Lecture 10: Introduction to Seismic zones and codes, Global and National seismic hazard assessment mapping programs

Topics

- Introduction to Seismic zones
- Need for Seismic Zonation
- Types of Zonation
- Seismic zonation scales
- Component of Seismic Microzonation
- Macrozonation and Codal Provisions in India
- First Seismic Code
- Third Zonation Map
- Our Seismic Zone
- Global seismic hazard assessment programme (GSHAP) - Bhatia et al (1999)

Keywords: *Seismic Zonation, Types of zonations, Indian seismic code, GSHAP*

Topic 1

Introduction to Seismic zones

- Seismic Zonation may be termed as the geographic delineation of areas having different potentials for hazardous effects from future earthquakes. Seismic zonation can be done at any scale, national, regional, local, or site.

- The term Zoning implies that the parameter or parameters that characterize the hazard have a constant value in each zone. If, for example, for practical reasons, the number of zones is reduced (from five as is the case in large majority of national codes), we obtain a rather simplified representation of the hazard, which in reality has continuous variation.

- A seismic zone is a region in which the rate of seismic activity remains fairly consistent. This may mean that seismic activity is incredibly rare, or that it is extremely common. Some people often use the term “seismic zone” to talk about an area with an increased risk of seismic activity, while others prefer to talk about “seismic hazard zones” when discussing areas where seismic activity is more frequent.

- Many nations have government agencies concerned with seismic activity. These agencies use the data they collect about seismic activity to divide the nation into various seismic zones. A number of different zoning systems are used, from numerical zones to colored zones, with each number or color representing a different level of seismic activity.

- A seismic zoning map for engineering use is a map that specifies the levels of force or ground motions for earthquake-resistant design, and thus it differs from a seismicity map, which provides only the occurrence of earthquake information. The task of seismic zoning is multidisciplinary and involves the best of input from geologist, seismologist, geotechnical, earthquake and structural engineers.

Topic 2

Need for Seismic Zonation

- These maps identify the regions of a country or province in which various intensities of ground shaking may have occurred or may be anticipated.

- Maps of probabilistic hazard give an idea of the underlying statistical uncertainty, as is done in calculating insurance rates. These maps give, for example, the odds at which specified earthquake intensity would be exceeded at a site of interest within a given time span.

- Seismic zoning is used to reduce the human and economic losses caused by earthquakes, thereby enhancing Economic development and Political stability.

- New probabilistic maps have been developed as the basis of seismic design provisions for building practice. These usually give the expected intensity of ground shaking in terms of peak acceleration. The peak acceleration can be thought of as the maximum acceleration in earthquakes on firm ground at the frequencies that affect sizable structures.

- The losses due to damaging earthquakes can be mitigated through a comprehensive assessment of seismic hazard and risk. Seismic zonation of vulnerable areas for bedrock motion thus becomes important so that the planners and administrators can make use of it after applying appropriate amplification factors to take into account the local soil conditions, for better land use planning and safe development.

Topic 3

Types of Zonation

- Macrozonation - After the adoption of some over-simplified approaches in the fifties using micro tremor analysis (Kanai, 1957), in the sixties Medvedev (1977), proposed a zonation method based on an empirical correlation between the seismic impedance ratio and the variation of macro seismic intensity.

- For larger area like, zonation of country or continent macro level is adopted. Macrozonation are carried out considering the seismicity, geology in lager scales without considering geotechnical aspects.

- Seismic macrozonation consists of dividing a national territory into several areas indicating progressive levels of expected seismic intensity for different return periods. These zones can be described in terms of expected intensity, peak ground accelerations, or any other strong motion parameter. The number of zones into which a country is divided is fairly arbitrary.

- Microzonation – is a process that involves incorporation of geologic, seismologic and geotechnical concerns into economically, sociologically and politically justifiable and defensible land-use planning for earthquake effects so that architects and engineers can site and design structures that will be less susceptible to damage during major earthquakes.

- Microzonation should provide general guidelines for the types of new structures that are most suited to an area, and it should also provide information on the relative damage potential of the existing structures in a region.

- It consists of mapping in detail all possible earthquake and earthquake induced hazards. Microzonation is subdivision of a region into zones that have relatively similar exposure to various earthquake related effects.

- Nanozonation – this map provides dominant period at any site within the city. The design spectrum at each site is constructed using five parameters, all of which are derived from the dominant period value.

- This has been possible by two factors. The first is that local amplification is strongly governed by the very large impedance contrast between a soft surficial layer and its substratum. The second is the large number of strong motion stations that were installed after the disastrous 1985 earthquake. When the records are analyzed using spectral ratios, and the resulting transfer functions interpreted in terms of a 1D model, it becomes possible to interpolate site effects and predict the response everywhere.

- Appealing as the “nanozonation” is, this approach is currently not feasible at most cities. In addition, this approach cannot be envisaged when more than one factor contributes significantly to site amplification.

Topic 4

Seismic zonation scales

- Macrozonation- Earthquake hazard and the associated risks are usually mapped at the sub regional level because geoscientists usually work at very small scales, covering large areas, whereas development planners work at large scales covering small areas. The most elegant approach would, therefore, be to proceed from whole to part hence scales for macrozonation usually used are more than 1:1,000,000

- Microzonation - shall be graded based on the scale of the investigation and details of the studies carried out shown in Table 10.1. The technical committee on earthquake geotechnical engineering of the International society of soil mechanics and foundation engineering states that:

    - The first grade (Level I) map can be prepared with scale of 1:1,000,000 – 1:50,000 and the ground motion were assessed based on the historical earthquakes and existing information of geological and geomorphological maps.

    - If the scale of the mapping is 1:100,000-1:10,000 and ground motion is assessed based on the microtremor and simplified geotechnical studies then it is called second grade (Level II) map.

    - In the third grade (Level III) map ground motion has been assessed based on the complete geotechnical investigations and ground response analysis with a scale of 1:25,000-1:5,000.

- Nanozonation – it may be termed as rigorous zonation, where a very high and very detailed level of zonation is required, for examples scales less than 1:5000, additional site investigation data will be needed, specific to the site in question. The findings from such investigation may be incorporated into computer aided analysis of seismic ground response, slope instability behavior, or liquefaction potential.

- This level of zonation, requiring detailed site specific information, is generally expensive, but for sites where hazard potential is considered very high, or existing or proposed development is regarded as critical or of high value, this level of investment may be warranted.

Table 10.1: Recommended Grade of microzonation with method range of scale

	Grade I	Grade II	Grade III
Ground Motion	• Historical Earthquakes and existing information • Geological maps interviews with local residents	• Microtremor • Simplified Geotechnical study	• Geotechnical Investigations • Ground response analysis
Slope Stability	• Historical earthquakes and existing information • Geological and Geomorphological maps	• Air Photos and remote sensing • Field studies • Vegetation and Precipitation data	• Geotechnical Investigations • Analysis
Liquefaction	• Historical earthquakes and existing information • Geological and Geomorphological maps	• Air photos and remote sensing • Field studies • Interviews • With local residents	• Geotechnical Investigations Analysis
Scale of Mapping	1:1,000,000-1:50,000	1:100,000-1:10,000	1:25,000-1:5,000

Topic 5

Component of Seismic Microzonation

- Figure 10.1 represents a scheme of microzonation methodology commonly adopted. As it is possible to see it encompasses the whole topics necessary to perform a microzonation that basically can be subdivided into three major items:

  (1) Evaluation of the expected input motion

  (2) Site effects analysis

  (3) Preparation of microzonation maps and recommendations for practical Application

- Now, whenever the scheme is worldwide applied, the relative importance one component has with respect to the others is subjected to large variability due both to the physics of the phenomenon and to goal of the study.

- Actually the following factors play the key role:

a) The administrative situation of the zone (regulations and seismic codes are significantly different country to country and in some cases even region by region)

b) The size of the expected earthquake (generally the stronger the earthquake the larger becomes the importance of the source with respect to the amplification factors),

c) The nature of soils (for instance, the presence of potentially liquefying soils urges detailed and expensive geotechnical investigations).

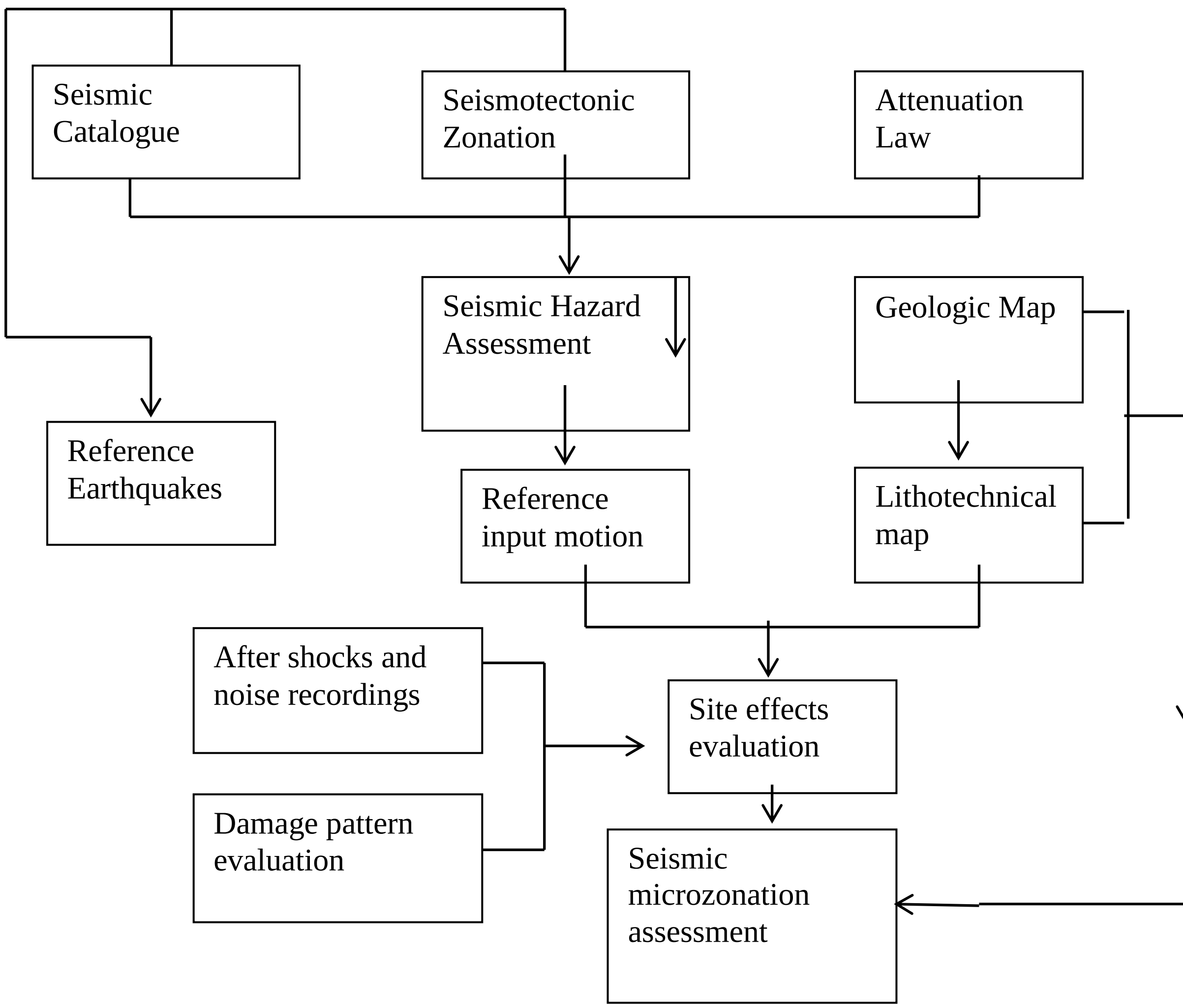

Fig 10.1: Scheme of microzonation methodology

Topic 6

Macrozonation and Codal Provisions in India

- The occurrence of earthquake in India is due to the drifting of the so called Indian Plate. Whenever and wherever these plates slide against each other, a tremendous amount of energy is released and causes the severe destruction.

- Indian earthquake problem cannot be overemphasized. More than about 60% of the land area is considered prone to shaking of intensity VII and above (MMI scale). In fact, the entire Himalayan belt is considered prone to great earthquakes of magnitude exceeding 8.0, and in a short span of about 50 years, four such earthquakes have occurred: 1897 Assam (M8.7), 1905 Kangra (M8.6), 1934 Bihar-Nepal (M8.4), and 1950 Assam-Tibet (M8.7).

- The structures located in the seismic zones should be analyzed and designed for the expected seismic force to minimize the structural damages from falling of beams/columns and to protect lives and property.

- Dr. Thomas Oldham, the first Director of the Geological Survey of India (GSI), is credited with laying the foundation of the scientific studies of earthquakes in India (West, 1937).

- He compiled the well-known catalogue of Indian earthquakes and carried out investigations of the Cachar earthquake of 1869. His son, R.D. Oldham, also went on to become Director of the GSI and contributed very substantially to the earthquake studies. His memoir (Oldham, 1899) of the 1897 Assam earthquake was considered by Richter (1958) as one of the most valuable source books in seismology.

- Indian sub-continent has been classified into five seismic zones as per IS1893-1984. The increased seismic activity during the last two decades forced the reclassification into four seismic zones as per IS 1893 (Part I): 2002.

- The main seismic code (IS: 1893-1962) has been revised in 1967, 1970, 1975, and 1984; its next revision is now in progress. The major modifications in this code are,

- The seismic zone map is revised with only four zones, instead of five zones. Zone I has been merged into Zone II.

- The values of seismic e peak ground acceleration considering maximum considered earthquake (Mc zone factors have been changed. These now reflect more realistic values of effective) and service life of structure in each seismic zone.

- Response spectra are now specified for three types of foundation strata, namely, rock and hard soil, medium soil and soft soil.

- Empirical formula for estimating the fundamental natural period T of multi-storied buildings with regular moment resisting frames has been revised.

- The idealization of response reduction due to ductile deformation or frictional energy dissipation in the cracks is brought into code by introducing response reduction factor.

- The Indian Concrete Journal brought out a special issue on the 1934 Bihar-Nepal earthquake with excellent well-captioned photographs. After the Anjar (Cutch) earthquake of 1956, two articles were published in the same journal outlining the design principles of earthquake-resistant buildings. A monograph on earthquake resistant buildings was published in 1954 which was revised in 1958 and 1965.

- Institutional base for earthquake engineering was established around 1958, when after a visit to the California Institute of Technology (Caltech), Professor Jai Krishna started teaching and research in earthquake engineering at the University of Roorkee. First of the four-yearly symposium on earthquake engineering was organized at Roorkee in 1959.

- In 1993, with publication of four new seismic codes (IS:13827, IS:13828, IS:13920, and IS:13935), India became perhaps the first country to have developed codes on low-strength non-engineered masonry constructions.

- Indian codes, developed by the Bureau of Indian Standards (BIS), are not mandatory and are only in the nature of guidelines. The construction as such is governed by the municipal byelaws which are within the jurisdiction of the state governments. Unfortunately, the seismic provisions have not yet been incorporated into the building bye-laws.

- Two major organizations, Geological Survey of India and Seismology Division of the India Meteorological Department, have had a long history of working on earthquakes. Besides, a number of research institutions in earth sciences were set up after independence which has considerable interest in earthquakes.

- The earthquake engineering developments in the 1930's were spearheaded by the professional engineers from railways and military. However, after the setting up of DEQ at Roorkee the discipline came to be regarded as some sort of a super-specialty and the professionals tended to leave the subject for the academics.

- Since 1992, IIT Kanpur has conducted numerous short courses on seismic design of reinforced concrete buildings, the most common type of multi-storey buildings in urban areas.

Topic 7

First Seismic Code

- Some of the largest earthquakes of the world have occurred in India and the earthquake engineering developments in the country started rather early. After the 1897 Assam earthquake a new earthquake resistant type of housing was developed which is still prevalent in the north-east India. The Baluchistan earthquakes of 1930's led to innovative earthquake resistant constructions and to the development of first seismic zone map.

- The earthquake historical records in India are available only for about 200 years. The records of the 19th century as mentioned above are mostly newspaper descriptions of what happened at different places during a particular earthquake.

- The 1935 Quetta earthquake was interesting from several view points. For the first time, serious and systematic efforts were made in the country at earthquake resistant constructions and for developing earthquake codes.

- The Geological Survey of India (GSI) first came up with the national seismic hazard map of India in 1935 after the 1934 Bihar-Nepal earthquake.

- In 1962, the BIS published the seismic zonation map of India (BIS, 1962) based on earthquake epicenters and the isoseismal map published by the GSI in 1935 (Table 10.2). The earthquakes of magnitude 5 and above with maximum Modified Mercalli Intensity (MMI) scale ranging from V to IX was considered.

Table 10.2: Seven seismic zones based on BIS 1962 and 1966 with its expected maximum MMI

Seismic zone	**Probable maximum intensities (MMI scale)**
0	Below V
I	V
II	VI
III	VII
IV	VIII
V	IX
VI	X and above

- The first Indian seismic code was published in 1962 (IS:1893-1962), It provides seismic design criteria for buildings, bridges, liquid retaining tanks, stacks, gravity dams, earth dams, and retaining walls.

- In the first zoning exercise (1959-1962) it was thought that since a map is being presented for the first time to the general public, it should conform to historical indications only. It was thus a useful historical picture of the severity of seismicity of a region. In this zoning map, the Himalaya and northeast India were graded into zones VII-IV, and the Deccan Plateau was marked as zone zero.

- The first formal zone map (IS: 1893-1962) shown in Fig 10.2 divided the country into seven seismic zones (0 to VI) corresponding to areas liable to MM intensity of: less than V, V, VI, VII, VIII, IX, X and above, respectively.

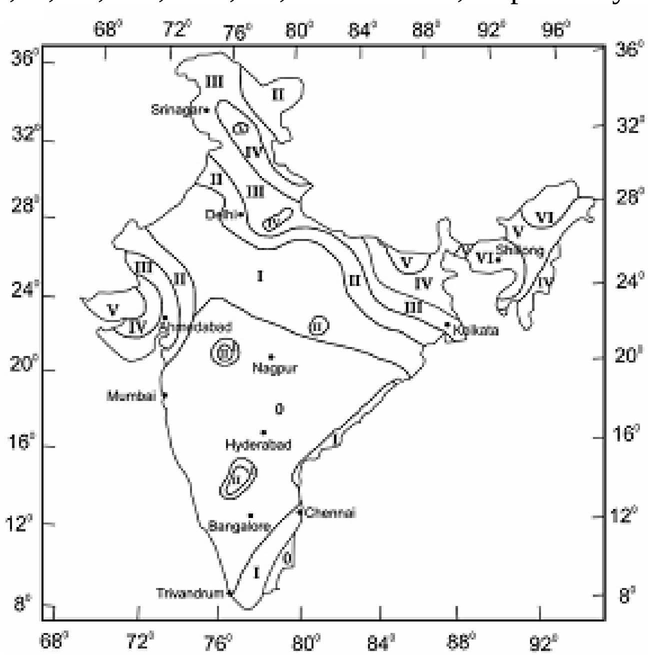

Fig 10.2: Seismic zonation map of India prepared in 1962 (BIS, 1962)

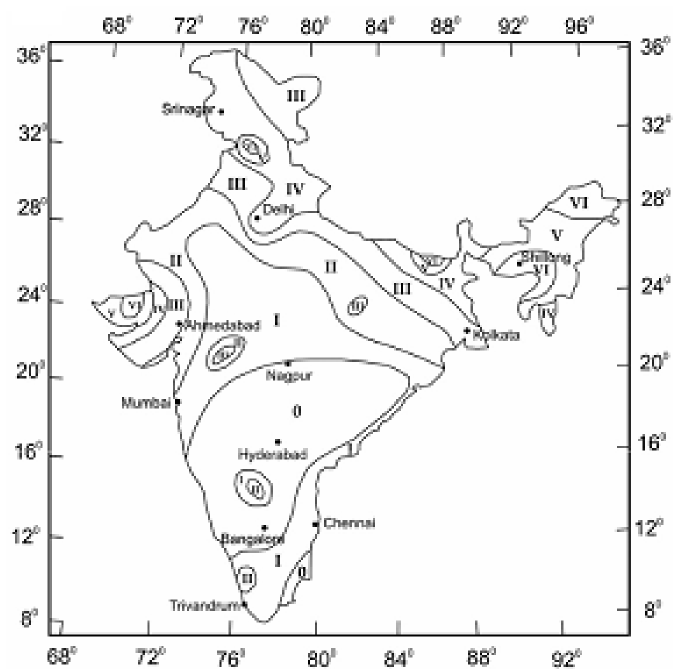

Fig 10.3: Seismic zonation map of India prepared in 1966 (BIS, 1966)

Topic 8

Third Zonation Map

- Another code (IS: 4326) was published in 1967 (revised in 1976 and 1993): it outlines the aseismic design and construction requirements for buildings. a comprehensive earthquake catalogue was published in 1983 (ISET, 1983).

- The 1967 Koyna earthquake, M 6.7, Necessity arose to review the zoning, particularly in the Deccan Plateau. Several updated geological, geophysical and seismological information were considered. The zone map went through a major revision (IS: 1893-1970). It reduced the number of zones from seven to five (I to V). Table 10.3 shows the zones and the corresponding probable maximum intensities.

Table 10.3: The five seismic zones based on the BIS 1970 and 1984 with its expected maximum MMI (Prakash, 2004).

Seismic zone	Probable maximum intensities(MMI scale)
I	V
II	VI
III	VII
IV	VIII
V	IX or more

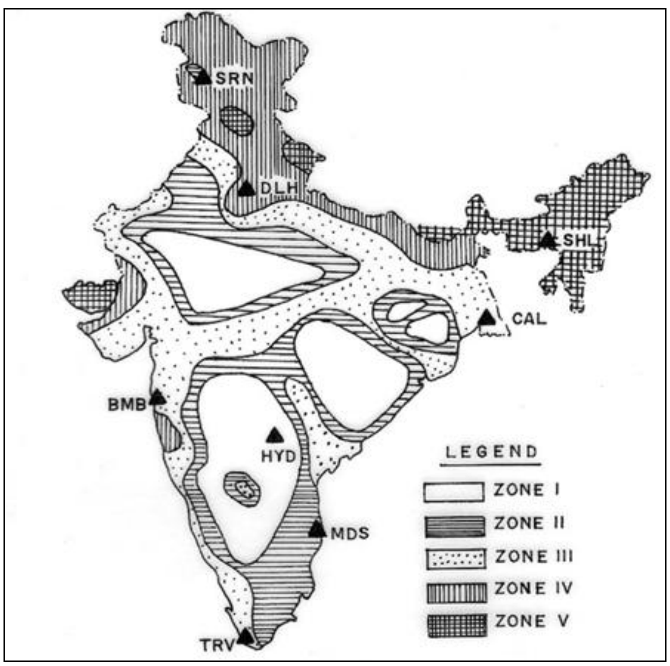

Fig 10.4: Revised seismic zoning map of India (BIS, 1893-1970). Solid triangles indicate WWSSN stations established in 1964. SRN: Srinagar, DLH: Delhi, SHL: Shillong, BMB:

Bombay, MDS: Madras, TRV: Trivandrum, HYD: Hyderabad observatory is run by the NGRI/GEOSCOPE.

- Occurrence of the 1993 Killari earthquake, mb 6.3, in the so-called 'safe zone' of Deccan Plateau, and subsequently the 1997 Jabalpur earthquake (mb 6.0), and the 2001 Bhuj earthquake (Mw 7.7) necessitated a review of the seismic zoning map of the country.

- In the 1996 revision exercise shown in Fig 10.3, the geological and geophysical data were considered. The tectonic features were accounted for in modifying the zoning lines. The main zones in the north were made more or less parallel to the Himalayan tectonic trends, and the Deccan Plateau was still showing as a 'safe zone'. Two major changes were made in this map; 'zero zone' in the Deccan Plateau was abolished, and merging of most of the zones V and VI into one zone (V). Total number of zones were thus reduced from 7 to 5 as shown in Fig 10.5.

- With more and more seismological data that are now available from the upgraded observatories and new networks, the map is upgraded and is shown in Fig. 10.5.

- Zones I and II were combined and the Peninsular India was modified too. The new zone placed the 1993 Latur earthquake in zone III. The areas falling under zone V is most vulnerable to earthquakes.

- Some of the country's most devastating earthquakes occurred in zone V. The areas under this zone are the Andaman and Nicobar Islands, the entire northeastern part of India, parts of northwestern Bihar, the Kangra Valley in Himachal Pradesh, the eastern part of Uttaranchal, the Rann of Kachchh in Gujarat and the Srinagar area in Jammu and Kashmir.

- Two major metropolitan cities, with a high population density, i.e. Delhi, lie in zone IV, and Kolkata, at the boundary of zone III and IV of the zonation map.

- The zone V is assigned peak ground acceleration (PGA) 0.40g, zone IV 0.25g, III 0.20g and zone II 0.10g. Table 10.4 below shows the seismic zones and the expected Intensity in Comprehensive Intensity Scale (CIS-64) (Prakash, 2004)

Table 10.4: The seismic zones and the expected Intensity in Comprehensive Intensity Scale (CIS-64) (Prakash, 2004)

Seismic zone	Intensity
II	VI and below
III	VII
IV	VIII
V	IX and above

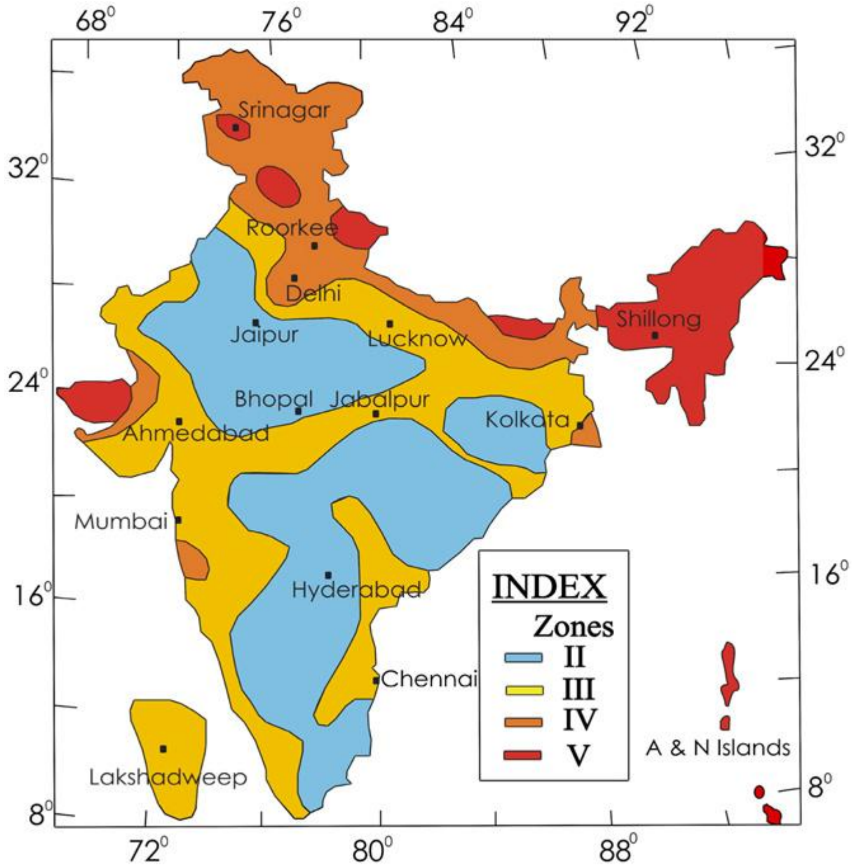

Fig 10.5: Upgraded seismic zoning map of India (BIS, 2004)

Topic 9

Our Seismic Zone

- Earthquake hazard of the country is being monitored mainly by Geological Survey of India (GSI) and the India Meteorological Department (IMD). A macro-level map has been prepared, which divides the country into four hazard zones, V to II, of various probable maximum intensities on a decreasing scale.

- Earthquake risk is the product of the hazard intensity and the vulnerability of buildings and the output of a seismic risk analysis could give the probability of damage and loss from a nearby earthquake. Quantification of risk would therefore require socio-economic and housing statistics.

- A comprehensive study of vulnerability of buildings and structures to various earthquake intensities has not been conducted in a systematic way in the country so far. A proper way of presentation of vulnerability versus earthquake intensity is to develop vulnerability functions such as those grossly developed for various building types under the earthquake intensities.

- Under the initiatives of the Ministry of Urban Development, a Vulnerability Atlas of India has been prepared during the period 1994–1997, in which the earthquake, cyclone and flood hazard maps for every state and union territory of India have been prepared to a scale of 1: 2.5 million. In these maps, the boundaries of the districts are clearly shown so that the areas of the districts prone to the various intensities of hazards are clearly visible.

- Based on the experience of the last decade in dealing with natural disasters in India, a national mission named 'Natural Disaster Management Information Services Through Space Technologies' is in the process of being launched in India on an operational scale during 1999–2003 for the entire country.

- Population pressure, environmental degradation and unplanned urbanization are some of the major factors contributing to increased vulnerability in the country. As such, need has been felt to accelerate the pace of disaster mitigation efforts in the country. It is planned to lay more emphasis on the following areas:

    1. Linkage of disaster mitigation with development plans;
    2. Effective communication system;
    3. Use of latest information technology;
    4. Insurance in all relevant sectors;
    5. Extensive public awareness and education campaigns, particularly in the rural areas;
    6. Legal and legislative support;
    7. Greater involvement of NGOs/private sector.

- The GSI has included the preparation of seismotectonic atlas of India in its program, which will consist of 43 sheets of maps covering 3° longitude × 4° latitude in each sheet to scale of 1: 1 m. The maps will be of derived nature, and intended to include earthquake data, gravity data, magnetic data, stress field data, geological faults, major and minor lineaments and geodetic data. Seismotectonic maps so generated could be used for the seismic hazard risk assessment and preparation of reliable seismic zoning map of India.

- For rapid progress towards appreciable reduction in the disastrous impact of natural hazards, the policy of the government may include the following:

    1. To invest on global observations, and to give a boost to the science of observation and measurement on which the real progress depends.
    2. To enhance the scientific content of prediction methodologies and reliability of forecast, if and when it becomes feasible.
    3. To map the earthquake hazards on a large scale and link the maps intimately with the process of development planning; to conduct micro-zonation of urban areas at earthquake risk.

4. To foster closer partnerships with financial and legal institutions, insurance companies, community-based organizations and industry.
5. To create an All India Institutional Network, to involve in disaster preparedness, mitigation management and prevention.
6. To invest more on public awareness, education, training and human resource development in the area of disaster mitigation.

Topic 10

Global seismic hazard assessment programme (GSHAP) - Bhatia et al (1999)

- A probabilistic seismic hazard map of India and the bordering region was prepared by Bhatia et al. (1999) shown in Fig 10.6 under the banner of the Global Seismic Hazard Assessment Program (GSHAP).

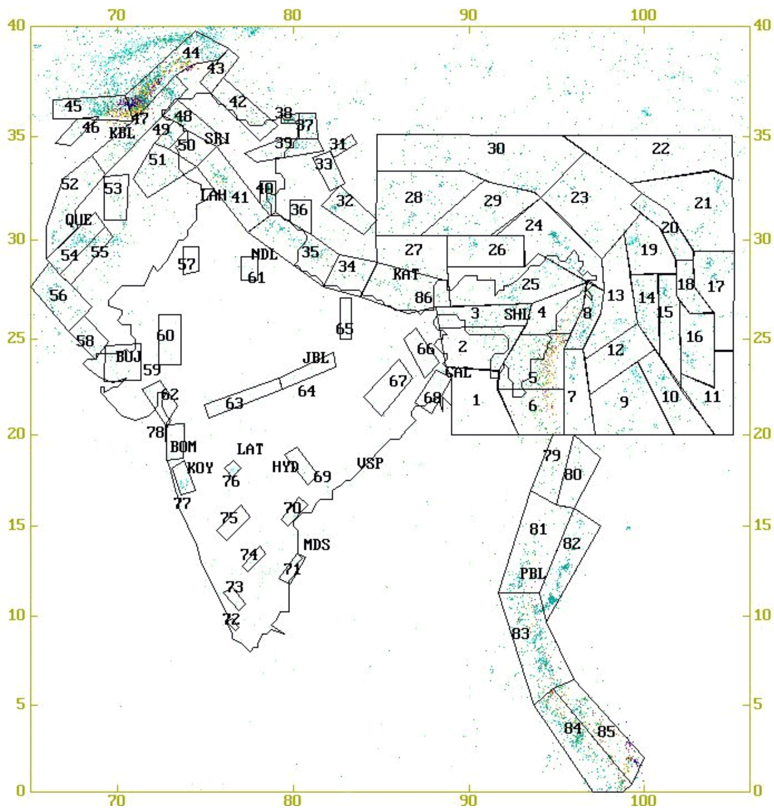

Fig 10.6: The eighty six potential seismic source zones considered for the probabilistic seismic hazard map of India (after Bhatia et al., 1999)

- They identified eighty six potential seismic source zones on the basis of the major tectonic features and seismicity trends. The hazard level was given in terms of PGA, which was derived from the Joyner and Boore (1981) attenuation relation.

- The PGA was computed for a probability of exceedance of 10% in 50 years. The PGA varies from 0.05 g to 0.5 g. The hazard level is higher along the plate margins as seen from Fig. 10.7.

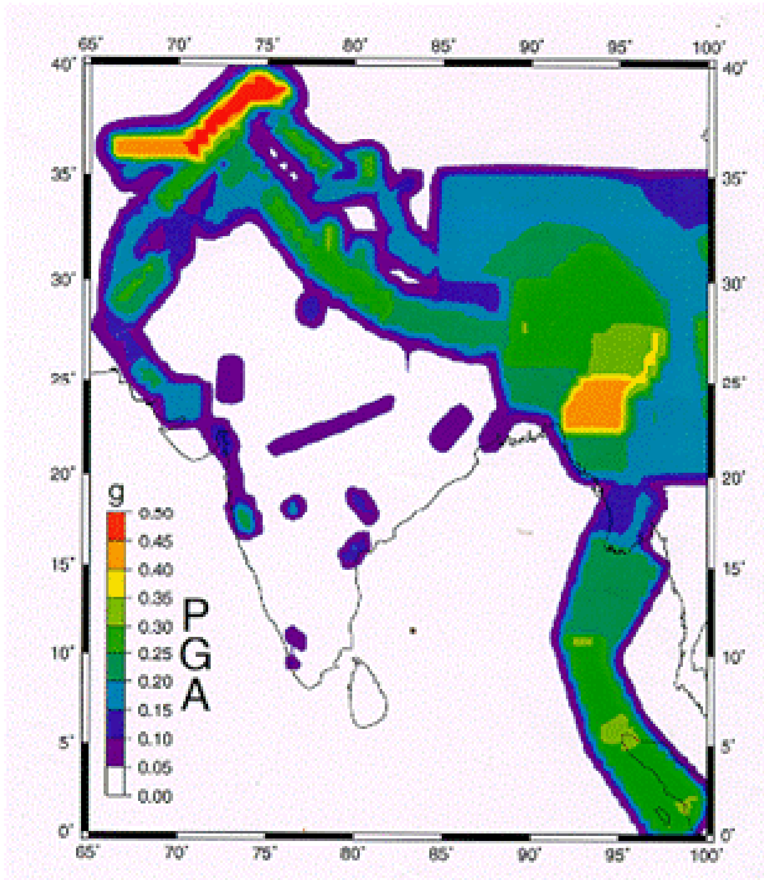

Fig 10.7: Seismic hazard map of India and adjoining regions for 10% probability of exceedance in 50 years (after Bhatia et al., 1999).

- The expected PGA for the Arakan-Yoma ranges is highest with the values ranging from 0.35 g to 0.4 g. The PGA for the Peninsular India is of order 0.05 g to 0.1 g. The hazard map was broadly classified into four zones with the hazard parameter as 0.1 g, 0.2 g, 0.3 g and 0.4 g (Table 10.6).

Table 10.6: The PGA predicted by GSHAP Model (Bhatia et al., 1999)

Seismic zone	PGA
I	Upto 0.1g
II	0.10-0.20g
III	0.20-0.30g
IV	0.30-0.40

- The use of the attenuation relationship of Joyner and Boore (1981) for the entire India is debatable as the attenuation relationship, which is applicable to a specific region, cannot be extended for the entire country that covers diverse geological provinces.

- The PGA estimated by Bhatia et al. (1999) is an underestimation of the hazard for certain regions of the country as has been shown by different authors (Panza, 2007; Mohanty and Walling, 2008a; Anbazhagan et al., 2009).

- The PGA of some past earthquakes has been compared in Table 10.7 with the expected PGA by GSHAP (Giardini et al., 1999) and it was found that the observed PGA is much higher than that estimated by the GSHAP.

Table 10.7: Comparison of the PGA estimated by GSHAP with the observed PGA (Panza, 2007)

Date	Location	Expected PGA(g)	Observed PGA(g)
1995, January 17	Kobe, Japan	0.40-0.48	0.70-0.80
2001,January 26	Gujarat, India	0.16-0.24	0.50-0.60
2003,May 21	Bourmerdes, Algeria	0.08-0.16	0.30-0.40
2003,December 26	Bam, Iran	0.16-0.24	0.70-0.80

- It can be seen that the ground motion given at a regional scale is insufficient for the hazard assessment and the hazard estimation has to be addressed at a local scale but nevertheless, the seismic zonation map can still provide a guideline for the building code and for the future planning.

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