When Pangaea broke apart about 200 million years ago, India began to move northward. About 40 to 50 million years ago India collided with the Eurasian continent. The northern-most part of the Indian continent was forced below the Eurasian continent, which resulted in a thickening of the crust - the mountain chain Himalayas was formed. The collision between the two continents has not yet ended. The Indian continent is still moving northward, and the Himalayas continue to rise more than one cm per year.

Converging plates - continetal plate vs. continental plate



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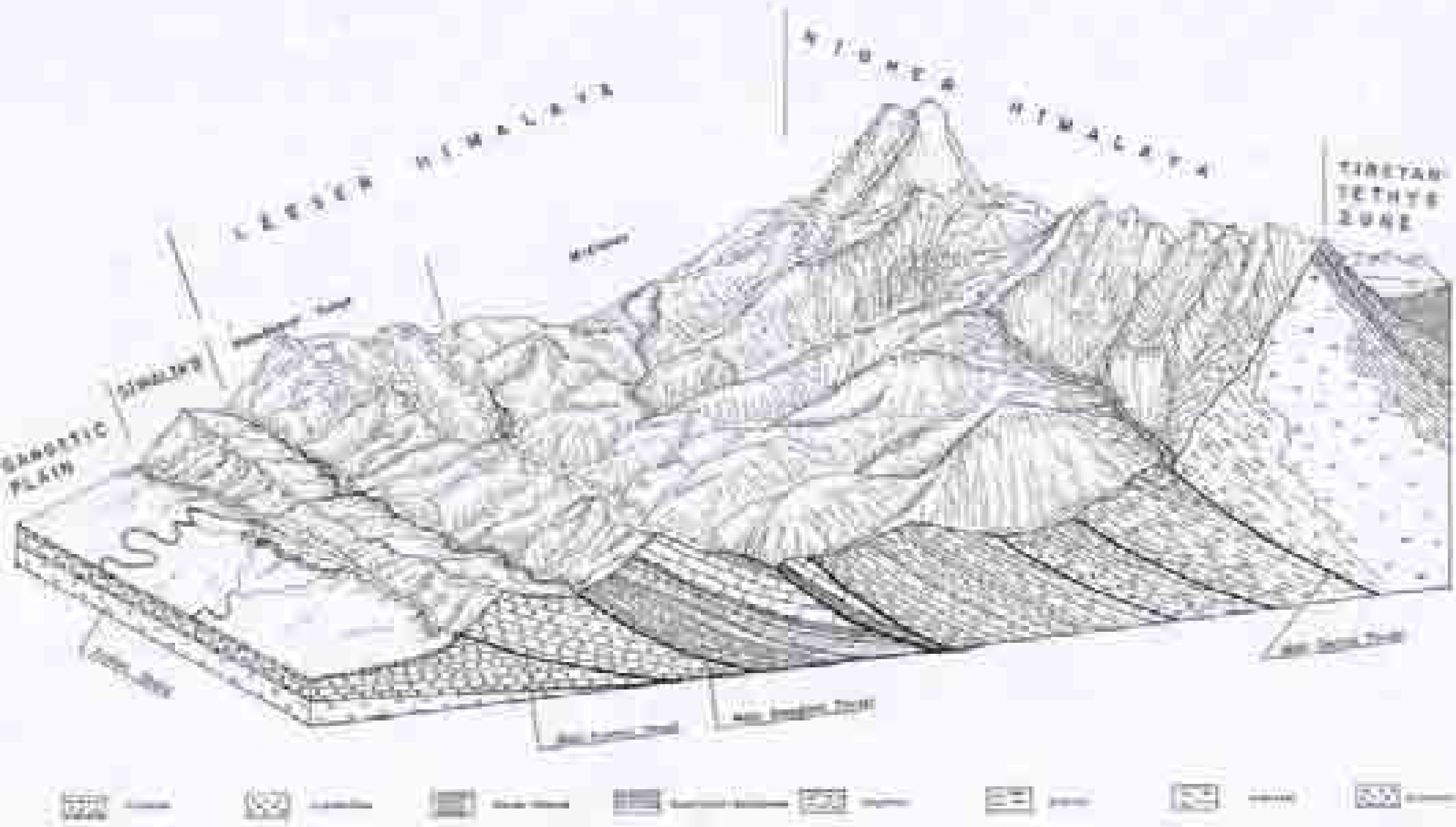
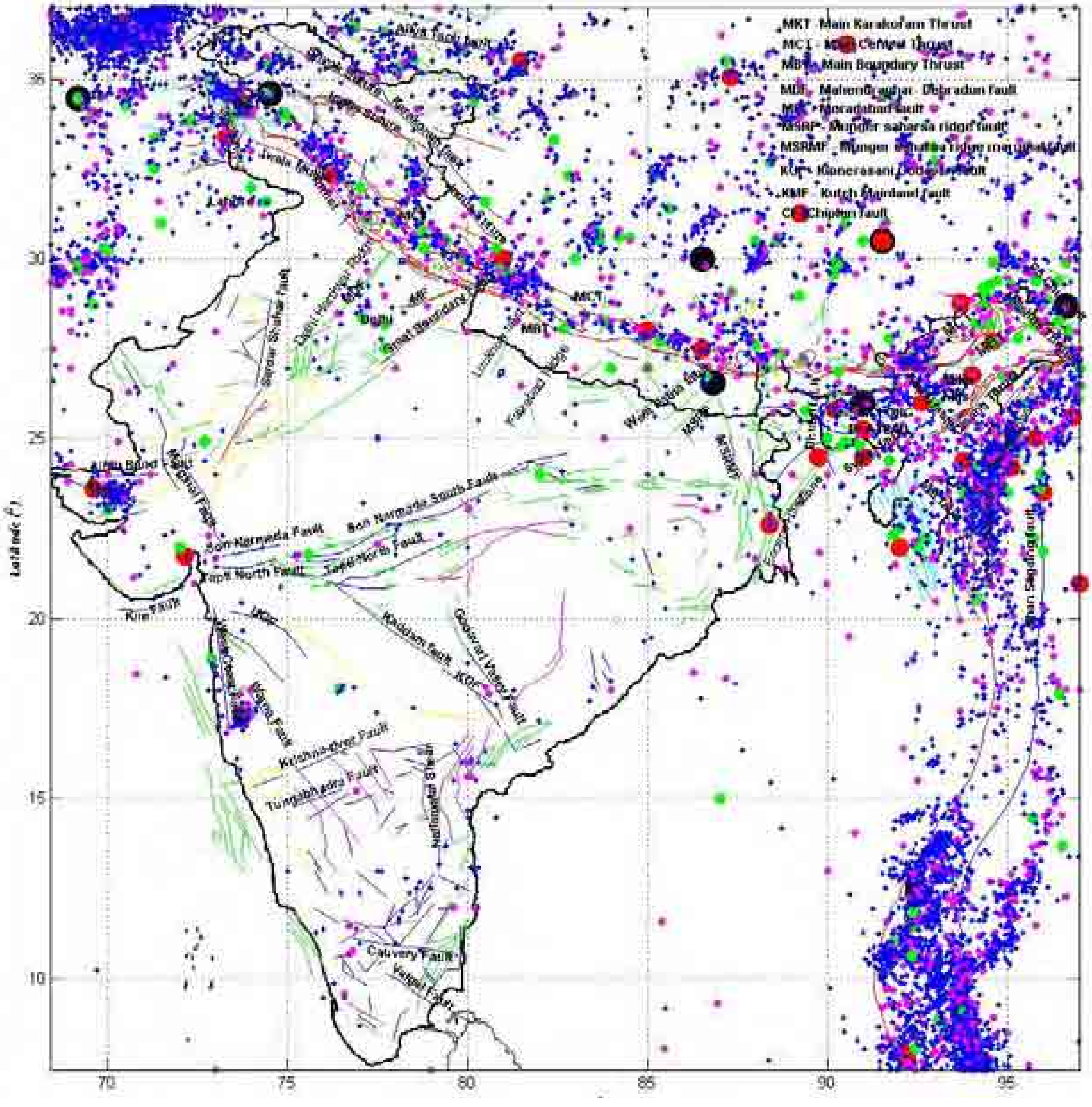


WHAT KIND OF FAULTS ARE THERE IN HIMALAYAS ?

Inter- and Intraplate Earthquakes

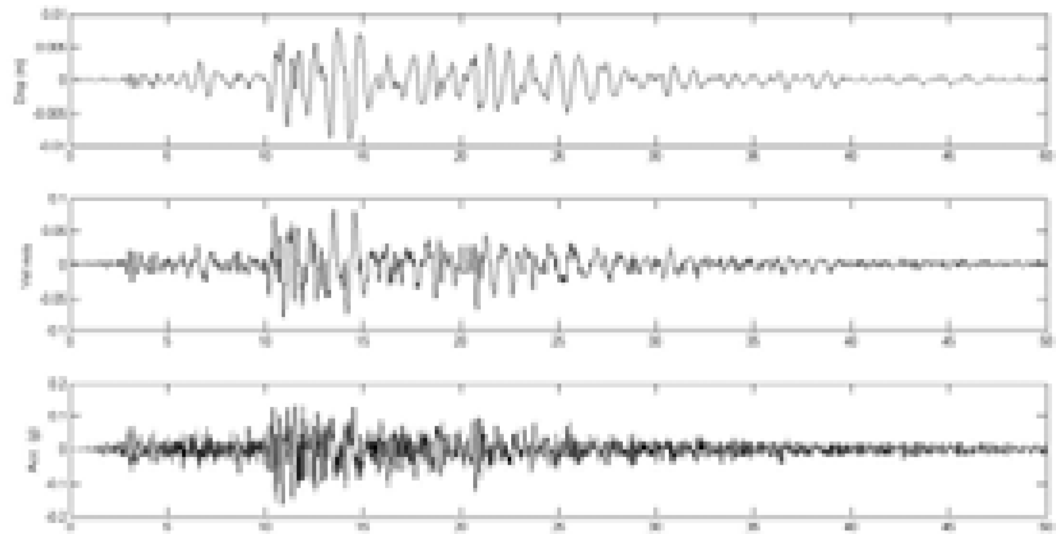
- Most earthquakes occur along plate margins because plate margins are relatively weak, but about 10% of earthquakes occur within the interior of plates.

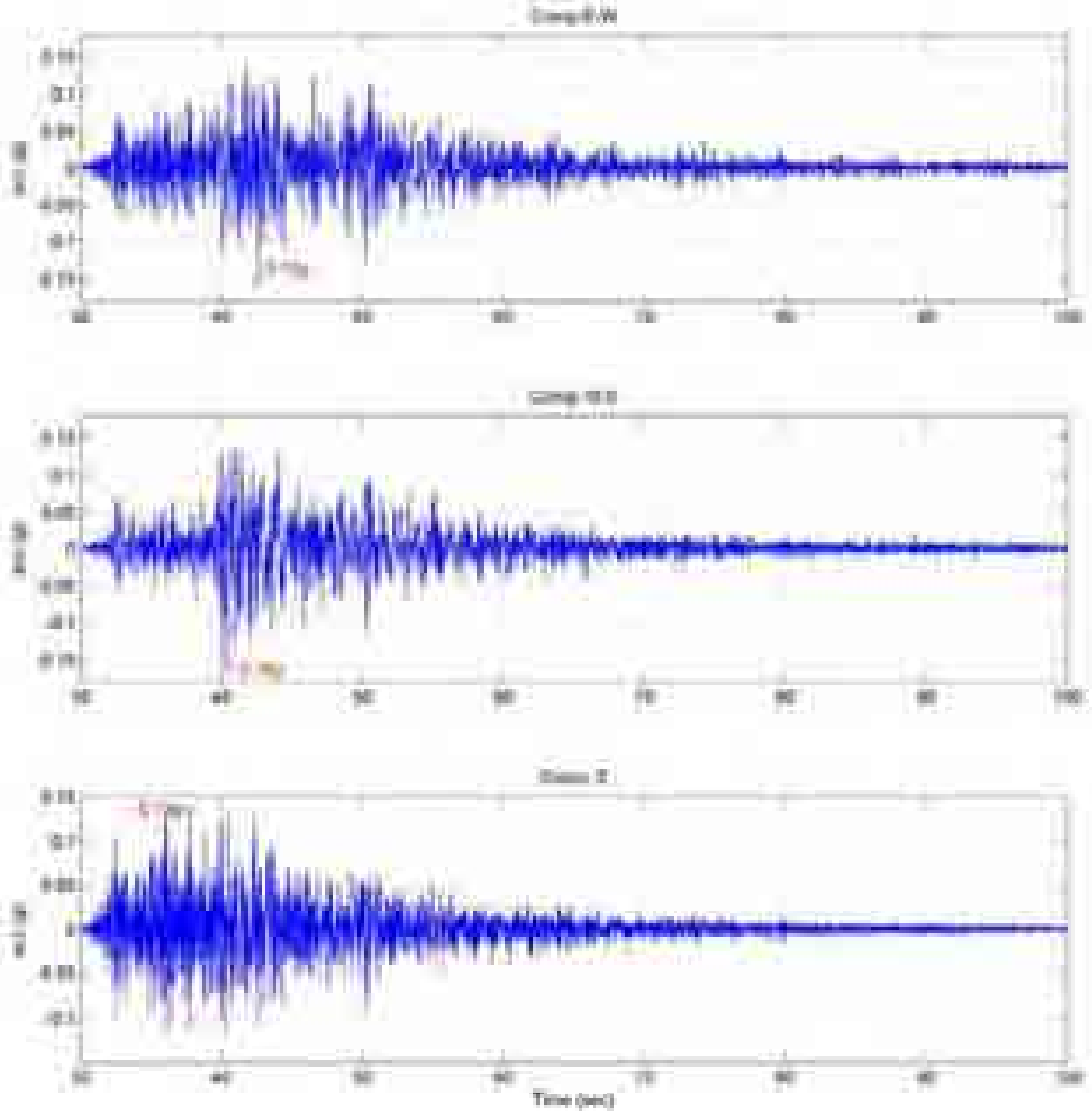
- We classify earthquakes depending on where they are located
  - Interplate - between plates
  - Intraplate - within plates



MKT Main Karakoram Thrust
KMF - Kutch Mainland fault
MCT
MBT
Son Narmada South Fault
Son Narmada Fault
Tapti North Fault
Cauvery Fault
Tungabhadra Fault
Latitude
70
75
80
85
90
95
10
15
20
25
30
35

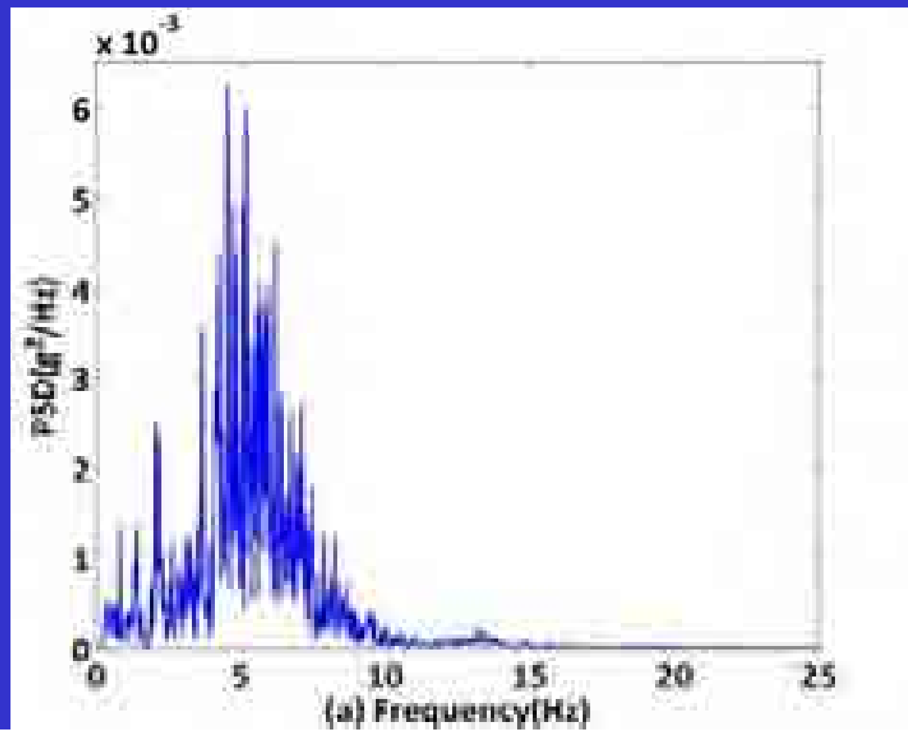
SEISMIC HAZARD
STRUCTURAL SAFETY
EARTHQUAKE – GROUND VIBRATION (DISPLACEMENT, VELOCITY, ACCELERATION TIME HISTORY)





Most of our engineering structures have resonant vibration frequencies in 0.1 Hz – 10 Hz range.

NAT. FREQ. = 1/(0.1N), N=number of stories



The economic losses estimated for the period 1929-1950 due to earthquakes are in excess of US$10 billion.

In the past 3 centuries over 3 million people have died due to earthquakes and earthquake related disasters.

2001 Bhuj earthquake – US$ 5 Billion
2005 Kashmir earthquake - US $5.2 billion
2008 China earthquake – US $75 Billion
2011 Japan Earthquake – US $ 300 Billion

2014 Indian Budget – $ 301 Billion dollars

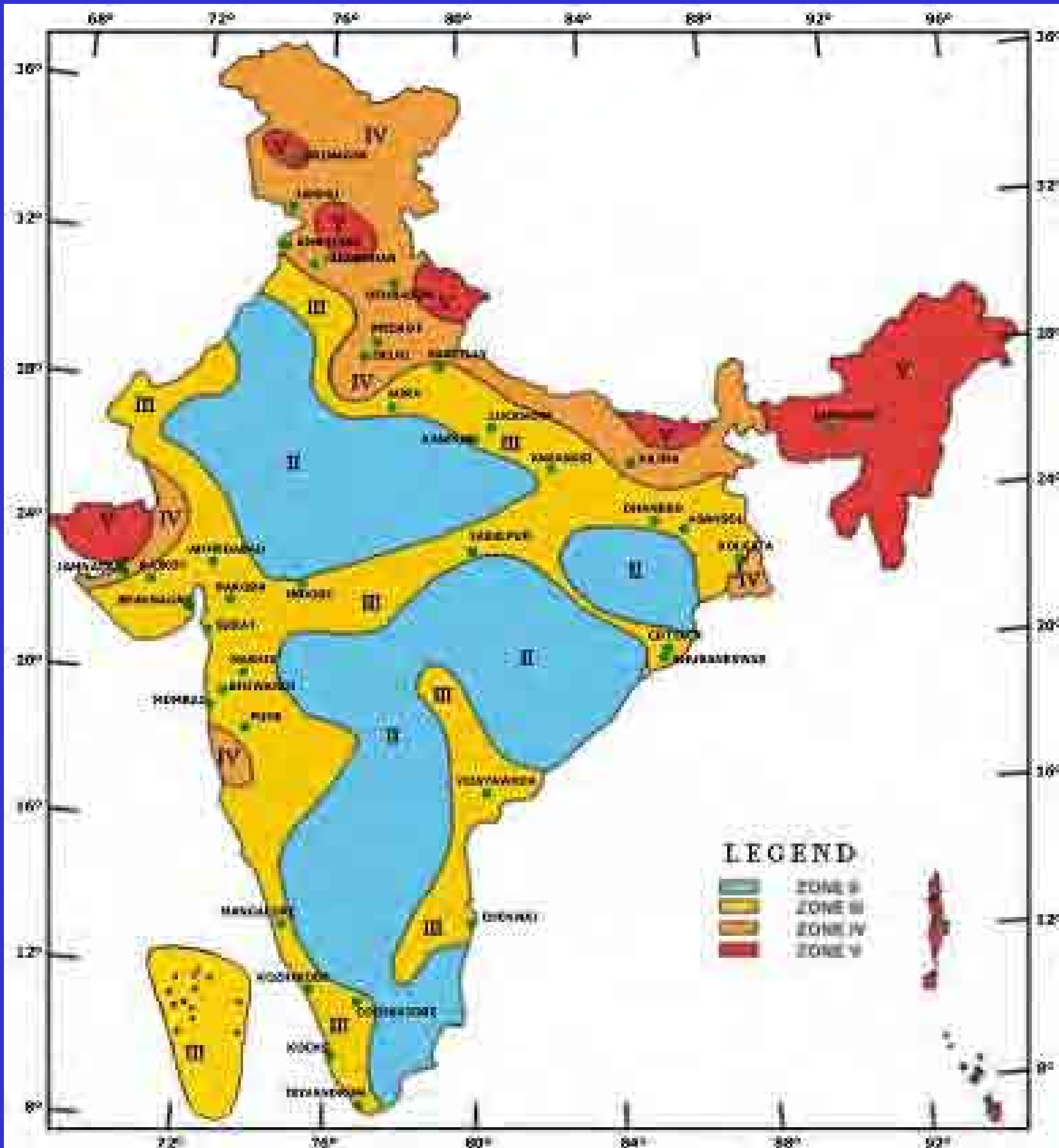
The next great earthquake in a major metropolitan region can cause damage at the multi-trillion dollar level

Table IV. Estimates of current disasters if repeats of historic earthquakes should happen. Expected deaths are calculated by QUAKELOSS, the reported numbers are from the IDD.

Date	Time (GMT)	Location	Latitude (degree)	Longitude (degree)	Depth (km)	*M*	Expected deaths	Reported deaths
1897/06/12	11:06	Shillong	26.0	91.0	20	8.3	90,000	1,542
1905/04/05	00:50	Kangra	32.1	76.4	25	8.0	70,000	20,000
1934/01/15	08:43	Bihar	27.55	87.09	30	8.1	18,000	6,000 (10,500)*
1950/08/15	14:09	Assam	28.5	96.5	30	8.6	40,000	1,500

Table II. Estimated human losses due to scenario earthquakes along the Himalayan plate boundary. Latitude, Longitude, depth, and magnitude, *M*, are assumed, based on parameters of historic earthquakes and the tectonic setting. The range of deaths and injured includes two standard deviations from the mean. The number of settlements expected to experience shaking of intensity, *I*, larger than 7 and 5, represents those where some people may be killed and those affected by the earthquake, respectively.

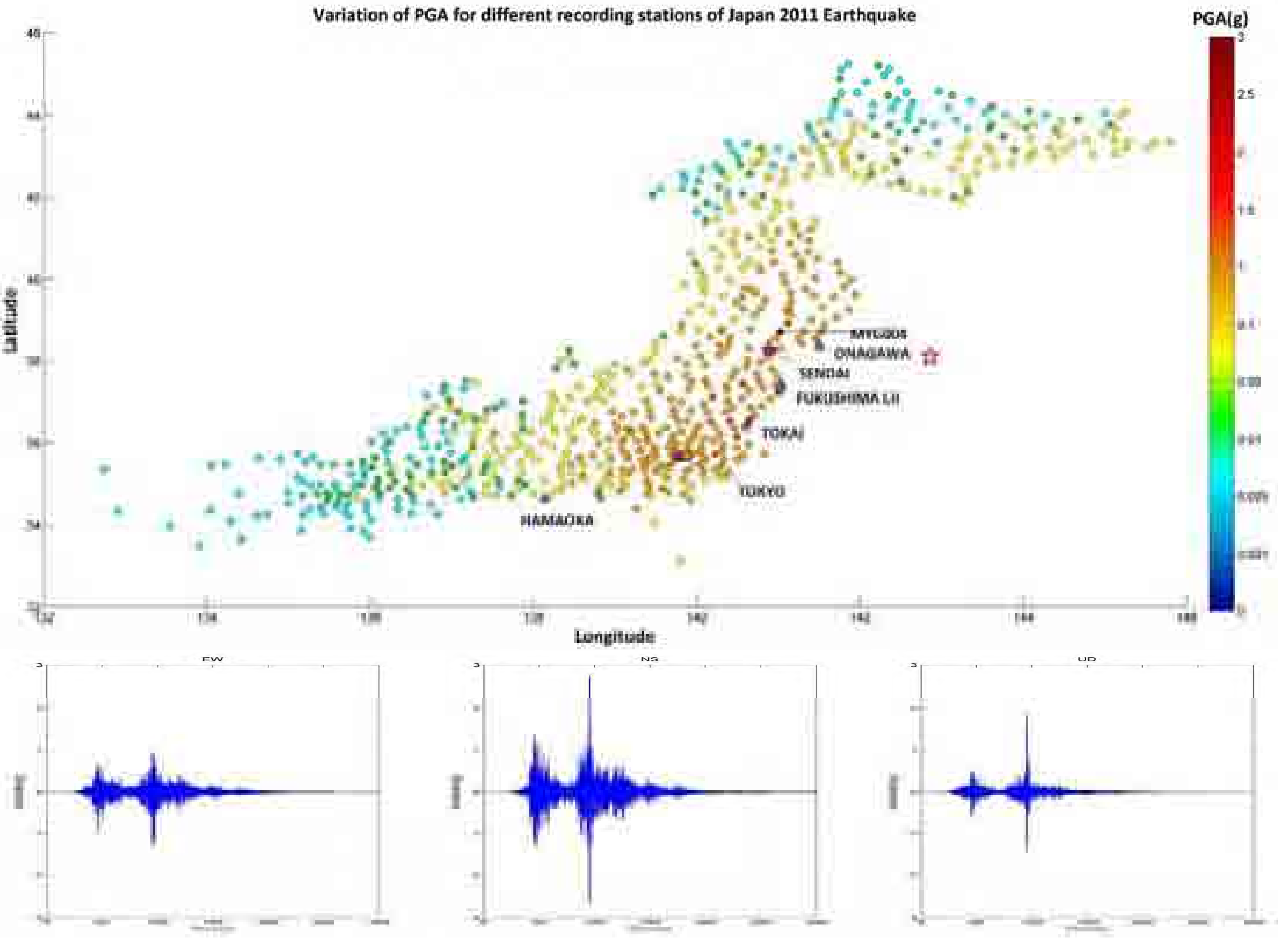
	Location	Latitude (degree)	Longitude (degree)	Depth (km)	*M*	Expected deaths (thousands)	Number injured (thousands)	No. settle $I \geq 7$	No. settle $I \geq 5$
1	Assam	27.8	92.3	25	8.1	24–49	52–99	160	1900
2	Bhutan	27.3	89.5	25	8.1	76–151	163–274	270	2500
3	Katmandu	28.1	84.2	25	8.1	21–42	45–86	330	2600
4	W. Nepal	28.7	81.8	25	8.1	11–22	24–53	370	2800
5	Garhwal	29.7	79.6	25	8.1	58–115	125–230	380	3000
6	Dehra Dun	30.7	77.7	25	8.1	96–199	210–433	450	3300
7	Kashmir	33.0	75.0	25	8.1	67–137	146–293	550	4000

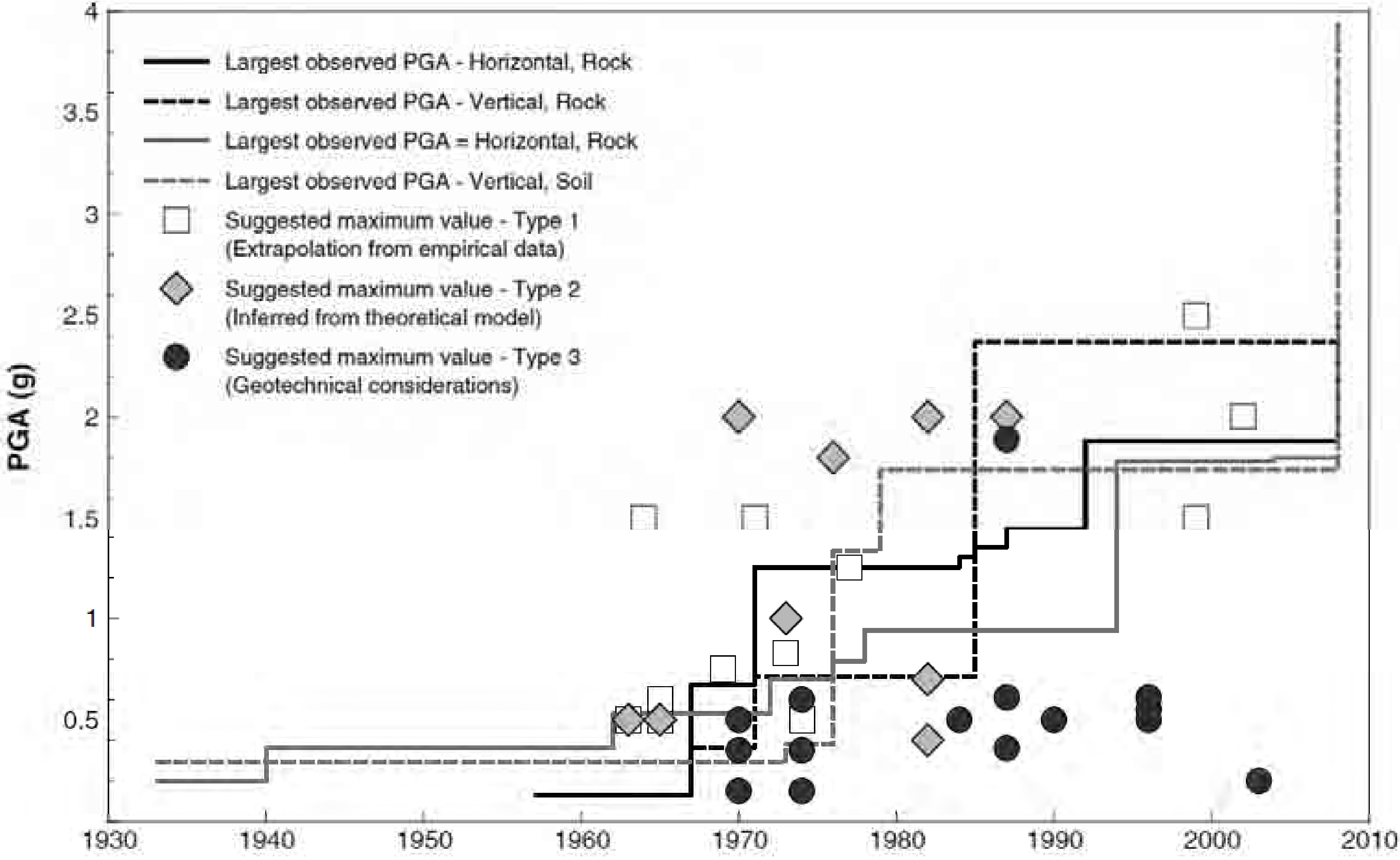


Seismic zone map of India (IS 1893 (Part 1) : 2002)

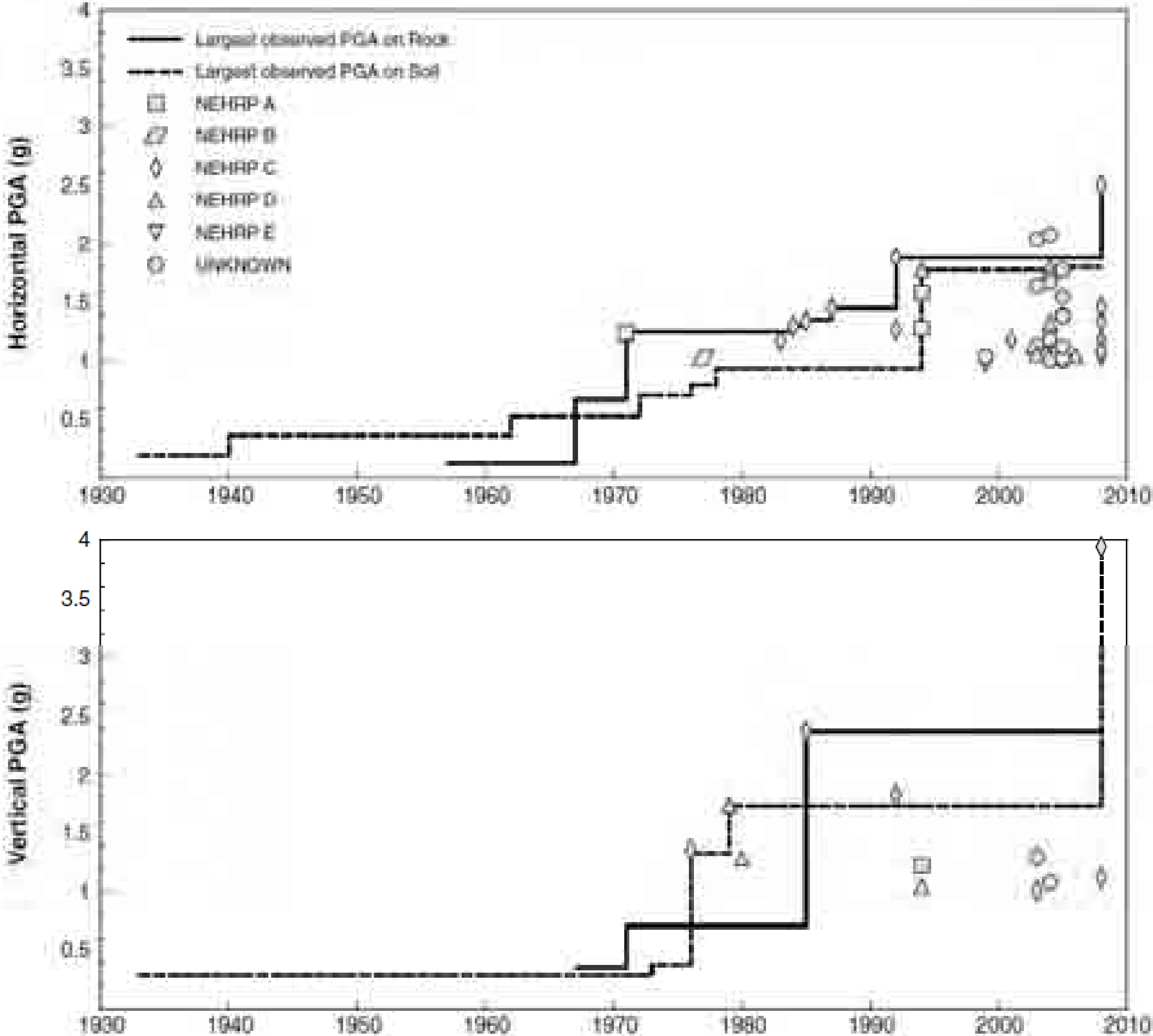
Zone	PGA
II	0.1g
III	0.16g
IV	0.24g
V	0.36g

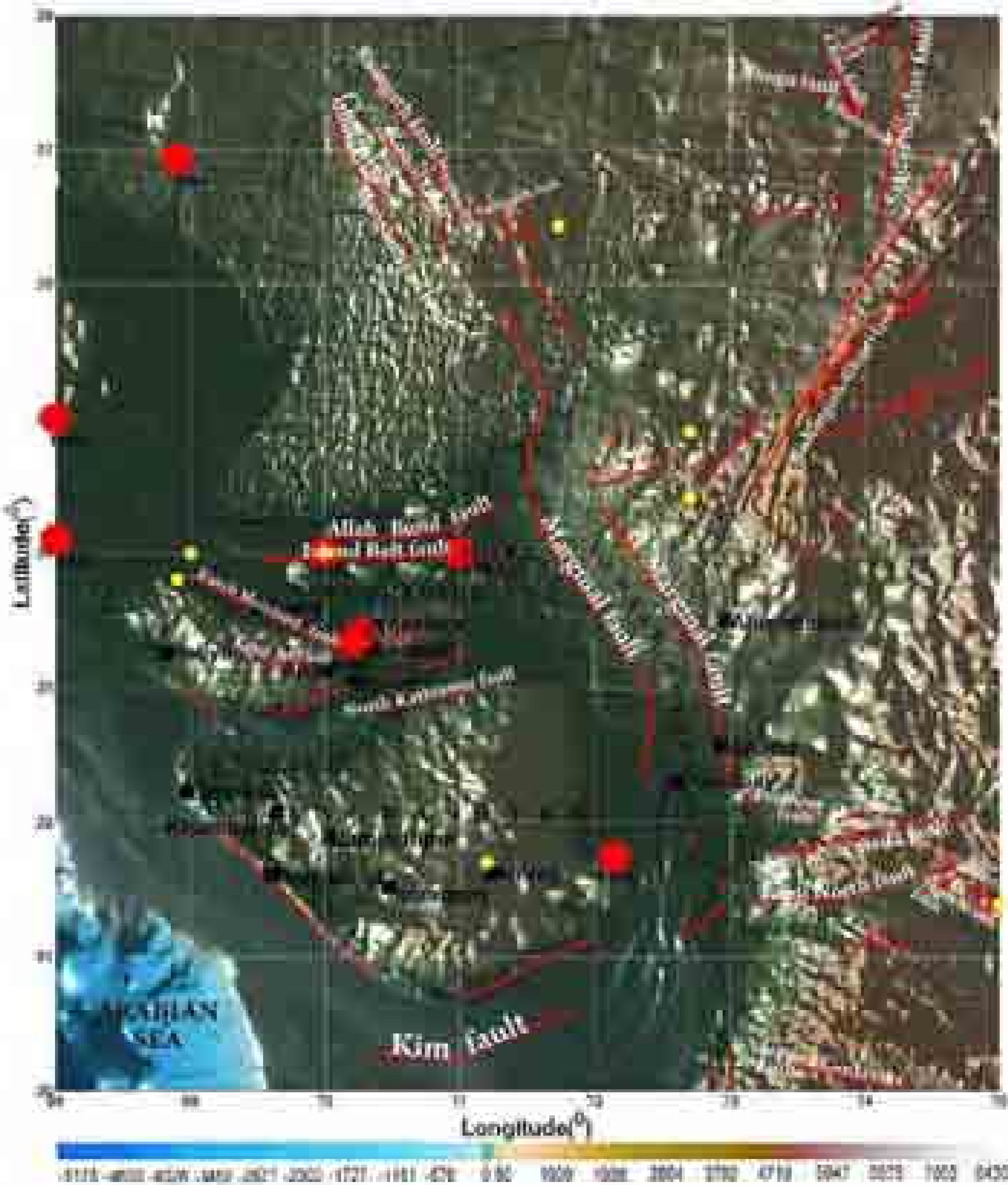
STRUCTURES HAS TO BE SAFE IN **FUTURE - UNCERTAINITY**


Variation of PGA for different recording stations of Japan 2011 Earthquake
PGA(g)
Latitude
Longitude
ONAGAWA
SENDAI
FUKUSHIMA
TOKAI
TOKYO
HAMAOKA
EW
NS
UD



Strasser and Bommer (2009)


Largest observed PGA on Rock
Largest observed PGA on Soil
NEHRP A
NEHRP B
NEHRP C
NEHRP D
NEHRP E
UNKNOWN
Horizontal PGA (g)
Vertical PGA (g)
1930
1940
1950
1960
1970
1980
1990
2000
2010
0.5
1
1.5
2
2.5
3
3.5
4



EARTHQUAKE CAN OCCUR ON ANY FAULT IN FUTURE

DESIGN FOR MAXIMUM VALUE – Too Costly

DESIGN FOR MINIMUM VALUE – Unsafe

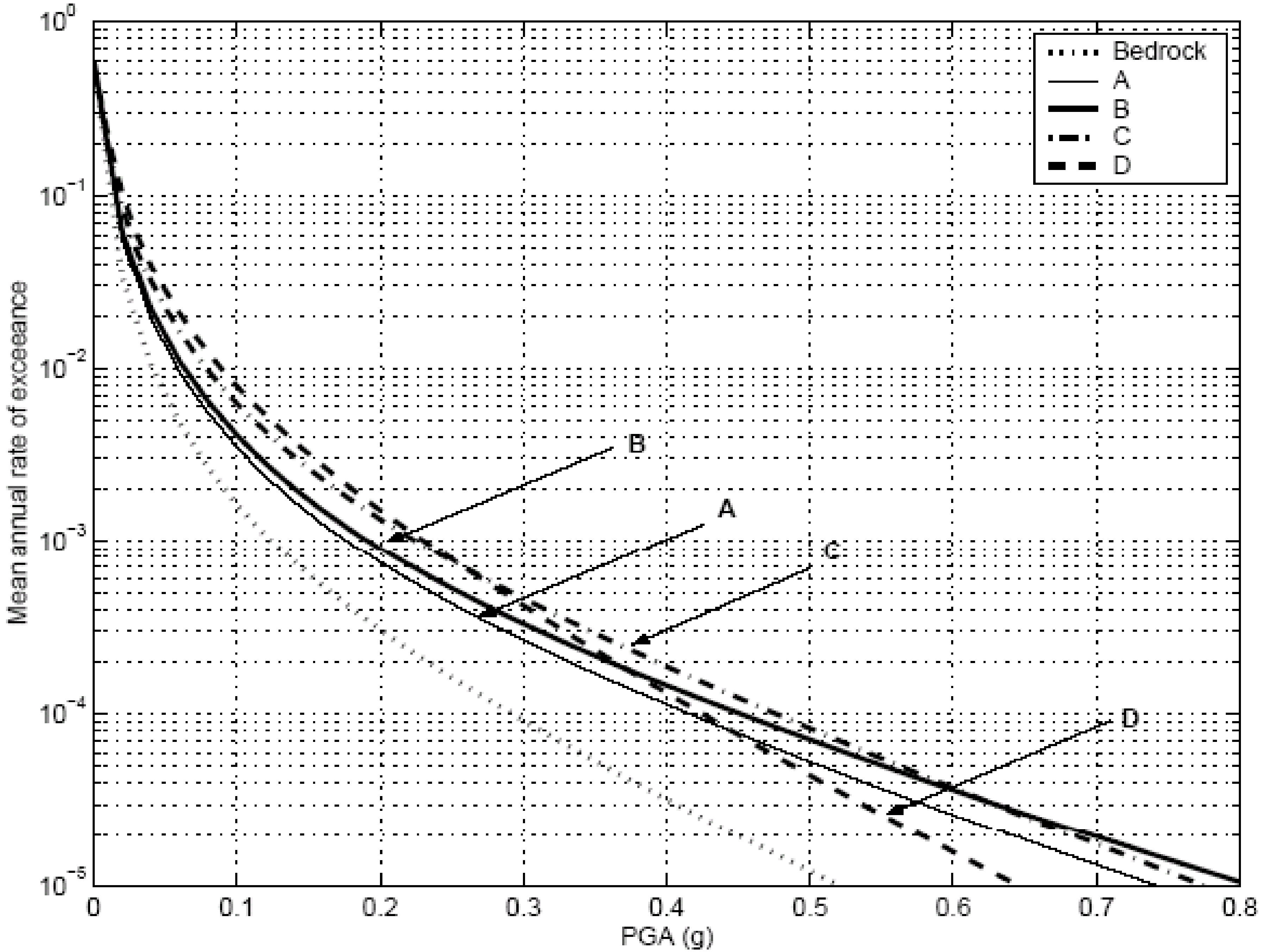
How to Take a decision ?

Nuclear reactors, Historical monuments - life time is high

Apartments – Life time (50 Yrs)

Design Value – Probability or Frequency

Cover the Risk - Insurance



Seismic Hazard Curve for Mumbai city

(Requirement for Engineers)

Bulletin of the Seismological Society of America. Vol. 58, No. 5, pp. 1583–1606. October, 1968

ENGINEERING SEISMIC RISK ANALYSIS

By C. Allin Cornell

ABSTRACT

This paper introduces a method for the evaluation of the seismic risk at the site of an engineering project. The results are in terms of a ground motion parameter (such as peak acceleration) versus average return period. The method incorporates the influence of all potential sources of earthquakes and the average activity rates assigned to them. Arbitrary geographical relationships between the site and potential point, line, or areal sources can be modeled with computational ease. In the range of interest, the derived distributions of maximum annual ground motions are in the form of Type I or Type II extreme value distributions, if the more commonly assumed magnitude distribution and attenuation laws are used.

Introduction

Owing to the uncertainty in the number, sizes, and locations of future earthquakes it is appropriate that engineers express seismic risk, as design winds or floods are, in terms of return periods (Blume, 1965; Newmark, 1967; Blume, Newmark and Corning, 1961; Housner, 1952; Muto, Bailey and Mitchell, 1963; Gzovsky, 1962).

The engineer professionally responsible for the aseismic design of a project must make a fundamental trade-off between costly higher resistances and higher risks of economic loss (Blume, 1965). It requires assessment of the various levels of performance and economic implications of particular designs subjected to various levels of intensity of ground motion. The engineer must consider the performance of the system under moderate as well as large motions. Sound design often suggests some economic loss (e.g., architectural damage in buildings, automatic shut-down costs in nuclear power plants) under these moderate, not unexpected earthquake effects.

This engineer should have available all the pertinent data and professional judgement of those trained in seismology and geology in a form most suitable for making this decision wisely. This information is far more usefully and completely transmitted through a plot of, say, Modified Mercalli intensity versus average return period than through such ill-defined single numbers as the "probable maximum" or the "maximum credible" intensity. Even well-defined single numbers such as the "expected lifetime maximum" or "50-year" intensity are insufficient to give the engineer an understanding of how quickly the risk decreases as the ground motion intensity increases. Such information is crucial to well-balanced engineering designs, whether it is used informally

SEISMIC HAZARD CURVE

Magnitude → GROUND MOTION

Distance from the seismic source → GROUND MOTION

What is the Frequency of Occurrence of earthquakes ?

Frequency of 6 magnitude earthquake on a particular seismic source?

Frequency of 7 magnitude earthquake ?

Frequency of 8 ?

$$\mu_{y^*} = \sum_{i=1}^{K} \mathrm{N}_i(m_0) \int_m \int_r P(Y > y^* \mid m, r)\, p_{R|M}(r \mid m)\, p_M(m)\, dr\, dm$$

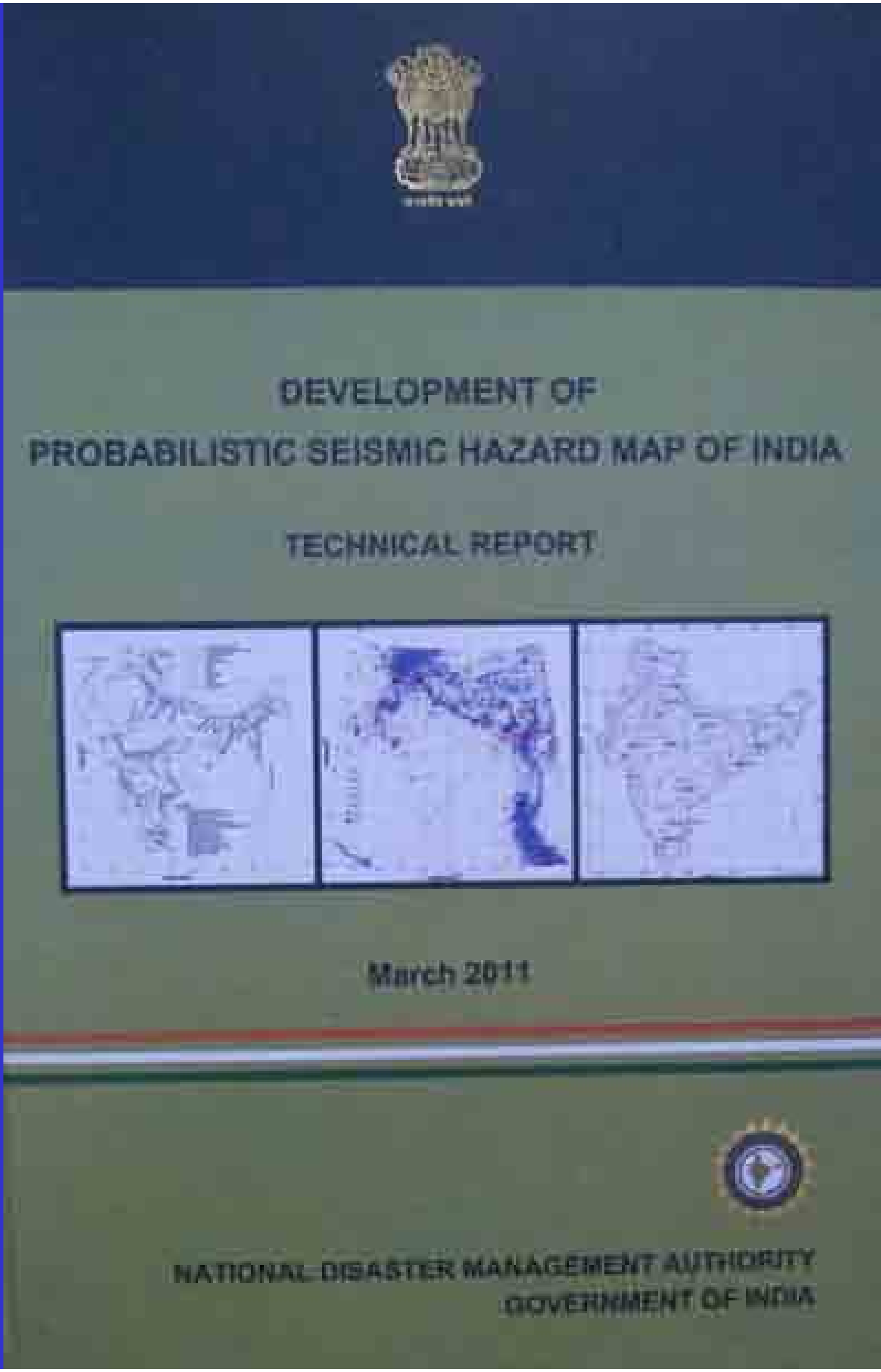
Activity rate of i^{th} fault

Ground motion

Location of fault

Magnitude

K = Number of faults



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Project Team

Dr.STG Raghukanth

CSIR – SERC

http://www.ndma.gov.in/en/study-reports-of-mitigation-division.html

PSHA METHODOLOGY

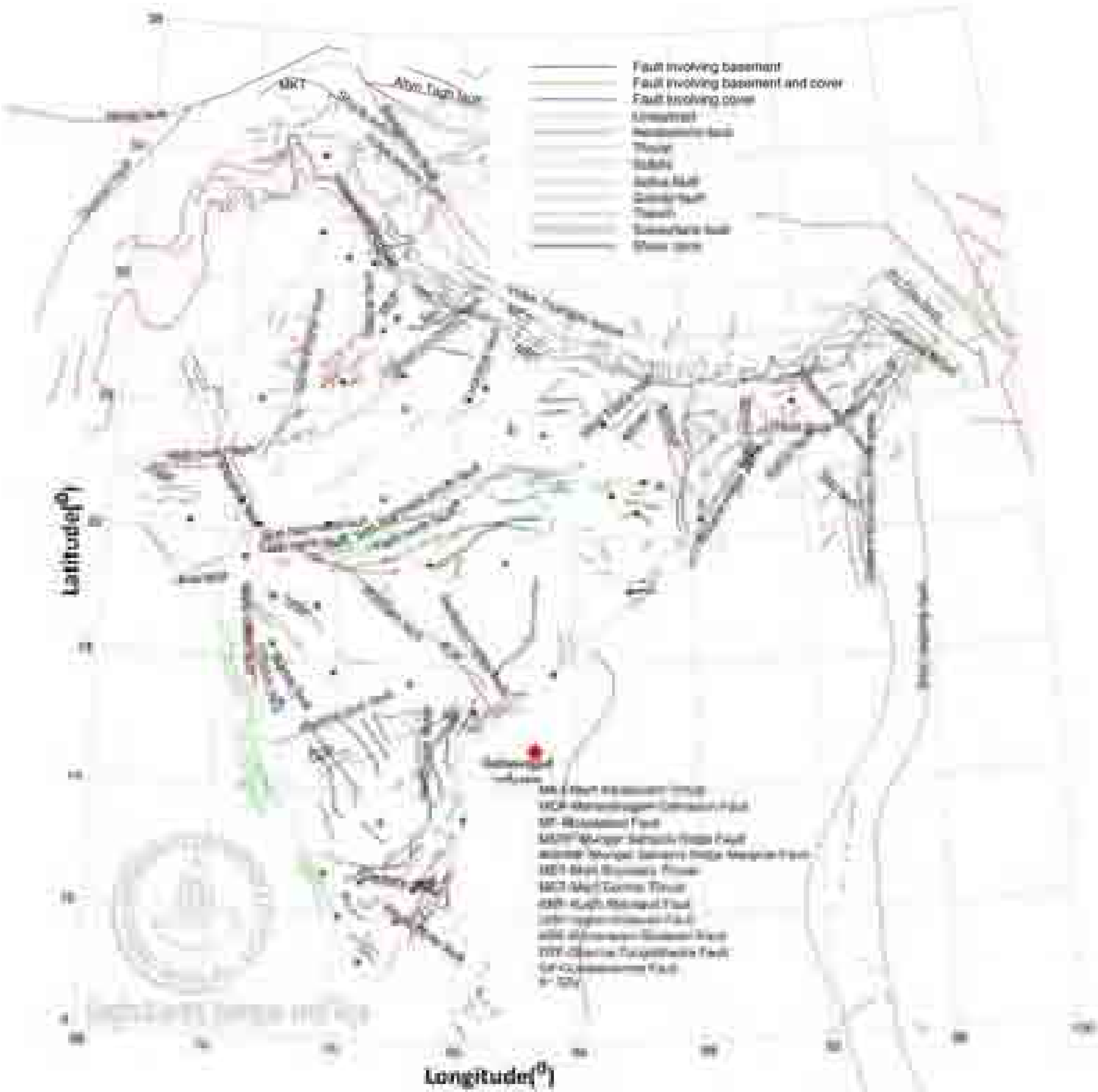
1. Identification of seismic sources and geological zones

2. Earthquake catalogue

3. Recurrence relationships

4. Strong motion attenuation relationships

5. Seismic hazard analysis



Fault involving basement
Fault involving basement and cover
Fault involving cover
MKT
Latitude(0)
Longitude(0)

www.sefindia.org

HISTORICAL AND PALEO-EVENTS

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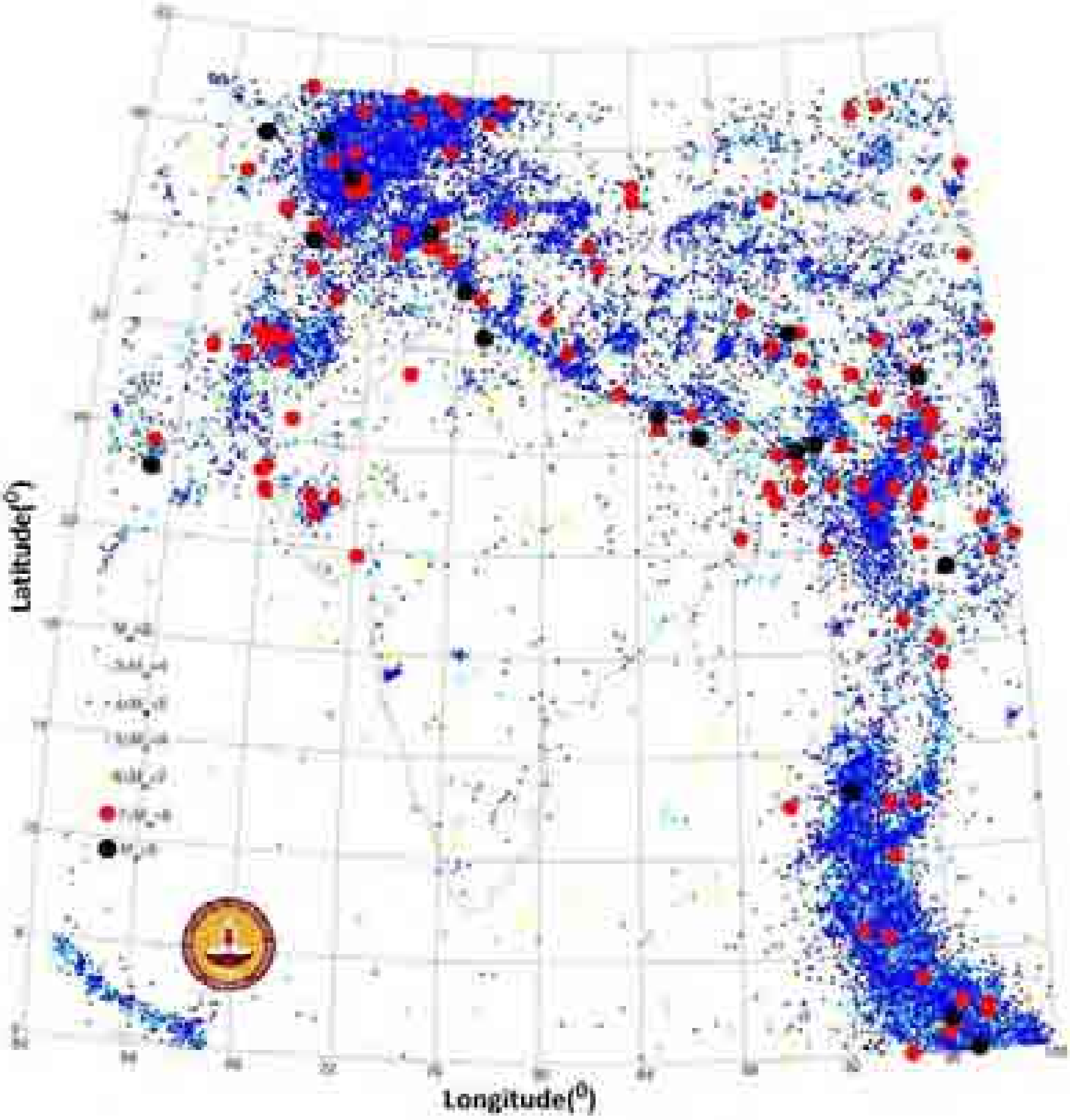
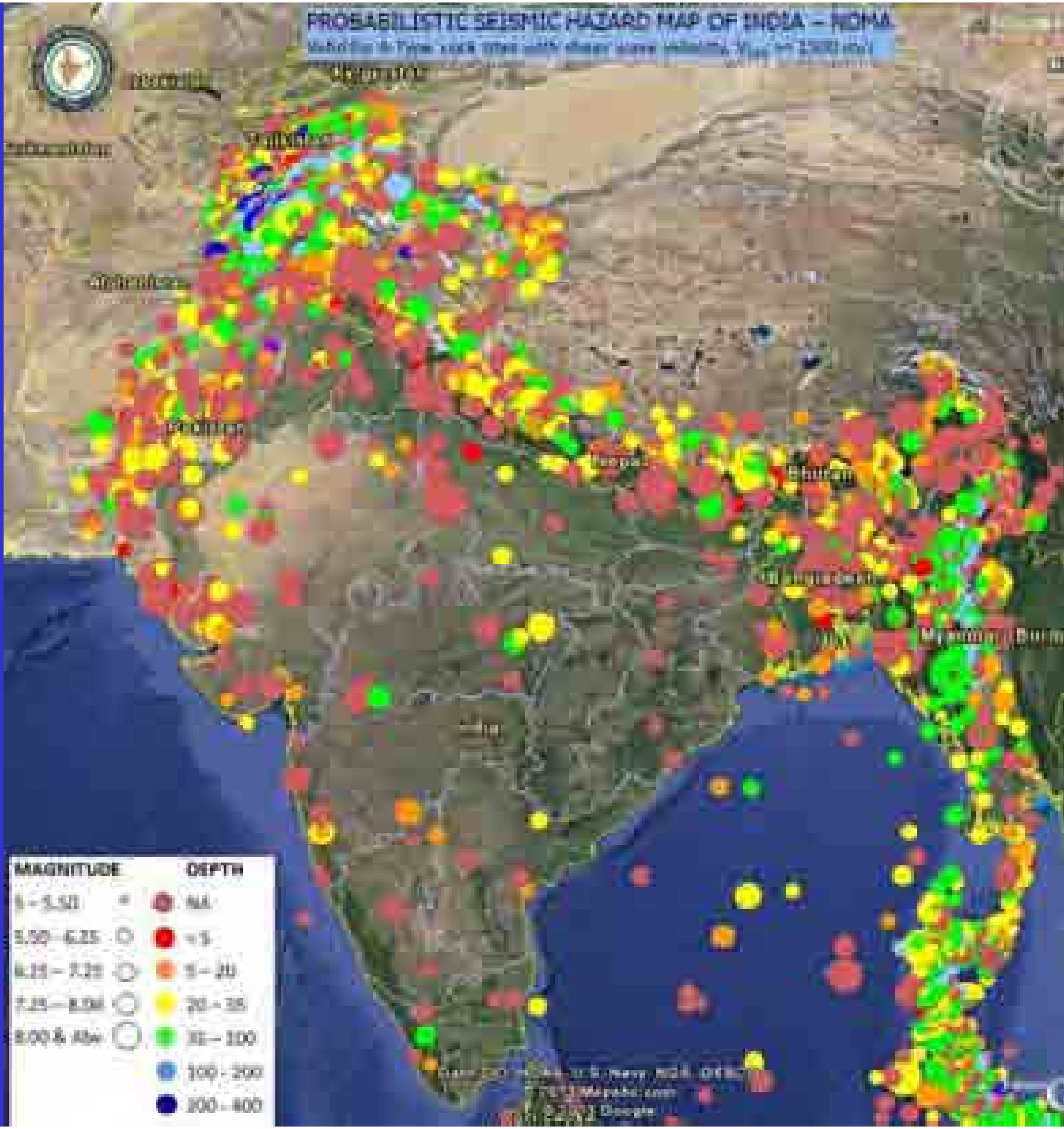
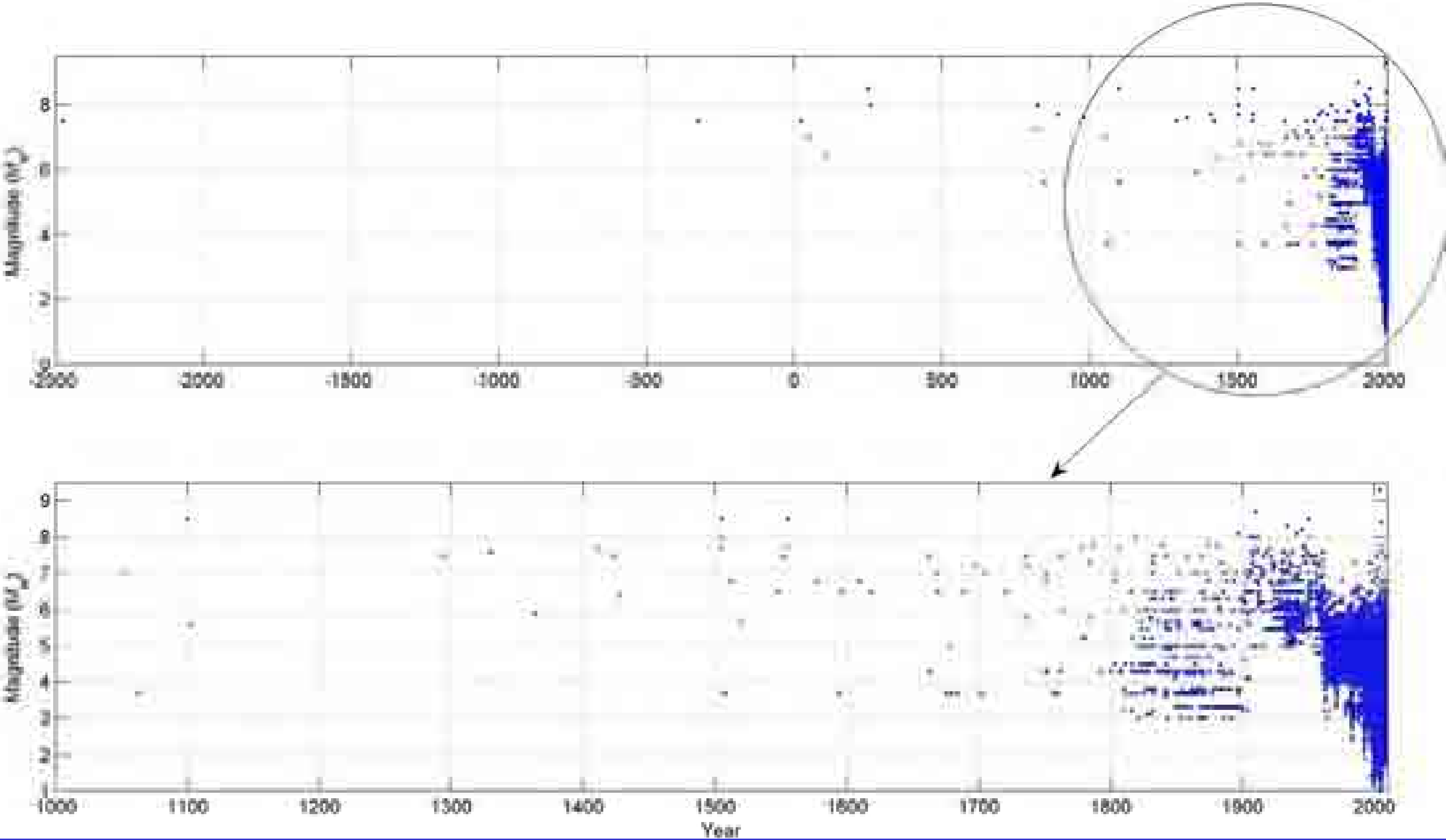


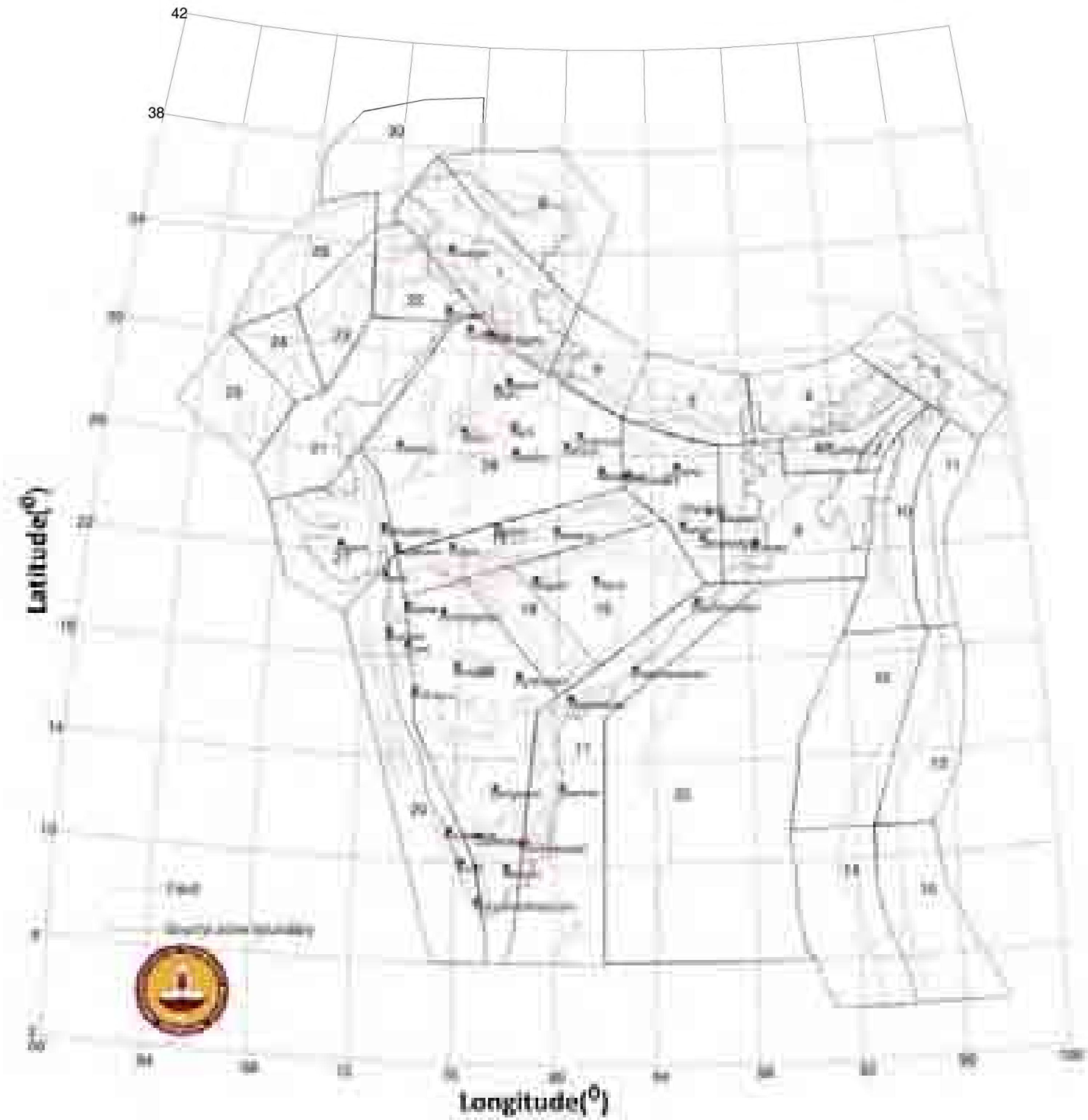
Assembled catalogue 2474 BC - 2008
38,860 events

The uncertainty in the reported magnitudes is taken as 0.5 in the extreme part. For the
complete part the magnitude uncertainty is assumed to be 0.3.


PROBABILISTIC SEISMIC HAZARD MAP OF INDIA – NDMA
Nepal
Bhutan
MAGNITUDE
DEPTH
5.50 – 6.25
NA
100 - 200
200 - 400



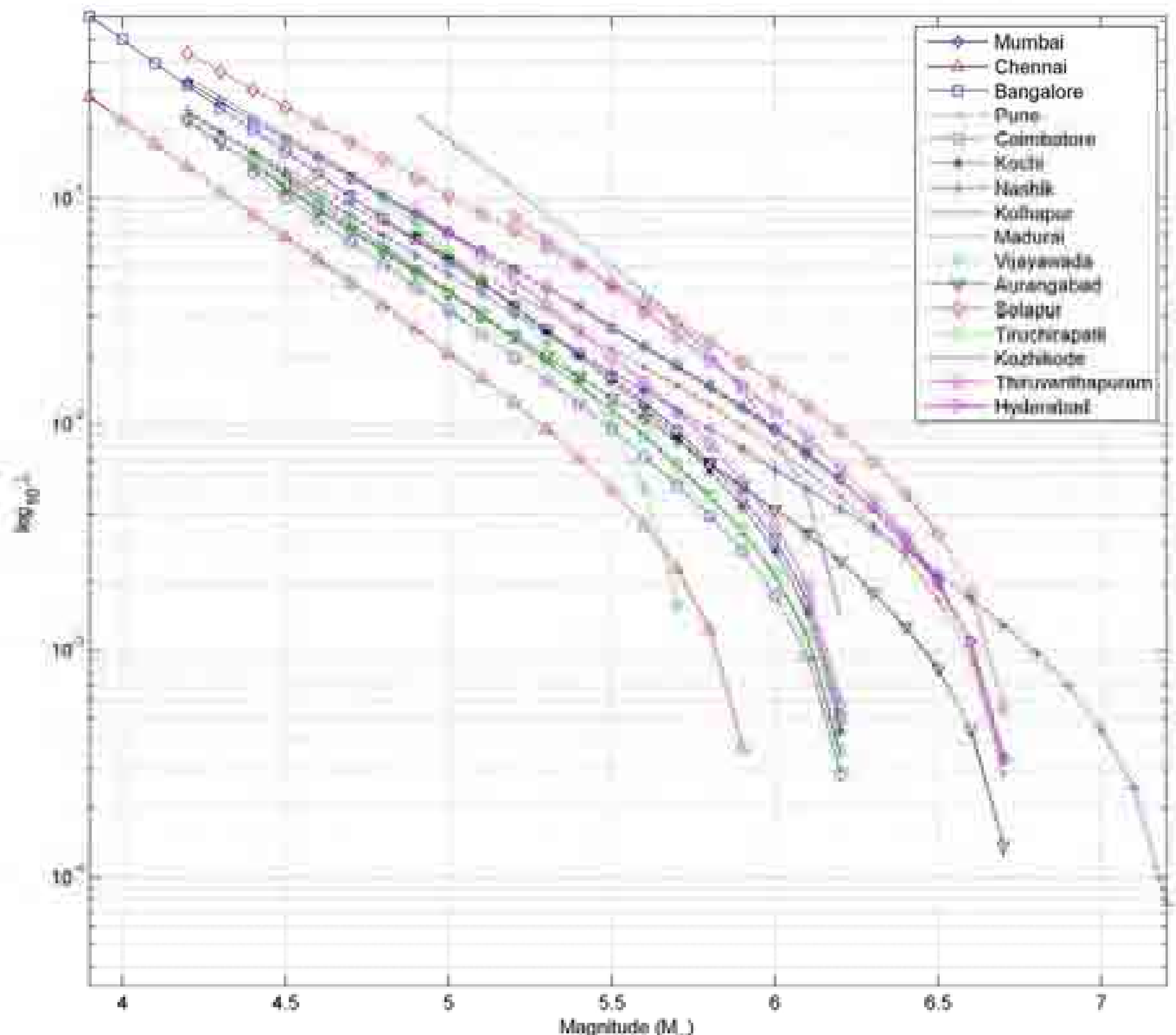
Magnitude (M_w)
-2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
Year



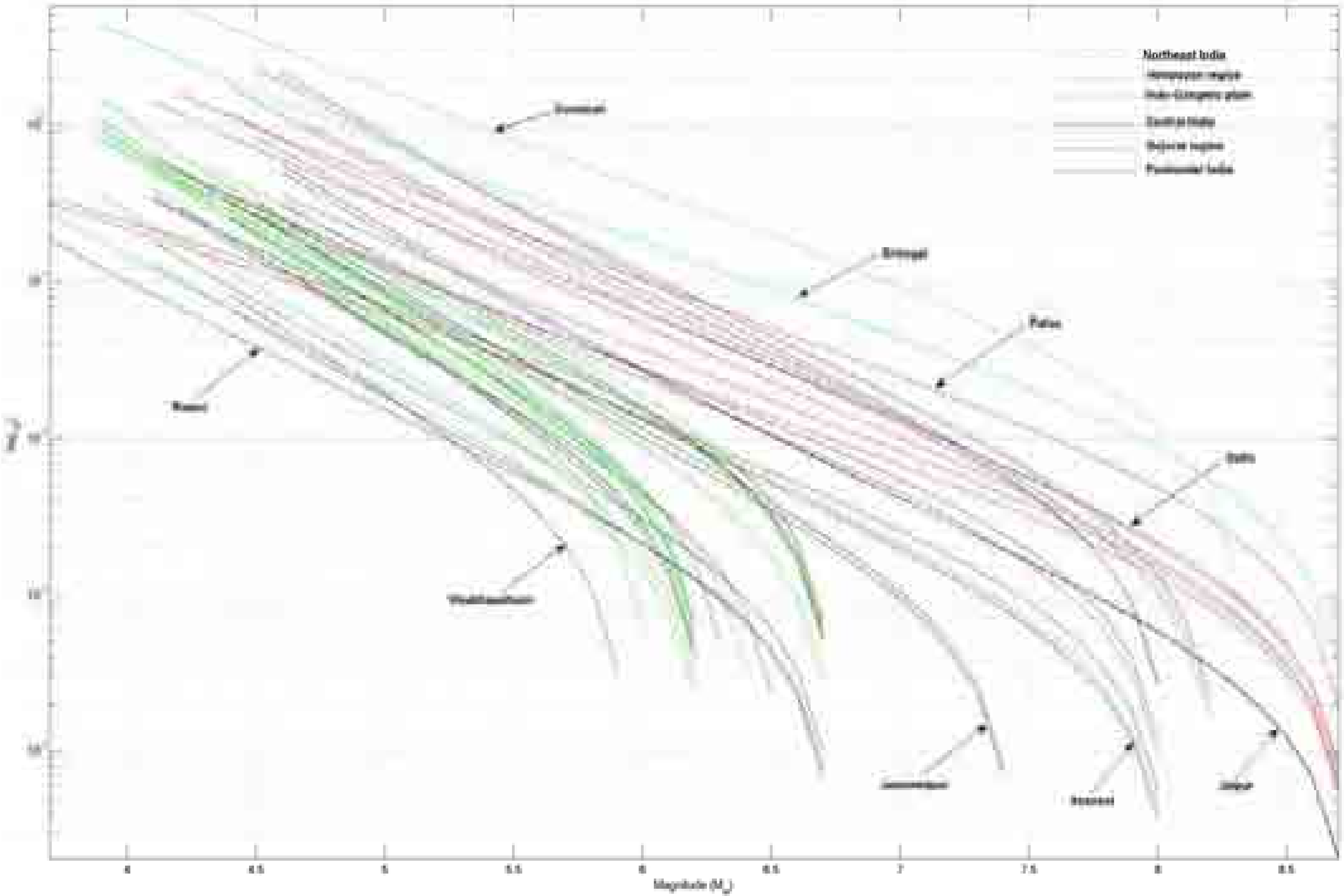
Latitude(°)
Longitude(°)

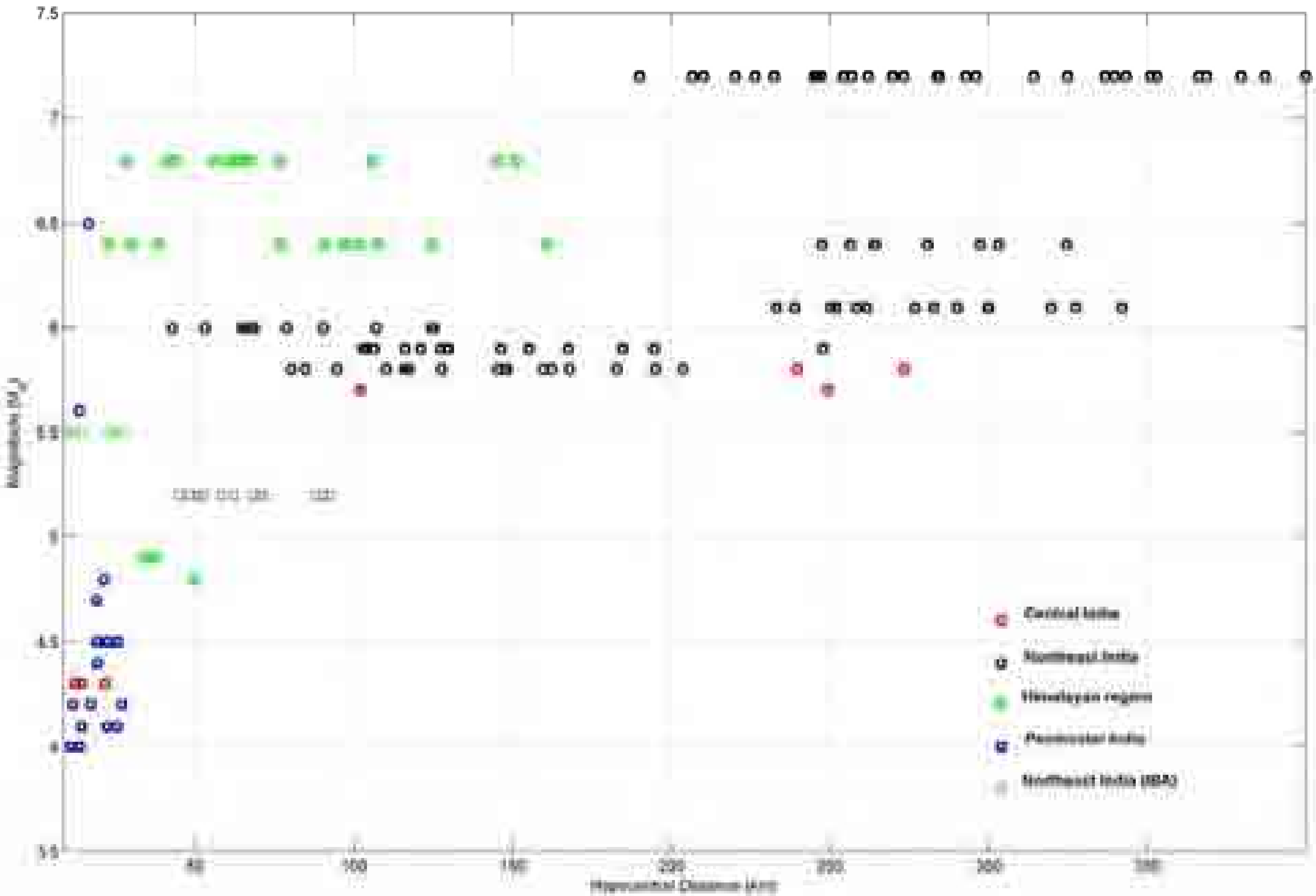
Source No.	Zones	*b*-value	*N(4)*	Max. Potential Magnitude (M_{max})	No. of earthquakes
1	Western Himalaya	0.88±0.02	5.37	8.8	901
2	Central Himalaya-I	0.73±0.04	3.15	7.8	306
3	Central Himalaya-II	0.78±0.04	2.30	8.8	340
4	Eastern Himalaya	0.71±0.04	3.12	8.0	223
5	Mishmi Block	0.66±0.03	3.72	8.8	219
6	Altya Tegh & Karakoram	0.91±0.03	7.10	7.3	726
7	Naga Thrust	0.67±0.08	0.18	6.8	32
8	Shillong Plateau & Assam valley	0.73±0.04	1.46	8.4	181
9	Bengal Basin	0.74±0.04	1.99	8.1	289
10	Indo-Burmese Arc	0.80±0.02	11.40	7.8	1055
11	Shan-Sagaing Fault	0.66±0.04	5.28	8.1	260
12	West Andaman-I	0.70±0.03	3.62	8.4	239
13	East Andaman-I	0.63±0.03	5.83	7.5	331
14	West Andaman-II	0.71±0.02	2.55	7.5	158
15	East Andaman-II	0.62±0.01	16.53	7.6	985
16	SONATA	0.64±0.08	0.24	6.8	24

17	Eastern Passive Margin	0.74±0.08	0.27	6.1	40
18	Mahanandi Graben & Eastern Craton	0.77±0.09	0.24	5.3	15
19	Godavari Graben	0.85±0.09	0.13	6.0	10
20	Western Passive Margin	0.76±0.07	0.37	6.8	70
21	Sindh-Punjab	0.77±0.06	0.60	8.0	89
22	Upper Punjab	1.01±0.05	1.68	7.8	224
23	Koh-e-Sulaiman	0.84±0.04	5.03	7.3	358
24	Quetta-Sibi	0.74±0.04	5.22	7.8	293
25	Southern Baluchistan	0.74±0.05	2.58	7.3	190
26	Eastern Afghanistan	0.89±0.04	5.59	8.3	534
27	Gujarat Region	0.87±0.06	1.31	8.0	93
28	Aravali-Bundelkhand	0.81±0.06	1.16	7.0	114
29	Southern Craton	1.19±0.08	0.47	6.8	45
30	Hindukush and Pamirs	0.93±0.01	83.54	8.0	6790
31	Gangetic region	0.84±0.09	0.17	6.3	25
32	Bay of Bengal	0.60±0.08	0.49	6.7	53

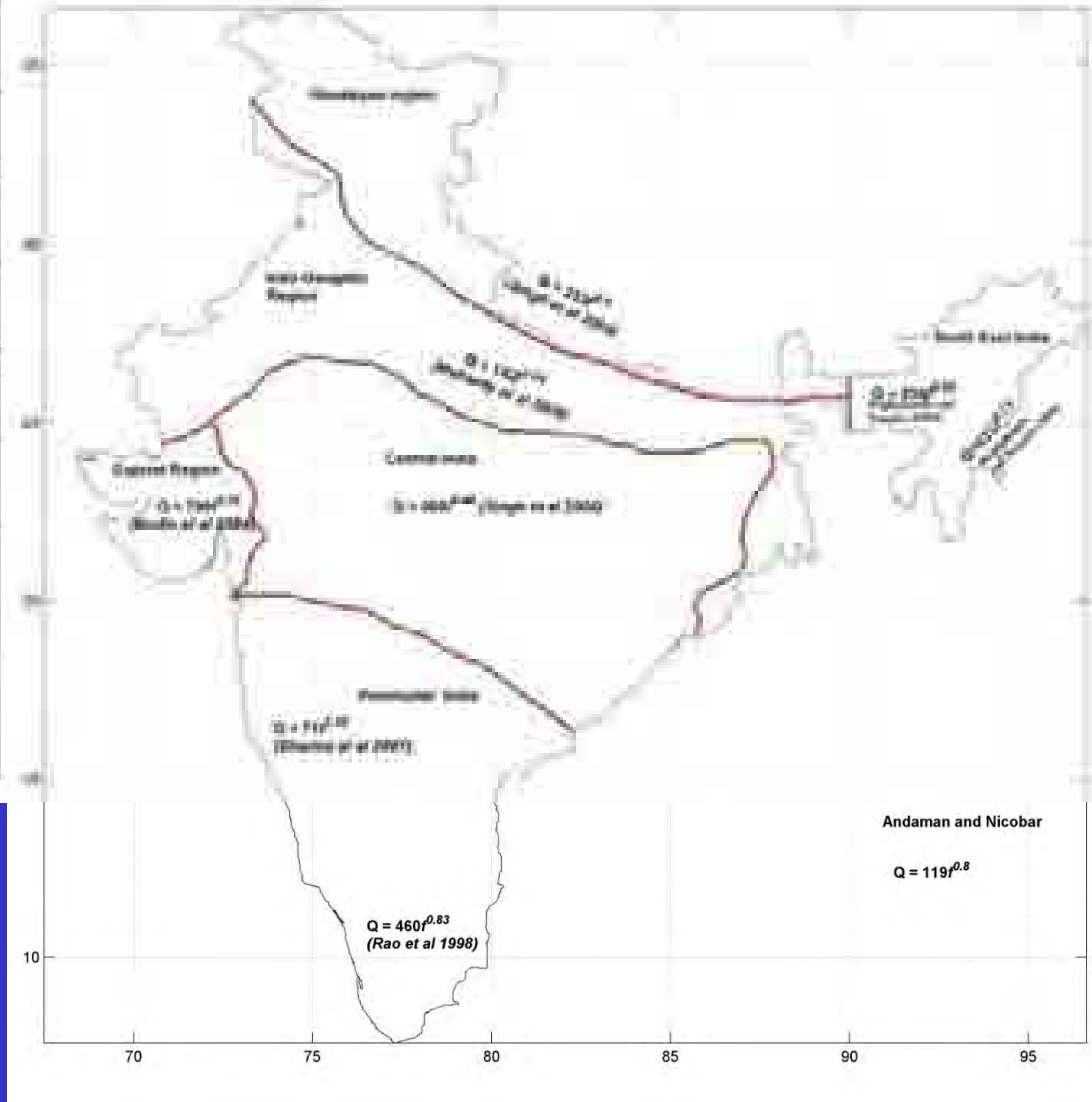


Mumbai
Chennai
Bangalore
Pune
Coimbatore
Kochi
Nashik
Kolhapur
Madurai
Vijayawada
Aurangabad
Solapur
Tiruchirapalli
Kozhikode
Thiruvanthapuram
Hyderabad
4
4.5
5
5.5
6
6.5
7
Magnitude (M_w)


Northeast India
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
Magnitude (Mw)



SMA DATA IN INDIA

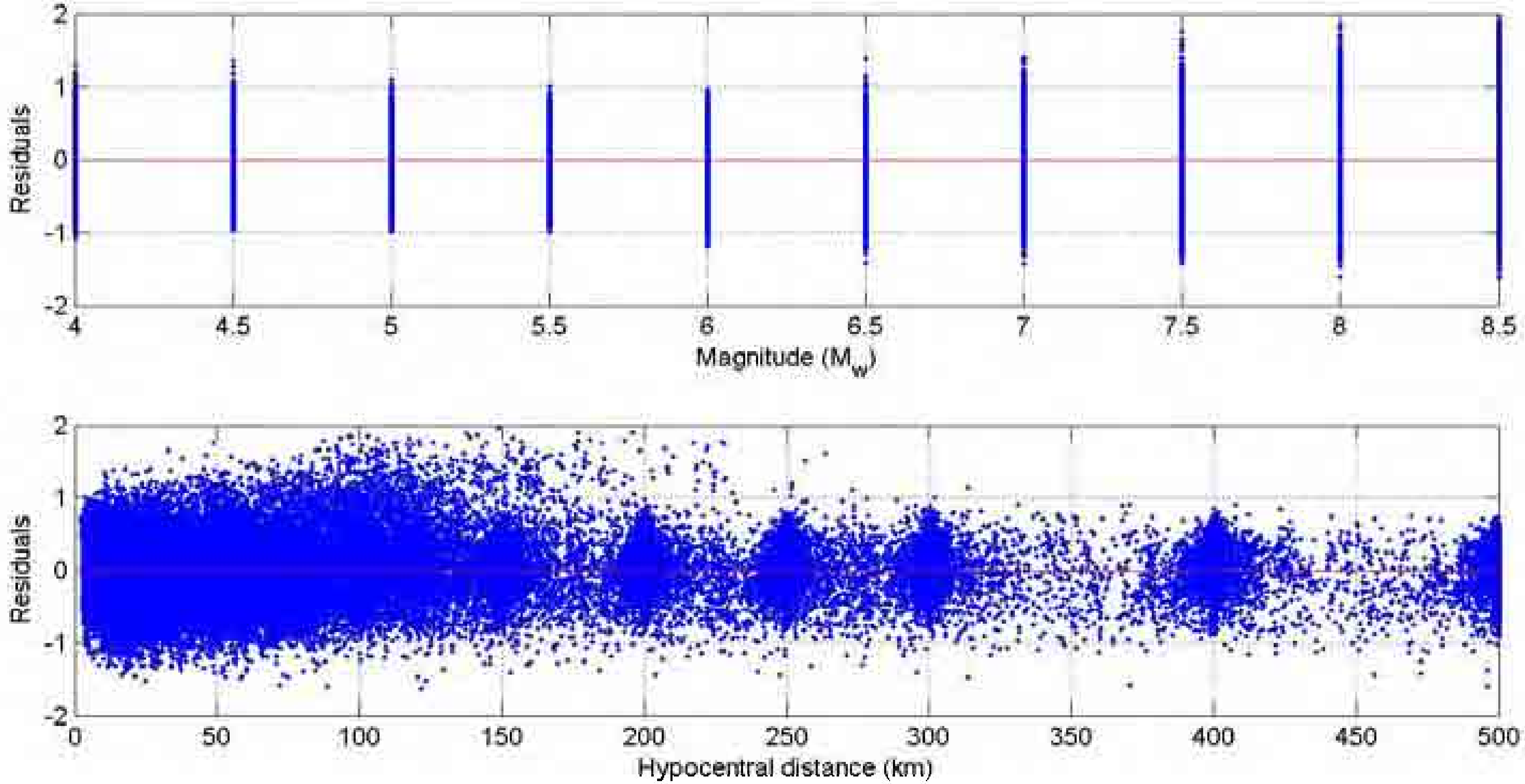


Andaman and Nicobar
Q = 119f^0.8
Q = 460f^0.83
(Rao et al 1998)
10
70
75
80
85
90
95

Table 1. Uncertainties in earthquake model parameters

Region	Q - factor	Investigator
Himalaya	$Q = 253f^{0.8}$	Singh et al (2004)
North East India	Indo-Burmese arc $Q = 431f^{0.73}$ Bengal basin-Shillong plateau $Q = 224f^{0.93}$	Raghukanth and Somala (2009)
Indo-Gangetic	$Q=142f^{1.04}$	Mohanty *et al* (2006)
Gujarat	$Q=790f^{0.22}$	Bodin *et al* (2004)
Central India	$Q=508f^{0.48}$	Singh et al (1999)
Peninsular India	Koyna-Warna $Q=71f^{1.32}$ South India $Q=460f^{0.83}$	Sharma et al (2007) Rao et al (1998)
Andaman-Nicobar	$Q = 119f^{0.16}$	Parvez et al (2008)

Region	Stress drop $\Delta\sigma$ (bars)	Dip (^{0})	Focal depth (km)	Reference
Himalaya	50-200	2^0-30^0	5-40	Kayal (2008)
Northeast India-crustal	100-300	10^0-80^0	5-50	Kayal (2008)
Northeast India-Subduction	100-300	50^0-90^0	50-140	Satyabala (2003)
Indo-Gangetic Plain	50-200	10^0-80^0	5-40	Kayal (2008)
Gujarat	100-300	10^0-80^0	5-40	Bodin *et al* (2004)
Central India	100-300	10^0-80^0	5-30	Singh *et al* (2004)
Peninsular India	100-300	10^0-80^0	5-25	Singh *et al* (2004)
Koyna-Warna	100-300	10^0-80^0	5-15	Talwani *et al* (1998)
Andaman-Nicobar	50-200	10^0-80^0	5-100	Parvez *et al* (2005)

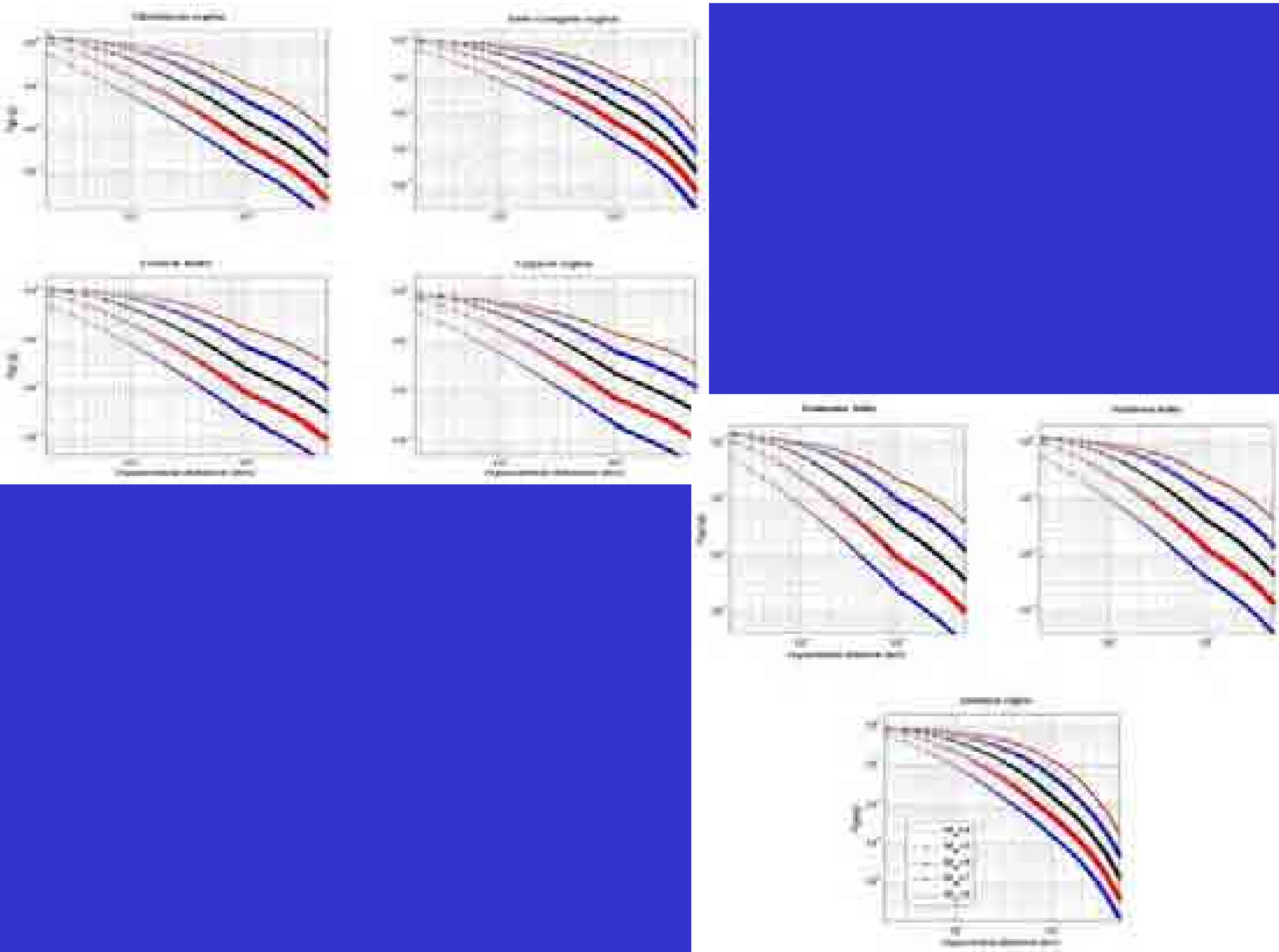


$$\ln\left(\frac{S_a}{g}\right) = c_1 + c_2 M + c_3 M^2 + c_4\, r + c_5 \ln\left(r + c_6 e^{c_7 M}\right) + c_8 \log(r)\mathrm{f}_0 + \ln(\varepsilon)$$

$$\mathrm{f}_0 = \max(\ln(r/100), 0)$$

Coefficients in the attenuation relation for Peninsular India

Period	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	$\sigma(\varepsilon)$
0.0000	-5.2182	1.6543	-0.0309	-0.0029	-1.4428	0.0188	0.9968	0.1237	0.3843
0.0100	-5.2204	1.6523	-0.0307	-0.0029	-1.4422	0.0187	0.9971	0.1237	0.3837
0.0150	-4.1862	1.4952	-0.0197	-0.0030	-1.4265	0.0162	1.0135	0.1209	0.4159
0.0200	-4.1018	1.5037	-0.0209	-0.0030	-1.4096	0.0146	1.0237	0.1202	0.4022
0.0300	-4.1365	1.5228	-0.0227	-0.0030	-1.3888	0.0137	1.0298	0.1161	0.3873
0.0400	-4.2520	1.5430	-0.0244	-0.0029	-1.3783	0.0137	1.0266	0.1149	0.3827
0.0500	-4.4128	1.5817	-0.0271	-0.0029	-1.3801	0.0142	1.0227	0.1140	0.3822
0.0600	-4.7225	1.6531	-0.0327	-0.0028	-1.3730	0.0159	1.0077	0.1132	0.3835
0.0750	-5.0947	1.7235	-0.0383	-0.0028	-1.3572	0.0146	1.0136	0.1121	0.3842
0.0900	-5.5186	1.8218	-0.0460	-0.0028	-1.3441	0.0145	1.0117	0.1113	0.3856
0.1000	-5.8239	1.8911	-0.0511	-0.0028	-1.3409	0.0157	1.0018	0.1103	0.3868
0.1500	-7.4663	2.2950	-0.0816	-0.0027	-1.3179	0.0213	0.9581	0.1055	0.3888
0.2000	-9.0431	2.6930	-0.1115	-0.0026	-1.2965	0.0239	0.9374	0.1020	0.3941
0.3000	-11.9934	3.4705	-0.1687	-0.0025	-1.2861	0.0384	0.8713	0.0989	0.4008
0.4000	-14.3305	4.0665	-0.2112	-0.0025	-1.2686	0.0462	0.8467	0.0984	0.4052
0.5000	-16.2504	4.5566	-0.2457	-0.0024	-1.2614	0.0533	0.8254	0.0975	0.4082
0.6000	-18.1350	5.0060	-0.2767	-0.0024	-1.2419	0.0473	0.8363	0.0949	0.4106
0.7000	-19.3494	5.3013	-0.2962	-0.0024	-1.2399	0.0508	0.8309	0.0934	0.4119
0.7500	-19.8904	5.4156	-0.3035	-0.0023	-1.2316	0.0472	0.8388	0.0922	0.4130
0.8000	-20.4426	5.5522	-0.3118	-0.0023	-1.2423	0.0529	0.8273	0.0938	0.4120
0.9000	-21.4875	5.7648	-0.3246	-0.0023	-1.2309	0.0473	0.8383	0.0922	0.4129
1.0000	-21.9767	5.8581	-0.3297	-0.0023	-1.2258	0.0438	0.8487	0.0927	0.4134
1.2000	-23.1660	6.0486	-0.3372	-0.0023	-1.2204	0.0401	0.8659	0.0939	0.4139
1.5000	-24.2031	6.1891	-0.3402	-0.0022	-1.2281	0.0371	0.8833	0.0924	0.4137
2.0000	-25.1523	6.2202	-0.3308	-0.0022	-1.2390	0.0324	0.9107	0.0975	0.4173
2.5000	-25.5577	6.1153	-0.3139	-0.0022	-1.2275	0.0213	0.9687	0.0982	0.4248
3.0000	-25.5807	5.8957	-0.2871	-0.0021	-1.2341	0.0150	1.0215	0.1003	0.4274
4.0000	-25.2671	5.5029	-0.2436	-0.0021	-1.2511	0.0122	1.0627	0.1034	0.4346



SEISMIC HAZARD CURVE

Magnitude → GROUND MOTION

Distance from the seismic source → GROUND MOTION

What is the Frequency of Occurrence of earthquakes ?

Frequency of 6 magnitude earthquake on a particular seismic source?

Frequency of 7 magnitude earthquake ?

Frequency of 8 ?

$$\mu_{y^*} = \sum_{i=1}^{K} N_i(m_0) \int_m \int_r P(Y > y^* \mid m, r)\, p_{R|M}(r \mid m)\, p_M(m)\, dr\, dm$$

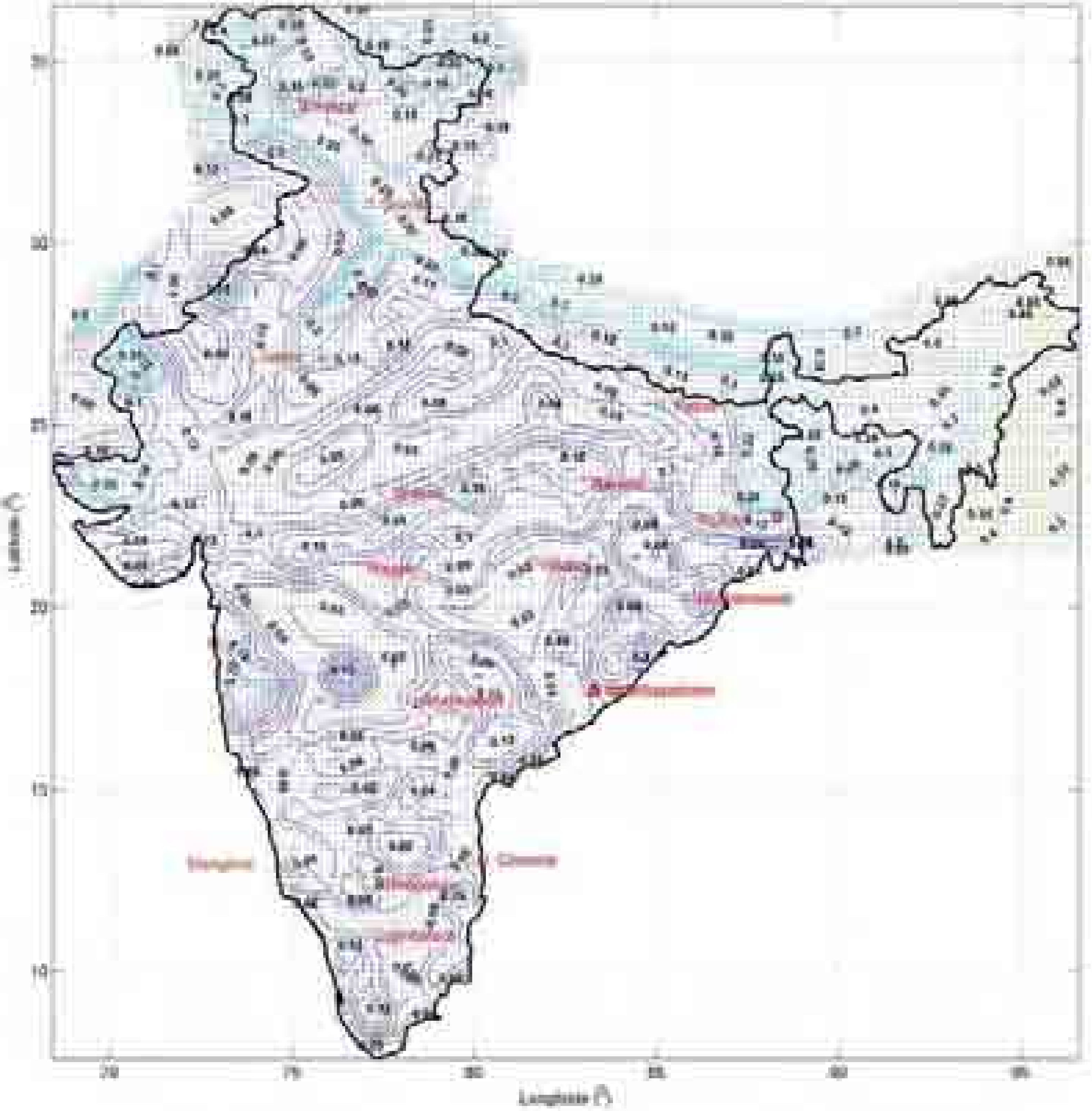
Activity rate of i^{th} fault

Ground motion

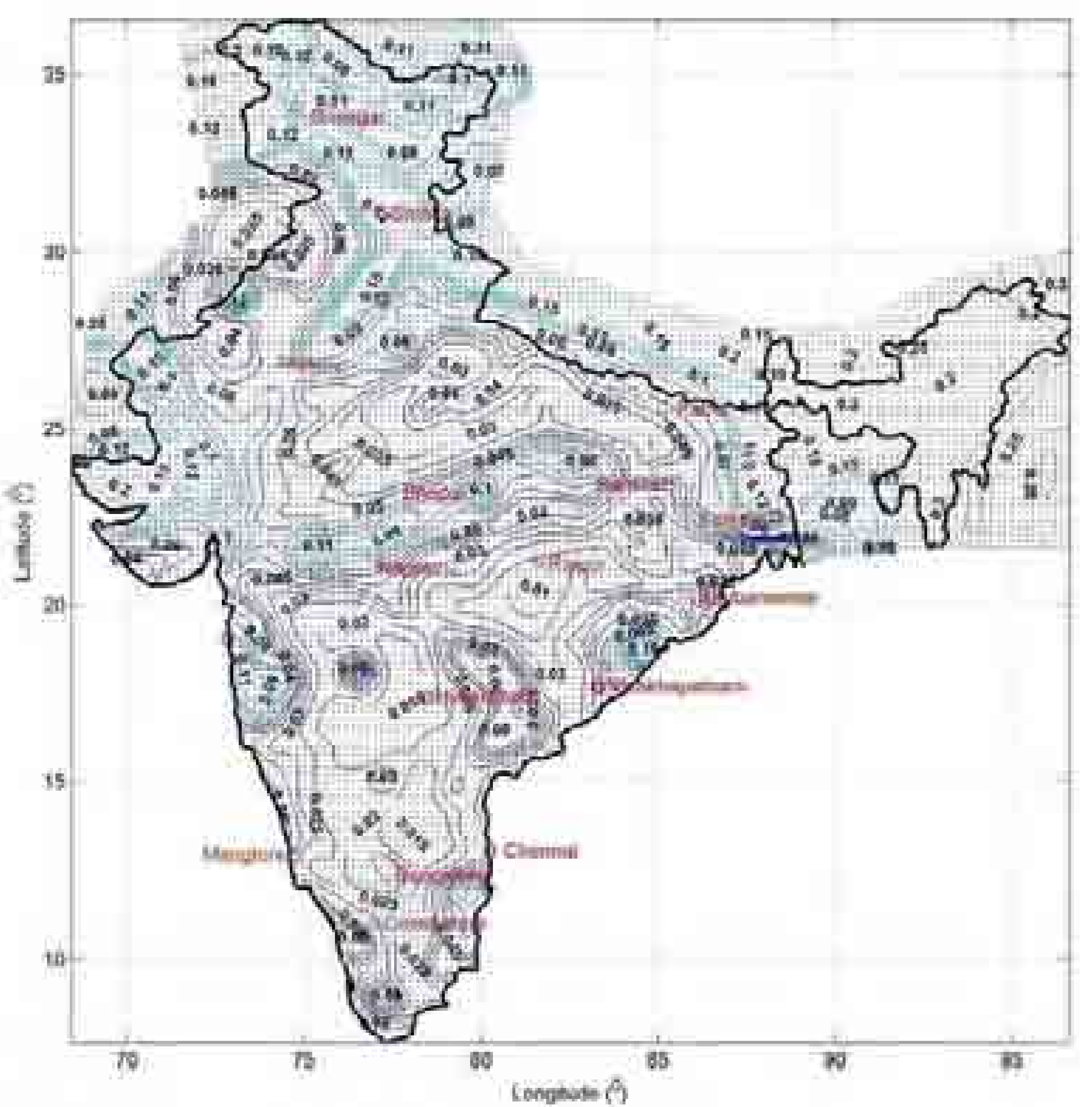
Location of fault

Magnitude

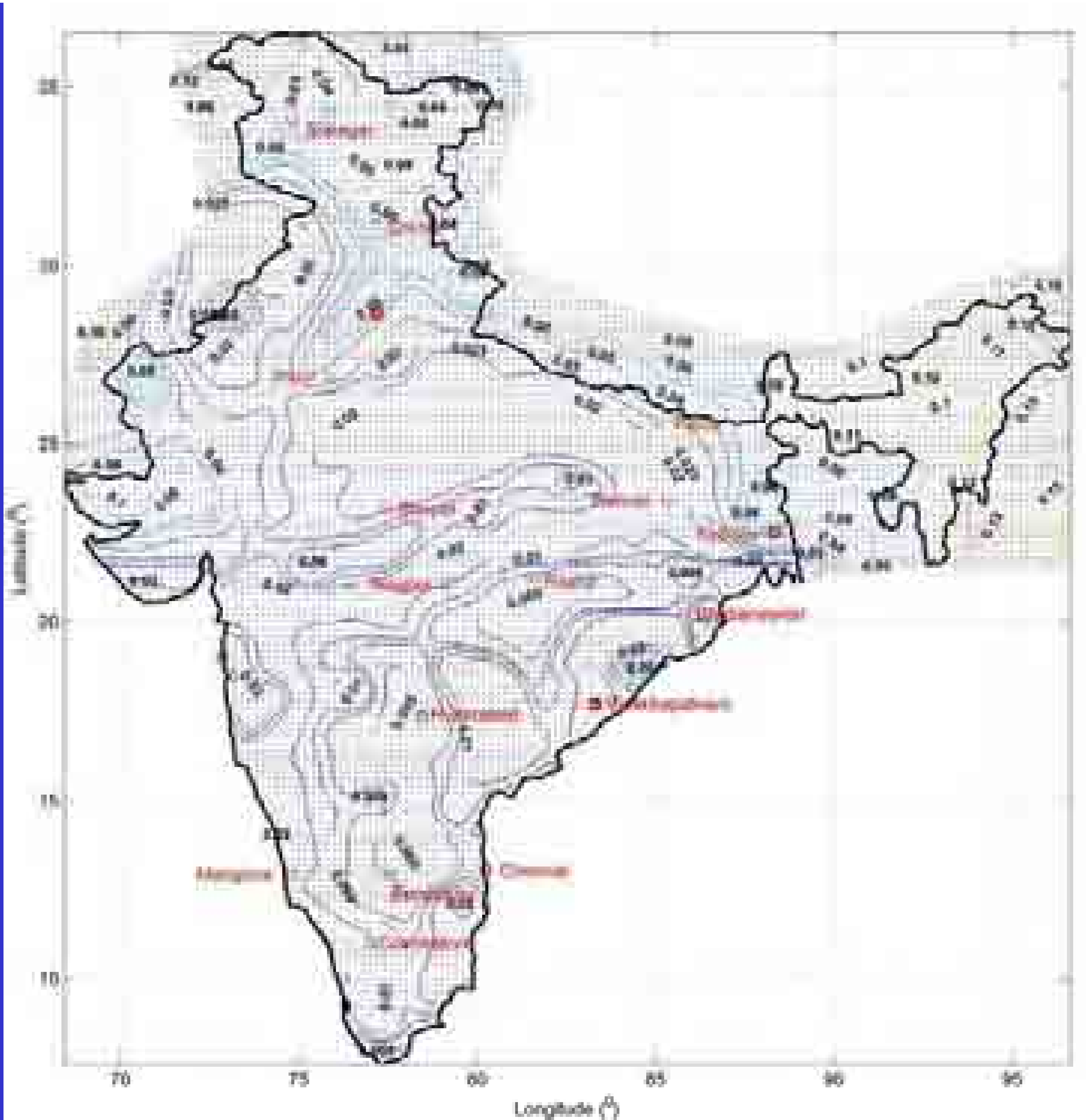
K = Number of faults



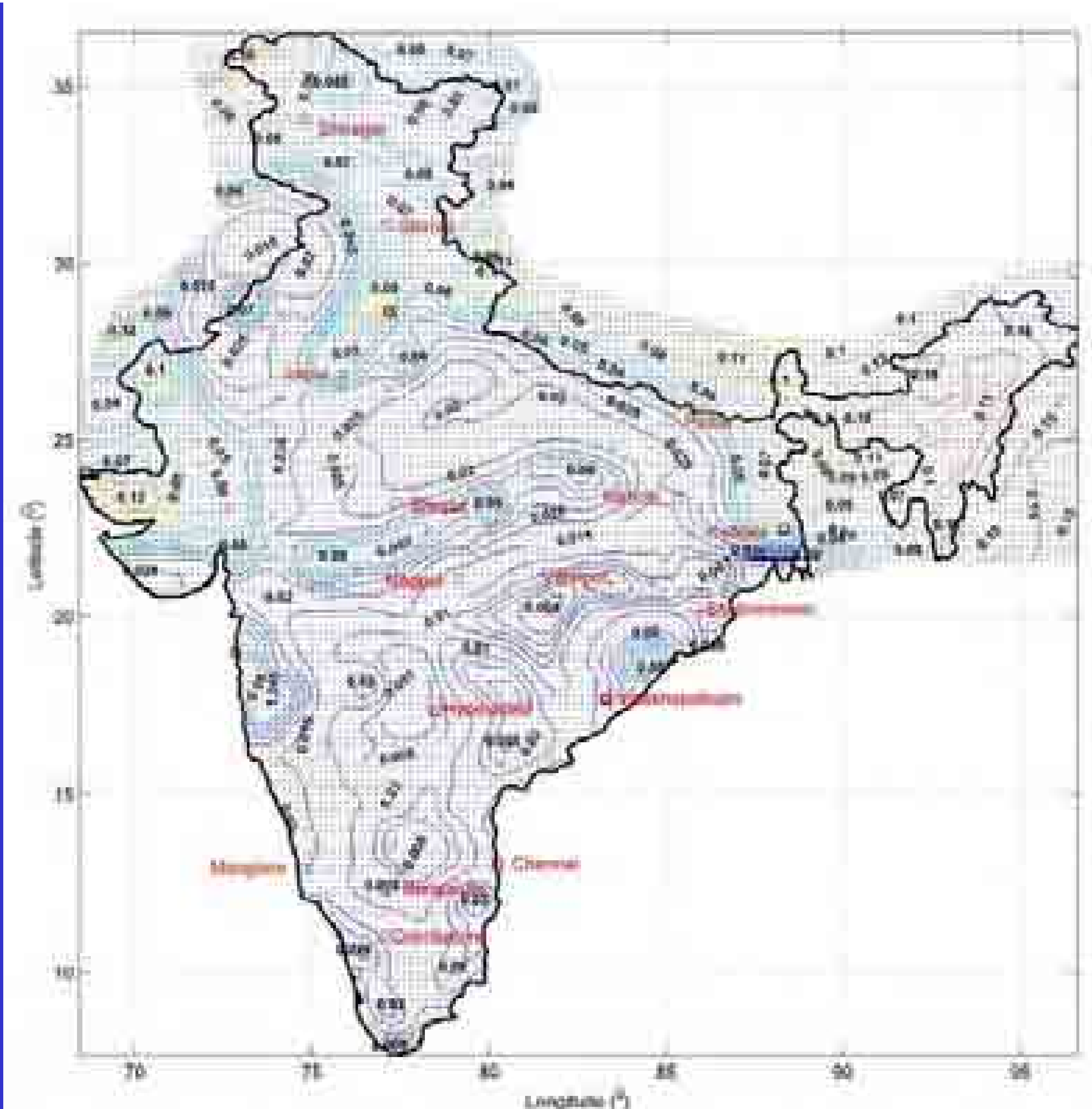
PGA Contours with 2% probability of exceedence in 50 years (Return Period ~2500 years) on A-type Sites



Spectral acceleration Contours at T =0.5sec with 2% probability of exceedence in 50 years (Return Period ~2500 years) on A-type Sites

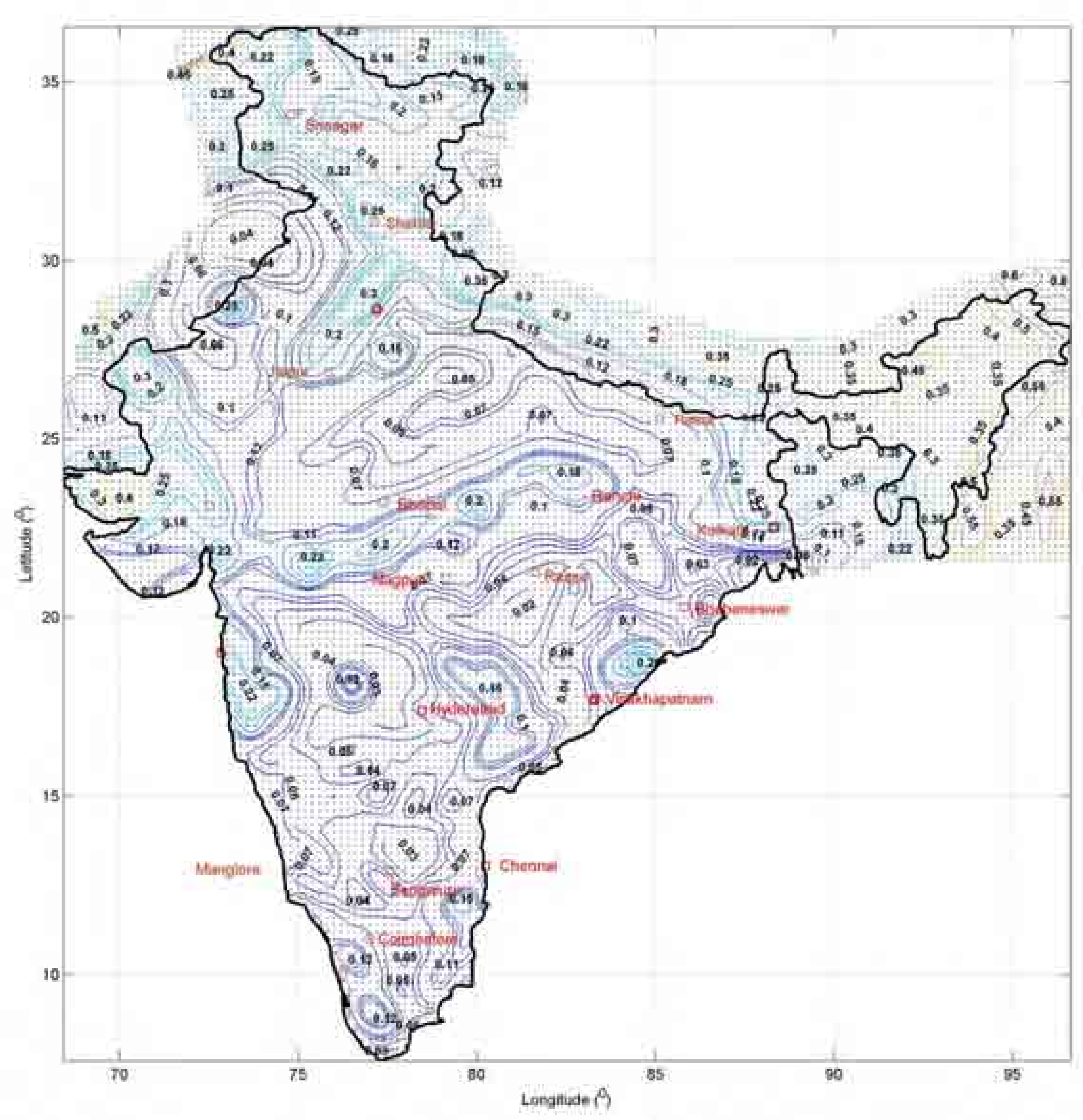


Spectral acceleration Contours at T =1.25sec with 2% probability of exceedence in 50 years (Return Period ~2500 years) on A-type Sites



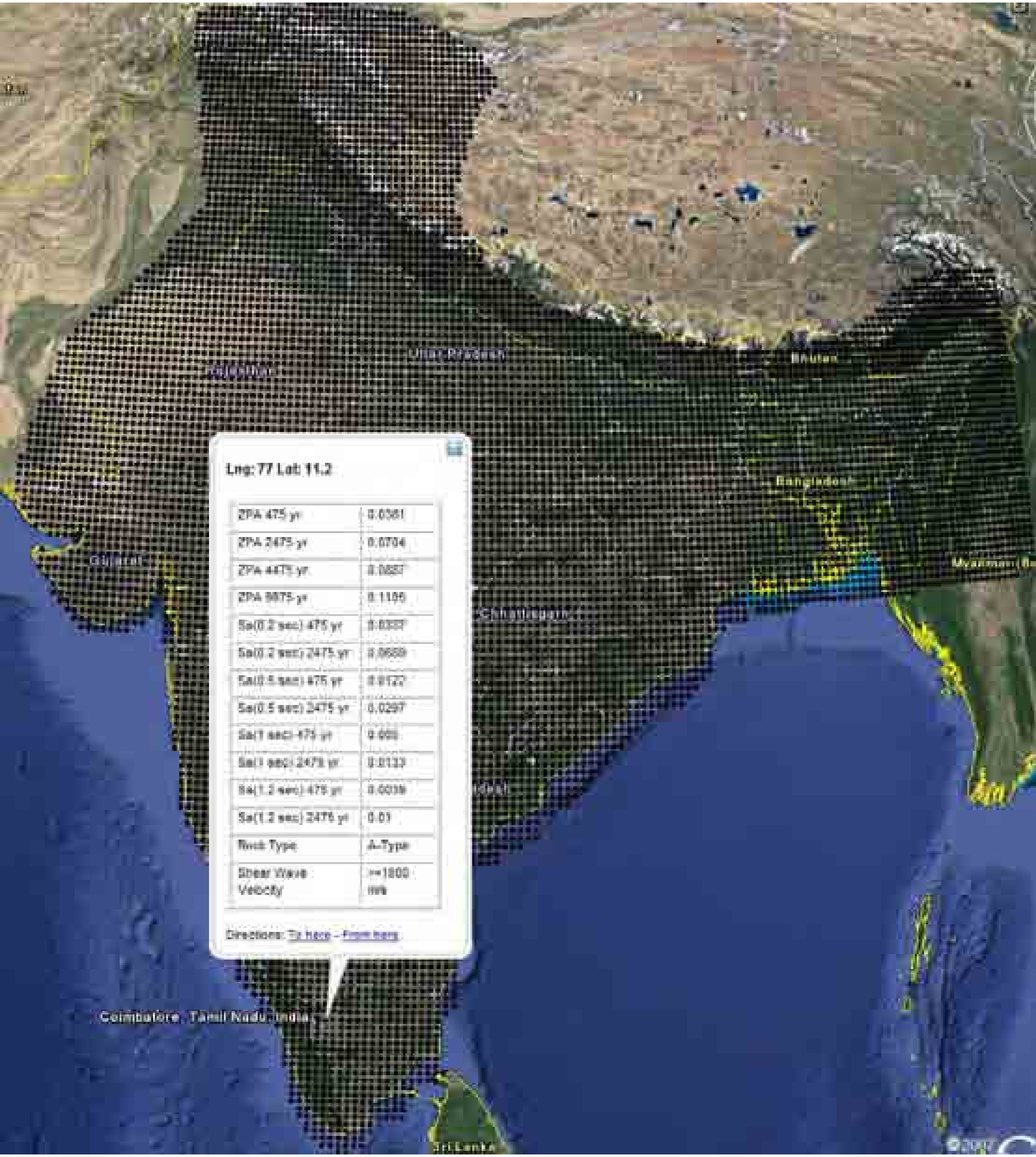
Spectral acceleration Contours at T =1sec with 2% probability of exceedence in 50 years (Return Period ~2500 years) on A-type Sites

IBC 2009



Spectral acceleration Contours at T =0.2sec with 2% probability of exceedence in 50 years (Return Period ~2500 years) on A-type Sites

IBC 2009



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Design Spectrum following IBC-2009; ASCE 7, 2005

Classification of sites based on the average shear wave velocity of the top 30 meters of the subsoil is popular among engineers as a quick way of understanding how ground motion during an earthquake differs on rock sites and soil sites. Standard documents such as IBC-2009, can be referred for classifying sites based on borehole data or velocity profiling. The standard site classification definitions are shown in Table A-1.

Table A-1. Site Class Definitions (Ref: International Building Code IBC-2009)

Site class	Average shear wave velocity (v_s^1)	Average standard penetration resistance (N^1 or N_{ch}^1)	Average undrained shear strength in the case of cohesive soils (s_u^1)
A : Hard Rock	>1500 m/s	Not applicable	Not applicable
B: Rock	760 to 1500 m/s	Not applicable	Not applicable
C:Very dense soil or soft rock	370 to 760 m/s	>50	>100kPa
D: Stiff soil	180 to 370 m/s	15 to 50	50 to 100 kPa
E: Soft soil	<180 m/s	<15	<50 kPa
	Any profile with more than 3 m of soil having Plasticity Index PI>20, Moisture content ω≥40% Average undrained shear strength s_u < 24 kPa		
F: Soils requiring site-specific evaluation	Soils vulnerable to potential failure or collapse (liquefiable, quick- or highly sensitive clays, collapsible weakly cemented soils) More than 3 m of peat and/or highly organic clays More than 7.5m of very high plasticity clays (PI>75) More than 37m of soft to medium clays		

IBC-2009 defines two site coefficients Fa and Fv corresponding to the 2500-year spectral acceleration (5% damping) value for representative short and long period ranges as shown in Tables A-2 and A-3.

Table A-2 Site coefficients F_a for short period range

SITE CLASS	Mapped spectral response acceleration at short periods				
	$S_s \leq 0.25$	$S_s = 0.50$	$S_s = 0.75$	$S_s = 1.0$	$S_s \geq 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	Site-specific analysis shall be performed				

Table A-3 Site coefficients F_v for 1-second period

SITE CLASS	Mapped spectral response acceleration at 1 sec period				
	$S_1 \leq 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 \geq 0.5$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	Site-specific analysis shall be performed				

Response Spectrum

Step 1: Determine, maximum considered earthquake spectral response acceleration at 0.2s period and 1s period as

$$S_{MS} = F_a S_S \quad \text{(A-1)}$$

$$S_{M1} = F_v S_1 \quad \text{(A-2)}$$

S_S and S_1 are mapped spectral accelerations for short period and 1 s period

Step 2: Determine design basis earthquake spectral response acceleration at 0.2s period and 1s period using the equations

$$S_{DS} = (2/3)S_{MS} \quad \text{(A-3)}$$

$$S_{D1} = (2/3)S_{M1} \quad \text{(A-4)}$$

Step 3: Calculate characteristic time periods T_o and T_s

$$T_o = 0.2\frac{S_{D1}}{S_{DS}} \quad \text{(A-5)}$$

$$T_s = \frac{S_{D1}}{S_{DS}} \quad \text{(A-6)}$$

Step 4: Design spectra construction:

Let T is the fundamental time period of the structure

a) For periods less than or equal to T_0, design spectral response acceleration, S_a is given by

$$S_a = 0.6(S_{DS}/T_0)T + 0.4S_{DS} \qquad \text{(A-7)}$$

b) For periods greater than or equal to T_0 and less than or equal to T_s,

$$S_a = S_{DS} \qquad \text{(A-8)}$$

c) For periods greater than or equal to T_s

$$S_a = S_{D1}/T \qquad \text{(A-9)}$$

Illustrative Example for a hypothetical D-type site at Chennai

The latitude and longitude of the site considered are 13.13° and 80.32", respectively. Based on interpolation of PSHA results available at the four grid points of the 0.2°x0.2° square encompassing the site, the values of S_s and S_1 for A-type rock level are obtained (Table.A-4).

Table A-4 PSHA at site for A-type rock level

Return Period Yrs.	$S_s(g)$	$S_1(g)$
2500	0.044	0.0074

It is given that the site has been classified as of D-type. Since the IBC procedure requires the maximum considered earthquake spectral response acceleration at 0.2s period and 1s period at Type B rock level, a correction factor of 1.25 has to be applied (Tables A-2, A-3). The maximum considered earthquake spectral response acceleration at 0.2s period and 1s period at Type B rock level are obtained as

$$S_s(g) = 0.044 \times 1.25 = 0.055$$

$$S_1(g) = 0.0074 \times 1.25 = 0.0093$$

The site coefficients F_a and F_v for D-Type site are obtained as 1.6 and 2.4 from Tables A-2 and A-3, respectively. The short period and long period MCE spectral response acceleration are obtained as

$$S_{MS}(g) = 1.6 \times 0.055 = 0.088$$

$$S_{M1}(g) = 2.4 \times 0.0093 = 0.022$$

The design basis spectral accelerations are:

$$S_{DS}(g) = \frac{2}{3} \times 0.088 = 0.058$$

$$S_{D1}(g) = \frac{2}{3} \times 0.022 = 0.0148$$

The characteristic time periods are:

$$T_o = 0.2 \times \frac{0.0148}{0.058} = 0.051s$$

$$T_s = \frac{0.0148}{0.058} = 0.253s$$

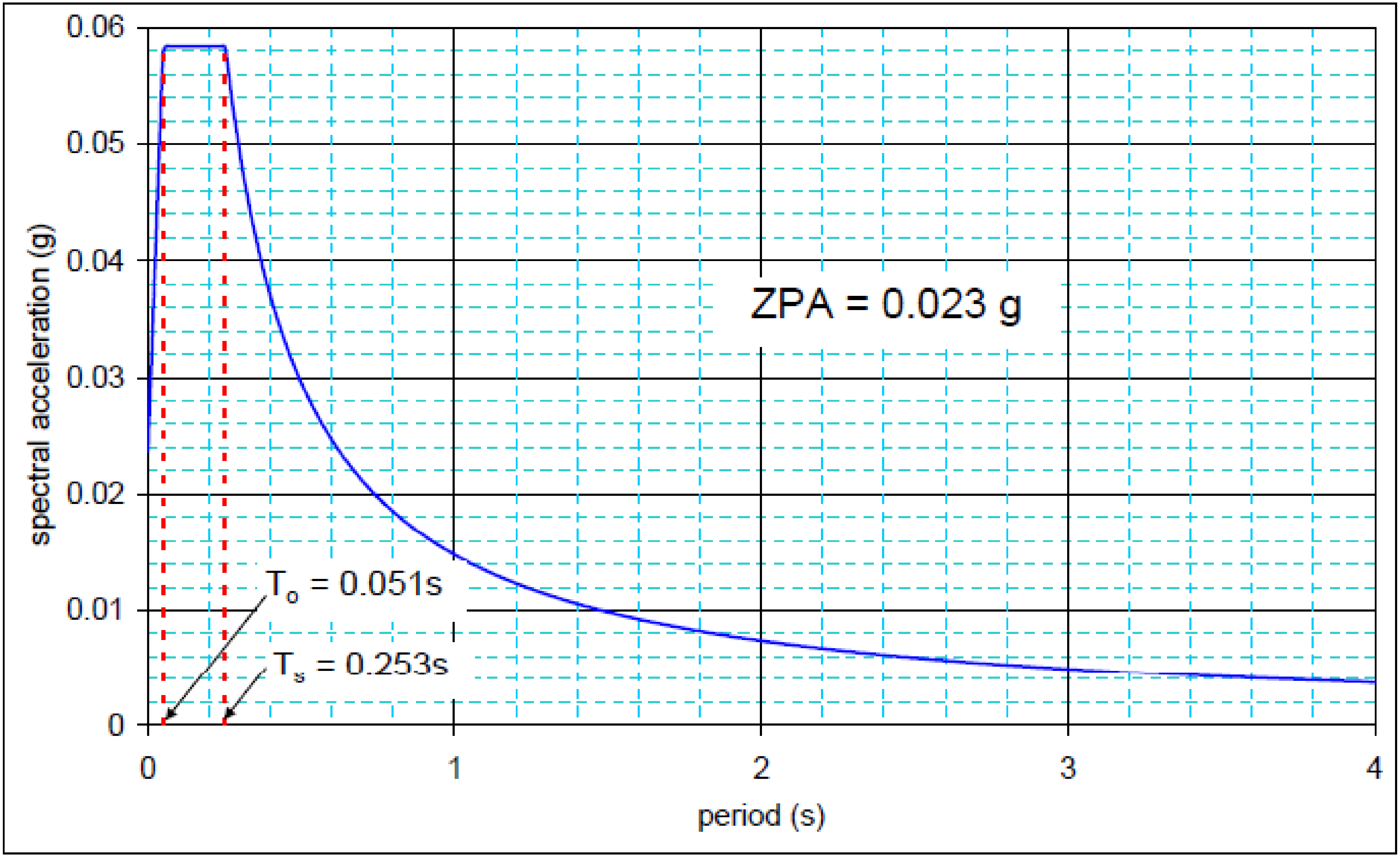
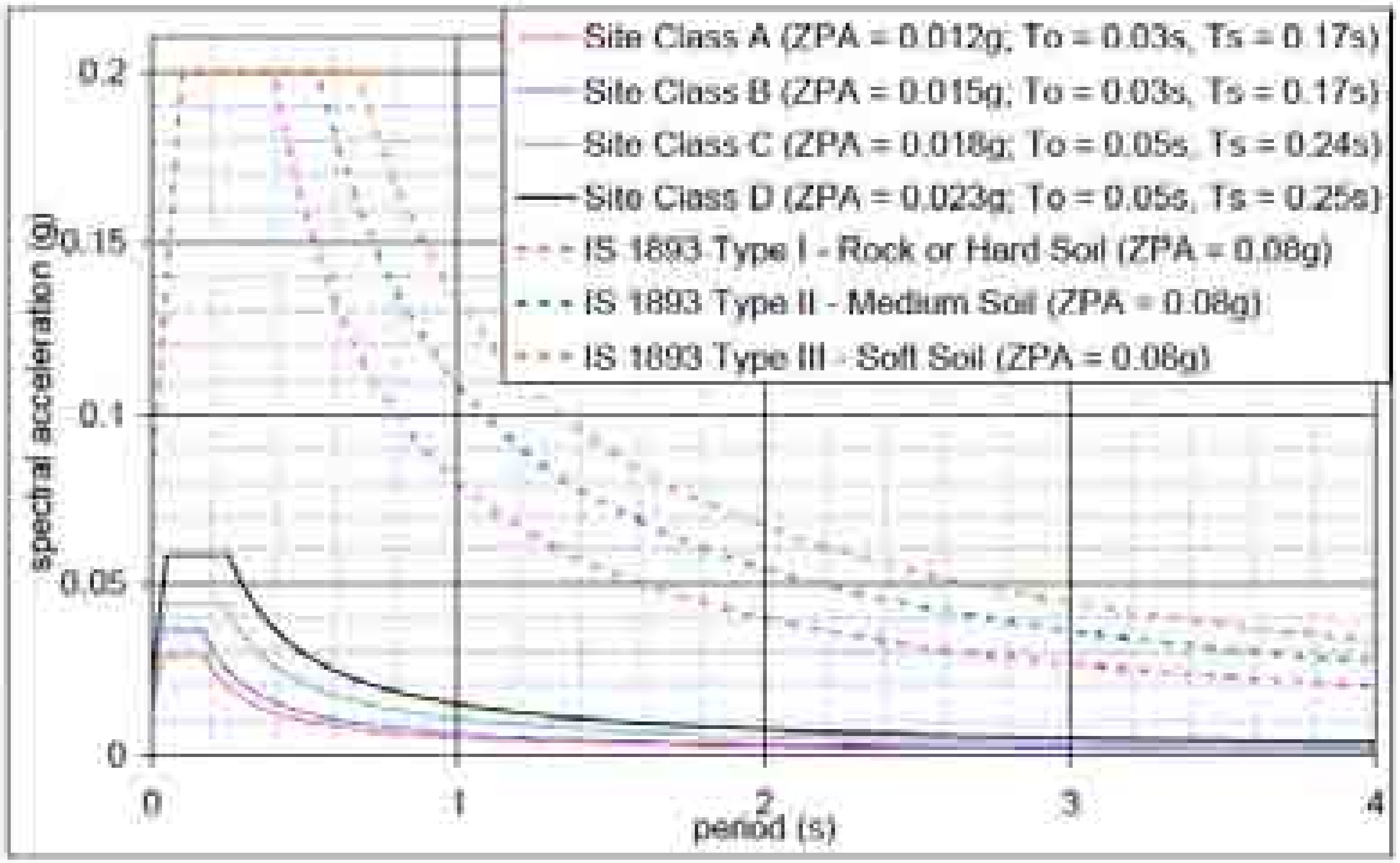


Figure A-1 Design spectra for D-type site in Chennai city (5% damping)

Note: ZPA is obtained as the ordinate at zero period. This need not be same as the mapped PGA value.

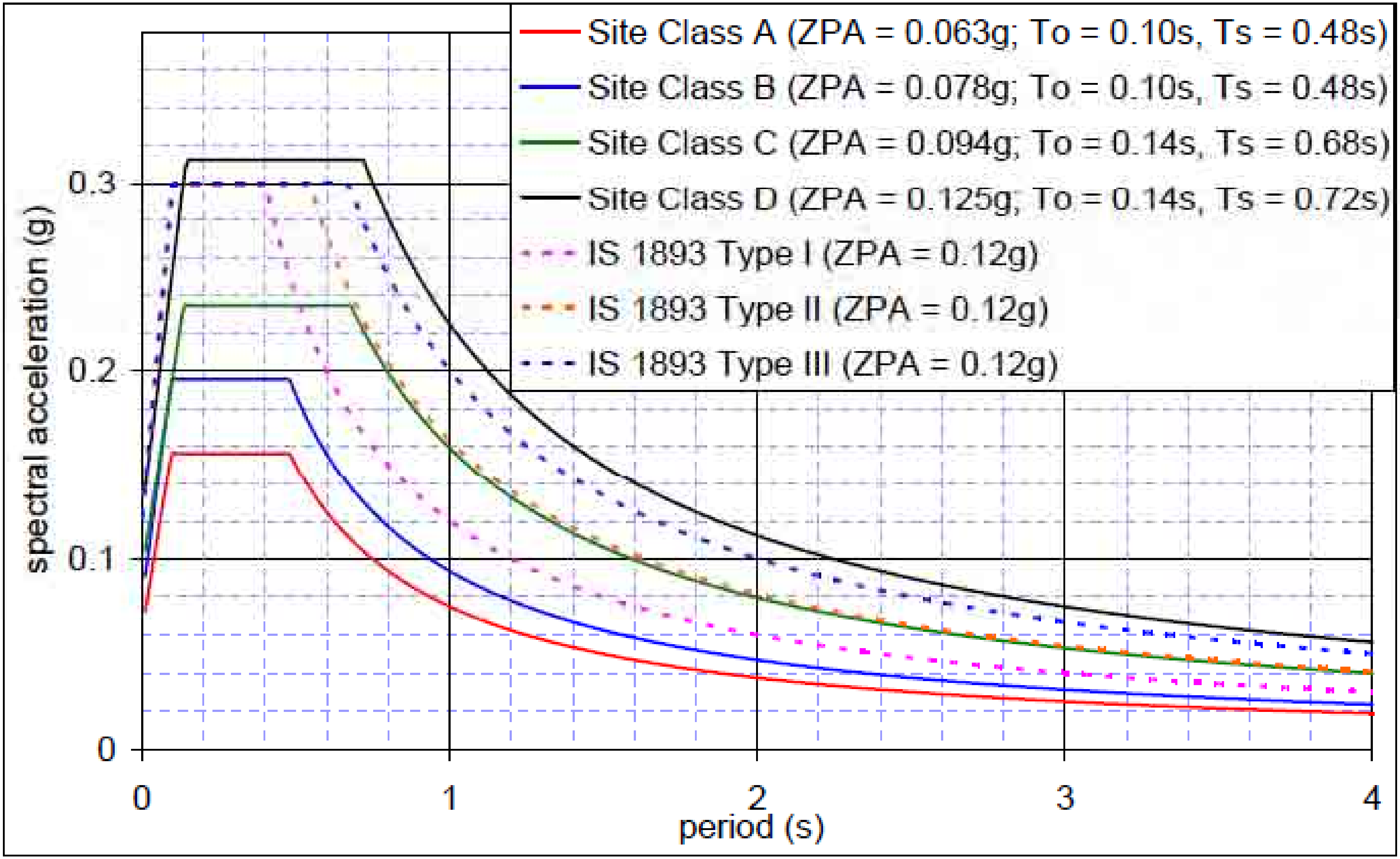
Design Response Spectra for Chennai, Delhi, Kolkata and Mumbai

Following the procedure described above, the design spectrum at any site in India can be constructed following the provisions of IBC-2009. This provides an opportunity to compare the design spectrum constructed based on PSHA results (with spectral accelerations corresponding to 2500-year mean return period as the MCE) with the response spectra provided in the BIS building code IS 1893:2002 which is based on deterministic hazard concepts and past damage intensity considerations. Here this comparison has been carried out for the four metropolitan cities of India. The results are shown in Figs A-2, A-3, A-4 and A-5. In plotting the design basis spectrum of IS 1893:2002, (Z/2) is taken as the ZPA ordinate.



Comparison of IBC design spectra obtained using PSHA results with that specified in IS 1893:2002 for Chennai (damping = 5%)

Comparison of IBC design spectra obtained using PSHA results with that specified in IS 1893:2002 for Delhi (damping = 5%)



Comparison of IBC design spectra obtained using PSHA results with that specified in IS 1893:2002 for Kolkata (damping = 5%)

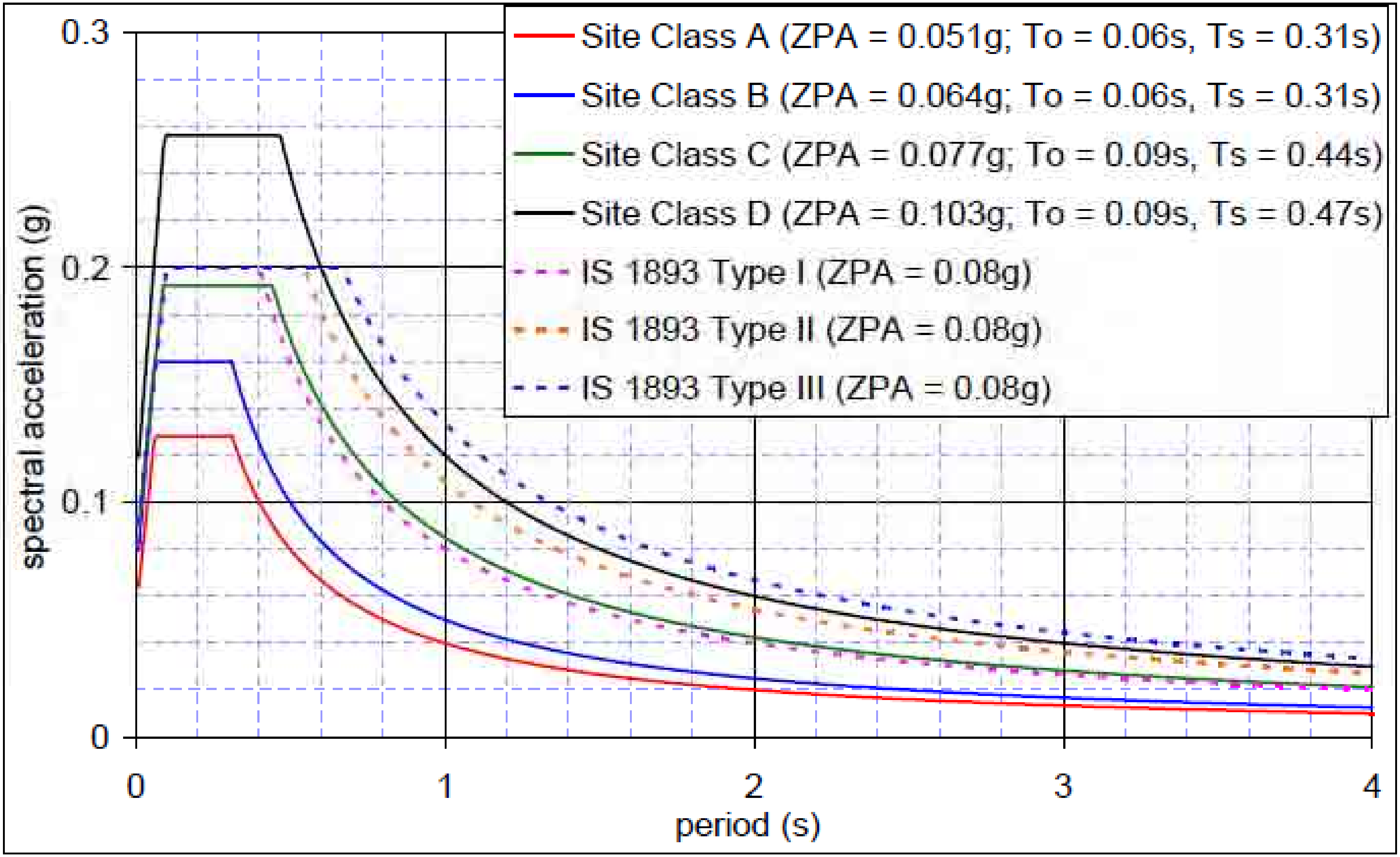
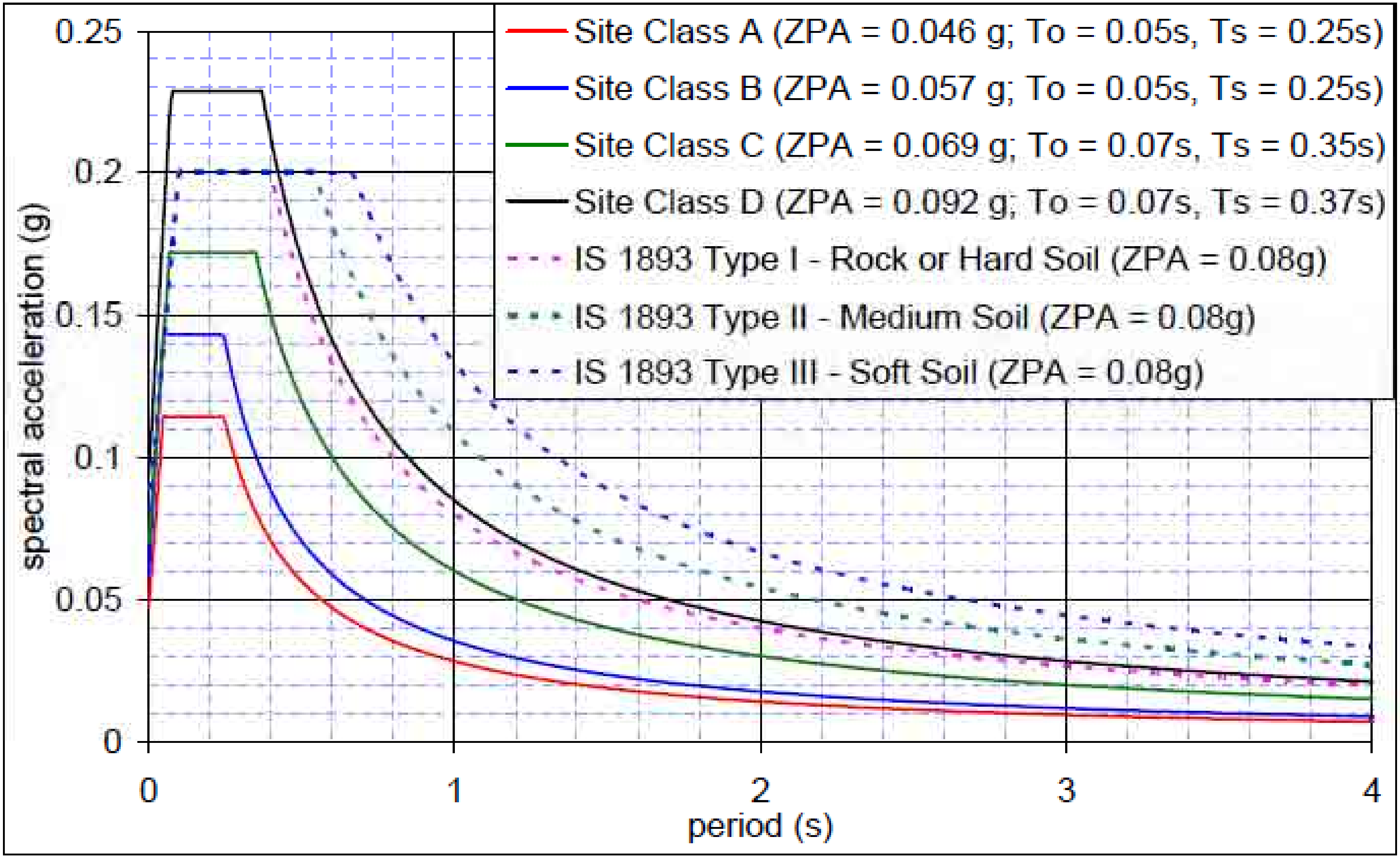


Figure A-4 Comparison of IBC design spectra obtained using PSHA results with that specified in IS 1893:2002 for Kolkata (damping = 5%)

Comparison of IBC design spectra obtained using PSHA results with that specified in IS 1893:2002 for Mumbai



Comparison of ZPA of Design Spectrum

City	Site Type IBC-Notation	PSHA ZPA (g)	Soil Type IS 1893:2002 Notation	IS 1893:2002 ZPA (g)
Chennai	A	0.012	Type I (Rock or Hard Soil)	0.08
	B	0.015	Type II (Medium soil)	
	C	0.018	Type III (Soft soil)	
	D	0.023		
Delhi	A	0.063	Type I (Rock or Hard Soil)	0.12
	B	0.078	Type II (Medium soil)	
	C	0.094	Type III (Soft soil)	
	D	0.125		
Kolkata	A	0.063	Type I (Rock or Hard Soil)	0.08
	B	0.078	Type II (Medium soil)	
	C	0.094	Type III (Soft soil)	
	D	0.125		
Mumbai	A	0.046	Type I (Rock or Hard Soil)	0.08
	B	0.057	Type II (Medium soil)	
	C	0.069	Type III (Soft soil)	
	D	0.092		

Dynamic Analysis of the Reinforced Concrete Framed Structure using Response Spectrum Method

The dynamic analysis of the reinforced concrete framed structure is carried out using the response spectrum method as specified in IS 1893 (Part 1):2002. The step-by-step procedure for carrying out dynamic analysis using response spectrum is given below:

1. Carry out free vibration analysis of the building to obtain the frequencies and mode shapes corresponding to different modes of vibration
2. Determine the modal masses and modal participation factors from the following equations:

   The modal mass of k^{th} mode is given by

$$M_k = \frac{\left[\sum_{i=1}^{n} W_i \phi_{ik}\right]^2}{g \sum_{i=1}^{n} W_i (\phi_{ik})^2}$$

where

g = Acceleration due to gravity,

ϕ_{ik} = Mode shape coefficient at floor i in mode k, and

W_i = Seismic weight of floor i.

The modal participation factor of mode k is given by

$$P_k = \frac{\sum_{i=1}^{n} W_i \phi_{ik}}{\sum_{i=1}^{n} W_i (\phi_{ik})^2}$$

3. Determine the number of number of modes to be used in the analysis such that the sum total of modal masses of all modes considered is at least 90% of the total seismic mass (Cl. 7.8.4.2 of IS 1893 (Part 1):2002)
4. Determine the peak lateral force(Q_{ik}) at floor i in mode k as

   $$Q_{ik} = A_k \phi_{ik} P_k W_i$$

   where A_k is the design horizontal acceleration spectrum value corresponding to the period of the k^{th} mode of vibration. This needs to be obtained from the ordinates of the response spectrum corresponding to the design basis earthquake, obtained from PSHA results.
5. Determine the peak shear force (V_{ik}) acting in storey i in mode k as

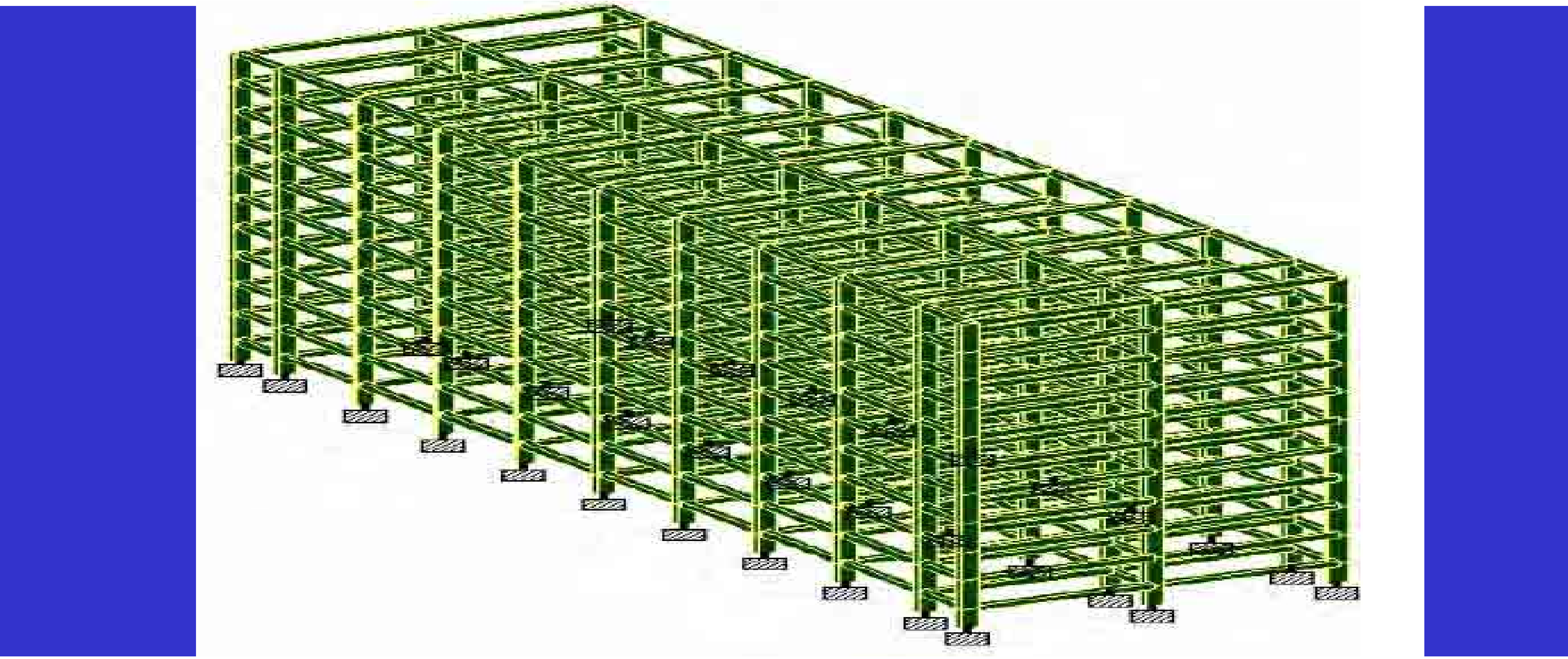
   $$V_{ik} = \sum_{j=i+1}^{n} Q_{ik}$$

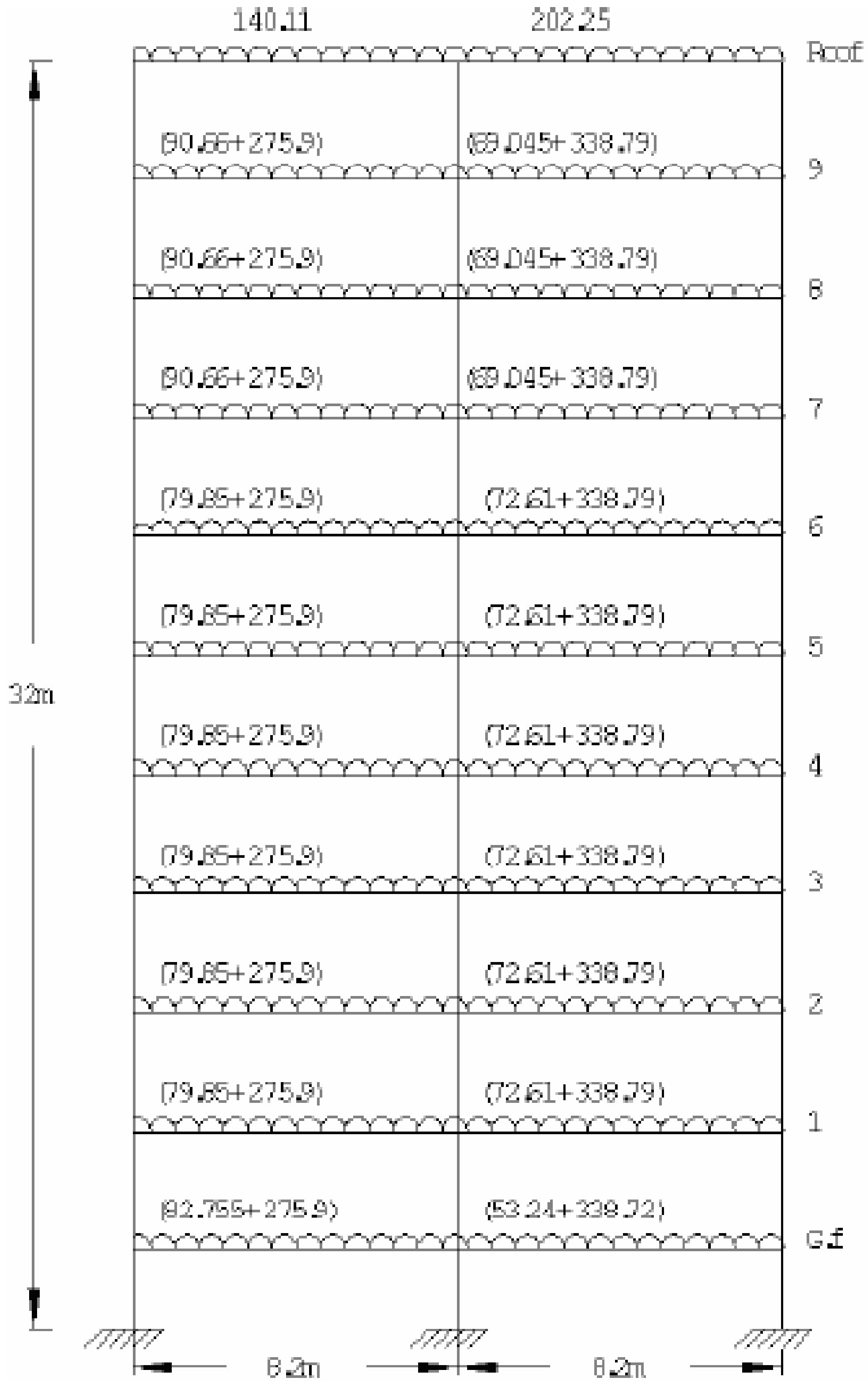
6. Determine the peak storey shear force (V_i) in storey i due to all modes considered by combining those due to each mode using Complete Quadratic Combination (CQC) method or Square Root of Sum of Squares (SRSS) when the modes are well separated.

7. Determine the design lateral forces (F_i) at each storey due to all the modes considered
8. Analyze the building for the design lateral forces

Illustrative Example

The building considered is an eleven storey reinforced concrete framed hospital building (see Fig. B-1) with 10 bays in the longitudinal direction (8-bays of span length = 6.2m and 2 bays of span length = 3.3m) and 2 bays in the transverse direction (span length of each bay = 8.2m), and located in Zone III (Adyar, Chennai). The building is assumed to be located in Type C soil (very dense soil and soft rock with shear wave velocity ranging from 360 m/s to 750 m/s) The total plinth area of the hospital building is 56.2m x 16.4m. The dead- and imposed- loads are computed according to IS 875-1987 Parts 1 and 2. The loads acting on a typical frame of the building is shown in Fig. B-2. The characteristic strength of concrete used is 40 MPa and the yield strength of steel is 415 MPa. The columns are of size 400mm x 800mm and the beams are of size 400mm x 600 mm.





Loads acting on Frame 2 (loads are in kN)

Results of free vibration analysis of the 11 storey hospital building

Mode	Frequency (Hz)	Period (s)	Modal Participation Factor	Modal Weight (kN)	Relative Modal Weight (%)
1	0.520	1.925	1.756	30238.43	73.34
2	1.798	0.556	0.686	4615.74	11.20
3	3.681	0.272	-0.456	2036.99	4.94
4	6.344	0.158	-0.350	1198.04	2.91
5	9.896	0.101	0.282	779.44	1.89
6	14.367	0.070	0.236	548.44	1.33
7	19.776	0.051	0.209	429.06	1.04
8	26.238	0.038	0.189	349.37	0.85
9	33.404	0.030	0.172	288.93	0.70
10	40.354	0.025	0.161	254.01	0.62
11	46.204	0.022	0.224	491.76	1.19

It is noted from Table that the first four modes needs to be considered in the dynamic analysis since the sum total of modal masses of these four modes will exceed 90% of the total seismic mass.

The response spectrum corresponding to DBE for Chennai city at Type C soil (very dense soil and soft rock with shear wave velocity ranging from 360 m/s to 750 m/s) has been computed using the procedure outlined earlier and is shown in Fig. B-3.

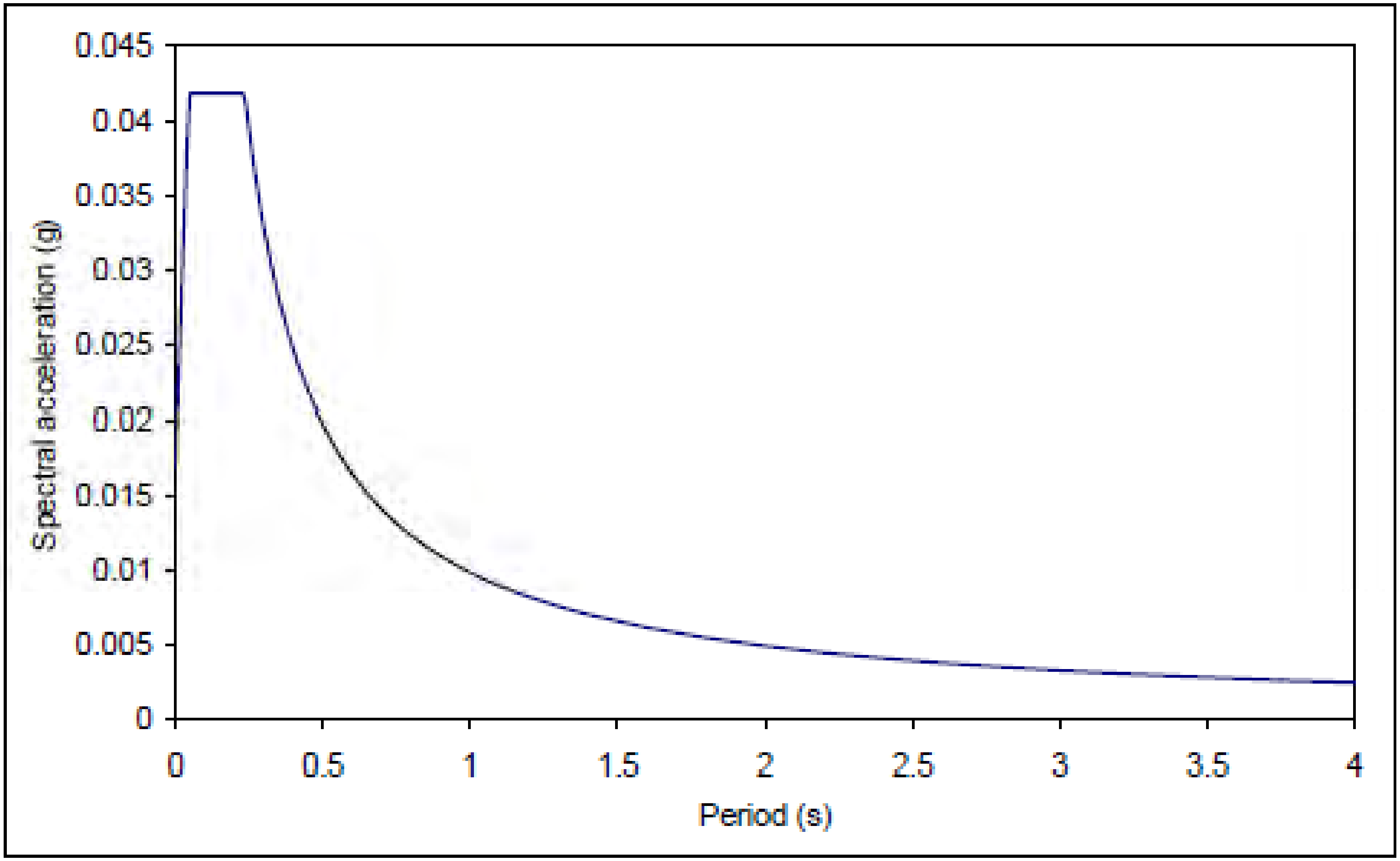


Figure B-3 Response spectrum for Chennai at Type C soil corresponding to DBE (MCE is taken as that corresponding to 2475-year mean return period and DBE is taken as 2/3rd of MCE)

The storey shear forces and the design lateral forces are determined using the procedure given above and are given in Table B-2.

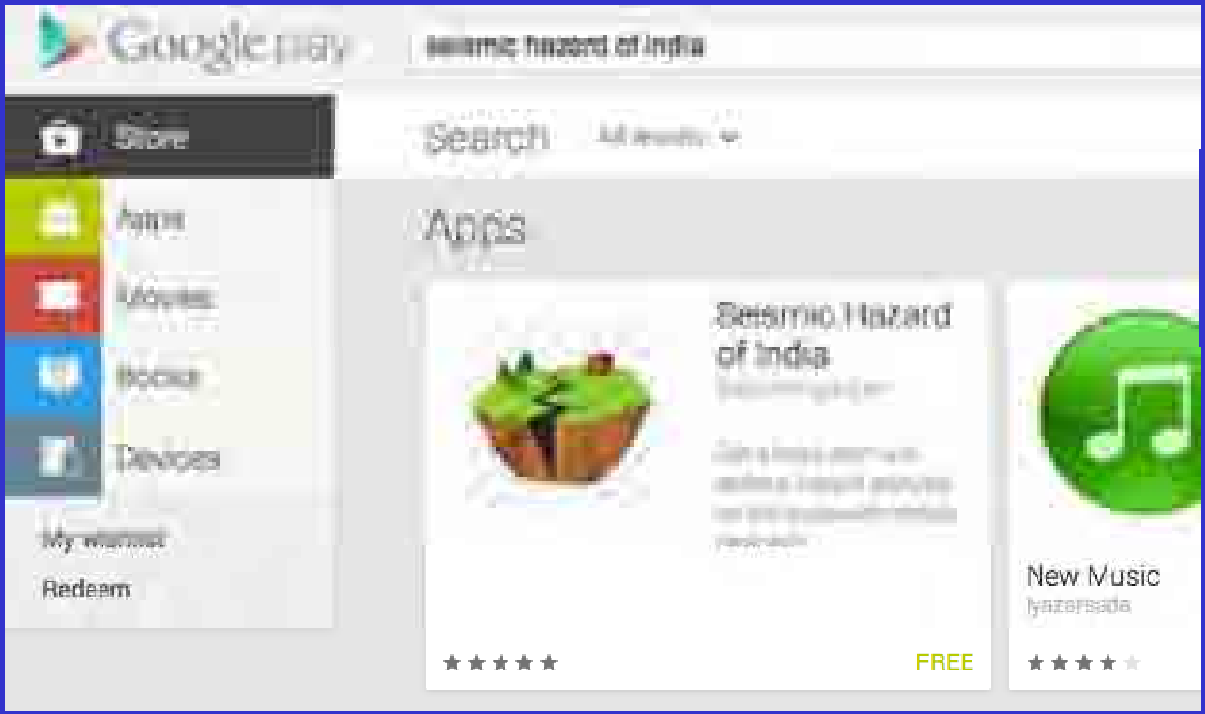
Table B-2 Storey shear forces and the design lateral forces for the hospital building considered

Storey No	Storey shear force	Design lateral force
11	55.26	55.26
10	102.53	47.28
9	120.64	18.10
8	140.81	20.17
7	158.78	17.96
6	173.60	14.82
5	188.48	14.88
4	199.18	10.71
3	214.79	15.61
2	235.52	20.73
1	243.04	7.51

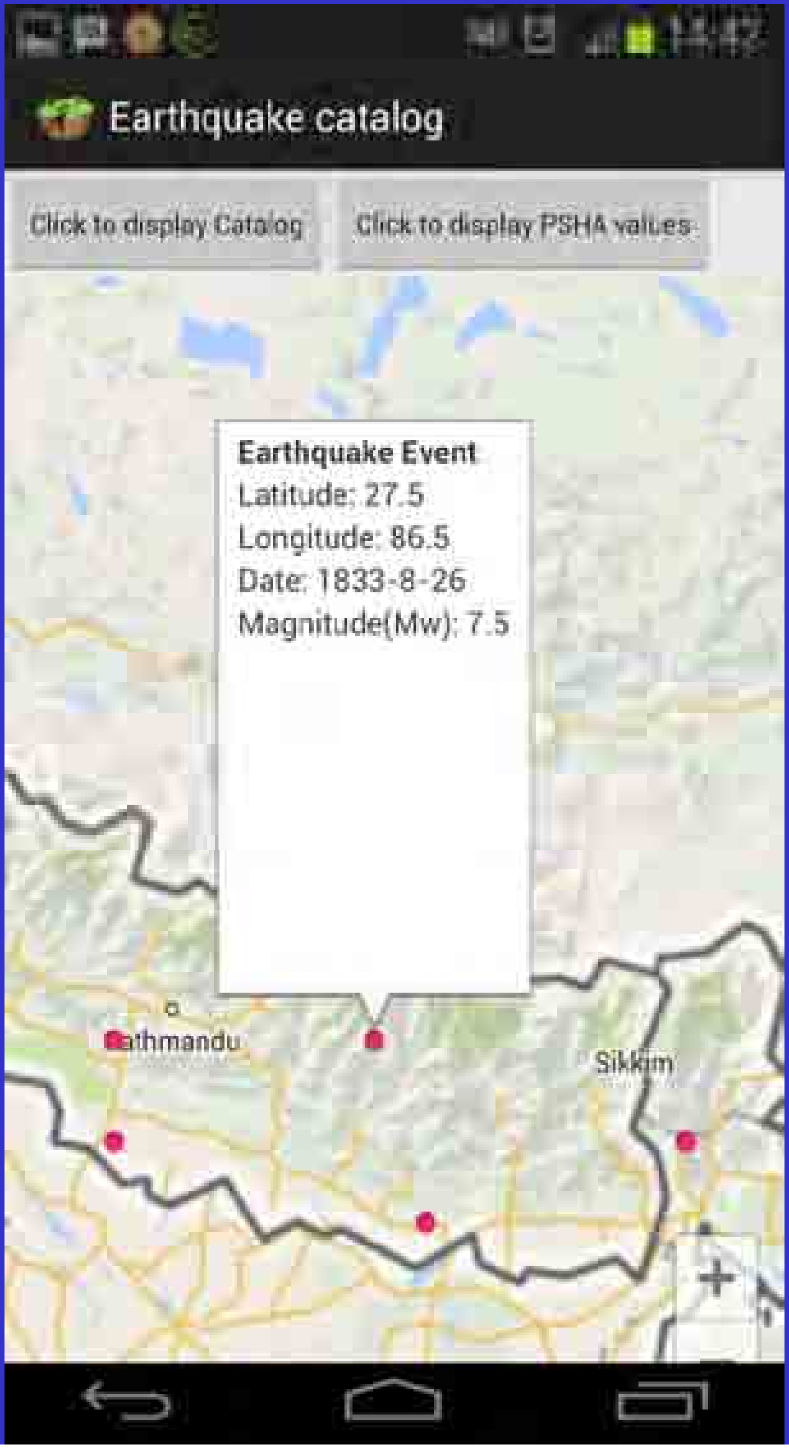
The building has been analyzed for the design lateral forces given in Table B-2. From the analysis, the drift at the top storey is obtained as 9.9mm.

Seismic Hazard of India – Installation details

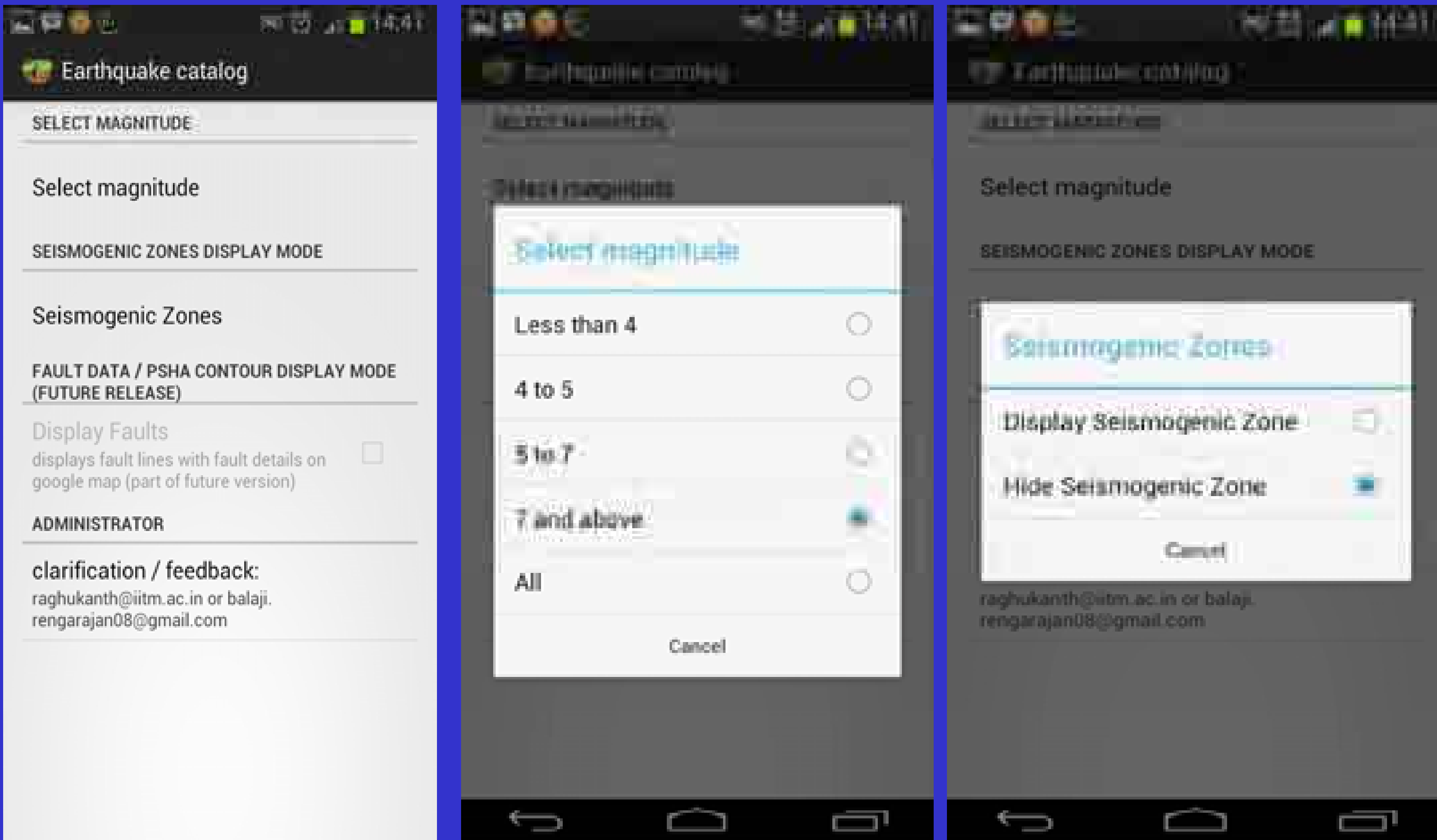
1. Navigate to Google Play or Play Store
2. Search “Seismic Hazard of India”
3. The application is available for Free on google play.
4. Read description and Install application on your android devices.
5. Compatible for android 3.0 and above (Mobile and Tablets).



Earthquake catalog

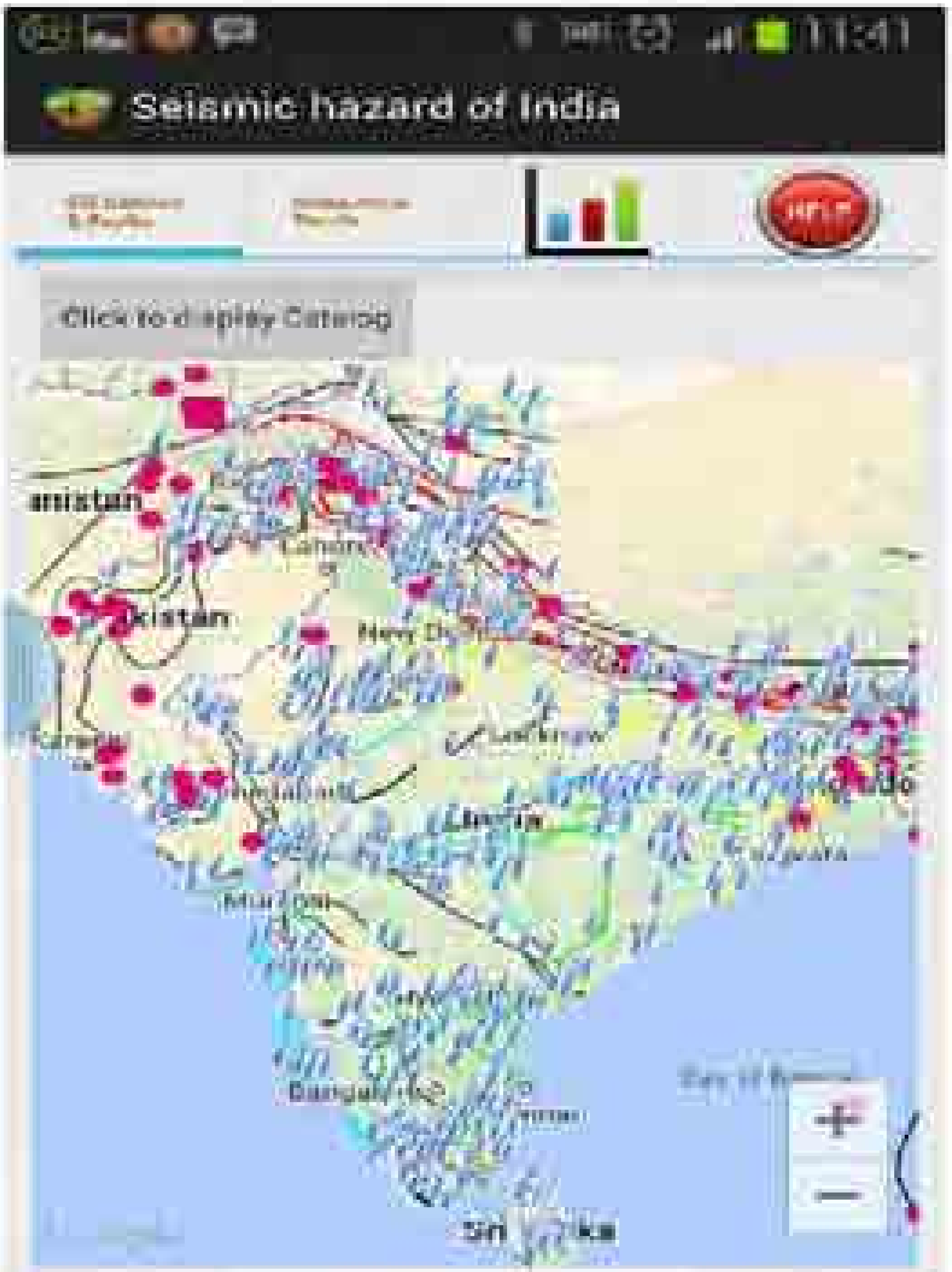


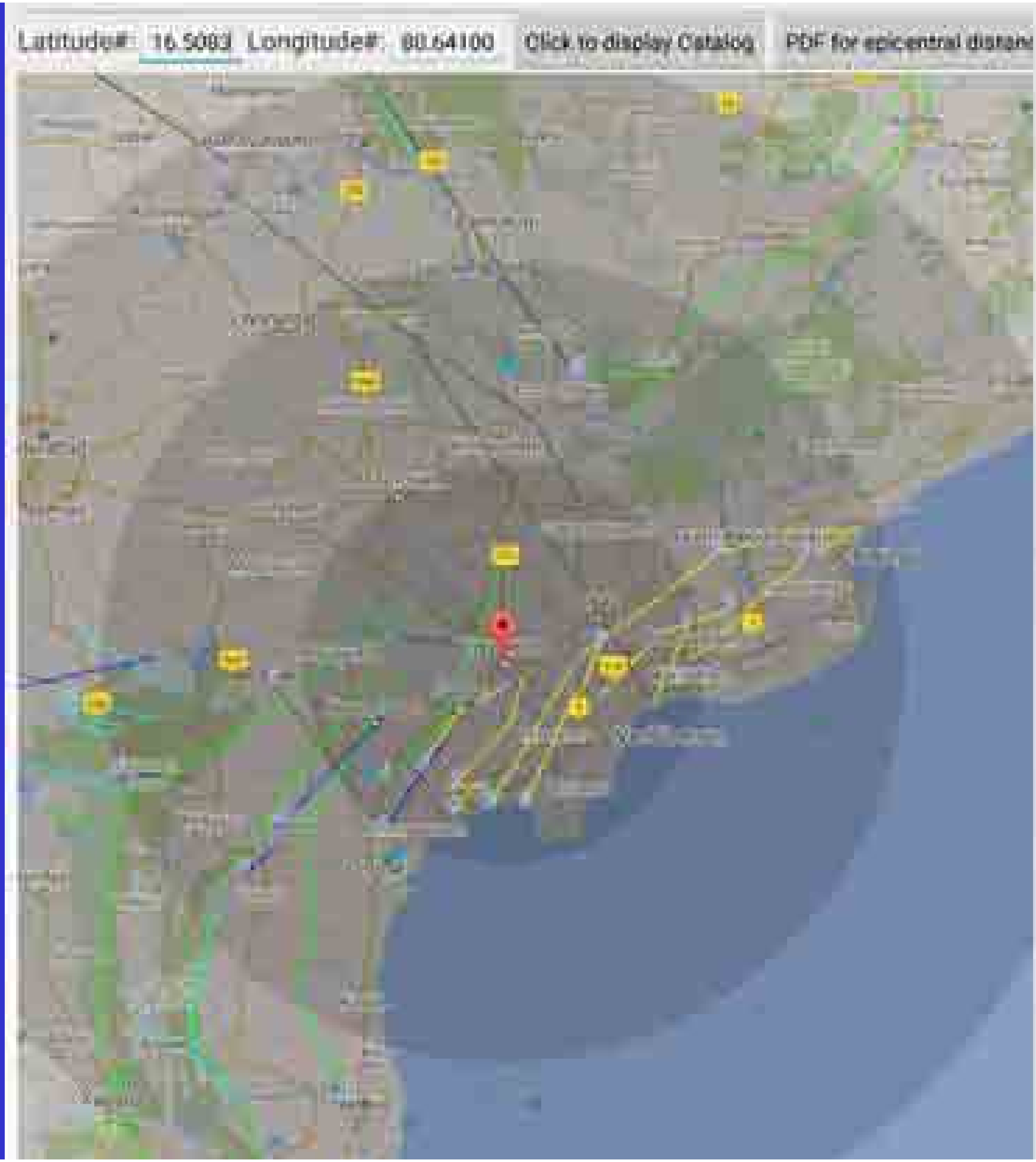
Setting Preferences for filter



Fault Map of India on Mobile Device

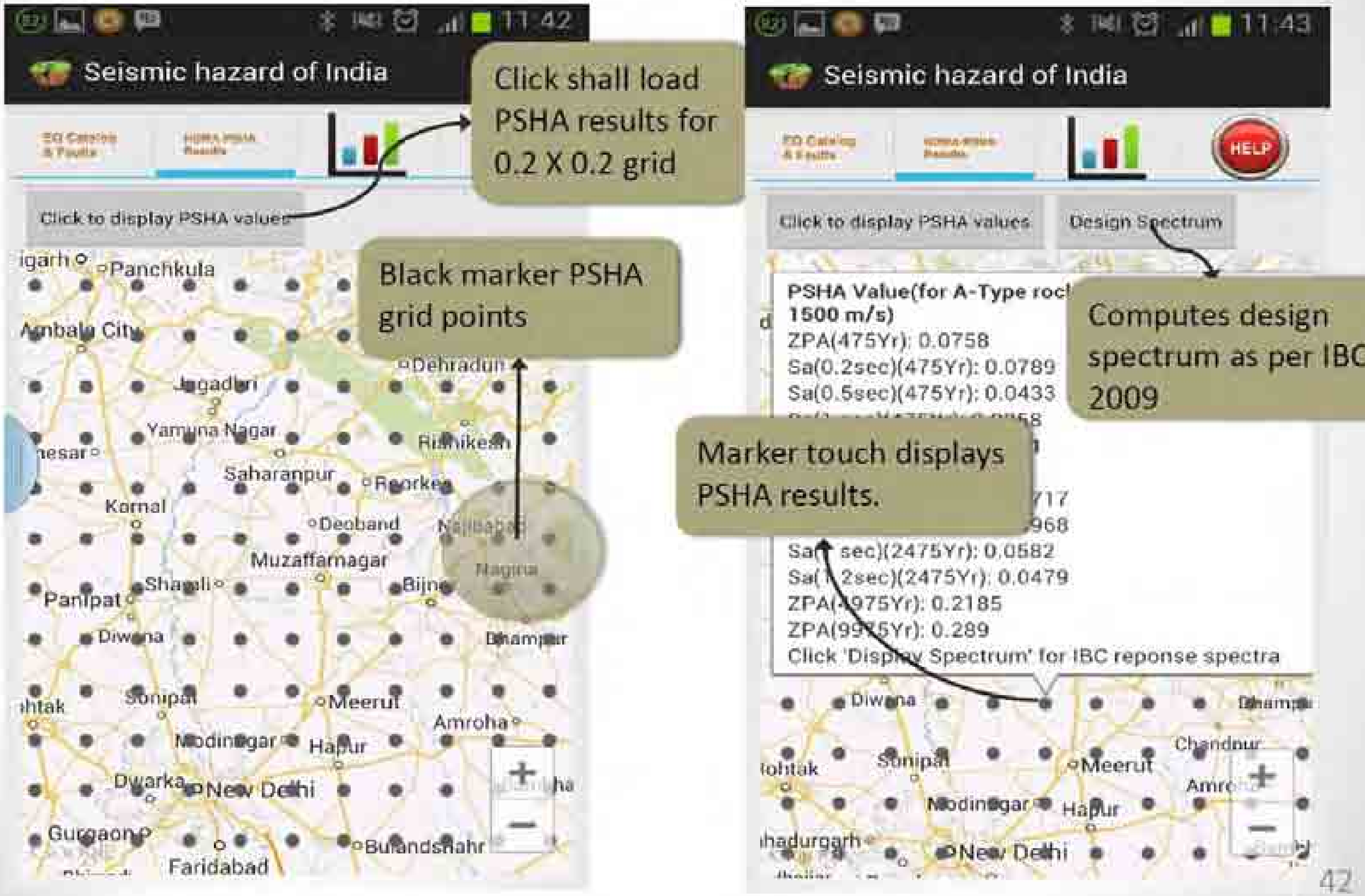
Fault Map of India on Mobile Device



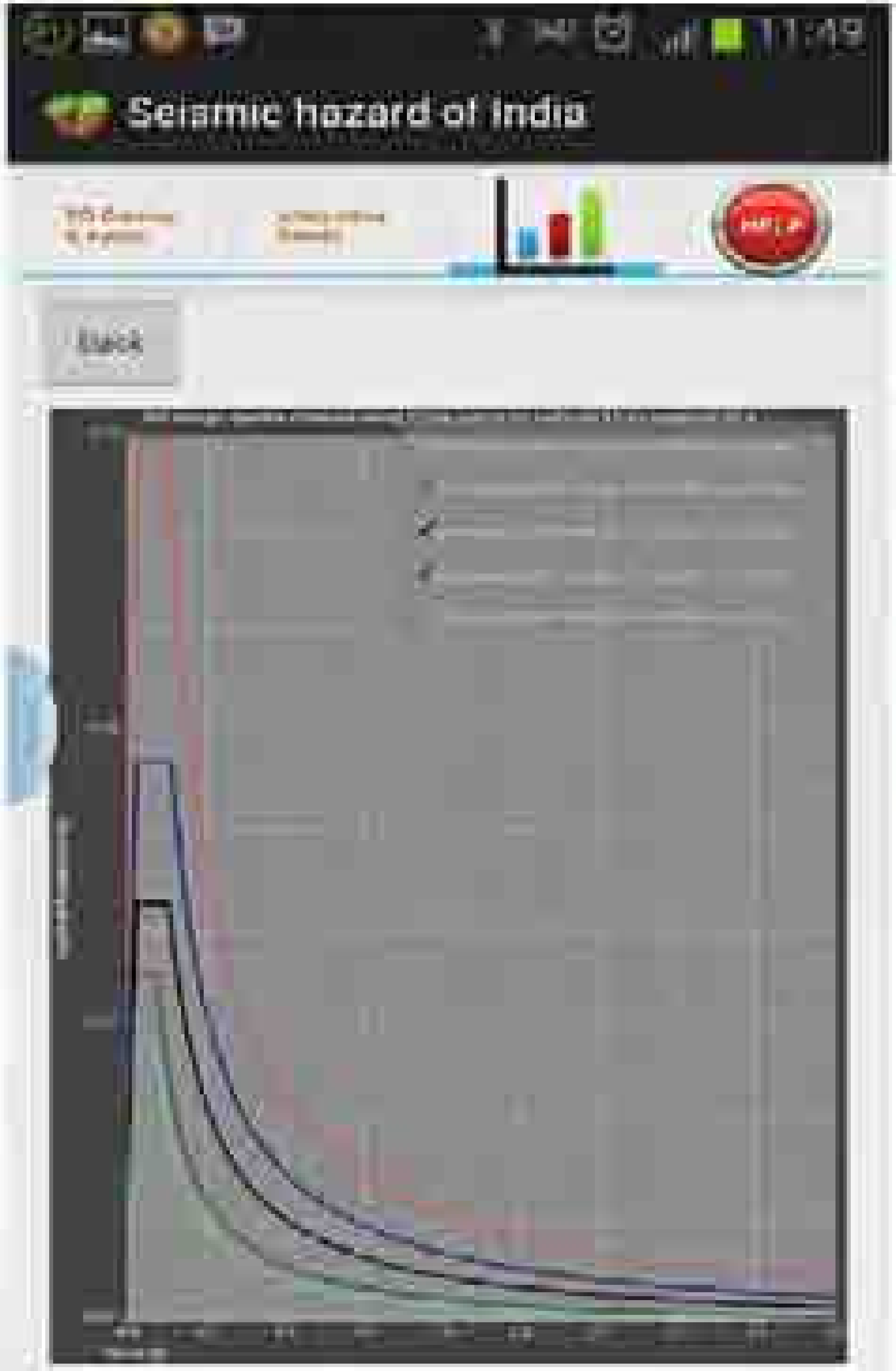

Latitude#: 16.5083
Longitude#: 80.64100
Click to display Catalog
PDF for epicentral

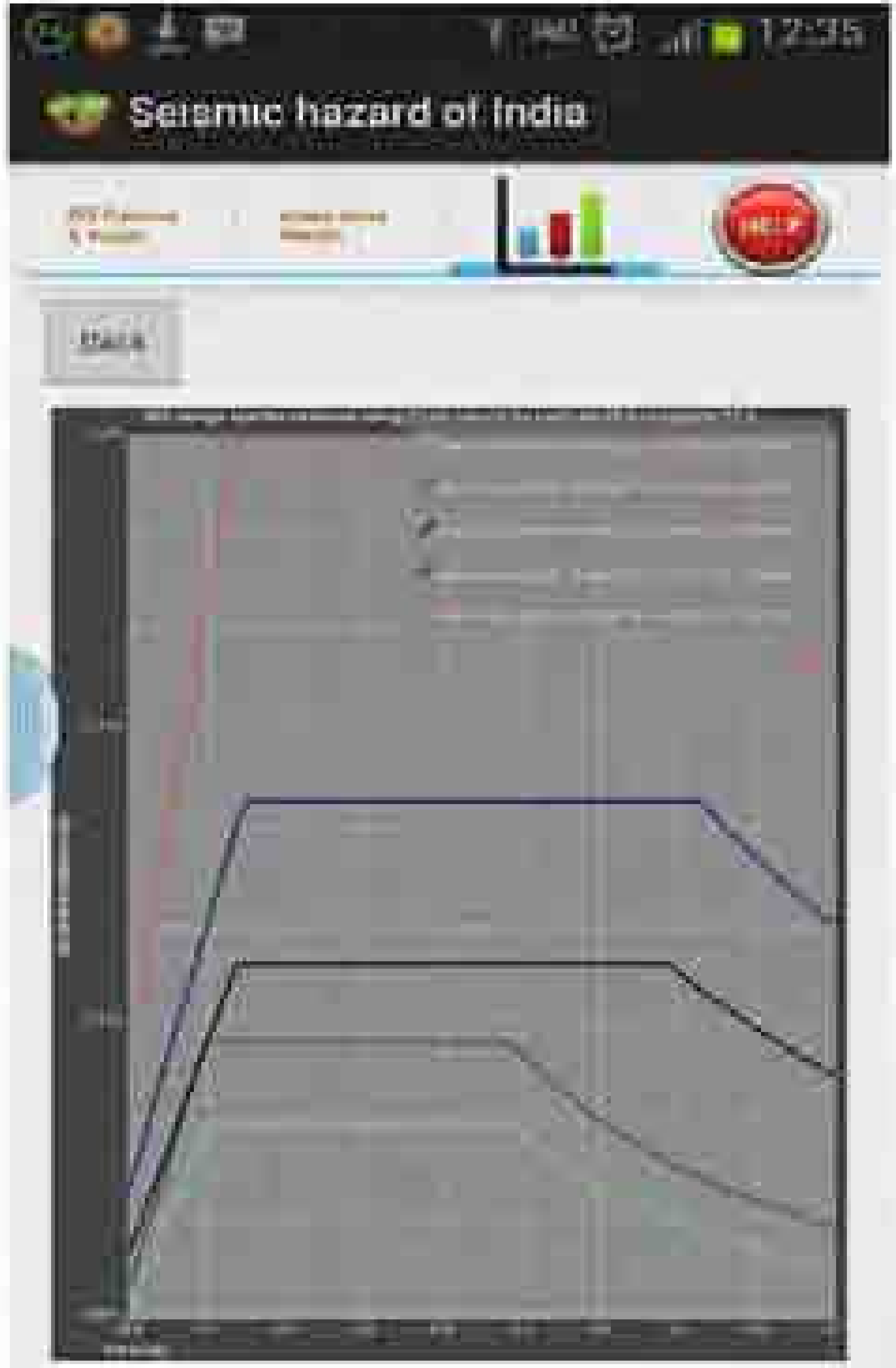
View PSHA Values

NDMA – PSHA Results on Mobile Device

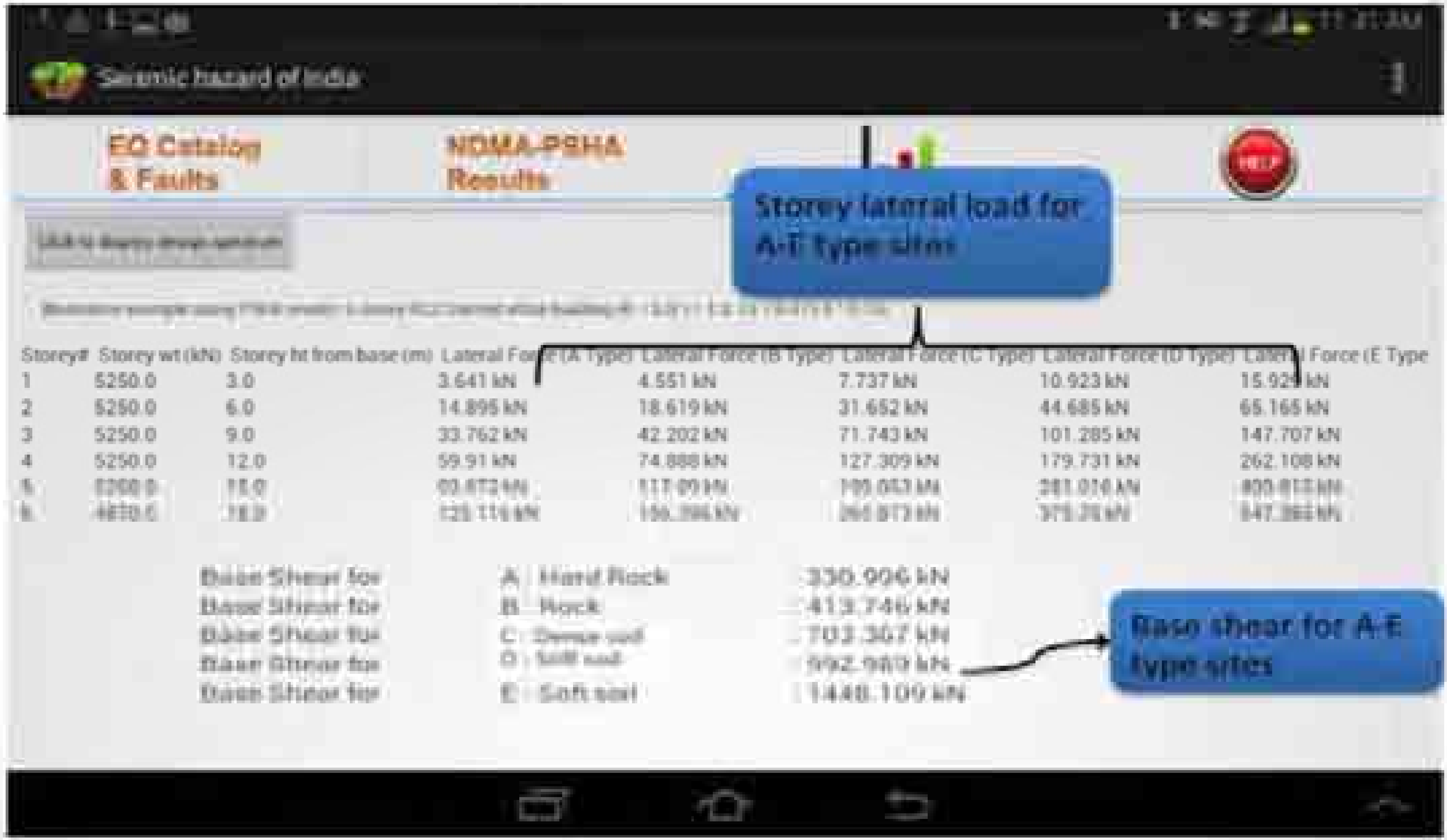


IBC 2009 Design Response Spectrum





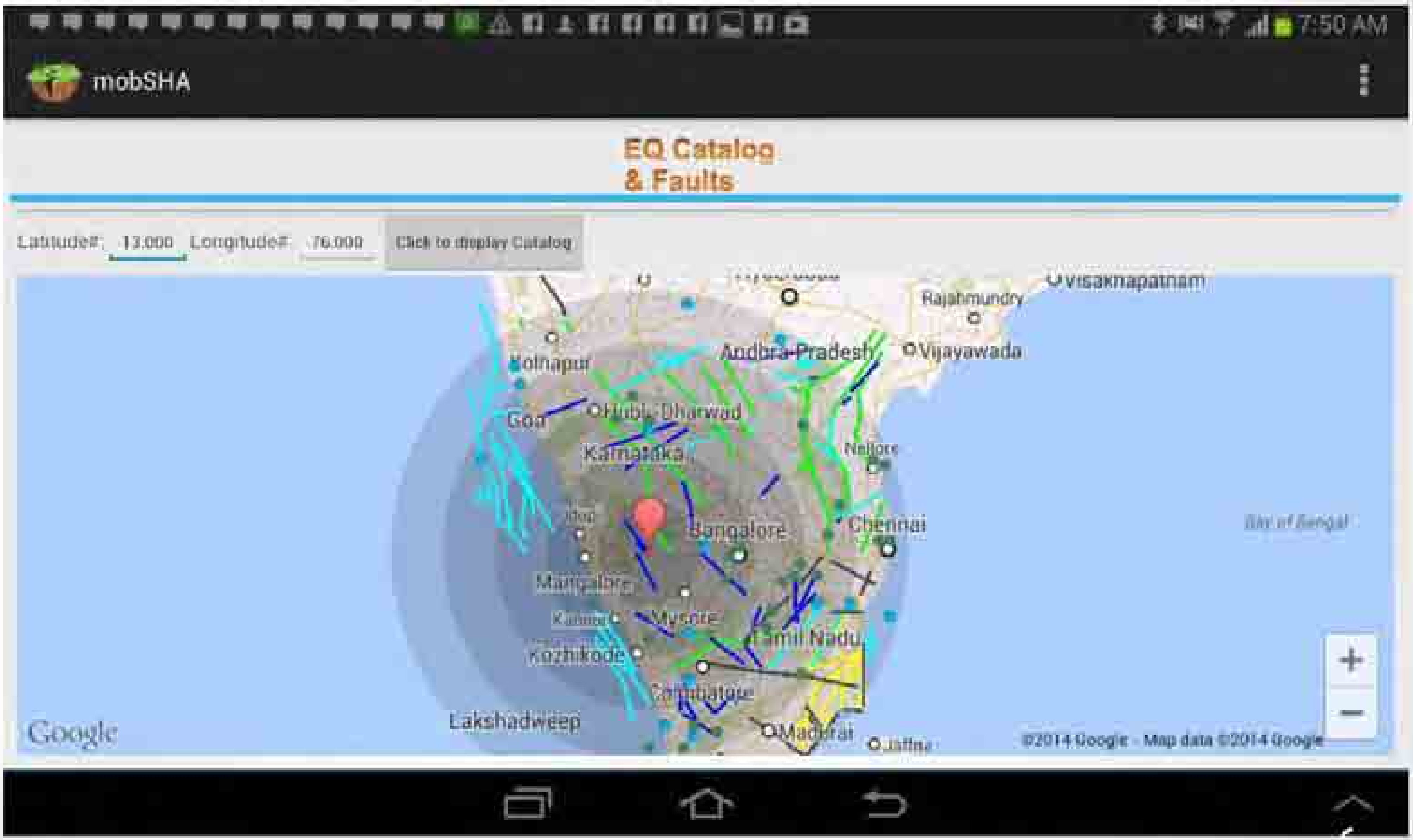
Building analysis for six storey RCC framed building



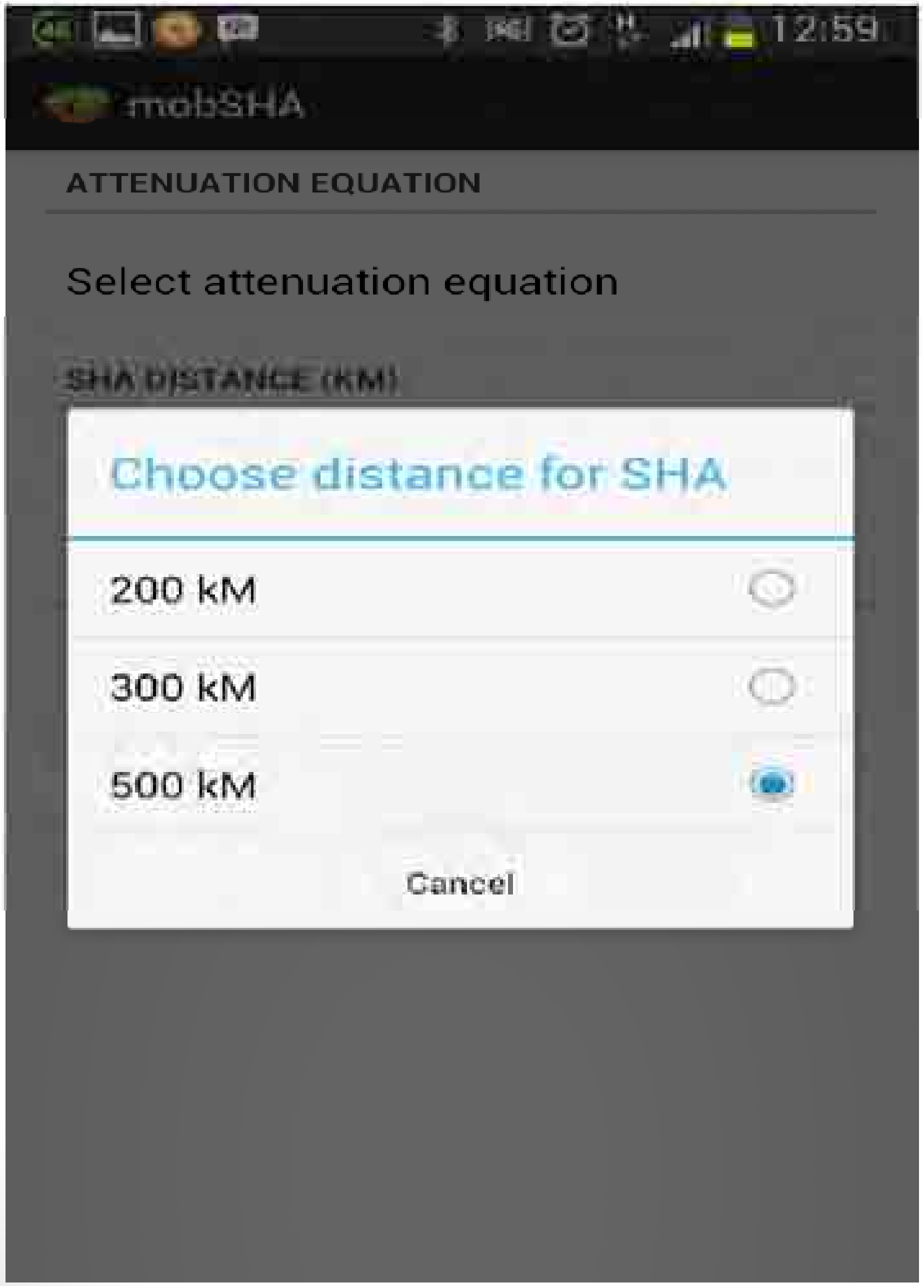
PSHA & DSHA Application - Capabilities

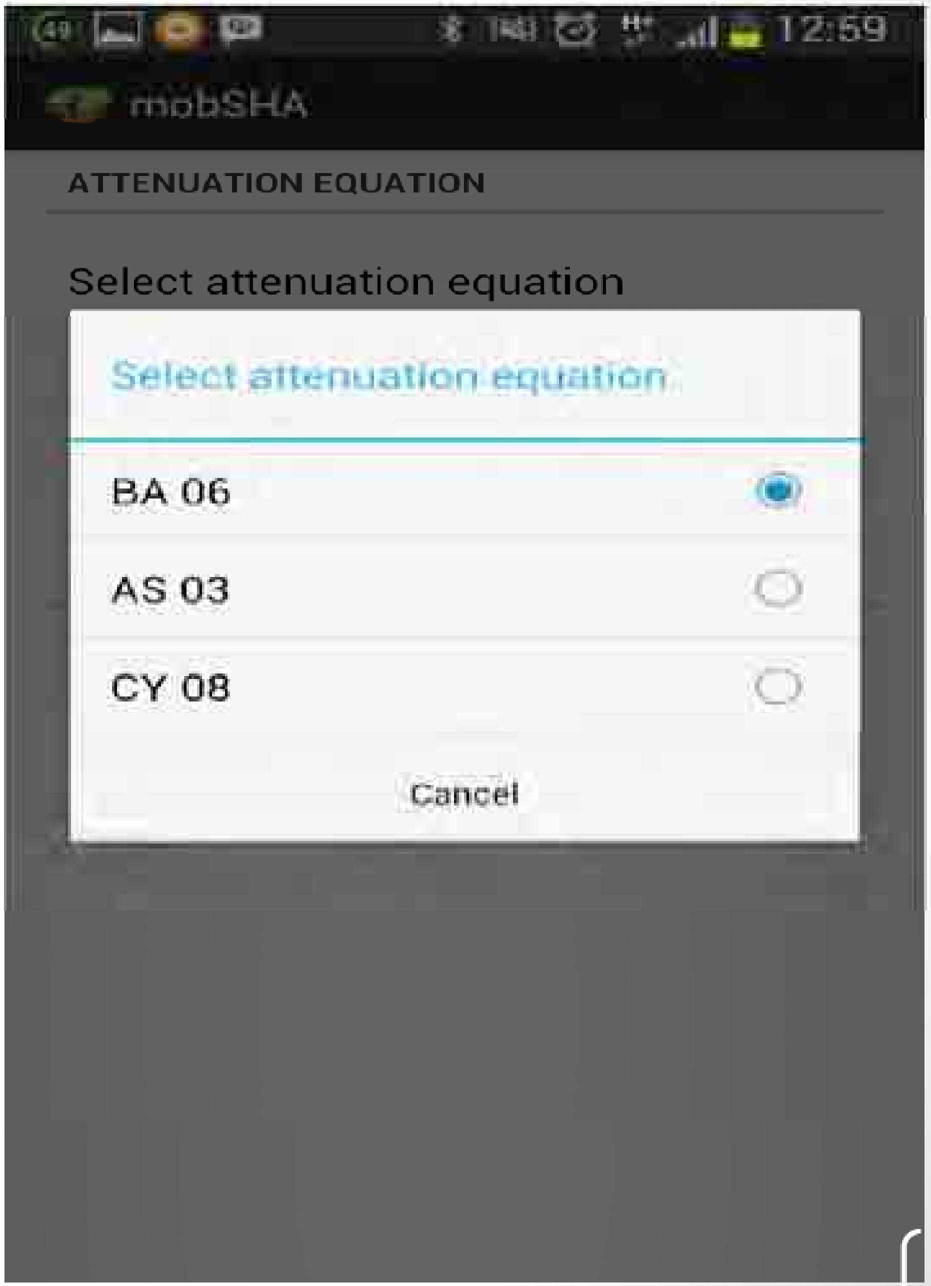
- Seismic source around the site
- Probability distribution plot for distance
- Probability distribution plot for magnitude for a particular source
- Mean annual rate of exceedance plot for various target accelerations
- Perform PSHA & DSHA using multiple attenuation models

Contributing seismic sources around the influence zone



SHA evaluation parameters and attenuation model

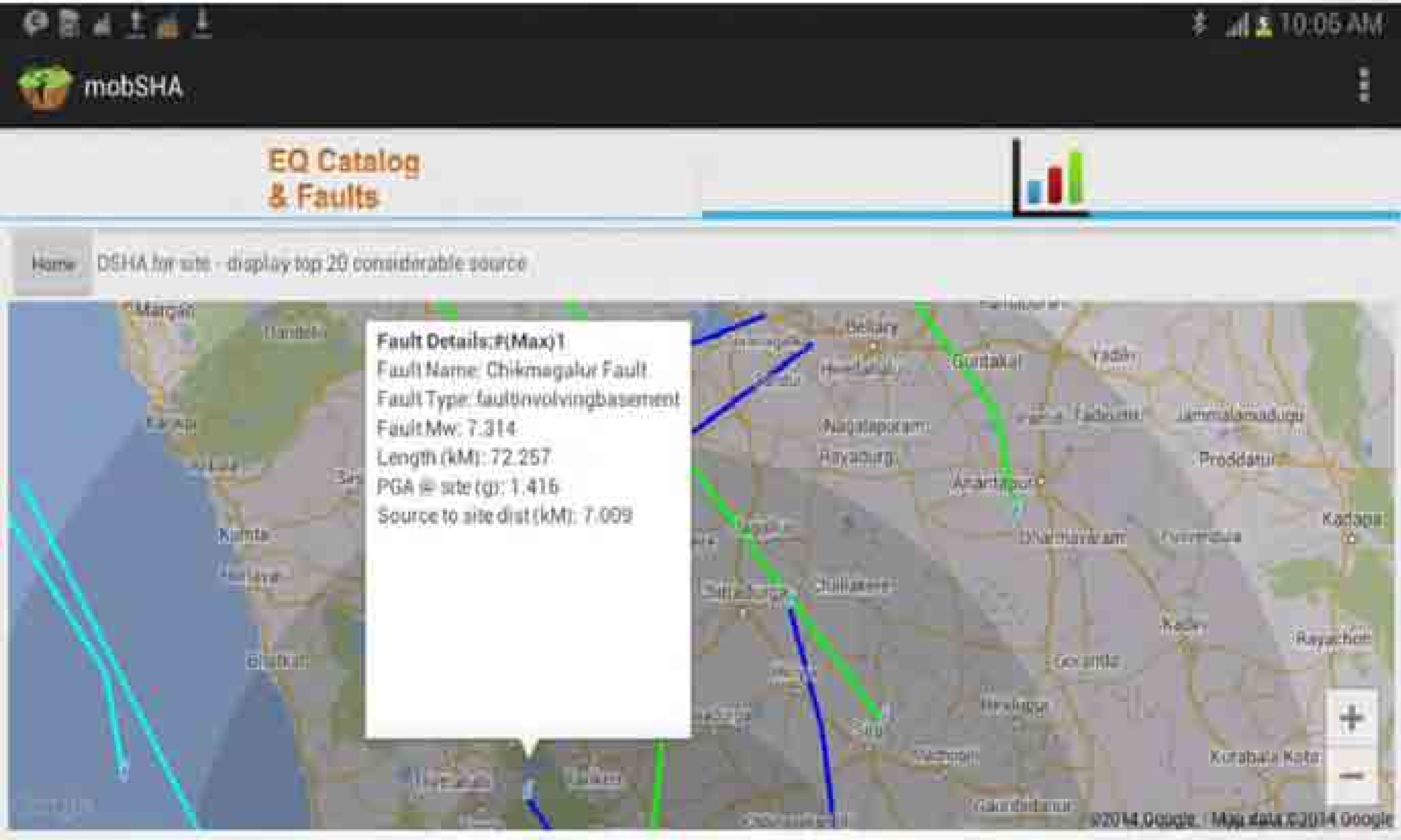




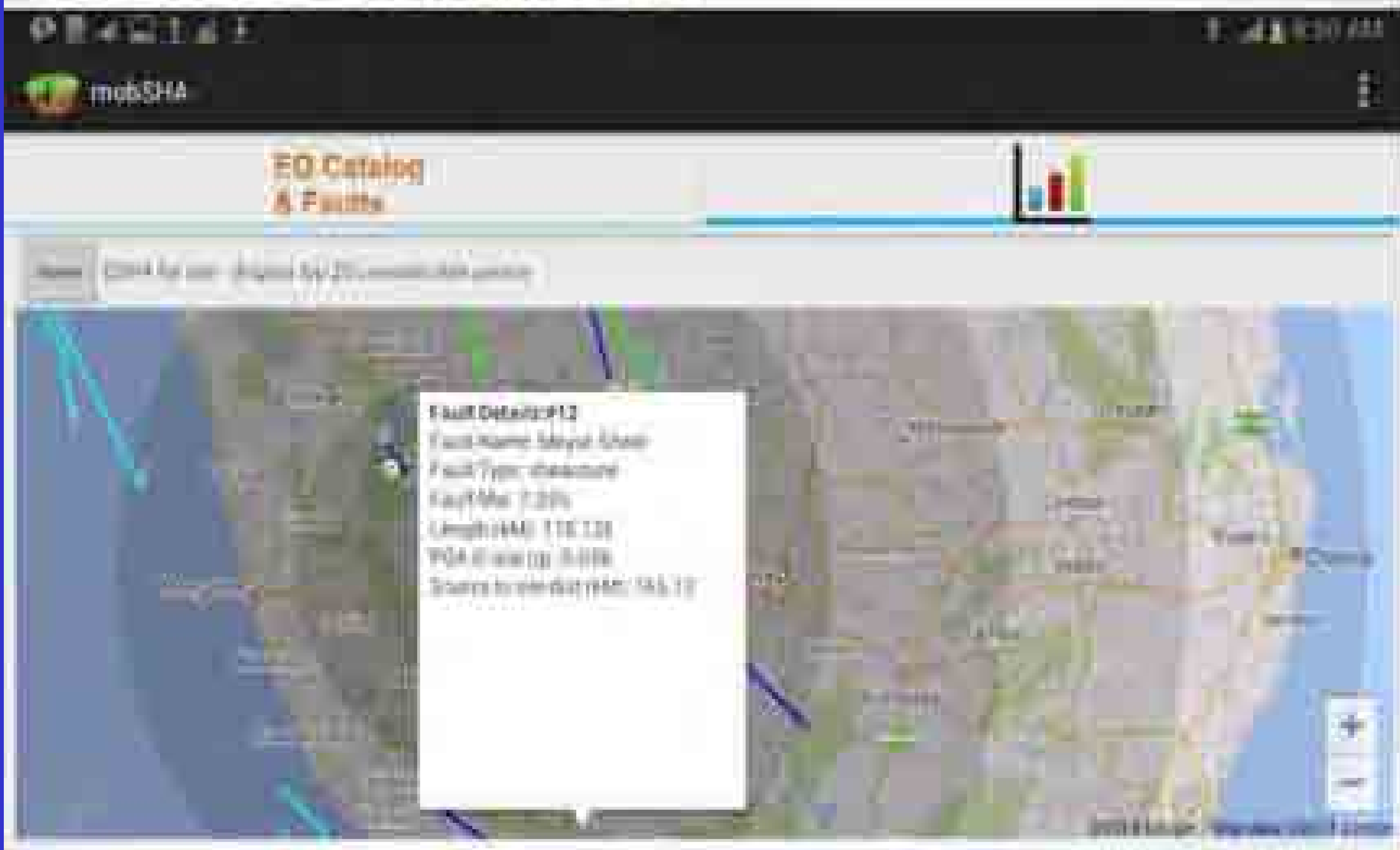
Probability Distribution Function for Epicenter Distance

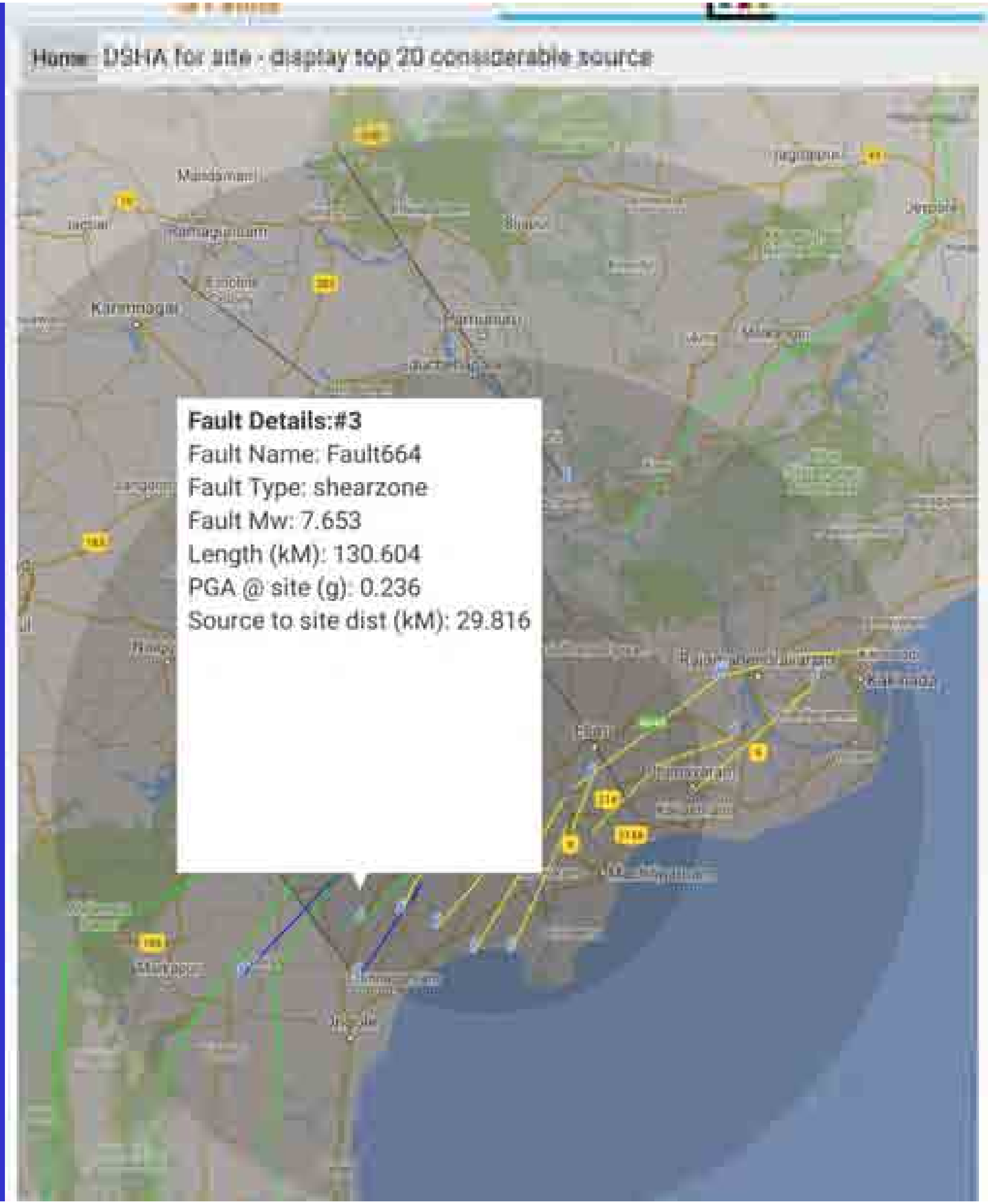
Probability Distribution Function for Magnitude

DSHA Results with PGA

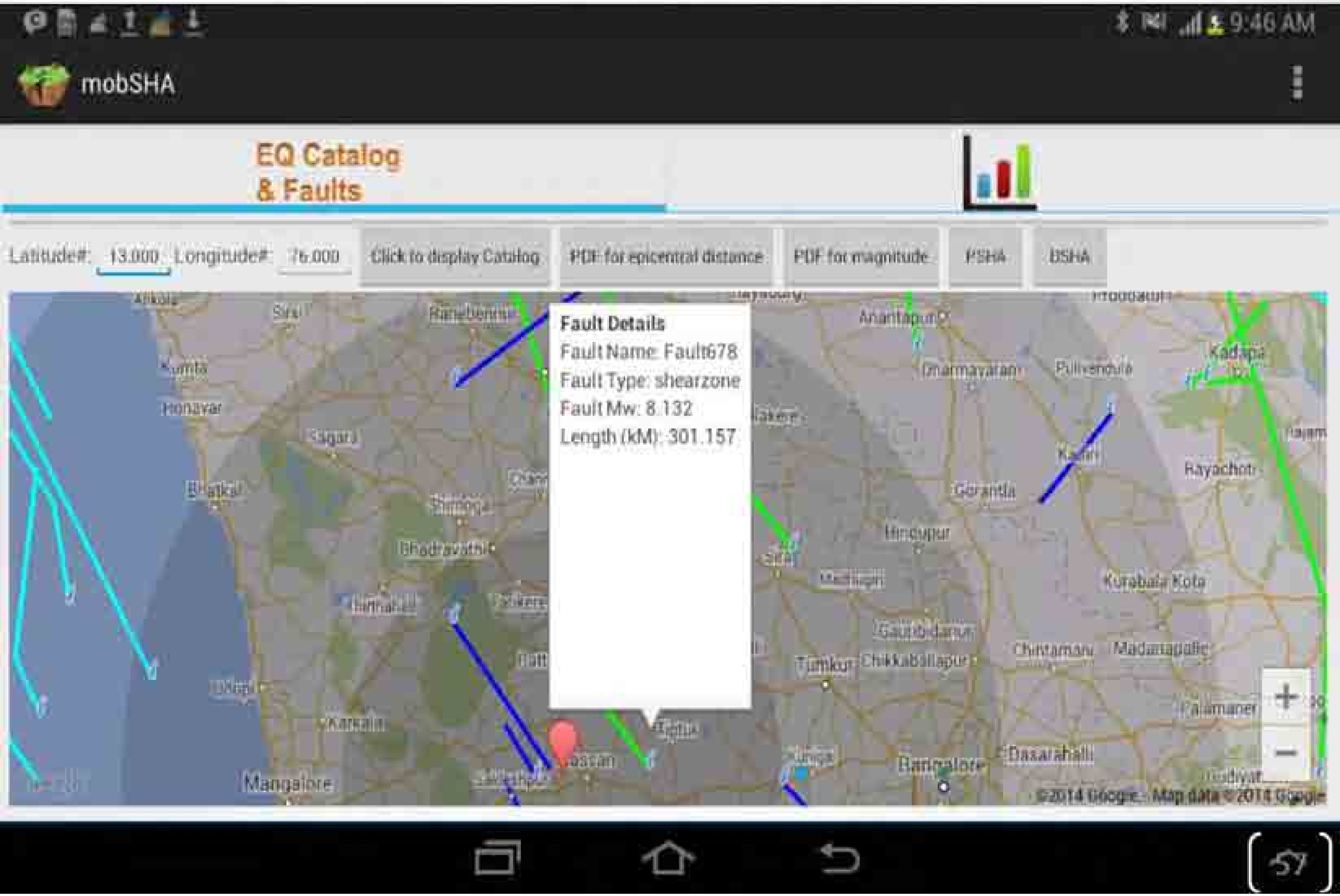


DSHA Results with PGA



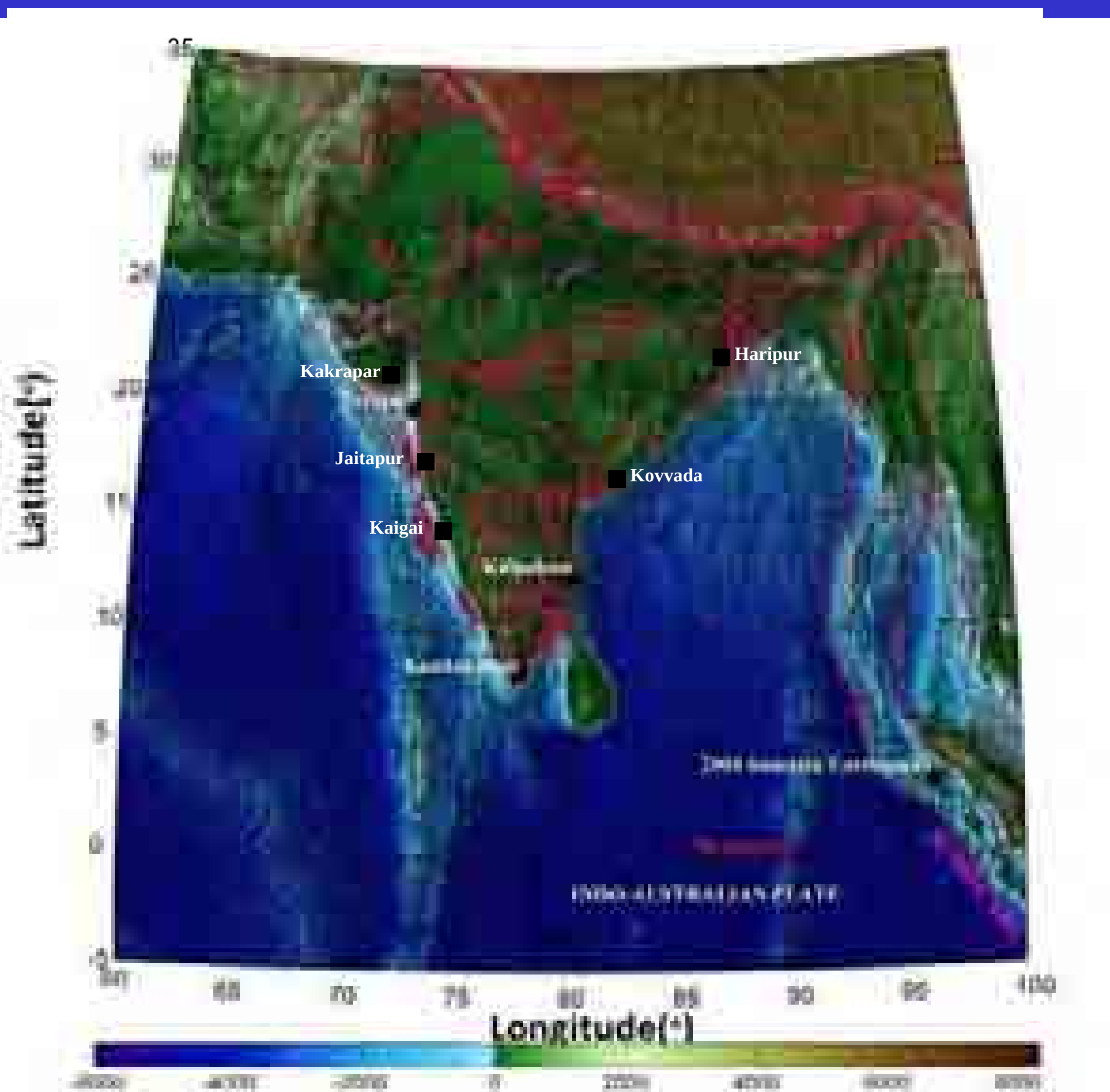

Home DSHA for site - display top 20 considerable source
Fault Details:#3
Fault Name: Fault664
Fault Type: shearzone
Fault Mw: 7.653
Length (kM): 130.604
PGA @ site (g): 0.236
Source to site dist (kM): 29.816

Perform probability evaluation



PSHA Hazard Curve

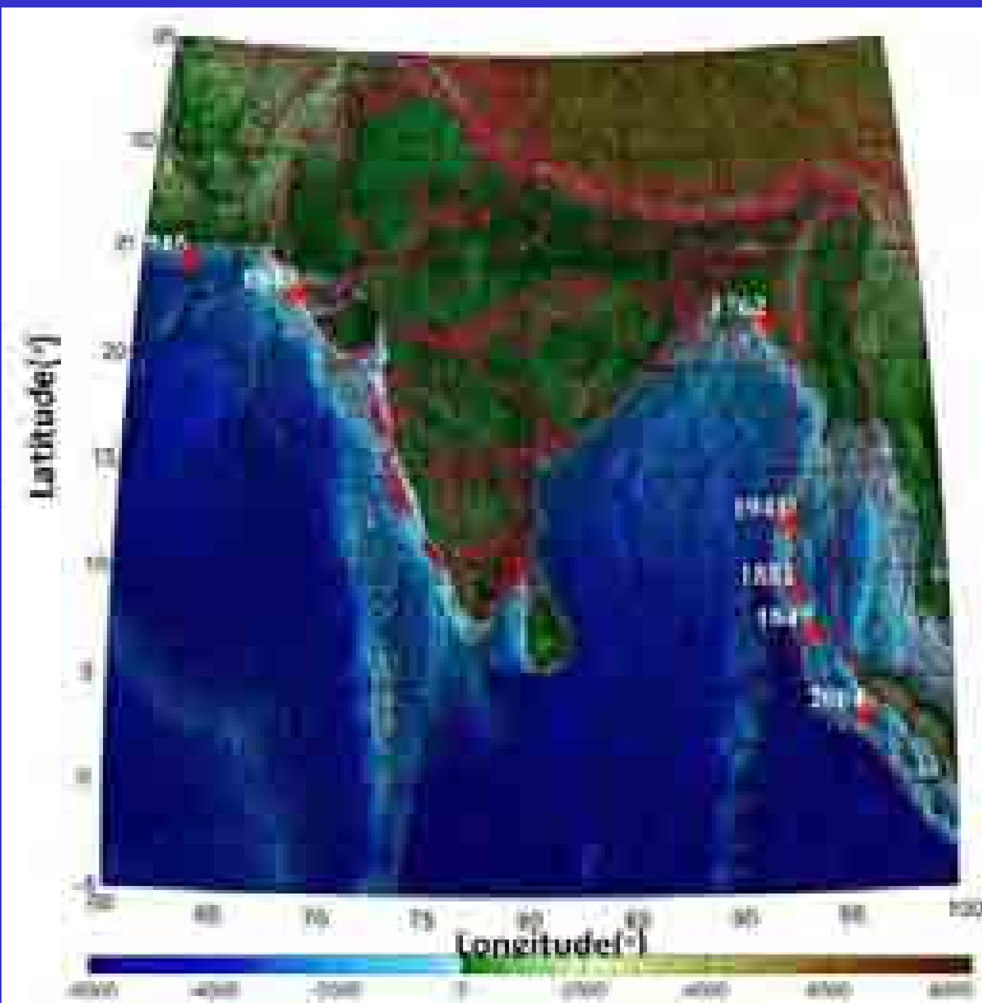
TSUNAMI HAZARD ANALYSIS



- India lies between latitude 8.07^{0}N and 37.10^{0}N and longitude 68.12^{0}E and 97.42^0 E.
- India has one of the longest coastal lines (7517 km)
- The total population coastal districts and Island territories is around 171.44million, which accounts to 14.20% of the total population
- Mega cities like Kolkata, Chennai, Mumbai are in the coastal belt of India
- There are 13 Major Ports
- 8 Nuclear power Plants

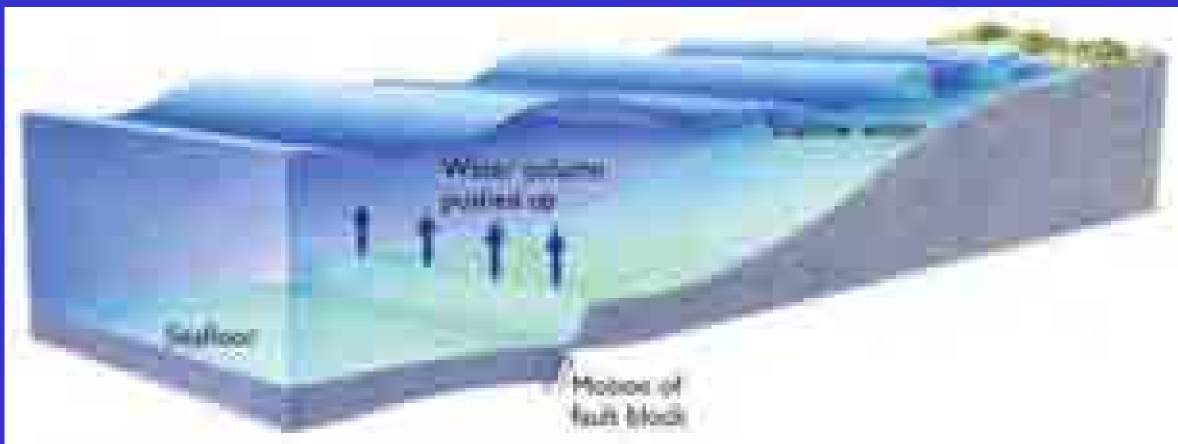
It is thus evident that the Tsunami hazard analysis of the Indian coastal belt is significant for the safety of both life and economy

EARHQUAKES THAT TRIGGERED TSUNAMI WAVES THAT AFFECTED INDIAN COAST



Date	Cause	Impact
12th April, 1762	Earthquake in Bay of Bengal.	Tsunami wave of 1.8m at Bangladesh coast
31st December, 1881	Magnitude 7.8 earthquake beneath the Car Nicobar	Entire East coast of India including Andaman & Nicobar coast was affected by tsunami
27th August, 1883	Eruption of karkatoa volcano (Sunda Strait) Indonesia	East coast of India was affected and 2 m Tsunami was reported at Chennai.
26th June, 1941	A 8.1 Magnitude earthquake in Andaman	East Coast of India was affected by tsunami.
27th November, 1945	Earthquake in the Makran subduction zone	West coast of India was affected by Tsunami.
26th December, 2004	Earthquake in Sumatra region	Affected the coastal India. Wave height in chennai around 3 m

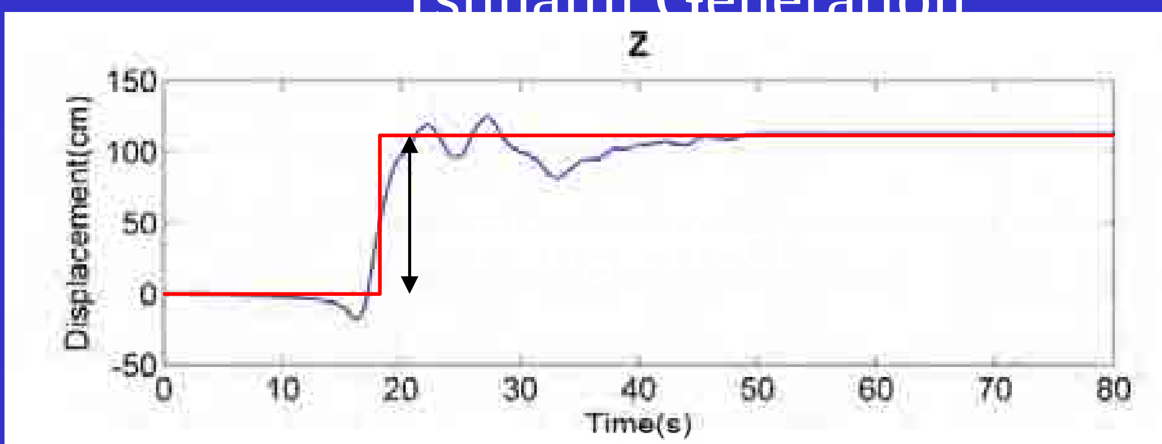
How can an earthquake cause tsunami



.com

Tsunami Generation

- Tsunami is triggered by the static displacement of the ground underneath the ocean body
- This static displacement of ground is termed as Fling
- The ground motion contains two parts the fling effect and the vibration component

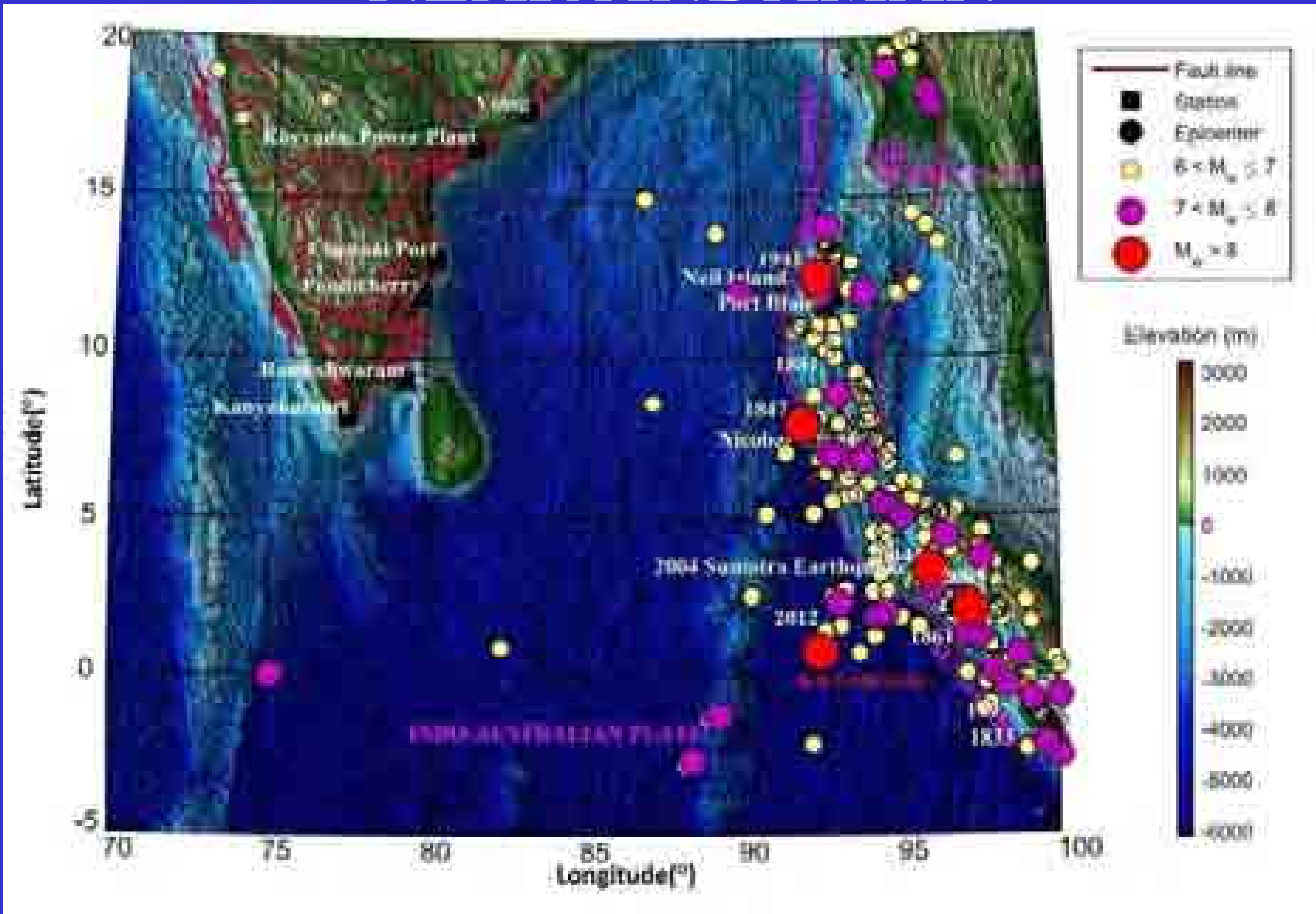


Motion of Fault Block

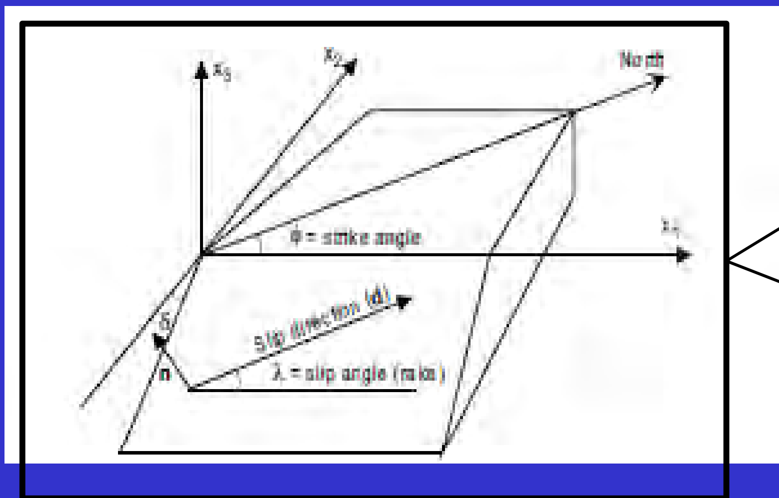
What intensity of fling can trigger a tsunami?

Does the vibration component in the ground motion has any effect on the tsunami waves?

SEISMICITY AT ACTIVE REGIONS NEAR ANDAMAN

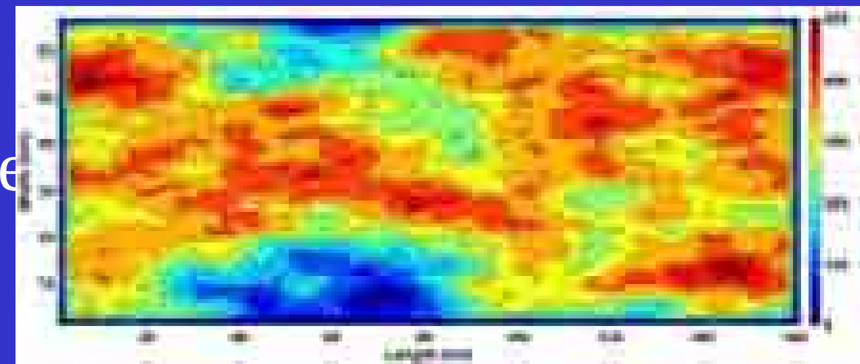


Analytical model - Source

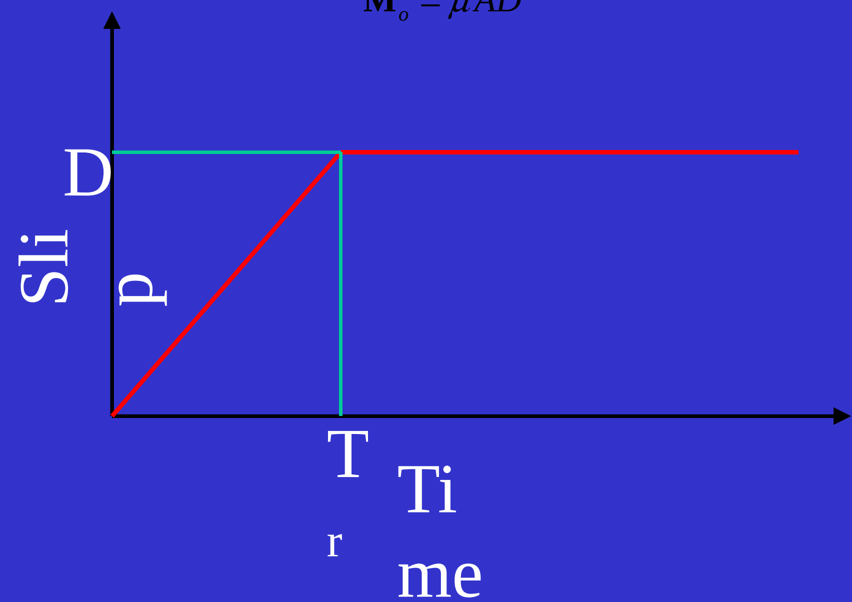


Point Source

Finite Fault

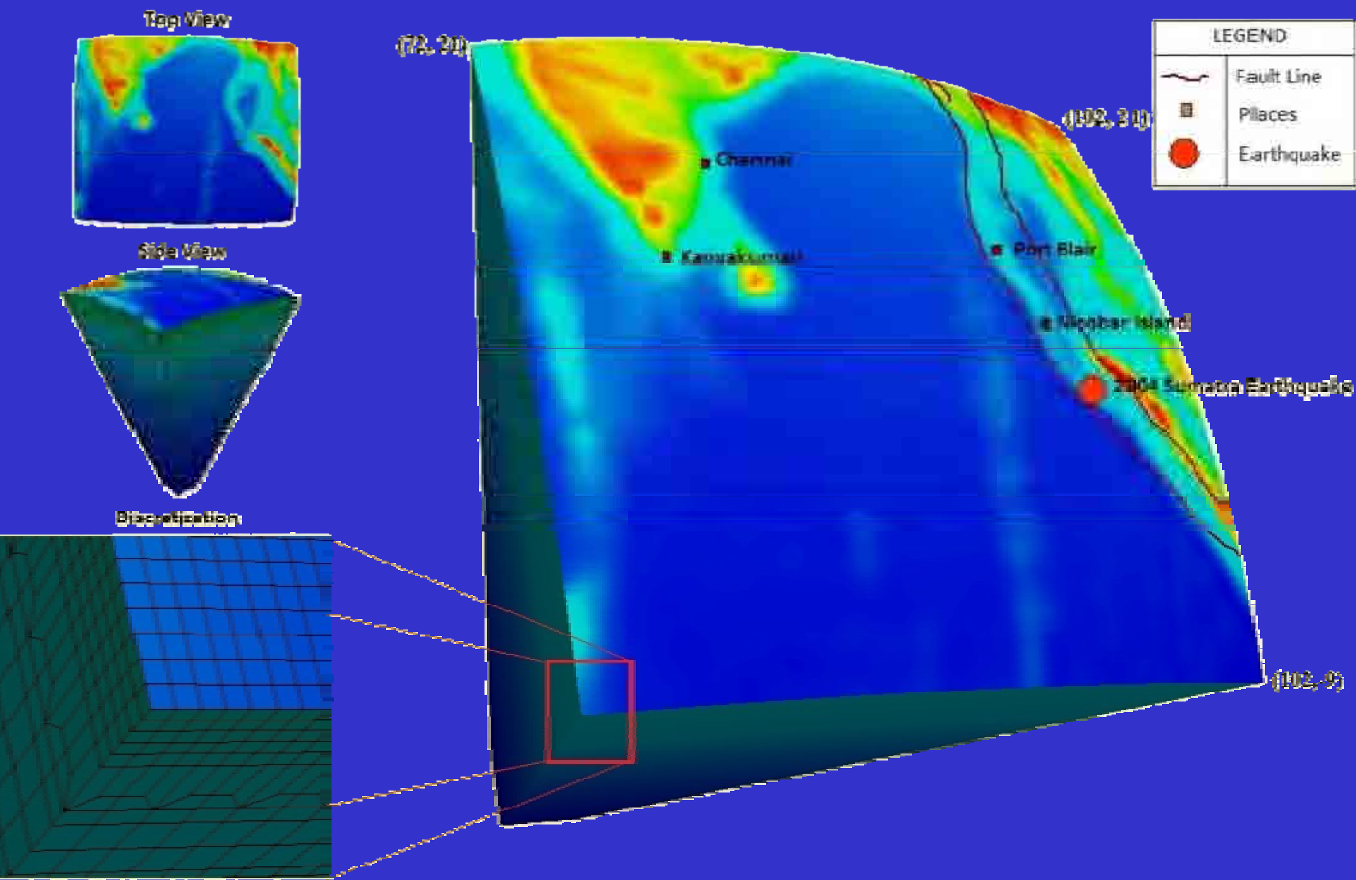


$$\mathbf{M}_o = \mu A D$$



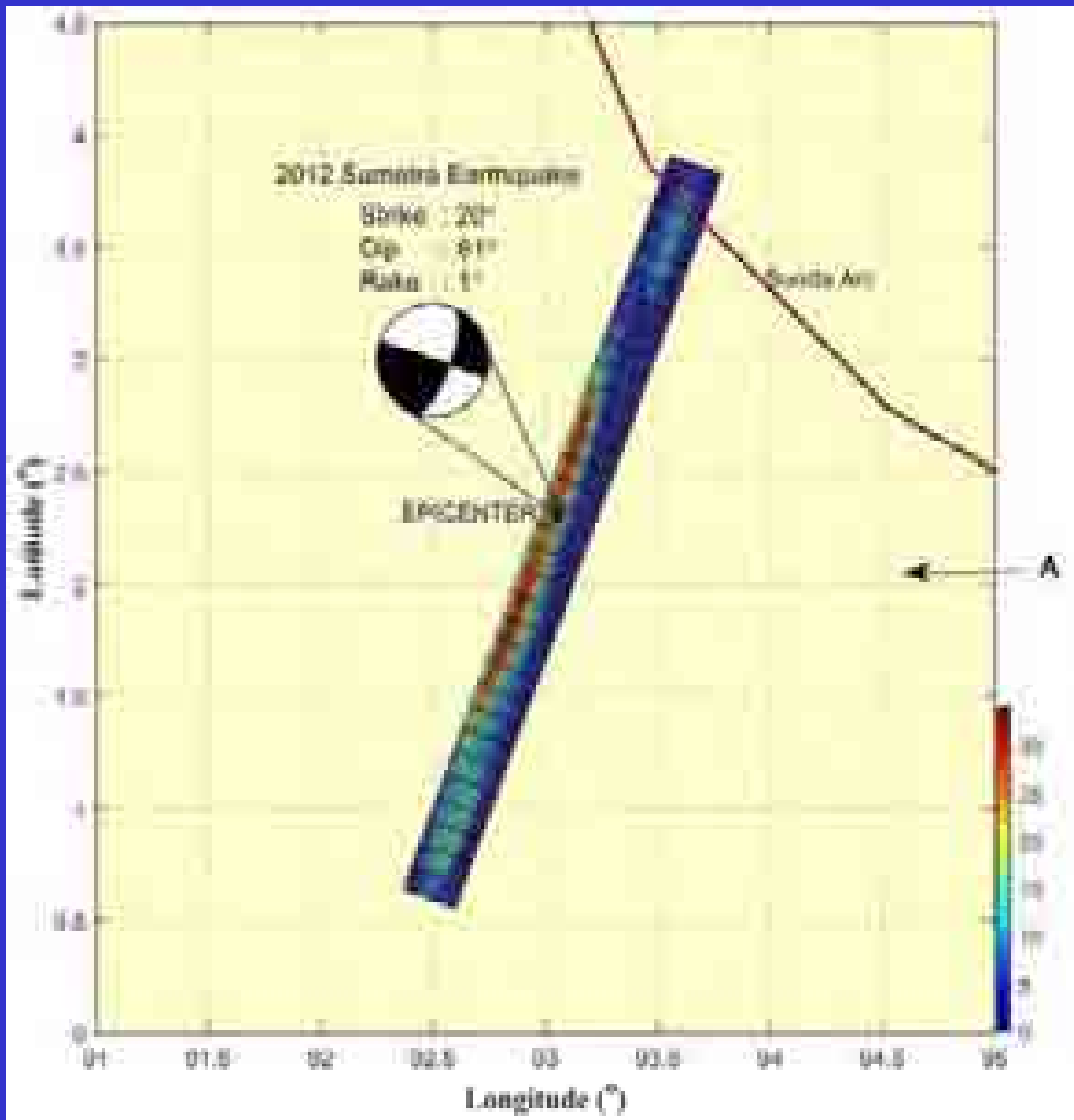
Magnitude (M_w)	Typical Dimension
5	4 × 3
6	13 × 8
7	45 × 24
8	161 × 67
9	567 × 190

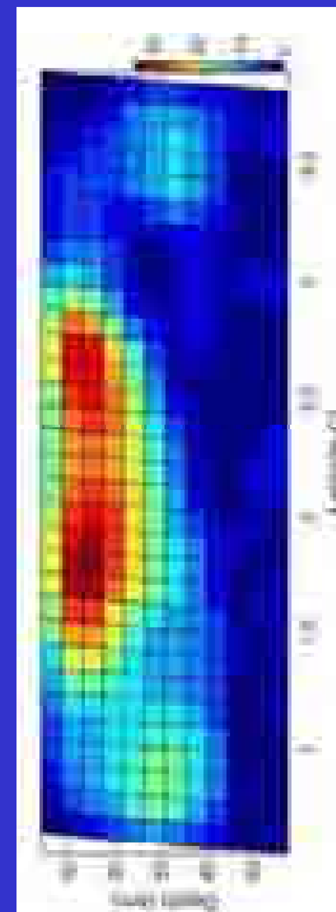
MESH USED FOR GROUND MOTION SIMULATION



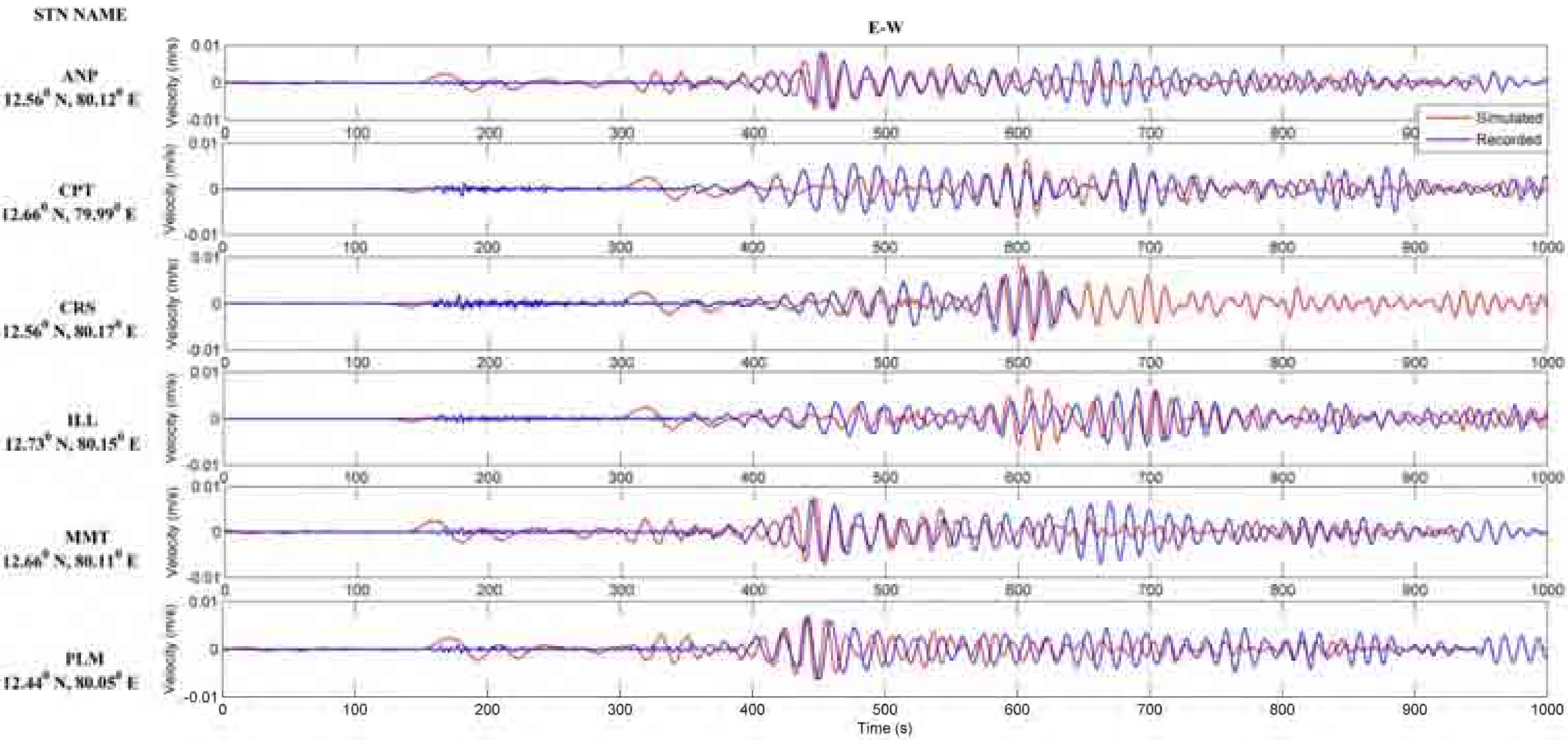
Characteristic	Value
Dimension: Angular width Center Latitude Center Longitude	$35^0 \times 35^0$ 25^0 82^0
Total no: of elements	11.49 Million
No of element at surface	0.2 Million
Average distance between points	5 km
Total no: of elements	68.96 Million
No: of nodes	0.46 Billion
Total Degree of freedom	1.38 Billion
Time Step used for simulation	0.02s
Total Time required for simulation	20 Hours

VALIDATION
Slip Model 2012 Mw 8.6 Sumatra Earthquake

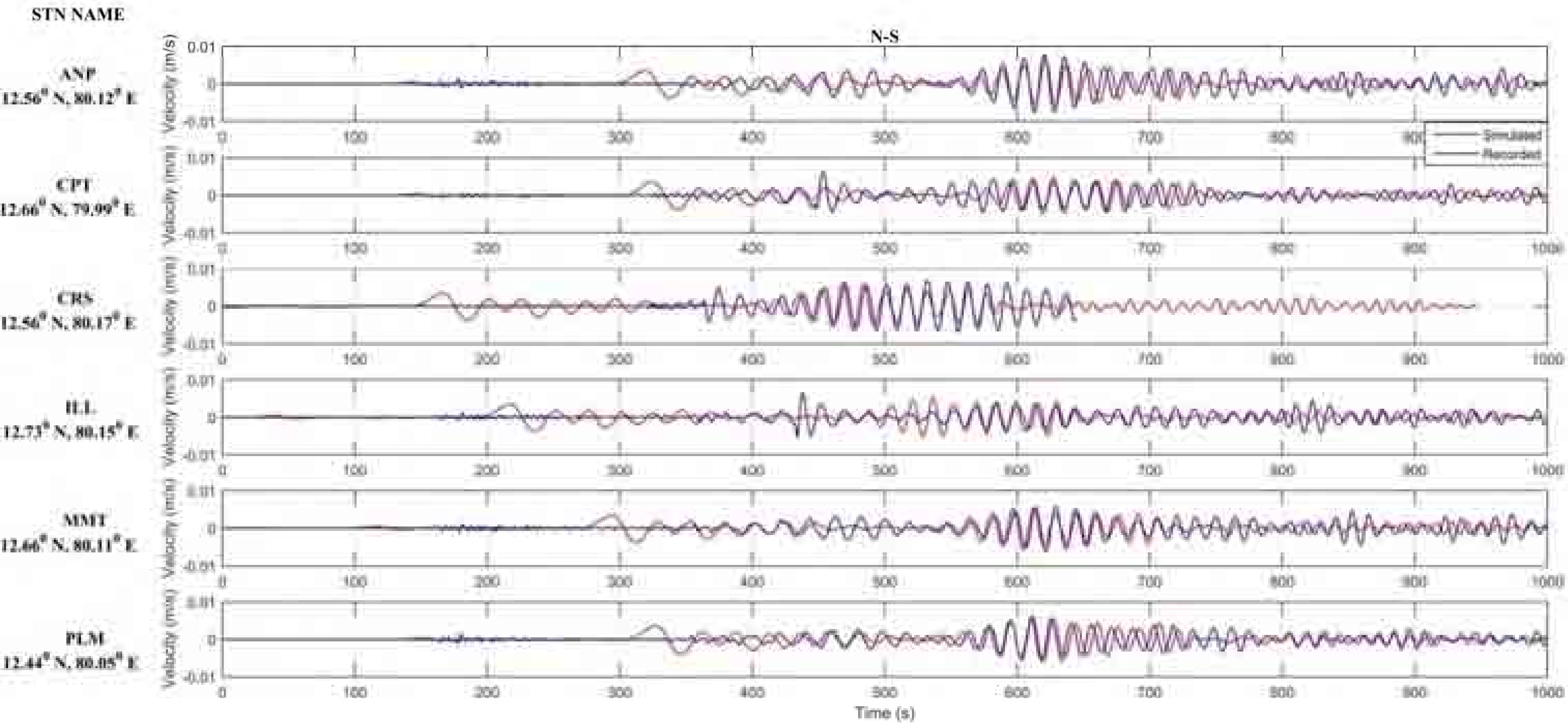




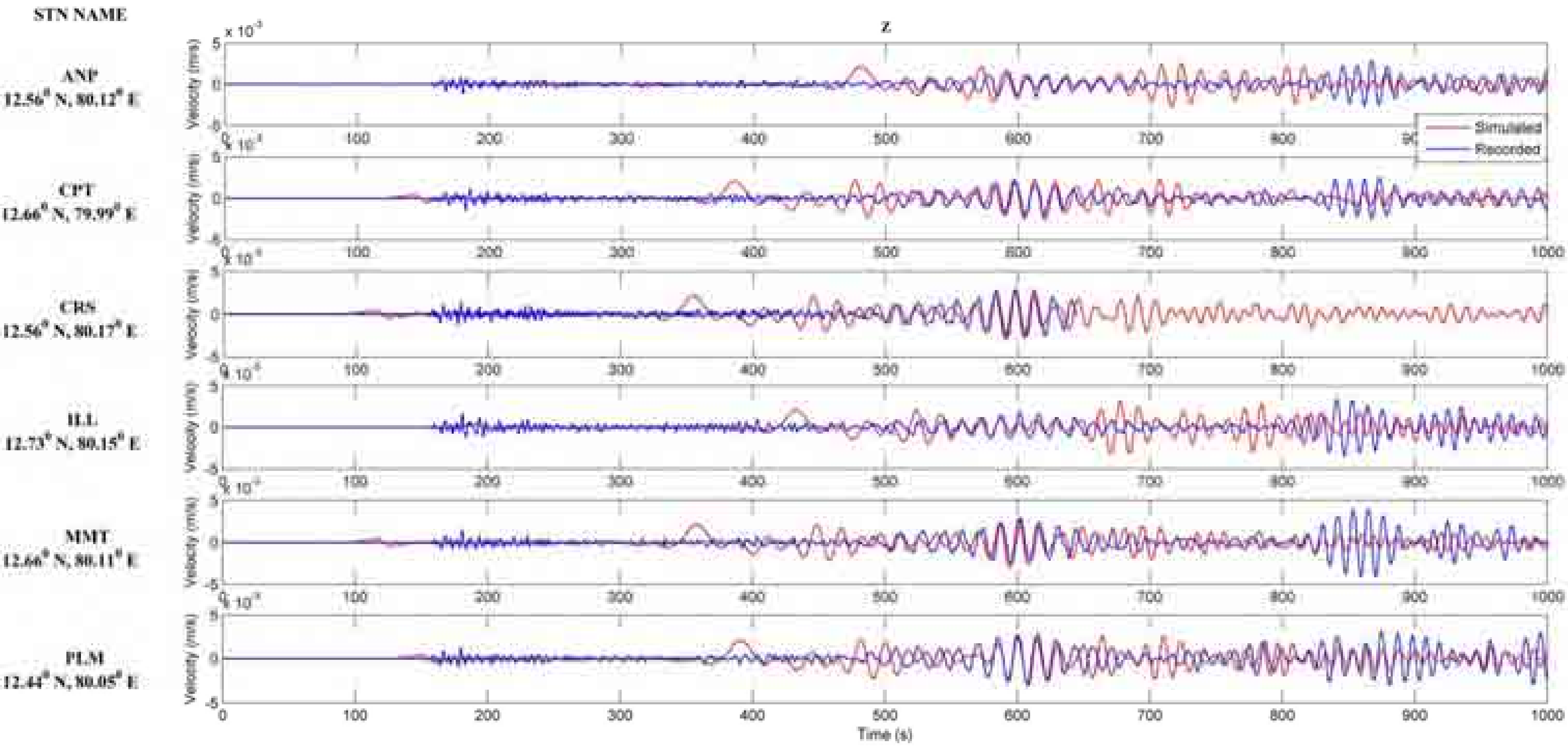
VALIDATION
Comparison with IGCAR data, EW direction



VALIDATION
Comparison with IGCAR data, NS direction

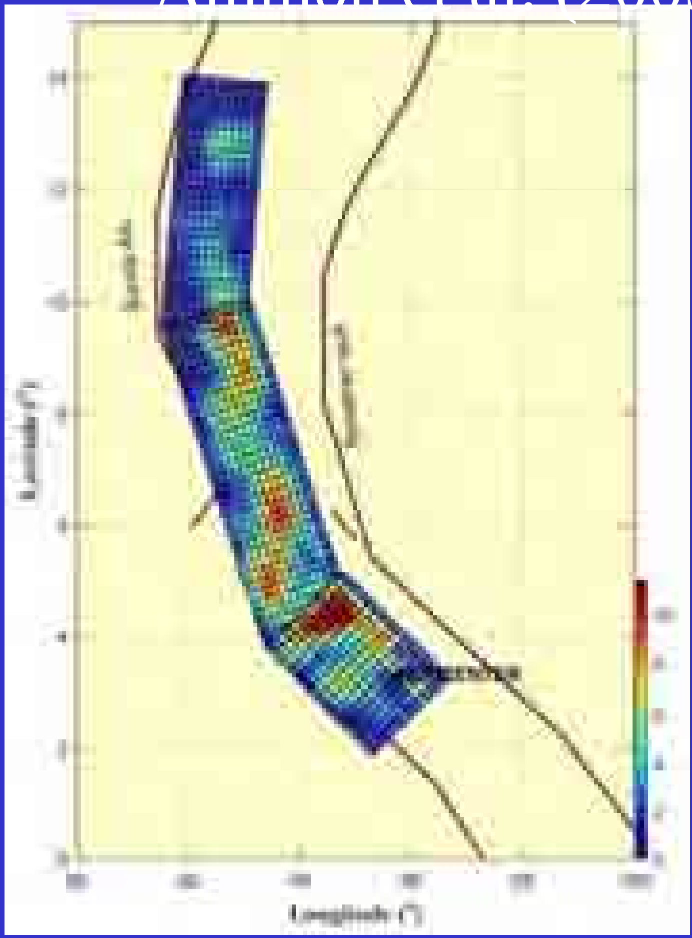


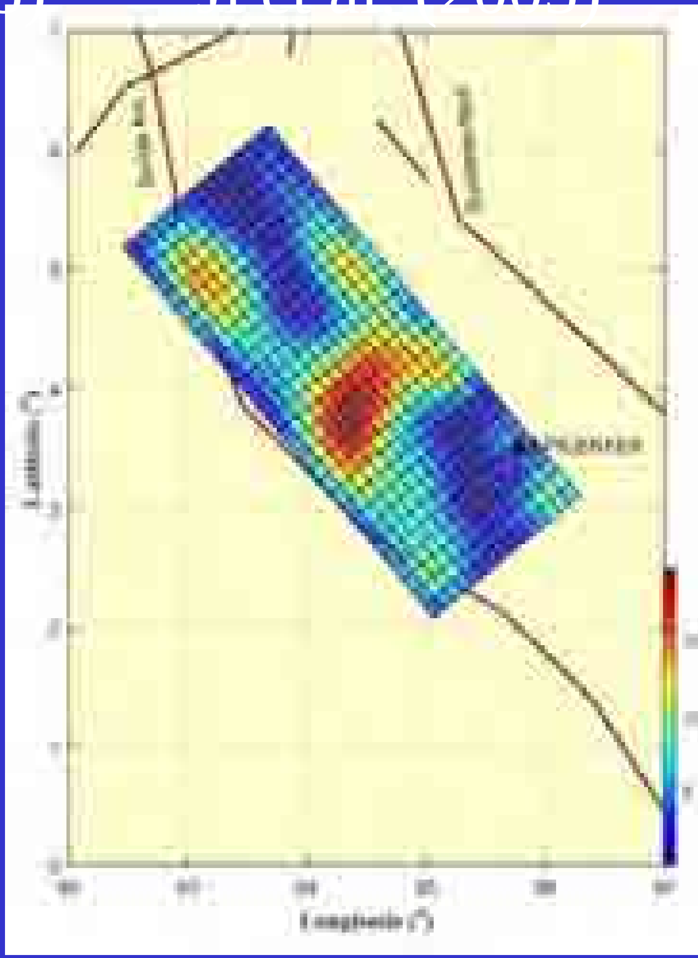
VALIDATION
Comparison with IGCAR data, Z direction

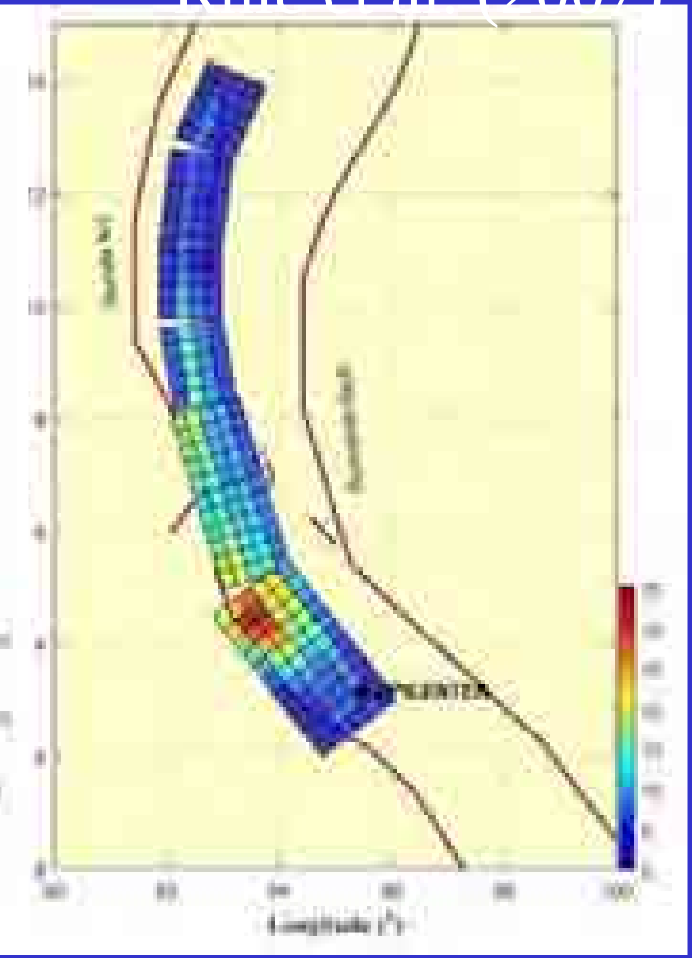


GROUND MOTION SIMULATION
Slip Distribution 2004 Mw 9.1 Sumatra Earthquake

Ammon et al. (2005) Ji et al. (2005) Rhie et al. (2007)



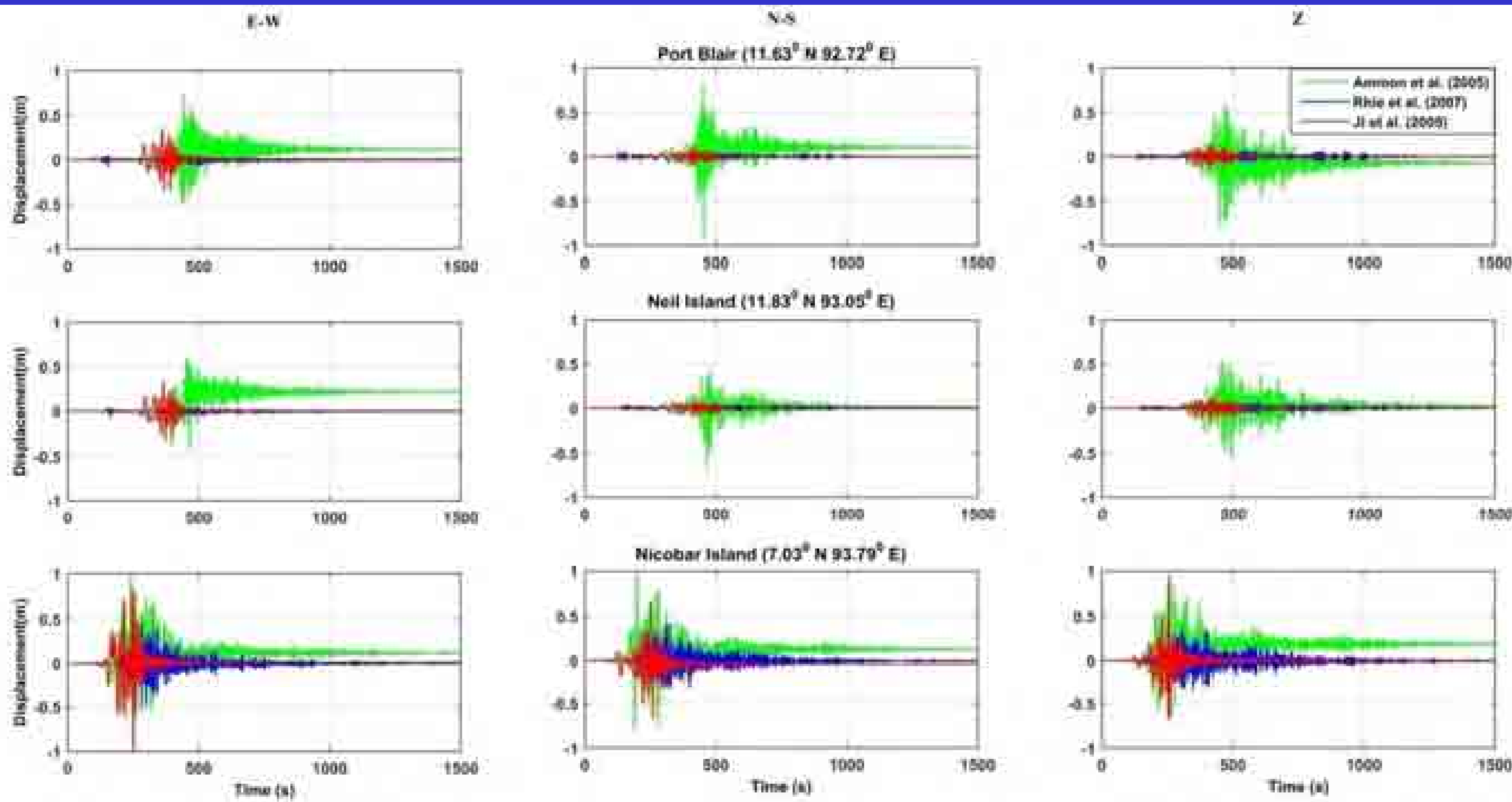




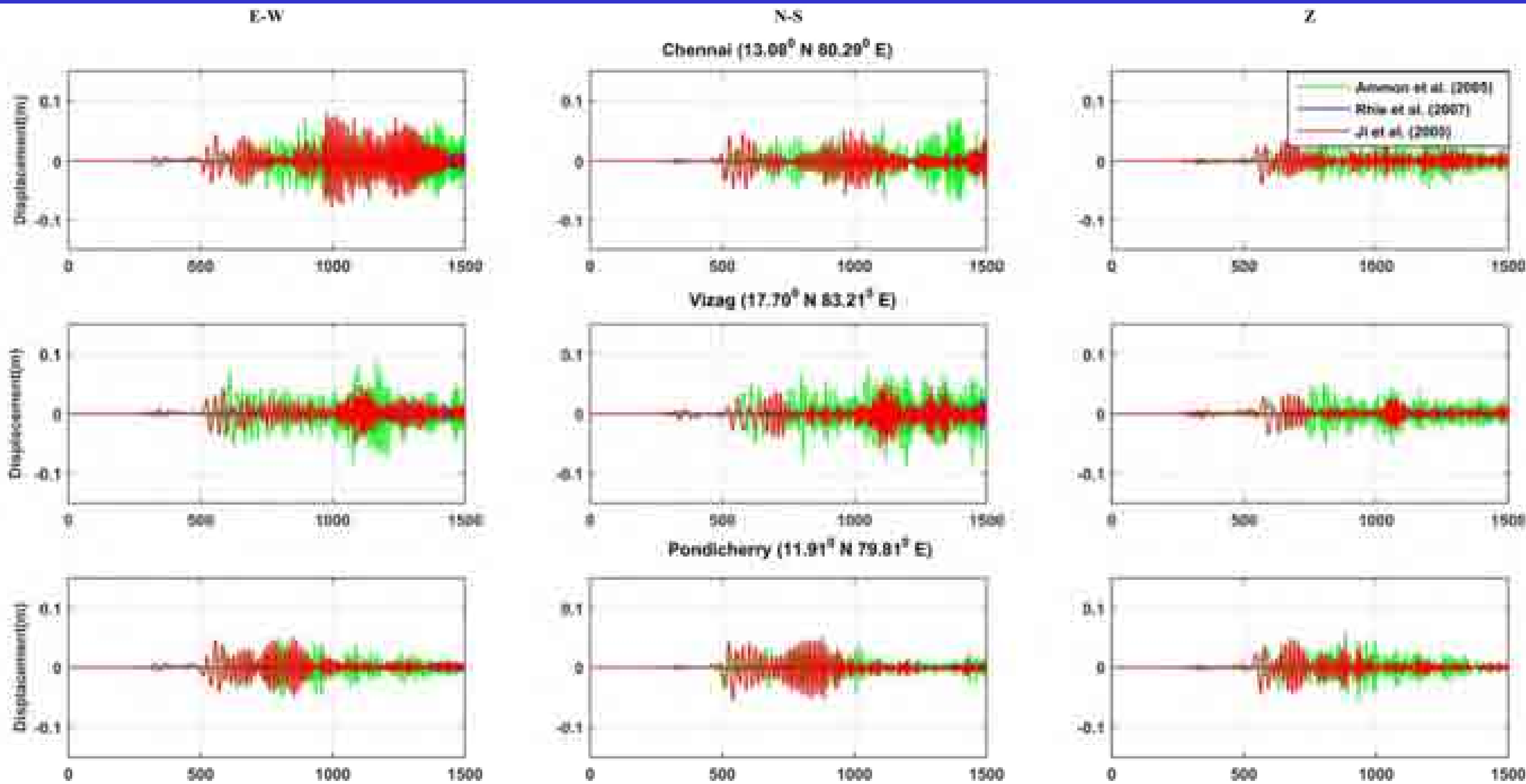
GROUND MOTION SIMULATION
Slip Distribution 2004 Mw 9.1 Sumatra Earthquake

	Ammon et al.	Ji et al.	Rhie et al.
(Longitude (º), Latitude (º))	(95.78, 3.3)	(95.78, 3.3)	(95.49, 3.12)
Depth (km)	35	35	27
Length (km)	1480	450	1355
Number of segments	3	1	6
Hypocenter :along strike	70 in Seg. 1	52.5	43.91 in Seg. 1
: down-dip	168 in Seg. 1	150	27 in Seg. 1
Segment: Length (km)	300, 680, 500	450	350, 343, 162.50, 162.50,165.50, 162.50
Width (km)	224, 192, 176	180	188.64, 144.88, 129.47, 129.47, 129.47, 129.47
Strike	315, 342, 5	320	322, 343, 350,0,7,24
Dip	12, 15, 17.5	11	11,15, 18, 18,18,18
Rake	99	91.7	-
Number of Sub-faults	210, 408, 275	450	66, 55, 20,20,20,20
Size of Sub-faults (km)	20 × 16	15 × 12	31.82 × 31.44
Avg. Rupture Velocity (km/s)	3	2	2.6
Avg. Rupture Time (s)			20
Max. Slip (m)	11.5	20	35

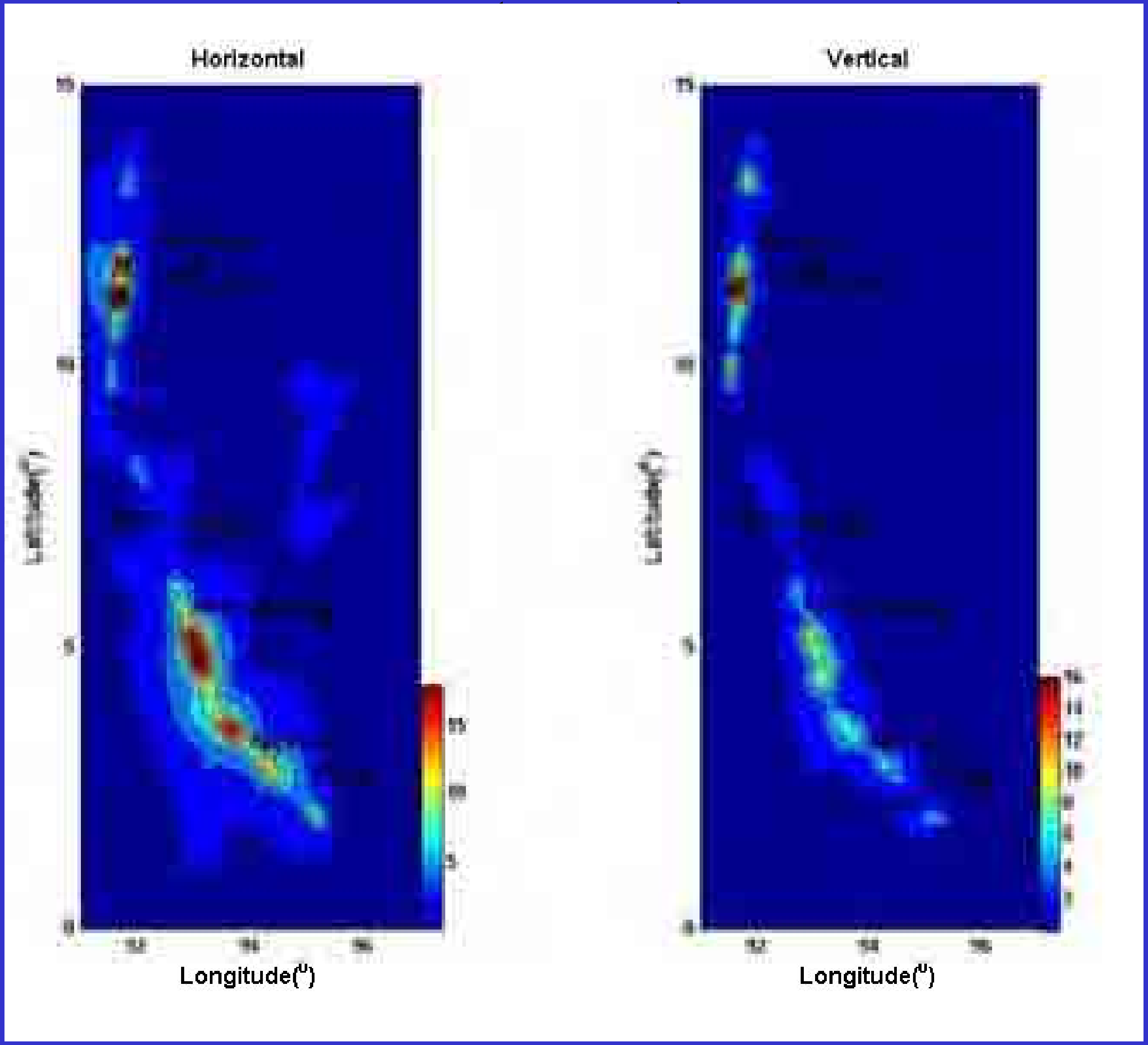
Displacement time history for 2004 (M_w9.1) Sumatra earthquakes:
Stations near the epicentral region (near-field)



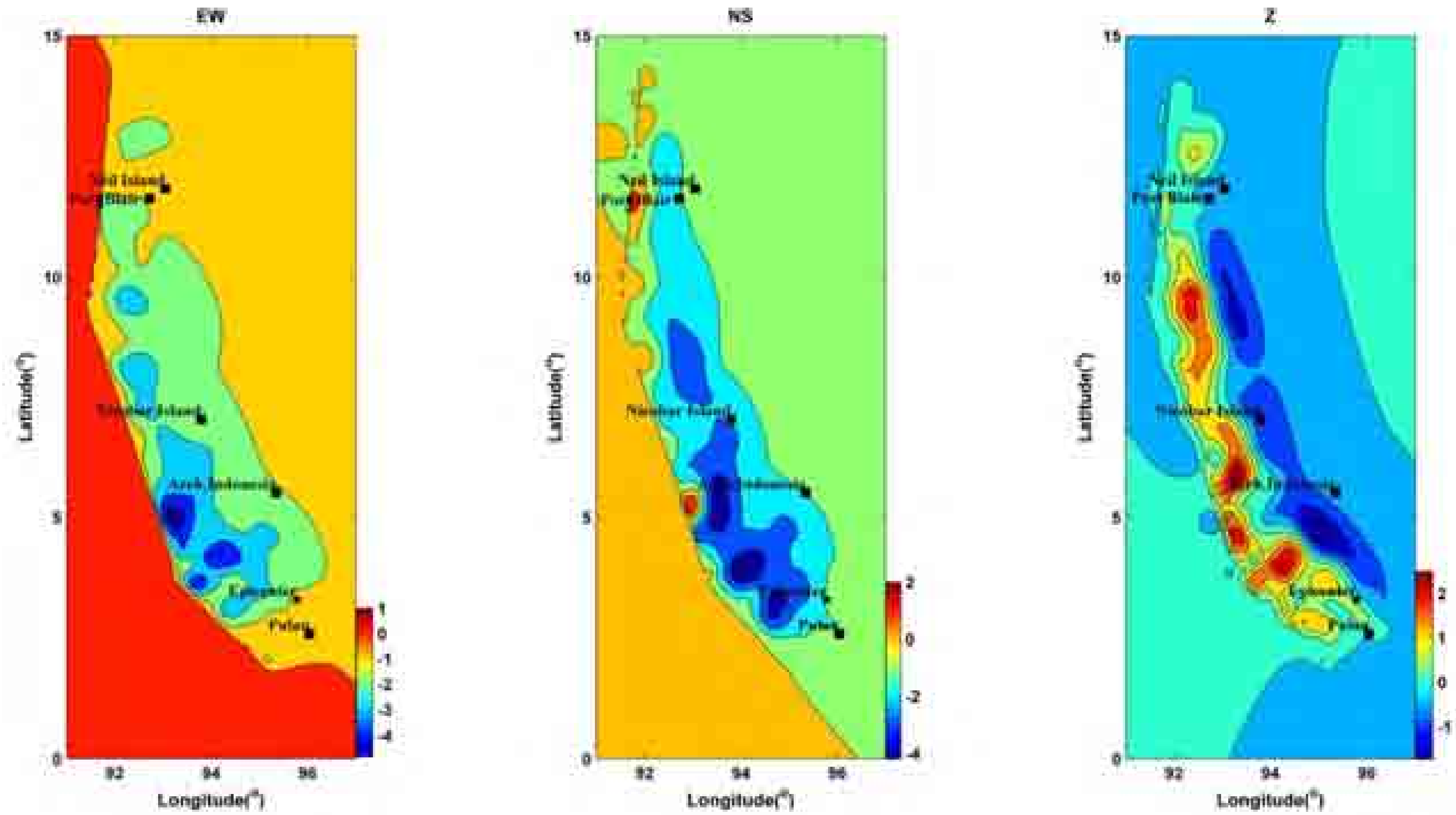
Displacement time history for 2004 (M_w9.1) Sumatra earthquakes:
Stations far from the epicentral region (far-field)



PEAK GROUND RESIDUAL DISPLACEMENT
The 2004 SUMATRA EARTHQUAKE: Ammon et al.



VERTICAL GROUND RESIDUAL DISPLACEMENT The2004 SUMATRA EARTHQUAKE: Ammon et al. (2007)



Wave Propagation- Finite Volume Method

$$\frac{\partial h}{\partial t}+\frac{\partial}{\partial x}(h\dot{u}_x)+\frac{\partial}{\partial y}(h\dot{u}_y)=0$$

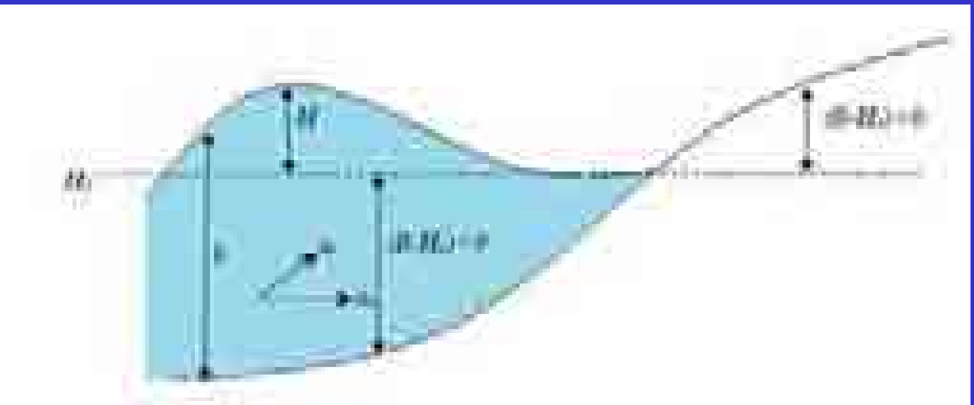
$$\frac{\partial}{\partial t}(h\dot{u}_x)+\frac{\partial}{\partial x}(h\dot{u}_x{}^2+\frac{1}{2}gh^2)+\frac{\partial}{\partial y}(h\dot{u}_x\dot{u}_y)=-gh\frac{\partial B}{\partial x}$$

$$\frac{\partial}{\partial t}(h\dot{u}_y)+\frac{\partial}{\partial x}(h\dot{u}_x\dot{u}_y)+\frac{\partial}{\partial y}(\frac{1}{2}gh^2+h\dot{u}_y{}^2)=-gh\frac{\partial B}{\partial y}$$

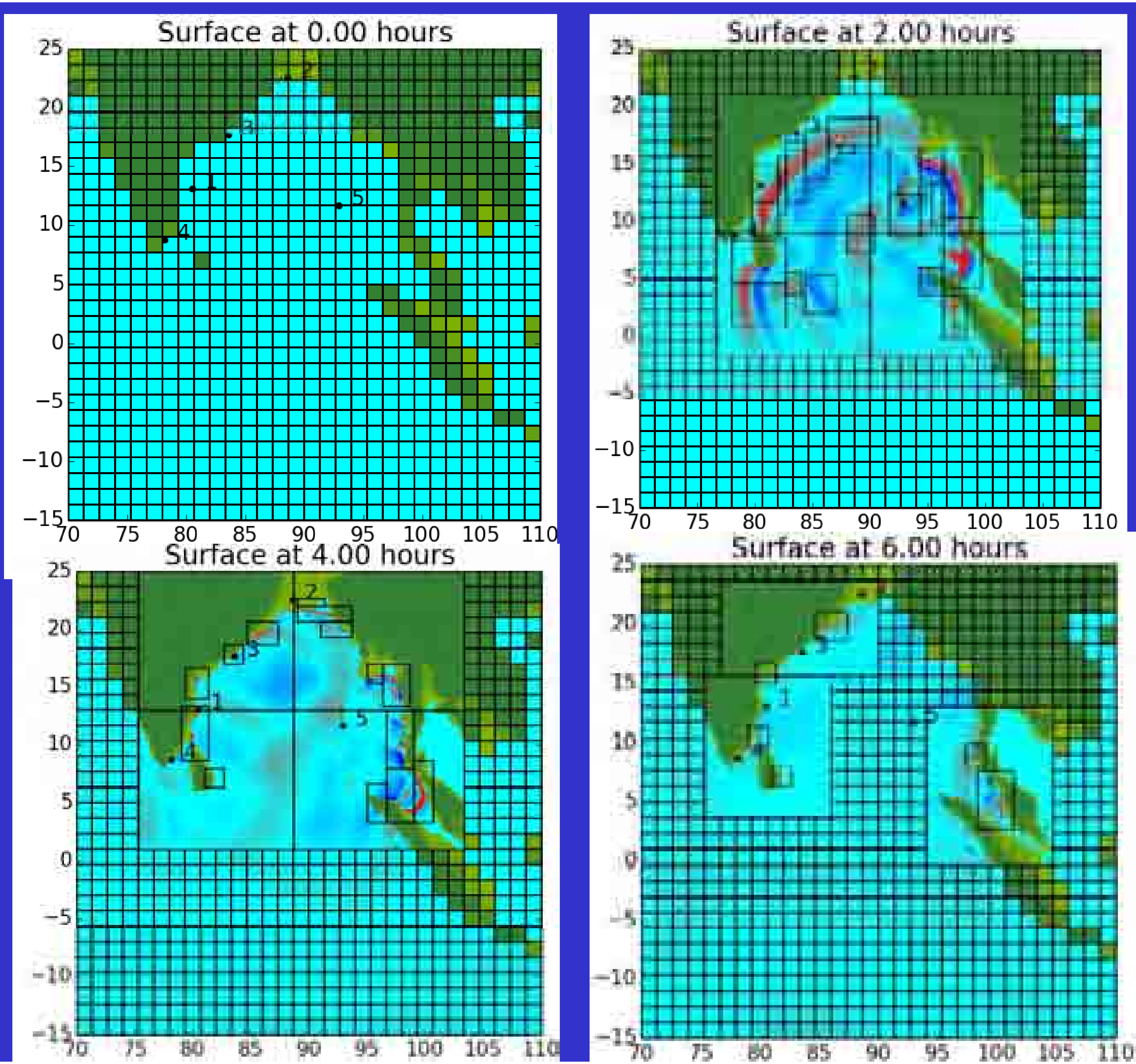
Shallow water wave can be concisely written as:

$$\frac{\partial q}{\partial t}+\frac{\partial f(q)}{\partial x}+\frac{\partial g(q)}{\partial x}=\psi(q,x,y)$$

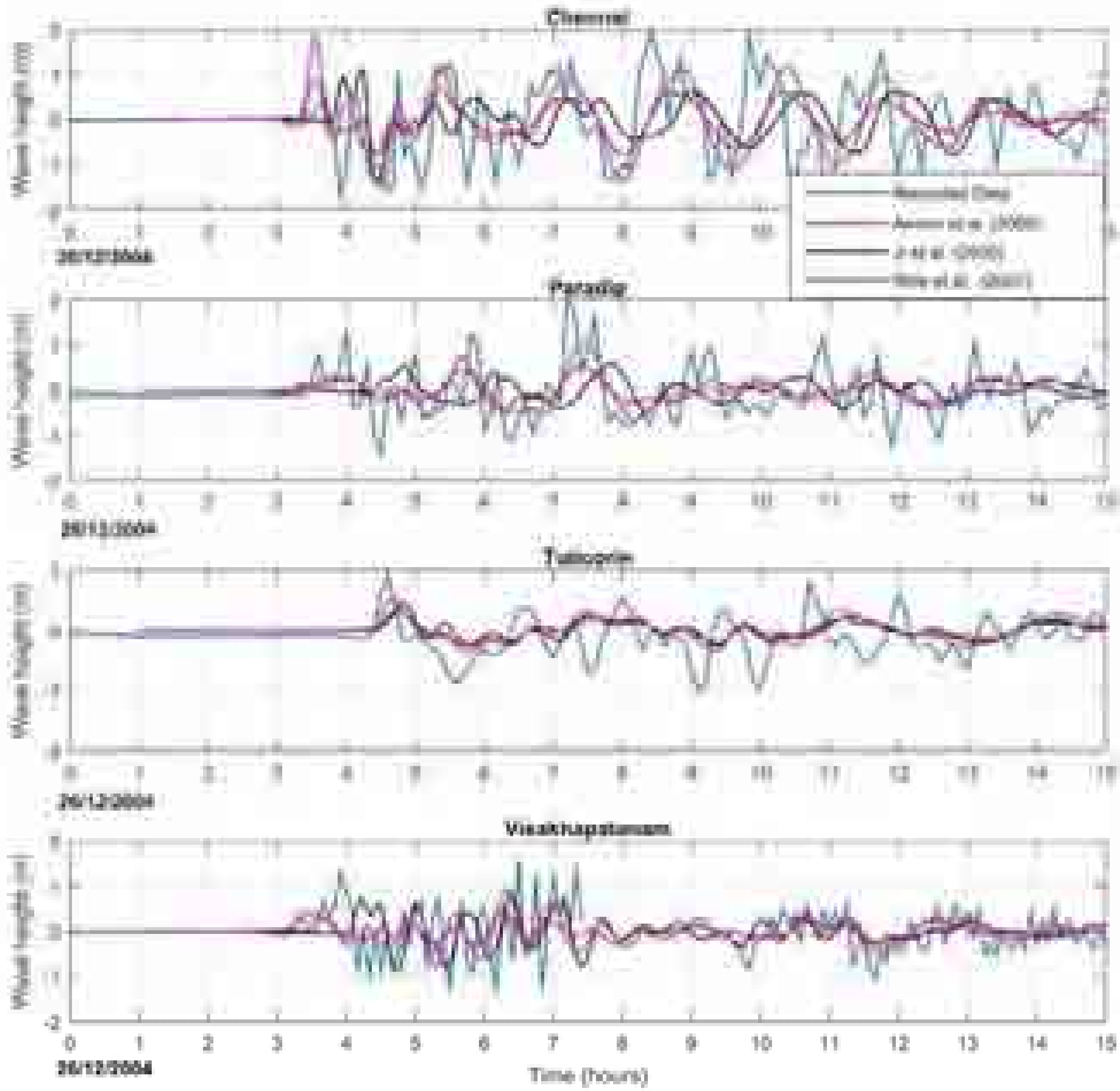
$$\boldsymbol{H}(x,t)=h(x,t)+B(x,t)$$



$$q=\begin{bmatrix} h \\ h\dot{u}_x \\ h\dot{u}_y \end{bmatrix},\quad f(q)=\begin{bmatrix} h\dot{u}_x \\ h\dot{u}_x{}^2+\frac{1}{2}gh^2 \\ h\dot{u}_x\dot{u}_y \end{bmatrix},\quad g(q)=\begin{bmatrix} h\dot{u}_y \\ h\dot{u}_x\dot{u}_y \\ \frac{1}{2}gh^2+h\dot{u}_y{}^2 \end{bmatrix},\quad \psi=\begin{bmatrix} 0 \\ -gh\frac{\partial B}{\partial x} \\ -gh\frac{\partial B}{\partial y} \end{bmatrix}$$


Surface at 0.00 hours
Surface at 2.00 hours
Surface at 4.00 hours
Surface at 6.00 hours
25
20
15
10
5
0
−5
−10
−15
70
75
80
85
90
95
100
105
110
1
2
3
4
5

VALIDATION OF WAVE HEIGHT TIME HISTORY FOR 2004 SUMATRA EARTHQUAKE



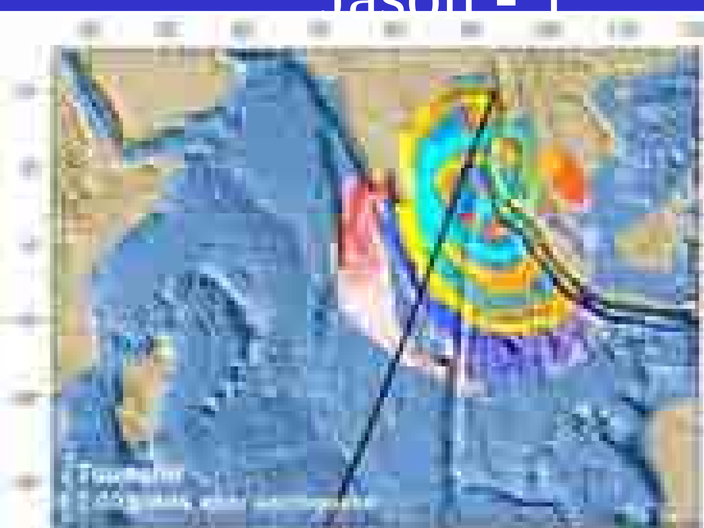
The recorded data corresponds to the detided tsunami signals at Tuticorin, Chennai, Vishakapattanam, and Paradip ports downloaded from:

http://www.nio.org/index/option/com_nomenu/task/show/tid/2/sid/18/id/11

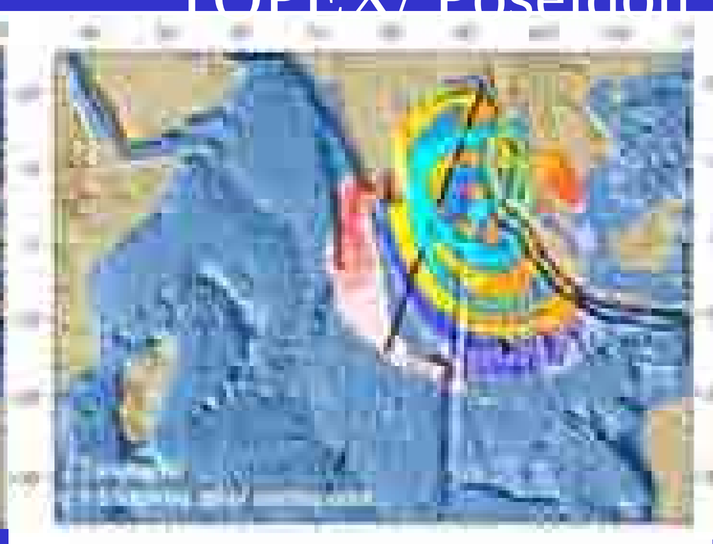
VALIDATION OF ALTIMETER READINGS FOR 2004 SUMATRA EARTHQUAKE

- Performance of the tsunami model in the open ocean is assessed by validating the results with the altimeter-derived sea surface height
- Jason-1, TOPEX/Poseidon, and ENVISAT altimeter have passed over the Bay of Bengal in Indian Ocean at 115, 120, and 200 min, respectively, after the December 2004 earthquake.
- Location along which Altimeter readings are recorded (black solid line) are as follows:

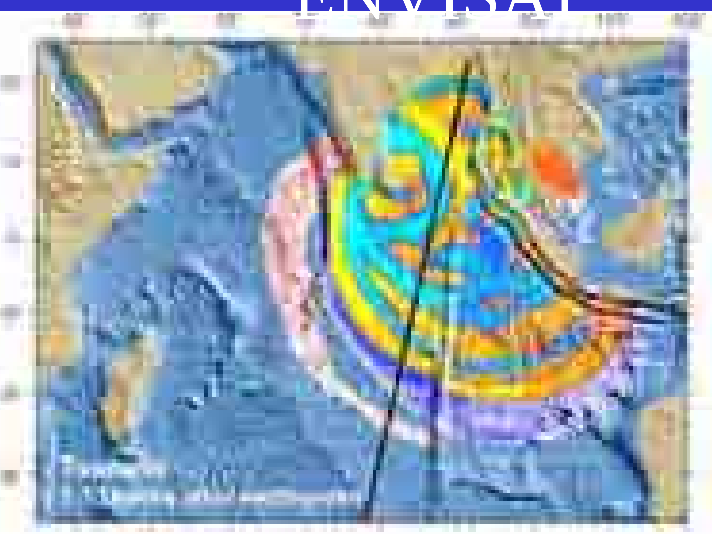
Jason - 1



TOPEX/ Poseidon

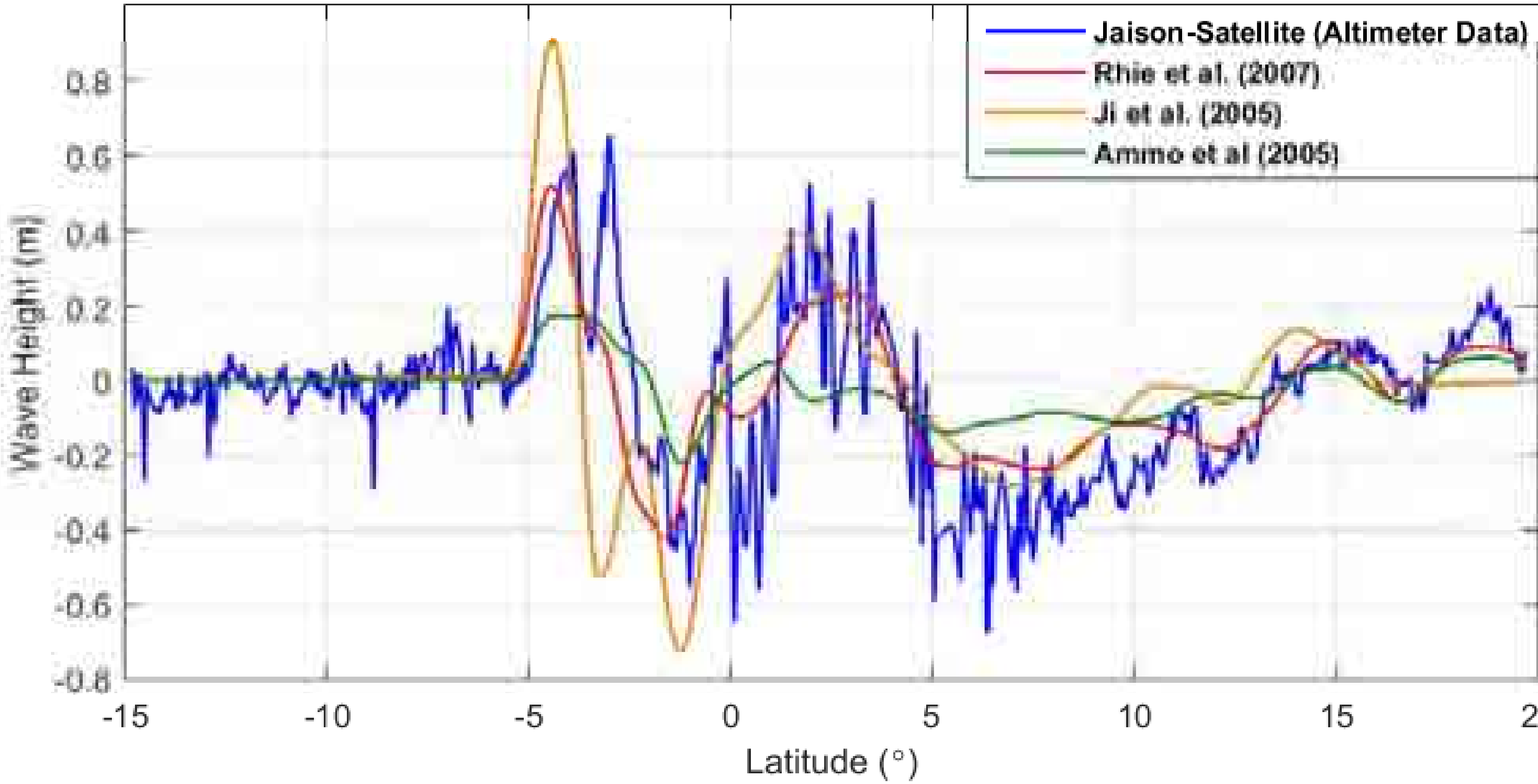


ENVISAT

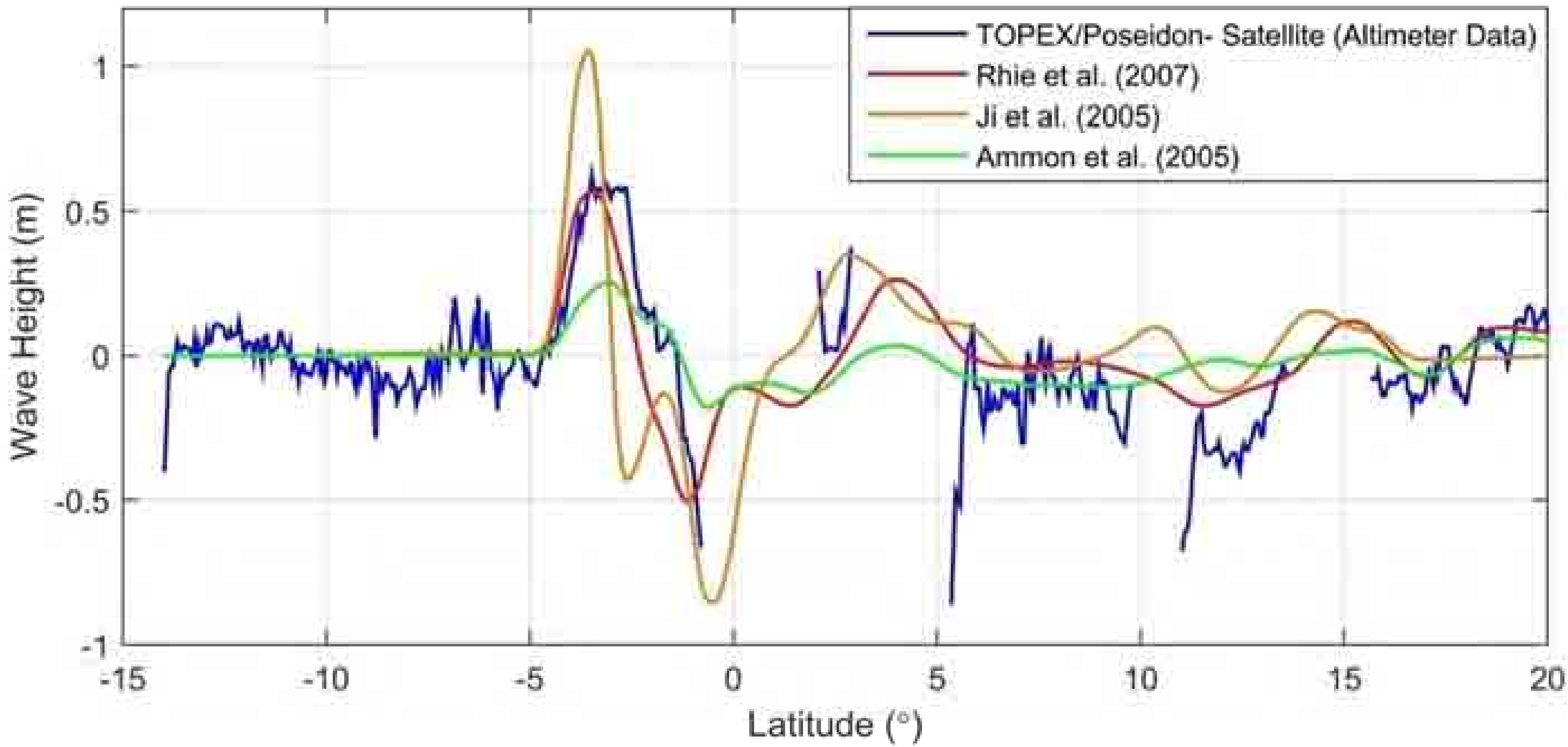


Source: NO

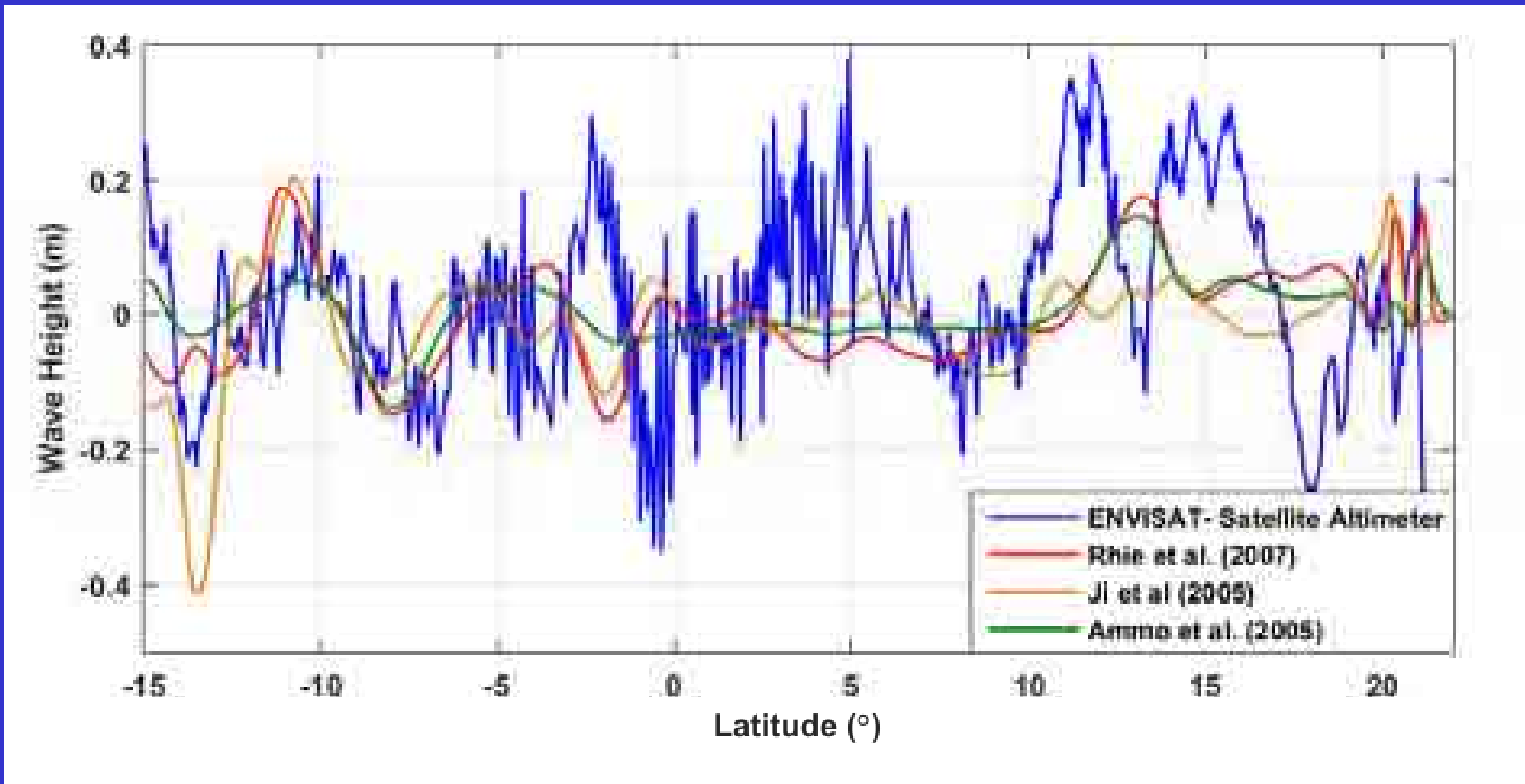
VALIDATION OF ALTIMETER READINGS FOR 2004 SUMATRA EARTHQUAKE: JASON -1



VALIDATION OF ALTIMETER READINGS FOR 2004 SUMATRA EARTHQUAKE: TOPEX/Poseidon



VALIDATION OF ALTIMETER READINGS FOR 2004 SUMATRA EARTHQUAKE: ENVISAT



How to generate tsunami hazard curve

Probability of occurrence of earthquake

$$P(k\ earthquake\ per\ year) = \frac{\upsilon^k e^{-\upsilon}}{k!} \quad k = 0,1,2...$$

Probability that wave height exceed a certain limit provided earthquake occurred

$$P(h > \bar{h})_{t\ year} = 1 - e^{-\left(\sum_{k=1}^{N_z} v_k p_k\right)t}$$

Total probability at a site due to all the identified seismic zones

$$P_r(h \geq \bar{h}; x, \Delta T) = 1 - \prod_{i=1}^{N_z}\left(1 - P_r(h \geq \bar{h}; x, \Delta T, z_i)\right)$$

Combined probability considering all scenarios

$$P_i(h \geq \bar{h}; x, z_i) = \mu_{Zi} \sum_{j=i}^{N_\sigma} \mathrm{P_r}(S_j \mid z_i)\, \mathrm{P_r}(h \geq \bar{h} \mid S_j; x)$$

- Cities situated at coasts are vulnerable to multiple disasters like floods, cyclones, storm surges and tsunamis.
- Odisha is a state located at eastern coast of India with a population of 4,19,47,358 (Census 2011)

Wind and cyclone zones of Orissa (Reference: OSDMA: http://www.osdma.org/)

1. Introduction

[illegible]

[illegible]

[illegible]

1.1 Objectives of the study

- [illegible]
- [illegible] of disaster to providing uninterrupted essential health services to the most disadvantaged children and women in the immediate aftermath of a disaster and in early recovery phase.
- To propose a number of long term recommendations to strengthen the infrastructure of health centres and offer short/mid-term recommendations to improve the [illegible]

1.2 State Background

[illegible]

1.3 Disaster Profile of the State

[illegible] **Table 1** shows the damage/loss happened due to floods in last decade.

Cyclones also occur frequently in the state, in the months of April-May (pre-monsoon) and September-November (post-monsoon). Super cyclones strike Odisha once every few decades. There are 250 cyclone-warning sets throughout the coastline of India, out of which 34 are in Odisha, covering 480 Km of coastline. The super cyclone of 1999 affected [illegible]

Table 1. Damage/Loss due to floods

Flood year	Damage/Loss
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]

[illegible]

Table 2. Damage to health facilities

Type of building	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
Total	[illegible]	[illegible]	[illegible]

(Source: Rapid damage and need assessment report, Cyclone Phailin in Odisha (2013))

Figure 1 and **2**, are the map representation of the TARU analysis, which highlight the flood prone and cyclone prone areas in the district of Odisha. Flood map represents the flood inundation area from 1999-2009. Map of cyclone frequency represents the number of cyclone or storm surge events that range from depression to super cyclonic storms.

1 Padhy, Gourikumari, et al. "A review on management of cyclone phailin: early warning and timely action saved lives." Indian Journal of Forensic and Community Medicine 2.1 (2015): 56-63.

2 Odisha National Disaster Risk Reduction Portal, NIDM http://www.nidm.gov.in/pdf/dp/Odisha.pdf

3 Rapid damage and need assessment report, Cyclone Phailin in Odisha (2013)

2. Vulnerability assessment: Methodology

2.1 Background

Structural and Non-structural building components

A hazard poses many different types of damages to the building. These damages can be structural and non-structural. Structural components of the building are the components of building infrastructure like load bearing system (i.e. vertical and lateral force resisting systems) walls and building frame. The non-structural components are those which do not affect the integrity of the structural support system but are important for functionality of the health facilities like accessibility, critical systems, staff and management. During disaster damage to structural components can render whole building inoperable but even if the structure is intact and the non-structural components are damaged, the healthcare facility cannot function when it is most needed. Thus, both structural as well as non-structural components play a key role in maintaining the operations of the health facilities during any disaster.

Assessment methodology

The assessment that will be carried out for the health facilities will follow an extensive process. Flow chart below shows an overview of the assessment methodology.

Desk Review	• Backgroud research • Discussions • GIS mapping • Sample size
Observation checklist	• Structural components • Non-structural components
Field Evaluation	• Scoping • Detailed assessment of selected facilities • Field level assessment
Interviews and FGD's	• Departments and officials • Community level
Analysis	• Structural analysis (simulation and field data), Non-structural analysis, interview and FGD summart
Workshop	• Presentation of results • Presentation of recommendation • Documentation of suggestions (if any)
Finalization of results	• Finalization of the report based on inputs from the workshop and UNICEF • Dissmination of the visualization system for the presentation of the findings

2.2 Desk Review

The first step involved the background research and study of healthcare infrastructure, various standards and guidelines, and existing methodologies on vulnerability assessment. Some of the documents reviewed were as follows:

- Indian Public Health Standards (IPHS) Guidelines
- Hospital Safety Index, WHO
- Field Manual for Capacity Assessment of Health Facilities in Responding to Emergencies, WHO; and various other research papers.

Desk review also included table discussions with the structural and non-structural experts, to evolve more relevant methodology to suit Odisha and its public health system.

The initial risk scoping across the state was also done at this stage, this helped in identifying stratified samples across the selected survey district. Flood mapping was undertaken on GIS using available data from CWC, IMD and Govt. of Odisha data to estimate peak discharges, levels and frequency of occurrence. Also, TARU repository of flood analysis based on previous studies in Odisha was used to further enhance the information. A set of cyclone 'corridors' and historical landfall locations based on the 130-year cyclone catalogue was identified. This provided basis of understanding the variation in storm intensities across the region.

Sample selection[1] included those districts which have been affected more than 5 times in last 20 years by large scale flooding and the districts which are frequently affected by cyclone.

Districts affected by cyclone	Districts affected by flood
• Ganjam • Puri • Jagatsinghpur	• Jajpur • Bhadrak • Cuttak • Kendrapara • Balasore • Jagatsinghpur • Puri • Sambalpur • Anugul • Sonepur • Khordha • Ganjam • Nayagarh • Gajapati

The health facilities were selected based on the criteria provided in the terms of reference: 50% of CHC's, 25% of PHCs and 5% of SCs in the flood affected blocks and 100% of CHCs, 50% of PHC and 10% of SCs in the cyclone affected blocks. The sample size is indicated within the **Table 5.**

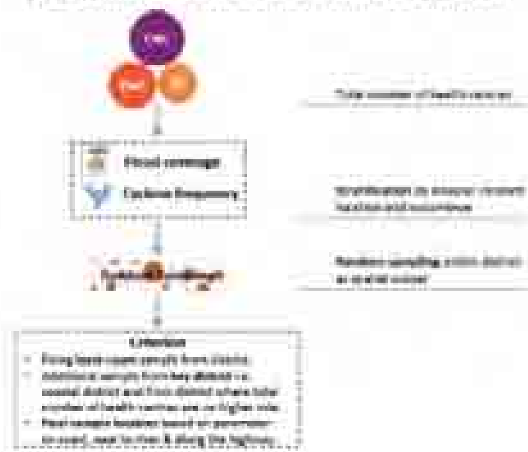
Table 5. Sample size

Facilities	Flood	Cyclone	Total	Sample size: Flood	Sample size: Cyclone	Sample size: Total
CHC	58	5	63	29	5	34
PHC	232	20	252	58	10	68
SC	1,160	100	1,260	58	10	68
Total	1,450	125	1,575	145	25	170

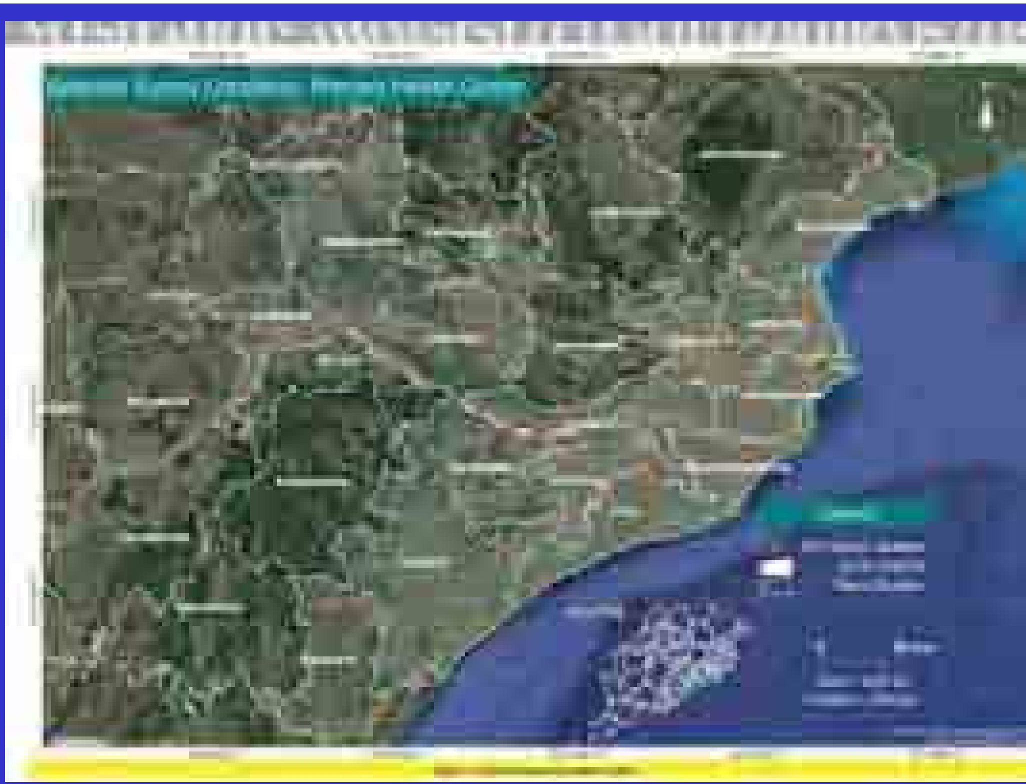
2.3 Sampling methodology

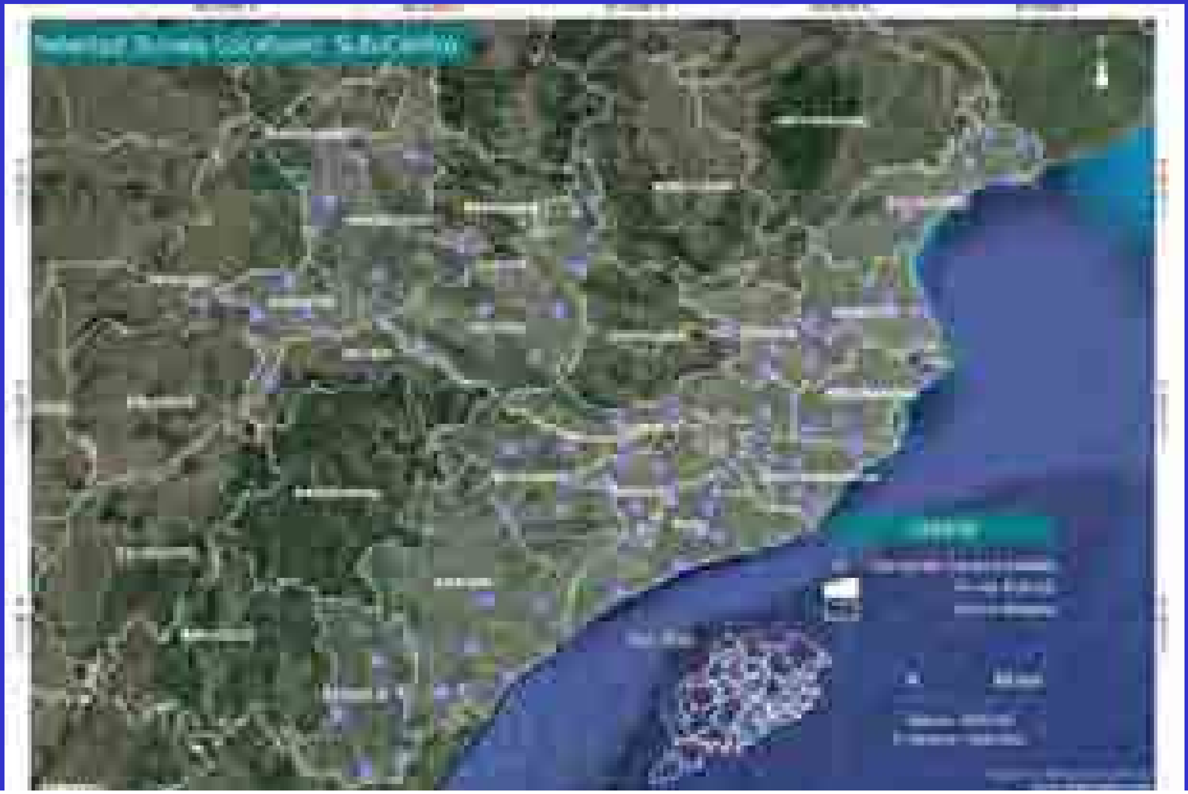
Stratified random sampling method was used for the selection of survey locations. This sampling process consists flood and cyclone based information as filter for stratification. Health centres which were intersecting with the flood and cyclone occurrence were selected. After filtrations from cyclone and flood information, residual location was used for random sampling process. Random sample selection was based on district as subset. Some parameters which were used for final sampling were as, selected location should be near to coast, river and along the road.

- For case of CHC – Minimum two samples per district were selected. Additional one sample for the key coastal districts and the districts where number of CHC are relatively more, were selected.
- For case of PHC and SC – At least six number of sample per district for both SC and PHC were selected.



1 As indicated in TOR





3. Comparitive analysis across districts

The analysis for every building was done based on several indicators. The questionnaire was divided into six main indicators:

Indicator 1: ACCESSIBILITY

Indicator 2: BUILDING INFRASTRUCTURE

Indicator 3: CRITICAL SYSTEMS

Indicator 4: LOGISTICS

Indicator 5: STAFFING PERSONNEL

Indicator 6: OPERATION AND MANAGEMENT

Description of indicators

Indicator 1: ACCESSIBILITY

Ease of access is essential if the health facility has to function properly, especially during the time of emergency when the number of affected population is high. The emphasis in this indicator was on the main access route to the hospital building, features of site and surroundings.

1.1 Site conditions

Site condition involves condition of the access road, its width and topographical factors of the neighbourhood. Effect of these parameters on accessibility of vehicles and pedestrian.

This section consists of the following 6 **sub sections:**

1. Condition of road- Condition of the road to the hospital was assessed, whether it was paved or unpaved, potholes/obstacles exist or not and situation of the traffic congestion.
2. Width of the access route- Width of access route was measured, to know, if it was wide enough for easy access of the ambulance or narrow such that three-wheeler, two-wheeler or only pedestrian can access.
3. Topographical factors for flood- Location of the health facility was observed with respect to the road level. If it was constructed on a high ground, flat land or low-lying area. Presence of any high obstruction in the near vicinity. These factors determine the situation during flood.
4. Topographical factors for cyclone- Location of the health facility was observed with respect to the site. If the site was shielded by wind barriers like strong trees or hillocks, which can protect the building during cyclone.
5. Building accessibility in case of flood and cyclone- Presence of certain elements in the site surrounding can hinder/block the access to the facility during flood or cyclone. Elements like construction material, debris, weak trees, etc. were observed near the building.
6. Site accessibility for vehicle and pedestrian- Any damage to the outer structure of the building and the damage to the road were observed, which can impede vehicular and pedestrian access to the building. Damage to structure, like falling of plaster, can endanger people outside the building.

1.2 Surrounding buildings

Arrangement of surrounding buildings and their distance from the health facility also affects the accessibility.

This section consists of the following 2 **sub sections:**

1. Surrounding building configuration- Pattern of the buildings surrounding the health facility was observed. Zig-zag pattern or row type arrangement of the buildings affect the flow of wind. Presence of no building in the surrounding, exposes the existing building to the strong winds.
2. Distance of surrounding buildings from hospital- Distance between the surrounding buildings and health facility was measured. A safe distance can avoid damage to one building, affect another building.

Indicator 2: BUILDING INFRASTRUCTURE

This indicator involved both the structural and non-structural components of the building. Structural components are the load bearing system like the walls and building frame. The non-structural components include the design and architectural elements like false ceiling, partition wall, fixtures, shelves, etc. Both the components play a key role in maintaining the operations of the health facility.

2.1 Layout

Layout includes the means of entrance to the building and; shape and configuration of the building plan and elevation, which can affect the building integrity.

This section consists of the following 3 **sub sections:**

1. Means of entrance- Presence of ramp and stairway was observed at the entrance of the health facility.
2. Building Elevation- Any irregularity or variation in the elevation of the building was observed.
3. Building Plan- The plan of the building was observed to be square, rectangle or with irregularities like the re-entrant corners.

2.2 Structural elements

Structural elements include the type of construction and design. The extent of roof overhangs which can make building vulnerable during high speed winds. Interaction of secondary structural components and the location of openings on the horizontal diaphragm which can affect the integrity of the structure. The height of plinth with respect to past flood levels which can help in determining the situation during flooding. Number of redundant members that can prevent collapse during disaster situation.

This section consists of the following **7 sub sections:**

1. Type of wall construction- Wall construction of the building was categorised into three types: RCC frame, reinforced brick masonry or unreinforced brick masonry/ mud walls.
2. Type of roof construction- Roof construction of the building was categorised into three types: Hipped/ pyramidal shaped, gentle sloped gable roof or flat/ mono-pitched roof.
3. Roof projection- Projection of the sloped or flat roof was measured at the eaves. If the projection was more than 450mm then its connection with the wall framework was observed.
4. Interaction of secondary structural components- Interaction of secondary structural elements like partition walls, suspended ceiling or facades with the structure was observed. For ex. Rigid connection of the secondary structure can damage the structure.
5. Distance of openings from wall intersection- Placement of openings on the walls are important during cyclone hazard. Distance of openings from wall intersection were measured, if they were at the centre of the wall or within 0.5m from the wall corner or just below the roof.
6. Plinth with respect to past flood levels- Plinth of the building was noted to be high, coinciding or lower, with respect to the past flood level.
7. Lines of resistance- Lines of resistance i.e. beams or load bearing walls were observed in each orthogonal direction of the building, to be > 3, = 3 or < 3.

2.3 Condition of building

Condition of the building involves condition of various building components like the walls, roof, floor, construction material, windows and doors, etc. which can help in determining overall condition of the building that whether it is safe or vulnerable.

This section consists of the following 13 **sub sections:**

1. Envelope- Hairline cracks and diagonal cracks were observed on the outside walls/facing of the building.

Annex 1. Questionnaire

Checklist for structural safety assessment

Name of the respondent: Contact No.:

Designation:

Structural Safety Assessment

General information:

Is there any water body in the site vicinity? If Yes, mention distance (in km):

Total no. of external walls: Average Length: Average Width: Wall thickness:

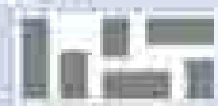
Thickness of slab:

Built up area (in sq.ft.):

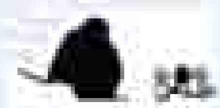
Height of the building/No. of storey:

Number of occupants (staff, patients): Day Night

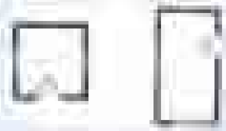
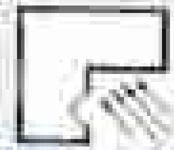
Is there a basement in the building?

S.No.	Basic building details	Safety levels			Observations
		High	Average	Low	
1	What is the age of the building in years?	0-25	25-50	>50	
2	How is the condition of the building?	No deterioration or cracks	Some deterioration (like flaking of plaster) caused only by weathering or normal aging	Cracks; Major deterioration caused by weathering or normal aging	
3	What is the configuration of surrounding buildings?	Surrounding buildings are in zig-zag model pattern 	Surrounding buildings are in row type arrangement 	No building in the surrounding	
4	What is the separation distance of the hospital building from the surrounding building?	Distance between the buildings is more than 15 m	Distance between the buildings is between 5 m and 15 m	Distance between the buildings is < 5m	
5	What is the type of construction? (wall)	Reinforced cement concrete frame	Reinforced brick masonry	Unreinforced masonry	
6	What is the type of construction? (Roof)	Reinforced concrete roof or hipped or pyramidal roof (30°-45° slope) 	Gentle slope gable roof (<30° slope) 	Asbestos or flat light roofs (<5° slope) 	

S.No.	Past events affecting safety	Safety levels			Observations
		High	Average	Low	
7	Are past structural damage or failure of the hospital building?	Minor (<1mm) or no cracks, or fully repaired	Moderate cracks (1-2mm) and partially repaired	Major cracks (>2mm) on load structural elements (i.e. walls, columns, beams) and no repair	
8	What is the effect of remodelling or modification on the structural behaviour of the hospital?	Minor or no; enhancing structural behaviour or no negative effect	Moderate; minor effect on performance	Major; compromising effect on performance	

S.No.	Facility site	Safety levels			Observations
		High	Average	Low	
9a	Site topography (for flood hazard)	Constructed on high ground (higher than the nearby road level) and no high obstruction (like hillock) in the near vicinity	On flat land, at the same level as the road level	On low lying area, lower than nearby road level	
9b	Site topography (for cyclone hazard)	Constructed on site shielded by hillock or strong trees 	No shielding 	Constructed along the ridges or valley	
10	Are there any elements in the site surrounding, resulting in debris movement (in case of flood) or flying debris (in case of cyclone), that can block access?	No such elements present	Few elements like trees, construction material, etc.	Considerable elements that can block access during hazard	

S.No.	Building integrity	Safety levels			Observations
		High	Average	Low	
11	How is the condition of the construction material? (Building)	Cracks less than 1 mm (concrete) no visible deformations, no rust	Cracks between 1 and 3 mm present (concrete), moderate and visible deformations (steel and wood) or rust with no flaking	Rust with flaking; cracks larger than 3mm (concrete), excessive deformations (steel and wood)	
12	How is the interaction of secondary structural (Partition walls, suspended ceiling) elements with the structure?	There are no secondary elements affecting the structure	Some of the preceding secondary structural elements interacting with the structure; damage would not affect the structure	Partition walls rigidly attached to the structure, suspended ceilings or facades interacting with the structure, damage would have significant effect on the structure	
13	Are there structural redundant members?	More than 3 lines of resistance (i.e. >3 structural components like beams) in each orthogonal direction of the building	3 lines of resistance in each direction or lines without orthogonal orientation	Fewer than three lines of resistance in each direction	
14	Is the plinth of the building in accordance with the past flood levels?	More than high flood level for that building	Coincide with flood level or lower	Very low with respect to flood level or no plinth	
15	Are there irregularities in building structure plan?	No, simple square or rectangular plan (<3:1)	No, long rectangular plan or minor irregularity	Irregular plan, can suffer torsion	

S.No.	Building integrity	Safety levels			Observations
		High	Average	Low	
					
16	Are there irregularities in elevation of the building?	No significant irregularity, elevation of the building is continuous	Irregularity exist, some setbacks in the elevation of the building	Significant irregularity, discontinuity in the elevation of the building	
17	How is the condition of the connections between roof and wall? (securely fastened, welded or cemented)	Connection of roof framing to wall by anchor bolts and base plates	Connection of roof framing to wall by nailed galvanized strap	No proper visible connection	
					
18	What is the width of the roof projection?	Restricted to 450mm on verandah and patio roofs built as separate structures	> 450mm the projected portion tied properly to the wall framework	> 450mm of length or lower	
					

S.No.	Facility water source	Safety levels			Observations
		High	Average	Low	
19	What is the source of water supply to the facility?	Piped supply from municipality as well as non-piped supply facility	Non-piped supply like hand pump, borewell, etc.	Supplied through water tanker	
20	What is the capacity of water storage in the facility?	Up to 7 days	At least 2 days	No means of water storage	
21	Are the water storage systems protected and in secure locations?	Covered storage, located at higher level	Uncovered storage, located at lower level	No means of water storage	
	Provide photograph for the location and condition of water storage system				

S.No.	Facility electricity connection	Safety levels			Observations
		High	Average	Low	
22	What is the status of alternative source of electrical supply?	High power alternative source exists (like generator, DG set)	Low power alternative source exists (like battery, solar power, inverter)	No alternative source	

S.No.	Facility electricity connection	Safety levels			Observations
		High	Average	Low	
23	What is the capacity of alternate source of electricity?	Alternate source(s) start(s) automatically in less than 10 seconds and cover(s) more than 70% of demand in critical areas	Alternate source(s) covers 31–70% of demand in critical areas and starts automatically in less than 10 seconds in critical areas	Alternate source(s) is(are) missing or covers less than 30% of demand in critical areas, or can only be started manually	
24	Are there regular tests of alternate sources of electricity in critical areas?	Tested at full load at least monthly	Tested at full load every 1 to 3 months	Tested at full load every 3 months or more	
25	How is the condition and safety for alternate source of electricity?	Well-secured, elevated from ground and in good working order for emergencies.	Partially protected, elevated from ground and working	No protective measures, not elevated from ground and not working properly	
26	How is the condition and safety measures for electrical equipment, control panel, cables and cable ducts	Good condition, well-protected and in good working order	Fair condition, some measures provide partial protection and security	Poor condition, there are no protective measures	
27	Provision and operation of emergency lights [for use between periods of power interruption and restoration of electrical supply with alternate source]	Automatic emergency lights provided at all important locations	Manually operated emergency lights provided at few locations	No provision	

Provide photograph for the location and condition of the alternate source and fuel storage

S.No.	Facility drainage and sewerage systems	Safety levels			Observations
		High	Average	Low	
28	What is the means of storm water drainage?	Proper closed piped drainage connected to main line	Open drain connecting to main line	No drainage connected to main line	
29	What is the means of sewage disposal?	Proper closed piped drainage connected to main line	Septic tank provided	No proper disposal system	
30	Does the facility handle biomedical waste?	Yes	No (the waste is dumped directly)		
30a	If yes, how it is managed?	Segregation of waste and disposal in designated coloured containers What is the frequency of transportation of waste off-site?			

Checklist for non-structural safety assessment

Name of the respondent: Contact No.:

Designation:

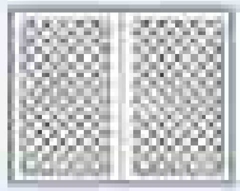
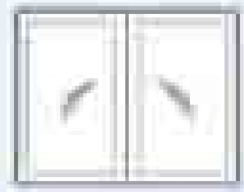
Non-Structural Safety Assessment

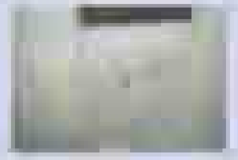
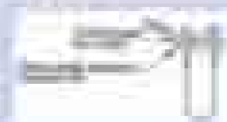
General information

Type of health centre: Population covered:

Deliveries conducted: Yes No

If Yes, deliveries conducted in the last month (December 2018):

S.No.	Architectural safety	Safety Index			Observations
		High	Average	Low	
1	Is there any major damage and hazard of non-structural elements?	Minor or no damage, or building fully repaired	Moderate damage, building only partially repaired	Major damage and no repairs conducted	
2	How is the condition and safety of doors (exits and entrances) that could affect the functioning?	Good condition, securely attached to jambs, no or minor potential for damage	Fair condition, subject to damage but would not impede the function	Visible damage which would impede the function	
3	What is the distance of openings from wall corner?	At a minimum distance of 0.6m from the wall corner	Within a distance 0.6m from the wall corner	Just at the wall corner or just below the roof	
4	How is the condition and safety of windows and shutter that could affect the functioning?	Good condition, well designed glass panes, smaller panel dimension, would be able to resist high wind speed and leak proof 	Fair condition, use of adhesive tape, subject to damage of limited breakage	Visible damage, large and thin unprotected glass area, will fail to resist high wind speed and leakage 	
5	Total no. of windows	[illegible]	[illegible]		
6	How is the condition and safety of other elements of building envelope (curtain walls, fascia)?	No cracks	Hairline cracks on the surface	Shear or diagonal cracks on the surface 	
7	Is the roof of the facility accessible? If yes, answer 7a, 7b	Yes		No	
7a	What is the height of the parapet?	900mm or more	Less than 900mm	No parapet constructed	
7b	How is the condition of the parapet?	Minor or no damage, good connections	Moderate damage, fair connections	Visible damage like cracks, improper or no connections	

S.No.	Architectural safety	Safety levels			Observations
		High	Average	Low	
8.	Are there obstacles or damage to structure or road and walkways that will impede vehicle and pedestrian access to buildings or endanger pedestrians outside the building?	No	Will not impede pedestrian access, but will impede vehicle access	Yes	
9.	Are there obstacles or damage to elements that will impede movement inside the building?	No	Will not impede movement of people, but will impede movement of stretchers, wheeled equipment	Yes	
10.	How is the condition of the internal walls and partitions?	Good condition	Damage that would not impede the function	Visible damage	
11.	How is the condition of the false or suspended ceiling?	Good condition	Damage that would not impede the function	Visible damage, not anchored properly to the ceiling	
					
12.	How is the condition of the stairways, ramps and handrails?	No obstacles or minor damage	Damage that would not impede the function	Visible damage and obstructions	
13.	In case of a trussed roof, is the roof covering properly bolted to the truss frame?	Yes, spacing between bolts is very less (up to 300mm) and J/U bolts are used	Yes, but spacing between bolts is more (up to 500mm) and J bolts are used	Regular straight bolts used with high spacing (>600mm) and no consideration for wind hazard	
					
14.	How is the condition of the flooring?	Non-slip flooring, free of cracks and undulations	Patchable damage, minor wear and tear	Damage and undulations in flooring	
15.	Does the building has a lightning arrester?	Yes		No	
16.	How is the condition of other architectural elements like:				
	Elements	Anchored properly		Material	
		Yes / No		Light / Heavy	
	Signboard				
	Solar panels				
	Lights/Antenna				
	AC units				
	Water/cooler				
	Parapet				
	Tower				

[illegible]
other, specify

S.No.	Safety of physical access to the facility	Safety levels: High	Average	Low	Observations
17	How is the condition of the [illegible] access road?	Well paved with no obstacles/ potholes and no traffic congestion	Paved with few obstacles/potholes and less traffic congestion	Unpaved access with obstacles/ potholes and traffic congestion at [illegible]	
18a	What is the width of the access route to the health facility?	Wide; ambulance can access	Narrow; only 3-wheeler or motorbike can access	Very narrow; only pedestrians can access	
18b	Mention width of the access route in feet				
19	What is the means of entrance to the health facility?	Through ramp and stairway both	Only through [illegible]		

S.No.	Safety of drug storage system	Safety levels: High	Average	Low	Observations
20	Is there a separate area for drug storage?	Separate closed area for storing drugs on shelves	No separate storage area but drugs stored with shelves	No separate storage area and drugs stored without shelves	
	If the safety level is high, in question 20 answer question 21.				
21	Are the shelving and staff cabinets safe?	[illegible] of shelving attached to walls and cabinets are secured	Shelving attached to walls and cabinets are secured in 10-40% of cases	Shelving not attached to walls in more than 70% of cases	
22	Where is the drug storage system located?	Ground floor		Upper floors (specify)	
23	What is the elevation within the floor where the drugs are stored (in ft)?				

S.No.	Staff capacity (indicate [illegible])	Safety levels: High	Average	Low	Observations
24	Number of staff in the facility based on [illegible] (as per MoH)?	Staff fulfilling sanctioned as well as desired number	Staff fulfilling sanctioned number	Staff less than the sanctioned number	
25	Is there a displayed contact list of medical, non-medical and other staff?	List displayed near the entrance and up to date	List displayed near the entrance but [illegible] by 3 months and not updated	List is not displayed near the entrance	
25a	If the list is displayed, what is the location of the display? (provide photograph)				
26	Are the staff members trained for disaster situation?	All members	Few members	None are trained	
26a	Any specific training programs conducted by the government? If so, which?				
27	Is there a hospital disaster committee?	Yes and is fulfilling functions effectively	Yes, but is not fulfilling functions effectively	No disaster committee exists	
28	Is there a designated disaster management coordinator?	A staff member has been assigned this as main task (who conducts and/or has conducted trainings in past)	A staff member has been assigned the task	No designated disaster management coordinator	

District: PURI

Indicators	
ACCESSIBILITY	Moderate
Site Location	Moderate
Surrounding buildings	Moderate
BUILDING INFRASTRUCTURE	Low
Layout	Low
Structural elements	Moderate
Condition of the building	Low
Prior events affecting the building	Low
CRITICAL SYSTEMS	High
Water and sanitation	Moderate
Electrical system	High
Biomedical waste	High
LOGISTICS	High
Drug storage	High
STAFFING PERSONNEL	High
Number of staff	High
Contact information	High
Disaster management	High
OPERATION AND MANAGEMENT	Moderate
Preparedness	High
Response	Moderate

VULNERABILITY: LOW | MODERATE | HIGH

Key Findings

Structural

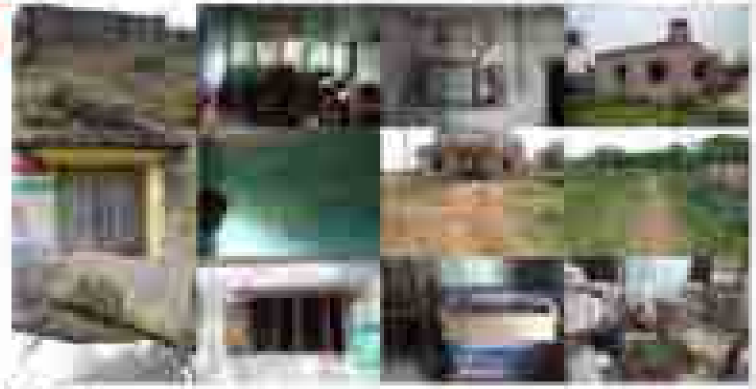
Non Structural

Key Recommendations

Short Term

Long Term

PHC	District: KENDRAPARA
1. [illegible] 2. [illegible] 3. [illegible] 4. [illegible] 5. [illegible] 6. [illegible]	General statistics: Road width: [illegible] Water body in vicinity: Yes [illegible] Age of building: 1 (Min.) & 41 (Max.) Population covered: 7,000 (Min.) & [illegible] (Max.) [illegible] Occupancy: [illegible] (Max.) Roof accessibility: No



INDICATORS
ACCESSIBILITY
Site condition
Surrounding buildings
BUILDING INFRASTRUCTURE
Layout
Structural elements
Condition of the building
Other events affecting the building
CRITICAL SYSTEMS
Water and sanitation
Electrical system
Biomedical waste
LOGISTICS
Drug storage
STAFFING PERSONNEL
Number of staff
Contact information
Disaster management
OPERATION AND MANAGEMENT
Preparedness
Response

VULNERABILITY: LOW | MEDIUM | HIGH

Key Findings

Structural

- [illegible], Aspua and Ayba does not have ramps at entrance.
- [illegible] health center does not have proper water storing system.
- There are some deterioration (like flaking of plaster) on roof slab at Ayba and [illegible] health center.
- Water to the facilities is from non-piped supply (hand pump, borewell, etc.)
- All facilities has capacity of storing water only for [illegible] days. (except [illegible] health center)
- Storm water drainage is provided through open drains connected to main line.
- Ayba health center has partial protected electrical conduit as loose hanging wires were evident.
- In all these centers, alternate source of electricity is not tested regularly.

Non-structural

- Drug storage room is located on first floor or above.
- No separate storage area is provided and drugs are stored without shelves.
- Quantity of essential medicines and supplies is less than [illegible], and less than [illegible] of drug shelves are secured to walls.
- Staff in the facilities are less than essential number stipulated within IPHS guideline.
- Staff members are not trained for managing disasters.
- Few supplies of the emergency kits are missing. Not fully prepared for disaster situation.
- Key staff are not aware of procedure for mobilization and recruitment of personnel during disaster situation.
- The facilities does not have provision for triage and no signage are present.

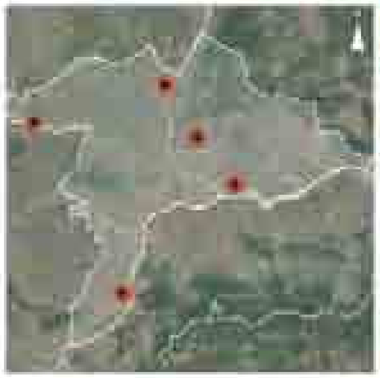
Key Recommendations

Short term

- Surrounding elements outside the premises should be kept clean and supervision should be carried out.
- Copies of building plan and structural drawings should be maintained within the facilities.
- Septic tanks should be cleaned regularly.
- Capacity of water storage tanks needs to be increased to cater to at least five days.
- Alternate electrical source should be tested monthly at full load.
- Drugs should be kept at high elevated secured position.
- Updated contact list of the medical staff should be displayed at the entrance of the health facilities.
- Staff members should be given proper training for disaster situation.
- All escape routes should be marked.

Long term

- Provision of ramps will increase the ease of access.
- Minor repairs are needed for windows and shutter.
- [illegible] need to be plastered.
- Damaged doors should be replaced or repaired by fixing with ply or wooden battens.
- Rebars are excessively corroded hence detailed NDT is required [illegible]
- Covered Storm water drainage system should be provided.
- Human resources should be strengthened.
- Location for triage should be identified and informed to the respective staff.



SC	District: SONEPUR
1. Sukha 2. Mahada 3. Ulunda 4. Brahmani 5. Sindurpur	General statistics: Road width- 8.4' Water body in vicinity- Yes (near 3 SC) Age of building- 1 (Min.) & 50 (Max.) Population covered- 5,800 (Min.) & 9,400 (Max.) Deliveries conducted- No Occupancy- 4 (Max.) Roof accessibility- No

INDICATORS	Vulnerability
ACCESSIBILITY	Moderate
Site condition	Moderate
Surrounding buildings	Moderate
BUILDING INFRASTRUCTURE	Moderate
Layout	Low
Structural elements	Moderate
Condition of the building	Moderate
Prior events affecting the building	Moderate
CRITICAL SYSTEMS	High
Water and sanitation	High
Electrical system	High
Biomedical waste	Moderate
LOGISTICS	High
Drug storage	High
STAFFING PERSONNEL	High
Number of staff	High
Contact information	High
Disaster management	High
OPERATION AND MANAGEMENT	High
Preparedness	High
Response	High

VULNERABILITY: LOW | MODERATE | HIGH

Key Findings

Structural

- Only stairway (no ramps) is provided at all these health centres.
- There are less than three lines of resistance i.e beams or load bearing walls in each orthogonal direction of the building.
- There are evidence of damage over doors, windows and shutter at Ulunda and Brahmani SC.
- There are cracks and major deterioration on roof slab caused by weathering and ageing (except Mahada and Sindurpur).
- Inner walls of all these centers shows evidence of dampness.
- There are deterioration like flaking of plaster on roof slab caused by weathering ageing at Sukha, Ulunda and Brahmani SCs.
- There have been past structural damage of major cracks on main structural elements i.e. walls, columns, beams.
- Water to the facilities is secured from water tankers and storm water drainage has no connection to main line.
- There is no proper system for sewage disposal.
- Electrical system of the facilities is in poor condition, there are no protective measures (except Sukha SC).
- Facilities does not have an alternate source of electricity.

Non-Structural

- Sindurpur SC does not handle bio-medical waste.
- The waste is dumped within site and incinerated at Sukha and Mahada SC.
- There is no separate storage area for drugs are stored without shelves.
- Quantity of essential medicines and supplies is less than required.
- Staff in the facilities are less than essential number stipulated within IPHS guidelines.
- Contact list of medical, non-medical and other staff are not displayed near the entrance.
- Staff members are not trained for managing disasters.
- Directory of local resource people are not maintained.
- The facilities does not have triage provision.
- Signage for evacuation were missing.

Key Recommendations

Short-term

- Surrounding elements should be kept clean and supervision should be carried out.
- Hair line Cracks needs to be plastered.
- Damaged doors should be replaced or repaired by fixing with ply or wooden battens.
- Drugs should be kept at high elevated secured position .
- Designated coloured containers should be provided for biomedical disposal.
- Staff members should be given proper training for disaster situation.
- Human resources should be strengthen to match IPHS guidelines.
- Provision of stairways with ramp will increase the ease of access for people.
- Area should be identified and assigned for triage.
- All escape routes should be marked.

Long-term

- Provision of stairways with ramp will increase the ease of access for people.
- Capacity of water storage tanks needs to be increased to cater to a atleast five days.
- Grouting need to be done for cracks >3mm.
- Electrical system like control panel should be placed in a secure, covered location.
- Rebars are excessively corroded hence detailed NDT is required.
- Damp proof coarse should be provided at the plinth level to avoid dampness.
- Trench can be constructed around the building to avoid inundation of water inside the building.
- Health center should plan and develop coordination mechanism with DDMA and local community including NGO's.

CHC

1. Pattamundai
2. Rajnagar

District: KENDRAPARA

General statistics:
Road width- 10'
Water body in vicinity- Yes (near 1 CHC)
Age of building- 5 (Min.) & 55 (Max.)
Population covered- 1,72,000 (Min.) & 1,98,000 (Max.)
Deliveries conducted- Yes (212 conducted in previous month)
Occupancy- 200 (Max.)
Roof accessibility- Yes (in 1 out of 5 building blocks)

INDICATORS

- **ACCESSIBILITY**
  - Site condition
  - Surrounding buildings
- **BUILDING INFRASTRUCTURE**
  - Layout
  - Structural elements
  - Condition of the building
  - Prior events affecting the building
- **CRITICAL SYSTEMS**
  - Water and sanitation
  - Electrical system
  - Biomedical waste
- **LOGISTICS**
  - Drug storage
- **STAFFING PERSONNEL**
  - Number of staff
  - Contact information
  - Disaster management
- **OPERATION AND MANAGEMENT**
  - Preparedness
  - Response

VULNERABILITY: LOW | MODERATE | HIGH

Key Findings

Structural

- Plinth of the buildings are lower than the past flood level.
- Building layout is irregular.
- Structural and non-structural building components are partially damaged.
- Dampness was evident across inner wall of the health facilities.
- Except one building unit of Pattamundai all other building are partially repaired.
- Damage to architectural elements were evident.
- Windows of Pattamundai health center are damaged, will fail to resist high speed wind and may not prevent water leakage.
- Obstacles were evident within passageway. These will not impede the movement of people but will impede movement of stretcher or wheeled equipment inside the building.

Non-Structural

- Staff in the facilities are less than essential number stipulated within IPHS guidelines and no staff member is trained for disaster situation.
- There is a hospital disaster committee but it is not fulfilling its functions effectively.
- Staff members are not aware of their disaster management duties and responsibilities.
- Limited signage for escape routes/ building layout diagram/assembly points were evident.
- Existing emergency sets were not complete.
- There is a directory of local resource people but information needs to be updated.
- Disease surveillance system is functioning as per their mandate.

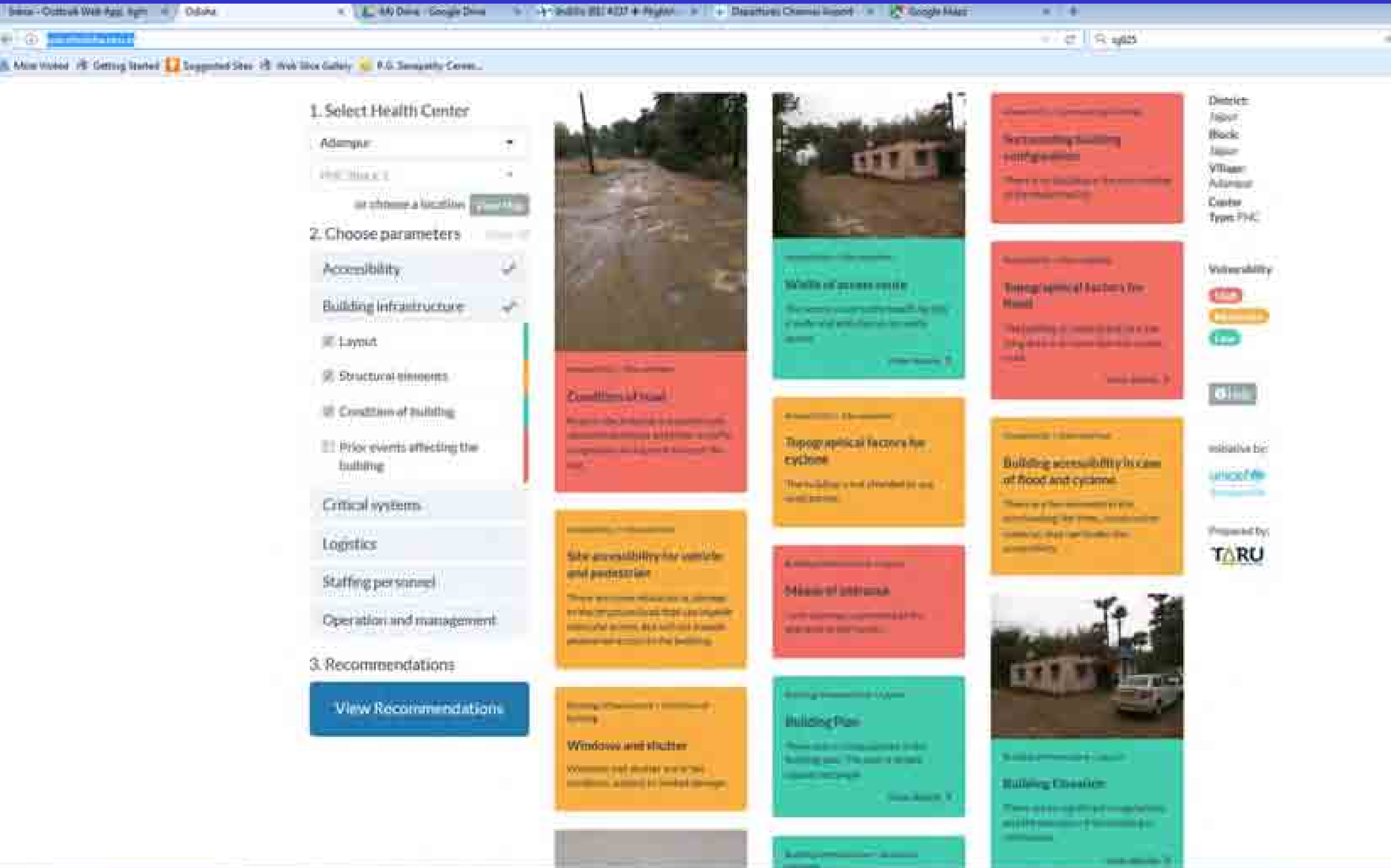
Key Recommendations

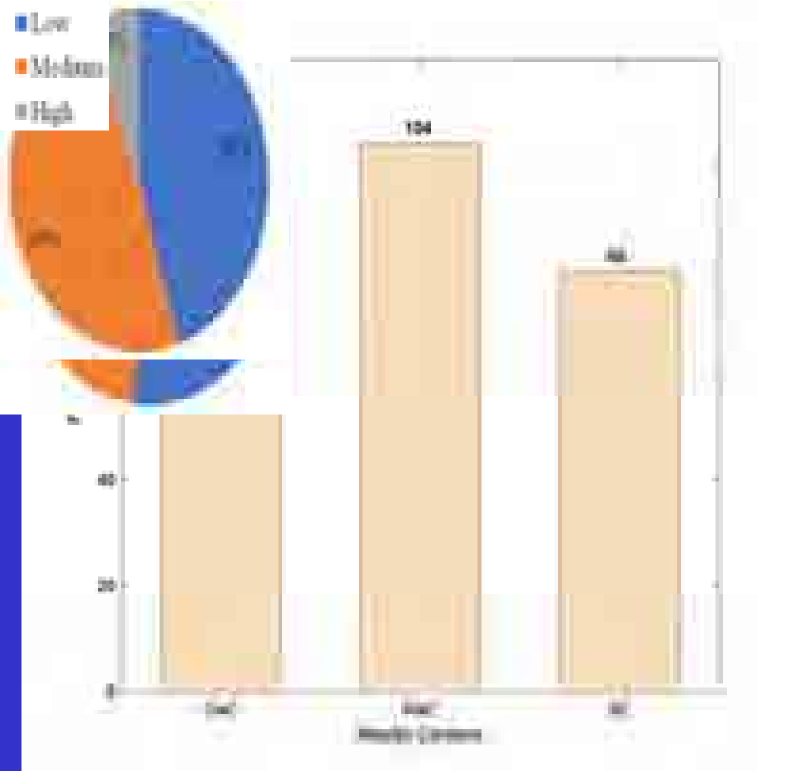
Short term

- Provision of ramps will increase the ease of access.
- Hair fine Cracks needs to be plastered.
- Minors repairs are needed for windows and shutter.
- Drugs should be kept at high elevated secured position.
- Staff members should be trained for disaster management.
- Covered storm water drainage system should be provided.
- Storage capacity of water tanks should be increased to cater to a minimum of five days.
- Septic tanks should be cleaned regularly.
- Markings for escape routes should be done across all facilities.

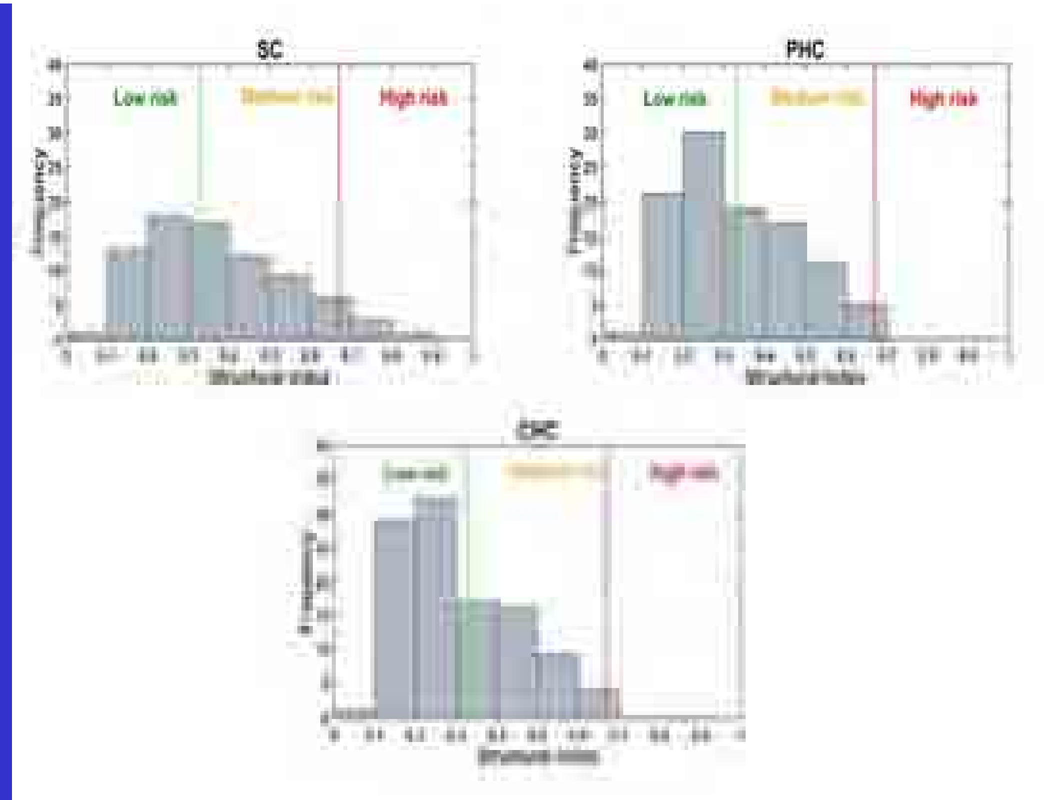
Long term

- Grouting need to be done for cracks >3mm.
- Damp proof coarse should be provided at the plinth level to avoid dampness.
- A cement concrete layer should be overlaid to strengthen the slab.
- Damaged panels of the false ceiling needs to be replaced.
- Thick designed glass panes with smaller panel dimension should be used for windows.
- Location for triage should be identified and informed to staff members.


1. Select Health Center
Adampur
or choose a location
2. Choose parameters
Accessibility
Building infrastructure
Layout
Structural elements
Condition of building
Prior events affecting the building
Critical systems
Logistics
Staffing personnel
Operation and management
3. Recommendations
View Recommendations
Condition of road
Width of access route
Surrounding building configuration
Topographical factors for flood
Topographical factors for cyclone
Building accessibility in case of flood and cyclone
Site accessibility for vehicle and pedestrian
Means of entrance
Windows and shutter
Building Plan
Building Elevation
District:
Block:
Village:
Adampur
Center Type: PHC
Vulnerability
Initiative by:
Prepared by:
TARU

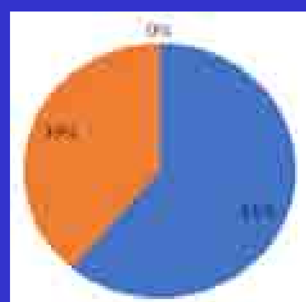


Histogram of the heath centers considered for rapid visual screening

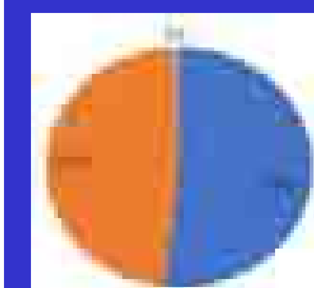


Histogram of Structural index

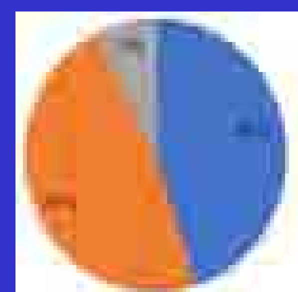
CHC



PHC

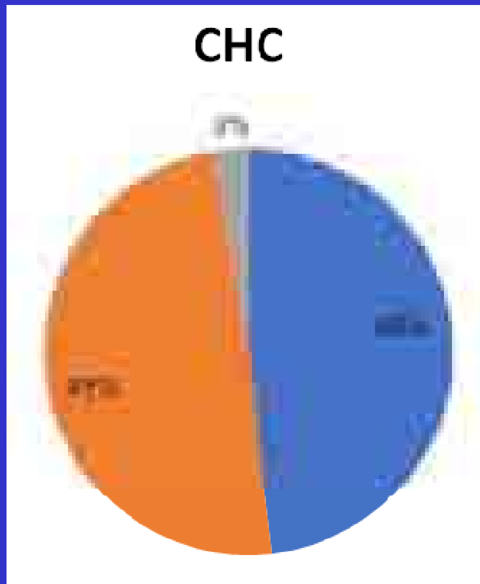


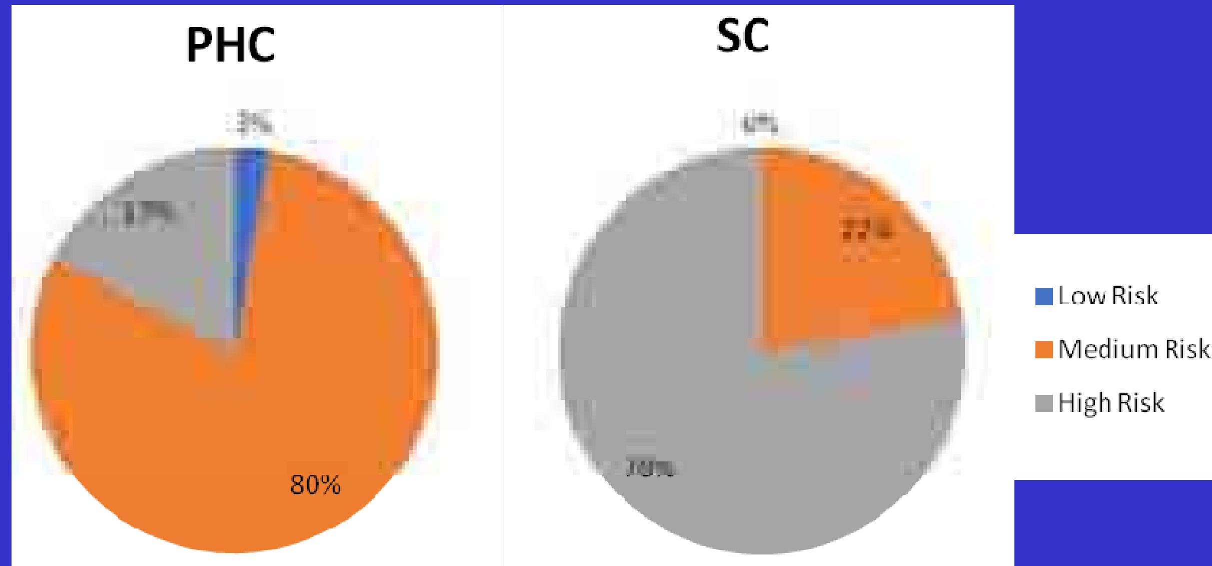
SC



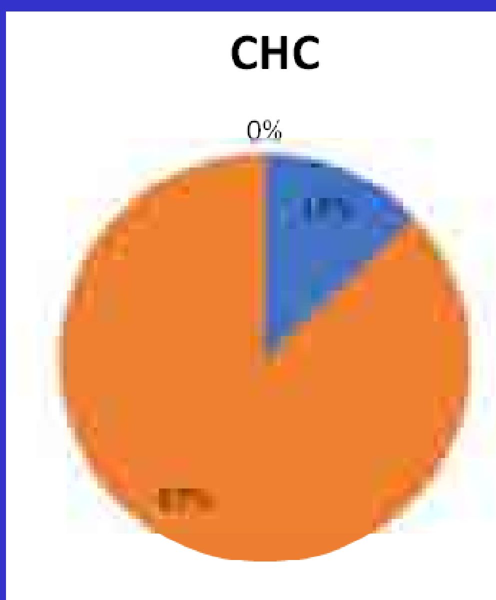
Histogram representing the percentage of Structural risk for different health centers

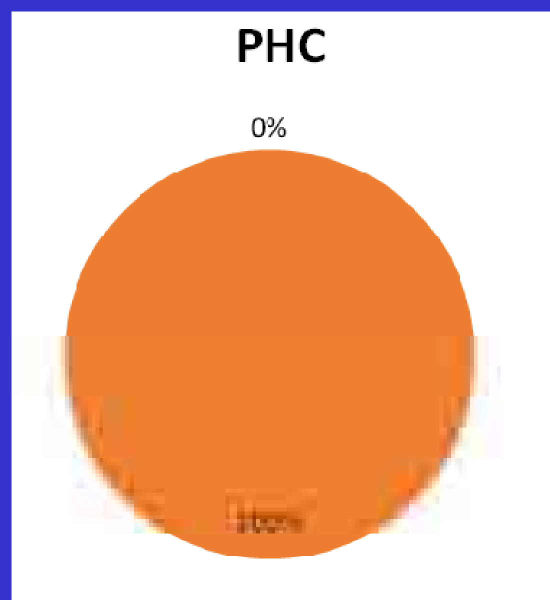
Non-Structural Index

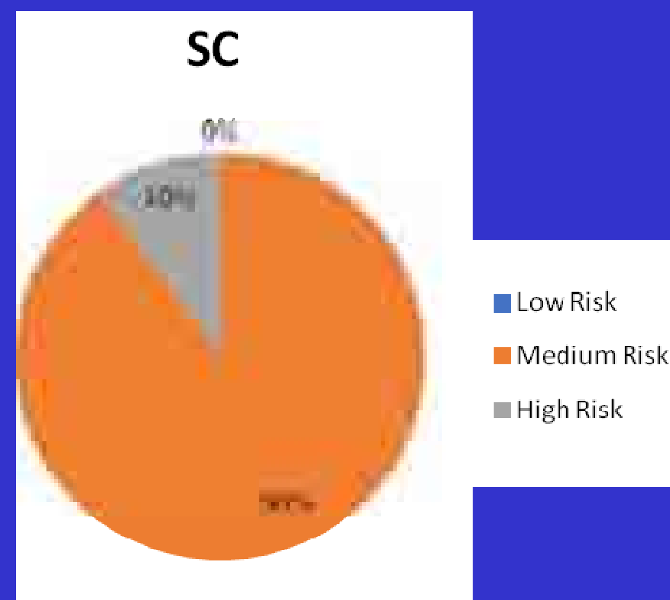




Organizational Index







Index of Vulnerability

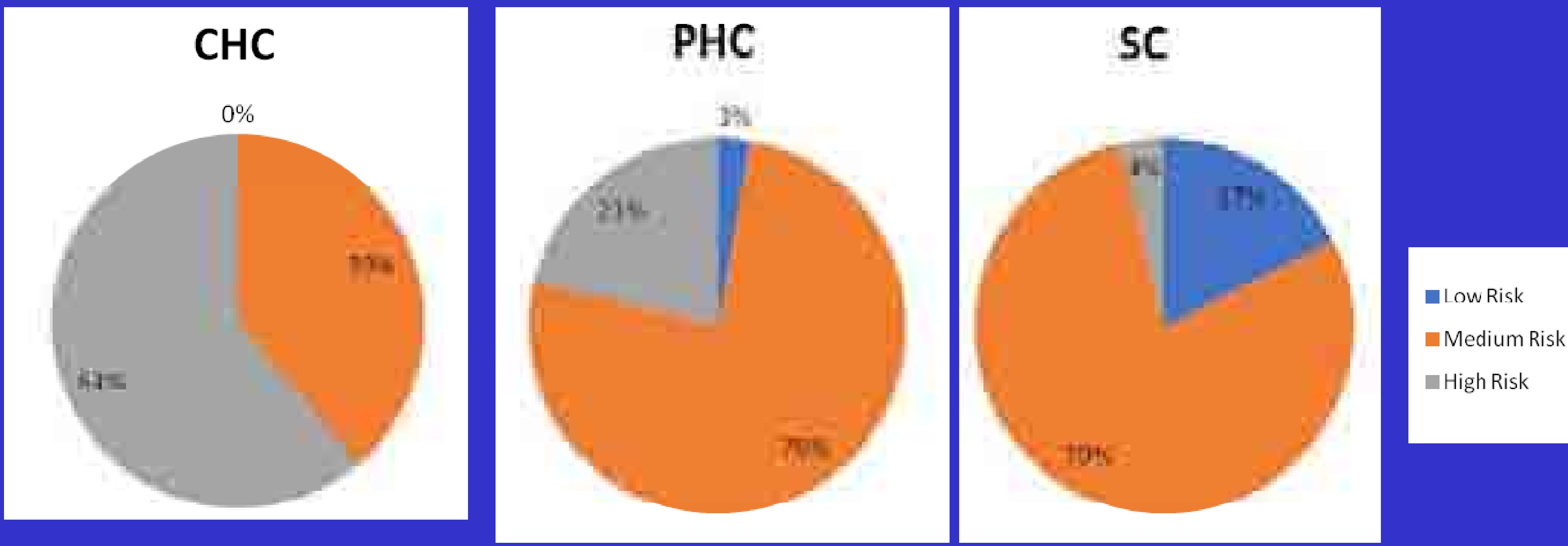
$$FUNC = \begin{cases} [1-(0.6\, I_{STR} + 0.4 I_{NSTR})] & \text{if } I_{STR} \le 0.67 \\ 0 & \text{if } I_{STR} > 0.67 \end{cases}$$

$$VULN = \begin{cases} [0.8-(0.8\, FUNC - 0.2 I_{ORG})] & \text{if } FUNC \ne 0 \\ 1 & \text{if } FUNC = 0 \end{cases}$$

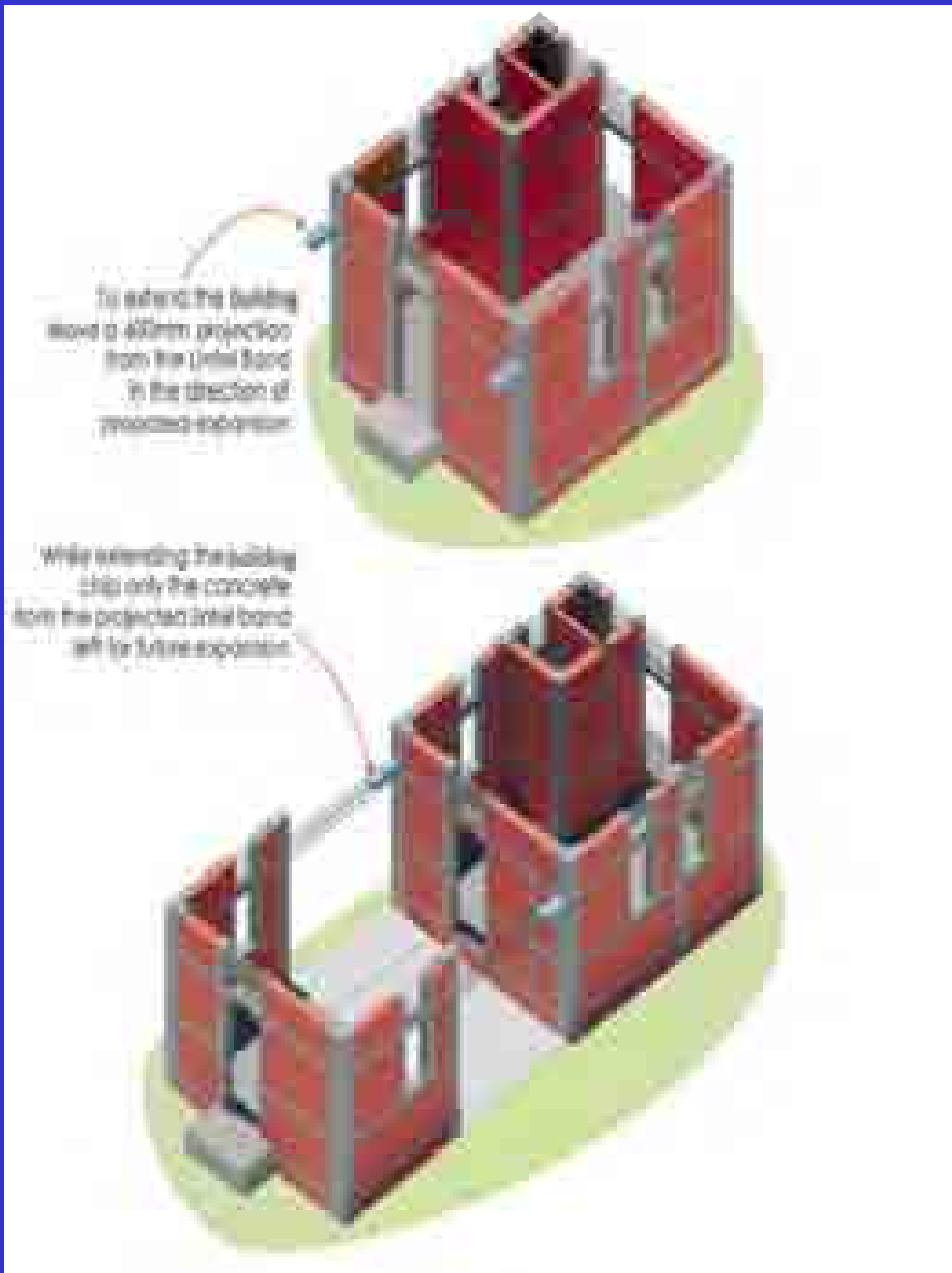
WHO CLASSIFICATION

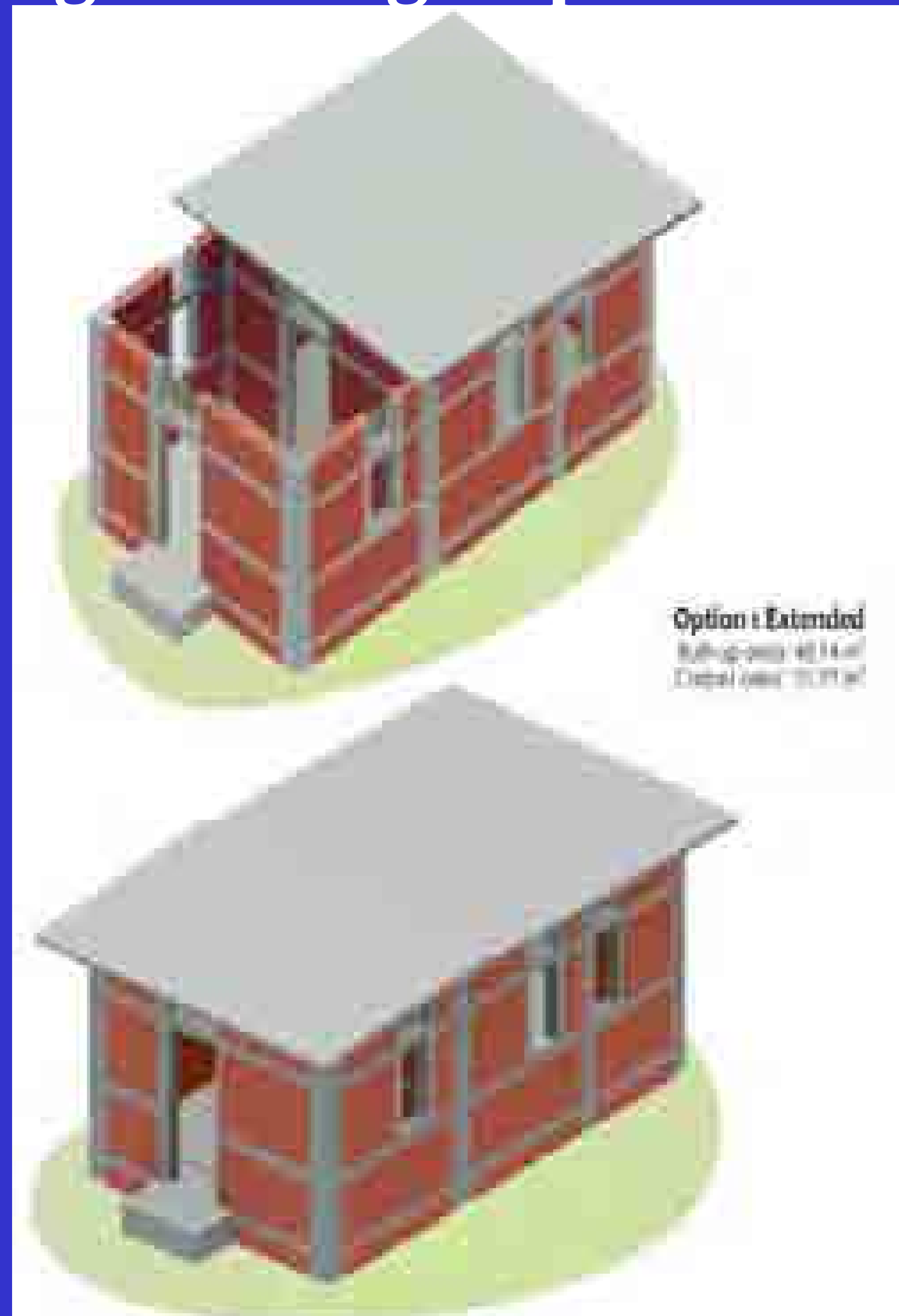
Safety index	Classification	What should be done?
0 – 0.35	C	Urgent intervention measures are needed. The hospital's current safety levels are inadequate to protect the lives of patients and hospital staff during and after a disaster.
0.36 – 0.65	B	Intervention measures are needed in the short-term. The hospital's current safety levels are such that patients, hospital staff, and its ability to function during and after a disaster are potentially at risk.
0.66 – 1	A	It is likely that the hospital will function in case of a disaster. It is recommended, however, to continue with measures to improve response capacity and to carry out preventive measures in the medium- and long-term to improve the safety level in case of disaster.

Safety Index



How to extend the existing building- Option 1





Summary

1. Seismic hazard assessment of India
2. Tsunami Hazard map of India (in Progress)
3. RVS of hospital buildings in Odisha

Acknowledgement

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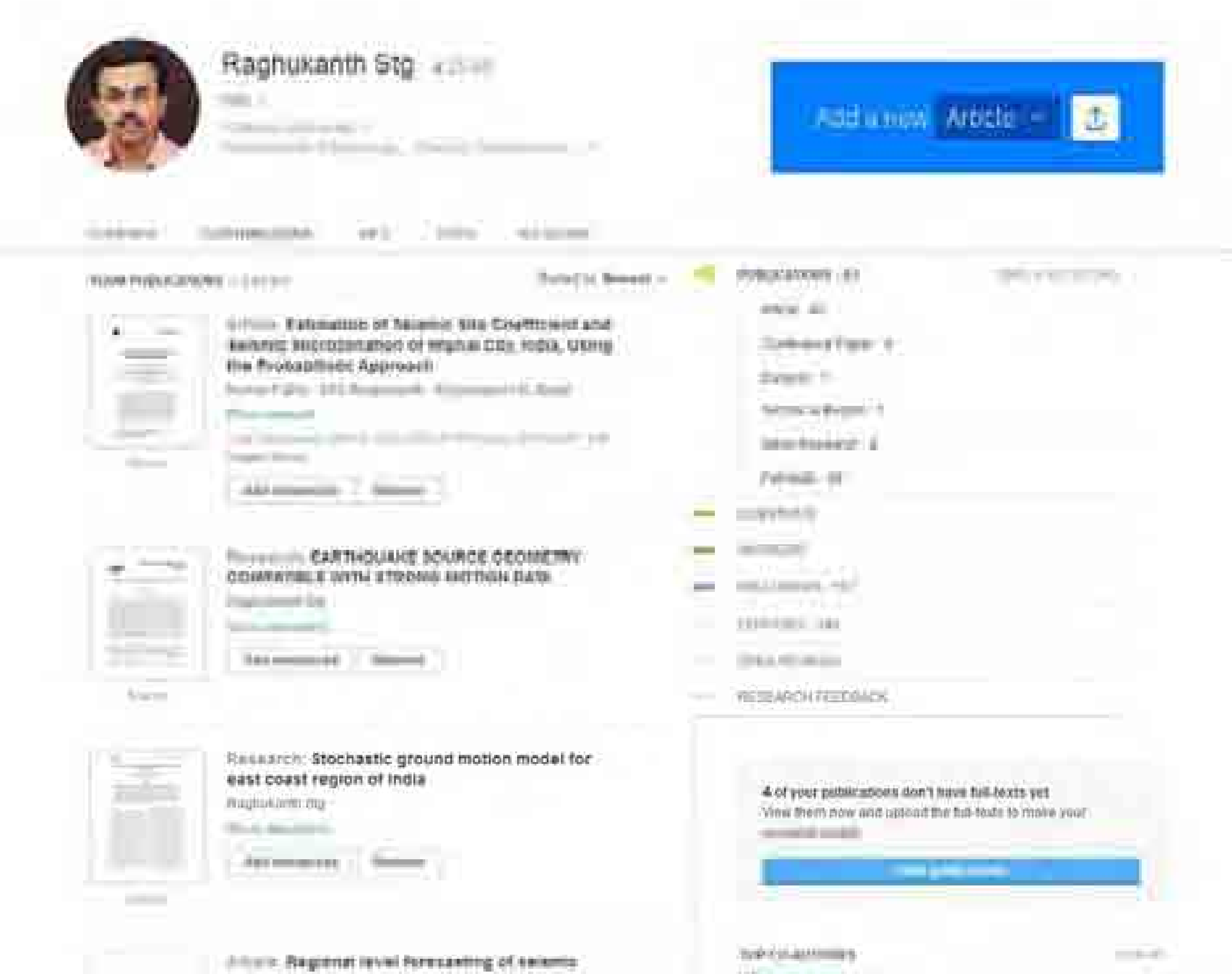
Bhargavi (MS)
Saikat Bagchi (MS)



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