LIQUEFACTION POTENTIAL SUSCEPTIBILITY MAPPING IN URBAN AREAS

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Abstract- Liquefaction is the measure of vulnerability of saturated sediment to compact during earthquake shaking and thus generate pore water pressures sufficient to cause possible ground instability or failure. Urban areas lying in the alluvial soil generally pose to threat of liquefaction even for moderate magnitude earthquakes. The buildings which are constructed over the liquefiable soil are more vulnerable during seismic shaking for a potential earthquake. The Chennai city of India is one of the most densely populated cities in the world, which consist of densely constructed high rise buildings in many parts. The city is under moderate seismic zone as classified by Bureau of Indian Standard where one can expected maximum magnitude of 6.9. The major part of the city covered by the Recent Alluvial soil with shallow water table, which is more vulnerable during earthquake shaking and quiet enough to trigger liquefaction. In this regard a study carried out to understand the liquefaction susceptibility of soil in the city using geotechnical parameters. Also the study reveals spatially 60% of the area is prone to liquefaction. The present study can be an eye opening for urban planners and decision makers and emergency responders for future developmental planning activity within the city.

Keywords- Liquefaction, Susceptibility, Urban Areas and Chennai

I. INTRODUCTION

Liquefaction is one the most important seismic hazards which plays a major role in urban disasters. Since most of urban areas nowadays goes with construction of tall buildings due to space constrain.

The study of liquefaction of soil will be an important input to assess the seismic hazards in built-up areas.

Soil liquefaction has been a major cause of damage to soil structures, lifeline facilities and building foundations in past earthquakes and clearly poses a significant threat to the integrity of structures and facilities during future earthquake (ISSMGE 1999).

Buildings in zones of liquefaction are particularly vulnerable to differential ground movements, results from the heterogeneity of stratigraphy and soil properties (Bird et.al 2005).

Globally many researches carried out studies on liquefaction assessment based on different methods (Youd and Hoose, 1977; Youd and Perkins, 1978; Iwasaki, 1982; Youd and Perkins, 1987; Obermeier, 1989; Power et.al. 1992; Wakamastu, 1992; Susumu Yasuda, 2000; Bird and Bommer, 2004; Wakamatsu et.al, 2006; El May et al. 2009; Holzer 2008; Vipin and Sitharam 2009; Ganapathy and Rajawat, 2012).

The Chennai city, the capital of Tamil Nadu State in India is one of the highly densely populated city in the world which consist of 90 percent built up areas. Many of the buildings in Chennai are multistory, such being the case safety of this city is extremely important for safeguarding human lives and property.

The shallow geological subsurface provides a physical environment that provides people with the natural resources to extract (minerals, groundwater and ground source heat for example) and with which to deposit wastes.

It also provides a medium to support the construction of engineered structures and the installation of below ground utilities and underground developments.

Very few researchers carried out liquefaction studies for the Chennai city.

Anbazhagan and Premalatha (2004) carried out liquefaction study using factor of safety based on SPT data of 15 locations.

Ganapathy and Rajawat (2012) assessed the liquefaction potential of Chennai based on integrating the lithologic and geomorphologic characteristics.

They have classified the city in to three zones viz, liquefaction likely, liquefaction possible, and liquefaction not likely.

However the there is no detailed study on liquefaction susceptibility work done so far for the city.

The present study aims to produce liquefaction susceptibility map in the built up areas of Chennai city, India.

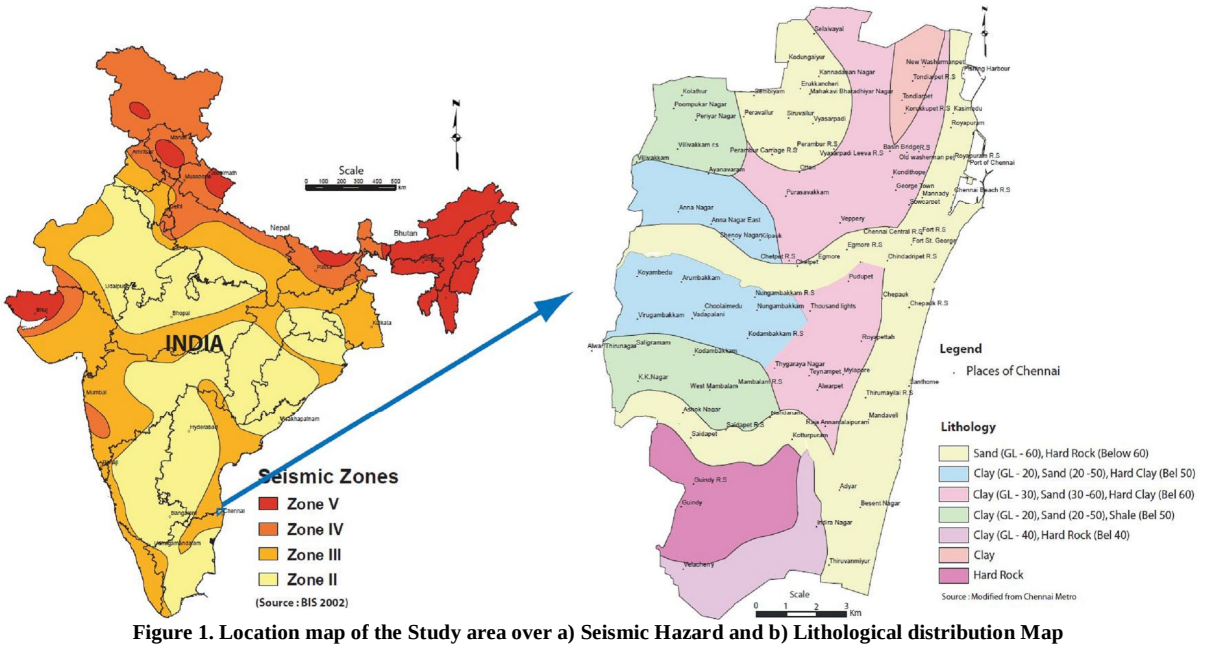


Figure 1. Location map of the Study area over a) Seismic Hazard and b) Lithological distribution Map

II. BASELINE INFORMATION

2.1 Lithology

The Archaean crystalline rocks, Gondwana & Tertiary sediments and Recent alluvium are the three group of geological formations are found in Chennai. (CGWB Report, 1993). The subsurface lithology of Chennai broadly grouped in to seven unit's viz. Hard rock, clay formation, clay over hard rock, clay - sand - shale formations, clayey sand - sand - hard rock, clay-sand-hard rock, and sand over hard rock. The south western part of the city is covered by hard rock of Charnockites.

The outcrops exposed over few meters in St. Thomas mount area near Guindy as residual hills (Figure 1).

2.2 Depth to water table and water level fluctuation

Liquefaction has been most abundant in areas where ground water lies within 10 m of the ground surface; few instances of liquefaction have occurred in areas with ground water deeper than 20 m.

The depth to ground water level in the city varies from 2 to 8 m in the city. The long-term water level fluctuation for the period from 1998 to 2007 indicates rise in water level in the area at the rate of 0.003 0 0.93 m/year. The fall in water level ranges between 0.037 and 0.798 m/year (CGWB, 2008).

2.3 Geomorphology

Chennai district forms part of coastal plains and major part of the city having flat topography with very gentle slope towards east. The land elevation varies from 10 m above MSL in the west to sea level in the east. Fluvial, marine and erosional landforms are noticed in the district. Marine transgression and regressions and neo-tectonic activity during the recent past have influenced the morphology and resulted in various present landforms (GSI, 2005 and CGWB, 2008).

2.4 Seismic hazard of Chennai City

The earthquake magnitude is an important parameter to trigger the liquefaction. The Chennai city has been classified under Zone III (moderate seismic hazard – Magnitude 6.9) as per seismic hazard map of India published by Bureau of Indian Standard (BIS, 2001). Further the city broadly classified into three zones, as high, moderate and low in terms of seismic hazard in an event of future earthquakes.

The part of Chennai falls in seismically moderate to high hazard prone areas (Ganapathy, 2011, Ganapathy and Rajarathnam, 2009). The expected maximum Magnitude 6.9 is quite good enough to liquefy the soils of Chennai.

III. APPROACH

The zoning of soil liquefaction potential can be done in various methods like i) based on pre existing data from available published resources, ii) estimation of liquefaction susceptibility based on existing data viz., Geological & geomorphological criteria and Liquefaction Severity Index (LSI), in-situ liquefaction susceptibility based on Standard Penetration Test and Cone Penetration Test (ISSMGE, 1999 and Bhandari, 2002).

In the present study a simple approach used to calculate the factor of safety in term of liquefaction susceptibility by using geotechnical details from the Standard Penetration Test (SPT) boreholes. The methodology used for the present study is given in Figure 2.

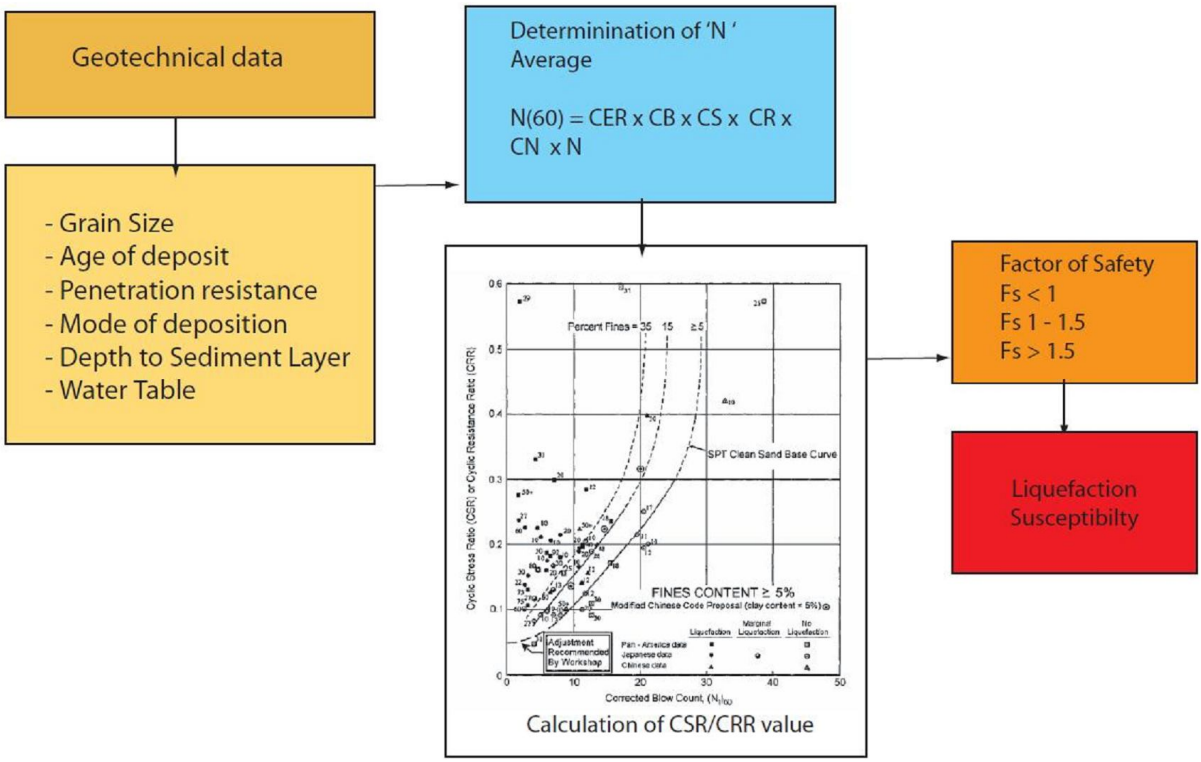


Figure 2. Methodology used to produce liquefaction Susceptibility Map

IV. ESTIMATION OF LIQUEFACTION SUSCEPTIBILITY

To attain the liquefaction susceptibility map of Chennai geotechnical data were collected from different authenticated source and used for the present study. Totally 45 boreholes collected and the parameters viz, grain size, effective stress, water table, soil layers, depth were studies and the SPT 'N' value.

Various corrections were made to synthesize the SPT data (using eq.1) and the N average for 4 m depth is calculated. $(N)_{60}$ is the N value corrected for the field procedures to an average energy ratio of 60 per cent.

$(N)_{60} = C_{ER} * C_B * C_S * C_R * C_N * N$ ----------eq. 1

Where CER is Energy ratio correction, C_B Borehole diameter correction, C_S Sampling method correction, C_R Rod length correction, N Measured SPT `N' Value blows / 30 cm, CN overburden stress correction factor. $(N)_{60}$ value was used to find CRR from energy ratio curve.

Then the average $(N)_{60}$ values are obtained for each borehole. The average N value for 4m depth were plotted in GIS platform and given in Figure 3. CRR values are taken from the standard graph as per the values of $(N)_{60}$.

The uniform cyclic shear stress amplitude for level (or gently sloping) sites can also be estimated from a simplified procedure (Seed and Idriss, 1971) used from eq 2.

$CSR = (\sigma_{VO} / \sigma_{VO}') = 0.65 (a_{MAX} / g) (\sigma_{VO} / \sigma_{VO}') r_d$ ----------eq. 2

Where a_{max} = Peak ground horizontal acceleration at the surface generated by earthquake.

σ_{VO} ,σ_{VO}' = Total and effective vertical stresses
rd = stress reduction coefficient, which is a function of depth and rigidity of soil column
= 1.0 - 0.00765z, for z <= 9.15m
= 1.174 -0.0267z for 9.15 m < z <= 23m
z = Depth below ground surface in meters

CSR @ DEPTH 4 M

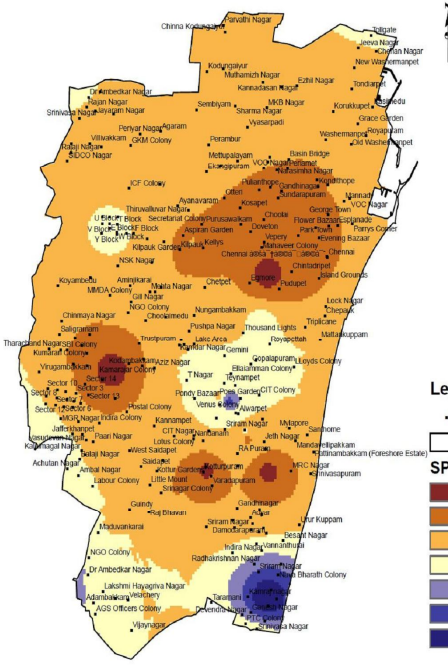
N = 6
I = 6.5
a_{MAX} = 0.37g

The CSR value is calculated based on following equation 3.

$CSR = 0.65 X a_{max} X \sigma_{vo} X r_d / g X \sigma_{VO'}$ ----------eq. 2

= 0.65 X 3.626 X 72.128 X 1.19 / 9.8 X 62.128
= 0.332

With the values of the CRR (6.5 magnitude), CSR and MSF values we get the factor of safety against liquefaction.



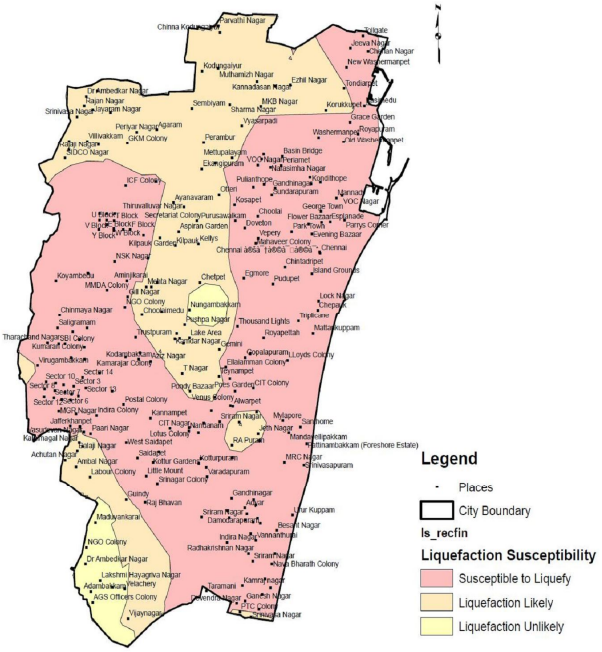


Figure 3. Spatial Distribution of SPT 'N' Value. Figure 4. Liquefaction Susceptibility map of Chennai City

The Factor of safety is calculated using CSR, CRR and MSF values. The factor of safety values ranging from 0.1 to 2.5 for the study area. The Factor of safety classified in to three categories viz., 0 to <1, 1 to 1.5, and > 1.5 based on the Susceptibility to liquefaction of the Soil.

The values 0 to <1 means the soils are highly susceptible to liquefy, 1 to 1.5 means liquefaction may be likelihood chances and > 1.5 will be no chance of liquefaction of soil for the magnitude 6.9 for 4 m depth. The factor of safety values are used in Spatial analyst tool to prepare the Liquefaction susceptibility map for Chennai city and presented in Figure 4.

CONCLUSIONS

Totally 45 SPT boreholes were selected to understand the subsurface soil characteristics of the Chennai city. Based on the analysis the areas are divided in to three zones of Liquefaction susceptibility viz., Susceptible to liquefy, Liquefaction Likely and Liquefaction unlikely. The present study is based in an hypothetical earthquake magnitude of 6.9 (for moderate seismic Zone) and the scenario of liquefaction will be different for the different magnitude earthquakes.

Also the present study purely based on available data collected from different sources and it is only spatially covered the area, however the liquefaction Susceptible map will be change if more number of data used with minor geological information's.

The present study can be used as first hand information for planning new settlements, lifeline structure for future development within the city. Also its need the tall buildings within the Liquefaction Susceptible areas are should have detailed site specific study for safety of the buildings.

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REFERENCES

[1]. Anbazhagan P, Premalatha K (2004) Microzonation of liquefaction factor of safety of Chennai city. Journal of Indian Geotechnical Congress : 227 – 230

[2]. Bhandari R.K Rajarathnam S, Janardhanan G, Ganapathy, G.P (2003) Seismic Microzonation, Monographv published by Centre for Disaster Mitigation and Management, Anna University, Chennai, 142

[3]. Bird, J.F, Bommer, J.J (2004) Earthquake losses due to ground failure. Eng. Geol 75, 2nd Edition: 147–179.

[4]. Juliet F. Bird , Helen Crowley, Rui Pinho, Julian J. Bommer (2005), Assessment of building response to liquefaction induced differential ground deformation, Bulletin of the New Zealand Society for Earthquake engineering, Vol. 38. No.4, December 2005, p 215 – 226.

[5]. BIS: 1893 (2001) Criteria for earthquake resistant design of structures. Bureau of Indian Standards, New Delhi.

[6]. CGWB Report (1993) Groundwater resources and development prospects in Madras district. Tamil Nadu, Central Ground Water Board, Southern Region, Hyderabad.

[7]. CGWB (2008) District groundwater brochure Chennai district Tamil Nadu, Technical report Series Central Ground Water Board South Eastern Coastal Region, Chennai, November 2008, pp 19.

[8]. Craig V. Nelson (2002) Liquefaction: A guide to land use planning, Geological Hazards Ordinance – Chapter 19.75, Appendix B, 6, 2002.

[9]. Ganapathy G.P. (2011), First level seismic microzonation map of Chennai city – a GIS approach, International Journal - Natural Hazards and Earth System Sciences, No. 11, pp. 549–559.

[10]. Ganapathy G.P. and Rajawat A.S (2012), Evaluation of Liquefaction Potential Hazard of Chennai City, India, Using Geological and Geomorphological Characteristics, International Journal – Springer - Natural Hazards, Journal of the International Society for the Prevention and Mitigation of Natural Hazards ISSN: 1573-0840, DOI 10.1007/s11069-012-0331-1, Vol.64, pp. 1717 – 1729.

[11]. Ganapathy G.P and Rajarathnam S (2009), Site Response Study for Urban Areas of Chennai City, India – A Geotechnical Approach, IS Tokyo 2009, Performance-Based Design in Earthquake Geotechnical Engineering – Case History to Practice – Kokusho, Tsukamoto & Yoshimine (eds) © 2009 Taylor & Francis Group, London, ISBN 978-0-415-55614-9, pp 365-371.

[12]. GSI (2005) District resource map of Chennai, published by Geological Survey of India (GSI), Hyederabad.

[13]. ISSMGE (1999), manual for Zonation on Seismic Geotechnical Hazards (Revised Version), Technical Committee for Earthquake Geotechnical Engineering, TC4, ISSMGE , ISBN 4 88644-809-7, Published by The Japanese Geotechnical Society, Tokyo, Japan, pp 210.

[14]. Iwasaki, T., (1982) Microzonation for soil liquefaction potential using simplified methods, in: Proceedings of the 3rd International Conference on Microzonation, Seattle, 3 : 1310-1330.

[15]. Obermeier, S.F. (1989) The New Madrid earthquakes: An engineering-geologic interpretation of relict liquefaction features, U.S. Geological Survey Professional Paper 1336-B : 114 pp.

[16]. Power, M.S., J.W. Wesling, R.C. Perman, R.R. Youngs, and L.A. DiSilvestro, (1992) Evaluation of liquefaction potential in San Jose, California, Report to U.S. Geological Survey, Award No. 14-08-0001-G1359, by Geomatrix Consultants, San Francisco, California.

[17]. Seed, H. B., and Idriss, I. M. (1971). ‘‘Simplified procedure for evaluating soil liquefaction potential.’’ J. Geotech. Engrg. Div. , ASCE, 97(9), 1249–1273

[18]. Susumu Yasuda (2000) Collection of surface data for the prediction of liquefaction potential (Partially quoted from the papers by Ishihara and Yasuda(1991) and TC4 (1999).

[19]. Wakamatsu, K (1992) Evaluation of liquefaction susceptibility based on detailed geomorphological classification, in: Proceedings: Technical papers of annual meeting architectural institute of Japan, B :1443–1444

[20]. Youd T.L. and Perkins D.M (1987) Mapping of Liquefaction Severity Index, J.GED, ASCE, Vol.113 : 11 : 1374 -1392.

[21]. Youd, T. L. and Hoose, S. N (1977) Liquefaction susceptibility and geologic setting, in: Proc. 6th World Conf. on Earthquake Engineering, New Delhi, 6 :37–42

[22]. Youd, T. L. and Perkins, D. M (1978) Mapping liquefaction-induced ground failure potential, J. Geotech. Eng. Div., ASCE, 104: 433–446.

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