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Criteria based liquefaction susceptibility analysis

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ABSTRACT

Examination of liquefaction susceptibility in an area is the primary step for any kind of liquefaction examination in that area. If the area is found to be susceptible to liquefaction, then further steps are required to verify whether liquefaction will occur or not. Various criteria and methodologies are provided by various research workers to find out liquefaction susceptibility. Historical, geologic, compositional, and state criteria of the soil is required to study liquefaction. Instances of liquefaction dates back to the 1960s. In this paper an attempt is made to study the detailed methodology for assessing the liquefaction susceptibility and the methodology is implemented in evaluating the liquefaction susceptibility of Guwahati city. The study that is been taken up requires soil parameters like liquid limit, clay content, plasticity index, etc. are used.

Keywords: earthquakes, Guwahati city, liquefaction susceptibility, soil properties.

1. INTRODUCTION

Liquefaction related phenomenon is caused when built up of excess pore water pressure occurs. Only sandy soils are believed to be liquefied in the past. But with more discoveries and research work, that fine-grained soils are similarly susceptible to liquefaction. The grading parameter limits of soils have been expanded to accommodate liquefaction susceptibility. Non plastic silts also exhibit liquefaction phenomenon in the laboratory and in the field as well [8], and as such represents that plasticity properties rather than grain size distribution characteristics affect liquefaction susceptibility. The clayey deposits remain outside the purview of liquefaction susceptibility, however in some cases strain-softening phenomenon can be seen similar to that of liquefied soil. As such to assess the susceptibility of such soils, lot of research is attributed for the last five decades. Development of processes for liquefaction susceptibility evaluation are given in the sections below.

2. LOCATION OF THE STUDY AREA

North east India's largest city is the city of Guwahati. It might be called as the center point of political organization, training, business and numerous different exercises of the area of Assam as well as of the complete north eastern region of India. Topographically the present Guwahati territory or the Greater Guwahati region lies in both the sides of the Brahmaputra River. It acts as the gateway for all the other North-Eastern states and is the largest city of the region. The Guwahati city got a major development boost after the transfer of the capital from Shillong to Guwahati in 1972. This caused in a huge arrival of people from the adjacent towns, villages, states, etc. in search of jobs and trades. This give rise to in an unexpected growth of the city, with people going for high rise buildings and filling of the marshes for construction making the region vulnerable to earthquake hazard. Moreover, cutting of hills of the city resulted in increased landslide hazard and also increased earthquake hazard for the houses constructed on the unstable slopes.

Hence keeping in view, the unplanned development of the city and its vulnerability due to earthquake related disasters due to the location of the city, studying the seismic vulnerability became imperative. Seismic hazards include ground shaking, ground settlement, ground subsidence, lateral displacements, soil liquefaction, landslides and mass movements, structural hazards, earth retaining structures, slope failures, lifeline hazards, tsunamis, etc. Out of the above seismically induced phenomenon, seismically induced liquefaction of soil causes severe damage to infrastructures. Hence, soil liquefaction study is of utmost importance in the region and hence the study is taken up for consideration.

The present study is done on the entire Guwahati city. The soil profiles used or the boreholes used were taken from different locations to give a decent spread of data across the city. The hills were excluded from the city and no borehole data is collected from the hilly areas of the cities. The number of boreholes locations used for conducting the study is 807. The borehole positions of the city and the border of Guwahati conferring to the Guwahati Metropolitan Development Authority (GMDA) 2025 master plan is shown with the help of a map below.

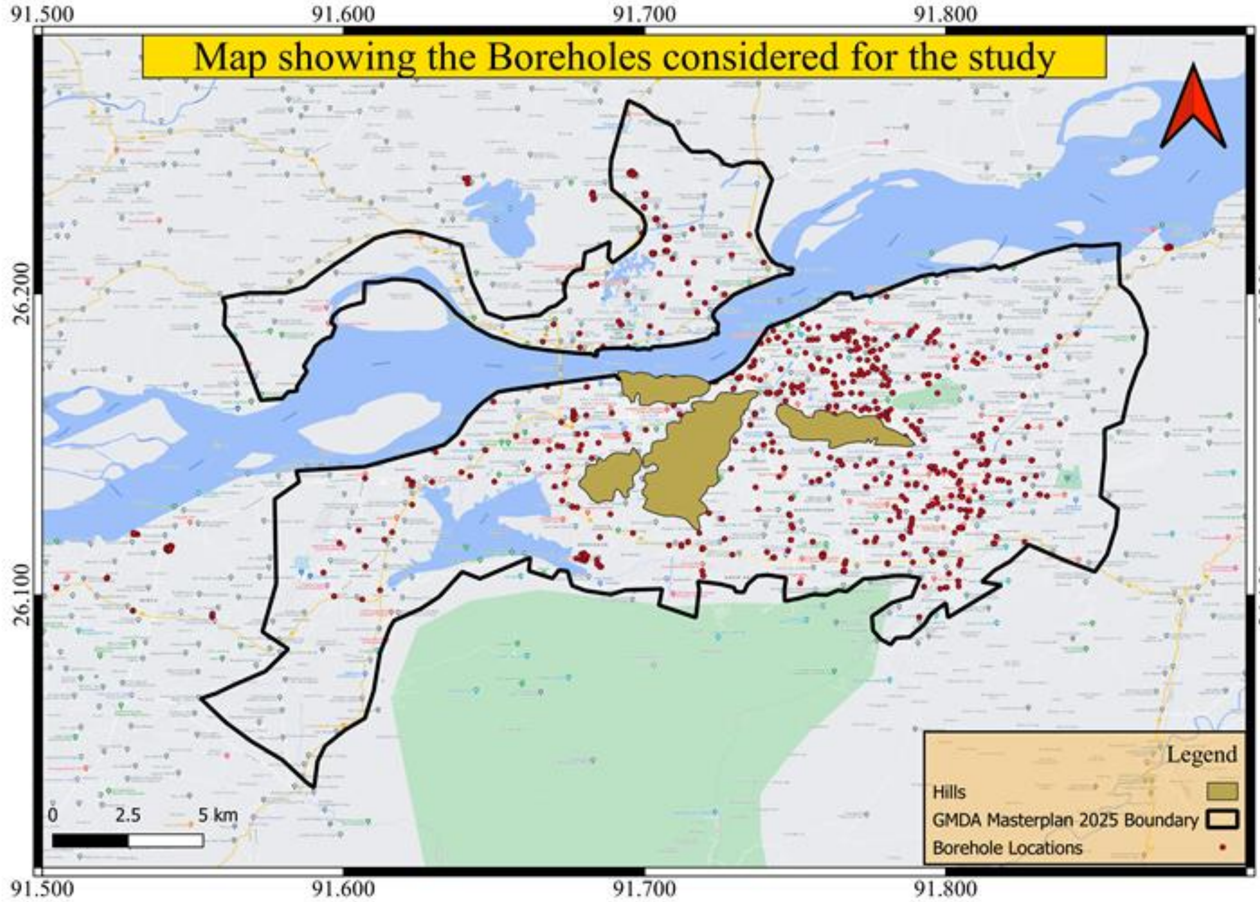

Figure 1. Map showing the borehole locations considered for the study

The map shows the location of boreholes, the GMDA Masterplan 2025 boundary and the hills of the city. Intervals of 1.5 m depths are chosen for carrying out the study. Later sections of the paper throws light into the methodology adopted for the study.

3. METHODOLOGY

The inception of the liquefaction susceptibility analysis dates back to around 1970s when the sand boils of the Nanaehama beach were considered in detail by Kishida [3] in the Tokachioki earthquake. Boils were detected which included of sandy silt with less than 10% clay content. The soil depth is from 1 m to 12 m. It was also observed that soils having clay content of 10% were not found to be liquefied. In the current study 12 methods, were applied to carry out the liquefaction susceptibility analysis of the Guwahati city. The first method applied is the Chinese criteria by Wang (1979) [16]. Widespread liquefaction damages were seen in the Haichang, 1975 and Tangshan, 1976 earthquakes where there was varying fines content and clay fraction were found in the liquefied soil. Following these earthquakes, the “Chinese Criteria” is introduced by P.C. Wang in 1979.

The next method applied is the Tokimatsu and Yoshimi 1983 [9], where it was found that liquefaction susceptibility is seen in silty sand to slightly sandy silt. Similarly, Tuttle et. al. 1990 [10], Finn et. al. 1991 [15] and Figueroa et. al. 1995 [7] was used in the study. In 2000, Andrews and Martin [1] defined criteria that separates liquifiable to non-liquifiable soil, which is a modification of the Chinese criteria. According to the research workers, the key parameters that that helps in the separation of liquefaction to non-liquefaction are clay content and Liquid Limit. Criteria by Youd 1998 [14], Seed et. al. 2001 [11] and Seed et. al. 2003 [12] were also used which are primarily based on Plasticity Index (PI), Fines Content (FC) and Liquid Limit (LL). The criteria which use the PI value as the governing factor for the separation of liquefaction susceptible soils to non-susceptible soils are Boulanger and Idriss, 2006 [13], Bray and Sancio, 2006 [6] and Gratchev et. al., 2006 [5]. The natural water content (w_n) to LL value is also used in these criteria. Hence, the above methods are incorporated into the study with the help of spreadsheets and in turn generating the liquefaction susceptibility scenario of Guwahati city.

The above discussed methods are incorporated into the study with the help of spreadsheets and in turn generating the liquefaction susceptibility scenario of Guwahati city. The results are discussed in the later sections.

4. RESULTS AND DISCUSSIONS

The “Chinese Criteria” defined the liquefaction susceptibility of soil based on the clay fraction (particle size < 0.005 mm), the water content, and the liquid limit. According to the criteria soil will only liquefy if all the three conditions viz. 1) Percent Finer than 0.005 mm: < 15%, 2) Liquid Limit (LL): < 35% and 3) Water content (w_n %): > 0.9 x LL. This is the first criteria applied for the study. Next criteria applied is Tokimatsu and Yoshimi 1983, where recorded data from 10 earthquakes comprising 70 case histories from Japan and 20 case histories outside Japan was used.

The grain sizes of the silty sand to slightly sandy silt soils which liquefied was shown. 20% boundary condition for clay content for liquefaction susceptibility is demarcated but was later modified to 15%. Tuttle et. al. in 1990 inferred that the soils have clay content of not more than 10% and the soils were either very silty sand or sandy silt. Finn et. al., 1995, recommended allowances for the uncertainties in the Chinese Criteria by subsequently changing the measured properties before applying the Chinese criteria (again disregarding the liquidity index).

The variations are decrease the fines content by 5%, decrease the liquid limit by 2% and increase the water content by 2%. Further, Figueroa in 1995, found that the liquefied soil had a clay content of less than 10% and the soil belong to very silty sand category. Similarly, Youd in 1998 gave the conclusion that fine grained soils will liquefy if LL < 35, Plot Below A-Line and PI < 7. Andrews and Martin, 2000, reduced the boundary of Liquid Limit to 32 from 35 because the LL is determined using Casagrande-type percussion apparatus and arrived at the conclusion that silty soils are also susceptible to liquefaction, but the LL and the clay fraction plays vital role. It is to be noted that the clay content is considered to be 0.002 mm instead of 0.005 mm.

In 2001, Seed, Cetin, and Moss, ascertained the Plasticity Index value of less than 10 is susceptible to liquefaction and Plasticity Index of 10 to 12 is ascertained to be falling into the “uncertain range”. Seed et. al. 2003, demarcated the soils into Zone A, as potentially susceptibility to liquefaction. Zone B may be liquifiable but has to undergo testing and Zone C where liquefaction susceptibility is assumed to be nil. The criteria specifically uses FC as a criteria for application. The applicability of the criteria limits to soils of FC ≥ 20% if PI > 12% and FC ≥ 35% if PI < 12%. Soils with LL<37 and PI<12 is potentially liquefiable and the category where PI lies within 12 and 20 and LL lies within 37 and 47. Boulanger and Idriss in 2006, assumed fine grained soils with sand like behavior and having PI<7 and soils with PI>7 are assumed to behave like fine grained soils having clay like behavior. Bray and Sancio (2006), concluded that soils having how PI value (PI<12) at high water content to LL ratios (w_n/LL>0.85) are highly susceptible to liquefaction under the influence of considerable cyclic loading.

The research worker also gave a moderate susceptibility range wherein soils, especially silty clays or clayey silts and PI value between 12 and 18 and (w_n/LL<0.8) might experience liquefaction. Gratchev et.al. (2006) showed indications that with the increase of PI value, there is an increase of resistance to liquefaction in the soil. The cut of range given is a PI value of 15 signifying that soils having PI value of more than 15 is not susceptible to liquefaction and below an PI value of 15 it is susceptible to liquefaction. The liquefaction susceptiblity analysis is done for the 807 boreholes of the city at depth of 1.5 m intevals. Some of the methodologies given above could not be applied at all depths of the borehole in the study. Some criteria applies to some locations while a different criteria is applicable to a different location. Hence the results are compiled in Table 1 to show the entire suuceptibility analysis.

The table displays the result in a depth wise way. “YES” signifies that the location is susceptible to liquefaction at that particular depth by that particular criteria. “NO” signifies that those number of borehole locations are not susceptible to liquefaction and “NA” signifies that number of boreholes where the particular criteria is not applicable. The numbers in the table signifies the total number of boreholes in that category. For example if we consider the first row at depth 1.5 m, inference could be made that, by using the Chinese Criteria, 1982, liquefaction susceptibility is found in 6 boreholes and 508 boreholes remains free from liquefaction and in 292 boreholes this criteria could not be applied. Similarly for all methods and for all depths upto 15 m a table is provided showing the results.

Table 1: Table displaying the total number of boreholes satisfying each criteria

Depth (m)	**Liquefaction Susceptibility**	**Chinese Criteria 1982**	**Tokimatsu and Youshimi 1983**	**Tuttle 1990**	**Finn 1991**	**Figneroa 1995**	**Youd 1998**	**Andrew & Martin 2000**	**Seed et. al. 2001**	**Seed et. al. 2003**	**Idriss and Boulanger 2006**	**Bray and Sancio 2006**	**Gratchev et. al. 2006**

1.5	YES	6	90	79	6	79	2	4	20	15	2	2	103
	NO	508	512	523	508	523	658	552	529	597	656	433	543
	NA	292	204	204	292	204	145	206	223	193	147	185	159
3	YES	3	64	53	3	53	1	3	21	11	2	1	55
	NO	507	517	528	507	528	674	548	527	616	671	547	605
	NA	276	205	205	276	205	110	206	214	158	112	154	125
4.5	YES	3	67	60	4	60	1	5	28	4	2	0	35
	NO	489	504	511	488	511	662	548	507	614	668	563	617
	NA	282	203	203	282	203	110	203	211	155	103	152	121
6	YES	2	78	68	5	68	0	3	21	6	1	0	52
	NO	467	483	493	464	493	644	528	500	584	640	511	571
	NA	291	199	199	291	199	116	199	207	170	118	165	136
7.5	YES	2	106	98	5	98	0	4	18	3	1	1	48
	NO	430	448	456	427	456	599	530	501	543	598	471	531
	NA	318	196	196	318	196	151	196	204	204	150	198	170
9	YES	1	143	136	1	136	0	1	15	2	1	1	45
	NO	383	404	411	383	411	545	529	489	495	546	415	484
	NA	352	189	189	352	189	191	189	202	239	188	233	206
10.5	YES	3	120	113	3	113	1	3	28	4	2	1	46
	NO	405	420	427	405	427	539	521	461	506	552	416	497
	NA	308	176	176	308	176	176	176	197	206	161	197	172
12	YES	0	161	147	1	147	0	1	23	4	1	3	57
	NO	367	373	387	366	387	483	502	456	455	498	376	430
	NA	330	163	163	330	163	214	163	196	238	198	230	210
13.5	YES	1	173	168	2	168	4	4	25	9	4	1	70
	NO	473	488	493	472	493	578	631	418	540	587	445	502
	NA	332	145	145	332	145	224	145	331	257	215	250	234
15	YES	3	177	166	4	166	2	2	13	4	2	3	46
	NO	331	340	351	330	351	420	497	413	392	428	314	372
	NA	317	134	134	317	134	229	134	194	255	221	249	233

YES- Susceptible to liquefaction
NO- Not Susceptible to liquefaction
NA- Not Applicable

It is to be noted that the Andrews and Martin, 2000 criteria give a category where further research is required to determine the liquefaction susceptibility. Moreover, Seed et. al., 2001 also gives an uncertain range. Exclusion of such borehole location is done for the liquefaction susceptibility analysis. The map below clearly demarcates the borehole locations where the is liquefaction susceptibility irrespective of the depth. If at any depth liquefaction susceptibility is detected then it is symbolized by a red dot on the map.

There are some locations where more than one criterion showed liquefaction susceptibility and, in some cases, only one criterion showed liquefaction susceptibility. Hence, if a particular location is found susceptible by at least one criterion, then also it is shown in the map. The map shows only liquefaction susceptibility which does not imply that liquefaction will occur in that location. Confirmation of the occurrence of liquefaction or liquefaction related phenomenon could only be ascertained after further examination.

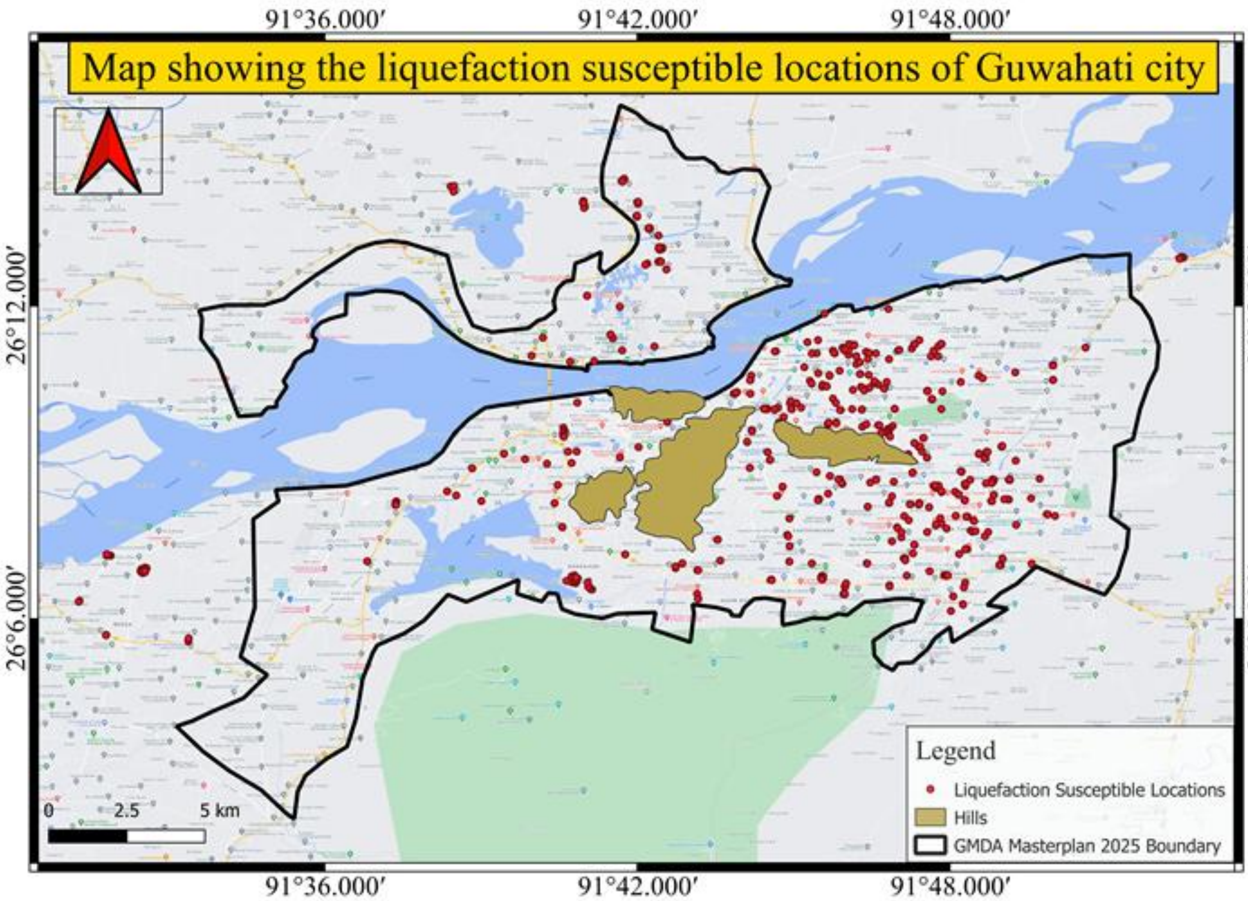

Figure 2. **Map showing the liquefaction susceptible locations of Guwahati city**

CONCLUSION

Liquefaction susceptibility study is attempted in this paper and the areas susceptible to liquefaction are demarcated and shown for the borehole locations considered for the study. Considering 807 boreholes spanning all across the city it can be concluded that in some areas there are liquefaction susceptible layers. The map delivers a clear idea about the positions where liquefaction susceptibility is found. However, it is to be noted that further analysis is required to confirm the occurrence of liquefaction or liquefaction related phenomenon at a location.

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