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Seismic Hazard Analysis for Tamil Nadu State : A Deterministic Approach

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Abstract

Tamil Nadu State, with an area of 130, 058sq.km located in the southern most part of the Peninsular India is selected for the present study on seismic hazard assessment. The part of northern and western Tamil Nadu State including its capital city Chennai have been categorized under Moderate Seismic Hazard (Zone III) areas, by Bureau of Indian Standard (BIS) in 2001. A catalog of historical/instrumental earthquakes/ earth tremors in the state has been prepared and used in this paper. The earthquakes having magnitude of greater than 3.0 have been considered for the present study. The seismic sources have been identified using remote sensing images with limited ground truth verification. Seven near potential seismic sources in the region delineated as area sources for seismic hazard assessment based on geological, seismological and geophysical information. Shortest distance from the each seismic source to the major cities of Tamil Nadu measured and the Peak Ground Acceleration (PGA) at bed rock level is calculated for the seven sources with their maximum credible earthquake events using available attenuation relationship formula. The maximum magnitude associated with these potential seismic sources is in the range of 6.0 to 5.0 in Richter scale and the estimated on Peak Ground Acceleration at the source is 0.212 to 0.078g. The PGA values are estimated from the closest potential source for major cities of Tamil Nadu viz., Chennai, Coimbatore, Salem, Madurai and Trichirappalli cities, which have PGA of 0.107g, 0.133g, 0.012g, 0.077g & 0.113g respectively. The result of the present study reveals that the seismic hazard in northeastern and western part of the state is closely matching with the Seismic Zonation map published by the BIS. However the east southeastern part of the state shows higher value because of the adequate earthquake data used for the present study for the years 1800 to 2004. The southern part of state shows comparatively low seismic hazard than the other parts of the Tamil Nadu state.

Introduction

Seismic hazard assessment is essential for carrying out safe and economic design of structures. Deterministic seismic hazard assessments seek to identify the Maximum Credible Earthquake (MCE) that will affect a site. The MCE is the largest earthquake that appears possible along a recognized fault under the presently known or presumed tectonic activity, which will cause the most severe consequences at the site. MCE assessment gives little consideration to the probability of future fault movements.

Tamil Nadu is one of the 13 identified seismotectonic zones of Peninsular India (Chandra, 1977). Study of lineaments can be useful in understanding the seismicity and assessing the seismic hazard of a given area. A number of studies carried out in India and abroad (Krishna Brahmam and Negl 1973; Allen, 1975; Khattari et al, 1988; Peshwa and Kale 1997; Ramasamy 2000; Vivek Laul, 2000 and Khanna, 2001) and have indicated a definite correlation between earthquakes and lineaments. Research studies have been undertaken on the seismicity of the

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Peninsular India based on the lineaments/ faults with their spatial association of the epicentres of the earthquakes. Chandra (1977) identified several seismic zones below latitude 28°N in Peninsular India and correlated the epicentres with known geological structures and faults and concluded that in southern India, the epicenters in seismogenic source zone have the scatter pattern and some of them could be correlated with the existing faults. Strong earthquakes from Peninsular India are generally confined to zones with active neotectonic movements (Srivastava 1985). Fault plane solutions of the earthquakes in Koyna, Ongole, Bhadrachalam have indicated that the faults are of the strike-slip type with lateral movement and reverse type in the case of Broach and Latur earthquakes (Arora et al 1971; Chandra 1976 and 1977; Rao et al 1975; Langeston 1976; Banghar 1972; Rastogi 1992; Seebar et. al 1996). Recent studies carried out in Tamil Nadu and the rest of India have revealed that lineaments/faults have a clear spatial association with earthquake incidences (Rajarathnam et al 1996; Rajarathnam and Ganapathy 2002; Ganesharaj et al 2001, Khanna 2001, Sitharam et.al, 2006).

Out of 38 earthquakes recorded in the southern part of the Peninsula between 1823 and 1968, 19 earthquakes have been occurred within 50km of the fault bearing N 45° E. Six have occurred on or adjacent to Archaean – Cretaceous boundary fault in Tamil Nadu. The region in which the deep main fault occurs is seismically active at the present time (Grady 1971). Earthquakes of magnitude 6.0 had been recorded in 1900 near Coimbatore. The various fault systems in Tamil Nadu seems to be active even during the present day (Vemban et al 1977).

Potentially seismic faults are area of sources, in which the configuration of each source zone is controlled mainly by the extent of active faults, the mechanism of earthquake faulting and the seismogenic part of the crust. The goal of potential seismic source identification is to identify and include in the analysis of all structures (mainly faults) that are believed to be tectonically active with faults of even low rates of activity (EERI Committee on Seismic Risk, 1989). The delineation of these sources is usually the major part of any seismic hazard analysis (Reiter, 1990). A total of 235 potential seismic sources in Iran and neighbouring region are delineated based on available geological, geophysical, tectonic and earthquake data for the seismic hazard assessment of the country (Mirzaei 1999).

Tamil Nadu experienced moderate earthquakes in the past earthquake history of 200 years is well evident from the published literatures. Twelve earthquakes of $M \geq 5.0$ have occurred in the State for the known

Table 1: Seismic Potential Sources of Tamil Nadu State

Source	Name of the Potential seismic sources	L	C.E	M_w	PGA
A	Lineament on the Northern boundary of Palghat gap (EW) – (No.47)	86	5	6.0	0.212
B	Nilgiris lineament (NE) – (No.44)	56	1	5.7	0.160
C	Basement fault following the western boundary of Thanjavore - Tranquebar depression (NE-SW) – (No. 50)	315	5	5.6	0.145
D	Lineament on the Northern boundary of Palghat gap(WNW – ESE) – (No. 49)	116	2	5.0	0.078
E	Adayar fault (EW) – (No.31)	42	1	5.3	0.107
F	Chengam – Alangayam Gudiyattam lineament (NNE – SSW) – (No .21)	160	3	5.0	0.078
G	Adanur - Thirukovilur- Ponnaiyar lineament (NE-SW) – (No.26)	45	3	5.0	0.078

Note : For details on fault number in bracket, refer Fig.1.
L : Length of the seismic potential source in Km
CE : Cumulative Number of Earthquakes
M_w : Magnitude observed from the historic/instrumental earthquake
PGA : Peak Ground Acceleration (PGA) in g determined using M_{max}

history. Bureau of Indian Standard (2001) categorized Tamil Nadu under Seismic Zones II and III, representing an area of 73% and 27% respectively. It should also to be noted that the major cities in Tamil Nadu viz., Chennai, Coimbatore and Salem fall in Zone III. Many researchers have carried out studies on seismicity of Tamil Nadu based on correlation of earthquake epicenters with the tectonic set up of the region. It is very much essential to know the potential seismic hazard of the state. The present study aims at producing seismic hazard maps in terms of Peak Ground Acceleration for Tamil Nadu State.

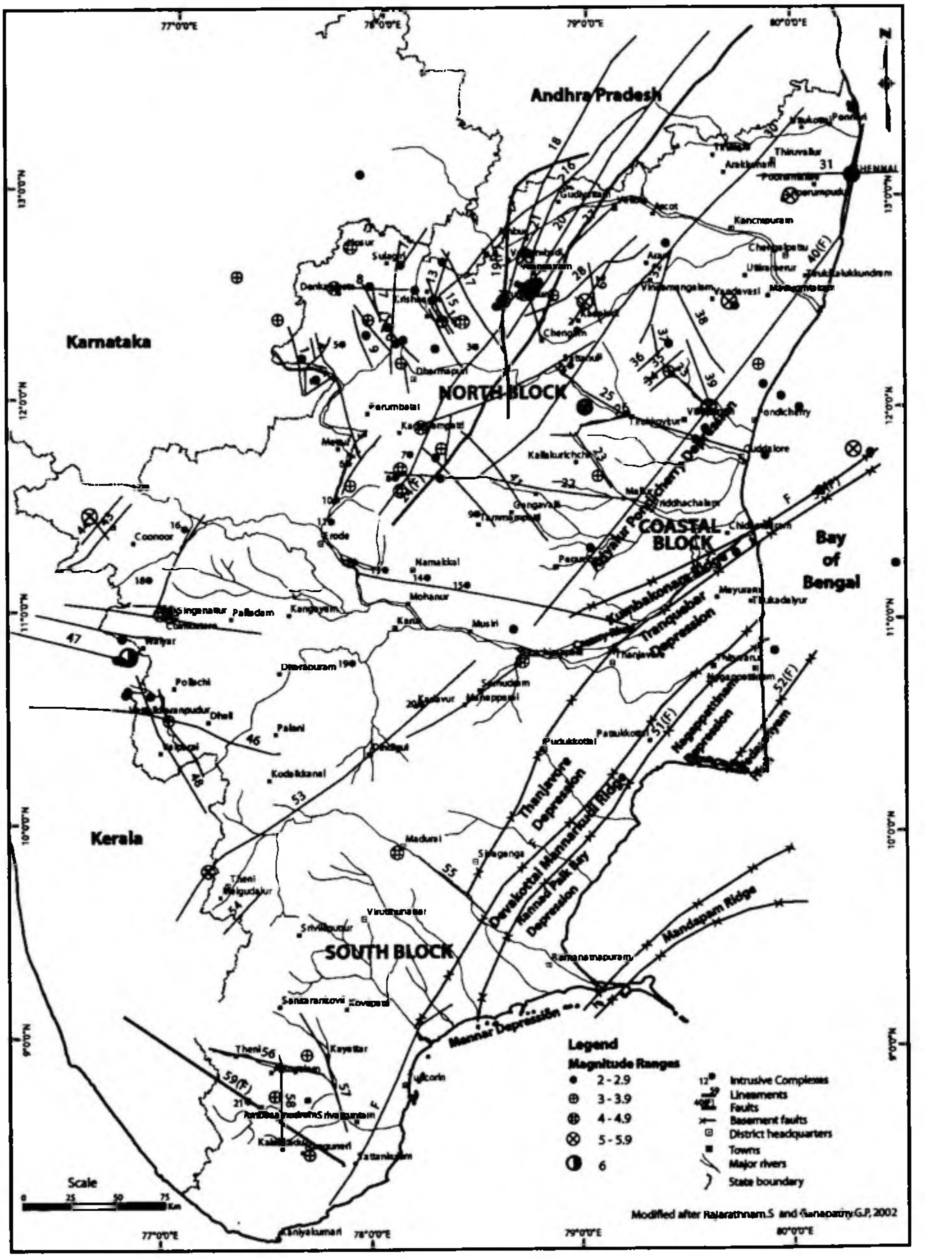

Fig. 1: Seismic Prone Lineaments of Tamil Nadu State

Seismo-tectonic set-up of Tamil Nadu

Detailed knowledge of geology, active faults/ lineaments and associated seismicity is required to quantify seismic hazard. The information on past earthquakes gives an idea of the seismic status of a place or region. The study requires a variety of geological and seismological information such as details of epicentres, origin time, focus, depth, and magnitude and fault systems to identify the currently active faults (Tandon 1992). Seismotectonic details have been collected for the study area lies between latitudes 08°00'00"N and 13°30'00"N and longitudes 76°15' 00"E and 80°18' 00" E.

Geology of the Study Area

The Geology of Tamil Nadu State represents a shield inland (85%) and 15% is the basement of the Cauvery basin in the east coast of Tamil Nadu forms the present study area (Fig.1). The shield area of Tamil Nadu consists of charnockites and gneisses with intrusive complexes viz., carbonatite, dolerite, syenite and granite. The Cauvery basin has thick successions of sedimentary formations of Mesozoic to Cenozoic eras. The basin came into being in the above region as a pull-apart following the rift along the eastern continental margin of the Indian sub continent in the early Mesozoic era (Kumar 1983).

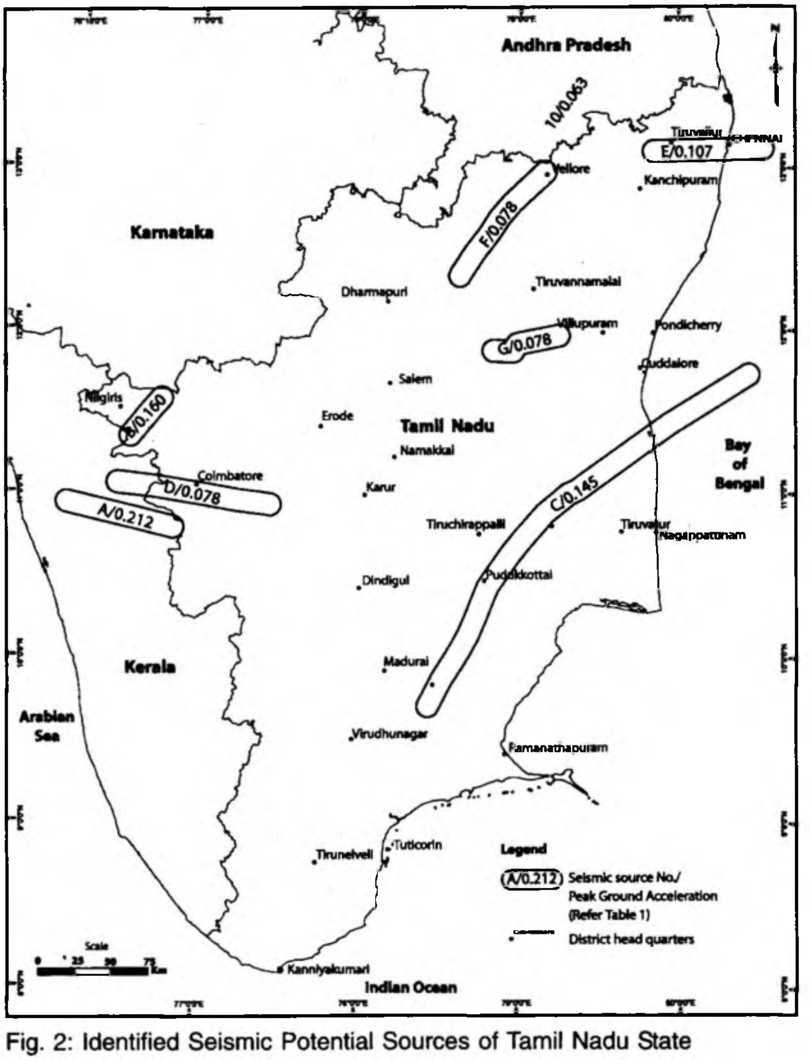

Fig. 2: Identified Seismic Potential Sources of Tamil Nadu State

Lineaments

Based on the satellite imagery, 257 lineaments have been identified. On the basis of distribution of lineaments Tamil Nadu has been broadly classified into North and South Blocks in the inland area and Coastal Block in the east coast. The Cauvery river course is the boundary in the inland area between the North and South Blocks (Fig.1). Amongst the selected 257 lineaments, 85% fall in the North Block and 15 % in the South Block (Rajarathnam and Ganapathy,2002).

In the North Block the lineaments have trends of NE – SW, NNW - SSE, N S and E W directions and in the South Block, the lineaments trend in NW – SE and NE –SW directions. The density of lineaments is comparatively more in the North than in the South Block.

The NE-SW lineaments are mega lineaments 100 km in length and NNW –SSE lineaments are intermediate lineaments around 50km in length as described by Gold (1980). The NE-SW lineaments are widely distributed and are

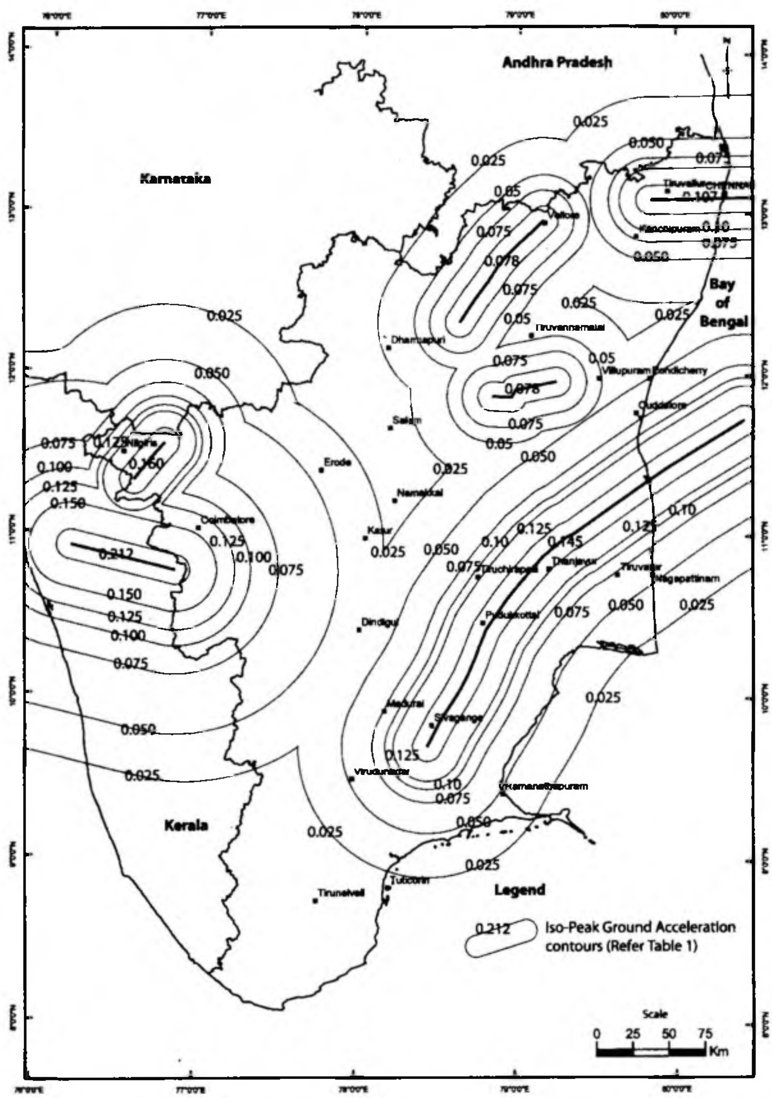

Fig. 3: Map showing the Seismic Hazard for Tamil Nadu State in terms of Peak Ground Acceleration

parallel to the trend of Eastern Ghats. The west of South Block represents NNW – SSE lineaments parallel to the trend of Western Ghats. The prominent lineament trends recognized in this Block are WNW-ESE, NNW-SSE and NW-SE. The NNW –NW to SSE - SW system lineaments can be generally related to the west coast fault (Ganesharaj et al., 2001). The WNW –ESE lineaments parallel to trend of Palghat Gap is a prominent break in the Western Ghat. The Palghat Gap represents parallel faults. The identified mega and intermediate lineaments are the result of the stress and strain caused by the onward thrust of the Indian Plate against the rigid Asian Plate.

In the Coastal Block of Tamil Nadu, the boundary fault recognized on surface separates Crystalline and Sedimentary formations and all others in the Block are of the horst and graben systems. These are identified mainly from gravity and reflection seismic geophysical data. Evidences from drilled wells by Oil and Natural Gas Corporation (ONGC) confirm their presence also. The regional alignment of the tectonic features is NE-SW, parallel to the Eastern Ghat trend. The basement has horst and graben morphology resulting from faults with considerable throw. The various tectonic features, which have been recognized are Ariyalur-Pondicherry depression, Kumbakonam ridge, Thanjavur depression, Tranquebar depression, Devakottai Mannargudi ridge, Nagapattinam depression, Ramnad - Palk Bay depression, Mannar depression and Mandapam ridge. These depressions are broad and occupy larger areas compared to the ridges, which are in narrow zones. Most of these tectonic features extend into the offshore areas. The sediment thickness in the depressions varies from 4000 to 7000 metres. The ridges have sediments in the range of 1000 to 2000 metres. The maximum thickness of 7000 metres is in the Ariyalur-Pondicherry depression (Kumar, 1983). These fault systems have commenced developing in Late Proterozoic period with the

Table 2. Estimated Peak Ground Acceleration (PGA) values at major cities of Tamil Nadu by the different potential seismic sources

Potential Source Number	Seismogenic Source for Lineament/Fault Name	PGA at Source	Maximum Magnitude	Epicentral Distance from the source to Major Cities					Peak Ground Acceleration at Major Cities				
				Chennai	Coimbatore	Salem	Madurai	Trichira-palli	Chennai	Coimbatore	Salem	Madurai	Trichirapalli
A	Lineament on the Northern boundary of Palghat gap (EW) – (No.47)	0.212	6.0	400	32	178	174	211	0.001	0.133	0.011	0.011	0.008
B	Nilgiris lineament (NE) – (No.44)	0.160	5.7	424	56	154	236	237	0.001	0.052	0.011	0.004	0.004
C	Basement fault following the western boundary of Thanjavore - Tranquebar depression (NE-SW) – (No. 50)	0.145	5.6	156	212	140	37	26	0.010	0.005	0.012	0.077	0.113
D	Lineament on the Northern boundary of Palghat gap(WNW – ESE) – (No. 49)	0.078	5.0	396	20	115	139	144	0.001	0.078	0.009	0.006	0.006
E	Adayar fault (EW) – (No.31)	0.107	5.3	10	389	240	397	286	0.107	0.001	0.003	0.001	0.002
F	Chengam – Alangayam Gudiyattam lineament (NNE – SSW) – (No .21)	0.078	5.0	155	245	98	276	174	0.001	0.078	0.009	0.006	0.006
G	Adanur - Thirukovilur-Ponnaiyar lineament (NE-SW) – (No.26)	0.078	5.0	174	225	76	231	126	0.001	0.078	0.009	0.006	0.006

Note: For details on fault number in bracket, refer Fig.1.

initiation of the breakup of Gondwana land and characterized by large-scale vertical movements (Gopalakrishnan, 1996).

Seismicity

A number of catalogues of past Indian earthquakes are available but none of them is up to date and comprehensive. The earliest publication is by Oldham (1883) which gives a list of significant Indian earthquakes upto 1869. Gubin (1968) published a list of significant earthquakes in Peninsular India. Tandon and Srivastava (1974) published a catalogue of earthquakes in India of $M \geq 5.0$ and above based on historical and instrumental and macro-seismic data available before 1970. Chandra (1977) compiled a list of earthquakes up to 1975 from different sources.

In order to understand the seismicity of Tamil Nadu, data regarding past earthquakes $M \geq 3.0$ have been collected for a period of around 200 years (1807 – 2002) from various sources (Seismic Array of Gauribindanur, Babha Atomic Research Centre (BARC), Karnataka State, National Geophysical Research Institute (NGRI), Hyderabad, India Meteorological Department (IMD), New Delhi, Bansal and Gupta 1998, Chandra 1977, Srivastava and Ramachandran 1985). The details of micro-tremors with magnitude of 2.0-3.0 from BARC publications are incorporated for 12 years from 1977 to 1988 (Gangrade et al 1987 and 1989). The maximum number of earthquakes identified from these sources for the present study is 103. The spatial locations of earthquake epicentre (latitude and longitude), with corresponding magnitude are depicted in Fig.1.

Out of the total 103 earthquakes/earth tremors 48, 23, 21, 10 and 1 event have been in the magnitude range of 2.0 – 2.9, 3.0 – 3.9, 4.0 – 4.9, 5.0 – 5.9 and ≥ 6.0 respectively. 52 earthquakes (51% of overall) are of $M \geq 3$ in the past 200 years of seismic history. Earthquakes of $M \geq 5$ are distributed around Chennai, Villupuram, Ooty, Coimbatore and Pondicherry - Off the Coast. The M 4 to 4.9 earthquakes are distributed, apart from above said areas, around Tiruppattur, Dharmapuri, Salem, Coimbatore, Trichirappalli, and Madurai areas (Fig. 1). M 2.0 to 3.9 earthquakes are distributed in northern eastern and southern part of Tamil Nadu.

The available seismic data have been plotted over a map representing 257 lineaments and the major percentage of the epicentres is aligned along with the NE-SW and NW-SE trend of lineaments. A few of them fall on the E-W and N-S trend of lineaments. The spatial association of epicenters with lineaments is categorised as seismic prone lineaments. The length of those lineaments is ranged from 10km to 315km.

Seismic Hazard Analysis

Seismic Hazard analysis models the occurrence of earthquakes on seismic sources. These sources may range from broad aerially distributed source zones to discrete three-dimensional units. The basic algorithm for seismic hazard analysis is created on the premise that the earthquake would occur randomly within a seismic source. The distance from the seismic source to the site is obviously important because attenuation would depend on it. In search of the seismic source, the first consideration goes to mapping the known faults or those which could be inferred to exist. Since the faults are spatially distributed in three dimensions, their detailed mapping is critically important for faults close to a site. Spatial pattern of seismicity will help link seismic source zones with faults.

The study on Seismic Hazard Assessment for Tamil Nadu carried out based on Deterministic Approach. The present study involving three principal tasks 1) Identification of potential seismic sources, 2) Estimation of maximum magnitude (M_{max}) and iII) Estimation Peak Ground Acceleration (PGA). The methodology involved is detailed in the following paragraphs.

Identification of Potential Seismic Sources

The present study prefers the model potential seismic sources as areas in which configuration of each source zone is controlled, mainly by the fault extent, seismogenic crust (a part of the earth crust in which large earthquakes usually nucleates), and mechanism of earthquake faulting or type of active faults.

For the width of seismic source (rupture width) researchers have taken 30 km for thrust fault zones and 20km for strike slip faulting. Since crustal thrust and reverse faults seldom occur individually, they are generally part of imbricate or overlapping systems made up of multiple faults and folds (Carver and Mc Caplin, 1996), the width of the seismic source zone is wider depending upon the individual cases.

The potential seismic sources of Tamil Nadu are delineated based on the geophysical and geological characteristics of the seismic sources along with the prevailing fault systems in the region. The association of cumulative number of epicentres of earthquakes or higher magnitude earthquakes on the respective active lineaments/faults has also been considered. Seven potential sources have been identified for the present study. These seven seismic sources have generated earthquakes in the magnitude range of 5.0 to 6.0 (sources A to G). The details are given in Table 1.

For the present study the rupture width of 20 km was considered assuming that the fault extended to the base of the seismogenic crust. Using create buffer tool in the Arc-GIS software buffer was created for a 20km width to the identified 7 seismic sources (Fig.2).

Prognosis of Most Credible Earthquake

In deterministic analysis, it is more common to define the maximum earthquake which is reasonably expected as the maximum credible earthquake. This earthquake is based on an evaluation of the processes, which are reasonably expected to be associated with an earthquake source. The maximum magnitude is an important variable in calculating the seismic hazard because it determines the strain energy released in larger earthquakes.

For the sources with the record of large earthquakes (M> 6.0), if the largest earthquake has occurred in a historical time-period, the observed largest magnitude is taken as the upper bound magnitude directly, or an increment of 0.5 to 1.0 magnitude unit is added based on frequency and accuracy of earthquake records in the source zone (Mirzaei et al 1999).

In the present study for the largest earthquake which occurred in a historical/instrumental time-period with good accuracy of the recorded event was considered as maximum possible magnitude in the potential seismic sources (Fig.2).

Estimation of Peak Ground Acceleration

The Peak Ground Acceleration (PGA) for Tamil Nadu due to the identified potential sources A,B,C,D,E,F&G has been calculated using the attenuation relation developed for South India by Iyengar and Raghukanth (2004). The attenuation relation used to calculate PGA is given below:

$$\ln y = c1 + c2(M-6) + c3(M-6)^2 - \ln R - c4\, R + \ln \in$$

Where y refer to Peak Ground acceleration (PGA) in g, M refer to magnitude and R refer to Hypocentral distance. Since PGA is known to be attributed nearly as a lognormal random variable ln y would normally distributed with the average of (ln ^{a}) being almost zero. Hence with e= l, coefficients for the southern region are (Iyengar and Raghukanth, 2004):

c1=1.7816; c2 = 0.9205; c3 = -0.0673; c4 = 0.0035; (ln∈) = 0.3136 (taken as zero)

The determined PGA value for the identified seven seismic potential sources of Tamil Nadu is in the range of 0.212g to 0.078g. The maximum PGA of 0.212 would be caused by the lineament on the northern boundary of Palghat Gap (Fig.2). The source is about 20km from the Coimbatore City. This lineament has been associated with 5 earthquake incidences in the past 200 year earthquake history and the Maximum magnitude (Mmax) so far generated is 6.0. The trend of the source in east west direction running with a length of 86 km starting from northern part of Kerala state and entering the western part of the Tamil Nadu (Fig.2). The details of PGA for the twelve potential sources are given in Table 1. The estimated PGA at major cities of Tamil Nadu viz., Chennai, Coimbatore, Salem, Madurai and Trichirapalli of Tamil Nadu due to the seven seismic sources are given in Table 2.

To calculate hazard in the area, a grid is formed dividing each degree of latitude and longitude in to three parts. Arc-GIS layout tool is used to perform the grid analysis. Each intersection of the grid is measured from the different seismic sources and using Microsoft-Excel the PGA value each point is calculated. By using this method a database was prepared for each seismic source, and contours were plotted for all seven seismic source.

To evaluate the combined seismic hazard of Tamil Nadu due to the potential sources, an attempt was made in Arc-GIS Spatial Analyst Software. The PGA of each potential source plotted over the State Digital Administrative Boundary of Tamil Nadu and interpolated for the assigned value to bring out the combined seismic hazard of Tamil Nadu State (Fig.3).

Discussions

The epicenters of earthquakes are related to the fault system in a region. From this study, the possibility of correlation between the epicenters of earthquakes and the fault systems has been explored to distinguish between the seismic prone and non-seismic prone crustal fractures.

From the available ground truths and literature published so far, the occurrences of various intrusive complexes and 103 epicenters of earthquakes (Magnitudes 2.0 - 3.0, 3.0 - 4.0, 4.0 - 4.9, 5.0 - 5.9, 6.0 and above) were plotted on those lineament map and 59 seismic-prone lineaments/faults were delineated out of the identified 257 lineaments of Tamil Nadu. The N 30°-50° E, N 10°-40° W and east west lineaments are prominent lineament directions.

Out of 59 seismic prone lineaments, 43 lineaments/faults have spatial association with 91 epicentres of earthquakes and the 16 lineaments closely spaced with epicentres. The balance 12 epicentres fall in blind faults zones, so those areas need to be studied in detail. This indicates a positive correlation between distribution of lineament and earthquake occurrences. The distribution of lineaments, epicentres of earthquakes and intrusive complexes confirm that the northern part of Tamil Nadu has a higher seismic activity than the southern part of the State.

The present study involves computation of Peak Ground Acceleration (PGA) at bedrock level, using the deterministic approach to understand the seismic hazard assessment of Tamil Nadu. The study area was divided into seven seismic sources (Table 1 and Fig.3) for which seismic hazard analysis was carried out using the seismicity data of the area from 1807 to 2004.

The seven sources have generated earthquakes in the magnitude range of 5.0 to 6.0 (Sources A to G). Among the seven seismic sources, the lineament on the northern boundary of Palghat Gap (Source A) and the Nilgiris lineament (Source B) are capable of producing the observed magnitude 6.0 and 5.7 based on the fault rupture area.

The ground motions were calculated in terms of Peak Ground Acceleration (PGA) at bedrock level. The estimated maximum PGA from the seven seismic sources was in the range of 0.212g to 0.078g (Table 1 and Fig.3). The PGA values are estimated from the closest potential sources for major cities of Tamil Nadu. Chennai, Coimbatore Salem, Madurai and Trichirappalli have PGA of 0.107g 0.133g, 0.012g, 0.077g, and 0.113g respectively (Table 1).

The whole western part of the study area is represented by the Western Ghat and has maximum PGA of 0.212g. The eastern part of the study area is represented by coastal areas and has medium level PGA in the range of 0.145 g to 0.107g (Fig.2). The northern part of the study area has PGA of 0.07g. The southern part of the Tamil Nadu state has lower magnitude of earthquake and lower would be the PGA value. This confirms that southern part of Tamil Nadu is less seismic prone than the other part of the State.

The contour of PGA values generated by the different potential sources indicates the anticipated PGA of various cities/towns of Tamil Nadu. The estimated PGA at various major cities of Tamil Nadu viz., Chennai, Coimbatore, Salem, Madurai and Trichirappalli due to the seven seismic sources are given in Table 1.

The Chennai city has maximum estimated PGA of 0.107g, which can be generated by the seismic source E. Coimbatore city which is close to seismogenic source A has a PGA of 0.133g. Salem has a maximum PGA of 0.0113g from the seismic source C. The cities of Madurai and Trichirapalli have maximum of observed PGA in the range of 0.077 and 0.113g which generated by the seismic source C (Table 2).

Conclusions

The results of the present study reveal the facts that the seismic hazard north eastern and western part of Tamil Nadu is closely matching with the regional seismic zonation prepared by Bureau of Indian Standard, 2002. However the east southeastern and northern part of the state show higher value because of the adequate earthquake data used until the year 2004 and the frequent earthquake activity in the northern part of the state. The southern part of state shows lower seismic hazard than the other parts of the Tamil Nadu State.

The resultant combined seismic hazard due to the identified seismogenic sources of the state reveals that there would be an extra attention required in for the east-southeastern and northern part of Tamil Nadu in the future research studies. The major cities of Tamil Nadu viz., Chennai, Coimbatore, and Trichirapalli have higher peak ground acceleration values. It is essential to have a detailed micro-seismic zonation studies for those highly and densely populated major cities.

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