

**Lecture 11: Safety of Individual Site; Concept of Seismic Microzonation; Need for Microzonation; Types and Scale; Methodology****Topics**

- Introduction to Seismic Microzonation
- Steps for Seismic Microzonation
- Seismic Hazard Estimation studies in Southern India
- Microzonation of Jabalpur
- Microzonation of Delhi
- Microzonation of Sikkim, Himalaya
- Microzonation of Guwahati
- PSHA for Northeast India
- Seismic hazard estimation for Mumbai city
- Seismic microzonation of Dehradun
- Seismic Microzonation of Haldia
- Seismic Microzonation of Talchir Basin
- Ongoing Seismic microzonation of other cities in India

**Keywords:** *Seismic Microzonation, steps for zonation, Microzonation in India,*  
**Topic 1**

**Introduction to Seismic Microzonation**

- Seismic microzonation can be defined as mapping of seismic hazard at local scales to incorporate the effects of local soil conditions.
- In general terms, microzonation is the process for estimating the response of soil layers under earthquake excitations and thus the variation of earthquake characteristics on the ground surface. Seismic microzonation is the initial phase of earthquake risk mitigation and requires multidisciplinary approach with major contributions from geology, seismology, geotechnical and structural engineering.
- Microzonation falls into the category of “applied research”, that is, to perform a microzonation that will not (or cannot) be applied is waste of time. It means that the typologies of expected results must be defined with local administrators (or in some cases central government).
- The important places of concern for which seismic microzonation needs to be carried out is the urban or upcoming urban area that falls under the high seismic hazard zone and also for places with moderate (or low) hazard but where amplification would be expected because of the local geological conditions.

- The damage pattern due to an earthquake depends largely on the local site condition and the social infrastructures of the region with the most important condition being the intensity of ground shaking at the time of the earthquakes.
- Contrasting seismic response is observed even within a short distance over small changes in the geology of the site. Moreover, designing and constructing all structures everywhere to withstand conceivable future earthquake is economically not viable.
- Rapid urbanization is a factor that calls for construction of mega structures, and the main reason for human loss and property damage is when due importance is not given for adequate preparation for possible hazard.
- Microzonation works are carried out in important cities like Delhi, Dehradun, Gujarat, Guwahati, Haldia, Jabalpur, Sikkim and Talchir.
- The microzonation map can serve many purposes for the Urban Development Authorities as
  1. It can offer valuable information to the engineers for the seismic designs of buildings and structures
  2. Assessment of seismic risk to the existing structures and constructions, land use management and also for the future construction of defense installation, heavy industry, and important structures like dams, nuclear power stations and other public utility services.
  3. Estimation of the potential for liquefaction and landslides. It also provides the basis for estimating and mapping the potential damage to buildings.
  4. Mapping the losses expected from a particular level of seismic shaking is called microzonation for risk.
  5. The main purpose of microzonation is to provide the local authorities with tools for assessing the seismic risk associated with the use of lands as well as to estimate the seismic motion to be used in the design of new structures and/or retrofitting existing ones.
- Microzonation for seismic risk is a mapping of the distribution of potential monetary losses associated with the occurrence of a mapped distribution of seismic hazard. In effect, microzonation for risk adds another layer of information to microzonation for seismic hazard.
- Seismic hazard analysis is the crucial element in a microzonation study. To plan and use a microzonation study effectively requires an understanding of how the input to the hazard analysis is developed, the ways in which the analysis may be carried out and the uncertainties associated with almost every component of the analysis.
- A Seismic microzonation study consists of three stages:

- (1) Estimation of the regional seismic hazard,
  - (2) Determination of the local geological and local geotechnical site conditions
  - (3) Assessment of the probable ground response and ground motion parameters on the ground surface.
- There may be differences among the adopted procedures with respect to these three stages. These differences mostly arise from different intentions that produced microzonation maps and different levels of accuracy achieved based on the available input data in terms of local geological and geotechnical site conditions.
  - One preference may be to produce microzonation maps to be used mainly for city and land use planning. A second preference is to use the microzonation maps to estimate the possible earthquake characteristics for the assessment of structural vulnerability in an earthquake scenario study. A third preference may be to provide input for the earthquake design codes

## **Topic 2**

### **Steps for Seismic Microzonation**

- Seismic hazard analysis and microzonation are grouped in to the following seven major groups as shown in Figure 11.1:
- The first step illustrates the assessment of the expected ground motion using the deterministic and probabilistic seismic hazard analysis.
- The Second Step involves the site characterized for the study area at local scale of 1:20,000 using geotechnical and shallow subsurface geophysical data.
- Third step is the study of local site effects using first and second part output data and producing the ground level hazard parameter.
- Forth step is the assessment of liquefaction potential considering the site amplification and soil properties.
- Fifth step is the landslide hazard assessment valid only for hilly terrains.
- The sixth step is the tsunami hazard mapping which is valid only for coastal regions.
- The final step is integration of all the above maps by assigning proper ranks and weights based on importance to prepare the final zonation map of region.

- Finally microzonation maps are prepared in terms of ground motion parameters and factor safety against liquefaction.

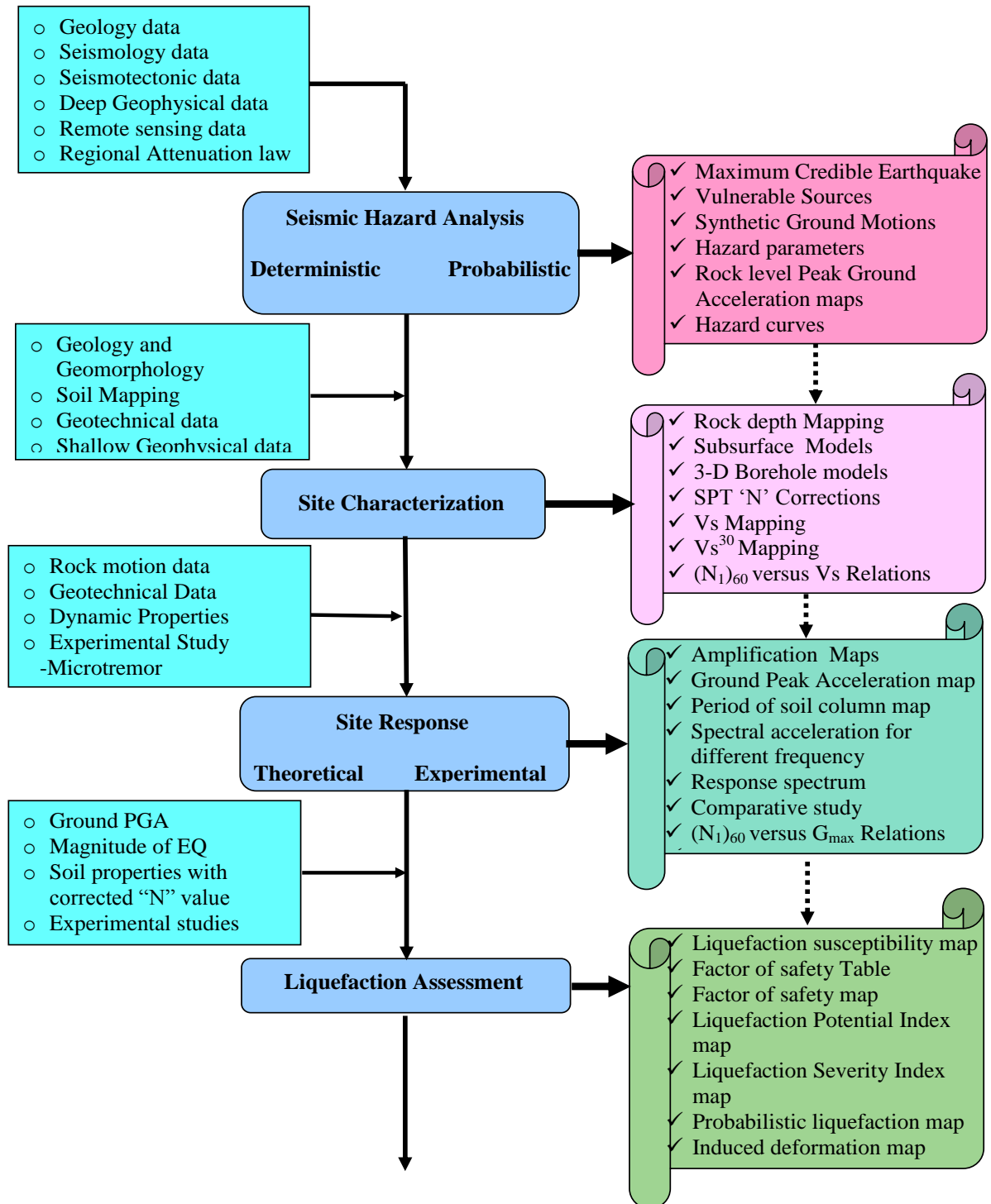


Fig 11.1(Part a): Steps followed for seismic hazard and microzonation.

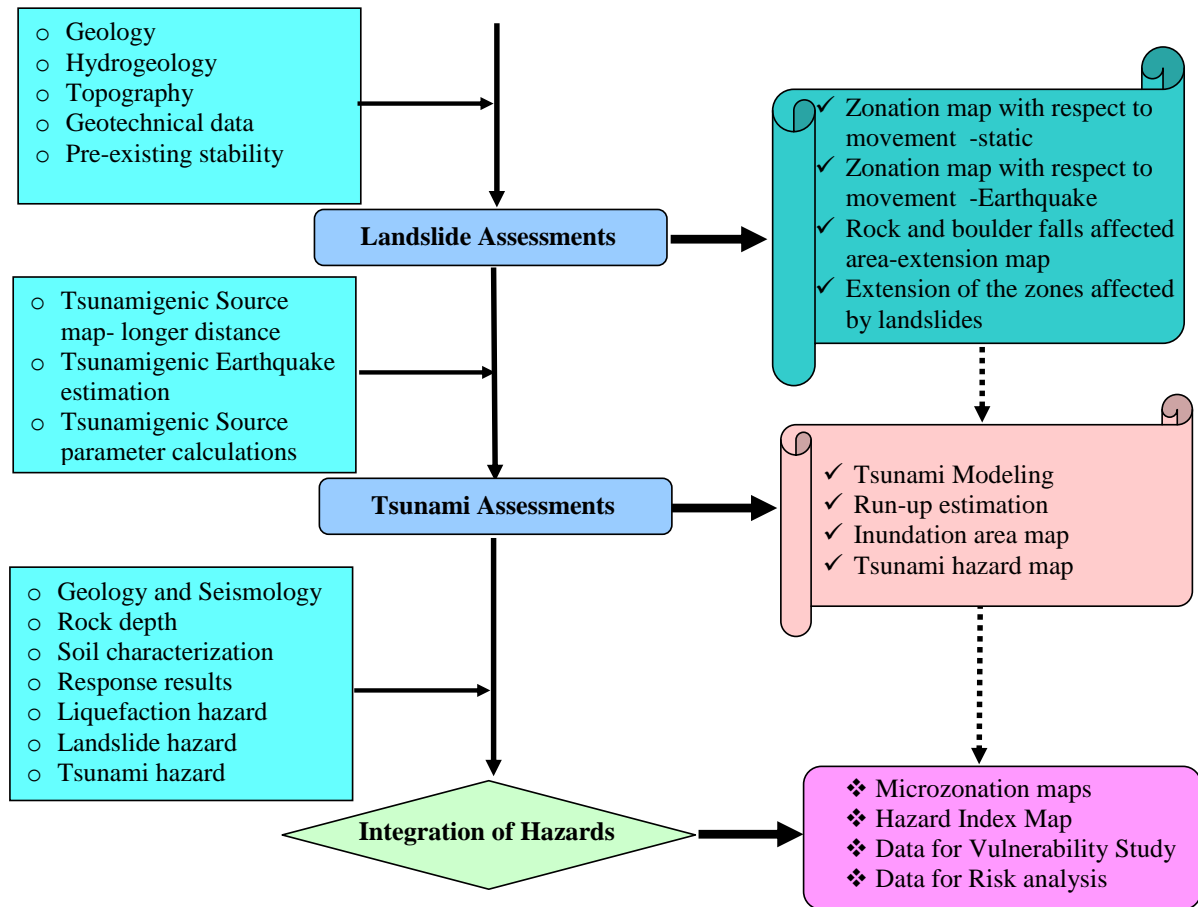


Fig 11.1(Part b): Steps followed for seismic hazard and microzonation.

- **Deterministic Seismic Hazard Analysis** - DSHA can be described in four steps as shown in Figure 11.2:
  1. Source characterization which includes identification and characterization of all earthquake sources which may cause significant ground motion in the study area.
  2. Selection of the shortest distance between the source and the site of interest.
  3. Selection of controlling earthquake i.e. the earthquake that is expected to produce the strongest level of shaking.
  4. Defining the hazard at the site formally in terms of the ground motions produced at the site by the controlling earthquake.

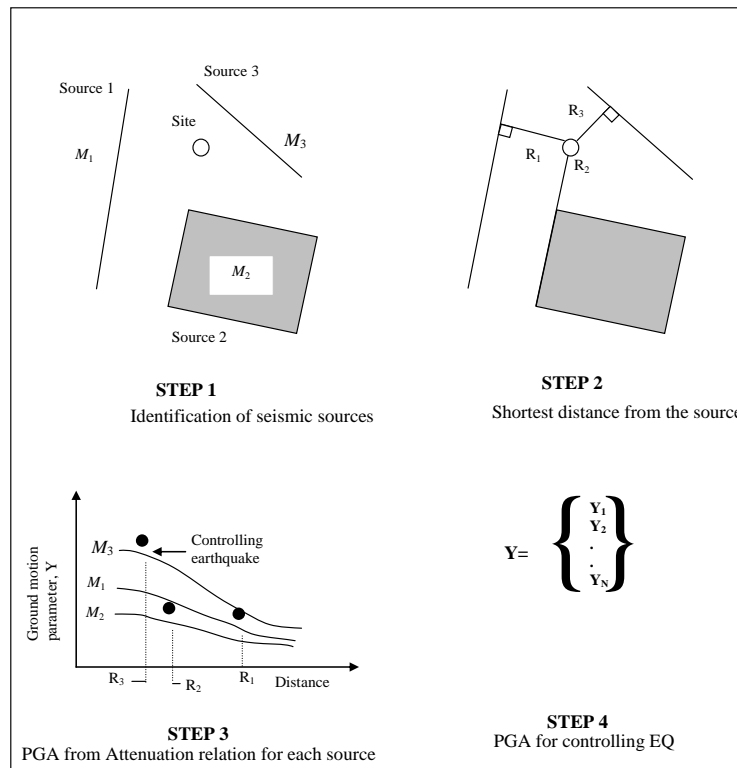


Fig 11.2: Different steps for deterministic seismic hazard analysis (after Kramer, 1996).

- **Probabilistic Seismic Hazard Analysis** - The PSHA procedure can also be described in four steps as shown in Figure 11.3:
  1. Identification of earthquake sources such as active faults, which may affect the study area. Characterize the probability distribution of potential rupture locations within the source.
  2. Characterization of the seismicity of each source zone using a recurrence relationship, which specifies the average rate at which an earthquake of some size will be, exceeded (recurrence relationship).
  3. Estimation of the ground motion produced at the site by earthquakes of any possible size occurring at any possible point in each source zone using predictive relationships.
  4. Obtaining the probability that the ground motion parameter will be exceeded during a particular time period.

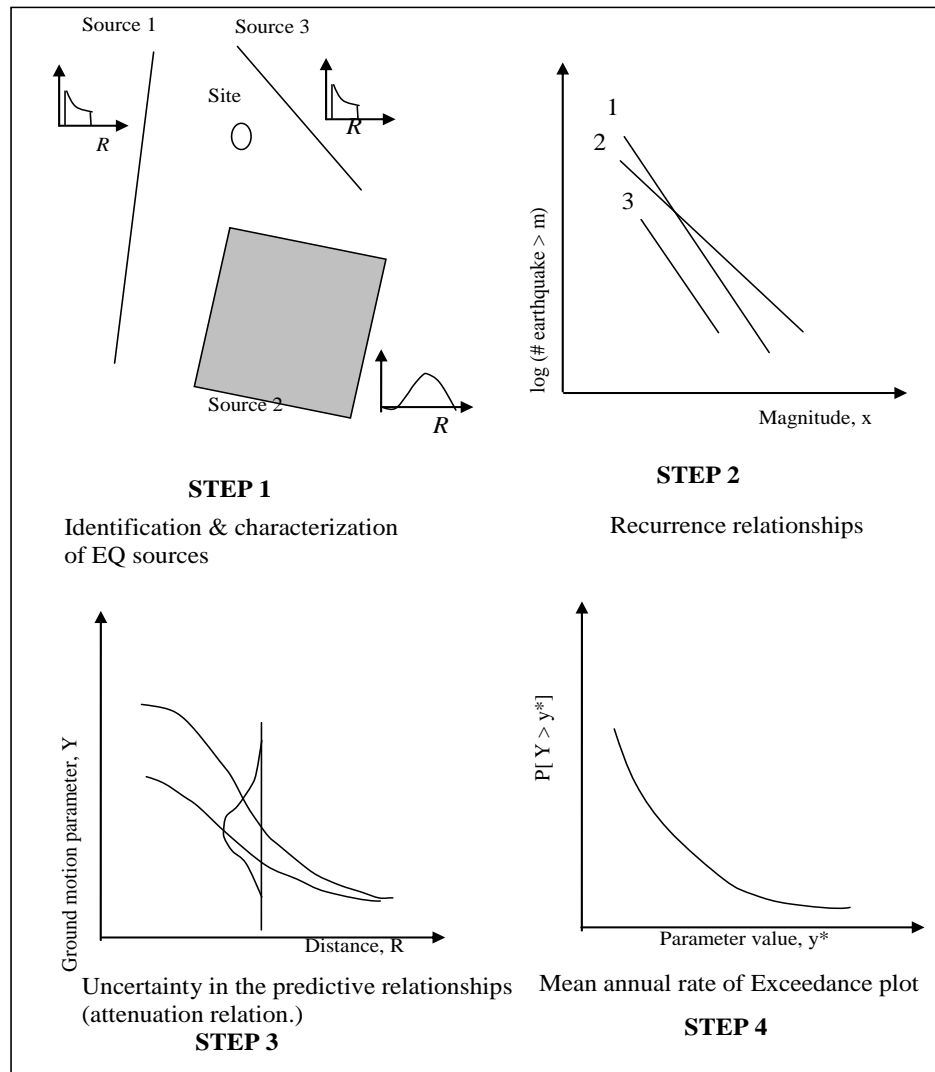


Fig 11.3: Different steps for probabilistic seismic hazard analysis (after Kramer, 1996).

- **Methodology adopted for Site Characterization** - A complete site characterization is essential for the seismic site classification and site response studies, both of them can be used together for seismic microzonation.
- Site Characterization should include an evaluation of subsurface features, subsurface material types, subsurface material properties and buried/hollow structures to determine whether the site is safe against earthquake effects. Site characterization should provide data on the following:
  1. Site description and location
  2. Geotechnical data
  3. Soil conditions
  4. Geological data

5. Hydrogeology/ ground water data
  6. Aquifer or permeable characteristics
  7. Presence and distribution of contaminants (if any)
  8. Climatic conditions (if needed)
- Assessment of available data should include an analysis of the sufficiency and validity of the data in relation to the proposed application/ study. As part of the site characterization, experimental data should be collected, interpolated and represented in the form of maps (see flow chart given in Figure 11.4). The representation maps can be further used for the site classification and seismic studies.

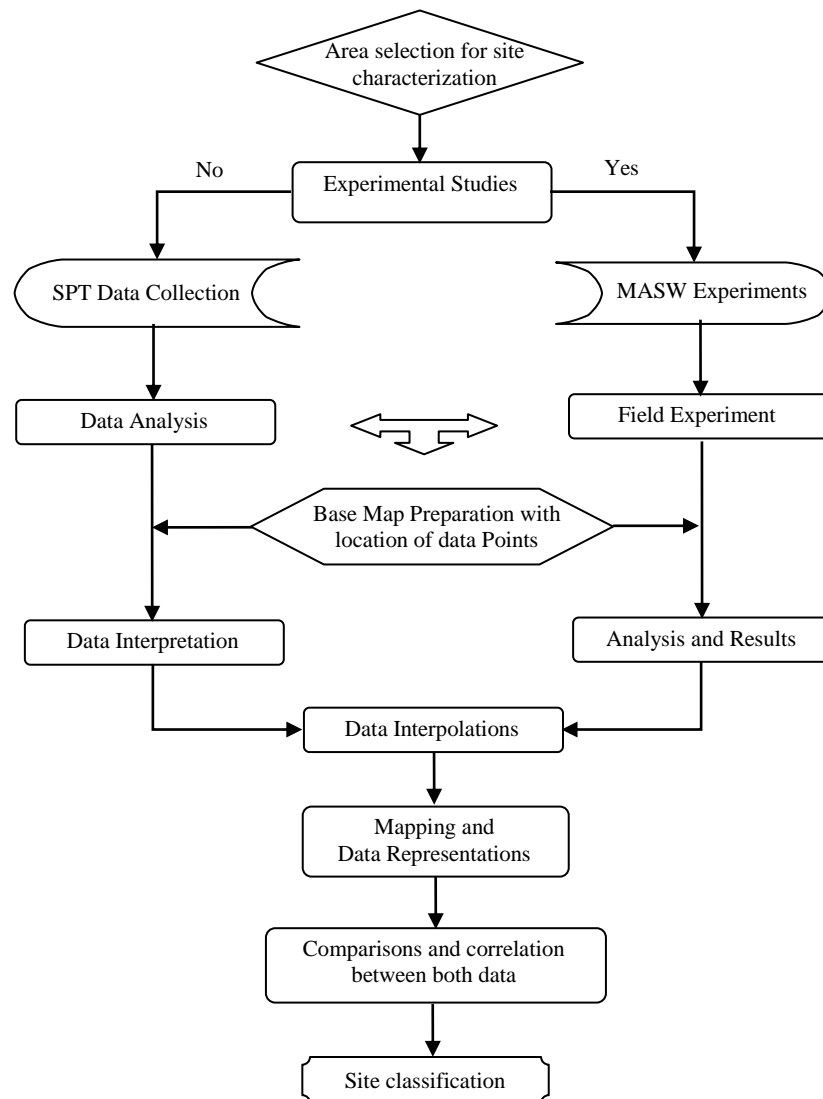


Fig 11.4: Steps involved for site characterization



- **Site Response Study** - Site response analysis aims at determining the response of a soil deposit to the motion of the bedrock immediately beneath it. Frame work of site response study shown in Figure 11.5. The overburden plays a very important role in determining the characteristics of the ground surface motion thus emphasizing the need for ground response analysis.
- A number of techniques have been developed for ground response analysis. These techniques can be grouped as one, two, and three-dimensional analyses according to the dimensionality of the problems they can address. A one-dimensional method can be used if the soil structure is essentially horizontal and is widely used in earthquake geotechnical engineering:
- Assumptions in one-dimensional ground response analysis are:
  1. The soil layer boundaries are horizontal and extend infinitely in the horizontal direction.
  2. Response of the soil deposit is predominantly caused by SH-waves propagating vertically from the underlying bedrock.

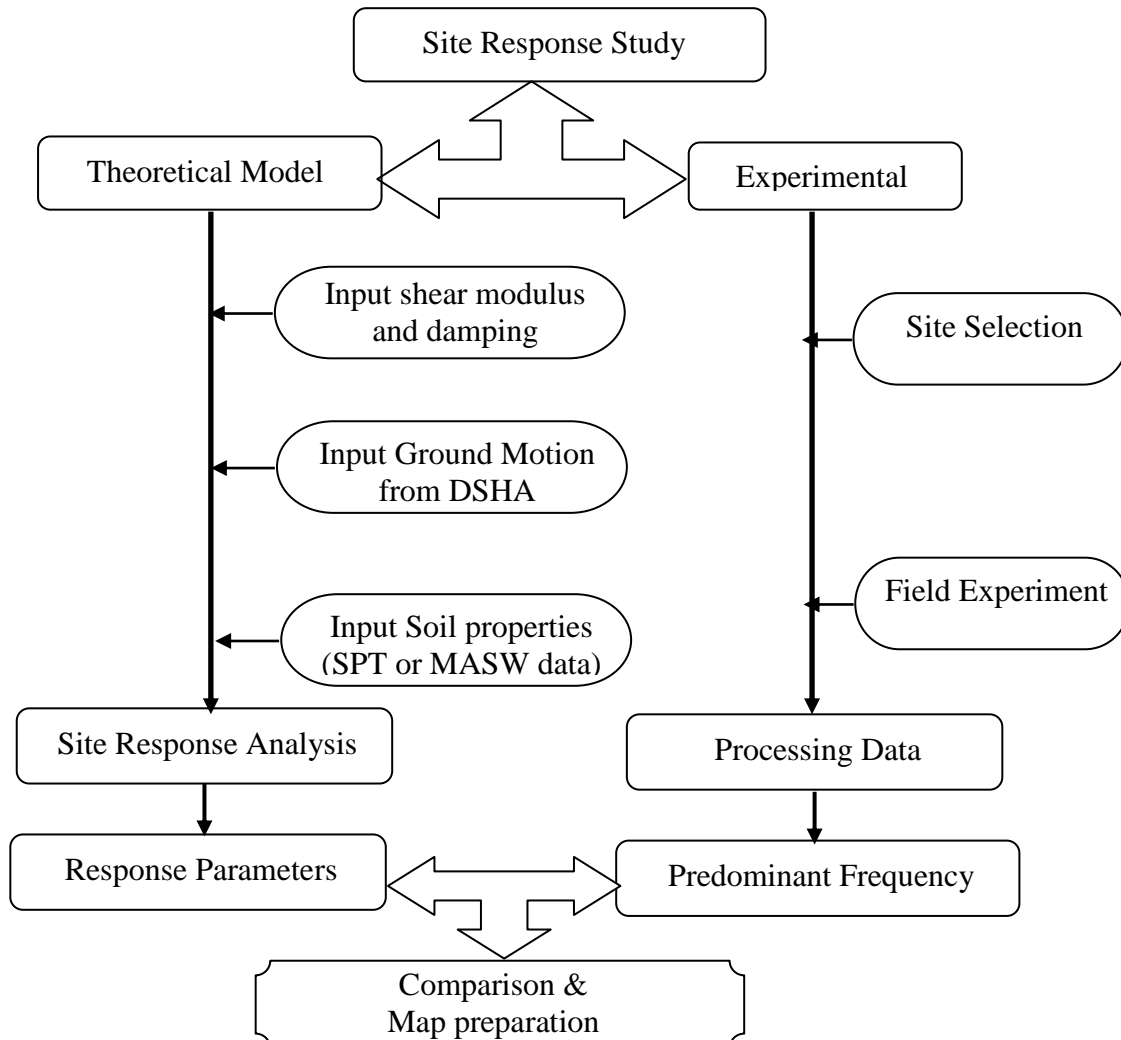


Fig 11.5: Flow chart for site response study

- A number of different techniques are available for one-dimensional ground response analysis. These methods can be broadly grouped into the following three categories:
  1. Linear analysis
  2. Equivalent linear analysis
  3. Nonlinear analysis
- Of the above, the most popular method used in professional practice is the “equivalent linear” approach which is incorporated in the computer program SHAKE. It requires three input parameters such as bedrock motion, dynamic material properties and site specific soil properties. The peak surface acceleration, ground response spectrum and period of soil column are obtained as output from this analysis. These values are used to get map indicating zones of amplification potential, spectral acceleration maps at various frequencies and period of soil column map.
- Site response studies mainly deal with the determination of peak frequency of soft soil, amplification and the nature of response curve defining the transfer function at the site which forms an important input for evaluating and characterizing the ground motion for seismic hazard quantification. The surface sources for the ambient noise generate Rayleigh waves which affect the vertical and horizontal motion equally in the surface layer. The spectral ratio of the horizontal component by the vertical component of the time series provides the transfer function at a given site. The dominant peak is well correlated with the fundamental resonant frequency.
- **Liquefaction Assessment** - The first step in calculation of liquefaction potential is to determine if the soil has the potential to liquefy during the earthquake. Liquefaction potential analysis usually carried out by using simplified empirical procedure.
- This simplified procedure represents the standard of practice in North America and in many other countries across the globe. Simplified procedures are reviewed periodically by groups of experts who make recommendations and changes according to data collected from new earthquakes and new developments in liquefaction hazard assessment.
- The potential for liquefaction is assessed with the aid of liquefaction charts or semi empirical equations, which are based on observations of whether liquefaction did or did not occur at specific sites during numerous past earthquakes.

- The earthquake loading is evaluated in terms of cyclic stress ratio using Seed and Idriss (1971) simplified approach. Cyclic resistance ratio (CRR) is arrived based on corrected “N” value using plots of CRR versus corrected “N” value from a large amount of laboratory and field data of earthquake using equation proposed by Idriss and Boulanger (2005)
- Flow chart for liquefaction assessment is given in Fig 11.6.

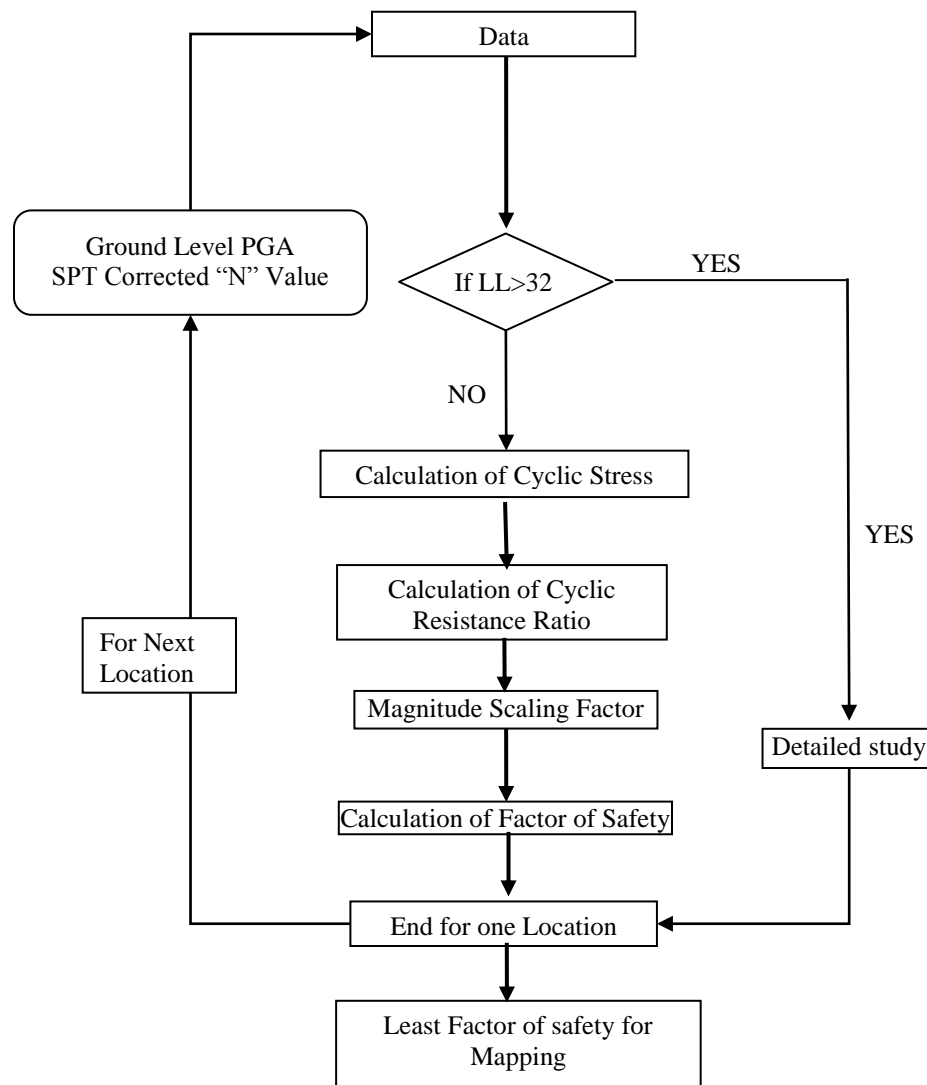


Fig 11.6: Flow chart for liquefaction assessment

## Topic 3

## Seismic Hazard Estimation studies in Southern India

- Many devastating earthquakes in recent times (Koyna, 1967; Killari, 1993, Jabalpur 1997; Bhuj 2001) have occurred in south India, a region that was predominantly considered as stable and aseismic shield region. It is very essential to estimate realistically the earthquake hazard associated with this shield region. The seismic hazard assessment can be quantified using either the deterministic or probabilistic seismic hazard analysis (PSHA) based on regional, geological, and seismological information.
- Reddy (2003) highlighted that the south Indian seismicity is neither understood properly nor given importance since it is of micro-dimensions. There are no notable detailed probabilistic hazard studies carried out in southern India except Mumbai region. The first seismic hazard map available for southern India is BIS 1893, it was revised many times but seismic status of southern India is not classified in smaller scale. Recent publication BIS 1893–2002 shows that many part of the southern India is upgraded from existing zones I, II, and III to II, III and IV.
- Parvez (2003) carried out the deterministic seismic hazard of India and adjacent areas using an input dataset of structural models, seismogenic zones, focal mechanisms and earthquake catalogues. The author generated synthetic seismograms at a frequency of 1 Hz at a regular grid of  $0.2^\circ \times 0.2^\circ$  by the modal summation technique. They expressed seismic hazard in terms of maximum displacement ( $D_{max}$ ), maximum velocity ( $V_{max}$ ), and design ground acceleration (DGA) using extracted synthetic signals and mapped on a regular grid. They highlighted that the DGA estimates in Peninsular India are less than 0.15 g, and only in the Latur region DGA values close to this upper limit.
- Raghukanth and Iyengar (2006) estimated the seismic hazard at Mumbai city using state-of-the-art probabilistic analysis considering the uncertainties in the seismotectonic details of the region. They developed design spectrum by incorporating uncertainties in location, magnitude and recurrence of earthquakes. Influence of local site condition was accounted by providing design spectra for A, B, C and D type sites separately. They highlighted that the results presented can be directly used to create a microzonation map for Mumbai City.
- Jaiswal P. K. and Sinha R (2006 and 2007) presented the probabilistic assessment of seismic hazard associated with the stable continental shield of peninsular India ( $10^\circ\text{N}$ - $26^\circ\text{N}$ ;  $68^\circ\text{E}$ - $90^\circ\text{E}$ ) in terms of peak ground accelerations for different levels of ground shaking. They discussed the procedure for evaluating the probabilistic seismic hazard using a knowledge-tree approach. Attenuation relationships proposed for peninsular India and those proposed for the other stable

continental regions such as Central and Eastern United States have been used in the study. The results show that for many parts of peninsular India, the estimated seismic hazard is higher than the level specified in the current seismic zoning map given in IS 1893-2002.

#### **Topic 4**

##### **Microzonation of Jabalpur**

- After the devastating 1997 Jabalpur earthquake (mb: 6.0), where more than 2000 people were injured the first pilot project in India towards microzonation of Indian cities, was taken up by Department of Science and Technology involving the relevant organizations, viz., GSI, NGRI, CBRI, IMD and Jabalpur Engineering College, for preparing the microzonation map of Jabalpur urban area.
- Mishra (2004) has carried out the seismic microzonation work of Jabalpur. Kumar and Rao (2007) carried out modeling of ground motion by the hybrid method of modal summation and finite difference approach, Seismic hazard analysis was carried out deterministically and deterministic peak ground acceleration map published based on the attenuation relation developed by Joyner and Boore (1981).
- The extensive work on ground characterization was presented based on the experimental study of geology, geotechnical and geophysical investigations. Based on this information, the first level microzonation map was published.
- The liquefaction hazard assessment was carried out using geotechnical data and simplified approach of Seed and Idriss (1971). Shear wave velocities from geophysical method of multichannel analysis of surface wave were measured and used for classification of sites in Jabalpur based on 30m equivalent shear wave velocity.
- Site response studies were carried out by conducting the experimental test of Nakamura type studies and receiver function type studies. The predominant frequency and peak amplification maps were developed and presented. The vulnerability and risk analyses have been carried out and second level microzonation map and preliminary seismic risk maps were produced.
- As per study, the total area has been classified into 3 zones: low, medium and high hazard (Fig 11.7). The last category being restricted to the alluvial fill, sediment covers etc.

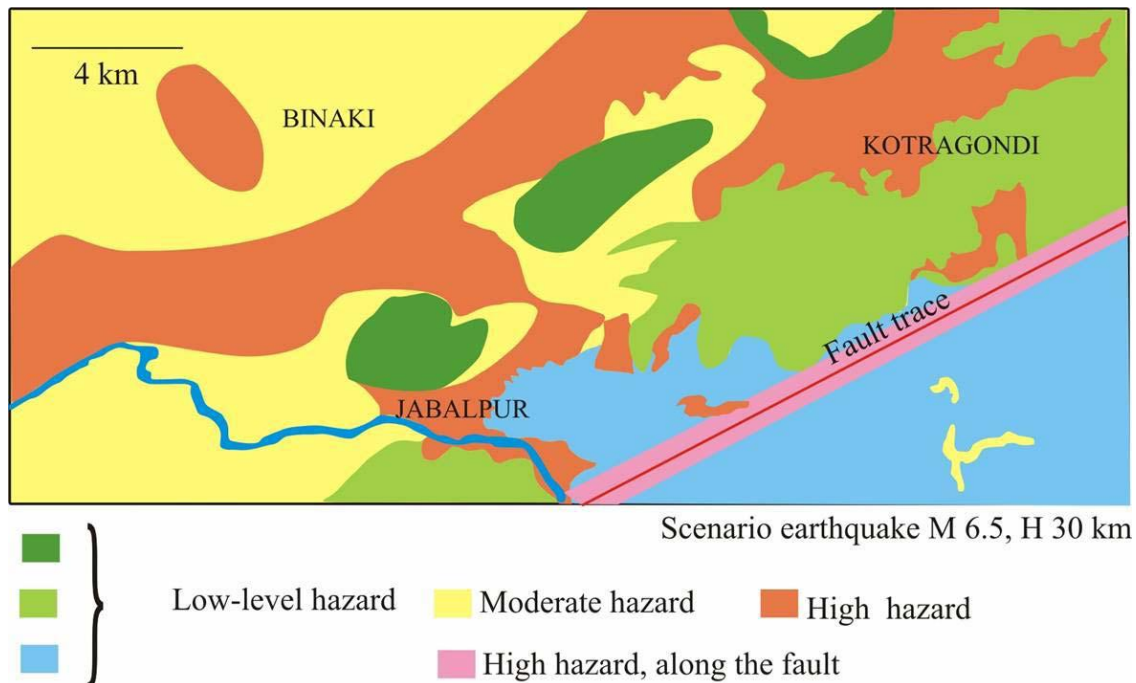


Fig 11.7: Final hazard map prepared for Jabalpur

## Topic 5

### Microzonation of Delhi

- A first order microzonation map at 1:50,000 scales have now been prepared for NCT of Delhi. The information has been integrated and converted into following maps: base map, geology, seismotectonic, ground water, bedrock depth, site response, liquefaction susceptibility, and shear wave velocity, peak ground acceleration and seismic hazard.
- Iyengar and Ghosh (2004) carried out complete seismic hazard analysis by both deterministic as well as probabilistic by considering the seismotectonic parameter around 300 km radius for Delhi. They presented probabilistic seismic hazard analysis of an area of 30 km x 40 km with its centre at India Gate, Delhi city with quantified hazard map in terms of the rock level peak ground acceleration value on a grid size of 1 km x 1 km, for a return period of 2500 years.
- Further they also carried out site amplification and local site effects using the geotechnical borelogs and SHAKE91, presented the frequency response functions at the seventeen sites and variation of natural frequency with depth.
- Rao and Neelima Satyam (2005) used computer code FINSIM, a finite fault simulation technique to generate the PGA map at bedrock for five different sources in Delhi. A Geotechnical site characterization was carried out by using

collected borehole data from various organizations. These data points were spread throughout Delhi region except in some parts of northwestern Delhi.

- Also site characterization of Delhi was carried out using geophysical testing at 118 sites and average shear wave velocity at 30m depth i.e.,  $V_S^{30}$  were calculated. Estimation of soil amplification was carried out by using DEGTRA software and microzonation map for amplification was generated.
- The seismic response of soil was also estimated using the microtremor measurements at 185 sites in Delhi exactly at the same locations where seismic refraction and MASW testing was done. Analysis was carried out using VIEW 2002 software and the average H/V resonance spectra were obtained. Based on the shape of the resonance spectra, H/V amplitude, predominant frequency and fundamental frequency map of Delhi was presented.
- With the collected bore hole data, liquefaction assessment was carried out using SPT based three methods e.g. Seed and Idriss (1971) Seed and Peacock (1971) and Iwasaki et al. (1982) and using SHAKE 2000 software, the liquefaction potential map was presented (Rao and Neelima Satyam, 2007).
- Mohanty et al (2007) prepared a first order seismic microzonation map of Delhi using five thematic layers viz., Peak Ground Acceleration (PGA) contour, different soil types at 6 m depth, geology, groundwater fluctuation and bedrock depth, integrated on GIS platform. The integration was performed following a pair-wise comparison of Analytical Hierarchy Process (AHP) wherein each thematic map was assigned a weight in the scale of 5:1 depending on its contribution towards the seismic hazard. Following the AHP, the weightage assigned to each theme is: PGA (0.333) soil (0.266) geology (0.20) and groundwater (0.133) and bedrock depth (0.066). The thematic vector layers were overlaid and integrated using GIS.
- Delhi has been grouped into three hazard zones i.e. low, moderate and high. Efforts are now being made by EREC to further refine these maps at large scale (1:10,000) incorporating Peak Ground Acceleration (PGA) values at the surface level.
- Figure 11.8 shows Final hazard map of Delhi

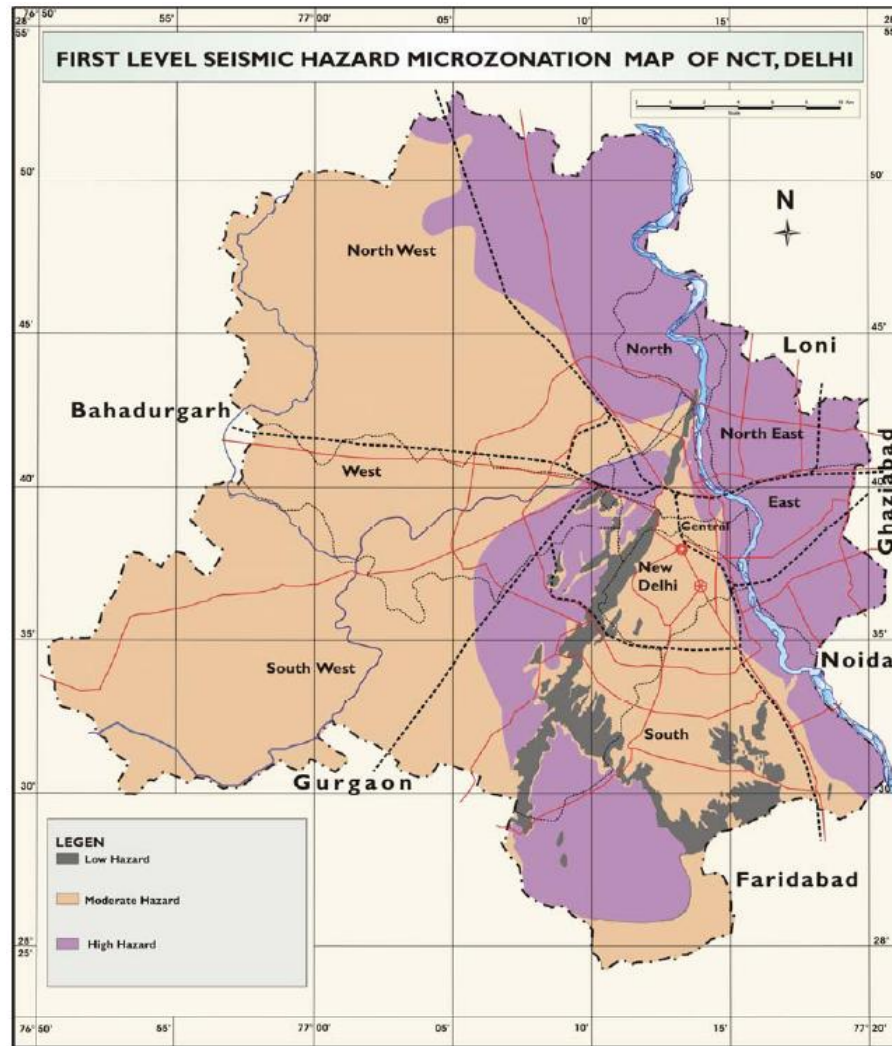


Fig 11.8: Final hazard map of Delhi

## Topic 6

### Microzonation of Sikkim, Himalaya

- Seismic hazard assessment of Sikkim Himalaya was carried out with the help of site response studies, fractal analysis and computing response characteristics. Seismic Microzonation map of Sikkim has been prepared by IIT, Kharagpur by integrating various data like site conditions, geology, soil types, slope, peak ground acceleration and resonant frequency.
- Seismic Hazard and Microzonation Atlas of the Sikkim Himalaya was prepared by Nath (2006) from research work of seismicity of Sikkim Himalaya and microzonation of Sikkim region funded by the Department of Science & Technology.



- Seismic Hazard analysis was carried out deterministically by considering the seismotectonic parameters and presented maximum credible earthquake for Sikkim. Site response study analyses were carried out using the techniques receiver function and generalized inversion considering the strong motion data.
- Also the author presented the simulation of spectral acceleration and hazard scenario assessment for Sikkim. From the above studies he developed new attenuation relation for Sikkim Himalaya, and finally he developed seismic microzonation map using geographical information system (GIS).
- Seismic microzonation map was presented in the form of geohazard map and quasi-probabilistic seismic microzonation index map. The geohazard map was prepared by integrating the weights and ratings of soil, surface geology, rock outcrop and landslides.
- Probabilistic seismic microzonation index map was prepared by integrating the weights and ratings of site response, peak ground acceleration, soil, rock outcrop and landslides. Figure 11.9 shows microzonation map of Sikkim

## Topic 7

### Microzonation of Guwahati

- Microzonation work for Guwahati was initiated about four years back. A number of organizations namely Assam Electronics Development Corporation, Guwahati, GSI, IMD, RRL (Jorhat), IIT (Kharagpur, Guwahati, Roorkee), State Department of Geology and Mining, CGWB, Assam Engineering College and Jorhat Engineering College, have played very active and important role in carrying out the study.
- Some of the major damaging earthquakes that affected Guwahati are the 1897 Shillong, 1918 Srimangal, 1930 Dhubri, 1950 Assam and 1988 Indo- Burma.
- The microzonation study of Guwahati city accounts for eight themes – geological and geomorphological, basement or bedrock, landuse, landslide, factor of safety for soil stability, shear wave velocity, predominant frequency, and surface consistent peak ground acceleration.
- Guwahati city is placed within the highest level of seismic hazard – the Zone V according to seismic hazard zonation of India (BIS 2002). GSHAP predicts high hazards in terms of PGA to the tune of 0.35 g (1 g = 980 gal) in the Guwahati region.

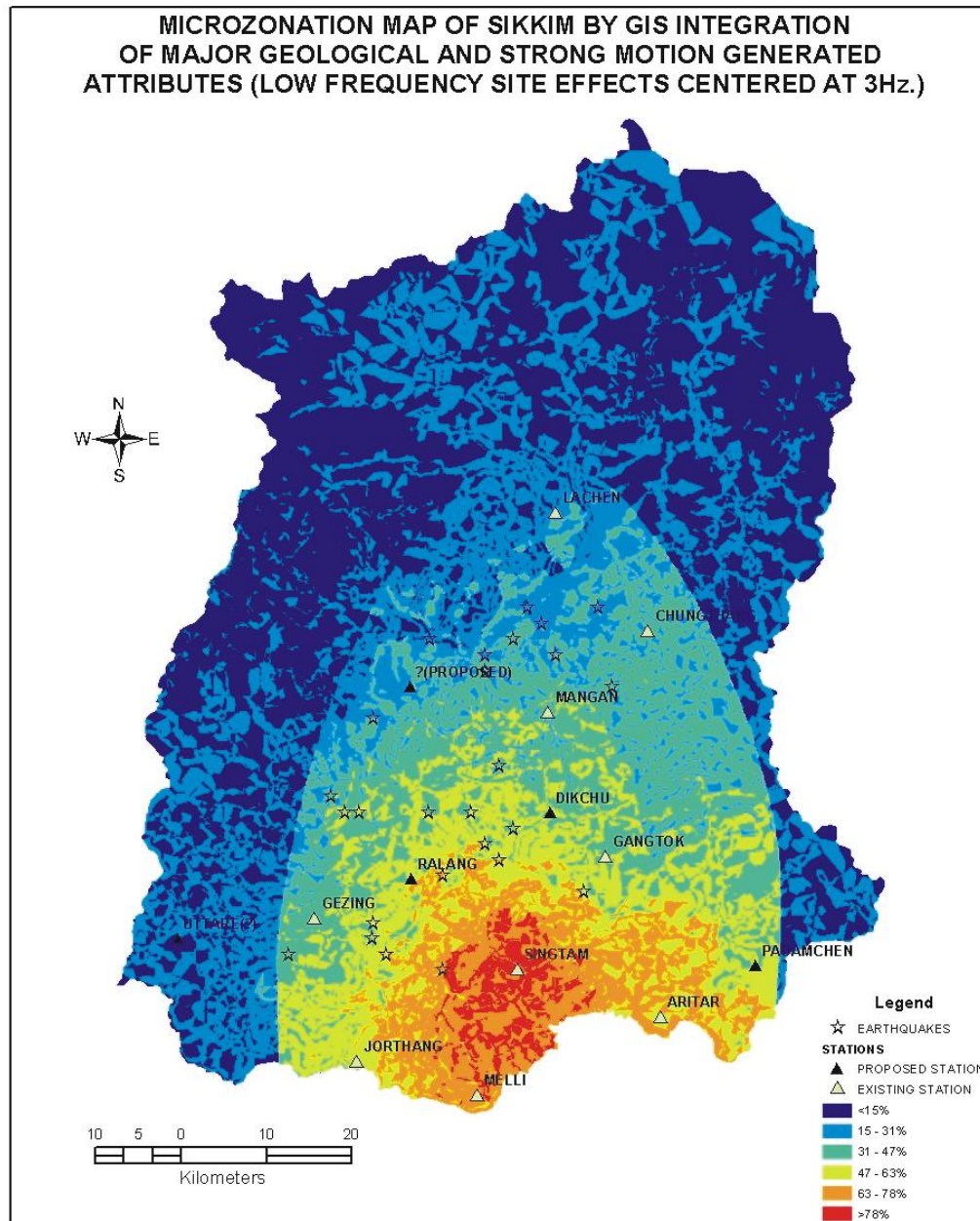


Fig 11.9: Microzonation map of Sikkim (Nath, 2007)

- Baranwal et al (2005) prepared the first level microzonation map, They categorized soil profiles in terms of their susceptibility to amplification. Where bedrock is very deep, the soil susceptibility category of the uppermost 35 m of soil profile that generally has the greatest influence on amplification was considered.

- The soil susceptibility categories were defined based on soil type, thickness and stiffness, which were used as a basis for defining mapping units. Considering these factors, map has been prepared which depicts the thickness of soils above bedrock based on geophysical results.
- The resistivity surveys were carried out and analyzed in the area. The seismic studies carried out in the area shows that  $V_s$  ranges from 166 to 330 m/s and corresponding amplification ratios varies from 3.1 to 2.2. The damage ratio (DR) calculated from these values were found to be 0.2 and 0.05.
- Microzonation of Guwahati, the total area has been grouped into five zones based on the hazard index values, categorized as very high ( $>0.50$ ) high (0.40-0.50) moderate (0.30-0.40) low (0.20-30) and very low ( $< 0.20$ ). Most of the residential area falls in a moderate zone.
- The microzonation map for Guwahati was prepared by Nath et al. (2008) and classified Guwahati into 5 broad zones of hazard, based on eight themes. The 5 zones are expressed in terms of different levels of HI, the higher being more hazard. The zones classified are lows (HI:  $\leq 0.2$ ), moderate (HI: 0.2– 0.3), moderately high (HI: 0.3–0.4), high (HI: 0.4–0.5) and very high ( $\geq 0.5$ ). The average PGA estimated for the 5 zones are 0.25 g, 0.28 g, 0.53 g, 0.63 g and 0.87 g.

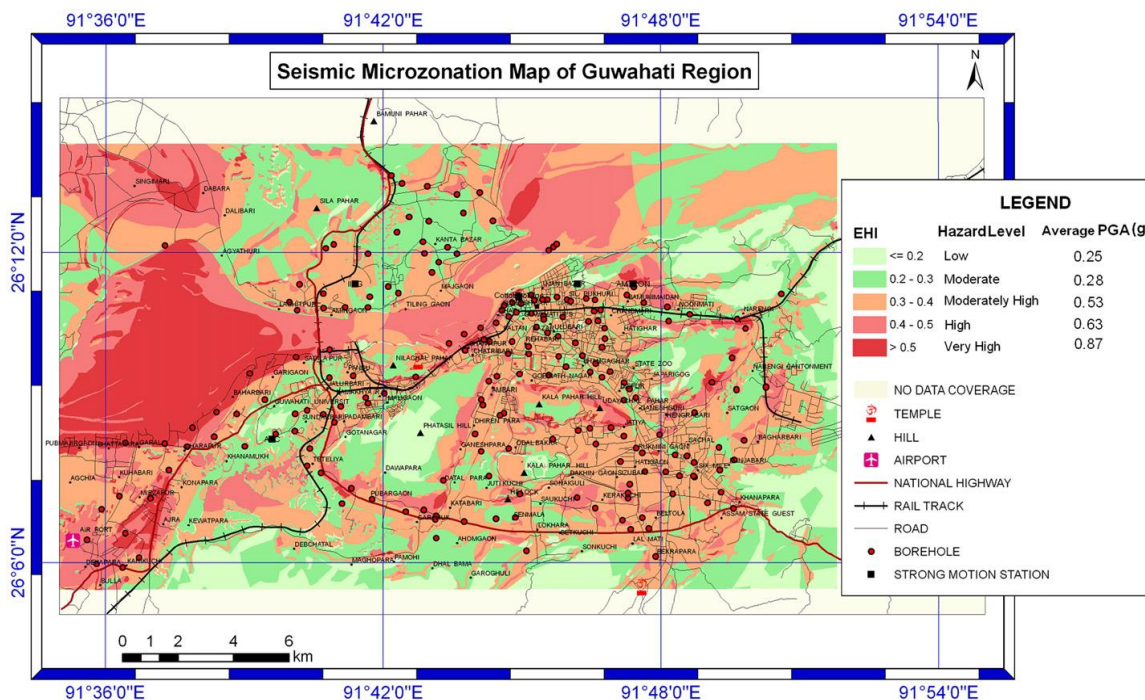


Fig 11.10: Seismic hazard map overlaid with the peak ground acceleration contours of Guwahati City (Nath et al., 2008).

## Topic 8

## PSHA for Northeast India

- Seismic hazard maps have been prepared for Northeast India based on the uniform hazard response spectra for absolute acceleration at stiff sites. An approach that is free from regionalizing the seismotectonic sources has been proposed for performing the hazard analysis.
- This is the most active region in the Himalayan seismic belt which is the junction of three plates, namely, the Indian plate, Eurasian plate and Burmese plate. This region has experienced two great earthquakes of magnitude Mw 8.1 in 1897 and Mw 8.5 in 1950 which caused widespread destruction in this region (Fig 11.11).
- The earthquake hazard has been assessed in terms of probability of occurrence of an earthquake during a specified time interval within a specified region. The estimation of recurrence of earthquakes in the different regions of the world has been carried out using different probabilistic models.
- UTSU (1984) compared different probabilistic models using different sets of earthquake data in several seismic regions of Japan, where large earthquakes occur repeatedly at fairly regular time intervals. He observed that the lognormal model gives the best results in some cases but worst in others.
- An intermediate result was observed for the Weibull and Gamma models. Nishenko and Bullard (1987) also applied Lognormal and Weibull models for the recurrence interval distribution and observed that Lognormal was the best. Rikitake (1991) estimated a high probability of occurrence of a devastating earthquake in the Tokyo area of Japan using Lognormal and Weibull models.
- This type of study has been carried out by Parvez and Ram (1997) in the Hindukush and northeast Indian region and latter for the whole Indian subcontinent (Parvez and Ram, 1999).
- It is observed that the Gamma model is the most suitable model for the northeast India region and Lognormal is the worst from the three considered models. The conditional and cumulative probabilities have been estimated using the model parameters estimated on the basis of past seismicity of the region.
- It is observed that the Weibull model shows the highest conditional probabilities among three models for small as well as large elapsed time (t) and time intervals (s), while the Lognormal model shows the lowest and the Gamma model shows intermediate probabilities. The estimated cumulative probability for an earthquake  $M \geq 7.0$  reaches 0.8 after about 15–16 (2010–2011) years and 0.9 after about 18–

20 (2013–2015) years from the occurrence of the last earthquake (1995) in the region.

- For elapsed time zero years, the estimated conditional probability also reaches 0.8 to 0.9 after about 13–17 (2008–2012) years in the considered region for an earthquake  $M \geq 7.0$ . However, the conditional probability reaches 0.8 to 0.9 after about 9–13 (2018–2022) years for an earthquake  $M \geq 7.0$  for elapsed time 14 years (i.e. 2009).
- The estimated cumulative and conditional probabilities show about a similar recurrence period of about 13–20 years from the occurrence of last earthquake (1995) for future large earthquakes in this region.

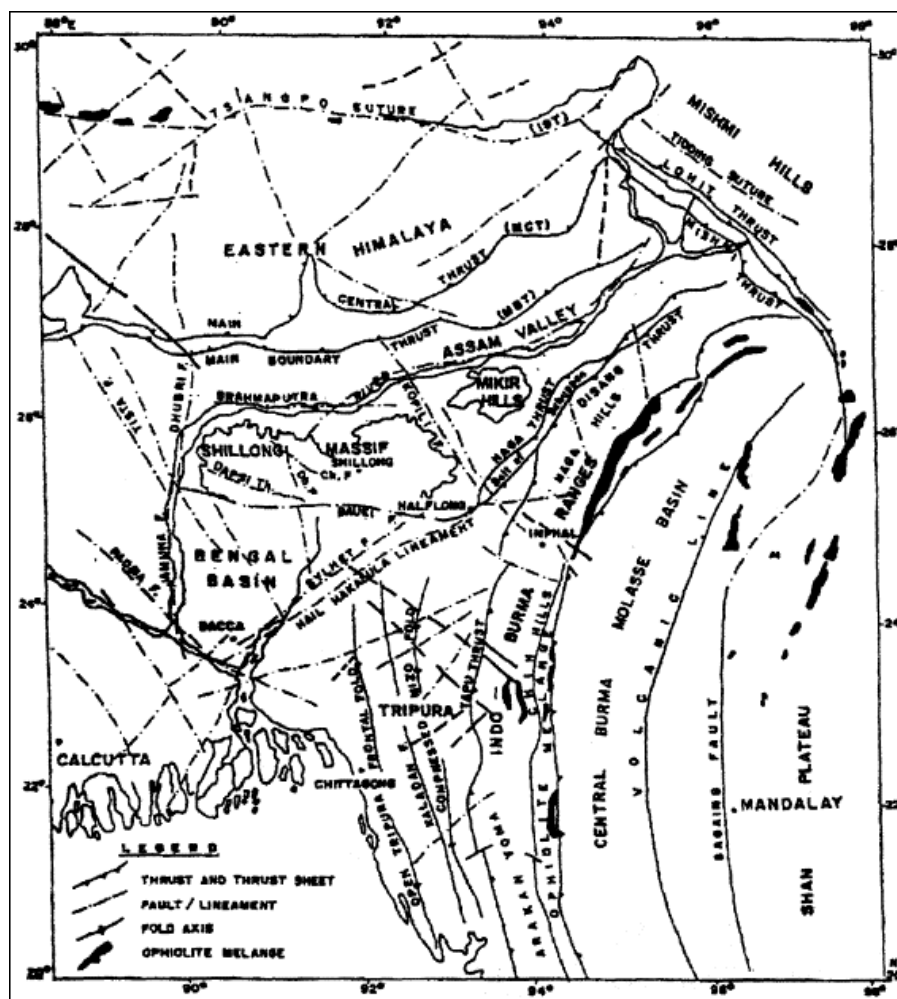


Fig 11.11: Tectonic setting of northeast India and surroundings

## Topic 9

## Seismic hazard estimation for Mumbai city

- Mumbai, the financial capital of India, is a mega city with a population exceeding ten million is located in Peninsular India (PI). Mumbai lies, according to the Bureau of Indian Standards (BIS), in Seismic Zone III the hazard in this part of India is considered to be less severe than in the Himalayan plate boundary region. This perception is based on the relative occurrence of past tremors in the various regions. However, intra-plate earthquakes are rarer than plate boundary events but usually tend to be more harmful.
- Jaiswal et al. (2004) have studied the probabilistic seismic hazard of Mumbai. Using different attenuation models they estimate depending on the return-period (T) PGA-values of 0.03 g (T = 100 years), 0.08–0.1 g (T = 475 years), and 0.16–0.20 g (T = 2000 years). These values correspond to intensities (MMI) of smaller than V (T = 100 years), VI (T = 475 years), VII (T = 2000 years).
- Soil conditions have been assumed as stiff soil to hard rock. The instrumental intensity that corresponds to MMI is determined by a method proposed by Chernov and Sokolov (1999) and further developed by Sokolov (2002). The method is based on the assumption that Fourier Spectral Amplitudes (FAS) at representative frequencies and the intensity of an earthquake are directly connected, so that the latter can be calculated from the FAS.
- Variations in intensities by soil conditions (site effects) can be high in Mumbai because of the soft ground that constitutes the filled land. During the recent Bhuj (2001) earthquake intensities have been observed in Mumbai ranging between VI and VII MMI.
- Twenty- three faults that can induce ground motion at Mumbai have been identified from the seismo-tectonic map of the region. Since slip rates of individual faults are not available, the recurrence relation of these faults has been estimated from the regional recurrence relation. The attenuation relations developed previously specifically for PI are used for computing spectral acceleration hazard curves.
- From these results, uniform hazard response spectra have been derived for 2 and 10% probability of exceedance in 50 years. Results obtained here compare well with those reported values. The design spectra developed here incorporate uncertainties in location, magnitude and recurrence of earthquakes.
- Hence, these are superior to spectra recommended by IS-1893. Influence of local site condition has been accounted by providing design spectra for A, B, C and D-

type sites separately. The results show that frequency content of the UHRS varies with the local site condition.

- The present work has been motivated by the needs faced by engineers. Hence in this study Mumbai is represented as a point. This is not a limitation since at bedrock level the hazard does not show strong spatial variation on city-scale distances. The results presented here can be directly used to create a microzonation map for Mumbai. However, for this to be credible, detailed shear-wave velocity profiles of the upper layers of the city are to be obtained. A seismic hazard map covering Mumbai and its environs on a finer grid will cater to the needs of city-level disaster management.

## **Topic 10**

### **Seismic microzonation of Dehradun**

- Dehradun, capital city of Uttarakhand, lies at the foothill of the Himalayan mountain belt and is located over the synformal valley of Quaternary deposits. It comes under the zone IV of the zonation map of India (BIS, 2002) and is evident from the damaging earthquakes of the 1905 Kangra (intensity VIII) and 1991 Uttarkashi (intensity VI) (Kandpal et al., 2007) from the Himalayan region.
- Dehradun is bounded by the MBT in the north, MFT in the south, Ganga Tear Fault in the east and Yamuna Tear Fault in the west. Mahajan et al. (2007) carried out the seismic microzonation of Dehradun by evaluating the shear-wave velocity ( $V_s$ ) using geophysical technique of Multichannel Analysis of Surface Waves (MASW). The hazard is addressed in terms of spectral acceleration with 5% damping at 5 Hz (two-storey building) and 10 Hz (one-storey building).
- The site response and spectral acceleration is calculated by using the shear wave velocity obtained from 50 sites in and around Dehradun and by considering the reference input motion of the 1999 Chamoli earthquake ( $M_w$ : 6.5).
- The spectral acceleration for the two-storey building ranges from 0.20 to 0.73 g, while for the one-storey building; the variation is from 0.14 to 0.28 g.
- The result of the response spectra at frequencies 5 Hz and 10 Hz will provide the city planners and civil engineers with information on the behavior of the building at those frequencies (Figures 11.12 and 11.13). But a detail seismic microzonation map will require more input data of recorded ground motion, borehole data and geotechnical properties of the individual soil layers underlying Dehradun.

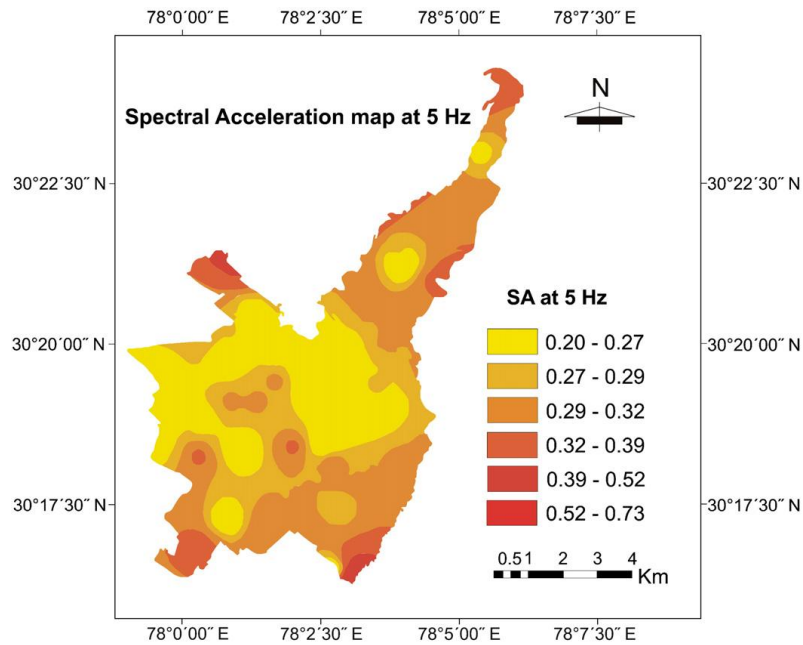


Fig 11.12: Seismic microzonation map of Dehradun in terms of spectral acceleration at 5% damping for two-storey structures (5 Hz)

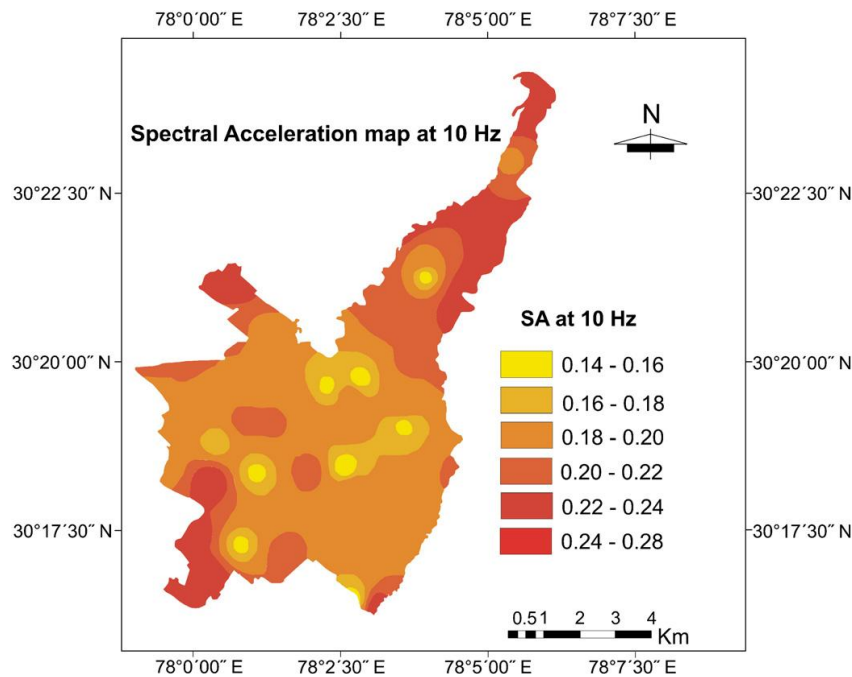


Fig 11.13: Seismic microzonation map of Dehradun in terms of spectral acceleration at 5% damping for single-storey structures (10 Hz)



**Topic 11****Seismic Microzonation of Haldia**

- The importance of Haldia is its industrial township. The strategic location of Haldia is the port facility that supports vital industrial and transportation infrastructure with many foreign investments.
- Haldia lies over the Bengal Basin and is located southwest of Kolkata at a distance of less than 100 km. It has been affected by earthquakes occurring from near source like the 1964 Calcutta earthquake and far sources like the 1897 Shillong earthquake (Seeber and Armbruster, 1981).
- A first order seismic microzonation map has been prepared by Mohanty and Walling (2008b) based on the integration of thematic maps of PGA, predominant (resonance) frequency and elevation map. Based on the tectonic framework of the region surrounding Haldia and the past seismicity, five source zones are delineated that can affect Haldia.
- The ground motion in terms of PGA from the five source zones was estimated using the attenuation relationship of Toro et al. (1997) and the combined effect was considered. The site specific predominant frequency is estimated employing the Horizontal by Vertical Spectral Ratio (HVSr) technique of Nakamura (1989).
- Low predominant frequency is observed along the flanks of Haldia indicating loose soil deposits. The PGA is estimated for the five potential seismic source zones surrounding Haldia and ranges from 0.09 to 0.19 g.
- Haldia is divided into 4 zones of seismic hazards with PGA ranging for each zone as, lowhazard (0.09–0.13 g), moderate hazard (0.13–0.15 g), high hazard (0.15–0.16 g) and very high hazard (0.16–0.19 g) (Fig. 24). The validation of the microzonation map can be done by recording the real time earthquakes.
- Seismic Microzonation map of Haldia is shown in Figure 11.14

**Topic 12****Seismic Microzonation of Talchir Basin**

- Talchir Basin is renowned for its coal reserve and has the distinction of containing the largest reserve of coal in India with many industrial investments. The Talchir coalfield caters to the need of coal for railways and also for power generation.
- The major tectonic structure of Talchir area is the North Orissa Boundary Fault (NOBF). Talchir has been affected by the earthquake of 27th March 1995 that

caused a maximum intensity of V in MMI (GSI, 2000). A temporary micro earthquake station set up by Geological Survey of India from February to March 1997 recorded 26 earthquakes and a clustering was observed at the junction on both sides of NOBF suggesting a reactivation. De et al. (1998) suggested the presence of an asperity and resulted in the accumulation of the strain produced by the movements of the plates.

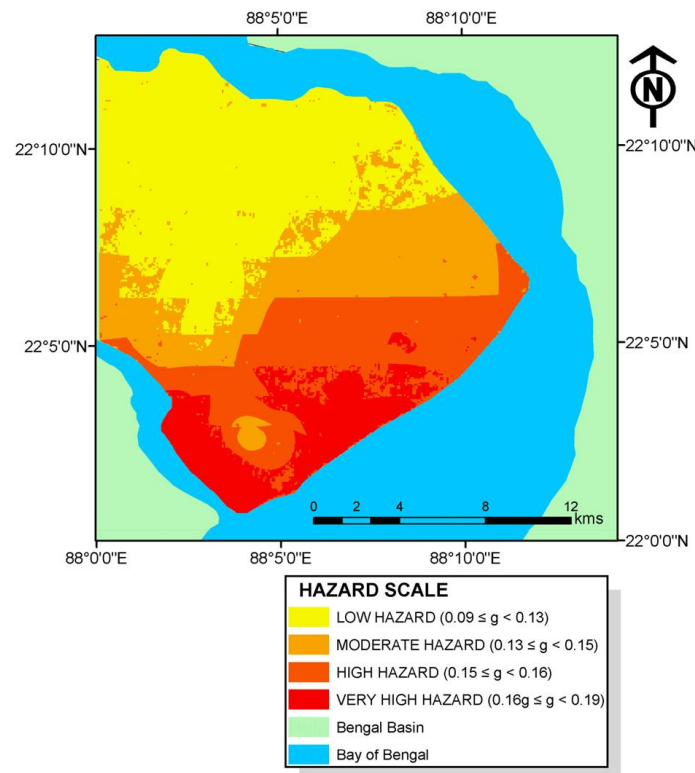


Fig 11.14: Seismic Microzonation map of Haldia after the integration of the three thematic maps.

- In the absence of strong motion records, synthetic seismograms are generated based on the principle of hybrid technique developed by Fäh et al. (1993 and 1994), which takes care of both the modal summation (Panza, 1985) and finite difference element method (Virieux, 1984, 1986). For the modeling of the ground motion, the earthquake source is taken along the North Orissa Boundary Fault (NOBF) with an earthquake of M: 6, where a dense array of accelerogram is arranged along eight profiles.
- The hazard parameters are discussed in terms of peak acceleration and response spectral ratio (RSR) and the higher values are observed over the younger sediments of the basin. The geotechnical properties of the individual soil layers of the basin are taken for the modeling of the ground motion.
- Mohanty et al. (2009) prepared a seismic zonation map of Talchir Basin by taking the RSR values and classified 3 zones of hazard with their respective RSR values:

low RSR (1.6–1.9), intermediate RSR (2.0–2.8) and high RSR (2.9–5.2) (Figure 11.15). The dense array of accelerogram provides a good resolution for the seismic hazard along the profiles but the results are generated synthetically and should be corroborated with the recorded strong motion data for its reliability.

- However, for the synthetic seismogram, the frequency at which the maximum amplification is observed ranges from 0.5 to 1.7 Hz. Walling et al. (2009) characterized the Talchir Basin by applying the Nakamura's (1989) HVSR technique on the microtremor data and observed the predominant frequency at the range from 0.3 to 2.4 Hz. The results between the synthetic seismogram and the recorded microtremor data, in terms of the predominant frequency, show a good correlation.

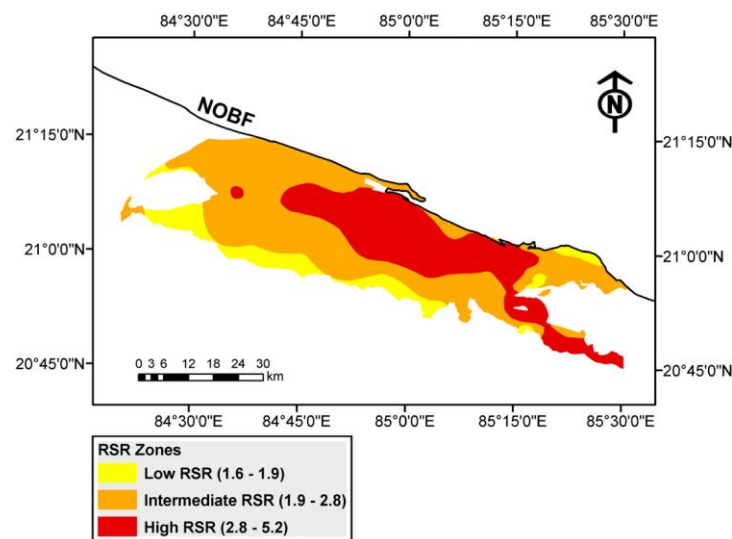


Fig 11.15: The three seismic hazard zones of Talchir Basin classified on the RSR distribution

### Topic 13

#### Ongoing Seismic microzonation of other cities in India

- The Department of Science & Technology, New Delhi initiated the seismic microzonation of Bhuj, Kachchh, Ahmedabad, Chennai and Kochi. These projects are ongoing, which are briefly presented below.
- After 2001 earthquake Mandal et al (2005) Parvez and Madhukar (2006) Trivedi et al (2006) and Mohanty (2006) are working towards microzonation of Bhuj, Kuchchh and Ahmedabad based on microtremor survey.
- Mandal et al (2005) estimated the site response in Kuchchh region using H/V ratio of the aftershocks. Parvez and Madhukar (2006) presented the preliminary

results on site-effects and shear wave velocity structures of sub-surface soil using microtremor arrays at twenty different sites in Ahmedabad. They highlighted that most of sites are having the fundamental resonance frequency of 0.6Hz and rest of them is having frequency of 2 to 6Hz using H/V spectral ratio.

- 1-D shear wave velocity obtained from microtremor array shows that, upper most layer having the shear wave velocity of 150-200m/s and below this 400-800m/s up to 60m depth.
- Trivedi et al (2006) carried out at 120 different stations and measurements were taken using velocity sensors for a period of 30 minutes at each station point by using microtremor of MR2002-CE vibration monitoring system.
- These tests were carried out exactly at the same locations where seismic refraction and MASW testing were conducted to study the detailed site response. Horizontal versus vertical (H/V) spectra using Nakamura method was estimated using VIEW 2002 software and compared with seismic refraction and MASW testing results.
- Mohanty (2006) carried out extensive study on identification and classification of seismic sources in the Kachchh and geological/ geophysical database was prepared using remote sensing and other conventional data sets (IRS WiFS, LISS-III & PAN images). Analyses and studies of the geological map of the region was used to establish empirical seismic attenuation model for Kachchh.
- Further, the authors computed probabilistic peak ground acceleration (PGA) values of the region. These PGA values computed for individual faults were superimposed to prepare a combined hazard zonation map of the area.
- Suganthi and Boominathan (2006) studied the site response behavior of Chennai soils as part of seismic hazard and microzonation of Chennai. They carried out the seismic hazard and site response study using SHAKE 91 and borelog information collected. They highlighted that the ground response analysis indicates that the occurrence of amplification is only in the low range of frequencies below 0.8Hz based on analysis at few regions in the study area.
- Center for Earth Science Studies planned seismic Microzonation of Kochi city, in GIS environment. It is planned to use site response by measuring ambient noise (microtremor) with the help of a City Shark seismic recorder and triaxial 3-component 1s geophones and to relate the responses (ground amplification) with the available information on geology, geomorphology, lineament patterns, soil type/lithology, structural features, earthquakes etc. in the region.

Lecture 11 in Safety of Individual Site; concept of seismic Microzonation; Need for Microzonation; Types and Scale; Methodology