Microzonation of Earthquake Hazard: Indian Experiences

T.G. SITHARAM* AND P.ANBAZHAGAN**

** Professor and ** Research Scholar,*

Department of Civil Engineering, Indian Institute of Science, Bangalore-560 012

* *sitharam@civil.iisc.ernet.in* *and ** anbazhagan@civil.iisc.ernet.in*

1. Introduction

Seismic hazard and microzonation of cities enable to characterize potential seismic areas that need to be taken into account when designing new structures or retrofitting the existing ones. Study of seismic hazard and preparation geotechnical microzonation maps will provide an effective solution for city planning and input to earthquake resistant design of structures in an area. **Seismic hazard** is the study of expected earthquake ground motions at any point on the earth. **Microzonation** is the process of sub division of region in to number of zones based on the earthquake effects in the local scale. Seismic microzonation is the process of estimating response of soil layers under earthquake excitation and thus the variation of ground motion characteristic on the ground surface. Geotechnical site characterization and assessment of site response during earthquakes is one of the crucial phases of seismic microzonation with respect to ground shaking intensity, attenuation, amplification rating and liquefaction susceptibility. Microzonation mapping of seismic hazards can be expressed in relative or absolute terms, on an urban block-by-block scale, based on local soil conditions (such as soil types) that affect ground shaking levels or vulnerability to soil liquefaction. Such maps would provide general guidelines for integrated planning of cities and in positioning the types of new structures that are most suited to an area, along with information on the relative damage potential of the existing structures in a region. In this paper, steps involved in microzonation and summary of Microzonation studies carried out / being carried out in India are presented. In India, seismic hazard analysis and microzonation were initiated in Jabalpur-MP, Sikkim, Mumbai, Delhi, North East India, Gauwhati, Ahmedabad, Bhuj, Dehradun, Chennai, and Bangalore Figure 1 shows theses locations indicating several cities are being done in Indian Shield. Also the detailed study of seismic hazard and microzonation of Bangalore is summarized in this paper.

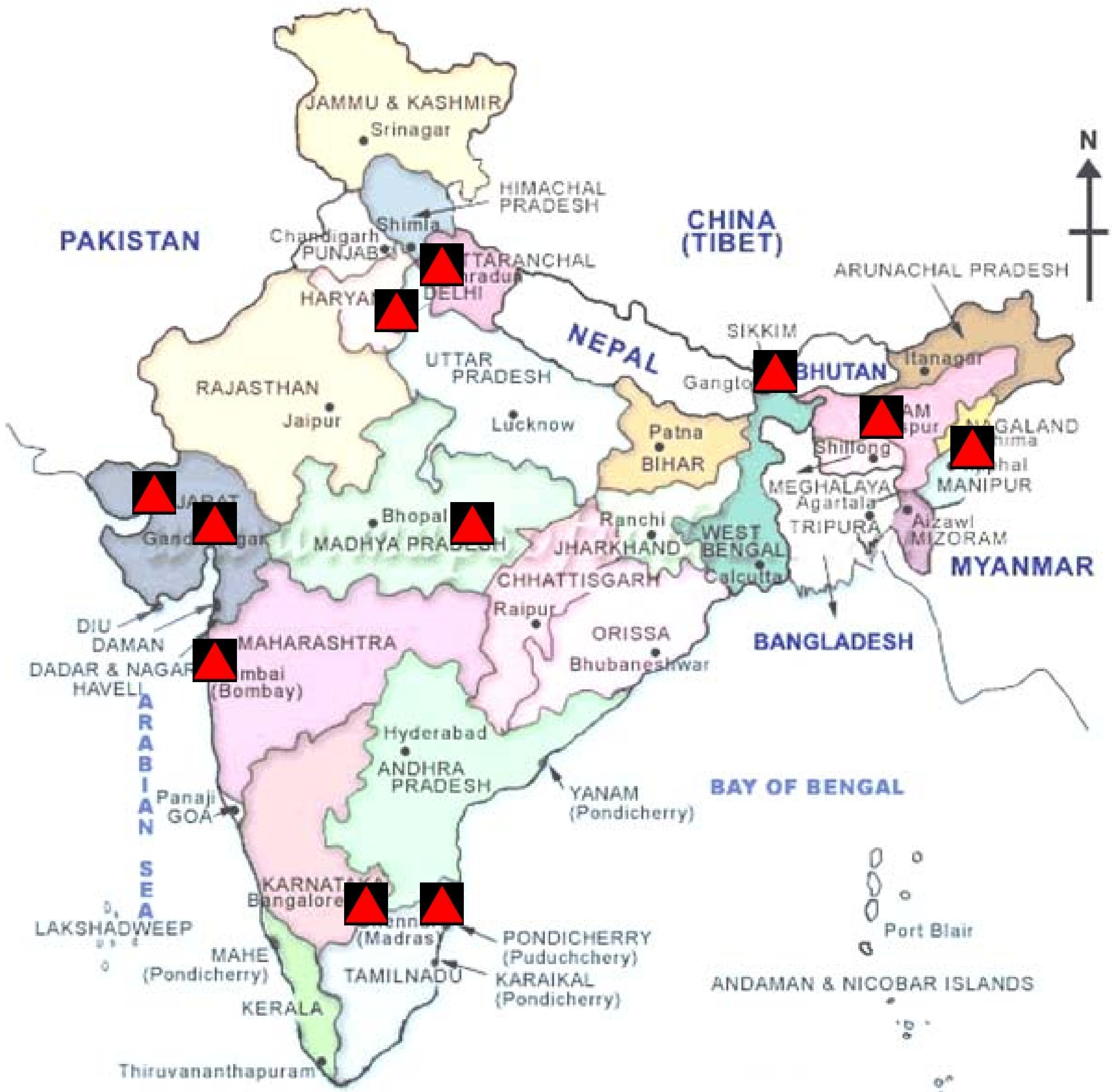

Figure 1: Area Initiated the Seismic Hazards and Microzonation in India

2 Seismic Microzonation of Jabalpur Urban Area

Very first work in India towards microzonation of Indian cities, was initiated as an experiment and example by the Department of Science & Technology, New Delhi (SMJUA, 2004). This work was carried out by the nodal national agencies viz.

Geological survey of India, Central Region Nagpur, Indian Metrology Department New Delhi, National Geophysical Research Institute (NGRI), Hyderabad, Central Building Research Institute(CBRI), Roorkee and Government Engineering College, Jabalpur. 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 these result 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 used to classification sites in Jabalpur based on the National Earthquake Hazard Research Program (1998) and uniform building code (1997). Site response study were carryout by conducting the experimental test of Nakamura type studies and receiver function type studies and predominant frequency and peak amplification maps was presented. The vulnerability and risk analysis were carried out and second level microzonation map and preliminary seismic risk maps were produced in the report.

3 Seismic Hazards and Microzonation Atlas of the Sikkim Himalaya

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 he presented the simulation of spectral acceleration and hazard scenario assessment for Sikkim. From the above studies he developed new attenuation relation for Sikkim Himalaya, a 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 land slides. Probabilistic seismic microzonation index map was prepared by integrating the weights and ratings of site response, peak ground acceleration, soil, rock outcrop and land slides.

The above case studies very clearly highlights that Jabalpur case study is done at a scale of a small city and other of Sikkim is carried out at a scale of state. Scale of less than 1:25000 is very essential for any microzonation study, which would be useful for urban planning.

4. Microzonation of Delhi

Seismic hazard and microzonation Delhi was carried out by many researchers, in particular seismic microzonation of Delhi for ground-shaking site effects by Mukhopadhyay et al (2002), Site-specific Microzonation Study in Delhi Metropolitan City by 2-D Modelling of SH and P-SV Waves by Parvez at al (2004), Microzonation of earthquake hazard in Greater Delhi area by Iyengar and Ghosh (2004), and Seismic Microzonation Studies for Delhi Region by Rao and Neelima Satyam (2005) and First Order Seismic Microzonation of Delhi, India Using Geographic Information System (GIS) by Mohanty et al (2006).

Mukhopadhyay et al (2002) carried out microtremor measurements in Delhi for estimation of seismic hazard microzonation for ground-shaking site effects. They were estimated resonance frequency and level of amplification (H/V ratio) at that frequency observed at various sites. Several peaks are noticed; frequency and H/V ratio of all the peaks are reported. They concluded that amplification of ground motion is very low on the ridge compared to the soft-soil sites. The resonance frequency is high at sites close to the ridge and also to Delhi west, compared to the sites close to river Yamuna. Amplification of ground motion is more at sites close to the river compared to that at the other sites investigated. They compared resonance frequency obtained by microtremor data with that estimated from strong motion records at site 14 highlighted that the parameters estimated were quite accurate. Based on their preliminary investigation, they conclude that a detailed study is required which can be done using microtremor data as well as the available earthquake data. The resulting information should be compared with available soil profile and basement depth information for a more accurate seismic hazard microzonation of the city.

Parvez at al (2004) computed the seismic ground motion in a part of Delhi City with a hybrid technique based on the modal summation and the finite-difference scheme for site-specific strong ground motion modelling. They determined response spectra computed from the signals synthesized along the laterally varying section and normalized by the response spectra computed from the corresponding signals, synthesized for the bedrock reference regional model. The sedimentary cover causes an increase of the signal amplitude (higher amplification), particularly in the radial and transverse component, it was verified with the site-effects by reversing the source location to the other side of the cross section and recomputed the site amplifications. They highlighted that the amplification of the vertical component is considerable at high frequency (>4 Hz.) when compared to lower frequency range.

Iyengar and Ghosh (2004) carried out complete seismic hazard analysis by both deterministic as well as probabilistic by considering the seismotectonic parameter around 300km radius from 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 first natural frequency with depth.

Rao and Neelima Satyam (2005) used computer code FINSIM, a finite fault simulation technique (Beresnev and Atkinson, 1998) 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 were carryout through geophysical testing at 118 sites and average shear wave velocity at 30m depth i.e., VS30 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 also estimated the microtremor measurements at 185 sites in Delhi exactly at the same locations were seismic refraction and MASW testing was done, analysis was carried out using VIEW 2002 software and the average H/V resonance spectra was obtained. Based on the shape of the resonance spectra, H/V amplitude, predominant frequency and fundamental frequency map of the 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.

Mohanty et al (2006) 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 weight in the 5-1 scale: depending on its contribution towards the seismic hazard. Following the AHP, the weightage assigned to each theme are: PGA (0.333), soil (0.266), geology (0.20), groundwater (0.133) and bedrock depth (0.066). The thematic vector layers were overlaid and integrated using GIS.

5. Seismic hazard estimation for Mumbai city

Raghu Kanth 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.

6. Seismic microzonation of Dehradun

Seismic Hazard Assessment and Site Response Study for Seismic Microzonation of Dehradun were initiated by the International Institute for Geo-Information Science and Earth Observation Enschede, Netherlands with Indian Institute of Remote Sensing, National Remote Sensing Agency (NRSA), Department of Space, Dehradun, India. The

Seismic microzonation of Dehradun was carried out has three components carried out by by Anusuya Barua (2005), Rajiv Ranjan (2005) and Brijesh Gulati (2006).

Anusuya Barua (2005) acquired, interpreted, compiled and analyzed information on geology and geomorphology of Doon valley in regional scale and subsurface strata at local scale for Dehradun city to aid study of seismic hazard assessment and seismic microzonation for ground shaking at specific site. The database generated for the seismic microzonation contains information on lithology, tectonic, landforms and associated neotectonics activity in regional scale as well as subsurface information in city part. These data of geological and geomorphological information can be used for study of seismic hazard assessment, Liquefaction hazard modelling and seismic microzonation.

Rajiv Ranjan (2005) carried out the field study at 31 locations and measured shear wave velocity and soil thickness using Analysis of Surface Waves (MASW). Measured shear wave velocities of different sites were compared with tube well lithologs and local geology. Then he used SHAKE2000 program with measured shear wave velocity and recorded ground motion for the site response study of Dehra Dun. Also he developed microzonation spectral acceleration map of Dehradun at different frequency.

Brijesh Gulati (2006) carried out the earthquake risk assessment (ERA) of buildings using HAZUS in Dehradun, India. The HAZUS is one of the ERA tools developed in the United States, which assesses the earthquake loss for the built environment and population in urban areas. He analyzed the applicability of HAZUS model for the assessment of earthquake risk of buildings in India. He highlighted shortcomings in the HAZUS approach for using it in India and suggested modifications in terms of parameters to fill the gaps identified and to find the strength of using this model in India.

7. Ongoing Seismic microzonation of other cities

The Department of Science & Technology, New Delhi initiated the seismic microzonation of Guwahati, Bhuj, Kachchh, Ahmedabad, Chennai, Kochi and Bangalore. These projects are ongoing, which are briefly presented.

Aa a part of the microzonation in Bhuj, after 2001 earthquake many studies are undertaken to understand the seismotectonic of regions, instrumentation for earthquake, site response studies, liquefaction studies and etc. In particular, Mandal et al (2005), Parvez and Madhukar (2006), Trivedi et al (2006) and Mohanty (2006) are working towards microzonation of Bhuj, Kachchh and Ahmedabad. 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 wav 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). Analysis and studies of the geological map of the region and it 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. They also planned to prepare a detailed seismic microzonation maps taking into account liquefaction.

Suganthi and Boominathan (2006) studying 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 planned to use site response by measuring ambient noise (microtremor) with the help of a City Shark seismic recorder and triaxial 3- component 1 sec 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.

Baranwal et al (2005) prepared the first level microzonation map of Guwahati based on amplification of ground motion, slope of exposed rocks, shape and constituents of overburden material inferred from geophysical surveys. 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 Vs 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.

8. Seismic Hazard Analysis for Bangalore

Deterministic Seismic Hazard Analysis (DSHA) for Bangalore has been carried out by considering the past earthquakes, assumed subsurface fault rupture lengths and point source synthetic ground motion model. The sources have been identified using satellite remote sensing images and seismotectonic atlas map of India and relevant field studies. Maximum Credible Earthquake (MCE) has been determined by considering the regional seismotectonic activity in about 350 km radius around Bangalore. To simulate synthetic ground motions, Boore (1983, 2003) SMSIM program has been used and the peak ground acceleration (PGA) for the different locations is evaluated. From the above approaches, the PGA of 0.15g was established for Bangalore. Figure 2hows the Peak ground acceleration distribution map for Bangalore. This value was obtained for a maximum credible earthquake having a moment magnitude of 5.1 for a source Mandya-Channapatna-Bangalore lineament. A completeness of the seismic data collected over a radius of 350km around Bangalore city using the method as proposed by Stepp (1972) has been carried out. From the analysis, it was found that the seismic data is homogenous for the last four decades irrespective of the magnitude. Seismic parameters were then evaluated using the data corresponding to the last four decades for Bangalore region and found to be comparable with the earlier reported seismic parameters for south India. The probabilities of distance, magnitude and peak ground acceleration have been evaluated for the six most vulnerable sources. The mean annual rate of exceedance has been calculated for all the six sources at the rock level.

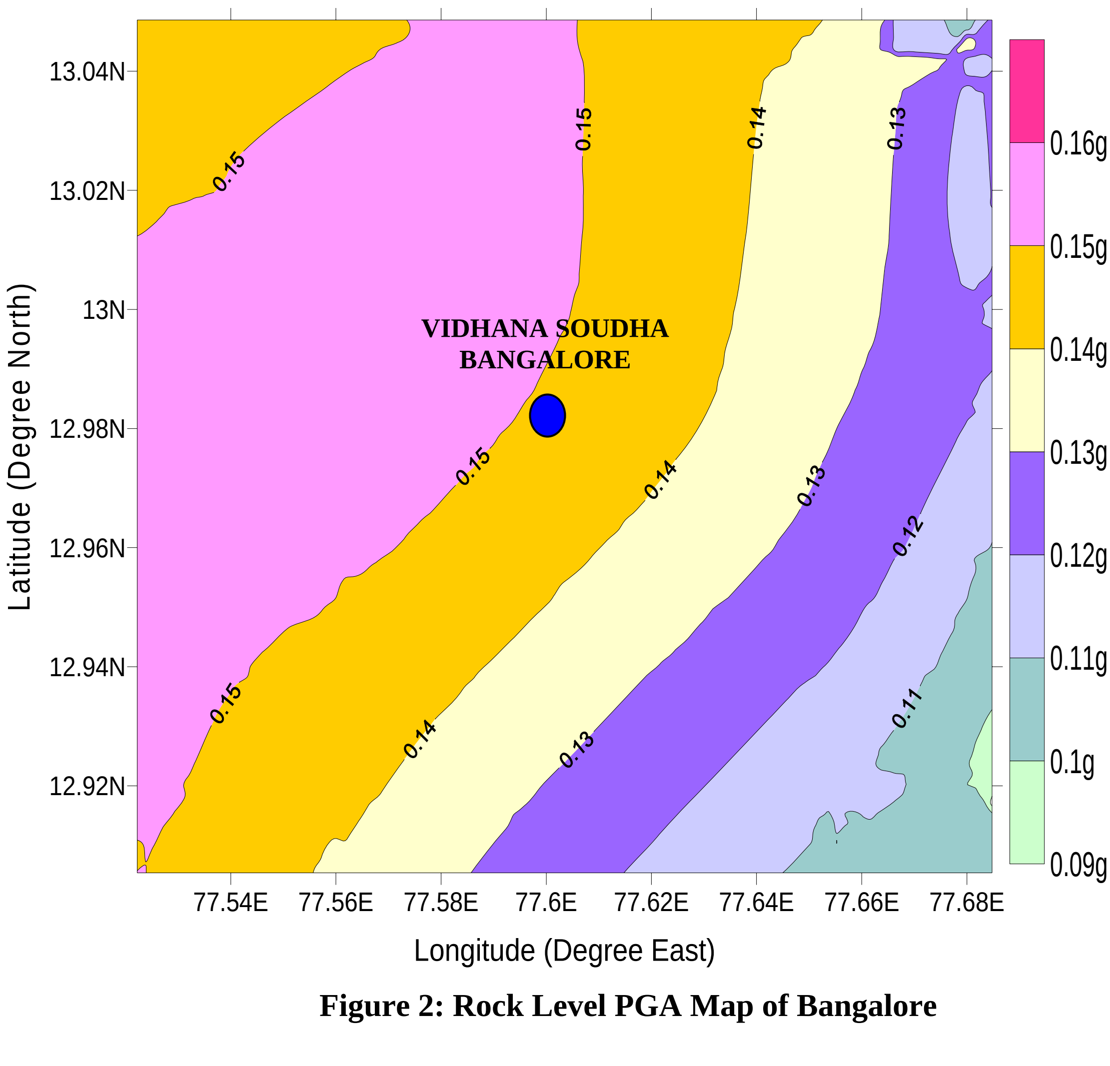

Figure 2: Rock Level PGA Map of Bangalore

The cumulative probability hazard curves have been generated at the bedrock level for peak ground acceleration and spectral acceleration. The spectral acceleration calculation corresponding to a period of 1sec and 5% damping are evaluated. For the design of structures, uniform hazard response spectrum (UHRS) at rock level is developed for the 5% damping corresponding to 10% probability of exceedance in 50 years. The peak ground acceleration (PGA) values corresponding to 10% probability of exceedance in 50 years are comparable to the PGA values obtained in deterministic seismic hazard analysis (DSHA) for the same area as reported by authors (Sitharam et al 2006) and higher than Global Seismic Hazard Assessment Program (GSHAP) maps of Bhatia et.al (1997) for the Indian shield area.

9. Site characterization of Bangalore for Microzonation

The 3-D subsurface model for geotechnical data has been generated with development of digitized map of Bangalore city with several layers of information. GIS database for collating and synthesizing geotechnical data available with different sources and 3 dimensional view of soil stratum presenting various geotechnical parameters with depth in appropriate format has been developed. In the context of prediction of reduced level of rock in the subsurface of Bangalore and to study the spatial variability of the rock depth, Geostatistical model based on Ordinary Kriging technique, Artificial Neural Network (ANN) and Support Vector Machine (SVM) models have been developed.

The shear wave velocity of Bangalore subsurface soil has been measured using Multichannel Analysis of Surface Wave (MASW) survey and correlation has been developed for shear wave velocity (*Vs*) with the standard penetration tests (SPT) corrected "N" value. The average shear wave velocity of Bangalore soil has been evaluated for depths of 5m, 10m, 15m, 20m, 25m and 30m (Vs^{30}) depths. The sub soil classification has been made by carrying out local site effect evaluation based on average shear wave velocity of 30m depth (Vs^{30}) of sites using NEHRP and IBC classification. Mapping clearly indicates that the depth of soil obtained from MASW is closely matching with the soil layers in the bore logs. The measured shear wave velocity of 34 locations close to SPT boreholes, has been used to generate the correlation between the shear wave velocity and corrected "N" values (N_{60}); with a regression analysis using a power fit. Also, developed relation corresponds well with the published relationships such as Japan Road Association shear wave velocity correlation with SPT "N" Values.

10. Local Site Effects and Site Response for Microzonation

Effect of site amplification of seismic energy due to soil conditions on damage to built environment was amply demonstrated by many earthquakes during the last century. The wide spread destruction caused by Guerrero earthquake (1985) in Mexico city, Spitak earthquake (1988) in Leninakan, Loma Prieta earthquake (1989) in San Francisco Bay area, Kobe earthquake (1995), Kocaeli earthquake (1999) in Adapazari are important examples of site specific amplification of ground motion even at location far away (100-300km) from the epicenter (Ansal, 2004). The recent 2001 Gujarat-Bhuj earthquake in India is another example, with notable damage at a distance of 250km from the epicenter (Sitharam et. al 2001, and Govinda Raju et. al 2004). These failures resulted from the effect of soil condition on the ground motion that translates to higher amplitude; it also modifies the spectral content and duration of ground motion. As seismic waves travel from bedrock to the surface, the soil deposits that they pass through change certain characteristics of the waves, such as amplitude and frequency content. This process can transfer large accelerations to structures causing large destruction, particularly when the resulting seismic wave frequency matches with the resonant frequencies of the structures. Site specific ground response analysis aims at determining this effect of local soil conditions on amplification of seismic waves and hence estimating the ground response spectra for future design purposes. The response of a soil deposit is dependent upon the frequency of the base motion and the geometry and material properties of the soil layer above the bedrock. Although not known as seismically very active, Bangalore, a fast growing urban center, with the low – moderate earthquake history (Sitharam and Anbazhagan ,2006) and highly altered soil structure (due to large reclamation of land) is been the focus of many of our recent studies. In the present study, an attempt has been made to site response using geotechnical, geophysical data and experimental studies. The subsurface profile was selected with 160 geotechnical bore logs out of 900 bore logs in the study area of 220sq.km. At about 55 locations, MASW survey has been carried out and the data has been used to study the site response. These soil properties and synthetic ground motions for each borehole locations are further used to study the local site effects using 1D ground response analysis with program, SHAKE2000. The response and amplification spectrum have been evaluated for each layer of borehole location. The natural period of the soil column, peak spectral acceleration and frequency at peck spectral acceleration of each borehole has been evaluated and presented as maps. The microzonation maps prepared indicates varied amplification potential. A peculiar feature of the study region is that it has reclaimed land from silted lakes/tanks leading to significant variations in ground response. With the amplification factors varying from 1 to 4.7 and period of soil column from 0.08 to 4.5 seconds, the region is moderately amplifying. The response spectrum for 5% damping at the ground surface obtained for 160 borehole and 55 MASW locations clearly indicate that the range of spectral acceleration (SA) at different frequencies varied from 0.01 to 2.172g at different frequency. The site response studies also carryout experimentally based on recording the ambient noise for a selected period of duration. The noise was recorded at 64 different locations using L4-3D short period sensors equipped with digital acquisition systems. The predominant frequencies obtained from experimental result range between 1.2 Hz - 11 Hz which matches well with the theoretical analyses using 1-d ground response analysis..

11. Liquefaction hazard assessment for Microzonation

The preliminary liquefaction hazard mapping of Bangalore city has been carried out using standard penetration test (SPT) data and bore log information. Cyclic Stress Ratio (CRS) resulting from earthquake loading is calculated by considering hypothetical local earthquake magnitude of 6 and 7 on Richter scale. Cyclic Resistant Ratio (CRR) is arrived using the corrected SPT “N” values and soil properties. Factor of safety against liquefaction is calculated using stress ratios and necessary magnitude scaling factor for these earthquake magnitudes. A simple spread sheet was developed to carryout all the calculation for each bore log. The factor of safety against liquefaction is grouped together and classified Bangalore city (of about 220 sq. km) area in to seven groups for liquefaction hazard mapping. Using 2D base map of Bangalore city, the liquefaction hazard map was prepared using AutoCAD and Arc info packages. At few locations, the undisturbed soil sample has been collected and laboratory cyclic triaxial tests have been carried out to validate the liquefaction susceptibility calculations. Laboratory tests show that soil samples are not liquefiable as observed from the analysis.

12. Conclusions

This paper presents the Indian experiences of microzonation of urban centers in India. A study of seismic hazard analysis considering local site effects along with microzonation of Bangalore has also been presented. The study shows that expected ground motion at rock level for Bangalore is about 0.15g. Bangalore soil is characterized using site characterization technique by using both standard penetration test and multichannel analysis of surface waves. Correlation between corrected SPT "N" values and measured shear wave velocity has been generated. Theoretical site response study has been carried out using SHAKE2000 by considering SPT and MASW data, these results are comparable. Correlation between corrected SPT "N" values and low strain shear modulus has been generated. Site response study also carried out using experimental method of Microtremor. Predominant period for Bangalore determined from above studies varies from 3Hz to 12Hz. Finally liquefaction hazard of Bangalore is estimated and from the study it is clear that Bangalore is safe against liquefaction.

13. Acknowledgements

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