Lecture 9: World Great Earthquakes, Large and Damaging Earthquakes of India

Topics

- World Great Earthquakes
- Earthquakes in the world and in Europe in the 11th Century
- Comparison among different types of natural catastrophes
- Fatality Model
- Great Earthquakes of India
- Large and Damaging Earthquakes of India
- Permanent Seismological Observatories in India
- National Network
- Other Permanent Seismological Stations/Networks
- Prediction of Earthquake
- Socio Economic Impacts and Adjustments to an Earthquake prediction
- Mitigation of Earthquake Risk
- Earthquake Preparedness

Keywords: *Large earthquakes, Damaging earthquakes, Impact, Prediction*

Topic 1

World Great Earthquakes

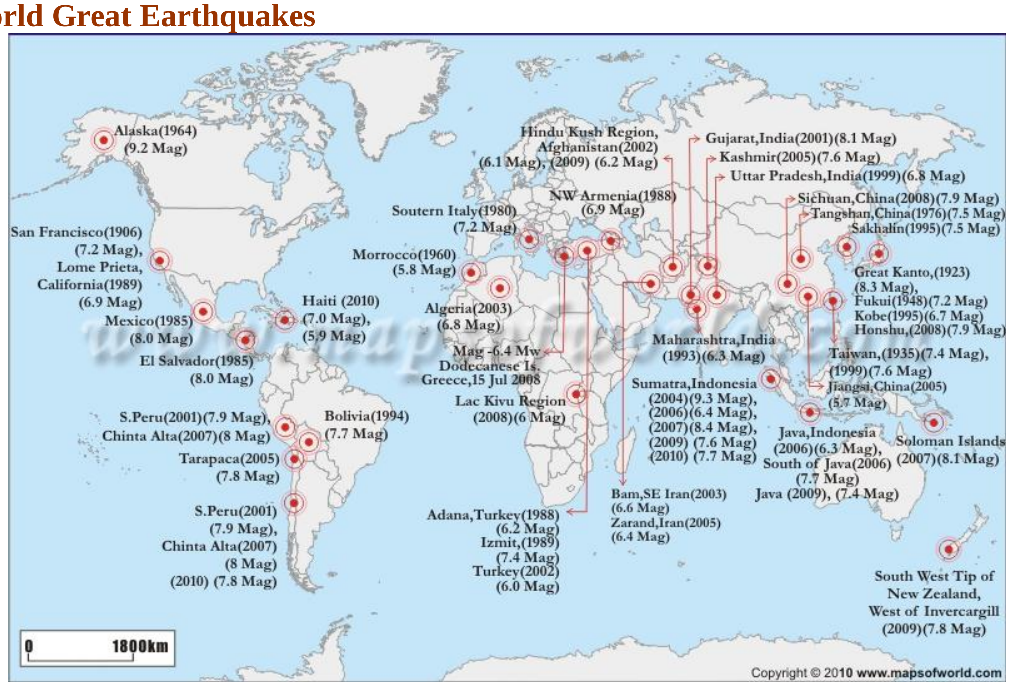

Fig 9.1: Major earthquakes of the world

- Earthquakes have occurred on earth's surface since times immemorial. Thousands and thousands of earthquakes happen every year however, most of which go unnoticed as they are either too weak on the Richter scale or happen in remotest of the areas. Earthquakes cause both loss of lives and property. Major Earthquakes of the World map Fig 9.1 shows all the major earthquakes that have occurred in various parts of the world. Apart form depicting the places i.e. the epicenters of the earthquake, the map also shows the year of its occurrences and its magnitude on the Richter scale

- May 22, 1960 witnessed the world's strongest earthquake in Valdicvia, Chile. The earthquake with a magnitude of 9.5 on Richter scale caused 20,000 fatalities. World's second strongest earthquake occurred on December 26, 2004 with a magnitude of 9.3 on Richter scale. Ocean floor of west Sumatra and Indonesia were the epicenter of this earthquake that caused over 300,000 causalities. This earthquake caused the disastrous tsunami in the Indian Ocean.

- On March 27, 1964 Alaska faced the world's third strongest earthquake. The earthquake measured 9.2 on Richter scale caused a great deal of damage in Anchorage. Kamchatka, 1952 having 9.0 magnitude and Off the Coast of Ecuador, 1906 having 8.8 magnitude, are the fourth and the fifth strongest earthquakes on the world till date.

- Table 9.1 shows U.S. Geological Survey (USGS) list of some of the most devastating earthquakes recorded around the world dating back to 1755:

Table 9.1: Important earthquake records

Location	Date	Magnitude	Casualties(in terms of no of people killed)
Lisbon, Portugal	Nov 1, 1755	8.6	60,000
San Francisco, California	Apr 18, 1906	8.3	700
Kansu, China	Dec 16, 1920	8.5	200,000
Tokyo-Yokohama, Japan	Sep 1, 1923	8.3	143,000
Agadir, Morocco	Jan 13, 1960	5.9	12,500
Tangshan, China	Jul 27, 1976	8.0	255,000
Mexico City, Mexico	Sep 19, 1985	8.1	9,500
Armenia, USSR	Dec 7, 1988	6.8	25,000
Loma Prieta, California	Oct 17, 1989	7.0	62
Northridge, California	Jan 17, 1994	6.8	60
Kobe, Japan	Jan 16, 1995	6.8	5,530
Gölcük, Turkey	Aug 17, 1999	7.6	17,000
Nantou, Taiwan	Sep 20, 1999	7.6	1,800
BengKulu, Indonesia	Jun 4, 2000	7.9	-
India/Pakistan Border	Jan 26, 2001	7.9	20,000+
Northern Sumatra, Indonesia	Dec 26,2004	9.1	230,000
Kashmir	Oct 8,2005	7.6	79,000
Sichuan, China	May 12,2008	7.9	69,197
Haiti	Jan 12, 2010	7.0	222,570

Topic 2

Earthquakes in the world and in Europe in the xxth Century

- A simplified analysis of the evolution of human casualties and economic losses all around the world caused by the seismic activity during the XXth century clearly indicates a steady increase of economic losses, especially in the last decade, in contrast with a slight decrease in human casualties (Figure 9.2).

- In fact, while casualty figures oscillate around the 150 000 per decade (in a total of 1.5 million) and are marked by the occurrence of very large events, the economic losses, corrected to the year 1997, show an exponential increase. Such increase can be attributed to earthquakes striking regions of high urban concentration, for which no seismic protection has been implemented due to difficulty in transferring of technology to the construction industry.

- Even though great advances in seismology and earthquake engineering have been acquired in the last 20 years, a great deal of implementation is still missing. Many International organizations have spoken out for this problem, but results from these campaigns are still difficult to judge. It is worth noting that the same pattern of damage (human and economical) has been observed in the first years of the XXIth century.

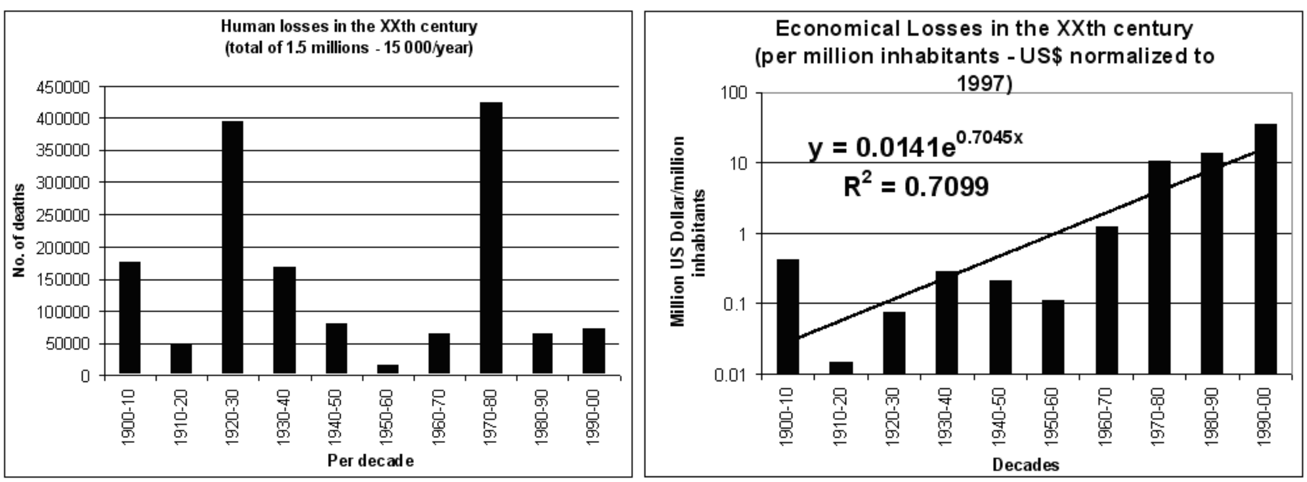

Fig 9.2: Human losses in the world during the XXth century to the left and Economical losses in the world during the XXth century to the Right

Topic 3

Comparison among different types of natural catastrophes

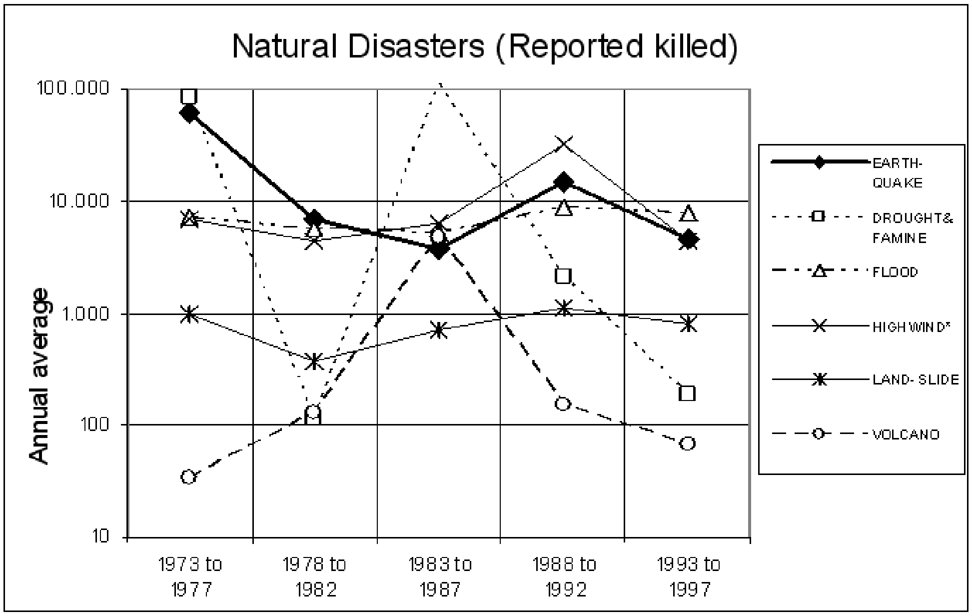

Fig 9.3: Natural disasters reported

- In relation to earthquake risk, it is interesting to analyze the tendency to divide the political world into two large geographic areas: the world of poor countries and the world of rich countries.

- For the former ones, human casualties are increasing throughout the century and are one order of magnitude above the rich countries, whereas, for these ones, the opposite tendency is observed when dealing with economic losses.

- On the other hand, it should be important to emphasize that in the last decade of the XXth century very large events took place with catastrophic consequences, both in human and in economic terms which is shown in Fig 9.3.

- Considering only the six earthquakes with magnitudes in the range 6.7 to 7.5, human casualties attained more than 70 000 and losses were above 150.000 x 10^6 Euros.

- The Kobe 1995 earthquake alone was responsible for more than 100 x 10^9 Euros, which is equivalent to almost 2% of the Japanese Gross National Product (GNP). This earthquake affected 3.6 million inhabitants from a total of 4.5 million residents in the region, causing 5500 casualties and 41 000 injures, important damage to 3500 buildings in reinforced concrete and steel, and destroying around 80,000 dwellings.

- The Northridge 1994 earthquake caused about one third of the Kobe losses, but economic loss estimation corresponding to the repetition of the Kwant (Tokyo) 1923 earthquake would surpass, in an order of magnitude, those numbers.

- The XXth century has finished with two very large events with magnitude greater than 7.5, separated in time by just less than a month. The Kocaeli earthquake in Turkey occurred in August 1999 and caused tremendous impact in the area east of Istanbul. Over 15 000 people were killed, about 24 000 were injured and 600 000 people become homeless. About 120 000 buildings and houses were considered beyond repair, among which about 5000 were seriously damaged or completely collapsed. The total economic impact of this earthquake is still difficult to establish.

- The second event, the Chi-Chi earthquake of September 1999, affected a large area of Taiwan causing over 2000 deaths and an economical impact of the order of 3.2×10^9 Euros.

- Whatever location around the world, the impact of earthquake activity is so large that, in recent years, a great concern has led to the development of impact studies in large metropolitan areas such as Mexico City, Tokyo, San Francisco, Istanbul, Bogotá, etc.

- These studies, known as scenario evaluations for Mega cities, are essential tools for several different applications, which run from simple evaluations of earthquake risks, to exercises for civil protection, indications for insurance companies, and re-evaluations of mitigation measures.

- Earthquake activity in time and space for a given region is not well known and cycles with certain stability can be interrupted by other type of cycles. In recent times, large earthquakes occurred in regions where no historical evidence was present.

- The cases of Kobe and Athens earthquakes in 1995 and 1999, respectively, are among these events occurring in regions of low seismicity. A great discussion was initiated on the reliability of hazard methods, which cannot present good results if long period observations are not taken into consideration. To avoid such difficulties, studies including paleo-seismology and arqueo-seismology information should be made for regions where long return period activity is suspected.

- The lack of regularity in the pattern of earthquake activity has been a characteristic of the seismic activity in continental Portugal. In fact, periods of long quiescence alternate with periods of great activity.

- From the end of the XIXth century to the second decade of the XXth century a high rate of activity was observed throughout the country, with the occurrence the

Benavento M=6.3 earthquake in 1909, followed by an enormous number of aftershocks. Since then, approximately 80 years of very low seismic activity have passed, only interrupted by two isolated episodes, one large M=8.0 event in 1941 with epicentre mid distance between the Azores and the Continent, and a M=7.2 event in 1969, in the Gorringe Bank, near the most seismic active interplate region SW of the Continent.

- But a similar pattern can be visualized for the large area running from the Azores to the Greek islands, in the neighboring of the Euro-Asiatic and African plates. With the exclusion of Greece, no event with magnitude larger than 5.8 was recorded in that area from 1920 till 1980.

- In the year of 1980, three larger events occurred: in the Azores (Jan, 1st), in El Asnam Algeria (Oct 10th), and in Irpinia, south Italy (Nov 23th). Since then, the most important events occurred in Algeria (1994) and in Italy (1997), the latter causing great impact over the historical heritage in the centre of Italy (**http://emidius.itim.mi.cnr.it/, 1997, 1998**)

- In summary, one can say that, in the period 1980 to 1995, about 5000 people lost their lives in the territory of the European Union due to earthquake activity leading to a total economic loss above 430 x 10^6 Euros.

- In the topic of natural catastrophes, earthquakes play a very important role, world-wide. As a matter of fact, statistics taken from the period 1973-1997 (**http://www.cred.be**), organized by 5-year bins, show that earthquakes are among the disasters with larger death impact, even though the total number of flood events is twice per year.

- This analysis on the effects of earthquakes on the built environment can be traced for the entire XXth century. This calls the attention to the communities that seismic risk has been increasing along the times in spite of all the great advancements achieved in scientific and technical grounds. Problems of bad use of "good engineering knowledge" and lack of quality control are behind these poor results.

Topic 4

Fatality Model

- Earthquakes can cause devastating effects in terms of loss of life and livelihood. The destructive potential of earthquakes depends on many factors. The size of an event, focal depth and epicentral distance, topographical conditions and local geology are important earthquake characteristics.

- However, the causes of fatalities and extent of damage depend to a great extent on the type of constructions and the density of population present in the area. Earthquakes exact a heavy toll on all aspects of exposed societal systems.

- During the twentieth century, over 1,200 destructive earthquakes occurred worldwide and caused damage estimated at more than $ 10 billion (Coburn and Spence, 2002). If these costs are averaged over the century, annual losses are about $ 10 billion.

- Monetary losses from earthquakes are increasing rapidly. Between 1990 and 1999, annual loss rates were estimated at $ 20 billion, twice the average twentieth century annual losses. The Federal Emergency Management Agency released a study (FEMA 366, 2001) estimating annualized earthquake losses to the national building stocks in the USA at $ 4.4 billion, with California, Oregon and Washington accounting for $ 3.3 billion of the total estimated amount.

- An update of the above landmark study was released in 2006 (www.fema.gov) to include in the estimation of the annualized losses three additional features of earthquake risk analysis, i.e. casualties, debris and shelter.

- In the latter study, it is estimated that the annualized earthquake losses to the national building stock are $ 5.3 billion and about 65% is concentrated in the State of California. The largest earthquake in modern times in the USA was the 1964 Alaska Earthquake, measuring 8.4 on the Richter scale. The earthquake caused $ 311 million in damage and 115 fatalities.

- In a historical context, the largest recorded earthquakes in the contiguous USA are the New Madrid earthquakes of 1811 and 1812. In the USA, 39 out of 50 states (nearly 80%) are at risk from damaging earthquakes.

- The Central and Eastern States in the USA now recognize earthquakes as a major threat. In particular, the eight central States of Illinois, Arkansas, Indiana, Tennessee, Kentucky, Mississippi, Alabama and Missouri have dedicated considerable resources to work with FEMA and other earthquake engineering organizations to assess the possible impact of earthquakes and to mitigate as well as plan for response and recovery from their effects.

- With regard to loss of life, on average 10,000 people per year were killed by earthquakes between 1900 and 1999 (Bolt, 1999). In 2001, three major earthquakes in Bhuj (India, M S = 7.9), El Salvador (M S = 7.6) and Arequipa (Peru, M S = 8.4) caused more than 26,000 casualties.

- The Bam (Iran, M S = 6.6) and Sumatra (Indian Ocean, M w = 9.3) earthquakes, which occurred in 2003 and 2004, both on 26 December, caused more than 26,000 and 280,000 deaths, respectively. The Kashmir earthquake of 8 October 2005 caused over 85,000 deaths.

- The human death toll due to earthquakes between 1906 and 2005 is given in Figure 9.4 (www.usgs.gov). Over this 108 - year period, deaths due to earthquakes totaled about 1.8 million. China accounted for more than 30% of all fatalities.

- Figure 9.5 compares the human death toll due to earthquakes with that caused by other natural hazards (www.usgs.gov). It is observed from the figure 9.5 that earthquakes rank second after floods; earthquakes account for about 3.6 million fatalities.

- If the death toll caused by tsunamis were added to that caused by earthquakes, the total figure would amount to around 4.5 million. Monetary losses due to collapsed buildings and lifeline damage are substantial. Furthermore, the economic impact of earthquakes is increasing due to the expansion of urban development and the higher cost of construction.

- For example, the 1994 Northridge earthquake, which is said to be the most costly natural disaster in the history of the USA, caused $ 30 billion in damage and $ 800 billion replacement value on taxable property (Goltz, 1994).

- In this event 25,000 dwellings were declared uninhabitable, while buildings with severe and moderate damage numbered 7,000 and 22,000, respectively. Damage to the transportation system was estimated at $ 1.8 billion and property loss at $ 6.0 billion.

- In the above - mentioned earthquake, the most severe damage occurred to non - retrofitted structures, designed in compliance with seismic regulations issued in the 1970s.

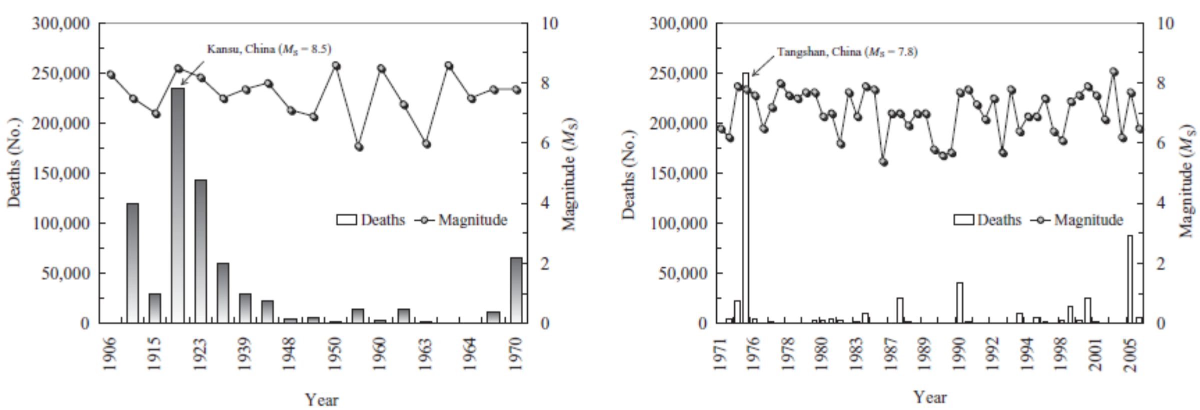

Fig 9.4: Human death toll due to earthquakes: 1906-1970(left) and 1971-2005(right)

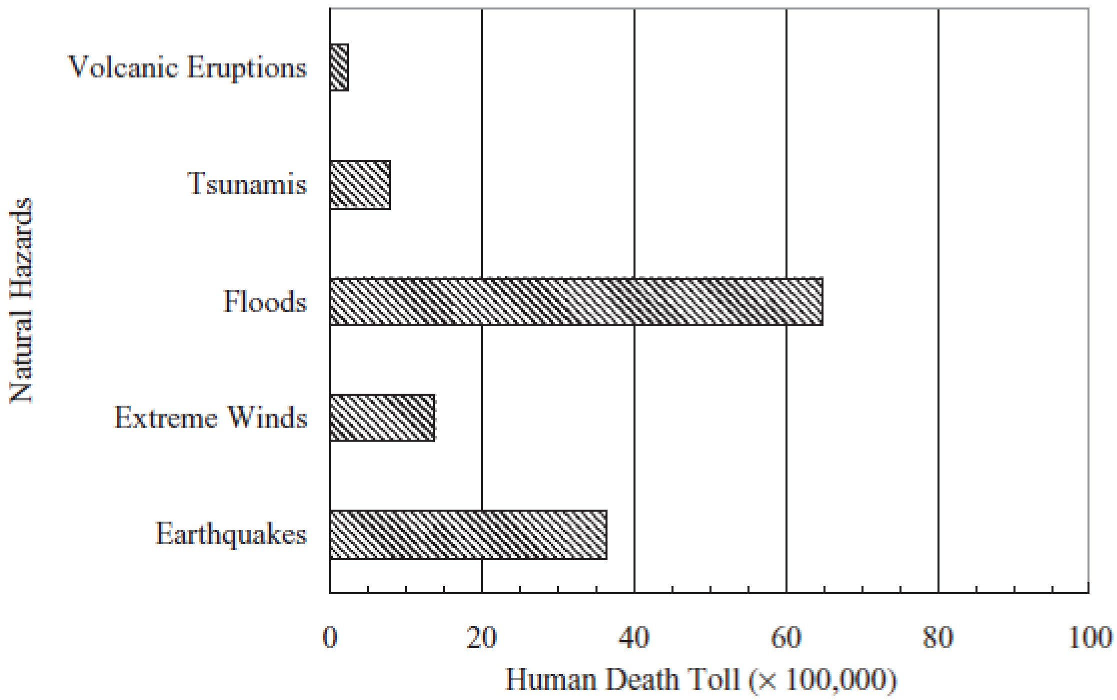

Fig 9.5: Human death toll caused by major natural hazards

- Several reconnaissance reports have concluded that building collapses caused 75% of earthquake fatalities during the last century. Other major causes of death were fi res and gas explosions, tsunamis, rockfalls and landslides. In the Loma Prieta earthquake, 42 out 63 deaths (about 63%) were attributed to bridge failures.

- However, in the 1995 Kobe earthquake in Japan, 73% of the deaths were caused by collapsed houses. The likelihood of the collapse of multi - storey RC structures in developing countries, where the quality of construction remains relatively substandard, is high.

- Earthquake damage resulting in the collapse of monuments, historical places of worship and stately buildings represents an irreplaceable loss in terms of cultural heritage, while their restoration costs exceed by far the gross national product (GNP) of many affected nations.

- The expense of reconstructing the world famous vault of the Basilica at Assisi (Italy) with its early Renaissance frescoes caused serious repercussions for the national economy after 1997. Even more problematic are the implications for important heritage sites in seismically active developing countries.

- The earthquakes of Gujarat (India), Bam (Iran), Arequipa (Peru) and Yogyakarta (Indonesia), have caused major damage to invaluable historical sites that may or may not be restored over a number of years and at an extremely high cost.

- One of the most severe consequences of earthquakes is the cost of recovery and reconstruction. It is instructive to note, however, that the absolute fi nancial loss is less critical to an economy than the loss as a percentage of the GNP. For example, in some 6 to 8 seconds, Nicaragua lost 40% of its GNP due to the 1972 Managua earthquake (Table 1.13), while the 800% higher bill ($ 17 billion versus $ 2 billion) from the Yerivan, Armenia earthquake constituted only 3% of the USSR ’ s GNP (Elnashai, 2002).

Table 9.2: Earthquake financial losses (after Coburn and Spence, 2002)

Country	Earthquake	Year	Loss ($ bn)	GNP ($ bn)	Loss (%GNP)
Nicaragua	Managua	1972	2.0	5.0	40.0
Guatemala	Guatemala City	1976	1.0	6.1	18.0
Romania	Bucharest	1977	0.8	26.7	3.0
Yugoslavia	Montenegro	1979	2.2	22.0	10.0
Italy	Campania	1980	45.0	661.8	6.8
Mexico	Mexico City	1985	5.0	166.7	3.0
Greece	Kalamata	1986	0.8	40.8	2.0
El Salvador	San Salvador	1986	1.5	0.8	31.0
USSA	Armenia	1988	17.0	566.7	3.0
Iran	Manjil	1990	7.2	100.0	7.2

Key: GNP=gross national product

- The ‘business interruption’ element of earthquake impact has emerged lately as a major concern to industry and hence to communities. This is the effect of largely non - structural building damage (e.g. suspended light fi xtures, interior partitions and exterior cladding), which affects businesses adversely, in turn leading to financial disruption and hardship (Miranda and Aslani, 2003).

- In several countries, such as the Mediterranean regions and Central America, where tourism is a vital industry, major economic losses have resulted from damage to hotels and negative publicity due to earthquakes.

- Another aspect of the economic impact is the ‘loss of market share’ , which results from interruption to production in industrial facilities and diffi culties in reclaiming the share of the market that the affected business previously held.

- The consequences of direct financial losses, business interruption, and loss of market share on communities and industry have led major multinationals to create risk management departments in an attempt not only to reduce their exposure, but also to minimize insurance premiums. Global seismic risk management is therefore one of the highest growth areas in industry.

Topic 5

Great Earthquakes of India

- The Indian subcontinent can be broadly divided into three sub-regions, the Himalaya, the Gangetic Plain and the Peninsular Shield. The Himalayan Arc is covexed southward and fronting the alluviated depression of the Gangetic Plain. In front of the Himalaya are the foothills, the Siwaliks and the Tertiary metasediments. The Gangetic Plain separates the Himalaya from the Peninsula. Archaean rocks are over more than half of the Peninsula, and a large part of the remainder is covered by basaltic flows of Deccan Traps.

- Epicenters of the great earthquakes M ~8.0 and above are shown by solid circles in Figure 9.6. Five great earthquakes (M > 8.0) have occurred in India during the last 100+ years since 1897; three in the Himalayan Arc (1905 Kangra, 1934 Bihar and 1950 Assam), one in the northwestern margin of peninsular shield (1819 Kutch) and one in the Shillong Plateau shield (1897) in northeast India.

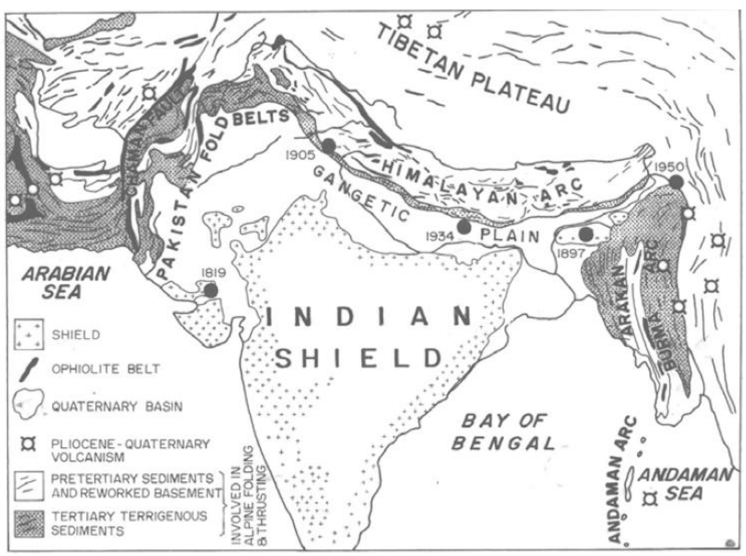

Fig 9.6: Epicenters of great earthquakes

The 1819 Kutch Earthquake

- The Kutch (also spelled Kachchh and Cutch) earthquake that occurred on June 16, 1819 in the northwestern corner of Peninsular India is considered to be the largest event of Stable Continental Region (SCR), and the first for which crustal deformation was quantified. The maximum intensity was reported to be XI on MM scale. This earthquake occurred before the invention of the seismographs.

- Based on the reported intensity, Gutenberg and Richter (1954) assigned ML=8.4, while Johnston and Kanter (1990) reviewed the stable continental earthquakes and assigned MW=7.8 for this event. A remarkable feature of this earthquake was the creation of an 80-90 km long and 2-3 m elevated tract of land, known as 'Allah Bund', (dam of God). The fault scarp appeared in the Rann of Kutch, close to the international border between India and Pakistan. ('Rann' means uninhabited salt flats that are neither sea nor land and are flooded periodically).

- The epicentre of the earthquake was given at 23.6°N and 69.6°E. The loss of life was over 1500. The earthquake was not felt all over the country as those of 1897 or 1934; it was, of course, violent at the Kutch area. Due to lack of instrumental data its exact source parameters are not known.

- Ground excavations in the area revealed large multiple liquefaction features with cross-cutting relations at different stratigraphic levels, and recurrence of earthquakes (M > 7.5) on multiple segments in the region has been suggested.

The 1897 Shillong Earthquake

- Among the great earthquakes of the world, the June 12, 1897 earthquake of the Shillong Plateau holds a very prominent place in seismology. Loss of life was only 1,542 compared to the magnitude of the earthquake.

- The loss of life was fortunately less because the earthquake occurred at 5.15 p.m. local time, when most of the people were outdoor. The epicenter was reported to be at 25.90°N and 91.80°E (Milne, 1912), and the maximum intensity reached XII on MM scale as rated by Richter (1958).

- Damage to property had been very great (see Intensity map given in Figure 9.7). Within an area of 30,000 square miles, all brick and stone buildings were practically destroyed. The ground rocked so violently that it was impossible to stand. Rumbling sound, visible waves and seiches were observed. Fissures were abundant over the whole area. Secondary effects like ejection of water and sand, rotation of pillars, rising of river height, crushing of soils into which houses sank were reported in the epicentral area.

- It was the first strong earthquake in the country, which was instrumentally recorded outside the country. The seismographs which recorded the 1897 earthquake, however, were not of modern type. So, it was difficult to use the records to determine its magnitude. In a detailed study of the large global earthquakes, Gutenberg and Richter (1954) assigned a magnitude ML = 8.7 for this earthquake.
- There was evidence of a surface fault, called Chedrang fault, in the epicentre area, which extended over 18-20 km with throws upto 35 feet in crystalline rocks.

Largest dimension of the meizoseismal area was reported to be 160 miles (~230 km) with highest intensity XII in the MM scale.

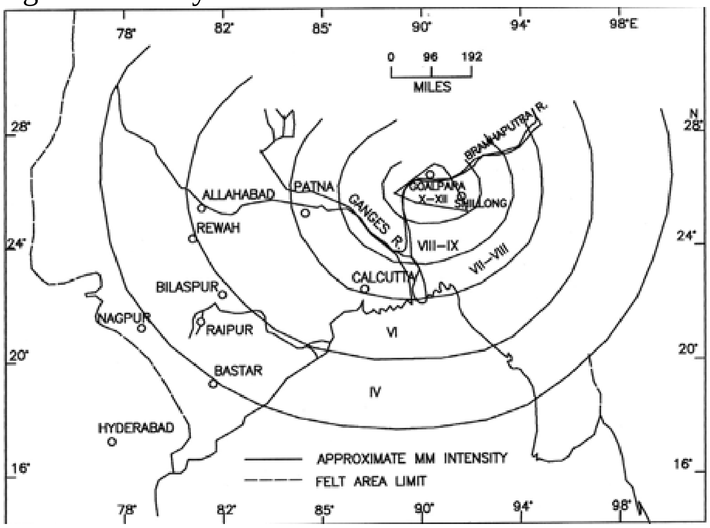

Fig 9.7: Isoseismal map of the great Shillong earthquake 1897; maximum intensity XII (MM scale), (modified from Richter, 1958)

The 1905 Kangra Earthquake

- This is a well documented earthquake which occurred in the Himachal Pradesh on April 4, 1905; the epicentre was reported to be at 32°N and 76°E. The initial magnitude was estimated to be ML = 8.6.

- Figure 9.8 shows Isosiesmal map of Kangra Earthquake

- The loss of life was maximum, about 19,000. The maximum intensity was reported to be X on MM scale. The isoseismals were oriented along the Main Boundary Thrust in the Himalaya. Two zones of high intensity, with an intervening region of low intensity, were identified; one in Kangra area and the other in Dehradun. The Kangra area had larger and higher intensity.

- A detailed study of the earthquake was done by Middlemiss (1910). He estimated the depth of focus at 21-40 km. Post earthquake elevation changes were reported by Chander (1988).

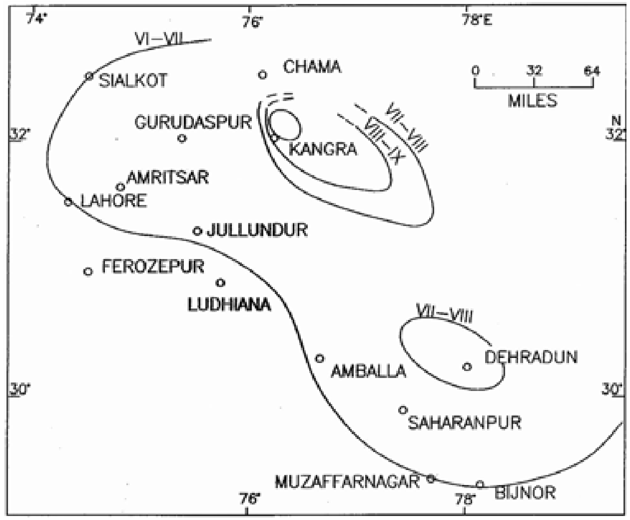

Fig 9.8: Isoseismal map of the great Kangra earthquake 1905; maximum intensity X (MM scale)

The 1934 Bihar Earthquake

- The January 12, 1934 Bihar earthquake is well documented. The seismograms of the National Seismograph Stations (India Meteorological Department) and Global Stations made it possible to locate the epicentre at 26.5°N and 86.50°E, and to assign the magnitude ML 8.4, and focal depth 20-30 km (Richter, 1958).

- The extent of the meizoseismal area was about 120 km long and 35 km wide. Two meizoseismal spots, separated by almost 150 km, one at Munger, east of Patna (Bihar) to the south and the other at Kathmandu, Nepal to the north, were identified.

- The maximum intensity was reported to be X on MM scale (see Figure 9.9). The loss of life in India is given about 7,250 and in Nepal 3,400.

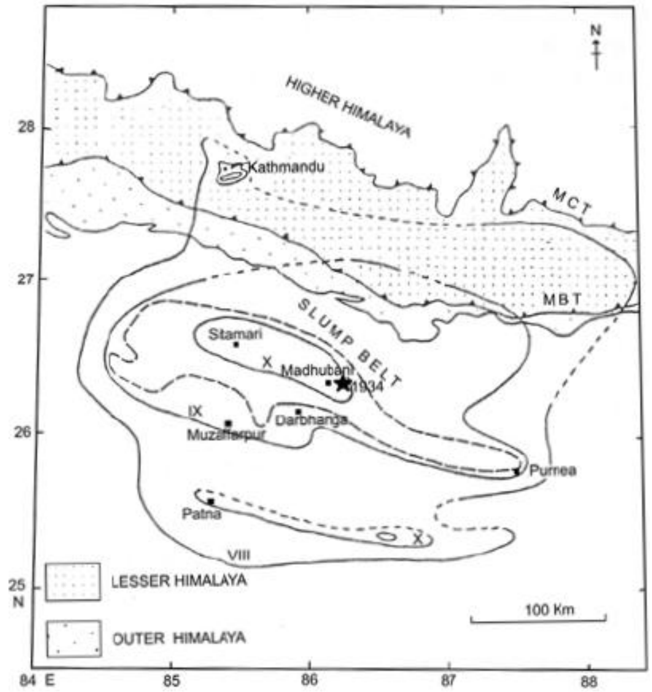

Fig 9.9: Isoseismal map of the great Bihar earthquake 1934; maximum intensity X (MM scale), (GSI, 1939)

The 1950 Assam Earthquake

- On August 15, 1950 at 19.00 hr. 39 min. (local time) the earthquake of Magnitude MS=8.7 occurred off the northeastern boundary of Assam. The epicentre was reported at 28.5°N and 96.70°E, and maximum intensity to XII on MM scale (Fig 9.10). This earthquake caused about 1520 casualties, and was more damaging in terms of property losses than the great earthquake of the 1897.

- The USGS determined the epicentre at 28.5°N and 97.0°E, and focal depth at 20 km. There was no strong-motion seismograph station in the affected area to calculate the acceleration. Acceleration of the order of 0.5g was, however, estimated from the damage survey in the epicentral region.

- Foreshocks and aftershocks were reported by many researchers. Fissures and sand vents occurred in many localities in the alluvial plain. Railway lines and road suffered a considerable damage. Landslides were observed at various places. A tragic death was reported in North Lakhimpur where a nine-year old girl was caught in a fissure which had immediately closed up burying her alive.

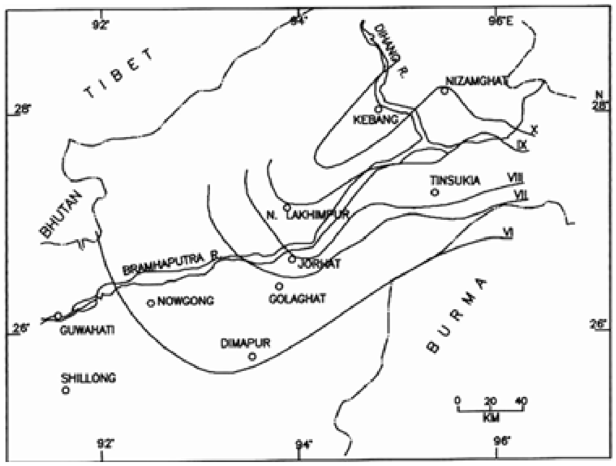

Fig 9.10: Isoseismal map of the great Assam earthquake 1950; maximum intensity XII (MM scale), (Poddar, 1950)

Topic 6

Large and Damaging Earthquakes of India

- The below Figure shows the epicenters of the large earthquakes of magnitude 7.0 and or intensity VIII and above, and also the great earthquakes of M > 8.0. One can discuss an arcuate belt of large earthquakes following the Himalayan mountain belt and the Indo-Burma ranges. Maximum number of large earthquakes is, however, in the Indo-Burma ranges and many of these are deep focus earthquakes; so, loss in terms of casualties was less for these earthquakes.

- Peninsular India presents a quiet picture except the 1819 great earthquake and some recent damaging earthquakes (6.0 > M < 8.0), which have caused considerable damages and loss of lives. Epicenters of these events are also shown. There were a number of moderate magnitude earthquakes M > 5.0 but less than 6.0, which caused considerable damages and loss of lives.

- Figure 9.11 shows locations of damaging earthquakes in India

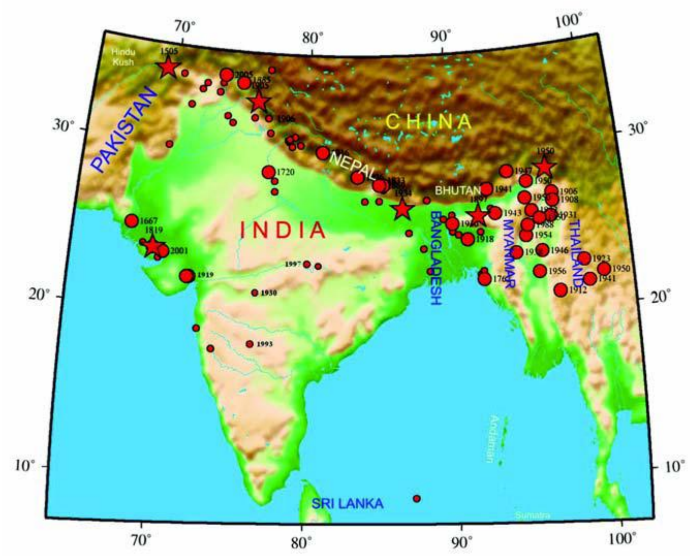

Fig 9.11: Map showing topography of the Indian subcontinent and epicenters of the great (stars), large M > 7.0 (larger circles) and earthquakes M>6.0 and/or Intensity VIII or greater (smaller circles) in India since 1505

Topic 7

Permanent Seismological Observatories in India

- The first scientific study of an Indian strong earthquake was carried out for the Cachar earthquake of 1869 by Dr. T. Oldham, the first Director General of the GSI. His illustrious son Dr. R.D. Oldham made a very thorough study of the great Shillong earthquake of 1897.

- The report of the 1897 earthquake (Oldham, 1899), is a classical work, and a great foundation for the present day modern seismology. After the occurrence of the great Shillong earthquake in 1897, the necessity of installing seismographs in the country was very much felt. The seismological Committee of the British Association recommended the installation of a few seismographs in India in 1898.

Topic 8

National Network

- The first seismological station in India was established in Calcutta (Alipore) on December 1, 1898 under the auspices of the India Meteorological Department (IMD). During 1898-99 two more observatories were started, one at Bombay (Colaba) and the other at Kodaikanal.

- These observatories used Milne seismograph. After the great Kangra earthquake in 1905, a seismological observatory was started in Simla with an Omori Ewing seismograph. In 1929 an observatory was started in Agra with a Milne-Shaw seismograph.

- During 1930s two more observatories were started, one at Dehradun and the other at Nizamiah (Hyderabad). In 1941, the Agra observatory was shifted to Delhi. The number of observatories increased to eight in 1950, and later rose to 15 in 1960 when more sensitive instruments like Benioff, Sprengnether and Wood-Anderson seismographs were added. At present, the number of IMD observatories under the national network in the country is about 60.

- Out of these four stations, one each at Delhi, Poona (Pune), Kodaikanal and Shillong, were equipped with sensitive seismographs under the World Wide Standard Seismograph Network (WWSSN) programme in 1964.

- The national network is modernised with 10 GSN (Global Standard Network) digital instruments with broadband seismometers in 1996, and 10 more are upgraded with broadband instruments in 1998.
- In these upgraded observatories high quality broadband digital data are being obtained. In addition to this, IMD maintains a few permanent small networks like a six-station network in Delhi, six observatories in Punjab and Himachal Pradesh since 1965-66, and three in Jammu and Kashmir since 1980s. The Delhi network is presently upgraded to a digital telemetric network.

Topic 9

Other Permanent Seismological Stations/Networks

- There are more than 150 permanent stand-alone seismological stations around the country, which are being maintained by various agencies other than the IMD. Figure 9.13 shows locations of permanent seismological stations with operating orating agencies. Some important agencies and their seismic stations are described below. However, these information need to be updated.

- **Bhaba Atomic Research Centre (BARC), Bombay** - A most significant addition to the national network of seismological stations was the establishment of a special seismological array at Gauribidanur near Bangalore by the BARC since 1965 in collaboration with U.K. The array is capable of recording smaller events compared to conventional seismographs due to its high sensitivity and low noise. The main purpose of this array is, however, to detect the underground nuclear explosions. In early 1988, the BARC also commissioned an indigenously-built analog telemetered seismic network of eight stations in and around Bhatsa dam, Maharashtra state, for monitoring Reservoir Induced Seismicity (RIS); the network was in operation till late 1990s.

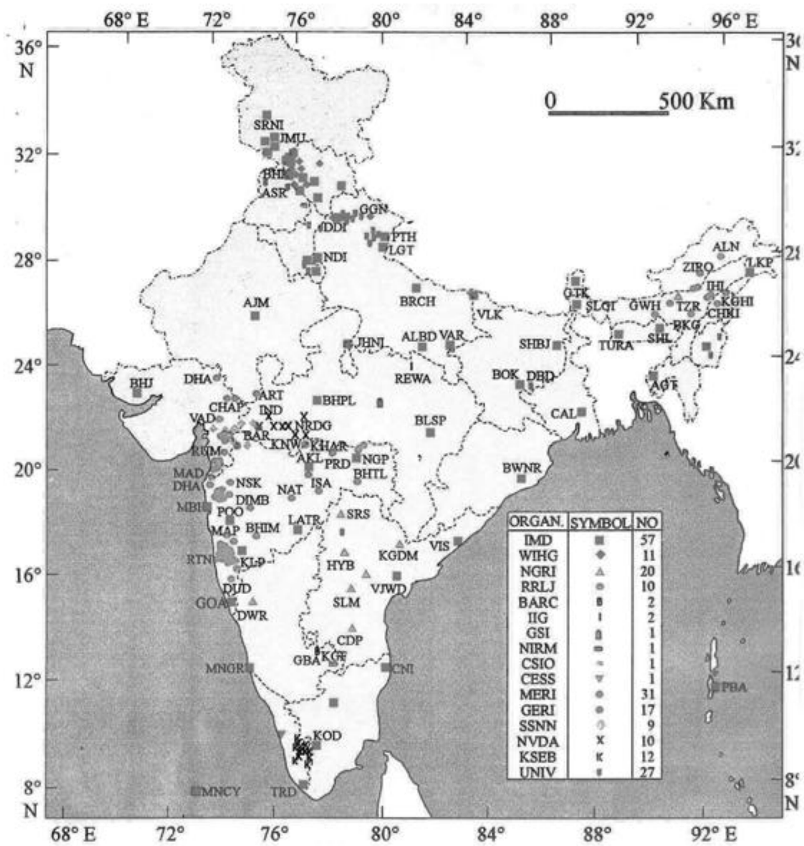

Fig 9.12: National network showing permanent observatories run by different organisations. Seismological Data Centre and the IMD Headquarter at Delhi

- **National Geophysical Research Institute (NGRI), Hyderabad** - Since 1970s the NGRI is maintaining a well equipped seismological observatory in Hyderabad. It has an equipment-set of three-component short period and three-component long period analog seismographs similar to the WWSSN. In early 1990s a broadband digital seismograph has been installed in the observatory in collaboration with the GEOSCOPE (France). Further, the NGRI was running a six to ten-station analog network since 1980 in the Koyna dam area to monitor the RIS (Gupta, 1992; Talwani, 1997; Mandal et al., 1998); the network is upgraded to digital telemetry in late 1990s (Rai et al., 1999a). In addition, since 1988 the NGRI is running a six-station analog/16 bit digital telemetered/stand alone network in Tezpur area of Assam state, northeast India. The 16-bit digital system now is upgraded to 24-bit resolution in early 2000.

- **Regional Research Laboratory (RRL), Jorhat, Assam** - In northeast India, the RRL (J) has also established a seismological network consisting of 14 vertical-component short-period seismograph stations progressively since 1980s. Out of these, six stations were running on analog/ 16-bit digital telemetric system. The 16-bit digital system was upgraded to 24-bit resolution, and the eight stand-alone stations were replaced by 24-bit digital/broadband systems in early 2000. Further, three more broadband stations were established in the epicentre area of the 1897 great earthquake in the Shillong Plateau.

- **Wadia Institute of Himalayan Geology (WIHG), Dehradun** - The WIHG is operating a network of 11 seismological stations with analog recording system since early 1990s. These stations are mostly in the Himachal Himalaya and a few in the Garhwal Himalaya. At five stations three component short-period seismographs are working and at other six stations only vertical component short-period seismographs are working. The network was upgraded with 24-bit digital/broadband instruments in early 2000.

- **Gujarat Engineering Research Institute (GERI), Vadodara, Gujarat**- The GERI is running a permanent seismic station at Vadodara, Gujarat state. The GERI is also associated with most of the major and medium irrigation projects in Gujarat. These projects run five-to-six station networks with short-period seismographs and digital accelerographs.

- **Institute of Seismological Research (ISR),Gandhinagar, Gujarat** - After the January 2001 devastating earthquake (Mw 7.7) in Bhuj, Gujarat State Government has established the ISR for monitoring earthquakes with much close-spaced network. About 22 broadband seismic stations are in operation in the region with a central recording station in Gandhinagar, the capital city of the State. About 10 strong motions instruments are also installed.

- **Maharashtra Engineering Research Institute (MERI),Nasik, Maharashtra** - The MERI is running about 30 seismological stations in different irrigation projects in Maharashtra state. A seismic station is also functioning at its headquarter in Nasik. Most of the stations have vertical component shortperiod smoked paper seismographs.

- **Kerala State Electricity Board (KSEB), Kottayam, Kerala** - The KSEB is operating 12 seismic stations in and around Idduki dam site in northern part of the Kerala state. Each station has short-period vertical analog seismograph.
- **Central Water and Power Research Station (CWPRS), Pune** - The CWPRS looks after two to three permanent analog microearthquake networks consisting of three to four seismic stations in each network in different dam sites in the Eastern Himalaya including Sikkim and Bhutan areas.

- **Centre for Earth Science Studies (CESS), Trivandrum** - The CESS is running one permanent observatory at the Centre using an analog microearthquake instrument. The station is equipped with a digital broadband instrument since 1998.

- **Indian Institute of Technology (IIT), Roorkee** - The Department of Earthquake Engineering (DEE), IIT Roorkee, runs a six station telemetric analog microearthquake network around the Tehri dam, Garhwal Himalaya since early 1990s. The network was upgraded with digital instruments. In addition, the DEE runs several strong-motion arrays in the western Himalaya and in northeast India region. Each array consists of 40 to 50 digital strong-motion seismographs.

- **University of Delhi, Delhi** - The Centre of Georesources, University of Delhi, is running seismic station in the University campus with a digital short-period 3-component seismograph and a short-period vertical analog seismograph since 1990s. The university is operating two more seismic stations in the adjoining Haryana state with short-period vertical seismographs. A broadband three-component digital seismograph has started working at the University campus since early 1998

- **Manipur University, Imphal** - A short period analog seismograph and a triaxial strong-motion accelerograph are working at the Manipur University campus, Imphal since 1994. During 1996 the University has set up three more seismic stations in the Manipur state with digital triaxial short-period seismographs. These stations are now upgraded with broadband instruments.

- **Indian Institute of Technology (IIT), Kharagpur** - The Indian Institute of Technology (Kharagpur) established an eight-station semi-permanent strong-motion array in the Sikkim Himalaya in 1998. The institute has also established a broadband seismic observatory in the institute complex, Kharagpur, in 2004.

- **Other Universities** - The Kurukshetra University is running seismic station with a short-period seismograph in its campus since 1970. The Andhra University and Osmania University in Andhra Pradesh state, the Indian School of Mines, Dhanbad in Bihar state and the Banaras Hindu University in Uttar Pradesh state established short-period seismograph stations at the respective campus since 1998, and most of them were upgraded to broadband seismic stations in 2003. The Gauhati University and the Tezpur University in Assam state and the Mizoram University in Mizoram state started broadband seismic stations, one each in their campus, since 2000. The University projects are mostly funded by the Department of Science and Technology (DST), New Delhi.

Topic 10

Prediction of Earthquake

- In the effort to predict earthquakes people have tried to associate an impending earthquake with such varied phenomena as seismicity patterns, electromagnetic fields (seismo-electromagnetics), ground movement, weather conditions and unusual clouds, radon or hydrogen gas content of soil or ground water, water level in wells, animal behavior, and the phases of the moon.

- Scientific evaluations of prediction claims look for the following elements in a claim:

    1. A specific location or area
    2. A specific span of time
    3. A specific magnitude range
    4. A specific probability of occurrence

Early Warning System

- Magnitude problem - The distinction between small and large earthquakes can be made from the very first seconds of seismic energy recorded by seismometers (Richard Allen).

- Earthquake early warning provides an alarm that strong shaking is due soon to arrive, and the more quickly that the magnitude of an earthquake can be estimated, the more useful is the early warning. However, earthquake early warning can still be effective without the ability to infer the magnitude of an earthquake in its initial second or two.

- Animal early warning - Animal behavior reports are often ambiguous and not consistently observed. In folklore, some animals have been identified as being more able to predict earthquakes than others, especially dogs, cats, chickens, horses, toads and other smaller animals.

- It has been postulated that the reported animal behavior before an earthquake is simply their response to an increase in low-frequency electromagnetic signals. The University of Colorado has demonstrated that electromagnetic activity can be generated by the fracturing of crystalline rock. Such activity occurs in fault lines before earthquakes. According to one study, electromagnetic sensors yield statistically valid results in predicting earthquakes.

- Tidal forces - are magnified during and after an eclipse. The solar tide is approximately a third of the lunar tide. When the sun and moon are in alignment these tidal forces are combined.

- It is found that, there is a significant relationship to tidal forces and earthquakes in China and Taiwan. The relationship between 21 major earthquakes ($M_s \geq 7.0$) in land and the offshore area of Taiwan Island in the 20th century and the variance ratio of the lunar-solar tidal force are considered. The result indicates that the time of these earthquakes is closely related to the variance ratio of the lunar-solar tidal force (Fig 9.13).

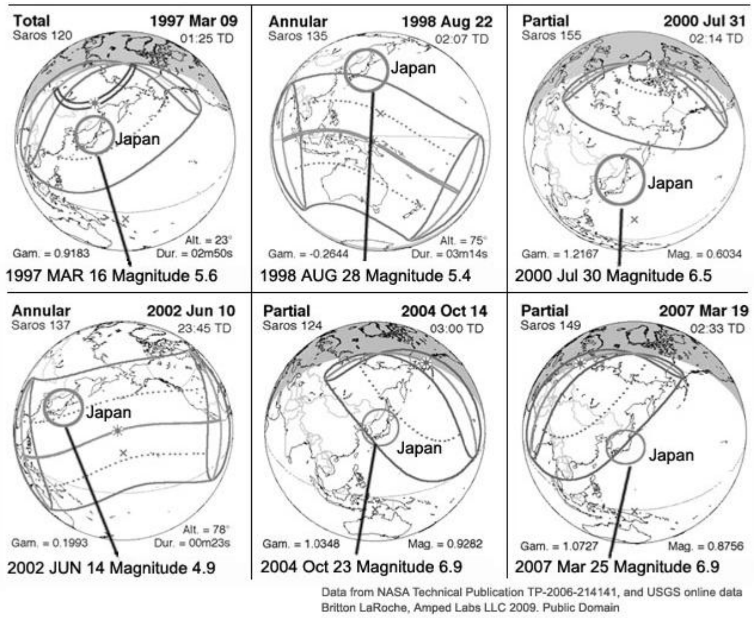

Fig 9.13: Eclipse and earthquake data, Japan 1997-2007

Topic 11

Socio Economic Impacts and Adjustments to an Earthquake prediction

- The social and economic consequences of earthquake forecasts are a subject of some controversy. Yet, as seismological research continues, numerous earthquake warnings from diverse sources will probably continue to be issued in various countries. For example, numerous forewarnings have been issued in China.

- In some countries, studies on the unfavorable as well as the propitious consequences of prediction have been made. For example, if the time of a large damaging earthquake in California were accurately predicted a year or so ahead of time, and continuously updated, casualties and even property damage directly resulting from the earthquake might be much reduced; but the communities in a wider region might suffer social disruption and decline in the local economy.

- The major social and economic responses nad adjustments that may occur are summarized in the Fig 9.14. Without an actual occurrence to draw upon, such assessments are, of course, highly tentative; the total reaction would be complex, because responses by the government, public, and private sectors could all vary.

- For example, if after the scientific prediction and official warning, massive public demand for earthquake insurance cuts off its availability, then temporary but drastic effects on property values, real estate sales, construction, investment, and employment might ensue in the region.

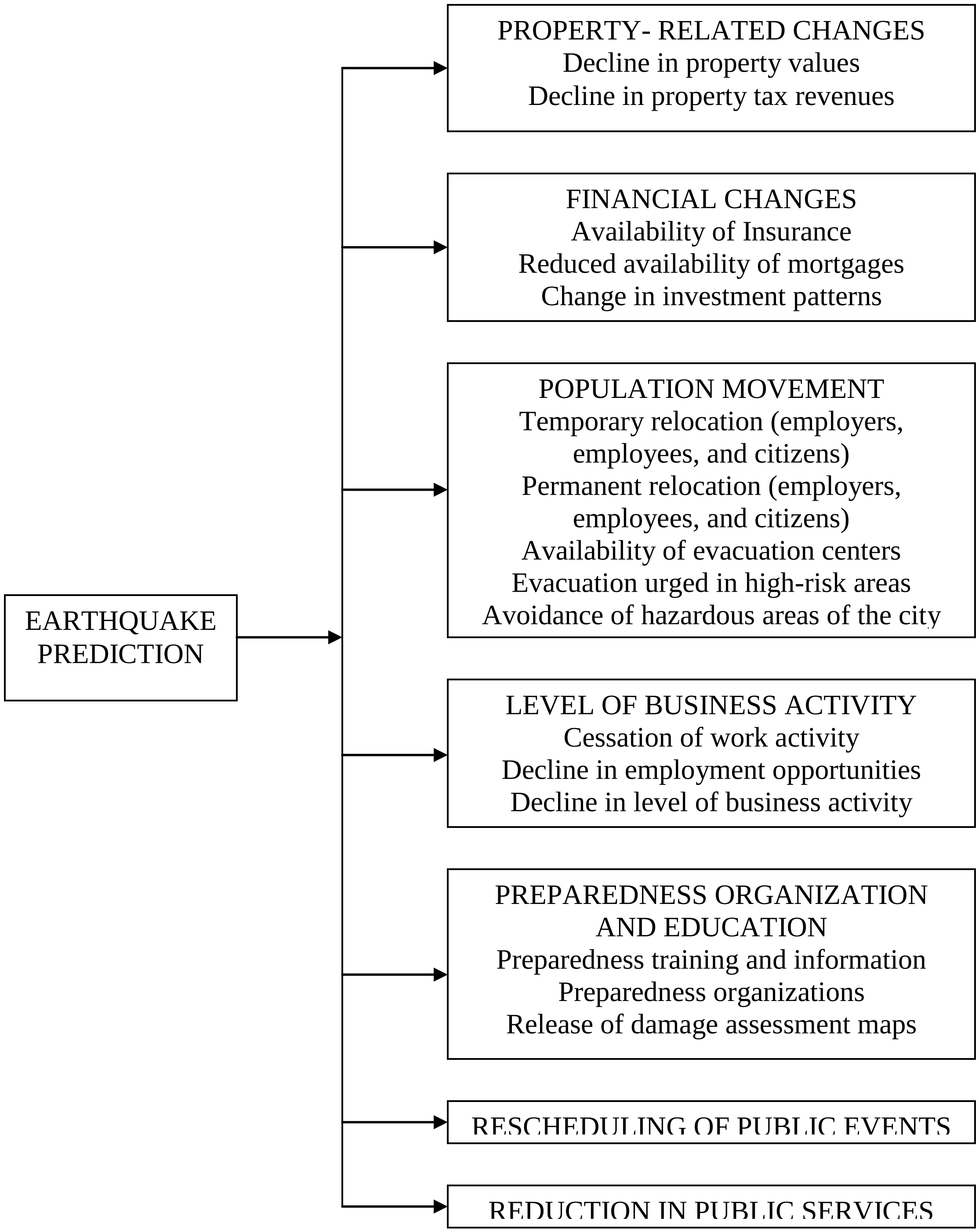

Fig 9.14: Socioeconomic Impact of Earthquake Prediction on Government, Business and Community.

Topic 12

Mitigation of Earthquake Risk

- The damage and loss caused due to earthquakes can be reduced, or mitigated, in a number of ways. Figure 9.15 indicates how, at each step of the earthquake risk process, mitigation of damage and loss is possible.

- Each of the mitigation approaches indicated in the spectrum of earthquake mitigation alternatives is a proven technology:

- Hazards such as faulting and shaking can be mapped. In many cases faults have been mapped in detail, with improved and more detailed mapping going on all the time. Shaking intensity maps are also readily available, This type of mapping identifies the existence of the specific hazard. If that hazard is poor soil, where liquefaction or ground failure might occur, then ground remediation may be required.

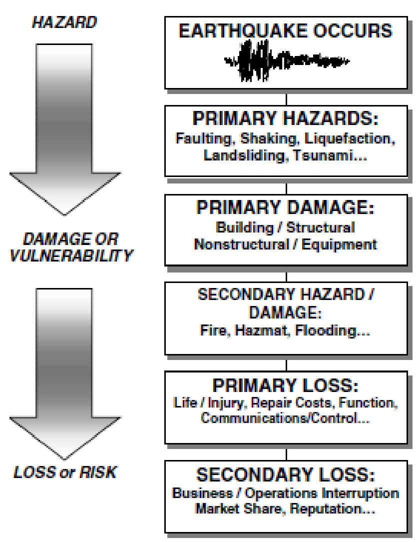

Fig 9.15: Earthquake Loss Process

- Primary damage mitigation is the purview of design professionals, who have developed a large toolkit for bracing, strengthening, or otherwise improving the earthquake performance of buildings and other structures, nonstructural elements, equipment, and contents.

- Secondary damage is typically due to the interaction of several problems, and can be a very complex issue. It is therefore best mitigated prior to the earthquake, through better handling of materials and improving of infrastructure.

- Loss is mitigated via damage control, that is, via improved emergency planning and response. Since the damage has not been prevented, coping with the damage so as to minimize loss is necessary.

- The other dimension of loss mitigation at this stage is financial, that is, earthquake insurance. Earthquake insurance can be effective in selected circumstances, but it does nothing for life loss or injury, and typically only partially offsets primary financial loss.

- Figure 9.16 shows different mitigation of earthquake damages

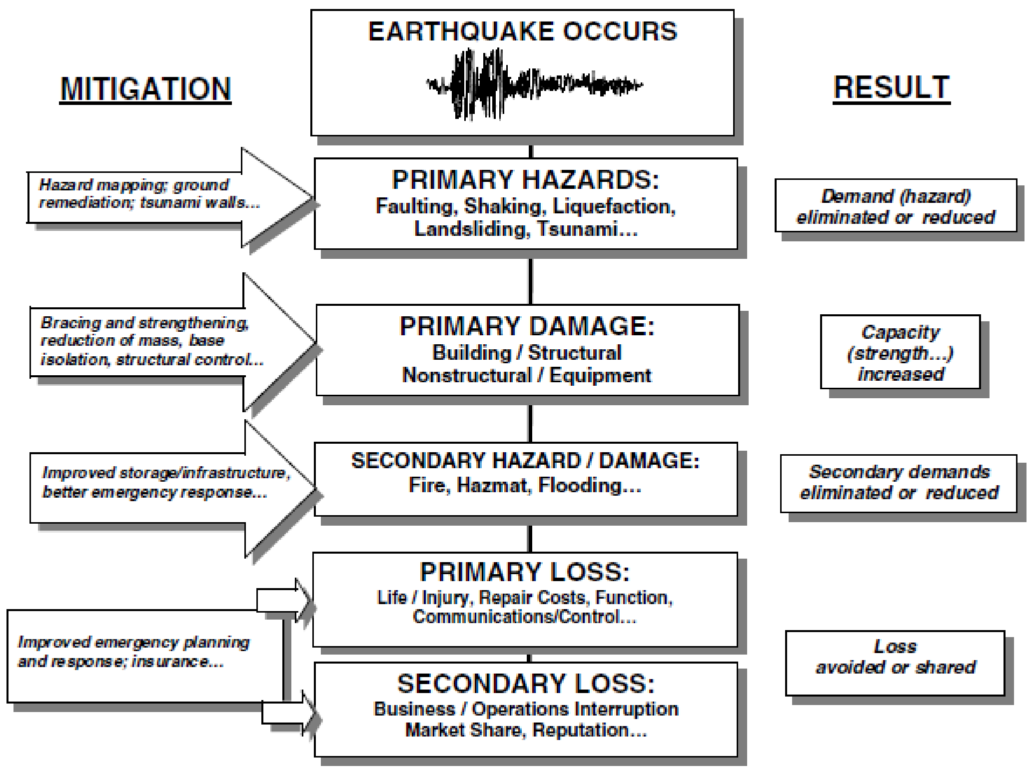

Fig 9.16: Mitigation of earthquake damage.

Topic 13

Earthquake Preparedness

- In order to mitigate the earthquake risk it is necessary to act at several levels of the society, in a pure scientific/technical point of view, involving the social, fiscal and political issues.

- The following general topics are of most importance:

  (i) Perception of the origin of earthquakes and of propagation of seismic waves;
  (ii) Understanding of the behavior of all kind of structures under seismic action;
  (iii) Rehabilitation and retrofit of existing structures;
  (iv) Development of appropriated code of practice,
  (v) Development of quality control to insure a correct application of all legislation.

In terms of earthquake preparedness, one can act at two different levels:

Institutional

1. Different Ministries (risk mitigation)
2. Civil Protection - Risk study; Information and education; Response preparedness (EMERGENCY PLANNING).

Individual

1. Home preparation;
2. Family emergency planning;
3. Self-protection measures.

- Because it is not possible to predict earthquakes, it is necessary to minimize the risk, preparing a Preventive Planning and to minimize the effects of the event, developing an Operational Planning.

- In order to minimize seismic risk, one should:

  (i) develop and enforce preventive measures;
  (ii) improve building regulations for construction and reinforcement;
  (iii) develop appropriate land use plans; and
  (iv) Carry out civil protection awareness and educational programs for the population, civil protection entities and decision makers.

- The measures to minimize the effects after the occurrence of the event should be prepared:

  (i) plan civil protection actions to activate when an earthquake occurs;
  (ii) Organize civil protection entities involved in aid operations, concerning its mission and operational procedures;
  (iii) Plan emergency means and resources and their allocation, and plan management.

These last issues require Emergency Master Plans and Detailed Response Plans for specific risks - i.e. the Seismic Risk Emergency Plan.

Lecture 9 in World Great Earthquakes, Large and Damaging Earthquakes of India