Deterministic Seismic Hazard Analysis and Estimation of PHA for Bangalore City

T.G.Sitharam [1], P.Anbazhagan [2] and K. Ganesha Raj [3]

ABSTRACT

Deterministic seismic hazard analysis (DSHA) has been carried out by considering the historic earthquake, assumed subsurface fault length and point source synthetic ground motion generation model. Active lineaments are identified using remote sensing data. MCE has been determined by considering the regional seismotectonic activity in about 350km radius around Bangalore city. The seismotectonic map has been prepared by considering the faults, lineaments, shear zones in the area and historic earthquake events of more than 150 events. Shortest distance from the Bangalore to the different sources is measured and then Peak Horizontal Acceleration (PHA) calculated for the different sources and moment magnitude using regional attenuation relation. By carrying out sensitivity analysis the matching sub surface rupture length for the each historic earthquake based on Wells and Coppersmith [21]. It is found that subsurface fault rupture length of about 4% of total length of the fault is matching with historic earthquake events in the area close to the each source. SMSIM- FORTRAN programs for simulating ground motions from the Earthquakes have been used by giving the regional seismotectonic parameters as input for the different sources, the PHA for the different locations are evaluated. From the above three approaches the higher PHA causing earthquake moment magnitude of 5.1 is maximum credible earthquake and corresponding source Mandya-Channapatna-Bangalore lineament is obtained as the vulnerable source for Bangalore region. Maximum credible earthquake found in terms of moment magnitude is 5.1 with PHA value of about 0.150g. Acceleration time history (ground motion) of corresponding magnitude has been generated using synthetic earthquake model by considering the revised regional seismotectonic parameter presented in Sitharam and Anbazhagan [18].The revised parameter gives the PHA of 0.146g corresponding to MCE of past event

Keywords: *DSHA, lineament, MCE, Synthetic Ground Motion.*

[1] *Professor, sitharam@civil.iisc.ernet.in, Department of Civil Engineering, Indian Institute of Science, Bangalore, India 560012.*
[2]*Research Scholar, anbazhagan@civil.iisc.ernet.in, Department of Civil Engineering, Indian Institute of Science, Bangalore, India 560012.*
[3] [1]NNRMS/EOS, ganeshraj@hotmail.com, ISRO Hq., Antariksh Bhavan, New BEL Road, Bangalore 560 094.

5.1 moment magnitude occurred in May 1972. In this paper, similar analysis with different seismotectonic parameters such as shear wave velocity, density and Q factor evaluated from literature and recent studies carried out in Bangalore region is presented. However the vulnerable source and MCE earthquake remains same. The predicted PHA value and vulnerable source can be used for the further microzonation of the region.

[1.0] INTRODUCTION

Seismic hazard analyses involve the quantitative estimation of ground shaking hazards at a particular area. Seismic hazards may be analyzed deterministically as when a particular earthquake scenario is assumed, or probabilistically, in which uncertainties in earthquake size, location, and time of occurrence are explicitly considered [10]. A critical part of seismic hazard analysis is the determination of Peak Horizontal Acceleration (PHA) for an area. Seismic hazard analysis and determination of PHA is crucial and very important base for any earthquake resistant design and Microzonation. In seismic hazard analysis, identification of the source for the future earthquake is a very important process. To evaluate seismic hazards for a particular site or region, all possible sources of seismic activity must be identified and their potential for generating future strong ground motion should be evaluated. Analysis of lineaments and faults helps in understanding the regional seismotectonic activity of the area. Lineaments are linear features seen on the surface of earth which represents faults, features, shear zones, joints, litho contacts, dykes, etc; and are of great relevance to geoscientists. Scientists believe that a lineament is a deep crustal, ancient, episodically reactivated a linear feature that exerts control on the make up of the crust and associated distribution of ore and hydrocarbons [12, 6]. In this paper, attempt has been made to carry out the deterministic seismic hazard, to determine maximum credible earthquake (MCE) and PHA for Bangalore region. Then the revised generation of synthetic acceleration time history plot for the Bangalore region by considering work carried out by Sitharam and Anbazhagan [18]. The authors considered regional seismotectonic activity in about 350km radius around Bangalore city. The seismotectonic map has been prepared by considering all the possible sources of seismic activity such as faults, lineaments, shear zones and historic earthquake events (of more than 150 events). This paper is the revised work of Sitharam and Anbazhagan [18] by considering the seismotectonic parameter from recent publications.

[2.0] BACKGROUND OF THE STUDY

Seismicity of an area is the basic issue to be examined in seismic hazard analysis for evaluating seismic risk for the purpose of microzonation planning of urban centers. Detailed knowledge of active faults and lineaments and associated seismicity is required to quantify seismic hazard and risk. Indian peninsular shield, which was once considered to be seismically stable, has shown that it is quite active. Large number of earthquakes with different magnitudes has occurred very often in this region [16, 2]. In recent years much of the seismic activity in the state of Karnataka has been in the south, in the Mysore-Bangalore region [6]. Seismotectonic map from Project Vasundhara [14] also shows that there are active faults that triggered earthquake magnitude of 2 to 4 close to Bangalore. 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. This is attributed 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 as discussed by Valdiya

[19]. In that figure the active faults speculated at present by Valdiya [19] in south of Bangalore on either side within 100 kms. Similarly, in the north, the Arkavathi River that follows a remarkably straight fault valley in the Manchenabele-Aganahalli-Ramagiri tract. Valdiya [19] highlighted that the recent uplift is in the order of 7 to 10 m on the eastern side formed gully erosion on the Manchenabele reservoir area corroborating to the recent movement of the faults. Valdiya [19] indicates that in Southeast of Kanakapura,the Hosdurga stream flows about 10 kms in a straight valley before entering on entrenched swing and they have pointed the evidence to the western block rising up a few meters and blocking the flow of the Hosdurga stream. As described by Radhakrishnan and Vaidyanadhan [15], 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 many workers consider it as a thrust on the basis of seismic evidence. Ganesha Raj and Nijagunappa [6] have identified an active lineament from Mandya-Channapatna-Bangalore using remote sensing data and neotectonic activity of the area. From the above discussion, it is clear that there are several active faults and lineaments in and around Bangalore Sitharam and Anbazhagan [18].

[3.0] STUDY AREA

Sitharam and Anbazhagan [18] summarized the detail of study which is as follows. Bangalore city covers an area of over 650 square kilometers and is at an average altitude of around 910m above mean sea level. It is situated on a latitude of 12^0 58” North and longitude of 77^0 37” East. The population of Bangalore city is over 6 million and Bangalore city is the fastest growing city and fifth biggest city in India. It is the political capital of the state of Karnataka. A number of strategic establishments have made Bangalore a very important and strategic city. Recent earthquakes in different parts of country, particularly the one at Bhuj during 2001 has influenced the importance of earthquake resistant design and construction. Because of density of population, mushrooming of buildings of all kinds from mud buildings to RCC framed structures and steel construction, improper and low quality construction practice and irregular and heavy traffic conditions; Bangalore is vulnerable even against average earthquakes. Thus there is a need to evaluate the seismic hazard of this area. As per IS 1893 [8] Bangalore is upgraded to Zone II from Zone I in the seismic zonation map. Further, findings from geologists have shown that in the Bangalore region the reactivated reverse/normal faults have a dominant strike-strip movement resulting in repeated rupturing at close intervals. This is also evident from rejuvenation of the transcurrent faults manifested in recurrent earthquakes [19]. Ganesha Raj and Nijagunappa [6] have also highlighted the need to upgrade the seismic zonation of Karnataka; particularly the areas surrounding Bangalore, Mandya and Kolar to zone III rather than the current zone II as these areas are quite active, based on the analysis using remote sensing data and neotectinic activity in the area. In this paper , as per Regulatory Guide 1.168 [17], regional geological and seismological investigations for the Bangalore city has been carried out considering a radius of 350km around the point of interest to identify seismic sources by using literature review, study of maps, remote sensing data and ground reconnaissance study. Study area lies between latitudes 9° 50”north to17°12” north and longitudes 74° 24”east to 81°42” east covering 350km radial distance from the city.

[4.0] GEOLOGY OF THE STUDY AREA

From Geology point of view, most part of Bangalore region is comprised of Gneissic 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 grey 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 granodioritic and granitic composition is found in the eastern part of the Karnataka 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 [15]. The rocks in this group range in age from 2700 to 2500 million years. The oldest rocks of Karnataka are the Sargur Group of rocks, which is followed by Peninsular Gneissic Complex, Dharwar Super Group, Closepet Granite, Kaladgi, Bhima's, and Deccan Traps; these are further followed by laterite and alluvium. The Peninsular Gneissic Complex occupies major part of the study area [18].

[5.0] REMOTE SENSING STUDY

Remote sensing studies have become an important now days in analysing the structural and tectonic aspects of an area. They are useful in groundwater, mineral, oil explorations, seismic studies and in engineering geological applications. Remote sensing techniques have given further boost to lineament studies as on a satellite image/aerial photograph identification of lineaments/linear features becomes easy because of the synoptic view, availability of data in different spectral bands, repetitively etc. Even lineaments of inaccessible terrains can be mapped and analysed using the remote sensing data. Dykes and ridges also appear as linear features on images but they can be segregated from other linear features because of their positive relief. Roads, railways, runways etc. though appear as linear features can be distinguished from others. Lineaments could be thought of as observable physical responses of a host of interrelated geodynamic phenomena such as lithospheric accretion and destruction, oceanization and cratonization, seismicity and vulcanicity, taphrogenesis and mountain building, pluton emplacement and metallogeneis [5]. The remote sensing data has been used to identify the lineaments in Bangalore region and it was mapped using standard image interpretation keys. In the lineaments map the historic earthquake epicentres was superimposed, which shows that most of the historic earthquakes near to the few mapped lineaments. Lineament with more number of earthquake occurrences is termed as active lineaments, which is used for the seismic hazard analysis. Figure 1 show the typical remote sensing image which is used for identifying one of the lineaments in the area. Also Figure 1: shows Satellite image (Landsat TM) of Bangalore, Mandya andsurrounding areas showing number of major lineaments like Lakshamana hirtha-KRS-Bangalore Lineament, Arkavathi-Madhugiri Lineament

[6.0] SEISMIC HAZARD ANALYSIS AND SYNTHETIC GROUND MOTION

The MCE is the largest earthquake that appears possible along a recognized fault under the presently known or presumed tectonic activity [20] it will cause the most severe consequences at the site. MCE assessment gives little consideration to the probability of future fault movements. For the vulnerable earthquake source identification minimum moment magnitude considered was 3.5 and above. The numbers of earthquake sources on which earthquake of greater than 3.5 moment magnitude have

Figure1: *Satellite image (Landsat TM) of Bangalore, Mandya and Surrounding areas*

occurred are 52 faults and lineaments which are upgraded from the original work of Sitharam and Anbazhagan [18]. Shortest distance from source to Bangalore city centre has been measured from the seismotectonic map shown in figure 2. With these distance and moment magnitude Peak Horizontal Acceleration is calculated at bedrock level by assuming focal depth of the earthquake of about 15 km from the surface. This depth is also arrived at considering past events of earthquake. The PGA for the Bangalore has been calculated using the attenuation relation developed for south India by Iyengar and Raghukanth [9]. The calculation of PGA values shows that least PGA value due to different sources is 0.001g and large PGA value is caused from Mandya-Channapatna-Bangalore lineament and it is 0.146g. In total, 10 sources have generated the higher PGA values close to Bangalore city. Among the 10, the active lineament of Mandya-Channapatna-Bangalore lineament (L15 in Figure 2) having a length of about 105km which is 5.2km away from the Bangalore causing a PHA value of 0.146g due to an earthquake with an M_W of 5.1 occurred on 16th May 1972 (corresponds to a latitude of 12.4^o N and longitude of 77.0^o E), it is also a instrumented earthquake of surface wave magnitude (M_S) of 4.6. Further DSHA carried out by considering fault rupture length, Wells and Coppersmith [21] relation of moment magnitude with subsurface rupture length (RLD) has been used. Mark [11] recommends that the surface rupture length may be assumed 1/3 to 1/2 of the total fault length (TFL) based on the world wide data. However, assuming such large subsurface rupture length yields very large moment magnitude and also it does not mach with the historic earthquake data. By parametric analyses, it is found that subsurface fault rupture length of 2 % to 4% of total fault length gives a moment magnitudes closely matches with historic earthquakes. By assuming RLD by parametric analyses, it is found that subsurface fault rupture length of 2 % to 4% of total fault length gives a moment magnitudes closely matches with historic earthquakes. By assuming RLD of 4% total fault length gives least PHA values is 0.001g and large PHA value of 0.159g.

Because of lack of regional strong motion data, it is necessary to generate the synthetic earthquake data (strong motion). SMSIM- FORTRAN program for simulating ground motions, seismological model by Boore [3, 4] is used for generation of synthetic acceleration-time response [1, 7]. For the synthetic model the density ρ of the crustal rock (where the earthquake is originating) is taken as 2.7 at a depth of 15 km from the surface [13]. The strong motion data simulated for the moment magnitude of all the 10 sources and PHA are evaluated from the model (see the Table 1). The PHA varies from 0.005g to 0.13g. The active lineament of L15 gives the highest PHA value of 0.136g for the hypocentral distance of 15.88km. The response spectrums for the simulated earthquake to the sources are drawn it shows that the predominant period of synthetic ground motion is 0.06 seconds irrespective of the magnitude and sources. Further PHA obtained from model for the L15 matches well with the PHA values from both the above approaches. All the above three approaches have given highest PHA value for the Bangalore city from the Mandya-Channapatna-Bangalore lineament (L15) for the historic earthquake of 5.1 moment magnitude. It clearly indicates that the maximum credible earthquake for the region is 5.1 moment magnitude and vulnerable source is active lineament of Mandya-Channapatna-Bangalore lineament (L15).

Table 1: *PHA obtained from Synthetic Earthquake Model*

Number and Name of Source		Length (km)	Distance (km)	Occurred Earthquake (M_W)	Hypocentral Distance (km)	PHA (g)
F47	Arkavati Fault	125.13	51.25	4.7	53.395	0.014
L14	Kunigal- Arkavathi	100.59	43.85	4.1	46.345	0.008
L15	Mandya-Channapatna- Bangalore	104.90	5.22	5.1	15.881	0.136
L16	Arakavathi- Doddaballapur	108.98	18.10	4.7	23.508	0.050
L17	Arkavathi - Madhugiri	156.49	29.69	4.2	33.260	0.015
L18	Doddabelvangala- Pavagada	125.37	24.07	4.1	28.357	0.017
L22	Nelamangala- Shravanabelagula	130.43	26.36	5.3	30.325	0.064
L31	Molakalmur-Hospet-Kushtagi-Krishna	190.25	58.68	4	60.567	0.005
L34	Sindhnur- Krishna	223.35	55.42	4.2	57.409	0.006
L20	Chelur-Kolar-Battipalle	110.89	57.60	5.2	59.516	0.022
L26	Holalkere- Herur	172.47	158.11	6	158.820	0.020
F52	Bhavani Fault	90.29	216.84	6.2	217.358	0.017

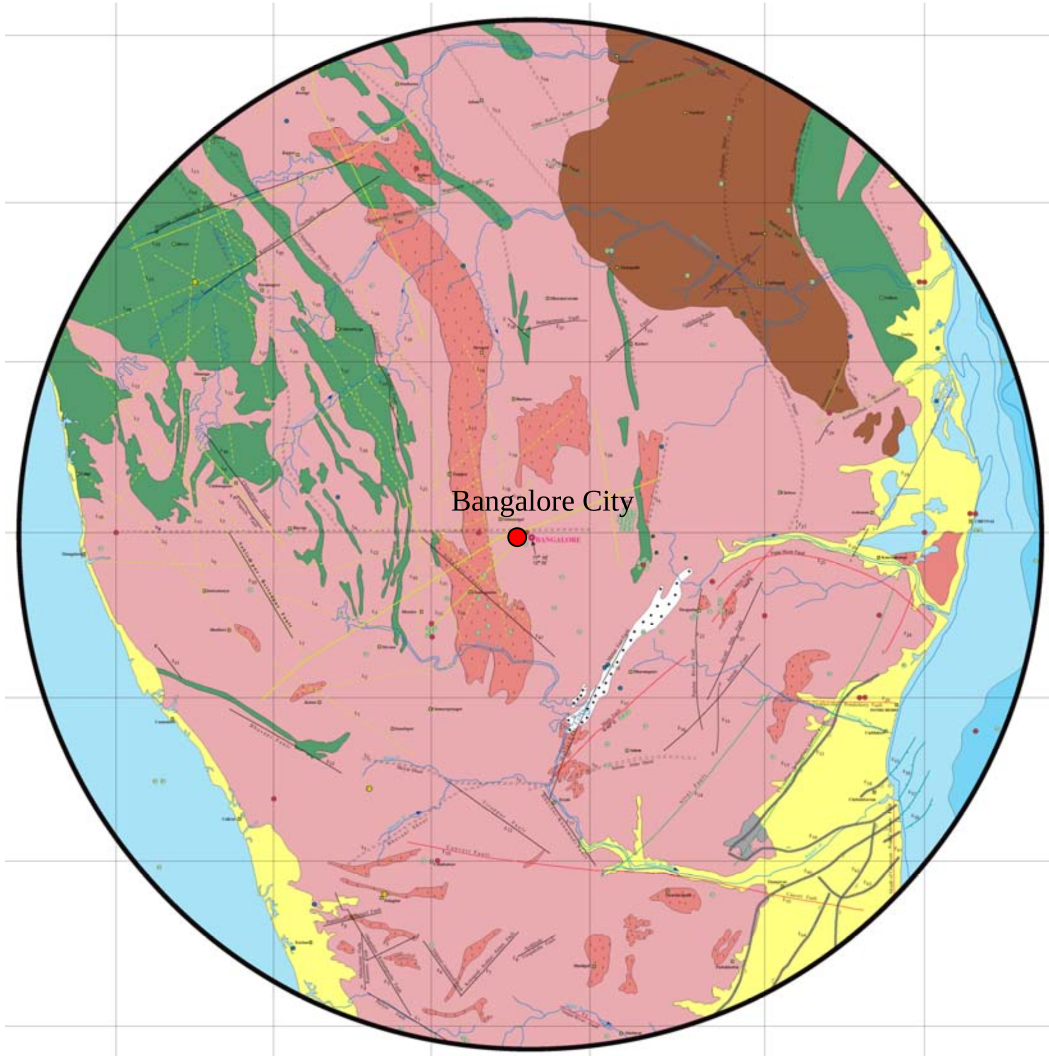

Figure 2: *Seismotectonic Map for Bangalore city and surroundings*
(after Sitharam and Anbazhagan, 2006)

CONCLUSION

The revised analysis of DSHA from Sitharam and Anbazhagan [18] has been carried out using the seismotectonic parameter published recently. This study shows that the vulnerable source of Mandya-Channapatna-Bangalore lineament (L15) remain same with Peak Horizontal Acceleration of 0.146g using the regional attenuation relation. The maximum credible earthquakes of 5.1 in moment magnitude also remain same.

ACKNOWLEDGMENT

Authors thank ISRO-IISc Space Technology Cell, Indian Institute of Science, Bangalore, India for funding the project titled "Use of remote sensing and GIS for Seismic Hazard Analyses of Bangalore Urban Area, (Ref no. ISTC/CCE/TGS/176/2006 Dated 29 March 2006)"

REFERENCES

[1] Atkinson, G. M. and Boore, D. M, “Ground-motion Relations for Eastern North America”, Bulletin of the Seismological Society of America, vol. 85(1), 1995, pages 17-30.

[2]Bansal, B.K. and Gupta, S, A Glance through the Seismicity of Peninsular India. Jour. Geol. Soc. India, vol.52, 1998, pages 67-80

[3] Boore, D. M, Stochastic simulation of high-frequency ground motions based on seismological models of the radiated spectra, Bull. Seism. Soc. Am., vol.73, 1983, pages 1865-1894.

[4] Boore, D. M, Simulation of ground motion using the stochastic method, Pure and Applied Geophysics, vol. 160, 2003, pages 635-675.

[5] Bhave, K.N; Ganju, J.L. and Jokhan Ram, Origin, nature and geological significance of lineaments; In: Qureshy, M.N. and Hinze, W.J. (eds.) Regional Geophysical Lineaments their Tectonic and Economic Significance. Mem. Geol. Soc. India, vol. 12, 1989, pages 35-42.

[6] Ganesha Raj. K and Nijagunappa. RMajor Lineaments of Karnataka State and their Relation to Seismicity: Remote Sensing Based Analysis, Jr.Geol.Soc.India Vol.63, 2004, pages 430-439.

[7] Hwang, H. and Huo, J. –R, Attenuation relations of ground motion for rock and soil sites in eastern United States, Soil Dynamics and Earthquake Engineering, vol.16, 1997,pages 363-372.

[8] IS 1893 (part 1): Criteria for Earthquake Resistant Design of Structure, Bureau of Indian standards, New Delhi,2002.

[9] Iyengar, R.N and Raghukanth, S. T. G, Attenuation of Strong Ground Motion in Peninsular India, Seismological Research Letters, 75, 4, July/August 2004, pages 530-540.

[10] Kramer. S. L. Geotechnical Earthquake Engineering, Published by Pearson Education, Pvt Ltd, 1996.

[11] Mark, R.K., Application of linear statistical model of earthquake magnitude versus fault length in estimating maximum expectable earthquakes, Geology vol.5, 1977, pages 464– 466

[12] O’Leary, D.W; Driedman, J.D. and Pohn, H.A. (1976), “Lineaments, linear, lineation: Some proposed new standards for old terms” Geol. Soc. Am. Bull. vol. 87, 1976, pages 1463-1469.

[13] Parvez. A.I, Franco Vaccari and Giuliano F. Panza October, A deterministic seismic hazard map of India and adjacent areas, Geophysical Journal International, vol.155, 2003, pages 489–508.

[14] Project Vasundhara, Regional Remote Sensing Service Centre/Indian Space Research Organisation, Airborne Mineral Survey and Exploration Wing/Geological Survey of India, -Status Report, 1991, pages 11-15.

[15] Radhakrishnan, B. P and Vaidyanathan. R, Geology of Karnataka Geological Society of India, Bangalore,1997.

[16] Ramalingeswara Rao, B. and Sitapathi Rao, P, Historical Seismicity of Peninsular India. Bull. Seismological Soc. America, vol.74, 1984, pages 2519 -2533

[17] Regulatory Guide 1.165, Identification and characterization of seismic sources and determination of safe shutdown earthquake ground motion, Published by U.S. Nuclear Regulatory Commission, March 1997.

[18] Sitharam T. G. and P.Anbazhagan, Seismic Hazard Analysis for the Bangalore Region” Journal of Natural Hazards, in Printing, 2006.

[19] Valdiya, K.S, (1998), “Late Quaternary Movements and Landscape Rejuvenation in South-eastern Karnataka and Adjoining Tamil Nadu in Southern India Shield”, Journal of Geological Society of India, India, Vol 51, Feb.1998, pages 139-166.

[20] USCOLD, Guidelines for Earthquake Design and Evaluation of Structures Appurtenant to Dams”, United States Committee on Large Dams. 1995, pages 75.

[21] Wells, D.L., Coppersmith, K.J New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement. Bull. Seismol. Soc. Am. Vol.4 (84), 1994, pages 975– 1002.