Dr. P. Anbazhagan PhD Thesis

ABSTRACT

Seismic hazard and microzonation of cities enable to characterize the 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 of 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 the present study an attempt has been made to characterize the site and to study the seismic hazard analysis considering the local site effects and to develop microzonation maps for Bangalore. Seismic hazard analysis and microzonation of Bangalore is addressed in this study in three parts: In the first part, estimation of seismic hazard using seismotectonic and geological information. Second part deals about site characterization using geotechnical and shallow geophysical techniques. An area of 220 sq.km, encompassing Bangalore Municipal Corporation has been chosen as the study area in this part of the investigation. There were over 150 lakes, though most of them are dried up due to erosion and encroachments leaving only 64 at present in an area of 220 sq. km and emphasizing the need to study site effects. In the last part, local site effects are assessed by carrying out one-dimensional (1-D) ground response analysis (using the program SHAKE 2000) using both borehole SPT data and shear wave velocity survey data within an area of 220 sq. km. Further, field experiments using microtremor studies have also been carried out (jointly with NGRI) for evaluation of predominant frequency of the soil columns. The same has been assessed using 1-D ground response analysis and compared with microtremor results. Further, Seed and Idriss simplified approach has been adopted to evaluate the liquefaction susceptibility and liquefaction resistance assessment. Microzonation maps have been prepared for Bangalore city covering 220 sq. km area on a scale of 1:20000.

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 seismic sources for region have been collected by considering seismotectonic atlas map of India and lineaments identified from satellite remote sensing images. Analysis of lineaments and faults help in understanding the regional seismotectonic activity of the area. Maximum Credible Earthquake (MCE) has been determined by considering the regional seismotectonic activity in about 350 km radius around Bangalore. Earthquake data are collected from United State Geological Survey (USGS), Indian Metrological Department (IMD), New Delhi; Geological Survey of India (GSI) and Amateur Seismic Centre (ASC), National Geophysical Research Institute (NGRI),Hyderabad; Centre for Earth Science Studies (CESS), Akkulam, Kerala; Gauribindanur (GB) Seismic station and other public domain sites. Source magnitude for each source is chosen from the maximum reported past earthquake close to that source and shortest distance from each source to Bangalore is arrived from the newly prepared seismotectonic map of the area. Using these details, and, attenuation relation developed for southern India by Iyengar and Raghukanth (2004), the peak ground acceleration (PGA) has been estimated. A parametric study has been carried out to find fault subsurface rupture length using past earthquake data and Wells and Coppersmith (1994) relation between the subsurface lengths versus earthquake magnitudes. Further seismological model developed by Boore (1983, 2003) SMSIM program has been used to generate synthetic ground motions from vulnerable sources identified in above two methods. From the above three approaches maximum PGA of 0.15g was estimated for Bangalore. This value was obtained for a maximum credible earthquake (MCE) having a moment magnitude of 5.1 from a source of Mandya-Channapatna-Bangalore lineament. Considering this lineament and MCE, a synthetic ground motion has been generated for 850 borehole locations and they are used to prepare PGA map at rock level.

The past seismic data has been collected for almost 200 years from different sources such as IMD, BARC (Gauribidanur array), NGRI, CESS, ASC center, USGS, and other public domain data. The seismic data is seen to be homogenous for the last four decades irrespective of the magnitude. Seismic parameters were then evaluated using the data corresponding to the last four decades and also the mixed data (using Kijko's analysis) for Bangalore region, which are 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 using PSHA (Probabilistic Seismic Hazard Analysis). The mean annual rate of exceedance has been calculated for all the six sources at the rock level. 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) and higher than Global Seismic Hazard Assessment Program (GSHAP) maps of Bhatia et.al (1997) for the Indian shield area.

The 3-D subsurface model with geotechnical data has been generated for site characterization of Bangalore. The base map of Bangalore city (220sq.km) with several layers of information (such as Outer and Administrative boundaries, Contours, Highways, Major roads, Minor roads, Streets, Rail roads, Water bodies, Drains, Landmarks and Borehole locations) has been generated. 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 (called as "engineering rock depth" corresponding to about Vs > 700 m/sec) in the subsurface of Bangalore and their spatial variability evaluated using Artificial Neural Network (ANN). Observed SPT 'N' values are corrected by applying necessary corrections, which can be used for engineering studies such as site response and liquefaction analysis.

Site characterization has also been carried out using measured shear wave velocity with the help of shear wave velocity survey using MASW. MASW (Multichannel Analysis of Surface Wave) is a geophysical method, which generates a shear-wave velocity (*Vs*) profile (i.e., *Vs* versus depth) by analyzing Raleigh-type surface waves on a multichannel record. MASW system consisting of 24 channels Geode seismograph with 24 geophones of 4.5 Hz capacity were used in this investigation. The shear wave velocity of Bangalore subsurface soil has been measured and correlation has been developed for shear wave velocity (Vs) with the standard penetration tests (SPT) corrected 'N' values. About 58 one-dimensional (1-D) MASW surveys and 20 two-dimensional (2-D) MASW surveys has been carried out with in 220 sq.km Bangalore urban area. Dispersion curves and shear velocity 1-D and 2-D have been evaluated using SurfSeis software. Using 1-dimensional shear wave velocity, 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 carried out for local site effect evaluation based on average shear wave velocity of 30m depth (Vs^{30}) of sites using

NEHRP (National Earthquake Hazard Research Programme) and IBC (International Building Code) classification. Bangalore falls into site class D type of soil. 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 at 38 locations close to SPT boreholes, which are used to generate the correlation between the shear wave velocity and corrected 'N' values using a power fit. Also, developed relationship between shear wave velocity and corrected 'N' values corresponds well with the published relationships of Japan Road Association.

Bangalore city, a fast growing urban center, with low to moderate earthquake history and highly altered soil structure (due to large reclamation of land) is been the focus of this work. There were over 150 lakes, though most of them are dried up due to erosion and encroachments leaving only 64 at present in an area of 220 sq km. In the present study, an attempt has been made to assess the site response using geotechnical, geophysical data and field studies. The subsurface profiles of the study area within 220sq.km area was represented by 170 geotechnical bore logs and 58 shear wave velocity profiles obtained by MASW survey. The data from these geotechnical and geophysical technique have 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 by conducting one-dimensional ground response analysis using the 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 peak spectral acceleration of each borehole has been evaluated and presented as maps. Predominant frequency obtained from both methods is compared; the correlation between corrected SPT ‘N’ value and low strain shear modulus has been generated. The noise was recorded at 54 different locations in 220sq.km area of Bangalore city using L4-3D short period sensors (CMG3T) equipped with digital data acquisition system. Predominant frequency obtained from ground response studies and microtremor measurement is comparable.

To study the liquefaction hazard in Bangalore, the liquefaction hazard assessment has been carried out using standard penetration test (SPT) data and soil properties. Factor of Safety against liquefaction of soil layer has been evaluated based on the simplified procedure of Seed and Idriss (1971) and subsequent revisions of Seed et al (1983, 1985), Youd et al (2001) and Cetin et al (2004). Cyclic Stress Ratio (CSR) resulting from earthquake loading is calculated by considering moment magnitude of 5.1 and amplified peak ground acceleration. 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 accounting necessary magnitude scaling factor for maximum credible earthquake. A simple spread sheet was developed to carryout the calculation for each bore log. The factor of safety against liquefaction is grouped together for the purpose of classification of Bangalore (220 sq. km) area for a liquefaction hazards. Using 2-D base map of Bangalore city, the liquefaction hazard map was prepared using AutoCAD and Arc GIS packages. The results are grouped as four groups for mapping and presented in the form of 2-dimensional maps. Liquefaction possibilities are also assessed conducting laboratory cyclic triaxial test using undisturbed soil samples collected at few locations.