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Seismic hazard microzonation of Chennai metropolis

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Abstract

Seismic Hazard Microzonation studies around Chennai for an area of 400 sq. km. were taken up to classify the urban agglomeration into different discrete zones of seismic hazard risk. An integrated multidisciplinary approach, using the inputs from geological, geomorphological, geophysical, geotechnical and geo-hydrological studies were undertaken, in order with a view to assess the seismic site response parameters of surface and subsurface soil media and overall assessment of seismic hazard in different parts of the area under investigation.

The Chennai area is essentially a plain country with an upland area of Charnockites and Gondwana sandstones, with its immediate vicinity covered by soil/alluvial overburden and marine / fluviomarine sediments. The plains essentially comprise of coastal and older flood plains of Coovum and Adyar Rivers. The geomorphic forms include present day beach, mud flats, older beach dune complex, paleo tidal flats and flood plains. This area is explored by 18 boreholes out of which 3 are located over beach dune complex, 2 over tidal flat, 3 over palaeo tidal flat, 1 each over older dunal complex and Gondwanas, and 8 over alluvial / flood plains comprising of fluvial-marine sediments.

Drilling aggregating to a total depth of 524.60m was carried out, Standard Penetration Test (SPT)'s were conducted at an average interval of 2m, and the required undisturbed samples have been collected to determine the geotechnical parameters. SPT was carried out up to a general depth of 30m. The seismic site response parameters like Shear Wave Velocity -Vs, amplification, impedance, frequency, etc., were derived from N-values deploying empirical relationships in vogue. Geo-hydrological data, together with geotechnical data, have been utilized to arrive at liquefaction potential of the area.
Geophysical surveys were conducted to determine the depth of bedrock and the nature of sediments in different parts of Chennai Metropolitan area. Besides, the processing of the data obtained from site response survey at various sites in Chennai Urban Agglomeration show variations of peak frequency in the range of 3.5 to 5 Hz and peak amplification from 3 to 8. By integrating the geological, geotechnical and geophysical inputs, Microzones of Chennai Metropolis, showing different seismic hazard levels were delineated. By the integration of various influencing parameters, four seismic Microzones have been arrived at for the Chennai Metropolitan area, representing relatively very low, low, moderate and high seismic hazard Microzones. The Microzones arrived at has a gross validation on comparing them with the effects of past seismic events which have been studied in details.

Keywords: Seismic Hazard Microzonation, Peak frequency, Peak Amplification, Urban agglomeration

1. Introduction:

Seismic microzonation studies:

The importance of seismic microzonation of urban terrains in zones of high seismic propensity, as a disaster mitigation effort, has been realized in relevant regions of many developed nations a long ago; the same gained great credence only after the Jabalpur

earthquake of May 1997 which manifested an interesting variable damage pattern / damage intensities that were, as ascertained later, dependent on the underlying lithology and other geological conditions like the thickness of weathered rock and soil profile, hydro geological set-up etc. The event provided the necessary fillip, in real terms, to take up such a study in India starting with Jabalpur town and it was taken up as a multi-institutional collaborative project, from the year 1997-98, that even had an international partner in the form of Italy. The Bhuj (Kutch) Earthquake of January 2001, which manifested severe damage intensities in some parts of Ahmedabad city, far away from the epicenter/meizoseismal area, in fact couple of hundreds of kilometers away from the epicenter, further underlined the need for taking up the seismic microzonation studies in other relevant parts of the country. It now constitutes one of the thrust areas of the activities of Geological Survey of India. Seismic Microzonation studies of Chennai Metropolis were carried out over an area of about 400 sq.km, to delineate the geographic domains (Seismic Microzones), having unique and distinctly different geotechnical and Seismicity.

The above acquired field data along with the relevant available geological and geophysical inputs were integrated and processed to yield a composite First Level Seismic Hazard Microzonation map of the area depicting seismic microzones which will behave uniquely and uniformly in the event of a damaging earthquake. It is to be mentioned that microzonation studies are dynamic and evolving in nature, wherein with more and more data acquisition and control, refinement and fine-tuning is possible. This is a first such attempt by Geological Survey of India and therefore designated as 'First Level', although data acquisition is fairly high with adequate control.

General:

Chennai, the charming capital of Tamil Nadu State, was founded in 1639 by Sir Francis who arrived with the East India Company. It is the oldest of the presidential cities in India and the fourth largest Metropolis of the country. The area has good communication by road, rail and sea. It is also the Detroit of India with many leading automobile and ancillary industries. The last decade saw the phenomenal growth of the city in IT and Electronic Sector. All these developments / urbanization have taken a heavy toll on the city with ever increasing high concrete structures.

Study Area:

Chennai Metropolitan area is located in the northeast corner of the state and is bounded by Bay of Bengal in east and Tiruvallur and Kanchipuram districts in the other directions. Study area is bounded by north latitudes12°59'10" and 13°08'50" and east longitudes 80°10'00" and 80°18'20" and forms part of survey of India topographical sheet nos. 66 C/4 and 8, covering the northern part from Tiruvottiyur to Puzhal (through Madavaram Miilk colony) and in southern part (just south of Adyar) from Besant Nagar to Alandurthrough Guindy. The western part is covering Koratur through Mugapper west and Ramapuram. Thus, an area of about nearly 400 sq.kms was covered in the study.

Physiography:

Most of the study area manifests a flat topography with a very gentle slope towards east. The low lateritic plateau of Puzhal area in the NW part and the inselberg hill of St. Thomas Mount in the SW part are the prominent positive relief. The area being a part of Tamil Nadu coastal plain, beach is wide all through the Chennai city and estuaries are prominent in the Adyar river mouth in the southern part. The city also has few lakes and temple tanks within the metropolitan area.

Present Study:

Earthquakes are one of the most destructive natural hazards of the world. These natural endogenetic processes can cause massive damages to structures and lead to total devastation of cities (metros) in particular due to its dense population and high rise structures. Chennai Metropolis, Tamilnadu, falls in Zone-III of the revised Seismic Zonation Map of India (IS: 1893-Part I (2002). Chennai city experienced moderate tremors during the 2001 Bhuj earthquake and the 2004 Sumatra mega thrust earthquake. All the recent Andaman events are felt in Chennai though in a low intensity.

The Seismotectonic Atlas of India and its Environs (GSI, 2000) shows that there were at least three events of intensity V-VI in and around Chennai city during 1807 to 1823 and two events of intensity III towards the close of 19th Century. There are also reports available about a 1966 Tambaram earthquake. This warrants a detailed evaluation of the Chennai urban agglomeration from an earthquake geological point of view, the results of which could be a basis for the urban planners and civil engineers as an important input to earthquake disaster mitigation effort in Chennai. Therefore, a comprehensive and detailed study of Chennai Metropolitan area have been taken up to assess the seismic hazard microzonation of Chennai metropolis, which was initiated during the F.S.2007-08, leading to preparation of zonation map of about 400 sq. km. area on 1:20,000 scale.

For seismic hazard Microzonation studies of Chennai metropolis, several thematic databases were prepared such as geology, geomorphology, seismicity and seism tectonics, hydrogeology, bedrock rock configuration,

Subsurface litho stratigraphy (sediment thickness), geotechnical parameters, geophysical information, etc. All these have been collected by detailed field investigation and by compilation of other existing information on 1:20,000 scale covering parts of SOI toposheets 66C/4NE & SE and 66C/8NW & SW. As a part of field study, to arrive at site characterization, eighteen boreholes, each for a maximum depth of 30m were drilled for conducting Standard Penetration Tests (SPT) and for collection of Undisturbed (U/D) and bulk soil samples for every 2.0 m depth. In addition the sub surface exploratory data of Chennai city were also collected from other government departments /agencies such as Chennai Metro water, CGWB, PWD, TWAD Board, Corporation of Chennai city, etc.

The geophysical input of seismic site response study to work out the seismic amplification and related factors was carried out at uniform grid intervals in the study

area. The ambient noise 'survey' was conducted by using micro seismometer. All the thematic layers generated were vectorised, integrated and analyzed on GIS platform, indigenously, to generate the desired Seismic Hazard Microzonation Map of Chennai Metropolis on 1:20,000 scale, based on due weightage assigned to the various delineated zones of each thematic layer. The final product depicts discrete 'Microzones' within the 400 sq.km. of Chennai Metropolis, that are likely to respond uniquely, in terms of site seismic amplification and damage intensity potential in the event of a damaging earthquake occurring at the proximal source within Chennai region.

2. Geomorphology:

Chennai city Metropolitan Area is Bounded by Bay of Bengal in the east, vast pediplain and alluvial plain in the west and marine dunal complexes in the north and south. Study Area is a part of Tamil Nadu Coastal Plain with flat topography and gently sloping towards east. The elevation ranges from10 m above MSL in the west, to sea level in the east. Major part is a built up area with flat topography. Four cycles of erosion have been identified (T.M. Parthasarathy,1989) and the landforms constitute assemblages of fluvial, estuarine and marine deposits. The residual hillock at Pallavaram and St. Thomas mount are important landforms in the south. There are number of sand dunes in the east. The landform got altered and number of water bodies existed in the early period of this century was modified by human encroachment and transported sand and clay. The sand dunes and beach ridges were also converted in to residential areas.

3. Geology of the Study Area:

The geological formations of the area can be grouped into three units, namely (i) the Archaean crystalline rocks, (ii) consolidated Gondwana and Tertiary sediments and (iii) the recent alluvium (Plate 4). Most of the geological formations are concealed since they are overlain by the alluvial materials excepting for a few exposures of crystalline rocks like charnockites along the railway track in Guindy area and Adyar riverbed near Saidapet.

In general Chennai city and surrounding areas have two distinct litho logical set up. On the eastern and southern side Archean high grade metamorphic rock (Charnockite and migmatite) occur as basement rock over which marine and fluvial sediments have been deposited. Contrastingly Gondwana group of rocks occur in the remaining part (central and northern part) of the study area and its thickness gradually increases towards west and North West. Gondwana sediments are laid over the Archean basement rocks conformably. Younger marine and fluvial unconsolidated sediments occur over Gondwana rocks too. The bedrock depth of Gondwana varies from place to place and the basin margin is aligned in general in NNE-SSW direction tentatively along , K.K. Nagar , Teynampet, Anna Salai (new Secretriat Complex), Tondiarpet, Tiruvottiyur areas. In view of the above general geological set up of the study area, the evolution of Gondwana basin along the east coast and its associated tectonics, etc. have considerable bearing in the present study.

Quaternary sediments:

Coastal quaternary geology mapping during 1974-75 has carried out by S. Subramanian (1976) and classified the various landforms and delineated erosional and depositional surfaces. V.Krishnan andR.Srinivasan (1993-96) has carried out geo-environmental resources appraisal and impact assessment studies along the entire Tamil Nadu coast (including Chennai coast) and assessment was made for the each coastal morphological units regarding their degradation and site modification. During the present study the surface geological mapping and borehole core logging has brought the following litho units:

Beach and back shore areas:

Pale greyish brown fine to medium sand with or without heavy minerals and shells.

Recent Dunal Complexes, Older Dunal Complex:

Pale grey to pale brown medium to fine sand, coarse to medium brownish sand - Palaeo dunes, Inter dunal flats, strandlines and strand plains.

Tidal Flats, Palaeo tidal flats:

Mud, black clay, sandy clay, grey to brown sandy clay - Lagoons and old lagoons.

4. Seismotectonic and Seismicity of the Region:

The study area is located at the junction of Northern Tamilnadu and southern Andhra Pradesh. Hence the tectonic framework of north Tamilnadu and southern Andhra Pradesh is relevant to the present study. Particularly the attention has been paid to the lineament and faults in the 300 km radius of the Chennai city, as it lies in zone III of Seismic Zonation map of India, 2002.

Major faults of Northern Tamil Nadu:

The Tamil Nadu granulitic terrain is traversed by number of weak zones and they can be grouped as per their structural trends**.** The crystalline sedimentary fault /lineament belong to NNE-SSW system and is affected by E-W trending fault and lineament with en-echelon shifts. The Moyar-Bhavani-Attur and Palghat -Cauvery lineamnets belong to E-W system. The Mettupalayam – Bhavanisagar fault at the foot of Nilgiri hills and Palar fault belongs to the ENE-WSW fault system. The N-S fault system is represented by Pambarriver in Vellore and Dharmapuri districts. The northern sector in Tamil Nadu is mainly characterized by NNE-SSW trending faults and shear zones represented typically by Mettur east faults, Main fault N45E, Kottapatti fault Gangavalli shear zone which coincides with the regional foliation trend of the host rock, etc. The major shear zones in central and northern Tamil Nadu are characterized by zones of mylonite, phyllonite and cataclasite. Within the 50 km radius of Chennai city known major faults do not appear to

exist. The nearest located NE-SW trending crystalline sedimentary contact fault is concealed and no surface manifestation is seen. Another close by located Palar fault is extending from North Arcot to Kalpakkam in an arcuate shape. Evidences for neotectonism (to know whether it is active are not) along its course was checked on the ground (V. Balachandran and R. Srinivasan, 1998) in the area adjoining to coast. No evidence of neo tectonic movements are seen along this stretch. But in the Vellore – Vaniambadi area surface and subsurface geological discordance is seen on either side of Palar and this is confirmed by aeromagnetic data also. In addition to surface manifested shear zones mentioned above, sub surface tectonic weak zones were brought out by ONGC. The coastal zone of Tamil Nadu and Pondicherry had experienced a series of block faulting with the formation of pericratonic basins where phanerozoic sediments were deposited. They are Ariyalur - Pondicherry graben, Kumbakonam - Shiyali horst, Madanam horst, Tanjore - Tranquebargraben, Devakottai - Mannargudi horst, Karaikal horst, Tirutturaipundi, - Nagapattinamgraben, Vedaranyam horst and Ramnad – Palk strait graben. NE-SW trending Gondwana basin is considered to be a faulted contact with Archean.

Major faults of south coastal Andhra Pradesh:

The region north of Chennai i.e. the Cuddapah, Chittoor, Nellore and Krishna districts of Andhra Pradesh are also transected by a number of lineaments and faults. Actually Chennai and adjoining area is located at the regional contact of granulitic suite of rocks in the south and Dharwar granite greenstone terrain with huge Cuddapah basin in the north. Thus, the study area is located in the critical geological contact zone extending westwards towards south of Bangalore and Mangalore along 13° latitude. Thus, the change in the geological sector has brought in a number of northwest/southeast and ENE- WSW trending faults and lineaments in the southern Andhra Pradesh. The most prominent faults within 300 km radius is the Gundlakamma fault in NW-SE direction of Ongole, as number of earthquake events have taken place around this fault. Cuddapah basin eastern main fault is considered to be thrust and forms a prominent arcuate and dislocated chain of faults. The Karkambadi and Tirumala fault at the southern part of Cuddapah basin in the ENE-WSW direction is quite close to Chennai area. The Papagni and Gulucheru faults are also located around the Pennar River.

Seismicity around Chennai:

GSI also has carried out macro seismic survey for Tamil Nadu for Bhuj earth quake of 26.1.2001 by (R. Pitchaimuthu and C. Thanavelu). They recorded that people from Chennai and its suburbs felt the vibration and reported shaking of objects for 1 to 2 seconds and classified Chennai and surrounding areas in the felt intensity III (MSK scale). During the Sep 2001 again macro seismic survey was conducted for the 5.6 magnitude Pondicherry (50 Km east of Pondicherry in Bay of Bengal) by GSI (Ramalingam et.al.). The isoseismal lines in general are elongated in NW-SE direction. Chennai city was included in their study in isoseist V with few ground cracks in the taxiway area of Chennai Airport. During the 26.12 2004 Indonesian earthquake which generated Tsunami affecting the east coast of Tamil Nadu and Andamans was also felt

significantly by the people of Chennai and can be classified with felt intensity V or VI. After this Tsunamigenic earthquake number of seismic events took place in the Andaman Sea with a magnitude of 5 to 6 on Richter scale. Many such events are feebly felt in Chennai city particularly by the people living in the higher floors, especially in the areas of T. Nagar, Mylapore, Kodambakkam and Ayanavaram.

The seismological information and seismotectonic features around Chennai city and surrounding area are also depicted in the Seismotectonic Atlas of India (2000) published by GSI. The Seismicity data available from Gauribidanur seismic array is also presented herewith. The lineaments and faults of the area are also duly taken into consideration with the background of similar such details available from Project Vasundhara (GSI publication).

Source Characterization:

Seismicity of the study area has been discussed in the earlier chapter. Past earthquake events occurs as cluster around 1.Ongole, 2.Cuddapah-Chittur and 3. Bangalore – Salem. Of these, the cluster of seismic events occurring south of Bangalore is large with magnitudes ranging from 3 to 5.5 m on Richter scale. In addition to these, two significant seismic events have been noted close to the Chennai city. List of major Lineament and faults (Project Vasundhara, GSI &Seimotectonic atlas of India, GSI) with in 300 Km radius from Chennai was prepared. Using the seismotectonic information and Seismicity details on associated with each identified fault, the PGA was arrived from each identified source. The maximum moment magnitude and hypocentral distance for each source was also calculated. Then PGA for the study area (center of the study area) varies from 0.0019g to 0.1261g. The maximum acceleration at bedrock level of 0.1261g has been taken for further hazard analysis. The tectonic source, which contributed a PGA of 0.1261g, is a NE-SW trending lineament southwest of Chennai with associated past seismic event of around 5.5 magnitude on Richter scale.

Maximum Credible Earthquake:

The maximum credible earthquake has been calculated by assuming the surface rupture length of the identified sources. Using Wells and Coppersmith (1994) equation along with a parametric study, it is found that the subsurface fault rupture length of about 3.8% of total fault length gives magnitudes closely matching with the past earthquakes. Excepting for the event around Chennai as described in the above table (as the nature of the source could not be properly ascertained), MCE was worked out for all other sources based on the empirical relation developed by Coppersmith, et. al. (1994). In general the derived magnitudes are closely matching with observed ones during the past earthquake events with the magnitude in the range of 4 to 5+ for most of events as described in the Table 5. As there is not much variation in the magnitude values derived from MCE, the PGA of 0.1261g, calculated using past earthquake events (Table 5) is considered for further analysis.

Site Characterization:

Geotechnical studies were carried out in and around Chennai Urban agglomeration to understand and assess the nature of the subsurface geological media of the area up to a maximum depth of 30 m. In this endeavor, due care was taken to represent the geological and geomorphological aspects of the study area for locating the boreholes. A total of 18 boreholes were drilled in the Chennai Metropolitan area, 3 are over beach dune complex, 2 over tidal flat, 3 over palaeo tidal flat, 1 each over older dunal complex and Gondwana, and 8 over alluvial / flood plains comprising of fluvio-marine sediments. Drilling aggregating to a total depth of 524.60m was carried out and about 202 SPT's were done and the required undisturbed samples have been collected to determine the geotechnical parameters. In addition borehole data from other Govt. agencies were also collected to represent gap areas.

Standard Penetration Test (SPT):

Standard penetration test is one of the important in situ field tests tounderstand the physical and mechanical properties of the subsurface soft soilmedia, in the form of N-values, which reflects indirectly on Seismicityparameters. In this test, a standard split spoon sampler is driven in to the soil byrepeated blows, using a 65kg hammer released from a height of 75cm. Theblow count is recorded for every 15 cm depth penetration. If full penetration isobtained, the blows for the first 15 cm are ignored, as it is a seating drive. The number of blows required for the next 30cm of penetration is recorded as Standard Penetration Resistance, called N values. This test procedure is standardized by ISI and set out in "IS: 2131-1981, Standard Penetration Test". There are number of factors which influences the N values like i) method of drilling and associated ground disturbance, ii) effective overburden pressure at the level of testing, iii) position of ground water table, iv) diameter of the drill hole and nature of drilling fluid, and v) loss of energy through drill rods. The SPT provides only averaged data over discrete increments, which will not distinguish data particular to thin inclusions (lenses and layers). The undisturbed sample is retrieved from the split spoon sampler. The 'N'value measured in the field were corrected for various influencing parameters and discussed in the hazard zonation chapter. The SPT and undisturbed samples were analyzed for the determination of grain size distribution of soil, which has a direct bearing on liquefaction resistance. Thus, the sub-surface exploration programme of Standard Penetration Tests at 1.5 to 2 m interval in about 18 boreholes (Annexure III) covering all the geomorphological units, each going to a maximum of 30 m depth, were carried out for geotechnical evaluation of the substrata media.

Site Response Study:

Geophysical surveys were carried out to determine the site response parameters, viz., the predominant frequencies and the amplification of the ground motion and decipher vulnerable zones of damage in case of an earthquake occurring in and around Chennai Metropolis. The seismic microzonation is based on the concept that the geological characteristics of the terrain amplify the intensity of ground shaking at certain frequency.

Seismic Microzonation can be achieved by rationally grouping the site-specific relevant geoseismological parameters, including the seismic site response data and synthesizing the same through a probabilistic seismic hazard assessment. Microzonation plays a vital role as a proactive disaster mitigation strategy in cities that are located in the region of relatively higher seismic propensity, particularly along the coast. Civil Engineers and Town Planners can effectively use the microzonation information to incorporate earthquake damage control / reduction measures in planning land-use and designing of structures. For example, high amplification areas can be earmarked as lung space for development of parks etc., whereas low amplification areas can be used for developmental activities such as construction of high-rise / heavy structures, public utilities etc. Ambient noise survey has been carried out in the area under investigation to determine the site response parameters viz., the predominant frequencies and the amplification factor of the ground motion. Precisely, these studies are aimed to delineate zones of varying site response and assess damage potential in case of occurrence of an earthquake in Chennai Metropolis or in the vicinity. The site response parameter is a very important factor under the microzonation study of an area. It is established that the ground shaking effect caused by an earthquake can vary widely within a small distance. This is because the seismic energy gets trapped at certain locations leading to amplification of vibrations resulting in damages to man-made structures. Theoretical analysis and observational data have shown that each site has a characteristic frequency called 'Fundamental Natural frequency' or Resonance Frequency' at which ground motion can get amplified in a damaging earthquake scenario. Low value of seismic rigidity (velocity x density) of ground / foundation media gives rise to higher order of seismic amplification.

Man-made structures, whose Resonance frequency matches with that of the site, have the maximum likelihood of getting damaged. Hence, in order to construct seismically safe structures, it is important to know the site response characteristics of the specific location.

Present work:

The Site Response Studies were taken up by deploying Digital Seismographs at 275 sites selected by Earthquake Geology Division, SR. Ten shallow seismic soundings were also conducted at feasible sites to bring out the subsurface information up to a depth of 30 m. During the course of this investigation MEQ monitoring studies were carried out for one month by deploying Digital recorders to find out if any relation exists between regional events and local events and to study the causative source for local increase in amplification intensity caused by the Moderate earthquake of the magnitude 6 triggered in Andaman Island on 27th July 2008 and 2nd August 2009.

Methodology:

Various methods are available for estimating the site response for hazard analysis in an area. The best method is to record the strong motion caused by a large local earthquake. However, such events are not frequent in all the places. Hence, this method is not very practical for site response studies. As an alternative, data from records of local micro-

earthquakes and tele-seismic events is used for site response studies in an area. For this purpose one need to have a dense array of stations to have good spatial resolution in microzonation and also records over a protracted period are required. Another method used for the site response studies is to carryout extensive seismic refraction and geotechnical surveys to determine the structure and physical properties of the soil and rocks present at the site and then use them to theoretically determine the site response. Since this method is expensive and time consuming, seismic noise study and analysis is carried out by deploying digital micro-earthquake recorders to study the noise at different sites and evaluate the predominant range of frequencies and amplification factor.

Since no significant local event was recorded during the monitoring of the network, the data analysis was confined to site response surveys. A total number of 275 stations (with a few repeated stations) were covered in an area of 300 sq. km. (Fig-2). At each site the instruments were deployed for about 4 -6 hours duration in continuous mode of operation. On an average, around 15 -20 Mb noise data was recorded at each site. The data thus acquired was converted to Seisan format using Seisan software, which is compatible with the Nakam software on Solaris operating system. Data from all sites were found to be suitable for calculating average relative spectral ratio of horizontal to vertical (H/V) component by Nakamura technique (1989), which was used to estimate the site response characteristics at each site. The average relative spectral ratio of horizontal (N-S & E-W) component to Vertical component (Z) is calculated using Nakamura technique for analyzing ambient noise of each site. The site responses are estimated by dividing horizontal component noise spectra by vertical component noise spectra. The seismic signal acquired in time domain is converted into frequency domain by using Fast Fourier Transform (FFT) technique. The amplitude of horizontal component AN(f) and AE(f) is divided by vertical component AZ (f) to get average relative spectra and the root mean square average amplitude A(f) is calculated as : A(f) = v[{AN(f)/AZ(f)}2 + { AE(f)/ AZ(f)}2]/2

From the average of relative spectra, the average experimental site response amplification at various predominant frequencies within 1-10 Hz with standard deviations is obtained by Nakamura technique. The maximum site average amplification with corresponding predominant frequency at each site is estimated. Maximum site average amplification at each station with corresponding predominant frequency has been tabulated. Some of the sites exhibited a high noise level and at some other sites the data was not properly recorded due to instrumental problem, which were not considered for data analysis.

5. Seismic Hazard Zonation:

An attempt has been made, by synthesizing the various geological, geotechnical, geophysical and seismic parameters, to delineate the Chennai Metropolis into discrete zones, rather Microzones of likely unique seismic response. In this process, different parameters, like shear wave velocity (Vs), amplification (A), frequency (f), Impedance, Liquefaction susceptibility, Ground Vulnerability Index (Kg), Residual damage Intensity (?I) are computed from N- values, deploying the empirical relationship in vogue as discussed in this chapter.

Bed Rock Configuration of Chennai City:

The data derived from GSI drilling and those collected from other organizations, along with the inputs from geophysical surveys carried out in the study area, a bedrock configuration map of 1m contour interval was prepared. The prepared bedrock contour map shows the depth of bedrock vary from 3m to 31m. The bedrock of study area is of two natures, one is the Archean Charnockites that forms the basement and the other is the Gondwana shale, siltstone and sandstone. The contact of crystalline and Gondwana rocks is estimated to pass along the eastern part of the study area extending from Manali – Korrukkupet – George Town – Chetpet – Royapetta – Mylapore – Kotturpuram – Guindy – Alandur. The map reveals that the basement crystalline rock is not showing any sudden variation in the depth of occurrence and hence there is absence of any signature regarding the significant structural discordance within the host rock.

Even though the Charnockite rocks indicates fracturing and minor shear bands, no major regional faults are known to occur, which is also indicated by the bedrock configuration map for the study area.

In the present study apart from deciphering of available borehole information, verbal enquiry from the local people and logging of wells / foundation pits at some of the major ongoing construction sites were taken up, to ascertain the subsurface medium. In most of the places, this matched with the borehole data. But ambiguity prevailed in Anna Nagar West near SBOA School where the local residence conveyed the presence of hard crystalline rocks in their bore wells. Due to the non-availability of suitable place for drilling and geophysical survey, the same could not be ascertained. Hence the probability of occurrence of shallow crystalline rocks in that area is not ruled out which may be due to either the faulting in the basement or due to erosion up warping. The most of the bedrock in the western part of the study area are upper Gondwana sediments comprising of shale, clay stone, siltstone and sandstone. They are weathered or and lateralized as in Puzhal area (BH-1) and occurs as outcrop also. In some areas weathered Gondwana shale rock is ferrugenised and covered be younger quaternary sediments. Thus, the bedrock map prepared indicates the top of weathered sedimentary bedrock or crystalline bedrock, as the case may be within the study area (Figure 1).

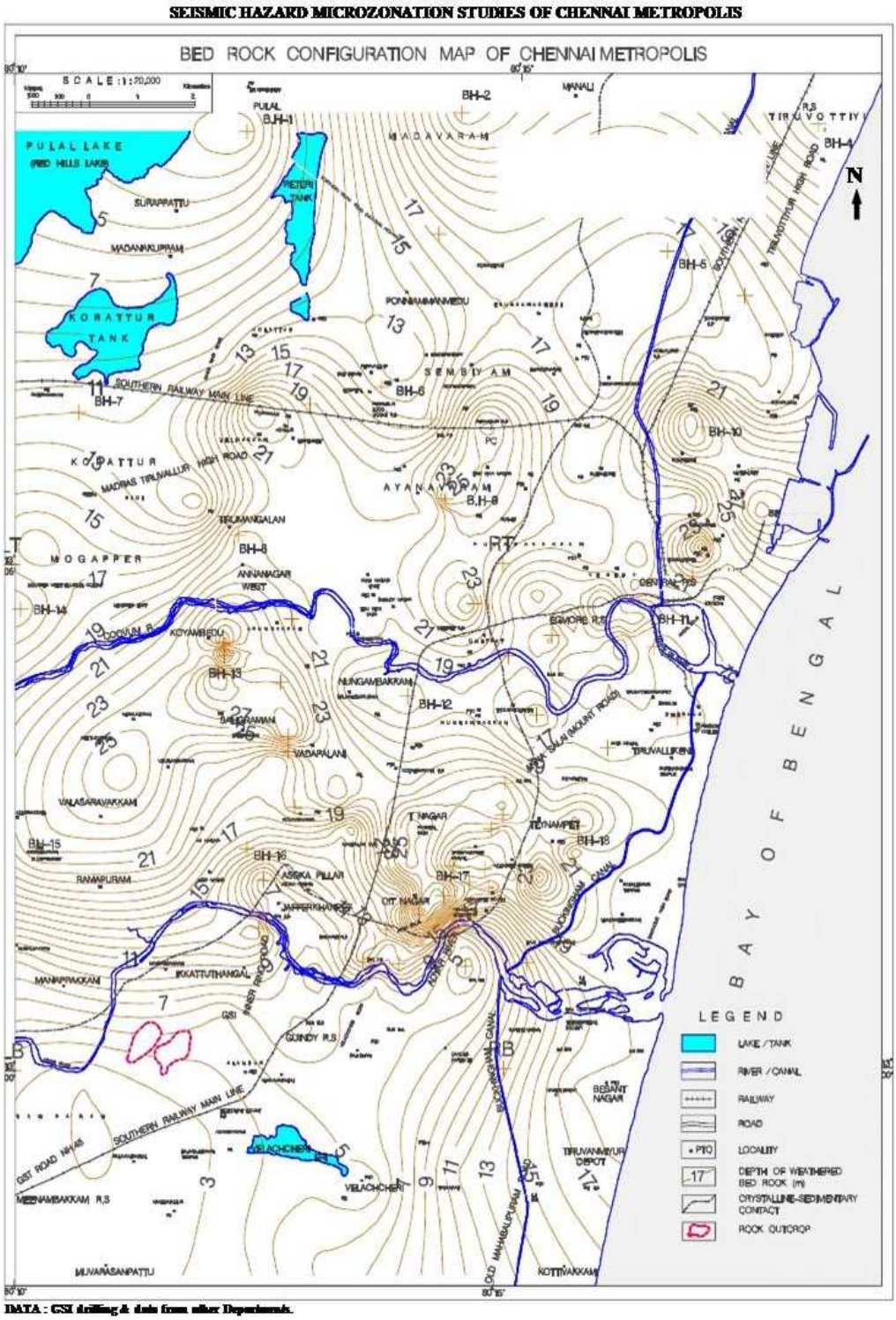

Figure 1 Bedrock depth contour map of study area

Integration and Zonation:

An attempt has been made to delineate the Seismic Microzones of discrete geographic domains, having similar geological, geotechnical and site response characteristics, which may behave uniquely, in case of any damaging earthquake event occurring in future, in the region under investigation. The steps and criteria that have been adopted in this endeavor to derive the First Level Seismic Hazard Microzonation Map of Chennai Metropolis on 1:20,000 scale, are summarized below. Parameters generated in the present study are:

1) Seismotectonic analysis of the region based on the available data has been carried out to understand the potential source areas of probable damaging earthquake events.
2) Detailed geological & geomorphological maps were prepared on 1:20,000 scale to understand the morphological relationship with the surface and sub surface substratum, which have direct bearing on site amplification, frequency and shear wave velocity parameters.
3) Land use and land cover map on 1:20,000 scale was prepared using LISS-IV data along with ground observations to understand the areal extent of built up and industrial areas under development, agriculture and open lands.
4) Ground water data was adopted based on the inputs provided by TWAD Board, PWD, etc., to assess the saturation levels of sand, sandy silt, silt and silty clay layers at various depths, which may influence the liquefaction susceptibility of sub surface layers.
5) Drilling was done up to a maximum depth of 30 m at selected locations, to delineate the sub surface lithology and to conduct Standard Penetration Tests (SPT) to determine the N-Values, which in turn gives indirect information on Shear wave velocity (Vs), which have direct bearing on amplification, frequency and site response parameters of sub surface soft media (Figure 2).
6) Site response studies were carried out by the team of Geophysicists to evaluate the peak amplification and corresponding peak frequency distribution of soft media, that have direct influence on resonance frequencies of built up areas, and to assess the range of frequencies to be adopted for the structures/ buildings in different localities, to minimize the damage/loss in the built up area of Chennai Metropolis.
7) The following criteria are used in delineation of the seismic micro zones in this area: The areas of dunal sand, flood plain, palaeo channels, etc. constituted by loose non-cohesive soils are normally having high susceptibility for liquefaction. Areas constituting shallow water table zones contribute to the water saturation of sediments, thus increasing the pore pressure especially during the ground shaking due to an earthquake of magnitude 5+. Sub surface layers having grain size ranging from gravely sand fractions to fine silt and clayey silt fraction with fines content less than 10% are identified, as they are more prone to liquefaction. Low N values in general exhibits high levels of susceptibility. Low weighted average shear wave velocity indicates high rate of susceptibility.

Figure 2 Shear wave velocity map of study area

As the overburden thickness increases, the natural frequency of sub surface media decreases and wavelength increases with low values of seismic rigidity, giving rise to higher order of seismic amplification, hence possible more damage. Higher amplification zones generally indicate higher levels of damage. Higher the ground vulnerability Index (Kg), higher the damage potential (Figure 3).

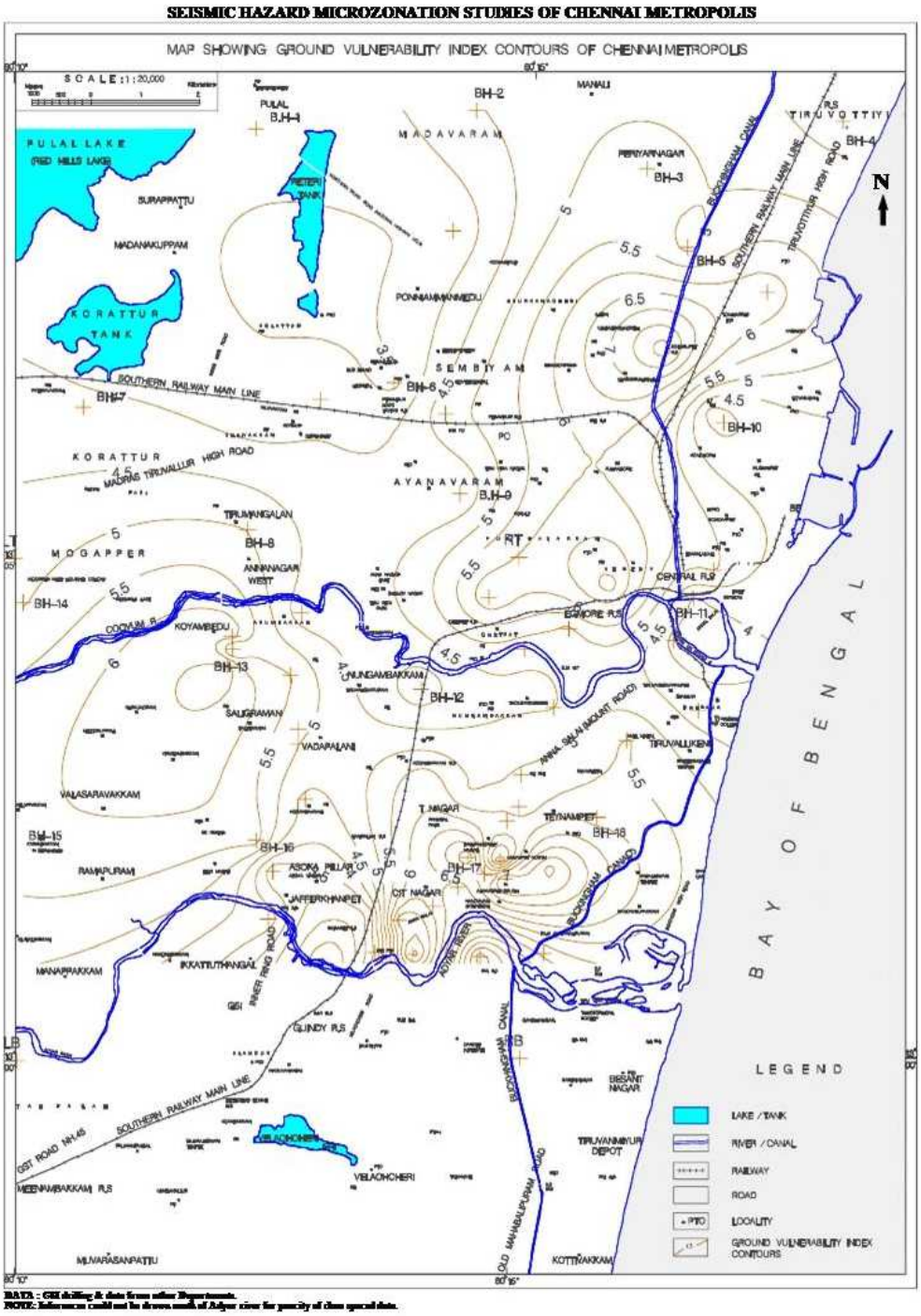

Figure 3 vulnerability Index map of study area

By the integration of various influencing parameters, to the extent possible, four seismic Microzones have been arrived at for the Chennai Metropolitan area **(Fig-4).**

Zone-I depicting Microzones of relatively very low seismic hazard, especially in the southern part of the study area, south of Adyar river, over the pediplain / pediment country, wherein Charnockite rock occurs at shallow depths or even as surface outcrops. Site response studies have supportively indicated higher frequency values for such areas. These areas generally have comparatively deeper ground water regime, exhibiting very low ground vulnerability index and practically very poor chances of liquefaction, with very high factor of safety against liquefaction. Interestingly this area is giving way to the infrastructure needs and developments of IT Sector. It may be noteworthy that, suitable inferences could not be drawn in the area south of Guindy, due to paucity of control data.

Zone-II depicting Microzones of relatively low seismic hazard, especially in the central and the north western parts of the study area, in general has alluvial deposits comprising of silt, clay and silty sand resting over the Gondwana rocks in the localities of Nungabakkam, Koratur, etc. The N values are moderate in this zone with moderately deep levels of ground water. In this zone weighted average shear wave velocity is in the range of above 200m/s with a low to moderate factor of ground vulnerability index and comparatively lower degree of liquefaction.

Zone-III depicting relatively moderate seismic hazard encompasses the western areas of Saligramam, Valasaravakam, Ramapuram, etc., northeastern areas adjacent to Royapuram, Purasavakkam, etc. and the south central parts adjoining Teynampet, etc. These areas are dominated by sandy horizons with moderately shallow ground water table having weighted average overburden shear wave velocities less than 200 m/s and moderate ground vulnerability index. Factor of safety against liquefaction is also found to vary between low to moderate levels indicating chances of liquefaction in case a higher intensity seismic event.

Zone-IV depicts areas of relatively high seismic hazard and is restricted to few small patches in the area west of Royapuram and southwest of Veppery. These are the areas having normally shallow ground water table over silty sands / sandy horizons, giving rise to low weighted average overburden shear wave velocities of the order of 140 to 180 m/s. The same is also indicated by the low factor of ground vulnerability index and the factor of safety against liquefaction (Fig-5).

Besides in these locations, the Charnockite forms the bedrock in most of the locations, which in turn may contribute to higher impedance contrast, resulting in more vulnerability.

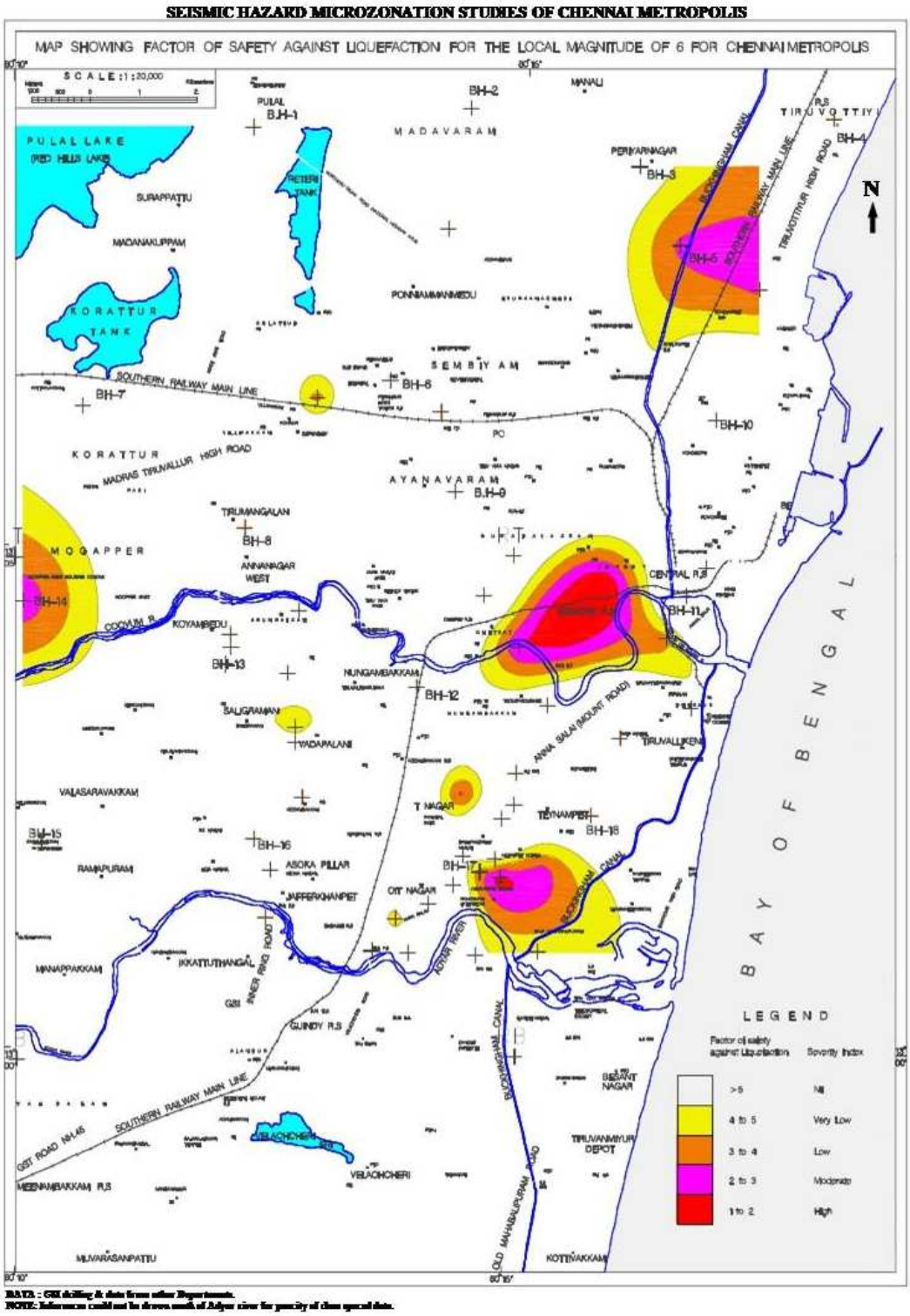

Figure 4 Seismic Hazard Zonation map of study area

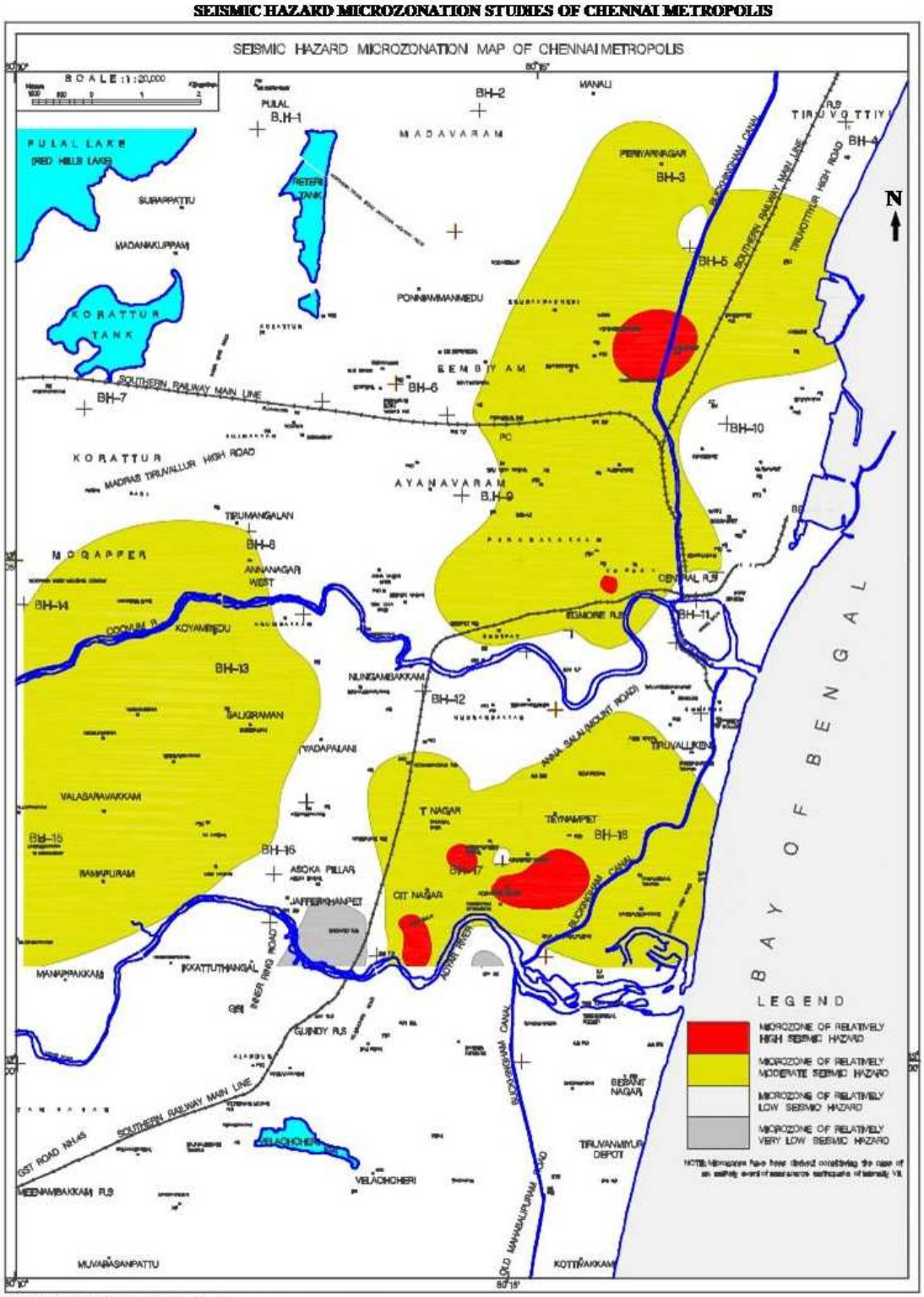

Figure 5 Liquefaction map of study area

6. Conclusions and Recommendations:

Chennai (the Detroit of India) with many leading automobile and ancillary industries, has seen phenomenal growth in the last decade especially in the IT and electronic Sector. All these developments of urbanization have taken heavy toll of the city with increasing demands of high concrete structures. Hence this city deserved due attention for taking up Seismic Hazard Microzonation studies, mainly due to its strategic coastal location and also due to the fact that some of the nearby coastal urban centers posses a relatively higher seismic propensity.

The area of about 400sq.km under investigation forms a part of Survey of India Topo Sheet No. 66 C/4 & 8 and falls in the Zone III of the revised Seismic Zonation Map of India. Hence this Seismic Hazard Microzonation study, the results of which may guide the civic planners and administrators to adopt necessary preparedness with regards to earthquake disaster mitigation and management. The Chennai area has essentially a flat topography with a very gentle slope towards east. The low level lateritic plateau in Puzhal in the northwest and the inselberg of St. Thomas Mount in the SW are the prominent physiographic features. By compiling the available seismotectonic information within the 300km radius of Chennai Metropolis, Peak Ground Acceleration was arrived from the different possible sources. The tectonic source, which contributed a PGA of 0.1261g, is a NE-SW trending lineament southwest of Chennai with associated past seismic event of around 5.5 magnitude on Richter scale. Eighteen boreholes were drilled in Chennai area; 3 are over beach dune complex, 2 over tidal flat and 3 over palaeo tidal flat, 1 each over older dunal complex and Gondwana, and 8 over alluvial / flood plains comprising of fluvio- marine sediments, aggregating to a depth of 524.60m. In all about 256 SPT and bulk samples have been collected to determine the geotechnical parameters relevant to the study. The grain size distribution curves of soil samples collected from different borehole locations of Chennai area are plotted against the standard boundary of potentially liquefiable soils (Tsuchida and Hayashi, 1971). It is found that the range of grain size tailings for few of the samples particularly the one from the shallow levels in beach dune complex and tidal flat, reaches slime with low resistance to liquefaction. The site response studies through noise surveys deploying digital MEQ recorders indicated that peak frequency varied in the range from 3.5 to 5 Hz and peak amplification varied from 3 to 6 in Chennai Metropolis. The study also indicated that the overburden thickness is large and is unconsolidated around Madhavaram area. Hence, it can be said that structures with natural frequency greater than 5Hz (fundamental period of 0.2 sec) are safe and suitable for northern part of the area. Further, it is recommended to avoid construction of heavy/ high-rise structures in that area. High amplification value near south of Ramapuram and its adjoining area with natural frequency of the order of 8Hz indicates that the area may be subjected to greater ground motion during a major seismic event. The characteristic site period for the typical formations, i.e. clayey sites, sandy sites and rocky sites are found to be 0.67s, 0.22s and 0.14s respectively.

By the integration of various influencing parameters, four Seismic Microzones have been arrived at for the Chennai Metropolitan area, representing Very Low, Low, Moderate and High Seismic Hazard Microzones. The Microzones has a gross validation on comparing

them with the effects of past seismic events which have been studied in details. It is found in this study that the areas of Saligramam, Valasarvakkam, Chinna Porur, etc., which fall in the zone III & IV (as per the hazard classification devised for the present study) depicts high & moderate hazard levels.

These areas felt the effect of Bhuj earthquake of 26.01.2001and subsequent Pondicherry earthquake more intensely than the other parts of Chennai. The macro seismic survey conducted by GSI after the above incidents designated an MSK intensity of III to V to these areas.

Similar felt effect of 25.09.2001 Pondicherry earthquake of 5.6 magnitude indicated increase in yield just before starting of vibrations in a bore well in the Old Washermanpet area that was classified under isoseist V, which falls in the boundary of high to moderate seismic hazard Microzones. As per the reports of Amateur Seismic Center in their website on the event of 6.6 Mw earthquake in the North Andaman Island; felt effect were noted in the areas of T. Nagar, Pursawakkam, Teynampet, etc. These localities are falling in the high & moderate hazard level categorized zones, as per the Seismic Hazard Microzonation map presented here.

The various Seismicity parameters discussed in this report i.e., liquefaction susceptibility, peak amplification and peak frequencies, of the demarcated seismic micro zones, though broadly assessed, are of regional and preliminary in nature, but still are of considerable significance from the point of view of land use and urban planning. However, it is suggested that a detailed site-specific study of the delineated areas may be duly conducted, before the planning and execution the civil construction works, particularly of high rise buildings which will greatly contribute to minimize the loss to life and property, in the unlikely event of any significant damaging earthquake occurring in the Chennai coastal segment. Further, detailed surveys may be warranted in the western extensions of the Chennai Metropolitan area, which is developing rapidly, owing to tremendous growth in the automobile sector, for arriving at a comprehensive picture with respect to seismic microzonation.

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