ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 5, May 2014

Soil Liquefaction Potential Studies of Guwahati City – A Critical Review

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Abstract: The study of liquefaction potential of a place is of utmost importance regarding the safety of both life and property. Liquefaction of soil followed by earthquakes has always been a source of danger for the people living in the highly vulnerable seismic zones of the world. Guwahati which is attributed under Zone V, the highest seismic zone level as per Indian Standard code of practice (IS 1893) is highly vulnerable to earthquakes, therein lies the hidden danger of liquefaction just after an earthquake. In this paper the various liquefaction potential studies of Guwahati city, which has been carried out is reviewed considering the significant role liquefaction has played in the past earthquakes and rising danger with increase in population. Besides this, the difference in their conclusions is shown and necessary approaches still required were discussed.

Keywords: Earthquake, Guwahati City, Liquefaction Potential, Liquefaction Studies.

I. INTRODUCTION

Guwahati City is situated in the North-Eastern region of India along the bank of the mighty Brahmaputra. Guwahati city fall on Seismic Zone V as per IS 1893 [11] which is considered as seismically most active zone of the world vulnerable to major earthquakes. The reason which makes this region prone to a major earthquake in near future is the drifting of the Indian sub-continental plate towards the Eurasian plate with the passage of time. So, an earthquake of magnitude 8 or above can never be too far which makes the proper study of liquefaction potential so important. Besides, Guwahati city has been developing thick and fast with every passing year and with the soaring rise in the population with unplanned development makes Guwahati city vulnerable to an earthquake of such intensity. As per Raghu Kanth and Dash (2010) [16] major part of Guwahati city has developed over soft sediment which can reasonably amplify the earthquake ground motion after an earthquake.

Liquefaction of soil is a phase generally observed in saturated cohesionless soil with rise in pore-water pressure due to a dynamic loading such as due to an earthquake. As a result of the rise in pore-water pressure the contact between the soil grains gradually decreases which results in decrease in the effective stress. This decrease in effective stress leads to reduction of necessary shear stress during liquefaction of soil. The effects that are generally seen due to liquefaction are mainly overturning of structures, sand boiling and destruction due to cyclic mobility of the soil mass. Liquefaction is further dependent on various factors such as grain-size distribution of sand, nature and magnitude of dynamic loading, method of soil formation and period under sustained load.

II. PAST HISTORY OF LIQUEFACTION

The 1897 great earthquake which had a magnitude of 8.1 which originated beneath the Shillong plateau brought about severe and large-scale liquefaction throughout the Brahmaputra plain. The phenomenon continued for half an hour following the main earthquake at various places and in the plains the ground water rose to the surface and gradually submerged vast stretches of land forming lakes. Mass destruction of houses, levees and embankments took place as they sank into the ground of liquefied sand. Sand boils were observed at various places of varying size and there were

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

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also reports of excessive settlements at different places. Such similar catastrophe was also observed after the Great Earthquake of 1950.

III. STUDIES ON LIQUEFACTION POTENTIAL OF GUWAHATI CITY

As Guwahati lies in Zone V, considering the seismic vulnerability a liquefaction potential study was firstly carried out by Raghukanth and Dash (2010) [16]. In their study, the liquefaction potential of Guwahati city was evaluated based on the two past earthquakes, which were 1869 Cachar Earthquake, 1950 Great Assam Earthquake and also a probable future earthquake which may occur after these decades of gap since 1950. A rectangular portion of Guwahati city was selected for study which covered a good stretch of the entire Guwahati city that was about 16 km by 9 km. The Standard Penetration Test (SPT) values of 100 borehole locations were than collected for the study. The Standard Penetration Test (SPT) is an in-situ test which is very useful in evaluating the geotechnical properties of soil. In the test a split spoon sampler is driven into the ground and is allowed to penetrate the soil by the impact of a hammer. The sampler is driven to penetrate to a depth of 450 mm and the number of blows of hammer that is required for the penetration of the last 300 mm is reported as the N-value which is essential for the determination of the liquefaction potential of a place. In their study, the N-value was measured at every 1.5 m interval. In most of the locations of study, the SPT was carried out up to a depth of 15 to 20 m excluding few locations where the depth was either exceeded or was less. From the bore log it was seen that the soil deposit mainly comprised of sand, silt and clay. Besides, majority of the reported SPT values were very low in the order of 20-30 barring few places where it was found to be higher in the order of 50-60. The location of majority of these boreholes were along the busy Guwahati-Shillong road or commonly known as G.S. road, near Chandmari, Bharalu and the Dispur-Downtown area.

In the study by Raghukanth and Dash (2010) [16], they used the Idriss and Boulanger method (2006) [10] which is an updated and better method for determining the liquefaction potential of a particular soil profile as compared to the semi-empirical method originally developed by Seed and Idriss (1971, 1982) [3][4]. They showed the liquefaction vulnerable zone of Guwahati city in the form of Factor of Safety (FOS) and Liquefaction Potential Index (LPI) contour maps. The Factor of Safety (FOS) is the ratio of the Cyclic Resistance Ratio and Cyclic Stress Ratio, which is evaluated as per Idriss and Boulanger method (2006) [10]. When FOS is less than 1, i.e. resistance is less than the stress developed liquefaction of soil is expected to occur.

The FOS is thus expressed as -

$$FS = CRR / (CSR)_{M = 7.5, \sigma = 1} \quad (1)$$

Also the CSR as referred above at any given depth z below the ground surface is given as –

$$CSR = 0.65 (a_{max} / g) (\gamma z r_d / \sigma'_v) \quad (2)$$

In the expression for CSR as given above, a_{max} is the peak horizontal ground acceleration; g for acceleration due to gravity; γ is the bulk nit weight of soil; σ'_v is the effective vertical overburden stress; and r_d stands for stress reduction co-efficient which accounts for the stability of the soil column. The CSR is calculated for an earthquake having a generalized moment magnitude M_w = 7.5 and the required correction for an earthquake of different magnitude is provided by the use of Magnitude Scaling Factor (MSF) [16].

Besides, this the Liquefaction Potential Index (LPI) as proposed by Iwasaki et al. (1982) [18] was also used to illustrate the liquefaction vulnerability which takes into account the effect of thickness and depth along with the FOS of the liquefiable layer. As per their evaluation they cited that the central part of the Guwahati city near Dispur, Chandmari and along the Guwahati-Shillong road were vulnerable to liquefaction. The reason of such highly vulnerability is due to large thickness of soft soil deposits and also shallow depth of the ground water table. It was clear from their contour maps [16] the above mentioned places had FOS and LPI values less than 1.

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

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After the evaluation by Raghukanth and Dash (2010) [16], it was Ayothiraman et al. (2012) [13] made another effort to evaluate the liquefaction potential of Guwahati city. In their evaluation they too studied 100 borehole data, which they collected from the Guwahati Metropolitan Development Authority (GMDA). The boreholes were scattered in an area of about 9 km by 7 km. They considered 0.36g as the peak ground acceleration for their evaluation. From the 100 borehole data studied 92 of them were classified as E-type and 7 belong to D-type and C-type as per IBC (2000) [7] shown in Table 1. Generally those which fall under E-type which has N-value less than 15 are prone to liquefaction after an earthquake.

TABLE 1
SITE CLASSIFICATION FOR SEISMIC PURPOSE AS PER IBC (2000)
(Here the N-value referred is after all the necessary correction)

Range of N	**Site Class**
N < 15	E
15 < N < 50	D
N > 50	C

From their study it was observed that the FOS in all the 100 boreholes tested was found to be less than 1indicating the vulnerability of the entire Guwahati city. It was further observed that the total thickness of soil upto a depth of 15 m is susceptible to liquefaction.

After Ayothiraman et al. (2012) [13], recently Sharma and Hazarika (2013) [2] have given another detailed evaluation on the liquefaction potential of Guwahati city. They also took help of the already developed semi-empirical relationship between the standard penetration test resistance and the cyclic stress ratio required to cause liquefaction by Seed and Idriss (1971, 1982) [3][4], Seed et al. (1983, 1985) [5][6] and Idriss and Boulanger (2004) [9].

In their study a soil database from 200 boreholes was used to determine the liquefaction potential of Guwahati city in terms of FOS. The boreholes were scattered over an area of 262 km^2. The liquefaction potential was then determined using the relations given by Seed et al. (1985) [6] and Idriss and Boulanger (2004) [9] and in the liquefaction potential map the areas to be vulnerable to liquefaction was clearly depicted. It was seen that as per Idriss and Boulanger (2004) [9] out of the 200 boreholes 49 of them are found to be susceptible to liquefaction while as per Seed et al. (1985) [6] 48 of them are found susceptible to liquefaction. As per their observation the southern bank of river Brahmaputra with the areas of Palashbari, Azara, Jalukbari, Pandu, Bharalumukh and Uzanbazar, some areas in G.S. road, Gorchuk and areas near Chandmari are found to be most susceptible to liquefaction. The northern bank of Guwahati city is also vulnerable to liquefaction. It can be further seen from the liquefaction potential map shown by them [2] that the area along the Lokhra-Lalganesh road which consists of stretches of low-lying swampy lands as well as the area along the by-pass for NH 37 and Dispur area are highly prone to liquefaction.

In all the above evaluations they were deterministic approach based on simple empirical and semi-empirical relations by Seed and Idriss (1971, 1982) [3] [4], Seed et al. (1983, 1985) [5] [6] and Idriss and Boulanger (2004) [9]. But though the deterministic approach is well accepted it had certain drawbacks as it was difficult to interpret FOS with traditional deterministic approach having certain uncertainties. Probabilistic and statistical approach rise above such uncertainties and recently this approach was experimented in the IIT Guwahati campus by Burman and Krishna (2013) [15] and probabilistic approach was found to be in good agreement with deterministic approach. In their study they tested the data from three boreholes for seismically induced liquefaction based on semi-empirical field procedures for three different magnitudes 5, 6 and 7 respectively. After their analysis all the three sites were found susceptible to liquefaction for the all three magnitudes and damages was expected to occur upto depths of 15-18 m. Some of the

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

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important probabilistic approaches were given by Christian and Swiger [12], Toprak [14], Halder and Tang [1], etc. This approach if applied for the entire Guwahati city will certainly help in better evaluation of liquefaction potential of this place.

IV. CONGRUENCIES IN THE ABOVE EVALUATION

The evaluations by Raghukanth and Dash (2010) [16], Ayothiraman et al. (2012) [13] and Sharma and Hazarika (2013) [2] all had the same base in their evaluations which were Seed and Idriss (1971, 1982) [3] [4], Seed et al. (1983, 1985) [5] [6] and Idriss and Boulanger (2004) [9].The CSR values were calculated pertaining to the equivalent uniform shear stresses generated by earthquake ground motions during an earthquake having a magnitude M based on In situ tests i.e. from SPT data available. The stress reduction coefficient r_d, which accounts for the flexibility of the soil column and magnitude scaling factor (MSF) required in the determination of CSR were based on relations given by Idriss (1999)[8] incorporates the primary features of behaviour identified by analytical and experimental studies. While the CRR values were based on Idriss and Boulanger (2004, 2006) [9] [10].

Besides it can be seen from the three evaluations that areas such as the Dispur area, some parts along the GS road, scattered places near Chandmari and Bharalumukh area were cited as highly vulnerable in all of them and it can be further seen from the FOS contour maps his places had FOS less than 1.

V. ANOMALIES IN THE ABOVE EVALUATIONS

In the evaluation by Ayothiraman et al. (2012) [13] the soil in Guwahati city was described as predominantly silty clay having fine content (60–100 %) out of which the silt is more than 70 %. Although the fine content is high, the city is susceptible to liquefaction, because of higher silt content soil. But as per the recent study by Sharma and Hazarika (2013) [2], they have found that the soil in Guwahati city is not predominantly silty clay, although in a number of locations silty clay soils were encountered. The silty clay soils were found to have classifications CL and CH and in some locations ML and ML-CL were encountered. The silts and silt–clay mixtures behave differently from sands, both with respect to development and build up of pore water pressures, and deformations under cyclic loading. Seed et al. (1983) [5] found that some soils with fines may be susceptible to liquefaction. As per the evaluation of Sharma and Hazarika (2013) [2] some boreholes studied were found to have fine grained deposits of cohesive soils upto the full depth of 30 m which were very much less susceptible to liquefaction which is also reflected in their evaluation where they have found only 25 % of the 200 selected boreholes as susceptible to liquefaction.

Another contrasting conclusion that was found after the three evaluations that as per the evaluation result of both Raghukanth ad Dash (2010) [16] and Ayothiraman et al. (2012) [13] FOS was found to be less than 1 in almost all the places under study which means almost entire Guwahati city is susceptible to liquefaction. But as per Sharma and Hazarika (2013) [2], FOS for most of the places in Guwahati city was found to be greater than 1 which according to them was non-liquefiable.

VI. AWAITED FURTHER STEPS

- In all the previous evaluations the CRR of the in-situ soil is primarily calculated based on empirical correlations given by Idriss and Boulanger (2004, 2006) [9][10] which were dependent on the SPT data. New evaluations based on proper cone penetration test (CPT) data can be utilized in order to cross-check the previous evaluation results which would help us to have a better knowledge of the liquefaction potential of entire Guwahati City. This initiative at first hand should be taken by the Guwahati Metropolitan Development Authority (GMDA) considering the hazards which Guwahati city may have to face in future occurrence of a high magnitude earthquake.

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

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- Use of probabilistic approach considering the study by Burman and Krishna (2013) [15] if applied for the Guwahati city would help in a better assessment of the liquefaction potential of the Guwahati city.

- The above analysis on the liquefaction potential of Guwahati city mostly had the influence of Seed and Idriss (1971) [3], Idriss (1999) [8] and Idriss and Boulanger (2006) [10] which adopted a simplified value of r_d where it was expressed as a function of depth and earthquake magnitude (M). But new studies has showed it is further influenced by the stiffness of a column being shaken (where the column is in relation to soil section) and severity and modal characteristics of shaking intensity besides depth and duration of shaking that existed before. So, it may have resulted in some amount biasness in determining the in-situ CSR in the above evaluations. So, further analysis is necessary based on latest recommendations for a more reliable assessment of the liquefaction potential of Guwahati city.

- The use of Shear-wave velocity (V_s) measurements can provide a promising alternative to the penetration measurements, which may be unreliable in some soils such as capped landfill which is predominantly common in the swampy lands of the Guwahati city or low lying areas which were filed for the purpose of new construction.

- Use of the shear wave vibrator method as proposed by Inazaki (2004) [17] which utilizes a shear-wave vibrator as a dynamic loading source and electrical cones to monitor the pore water pressure at specific horizons at distances under the vibration. The pore water pressure response at various depths and distances indicates the layered structure of near surfaces which strongly the controls the liquefaction phenomena.

- A proper soil profile map for entire Guwahati city has become necessary in order to promote future efficient studies and research on this field, which is now lacking. A Proper bore log data with boreholes at optimum spacing if possible of the entire Guwahati city can fulfill this demand which requires a good financial back-up. So schemes from Government of Assam are necessary in this regard.

VII. CONCLUSION

Guwahati being in one of the highest seismic zone of the world, evaluation of liquefaction potential is of utmost importance. This paper discusses the various evaluations regarding the liquefaction potential of Guwahati city which was carried out during the last few years. The evaluations had different conclusions, as per two evaluations almost entire Guwahati was found susceptible to liquefaction while as per another evaluation it is not so as only in 25 % of the tests it was found susceptible to liquefaction. Such anomalies need to be checked and a probabilistic analysis of the liquefaction potential of the entire Guwahati city would certainly help in that case.

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