Earthquake Hazards in India and Mitigation Methods

Prof.T.G.Sitharam
Department of Civil Engineering
Indian Institute of Science
Bangalore - 560012
URL: http://civil.iisc.ernet.in/~sitharam

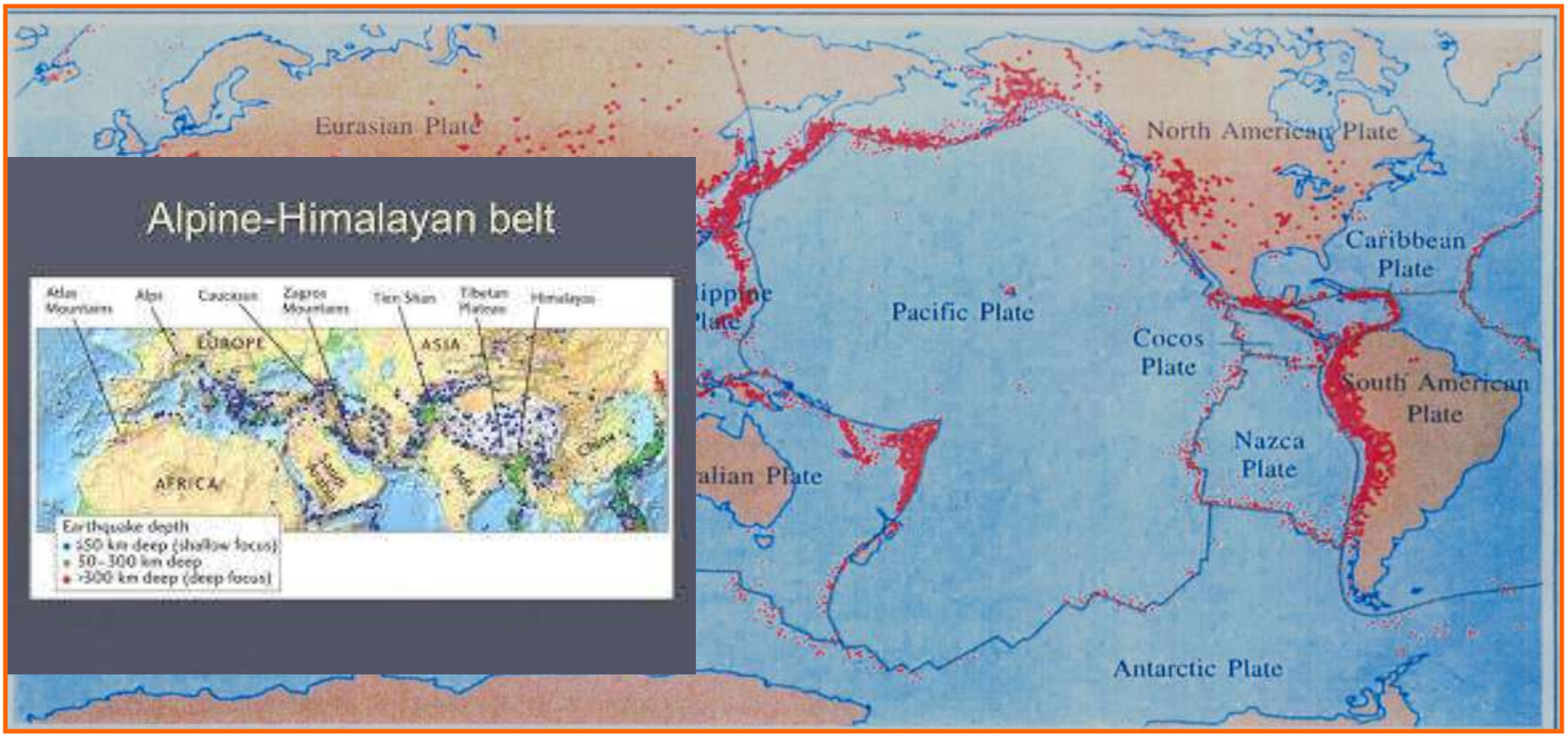
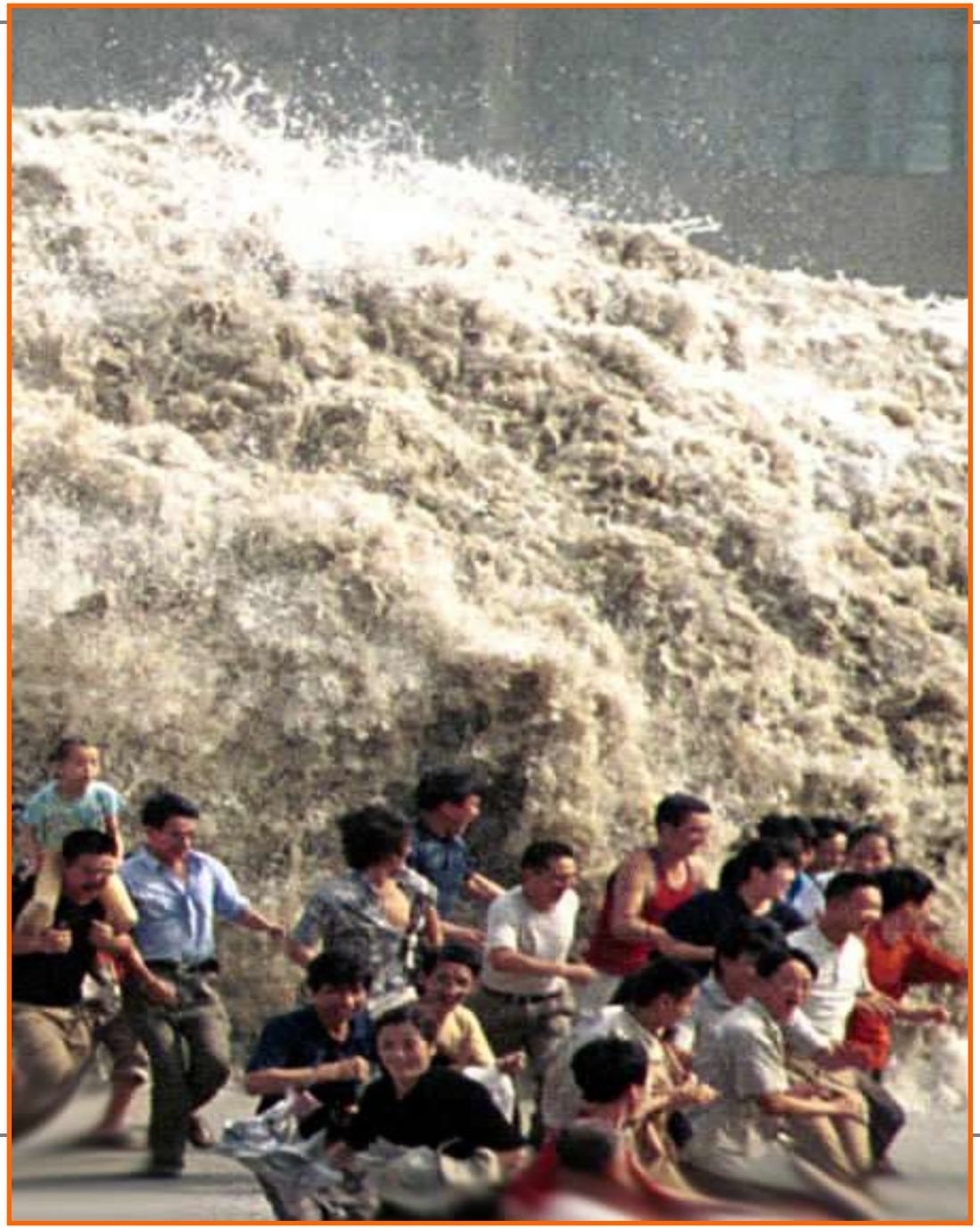


Diagram showing the distribution of earthquakes and major plate boundaries. It may be noted that globally, more than 75% of earthquake energy is released in the circum-Pacific belt, about 20% in the Alpine-Himalayan belt, and remaining 5% through the mid-oceanic ridges and other Stable Continental Region earthquakes.

SUMATRA EARTHQUAKE

- **26th DECEMBER 2004** **06 Hours 29 Minutes of IST**
- **Mw 9.3** **Latitude: 3.7 degree North**
- **Longitude: 95.0 degree East --**
  Off west coast of Sumatra Island (Indonesia)
- **GIGANTIC TSUNAMI**
- **HUMAN LIVES LOST ~ 300,000**
- **ECONOMIC LOSS - NO RELIABLE ESTIMATES MAY BE IN EXCESS OF 100 US B $**




Banana
DANCE THE NIGHT


Marina Beach, Chennai


Marina Beach, Chennai


Marina Beach, Chennai

Marina Beach, Chennai


Marina Beach, Chennai

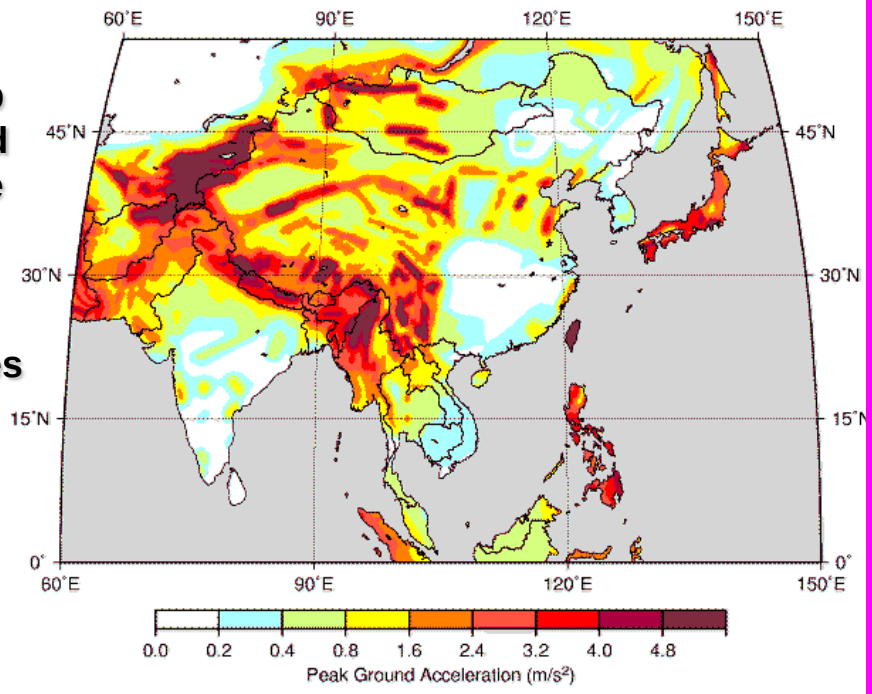

Kanyakumari

Earthquake Hazards in India

- India has a long history of earthquake occurrences.
  - About 65% of the total area of the country is vulnerable to seismic damage of buildings in varying degrees.
  - Most vulnerable areas - the Himalayan and sub-Himalayan regions, Kutch and the Andaman and Nicobar Islands.

Seismic regions:

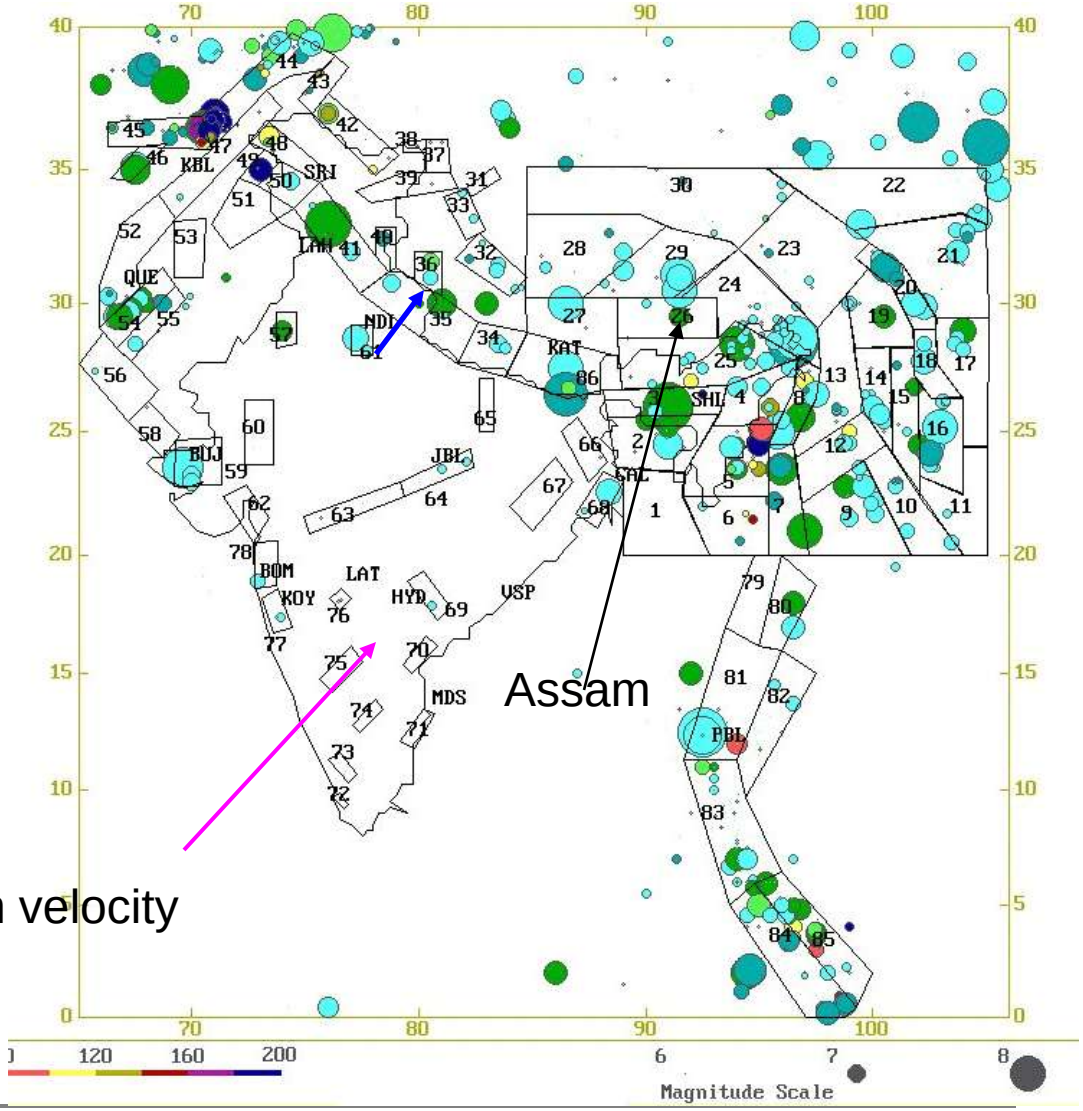
1. **Kashmir and Western Himalayas - Covers the states of Jammu and Kashmir, Himachal Pradesh and sub-mountainous areas of Punjab**
2. **Central Himalayas - Includes the mountain and sub-mountain regions of Uttar Pradesh and the sub-mountainous parts of Punjab**
3. **North-east India - Comprises the whole of Indian territory to the east of north Bengal**
4. **Indo-Gangetic basin and Rajasthan - comprises of Rajasthan, plains of Punjab, Haryana, Uttar Pradesh and West Bengal**
5. **Cambay and Rann of Kutch**
6. **Peninsular India, including the islands of Lakshwadeep**
7. **The Andaman and Nicobar Islands**



Earthquakes in India

Global Seismic Hazard Assessment Program (GSHAP)

- Collision of India with Asia
  - region of greatest continental tectonic deformation in the world
- 15% of great earthquakes (M 8.0) in the 20th Century
- Assam EQ =8.5 – 7th largest
- Major earthquakes are at plate boundaries, intraplate, and along known faults



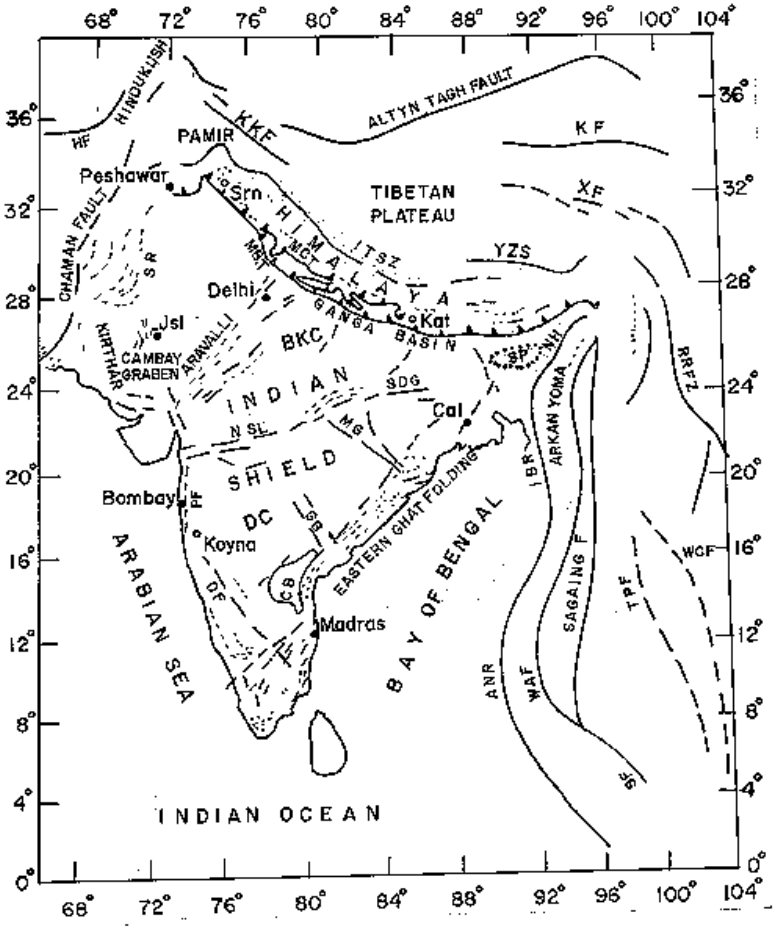
Seismic sources

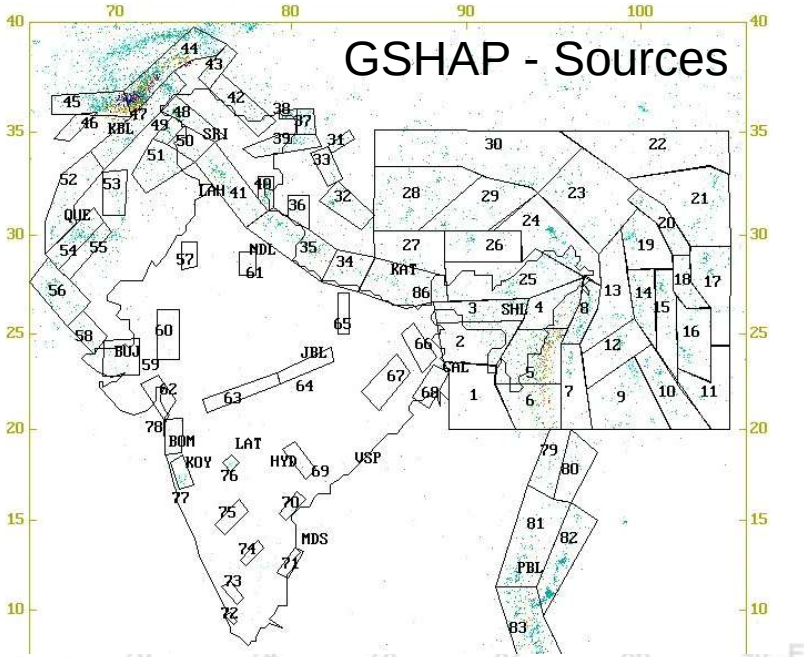
List of Major Earthquakes in India in the last 100 years

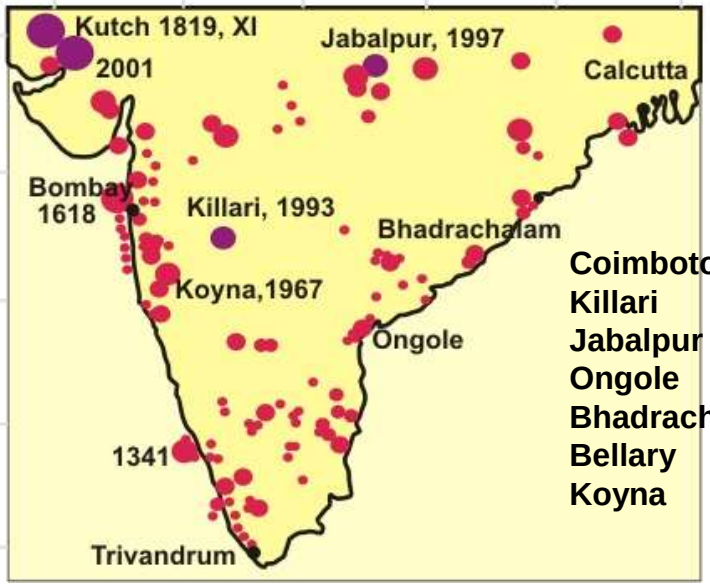
Date	Event	Time	Magnitude	Max. Intensity	Deaths
12 June 1897	Assam	16:25	8.7	XII	1500
8 Feb. 1900	Coimbatore	03:11	6.0	X	Nil
4 Apr. 1905	Kangra, Himachal Pradesh	06:20	8.6	X	19,000
15 Jan. 1934	Bihar-Nepal	14:13	8.4	X	11,000
31 May 1935	Quetta	03:03	7.6	X	30,000
15 Aug. 1950	Assam	19:31	8.5	X	1,530
21 Jul. 1956	Anjar	21:02	7.0	IX	115
10 Dec. 1967	Koyna	04:30	6.5	VIII	200
23 Mar. 1970	Bharuch	20:56	5.4	VII	30
21 Aug. 1988	Bihar-Nepal	04:39	6.6	IX	1,004
20 Oct. 1991	Uttarkashi, Uttranchal	02:53	6.6	IX	768
30 Sep. 1993	Killari (Latur)	03:53	6.4	IX	7,928
22 May 1997	Jabalpur, Madhya Pradesh	04:22	6.0	VIII	38
29 Mar. 1999	Chamoli, Uttranchal	12:35	6.8	VIII	63
26 Jan. 2001	Bhuj, Gujarat	08:46	7.7	X	13,805
08 Oct 2005	India-Pakistan	09.20	7.4	X	20,600

EQ's happened both at plate boundaries, intra plate and known faults (even in the shield region)

Peninsular India



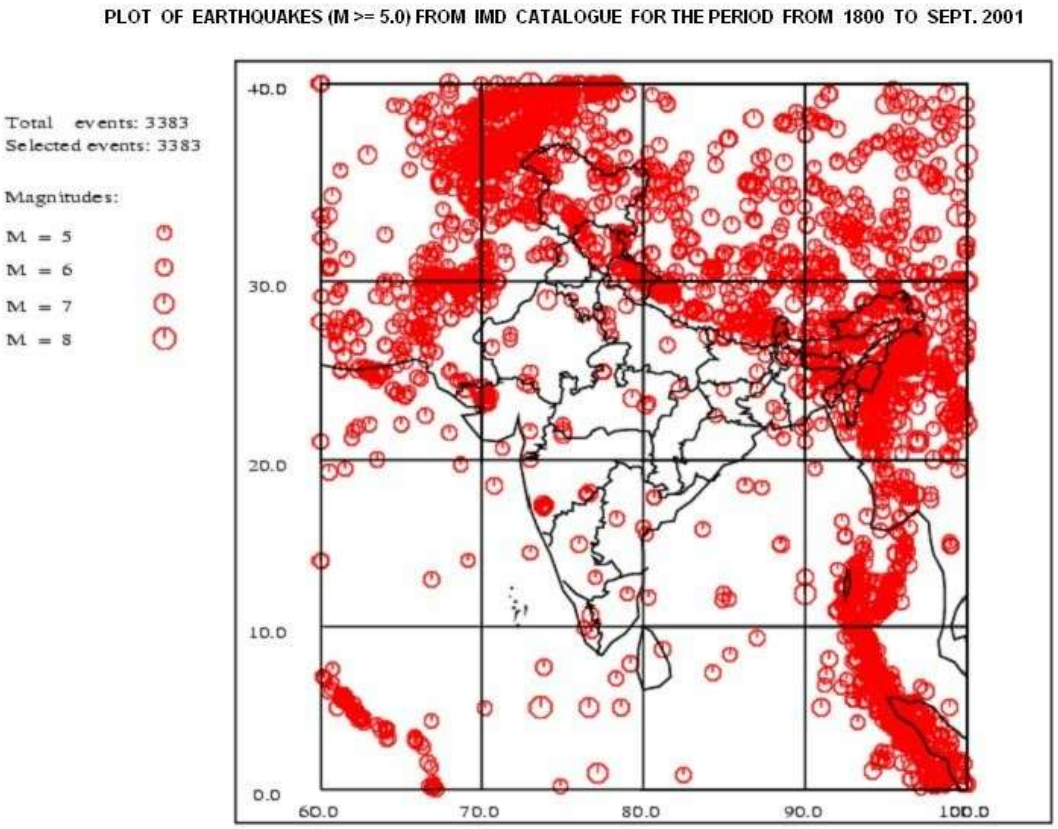




Shield regions also generate earthquakes, much less frequently and of smaller magnitude, the activity occurring on paleorifts and other pre-existing structures.

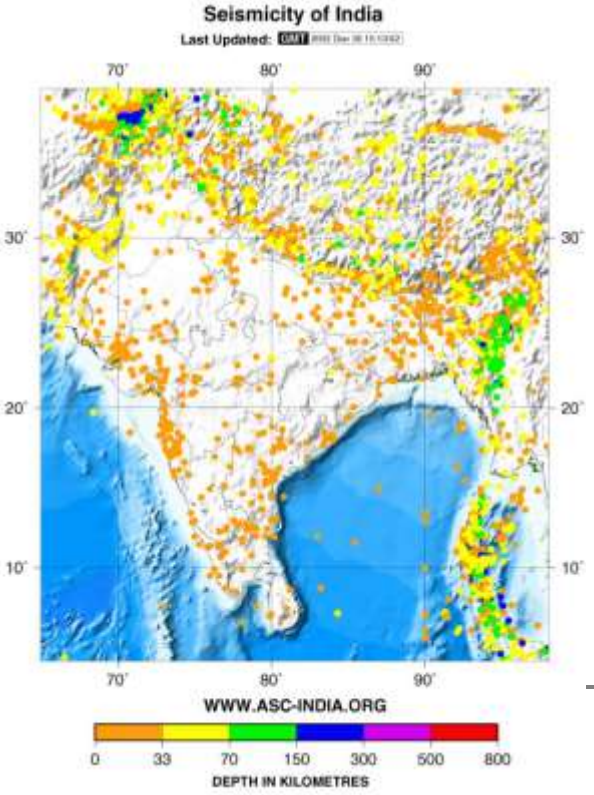
Historic seismicity in peninsular India →

Recent Seismicity of Southern India



This region has experienced many EQ of magnitudes Mw 6.0
-Ramalingeshwara Rao (1998)

Mahebaleshwawar (1764)
Kutch (1819)
Damooh Hill (near Jabalpur) 1846
Mount Abu (1848)
Coimbatore (1900)
Son-Valley (1927)
Satpura (1938)
Jabalpur (1997)
Koyna 1967 – 6.3 (RIS)
Latur 1993 – Mw 6.1



Major Hazards of Earthquakes

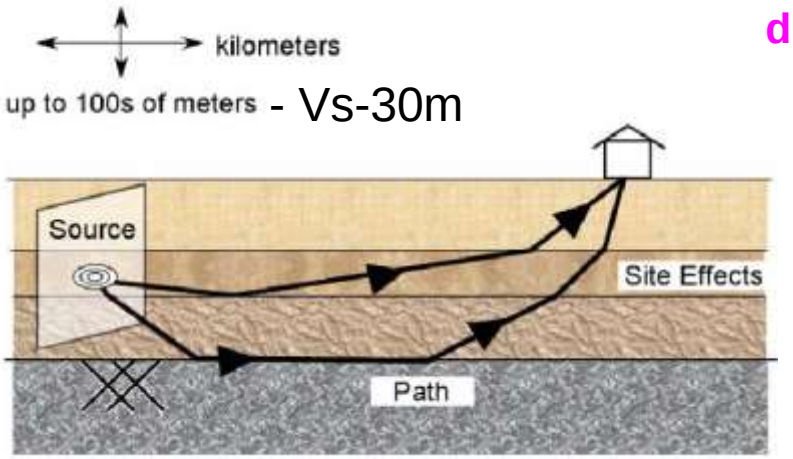
- Ground Shaking
- Liquefaction
- Landslides
- Tsunamis

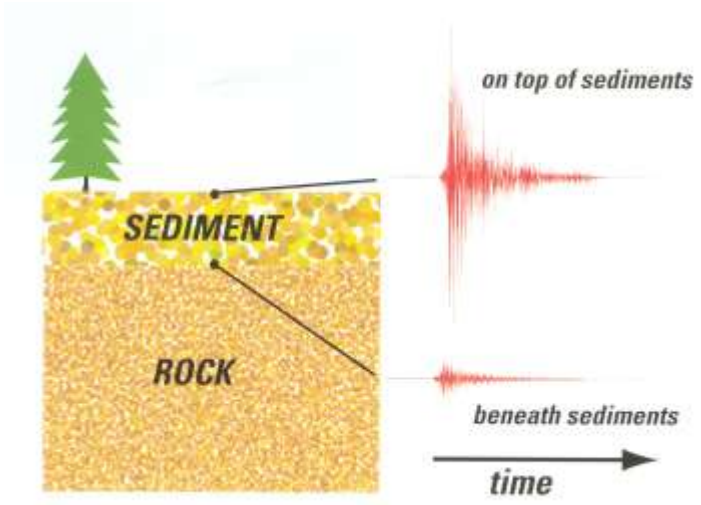
Damages due to Ground Shaking

- Structural damage due to Inertia force during intense ground shaking
  - Frequency matching leading to resonance

Local Site Effects

Modification of the incoming wave field characteristics (amplitude, frequency, duration) due to soil characteristics and topography.





✓Seismic action at bed rock level

- ✓depends on the magnitude, source properties and properties of the path medium.
- ✓ Convolution of the input motion at the bed rock with the response of the upper soil layers will give surface result (Site conditions)
  - ✓ 1D representation with horizontal layers characterized by thickness and Vs-30m (geotechnical properties)
  - ✓ Field experiments – Ambient noise survey with reference sites

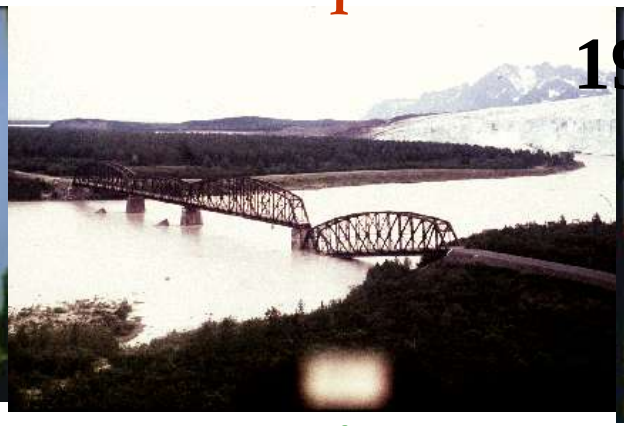
- 2D and 3D geometry, with linear and non-linear constitutive relations, topographical implications, etc influence the results

✓ Wave amplification in sediment layer

✓ Wave amplification due to Local topography

Damages due to local site effects and liquefaction in earthquakes

Earthquake Damage in Mexico City, Mexico, September 19, 1985 - resonance



Million Dollar Bridge after 1964 Alaska earthquake

Showa Bridge after 1964 Niigata earthquake

Building in Kobe after 1995 earthquake

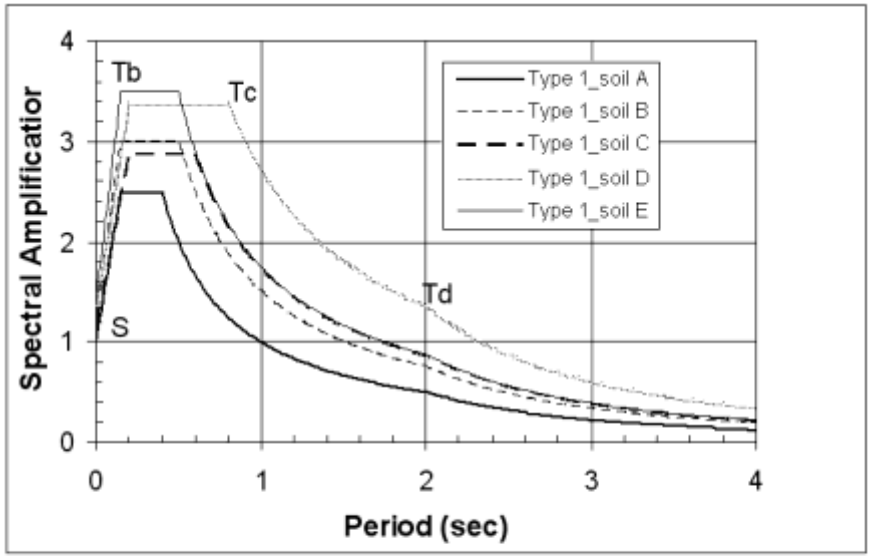
Bridge in Taiwan after 1999 Chi-Chi earthquake

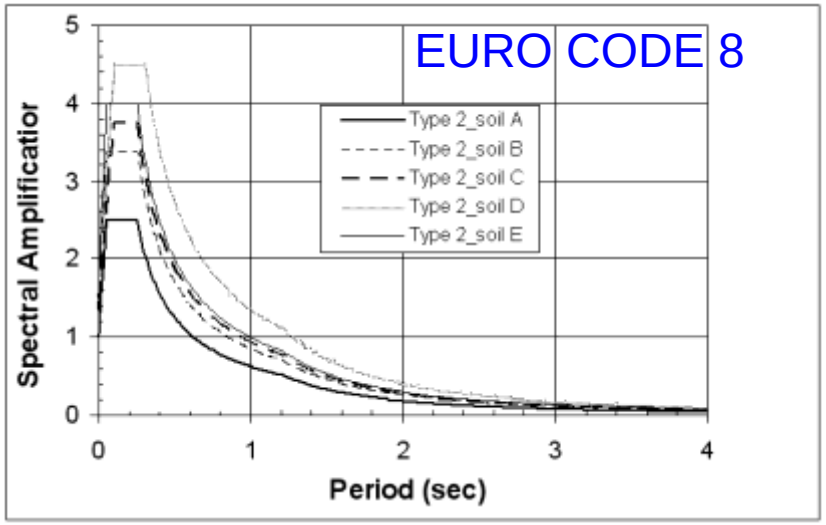
Kandla port building after 2001 Bhuj earthquake

The effect of the subsoils on the earthshaking and building damage is emphasized.

The issue of site response – codes

Based on classification of subsoil – Vs 30 or N or Cu (kPa)





EC8-00 TYPE 1	S	Tb	Tc	Td
soil A Vs > 800 m/s	1,00	0,15	0,4	2,0
soil B 360<Vs<800 m/s	1,10	0,15	0,5	2,0
soil C 180<Vs<360 m/s	1,35	0,20	0,6	2,0
soil D Vs < 180 m/s	1,35	0,20	0,8	2,0
soil E (h < 20 m)	1,40	0,15	0,4	2,0

Type 1- Mw > 5.5

EC8-00 TYPE 2	S	Tb	Tc	Td
soil A Vs > 800 m/s	1,0	0,05	0,25	1,2
soil B 360<Vs<800 m/s	1,2	0,05	0,25	1,2
soil C 180<Vs<360 m/s	1,5	0,10	0,25	1,2
soil D Vs < 180 m/s	1,8	0,10	0,30	1,2
soil E (h < 20 m)	1,6	0,05	0,25	1,2

Type 2- Mw < 5.5

- ✓ Ground motion in terms of response spectra for each soil class
- ✓ Five different classes are generally considered (A, B, C, D, E)
- ✓ Supported by strong motion data recorded at the surface of soils
- ✓ Average Vs for top 30m

IS 1893 2002
Considers 3 types- Rock, medium soil and soft soils

Mitigation of Earthquakes

- Damaging EQs will continue to occur in the Circum Pacific and Alpide Himalayan belt.
- EQ forecast not yet possible
- Areas prone to EQ and damage scenarios are known
- Suitable building codes need to be developed.
- Building codes exist for several countries. Their implementation should be made mandatory
- Retrofit important buildings, located in zones of high seismicity.
- Microzonation of important cities of the country is a must.

ESTIMATING RISK OF EARTHQUAKE DISASTER

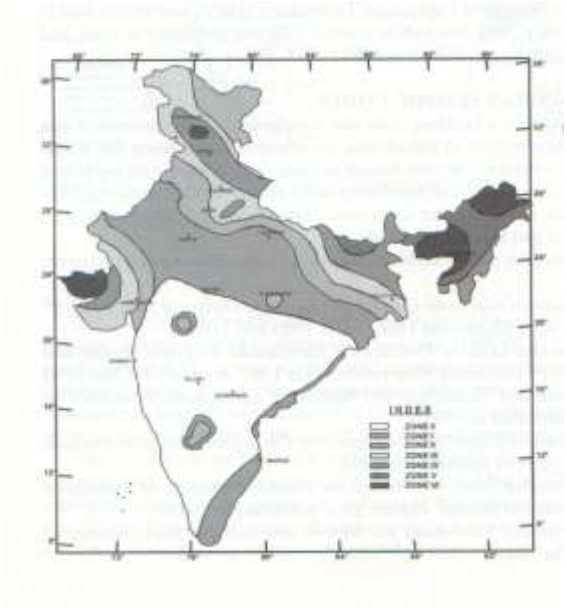
- ***Seismic Risk***
  - ***Intensity at the epicenter (hazard),***
  - ***Objects and structures (exposure),***
  - ***Damageability (vulnerability),***
  - ***how far from the source and type of topography, soil deposits, water table (local site effects) – evaluation of local hazard***
- ***Reduction of vulnerability of our buildings and other structures, those existing and those being built or to be built, is the key to earthquake protection.***
- **It is here, the engineers have their most critical role to play.**

Microzonation is an important component of earthquake disaster risk management framework

India's urban and semi-urban centers hazard assessment -considering local site effects is Important

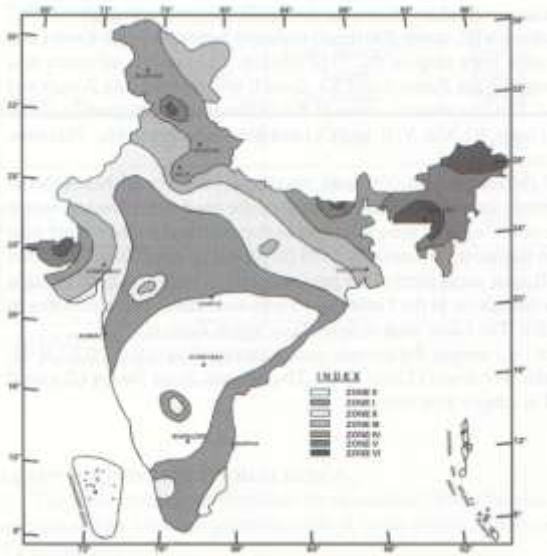
Development of Seismic Zonation Map (BIS-1893)

1962



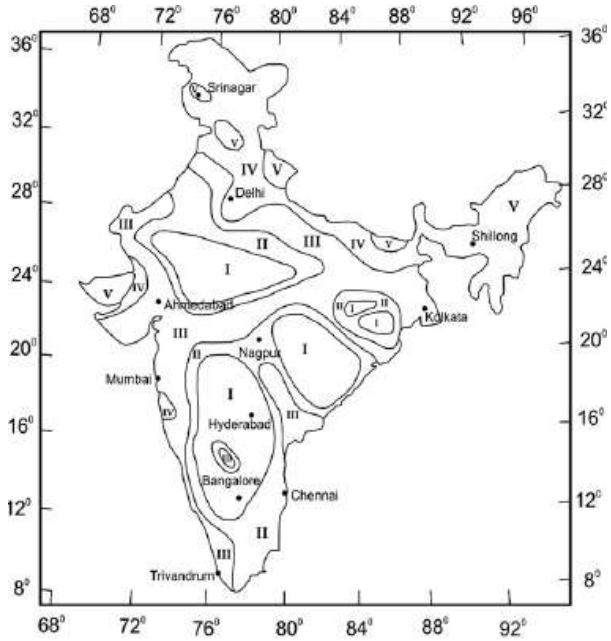
Based on EQ epicenters

1966



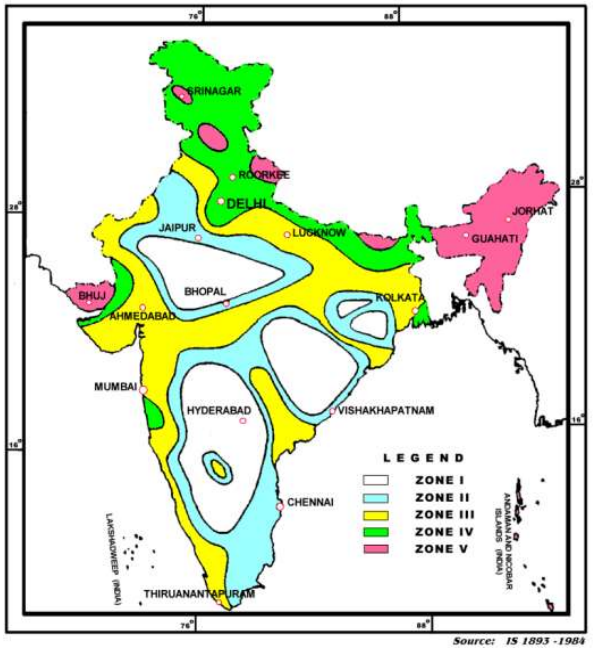
Geology and tectonic features

1970



After 1967 Koyna Earthquake.

1984

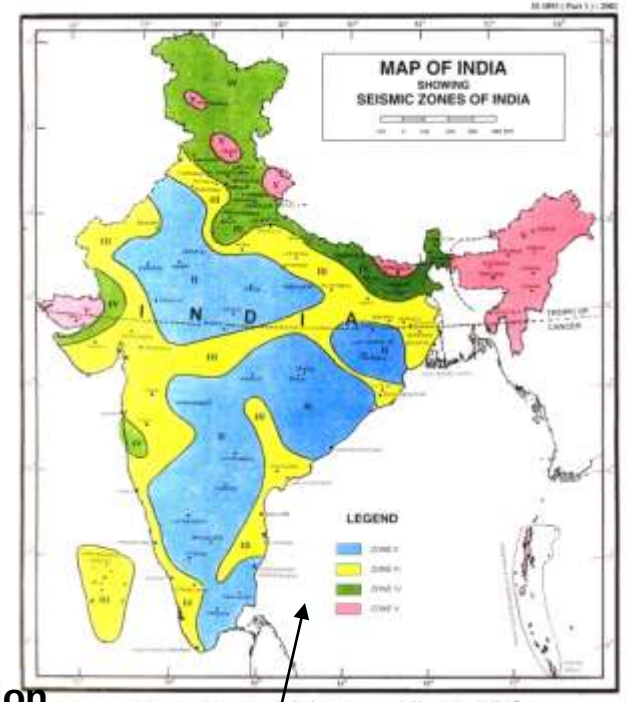


Past EQs and Regional tectonics.

Mitigation Strategies to reduce EQ Damages

- To Reduce Earthquake Disasters

1. Understand the origins and forces caused by earthquakes- Assessment of seismic hazard
   - ❑ **Microzonation of a region.**
2. Understand the behavior of structures under seismic action
3. Know how to design buildings to prevent non-structural damage.
4. Put that knowledge into practice- retrofit and rehabilitation of existing structures
   - ❑**Development of appropriate code of practice**
   - ❑ **Development of quality control to insure correct application**
   - ❑ **Legislation**

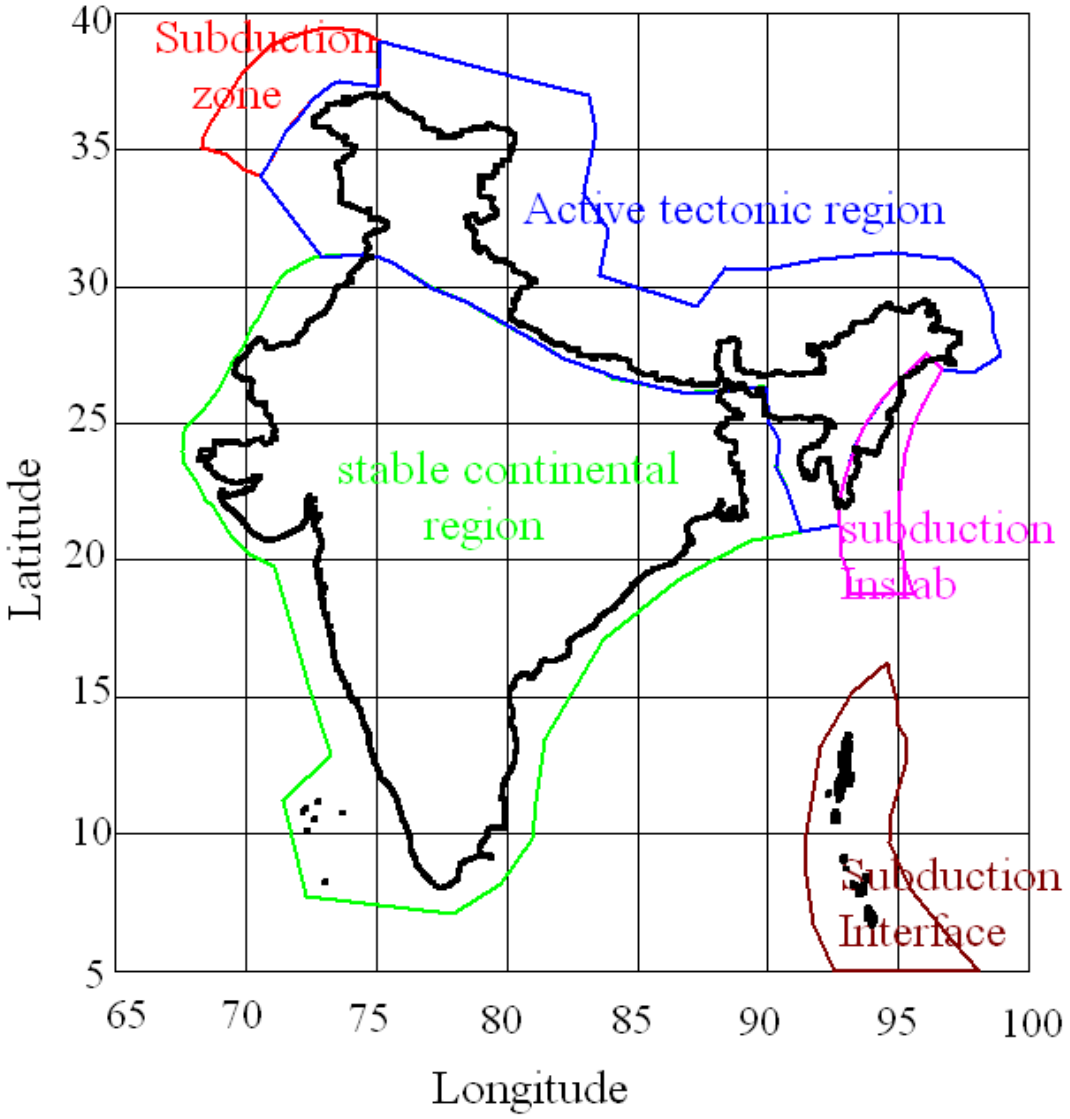


▪ Buildings codes base seismic design forces on intensity of shaking during an earthquake. Design parameters are: Acceleration, velocity or spectral acceleration with a specified probability of exceedance. Mapping of these parameters on a national scale is called as MACROZONATION

-Macrozonation are at small scales

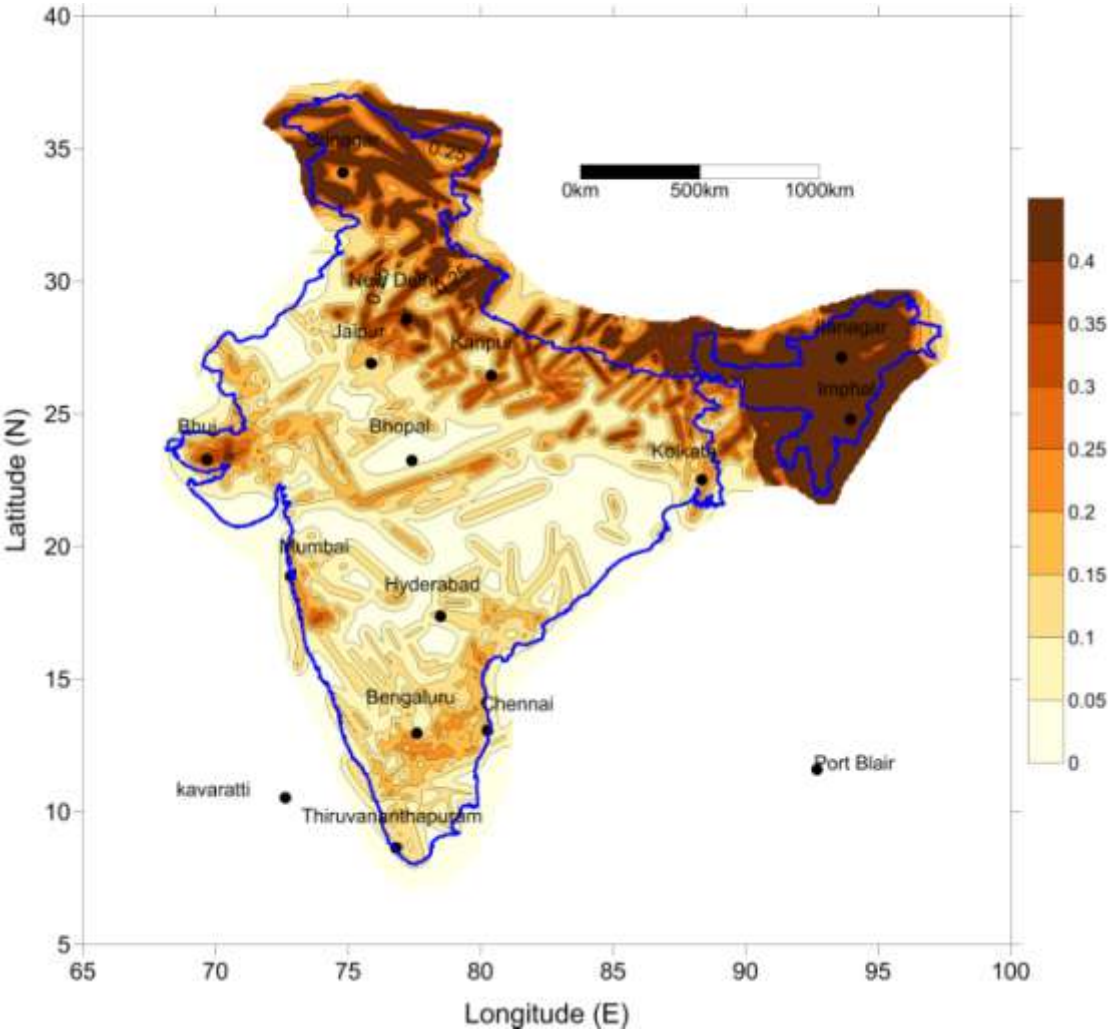
Scale is in important issue: 1: 25000 or less for microzonation

Seismicity of Indian Region



Tectonic provinces in and around India (After Sreevalsa and Sitharam, 2011)

SEISMIC HAZARD IN THE CONTEXT OF ENGINEERING DESIGN IS DEFINED AS THE PREDICTED LEVEL OF GROUND ACCELERATION WHICH WOULD BE EXCEEDED WITH 10% PROBABILITY AT A SITE UNDER CONSIDERATION DUE TO OCCURRENCE OF AN EARTHQUAKE ANYWHERE IN THE REGION, IN THE NEXT 50 YEARS.



PHA values for India corresponding to a return period of 475 years (10% probability of exceedence in 50 years) estimated using Linear sources

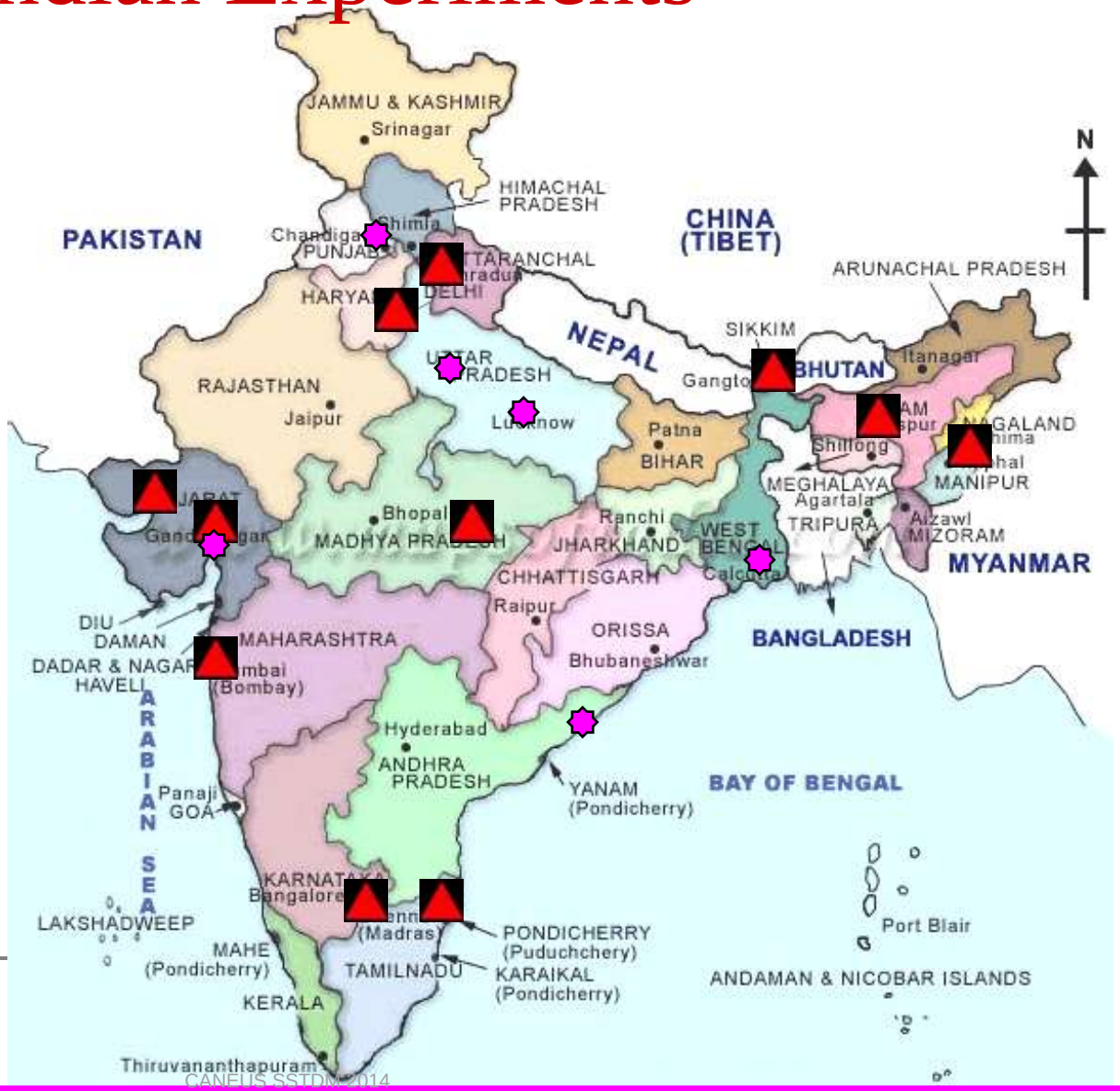
Sreevalsa and Sitharam, 2012

Microzonation Levels with Scale

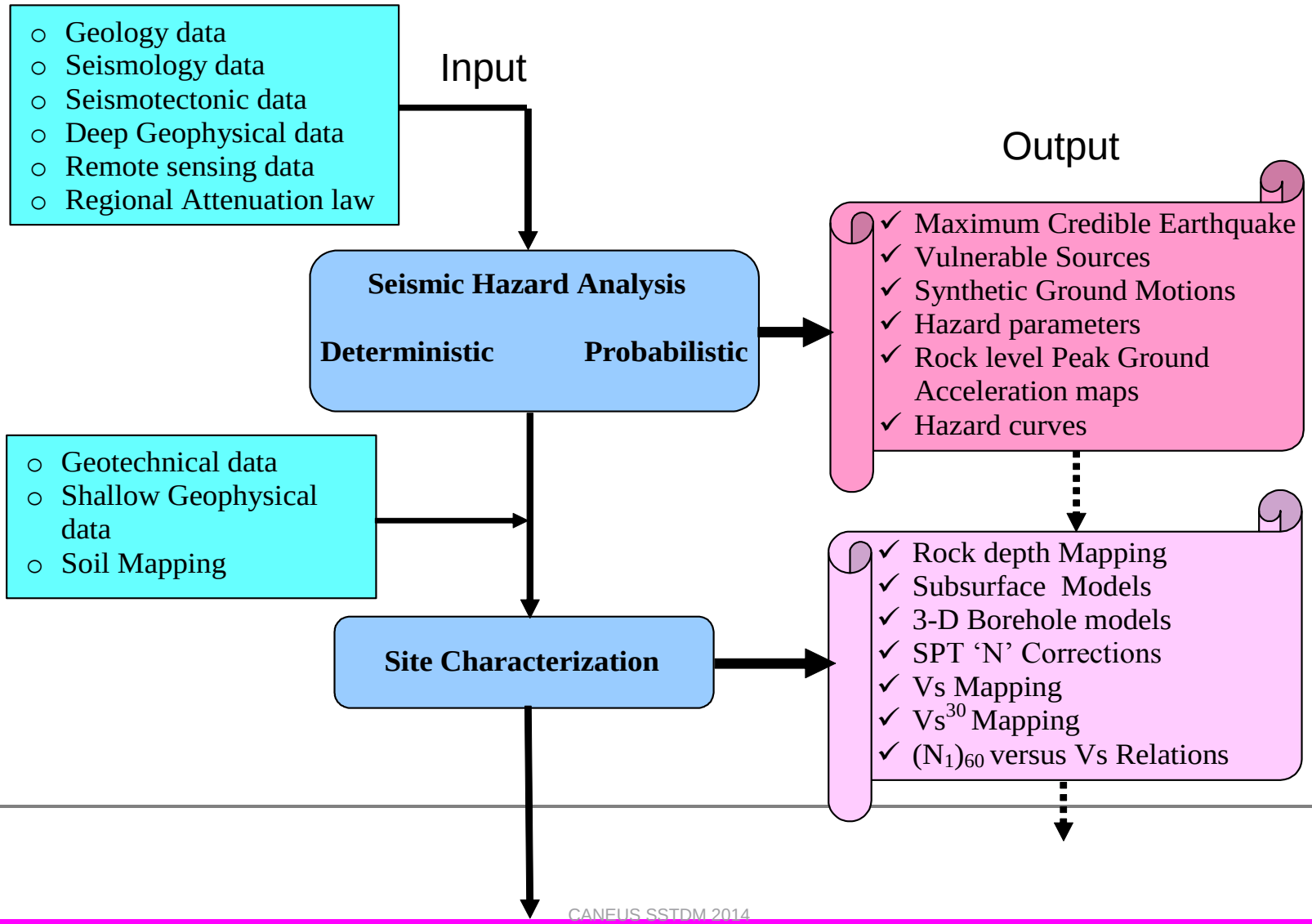
- ✓ First grade (Level I) map - with scale of 1:1,000,000 – 1:50,000 Ground motion was assessed based on the Historical earthquakes and existing information of geological and geomorphological maps.
- ✓ Second grade (Level II) map - with scale of 1:100,000-1:10,000 Ground motion is assessed based on the microtremor and simplified geotechnical studies
- ✓ Third grade (Level III) map-with scale of 1:25,000-1:5,000 ground motion has been assessed based on the complete geotechnical investigations and ground response analysis

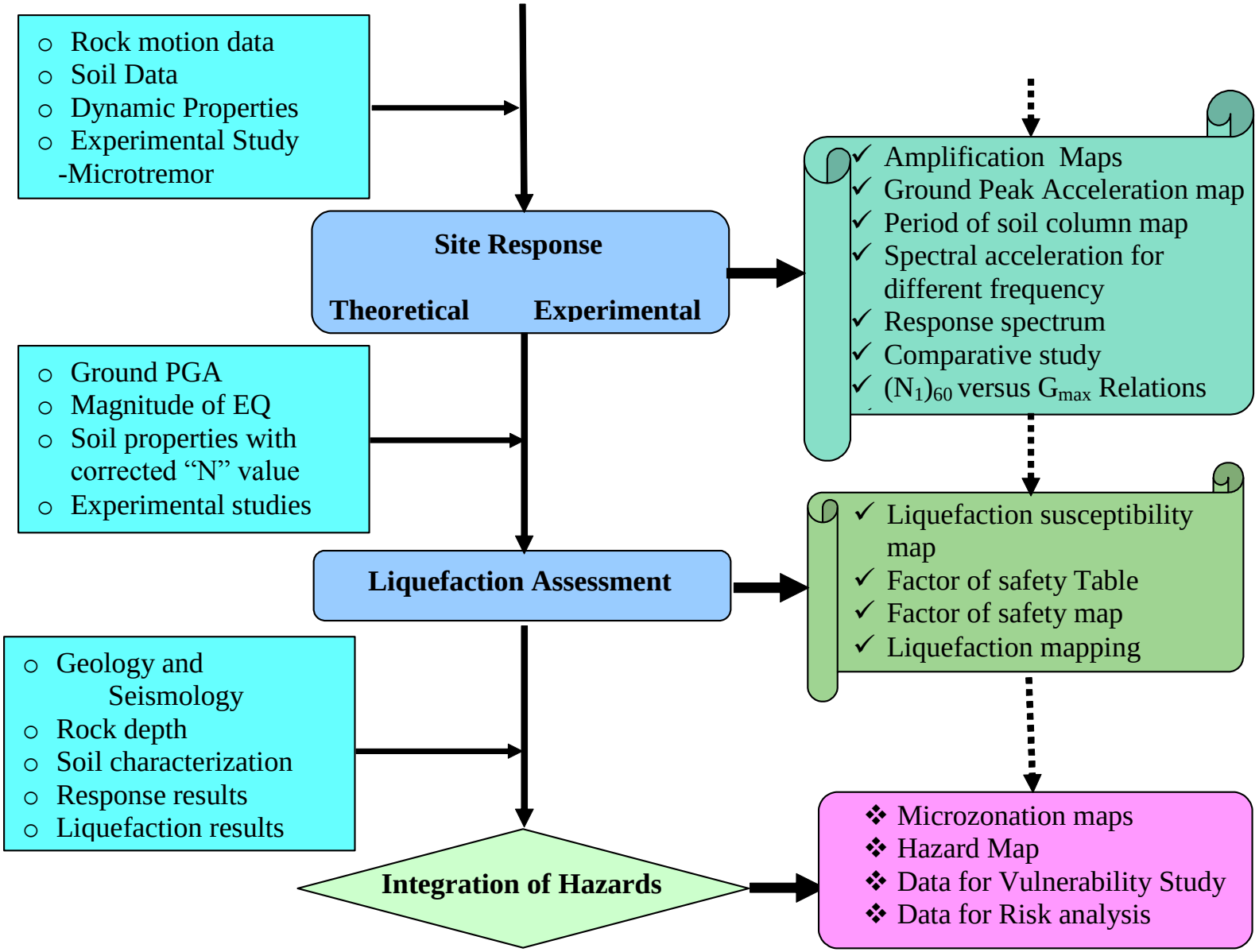
Microzonation of earthquake hazard Indian Experiments

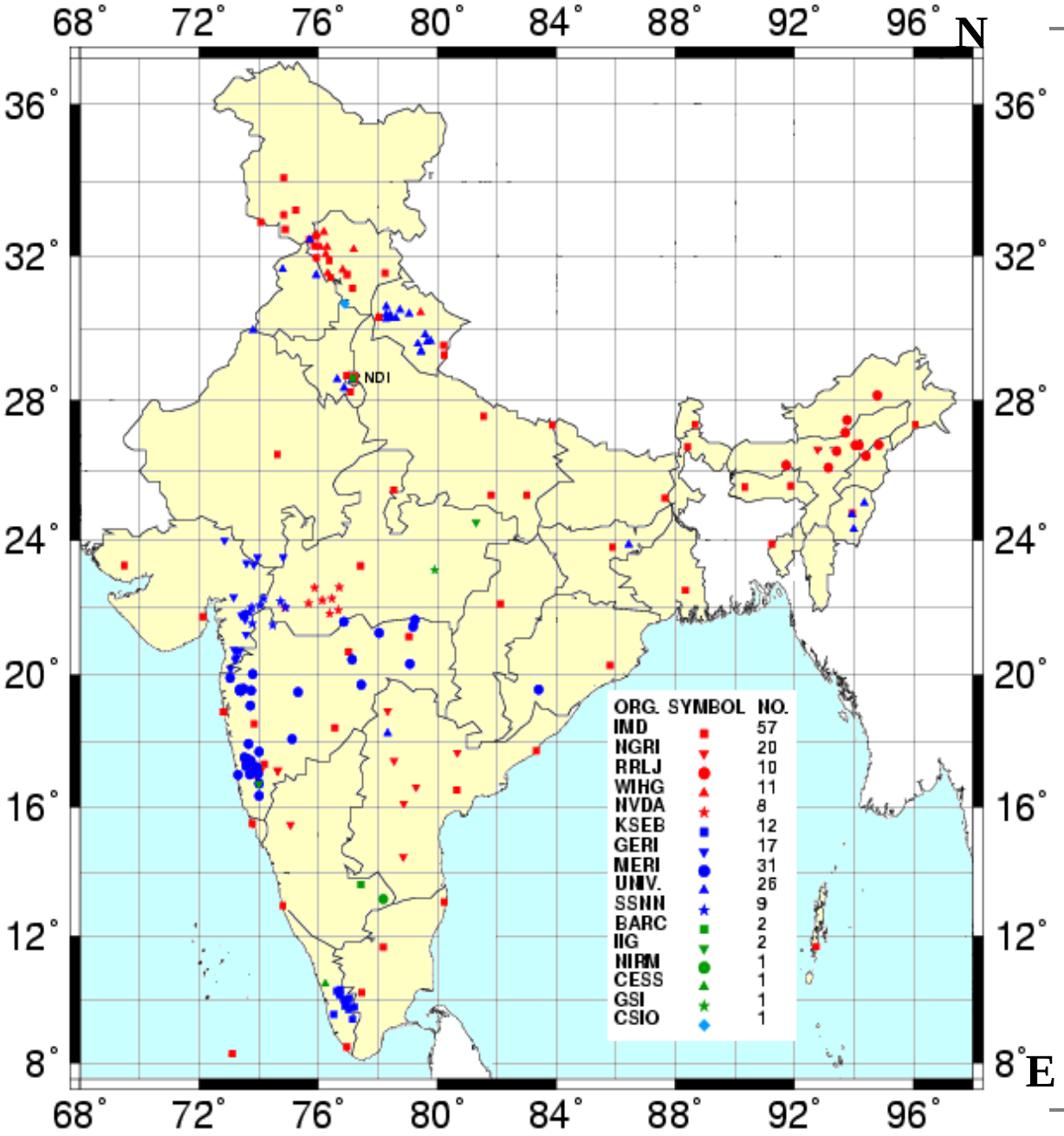
City / Areas
Jabalpur, MP
Sikkim
Mumbai
Delhi
North East India
Gauwhati
Ahmedabad
Dehradun
Bhuj
Chennai
Bangalore
Gandhidham
Vishakpatnam
Kolkata
Chandigarh



Steps for Seismic Hazard Analysis and Microzonation of Bangalore



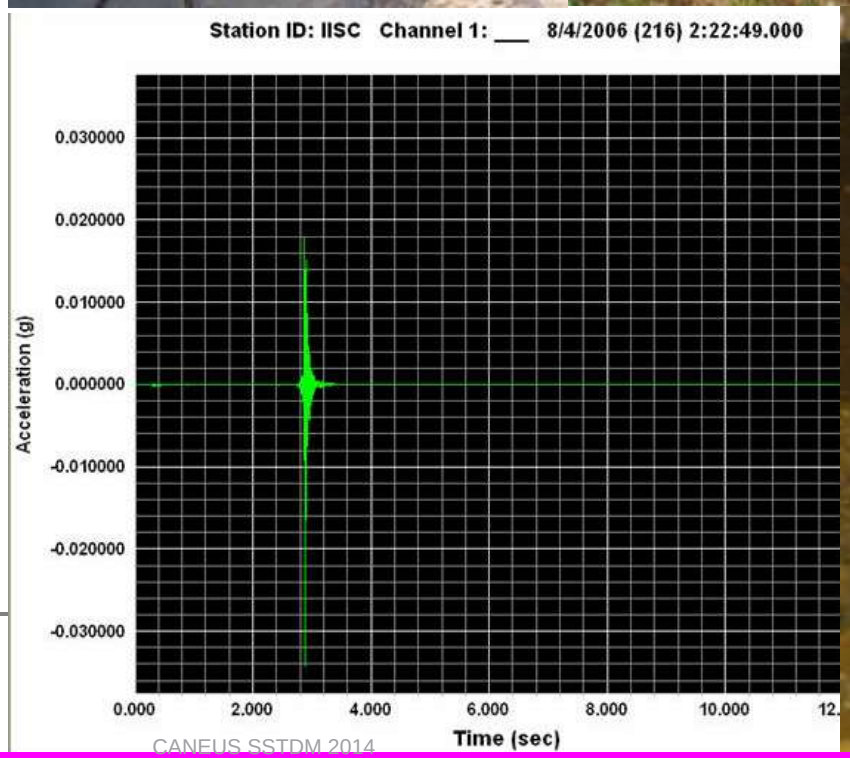

Rock motion data
Soil Data
Dynamic Properties
Experimental Study
-Microtremor
Site Response
Theoretical
Experimental
Amplification Maps
Ground Peak Acceleration map
Period of soil column map
Spectral acceleration for different frequency
Response spectrum
Comparative study
$(N_1)_{60}$ versus G_{max} Relations
Ground PGA
Magnitude of EQ
Soil properties with corrected "N" value
Experimental studies
Liquefaction Assessment
Liquefaction susceptibility map
Factor of safety Table
Factor of safety map
Liquefaction mapping
Geology and Seismology
Rock depth
Soil characterization
Response results
Liquefaction results
Integration of Hazards
Microzonation maps
Hazard Map
Data for Vulnerability Study
Data for Risk analysis



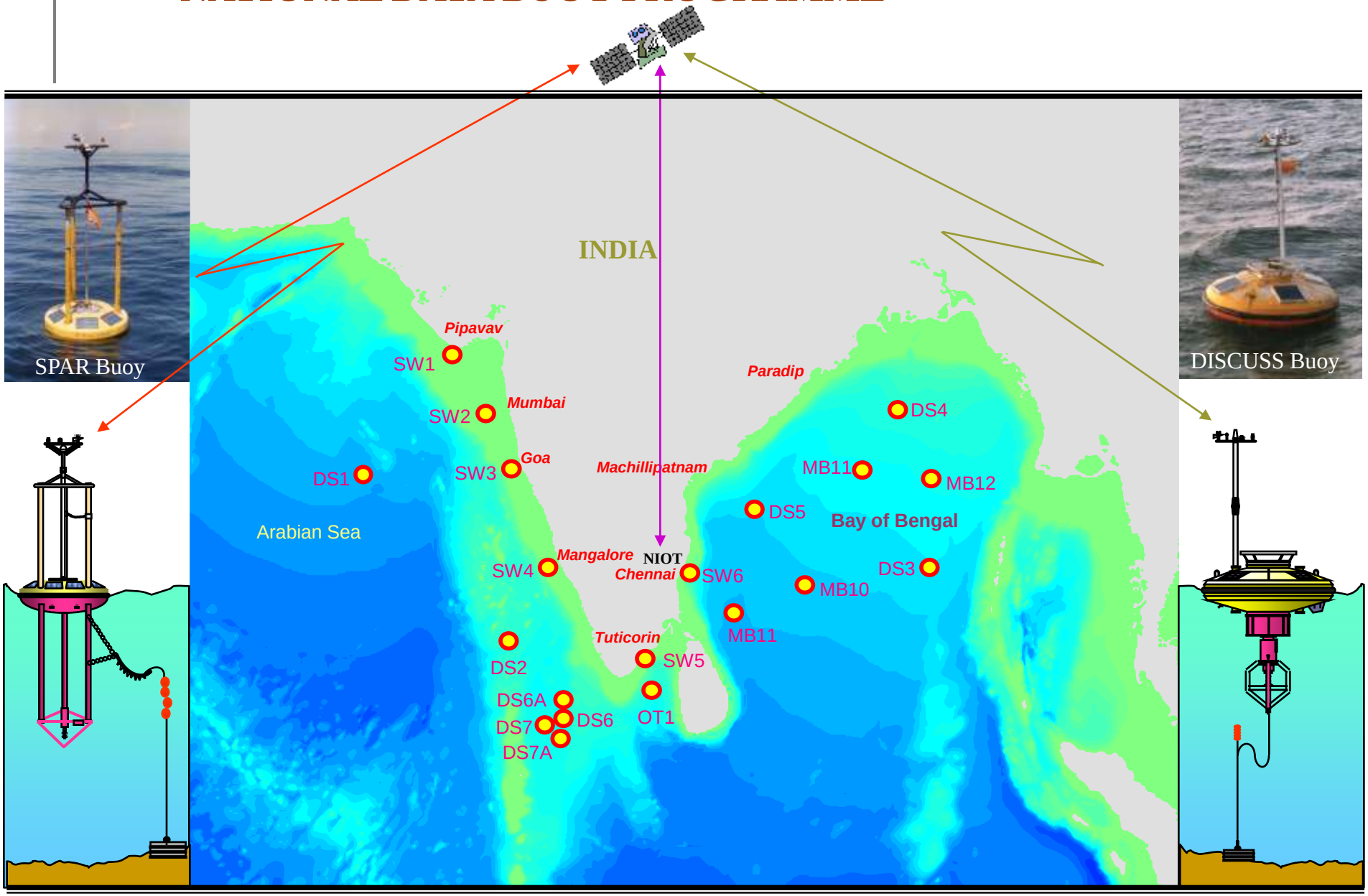
Existing Seismological Observatory Network

Installations of Strong Motion Accelerographs and BBS

- 8 SMA procured from M/s Kinemetrics, USA installed in Bangalore (1 in Mysore)
- 6 surface and 2 borehole sensors.
- Many mild earthquakes recorded.
- EQ of 3.4 in the border of Andhra, Tamil Nadu and Karnataka recorded.
- BROAD BAND SEISMOGRAPH STS 2 – M/s Kinemetrics is installed



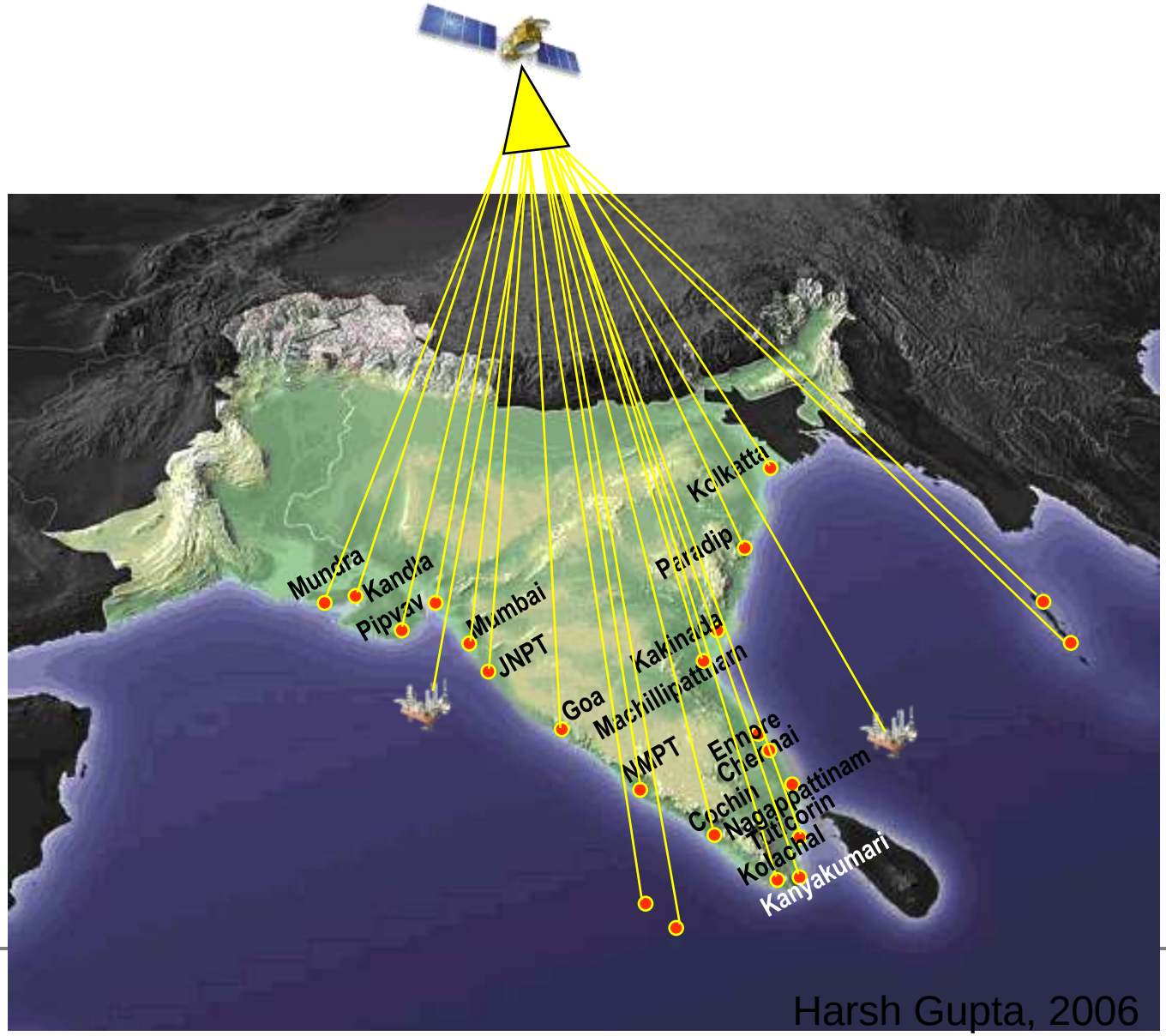
NATIONAL DATA BUOY PROGRAMME



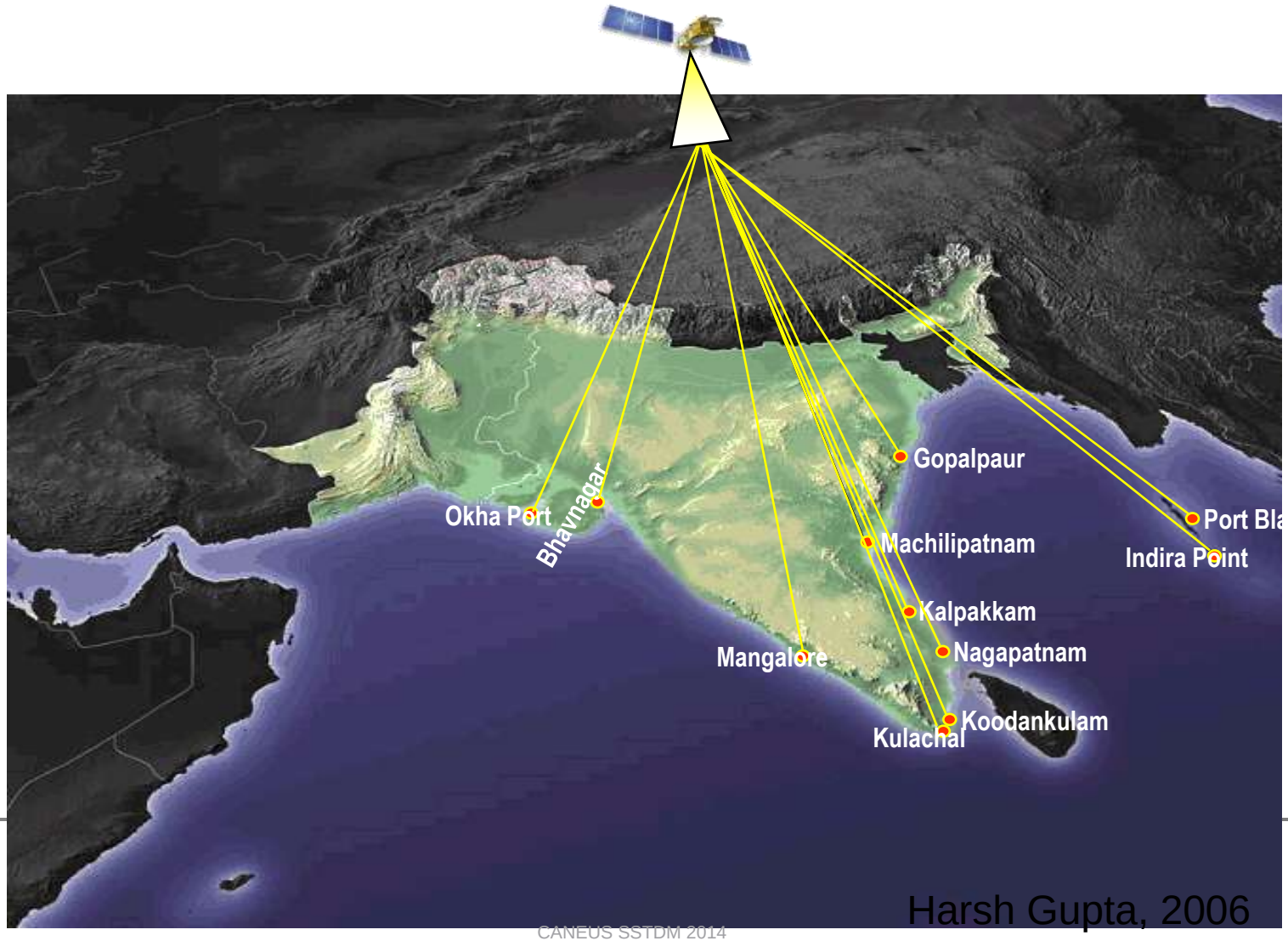
2002-03 20- Buoy Network

Harsh Gupta, 2006

Sea Level Monitoring Stations



HF Radar-based Monitoring of Surface Current and Wave



Harsh Gupta, 2006

Partners in Project Implementation of Tsunami Warning System

Nodal Implementing Agency
DOD through its Institutions (INCOIS, NIOT, ICMAM)

Partners	
Seismic Stations, Detection of Earthquake	DST
Communication between Seismic stations, Sensor Selection for Bottom Pressure Recorder, Communication from BPR	DOS
Coastal Topography	DST and DOS
Research inputs in Geophysics, Ocean Sciences	CSIR, DOD, Academia

Harsh Gupta, 2006

Conclusions

✓Reliable information on the active faults and geodetic measurements of fault movement rates would go a long way in redefining seismogenic sources in India.

✓As strong ground-motion records of earthquakes in the region become available, region specific attenuation equations for the various parts of the country could be developed.

✓ Methods are available to strengthen their dwellings by some simple, very inexpensive approaches. These should be popularized.

✓public awareness of what to do and what not to do before, during, and after earthquakes.

Thank you one and all…

Download all relevant publications from
URL: http://civil.iisc.ernet.in/~sitharam

Questions ???