SEISMIC HAZARD STUDIES USING GEOTECHNICAL BOREHOLE DATA AND GIS

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ABSTRACT

Seismic Hazard Analyses of Bangalore city has been done based on the local soil conditions using a geotechnical data. Seismic hazard analyses parameters are evaluated in terms of amplification rating, peak ground acceleration and factor of safety against liquefaction by considering hypothetical earthquake. Amplification rating is done based on soil profiles by using Finn (1991) recommendation. The peak horizontal ground acceleration in Bangalore is predicted using Boore. et. al (1994). The theoretical PGA curve was developed using different methods by considering Ramanagara fault, which is about 48Km away from Bangalore. The factor of safety against liquefaction was determined using Seed and Idriss (1983) simplified approach. The seismic hazard maps for these three parameters have been prepared in 2-dimension by using AutoCAD and Geographic Information System (GIS), ARCINFO packages. The seismic hazard maps of amplification rating, peak horizontal ground acceleration and factor of safety against liquefaction by considering earthquake magnitude 6 and 7 in Richter scale have been prepared for Bangalore city. These seismic hazards maps are the first level microzonation maps for Bangalore city.

INTRODUCTION

Microzonation is the processes of subdivision of region in to number of zones that involves incorporation of geological, seismological and geotechnical concerns into justifiable land-use planning for earthquake effects. Microzonation would provide general guidelines for the types of new structure that are most suited to an area, and it would also provide information on the relative damage potential of the existing structures in a region. Seismic hazard maps increasingly are being incorporated into earthquake hazard mitigation practice. Seismic hazard maps results from geotechnical data including field investigation carried out by geotechnical engineers. The seismic microzonation maps produced in this study are based on the present techniques and available geotechnical data for Bangalore city. The maps prepared are the level-1 microzonation maps for seismic hazard. These maps therefore can be modified at any time, as more and more data is available and also as the new methods are being developed. These maps display areas in function of their capabilities to alter the ground motion and they are useful tool for seismic hazard studies.

METHODOLOGY

Site conditions play a major role in establishing the damage potential of incoming seismic waves from major earthquake. In an attempt to develop an elementary and simple microzoning of Bangalore metropolitan area for hazard, local soil conditions based on large amount of geotechnical data has been collected and analyzed. First level seismic microzonation maps have been prepared by analyzing the various data in the following stages:

Stage 1**:** Collection of pre-existing historic seismic data – magnitude and history of earthquake occurrence, epicenters, etc. for Bangalore city.

Stage 2**:** Collection of geomorphological data and topographical map – fault & lineaments -locations and directions of active fault in and around Bangalore.

Stage 3**:** Collection of field SPT soil data with bore log characteristics – soil profile and shear strength with depth for about 900 bore hole locations in Bangalore.

Stage 4**:** Analysis of SPT-N values with appropriate corrections with bore log characteristics and identification of various deposits. The corrections are applied for overburden pressures (C_N), hammer energy (C_E), borehole diameter (C_B), presence or absence of liner (C_S), rod length (C_R) and fine content (C_{fines}) as followed by Anbazhagan and Premalatha (2004).

Stage 5**:** Computation of Amplification rating, Attenuation potential in terms of PHA (g) and Factor of safety against liquefaction.

Stage 6**:** Grouping the determined Amplification rating, Attenuation Potential in terms of PHA and Factor of Safety against Liquefaction Values.

Stage 7**:** Zoning the severity group index for Bangalore city and development of first level seismic hazard maps using AutoCAD and GIS package.

SEISMIC HISTORY OF THE REGION

In recent years much of the seismic activity in the state of Karnataka has been in the south, in the Mysore-Bangalore region. Historically tremors have occurred in many other parts of the state such as Bellery, which is in the north part of Karnataka. The seismic history of Karnataka state was collected from different sources and few of these events are presented in Table 1. Table 1 shows that the earthquakes, which has occurred close to Bangalore, was in the range of 2.0 to 5.5 in Richter magnitude. However, for the future planning an earthquake magnitude of 6 and 7 in Richter scale has been considered for the seismic hazard analyses in this study.

Table 1. : Historic Earthquake events in Karnataka (BARC, Gauribidanur; & www.asc-india.org)

DATE&YEAR	MAGNITUDE	LATITUDE in N	LONGITUDE in E	NEAREST PLACE
12 March 1829	5.7	13.000	75.500	Mangalore Area
13 March 1829	**5.8**	**13.000**	**77.600**	**Bangalore Area**
01 April 1843	6.0	15.200	76.900	Bellary-Kolagallu Area
23 August 1858	**5.8**	**13.000**	**77.600**	**Bangalore Area**
07 Janury 1961	**5.0**	**13.000**	**77.300**	**Bangalore Area**
12 February 1970	5.0	13.000	76.100	Hassan Area
16-May-72	4.6	12.400	77.000	Malavalli Area
17-May-72	4.5	12.400	77.000	Malavalli Area
15 November 1973	4.0	17.000	76.300	Almel Sindgi Area
12-May-75	4.7	13.800	75.300	Shimoga Area
30-April-1983	**2.3**	**12.70**	**77.12**	**West of Ramannagara**
20-Mar-84	4.6	12.550	7.770	Denkanikota Area
27-Nov-84	4.5	12.870	78.000	Masti Berikal Area
17-Oct-1985	2.3	12.62	77.45	North of Kanakapura
17-Oct-1987	2.3	12.62	77.45	North of Kanakapura
3-May-90	4.6	13.000	75.500	Dharmasthala Area

30-Nov-1991	2.3	12.85	77.63	South-east of Bangalore
24-Jul-1993	**2.9**	**12.94**	**77.59**	**Bangalore**
30-Sep-93	6.2	18.066	76.451	Khilari
14-Nov-93	4.5	12.200	77.050	Tallakad-Kollegal Area
1-Oct-1995	**2.4**	**13.02**	**77.54**	**Bangalore**
29-Jan-01	4.3	12.444	77.360	Mandya Area

EPICENTER AND FAULTS

Data from satellite remote sensing, airborne geophysics and ground geological, geophysical and geochemical data for the peninsular Indian shield south of 17^0 latitude which includes whole of Karnataka has been synthesized under the project Vasundhara operated by the Air born mineral survey and exploration wing of GSI, the regional remote sensing service center and ISRO Bangalore (Project Vasundhara, 1994). The thematic map, T-I Lineaments and Faults and T-VI Seismotectonic Map from project Vasundhara shows that there are active faults that triggered earthquake magnitude of 2 to more than 4 close to Bangalore. Project Vasundhara identified the major crustal shear zone which act as channel ways for ore-bearing fluids and there is transition zone in between low-grade gneiss terrain and high-grade granulite zone, which is 30-60 km wide zone marking a transition from the low-grade gneiss terrain to the north and the high-grade granulite zone to the south. These crustal shear zones may be source for future earthquakes in this region (Radhakrishna and Vaidyanadhan, 1997). The morphology of Karnataka shows that the series of water falls, cascades and rabid along the Cauvery river, particularly between Sivasamudram in Karnataka and Mettur in Tamil Nadu, could be due to reactivation of Precambrian faults across part of the old course here and lateral displacement of the uplifted blocks, giving rise to change in the course of the river which is shown in Fig1 (Valdiya, 1997). Figure 1 shows the active faults present south of the Bangalore city on either side of Bangalore within 100 kms. The revised seismic map of India shows that the greater part of the Bangalore district falls under seismic zone II (IS 1893 part I-2002).

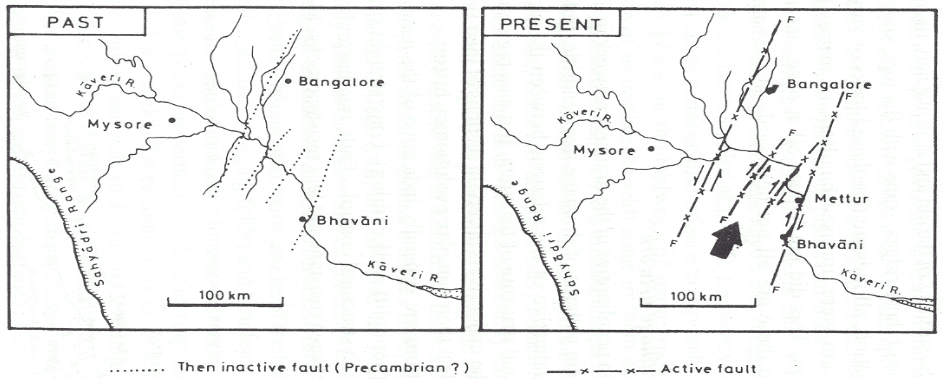

Fig 1. : Showing the Active Faults present nearer to Bangalore (after K.S. Valdiya, 1997)

GEOLOGICAL AND GEOTECHNICAL SITE CONDITIONS

From Geology, most part of Bangalore region comes in Gneiss complexes, which is formed due to several tectonic-thermal events with large influx of sialic material, are believed to have occurred between 3400 to 3000 million years ago giving rise to an extensive group of gray gneisses designated as the “older gneiss complex”. These gneisses act as the basement for a widespread belt of schist’s. The younger group of gneissic rocks mostly of granodiomitic and granitia composition is found in the eastern part of the state, representing remobilized parts of an older crust with abundant additions of newer granite material, for which the name “younger gneiss complex” has been given (Radhakrishna and Vaidyanadhan, 1997). The rocks in this group range in age from 2700 to 2500 million years. The Eastern part of Karnataka (Bangalore) is surrounded by remobilized terrain and it is marked by a 5 km wide steep-dipping mylonite belt, which can be traced for nearly 400 km. Despite its steep dip most workers consider in it as a thrust on the basis of seismic evidence. A narrow belt of younger granite plutons separates the two blocks (Radhakrishna and Vaidyanadhan, 1997).

Geotechnical data for Bangalore city, which described the soil and rock profiles was basically collated from archives of Torsteel Research Foundation in India (TRFI) and Indian Institute of Science (IISc) for geotechnical investigations carried out for several major projects in Bangalore. The data collected is of very high quality carried out by senior geotechnical engineers for important projects in

Bangalore during the years 1990-2003. So far about 900-borelog information has been keyed in into the database. Most of the data so far selected for the database is on average to a depth of 20m below the ground level with an interval of 0.5m. Another of about 1000-borehole information is still available at different locations up to different depths (about 6-30m), which were carried out in connection with geotechnical investigations for buildings and infrastructures all over Bangalore. The GIS model has been developed, which consists of about 900 borehole locations marked on the digitized Bangalore map of 1:20000 scales. The boreholes are represented as 3dimensional objects projecting below the map layer in 0.5m intervals. Also image files of bore logs and properties table have been attached to the location in plan. These 3-D boreholes are generated with several layers with a bore location in each layer overlapping one below the other and each layer representing 0.5 m interval of the subsurface. Each layer of this model is attached with bore log data at that depth. The data consists of visual soil classification, bore hole location, ground water level, time during which test has been carried out, other physical and engineering properties of soil. As such when this model is viewed in 3D, subsurface information on any borehole at any depth can be obtained by clicking at that level. Also typical information of a bore-log at a particular depth is shown in Table 2.

Table 2 : Properties attached at each depth of in a bore

1. BH No.	8. Thickness of the layer
2. Location	9. SPT N value
3. Ground RL	10.Bulk density
4. Depth	11.Water content
5. Ground water table	12.Grain size distribution (Percentage gravel, sand, sit and clay)
6. Duration	13.Liquid limit
7. Visual soil Classification	14.Plastic limit

ANALYSES

Typical information obtained from the bore log SPT test, which is shown in Table 2, is used to arrive at the seismic bore log. This seismic bore log contain information about depth, observed SPT N values, density of soil, total stress, effective stress, fine content, correction factors for observed N values, and corrected N value. A typical seismic bore log generated for a single bore hole data at a selected site is shown in Table 3.From the seismic bore log data, the amplification rating, peak ground horizontal acceleration (g) and factor of safety against liquefaction are evaluated as explained in the following sections.

Table 3. Seismic bore log

Depth m	N Value	Density kN/cum	T.S kN/sq.m	E.S kN/sq.m	Cn	Correction Factors For				C.N1	F.C %	C.F.C	Corrected N value
						Hammer Effect	Bore hole Dia	Rod Length	Sample Method				
1.00	15	20.00	20.00	20.00	1.57	1	1.05	0.75	1	18.56	36	1.241	23
2.00	12	20.00	40.00	30.19	1.46	1	1.05	0.75	1	13.84	18	1.137	16
3.00	32	20.00	60.00	50.19	1.29	1	1.05	0.8	1	34.75	29	1.158	40
4.00	29	20.00	80.00	70.19	1.16	1	1.05	0.85	1	29.94	40	1.227	37
5.00	32	20.00	100.00	90.19	1.05	1	1.05	0.85	1	29.89	41	1.233	37
6.00	30	20.00	120.00	110.19	0.96	1	1.05	0.95	1	28.60	59	1.339	38
7.00	29	20.00	140.00	130.19	0.88	1	1.05	0.95	1	25.44	61	1.364	35
8.00	28	20.00	160.00	150.19	0.81	1	1.05	0.95	1	22.74	60	1.372	31

(a). Amplification Rating

Amplification is defined as an increase in seismic ground motion intensity greater than that expected for firm ground or rock. Amplification of ground motion often occurs at sites overlain by thick, soft soil deposits especially where the predominant period of the earthquake motion matches the predominant period of the ground. The intensity of seismic ground motion is a function of earthquake magnitude and distance from the seismic source as well as the local soil conditions, topography and geological conditions. The greatest challenge to any microzonation programme for the seismic hazard is to reflect the possible amplifications of spectral acceleration due to site effects. Finn (1991) method is based on local soil profile and shear wave velocities along with soil properties (see the Table 4). In this work, amplification rating is carried out based on the local soil profiles. It is suitable for the 1st level amplification mapping.

(b). Peak Ground Acceleration

As the seismic waves propagate away from the source, the amplitude decreases, and this result in the so-called attenuation of the ground motion. Attenuation is the reason why even the strongest motion cease to damage after a certain distance from the source. Ground motion attenuation which defines how ground motion parameters decay with distance from the source, are used to provide ground motion estimate for a site. Since peak acceleration is the most commonly used ground motion parameter, many peak acceleration relationships have been developed. The seismic hazard analysis includes a site seismicity study. Through such studies, one can evaluate the Peak Ground Acceleration. Many researchers have developed PGA equations for their own region. Pandey et. al. (2001) has used a similar approach to Chamoli Earthquake of 1999 and have shown the usefulness of these equations. The authors have highlighted that the Boore et al. (1993) equation is more realistic for shallow earthquake and up to distance of 50 km. In this study, Boore et.al (1993) relation is used to get PGA at a site by considering that the site is 50 km away from the focal point and hypocenter is at a depth of 5.57 km.

Table 4 : Soil Amplification Rating based on Soil Susceptibility (Finn 1991)

Soil Category Label	General Description	Soil Category Definition	Susceptibility Rating
A	Competent/hard rock	V_{ave}760m/sec	Nil
B	Deep cohesionless soils, stiff cohesive soils or mix of cohesionless With stiff cohesive soils, not soft clay	360m/sec< V_{ave}<760m/sec	Low
C	Sands, silts and/or stiff/very stiff clays, some gravels; soft clay thickness<3	180m/sec< V_{ave}<360m/sec	Moderate
D_1	Profile containing a small to moderate total thickness (H_c) of soft to medium stiff clay	V_{ave}<180m/sec, and/or 3m <H_c<15	High
D_2	Profile containing a large total thickness,(H_c) of soft/medium stiff clay	V_{ave}<180m/sec, and/or 15 m<H_c<35m	High
E_1	Pests or highly organic clays	H_p>3m	Very High
E_2	Very high plasticity clays	H_{cp}>7m and PI<75%	Very High

Boore et.al (1993) has developed for western North America earthquake of magnitude 5.0 to 7.7 at a distance 100km of the projection of the fault to develop the predictive relationship for peak horizontal acceleration (PHA):

$$\log PHA(g) = b_1 + b_2 (M_w-6) + b_3 (M_w-6)^2 + b_4R + b_5 \log R + b_6G_B+b_7G_C$$

Where

$$R = \sqrt{d^2 + h^2} \qquad (2)$$

d = closest distance to the surface projection of the fault in kilometers

G_B = 0 for site class A
= 1 for site class B
= 0 for site class C
G_C = 0 for site class A
= 0 for site class B
= 1 for site class C

They have defined the site classes on the basis of the average shear wave velocity in the upper 30m as shown in Table 5. Table 6 shows the values of different coefficients they have used in their equations. It is to be mentioned here that as a trial, we have adopted the site classes mentioned by Boore et.al. (1993) in this work. However, in the next stage, we will adopt the soil category table developed for Bangalore city as detailed in the previous section. The wave velocities through this type of soils will be measured using Multichannel Analysis of Surface Wave (MASW) system on Bangalore.

Table 5. Site classes for Boore et. al (1993) attenuation relationship

Site Class	Vs in Upper 30m
A	>750m/sec
B	360-750m/sec
C	180-360m/sec

Table 6 : Coefficients for Boore et. al (1993) equations of attenuation relationship.

	b_1	b_2	b_3	b_4	b_5	b_6	b_7	h	σ_{logPHA}
Random	-0.105	0.229	0.0	0.0	-0.778	0.162	0.251	5.57	0.230
Large	-0.038	0.216	0.0	0.0	-0.777	0.158	0.258	5.48	0.205

Using the above relationship (equ.1), PGA has been calculated for each site and a typical calculation table is shown for a borehole in Table 7. Table 7 also contains the soil profile and shear velocity of layers. Shear wave velocities were estimated using Japan Road Association (1980) equations (for clayey soil $V_s = 100\ N^{1/3}$ and for sandy soil $V_s = 80\ N^{1/3}$). Table 7 also gives, PGA (g) and amplification rating for each site with depth.

(c). Factor of safety against liquefaction

The response of soil due to seismic hazards producing a significant amount of cumulative deformation or liquefaction or liquefaction has been one of the major concerns for geotechnical engineers working in the seismically active regions. Liquefaction can occurs in moderate to major earthquakes, which can cause severe damage to structure. The pressure generated by seismic wave vibrations will cause the ground water to flow up and out. When this occurs the sand grains looses its effective shear strength and will behave more like a fluid. The liquefaction potential of soil is either estimated from

Table 7. Amplification rating and Attenuation values

Magnitude, M_w= 6.0 Distance From Epicentre =50 Km

Depth (m)	N value		Classification				Depth	Description	Susceptibility Rating
1.00	23	228	C	0	1	0.066		silty sand	Low-B
2.00	16	200	C	0	1	0.066	2	silty sand	Low-B
3.00	40	343	C	0	1	0.066	3	clayey sand	Low-B
4.00	37	332	C	0	1	0.066		clayey sand	Low-B
5.00	37	333	C	0	1	0.066	5	sandy clay	Low-B
6.00	38	337	C	0	1	0.066		sandy clay	Low-B
7.00	35	326	C	0	1	0.066		sandy clay	Low-B
8.00	31	315	C	0	1	0.066	8	sandy clay	Low-B

laboratory tests or field tests. Liquefaction is controlled by grain size of soil, durations of earthquake and amplitude and frequency of shaking, distance from epicenter, location of water table, cohesiveness of the soil, permeability of the layer (Seed and Idriss, 1971). The rate majority of liquefaction hazard are associated with saturated sandy and silty soils of low plasticity and density. Among the field in-site tests, the SPT test which has been widely used for this purpose. In this paper, SPT test result with number of corrections for the raw data has been used for direct assessment of ground's liquefaction resistance.

The simplest reliable common procedure for calculation of liquefaction factor of safety is Seed and Idriss (1971) simplified approach, this simplified approach was used to arrive the factor of safety of site up to 15m depths in each Bore log. In this method, the earthquake induced loading is expressed in terms of cyclic shear stress and is compared with the liquefaction resistance of the soil, which is also expressed in terms of cyclic shear stress. The liquefaction potential and resistance calculation procedure is given below. The Cyclic Stress Ratio is calculated based on simplified approach recommended by Seed and Idriss (1971).

$$\text{Cyclic stress ratio (CSR)}=0.65\left(\frac{a_{\max}}{g}\right)\left(\frac{\sigma_{vo}}{\sigma_{vo}'}\right)r_d$$

The parameter a_{max} is the peak horizontal acceleration at the ground surface generated by an earthquake.

The N value observed in the field, using the SPT and the standard test procedure must necessarily be corrected for various corrections, such as:(a) Overburden Pressures (C_N), (b) Hammer energy (C_E), (c) Bore hole diameter (C_B), (d) presence or absence of liner (C_S), (e) Rod length (C_R) and (f) fines content (C_{fines}). Corrected N value i.e., (N_{60}) is obtained using the following equation (Anbazhagan and Premalatha 2004):

$$N_{60}=N^{x}C_N^{x}C_E^{x}C_B^{x}C_S^{x}C_R^{x}C_{fines} \quad (4)$$

Correction for overburden pressure C_N (Seed and Idriss, 1982)

$$C_N = 2.2 / (1.2+\sigma_{V0}'/P_a) \quad (5)$$

Where, σ_{V0}' = effective overburden pressure

P_a = 100 kPa

C_N should not exceed a value of 1.7

Correction for hammer energy ratio

A term energy ratio is defined to convey ratio of energy delivered to the split spoon sampler to the free falling energy of the hammer. The energy delivered to the sampler depends on the type of hammer, anvil, lifting mechanism and the method of hammer release. Approximate correction factors to modify measured N values to a 60% energy ratio for various types of hammer and anvils are listed in Table 8.

Table 8 : Hammer Correction Factor (Robertson and Wride 1988)

Type of Hammers	Notation	Range of correction
Donut Hammer	C_{ER}	0.5-1.0
Safety Hammer	C_{ER}	0.7-1.2
Automatic-trip Donut Hammer	C_{ER}	0.8-1.3

The other correction factors such as correction for **borehole diameter, rod length and sampling methods** are presented in Table 9.

Correction for Fine Content (Finn et.al 1995)

The corrected N Value $C_{N\ 60}$ are further corrected for fines content using the following sections:

$$N_{1\,(60)} = N_{60} * C_{fines} \quad (6)$$

Where, $C_{fines} = 1 + 0.004FC + 0.055(FC/N_{60})$, and, (7)

FC = percent fines content (percent dry weight finer than 0.074mm).

After the above corrections, the Atterberg limits of soil are considered for clayey type of soil. As per the Modified Chinese Criteria, if Liquid limit of the soil is greater than 35 the deposits are non liquefiable. For the other deposits, cyclic resistance ratio is arrived based on corrected N value (Seed et. al 1985) and this is proposed for a magnitude of 7.5 on the Richter scale. For the present study of microzonation, for the earthquake magnitude of 6 &7, the Magnify Scaling Factor (MSF) has been applied to relate the assumed earthquake magnitude to the magnitude of 7.5 earthquakes. The magnify scaling factor for the magnitude less than 7.5 is calculated as below:

$$MSF = \left[\frac{10^{2.24}}{M_W^{2.56}} \right] \tag{8}$$

Finally, factors of safety for liquefaction is calculated using:

$$FS = \left[\frac{CRR_{7.5}}{CSR} \right] MSF \tag{9}$$

The factor of safety of each layer for soil was arrived and Table 10 shows the results. It is noted here that, apart from Seed and Idriss (1983) recommendation, the Modified Chinese criterion was also used to derive factor of safety for the clayey sand and silty clayey soils. The factor of safety for liquefaction versus depth is prepared for each bore log (as shown in Figure 2) to easily identify the liquefiable layer. It is to be noted here that peak acceleration of 0.3g has been used for all locations as a first approximation. For the level-2 maps in the future, actual peak horizontal acceleration [PHA (g)] would be used to estimate the factor of safety against liquefaction.

Table 9 : Correction factors for Borehole Diameter (C_B), Rod Length (C_R) and Sampling Method (C_S)

Factor	**Equipment Variable**	**Notation**	**Correction**
Borehole Dia.	65-115mm	C_B	1.00
Borehole Dia.	150mm	C_B	1.05
Borehole Dia.	200mm	C_B	1.15
Rod Length	<3m	C_R	0.75
Rod Length	3-4m	C_R	0.80
Rod Length	4-6m	C_R	0.85
Rod Length	6-10m	C_R	0.95
Rod Length	10-30m	C_R	1.00
Sampling method	Standard samplers	C_S	1.00
Sampling method	Sampler without liners	C_S	1.1-1.3

Table 10. Typical liquefaction analysis for a borehole

NP3 pipeline, Agaram Tank, Bangalore.-BHL-1131-1										
Magnitude, M_w =		6.0					Peak Acceleration, g =			0.3
Depth	Corrected N value	σ_{vo}	σ_{vo}'	r_d	CSR	FC	Liquid Limit	CRR	MSF	FS
(m)		kN/sq.m	kN/sq.m			%	%			
1.00	23	20.00	20.00	0.99	0.19	36	31	0.55	1.77	5.07
2.00	16	40.00	30.19	0.97	0.25	18	20	0.25	1.77	1.77
3.00	40	60.00	50.19	0.96	0.22	29	23	0.55	1.77	4.37
4.00	37	80.00	70.19	0.94	0.21	40	34	0.55	1.77	4.66
5.00	37	100.00	90.19	0.93	0.20	41	39	0.55	1.77	NL
6.00	38	120.00	110.19	0.91	0.19	59	37	0.55	1.77	NL
7.00	35	140.00	130.19	0.90	0.19	61	38	0.55	1.77	NL
8.00	31	160.00	150.19	0.88	0.18	60	39	0.55	1.77	NL

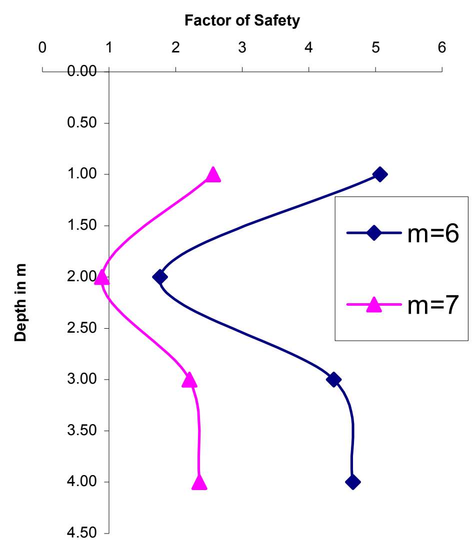

Figure 2 : Factor of safety against liquefaction vs. depth

PREPARATION OF ZONATION MAPS

To prepare the zoning map, GIS along with geotechnical data of Bangalore (Sitharam et.al 2004) has been used. Generally the amplification rating for Bangalore city comes under three groups, which are listed Table 11. The group Nil-A identifies the rock out crops and shallow depth rock areas. Sandy silt, sandy clay and silty soil come under the Low-B group. Soft clay and clay soil having depth more than 3m,comes under the Moderate-C group. Peak ground horizontal acceleration (PHA) of sites has been resulted in two groups. The analyses reveals that if the shear wave velocity of site is less than 360m/s, the PHA of site is 0.06g and if it is more than 360m/s, the PHA of site is 0.05g for the earthquake magnitude of 6 in Richter scale. If the velocity of site is less than 360m/s, the PHA of site is 0.112g. For more than 360m/s, the PHA of site is 0.092g for the earthquake magnitude of 7 in Richter scale. The factor of safety against liquefaction has been grouped in to 5 groups as shown in Table 12.

Table 11 : Amplification Rating

Description	Degree	Symbol
No Amplification	Nil	A
Low Amplification	Low	B
Moderate Amplification	Moderate	C

Table 12 : Factor of safety against liquefaction groups

Group	Factor of safety range	Severity Index
1	<1	High
2	1 to 2	Moderate
3	2 to 3	Low
4	>3	Nil
5	Non Liquefiable (NL)	Nil

Figures 3,4 and 5 show the zonation maps for the amplification rating, PHA (g) and factor of safety against liquefaction for earthquake magnitude of 6 in Richter scale for the Bangalore city. The factors of safety against liquefaction presented in this paper are much lower, as a maximum value of peak ground acceleration has been used. This exercise shall be treated as a first attempt to prepare level-1 microzonational map based on seismic hazard analyses for Bangalore city.

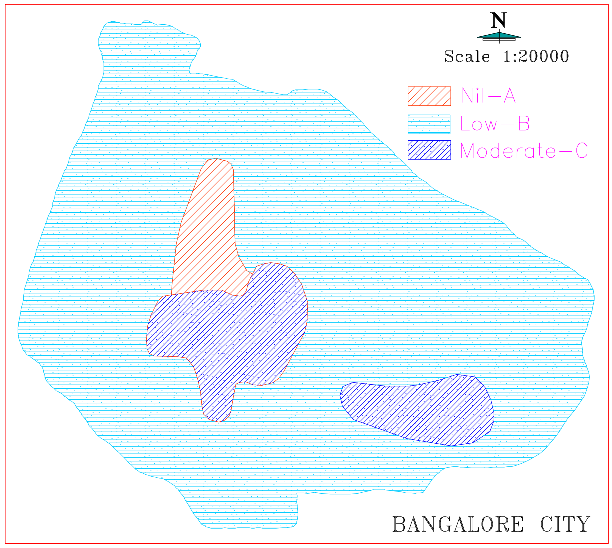

Figure 3 : Amplification rating map for Bangalore city

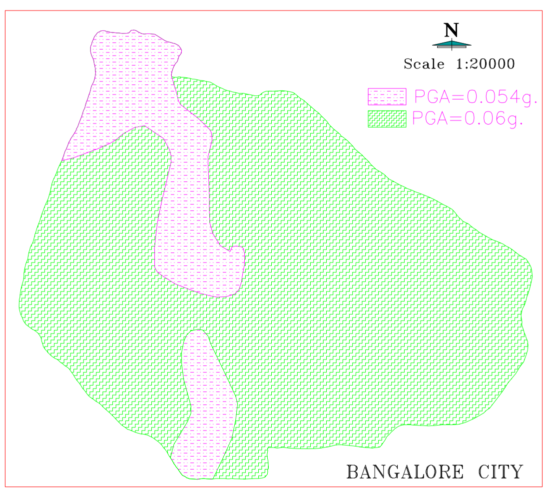

Figure 4 : Peak Ground Acceleration distribution for Bangalore city

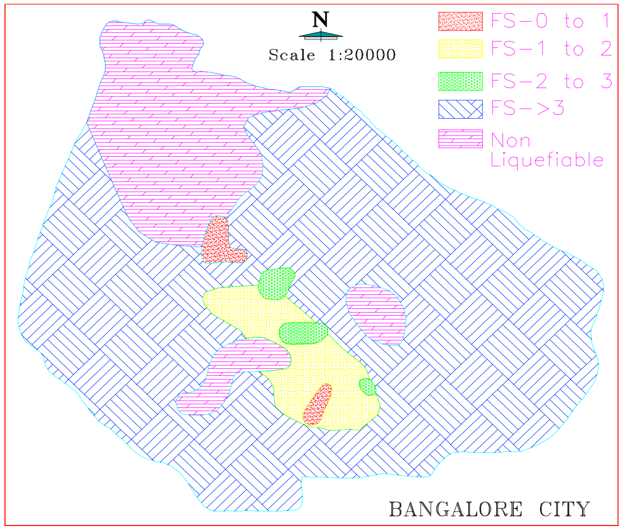

Figure 5 : Factor of safety against liquefaction for Bangalore city

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