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Evaluation of Vertical Ground Settlement due to Liquefaction

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Abstract: **Liquefaction is associated with a host of related phenomenon. Liquefaction driven settlements in sands is such a phenomenon. Liquefaction susceptible areas are prone to such settlements. The densification of loose sand deposits when acted upon by seismic loading is a well-established fact. However, the matter becomes critical when the sand deposit is saturated and there is no chance of drainage. Due to this phenomenon, excess pore water pressure builds up during the earthquake loading, leading to loss of strength or liquefaction. Settlement occurs after the release of excess pore water pressure, leading to a reconsolidation phenomenon. However, the settlement induced depends upon a lot of factors, like length of the drainage path, gradation, etc. However, in the case of dry sands, the seismic settlement is induced under constant effective vertical stress. In both the cases, for dry as well as saturated, settlement of sand occurs due to cyclic loading. In this paper an attempt is made to calculate the settlement of sands in liquefaction susceptible areas of Guwahati city.**

Index Terms – **earthquake loading, Guwahati city, liquefaction related settlement**

I. Introduction

The 1964 Niigata earthquake shows evidence of liquefaction induced settlement [1] causing widespread damages to existing structures like buildings and roads. Further, the utility structures are also damaged due to such settlements in that event in the entire city leading to the advent of studies related to liquefaction induced settlements. In 1953, Mogami and Kubo [8], identified soil behavior due to vibrations, and is considered as one of the earliest of research done in liquefaction. Extensive research on seismic induced settlements became popular in the early 1970s when Silver and Seed (1971) [14] performed studies on settlement calculation. Since then, various method of seismic settlement calculation started evolving. Studies by Tokimatsu and Seed 1987[19]; Ishihara and Yoshimine 1992[3]; Zhang et al. 2002[24]; Idriss and Boulanger 2008[2], etc. worth mention. The SPT-N value or the CPT represents the soil characteristics for the calculation of seismic settlement. Example of such studies are the work of Tokimatsu and Seed 1987[19]; Ishihara and Yoshimine 1992[3], Zhang et al. 2002; Idriss and Boulanger 2008[2] and Yi 2009[22]. Recent studies reveals that the Shear Wave Velocity could also be utilized in the evaluation of seismic induced settlements.

II. Seismic Settlement of Saturated Sands

As mentioned earlier, the studies based on the liquefaction induced settlements came to recognition in the early 1970s by the research works of Silver and Seed (1971)[14] and Lee and Albaisa (1974)[5]. However, there was a gap of almost 10 years, when the next research on liquefaction induced settlements took place by Tatsuoka et al., 1984[15]; Tokimatsu and Seed, 1987[19]. The methodologies involved the use of relationship between cyclic stress ratio, corrected SPT blow counts, and volumetric strain. The cyclic loading causing pore water pressure dissipation, studied by Lee and Albaisa (1974)[5], found a reconsolidation volumetric strain increase, directly proportional to grain size of soil and inversely proportional to relative density of the soil. Influence of the maximum shear strain developed and the relative density is substantial to the amount of settlement after studying the volumetric strain after initial liquefaction (pore pressure ratio= 100%), Tatsuoka et. al. (1984)[15]. Post liquefaction settlements is influenced by maximum shear strains developed, even with little change in maximum pore pressure development after liquefaction. A chart is developed by Tatsuoka, et al. (1984)[15], shows plots between relative density and volumetric strain after initial liquefaction, refer figure 1. The data points shown on the curves represents maximum shear strains and the plots of volumetric strains, relative density and $(N_1)_{60}$ by various researchers.

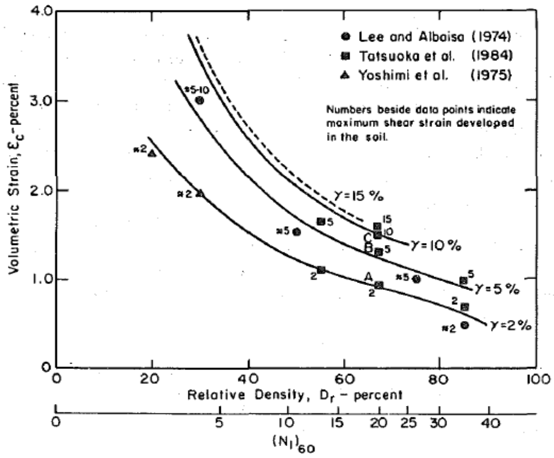

Figure 1. Volumetric Strain relationship with Induced Strain, and Relative Density for Sands, Tokimatsu and Seed, (1987)

The tests conducted by Yoshimi, et al. (1975)[20] is represented in the figure 1. All tests were conducted on different soil samples, but the results showed good consistency with one another. Significant increase in volumetric strain is observed with the decrease of relative density and induced strain from the above figure.

Cyclic stress ratio, τ_{av}/σ'_o where τ_{av}=the average induced cyclic stress and σ'_o=the effective overburden pressure at the initial stage, determines the liquefaction resistance of sands along with the stress history of the soils. But post liquefaction volumetric strain is large strain phenomenon, where the cyclic stress ration becomes less significant. Such phenomenon is only associated with the relative density as well as the maximum shear strain. If the density of the sand can be accurately measured, then figure 1 could show reasonable consistency for settlement of other sands due to liquefaction. Seismic activity induced shear strains is measured by Seed at. el. 1984, which shows shear strain for different combinations of normalized SPT N-value and cyclic shear stress ratio for an earthquake of Magnitude 7.5. Similarly, Tokimatsu and Yoshimi (1983)[17] are provided plots on the basis of Japanese standards. If compared with the effective hammer energy delivered by the US standards, the Japanese standard shows higher than the recorded. The limiting strain potential proposed by Seed (1979)[9] and the study by Tokimatsu and Yoshimi (1984)[18] gave consistent results when the difference in the energy ratios is considered.

The Tokimatsu and Seed (1987)[19] method of analysis of settlements of sands, subjected to seismic loading, analyzes previous studies related to settlements of sands, gives approach predicting settlements in saturated and dry sands by summarizing previous literature on settlement of sands.

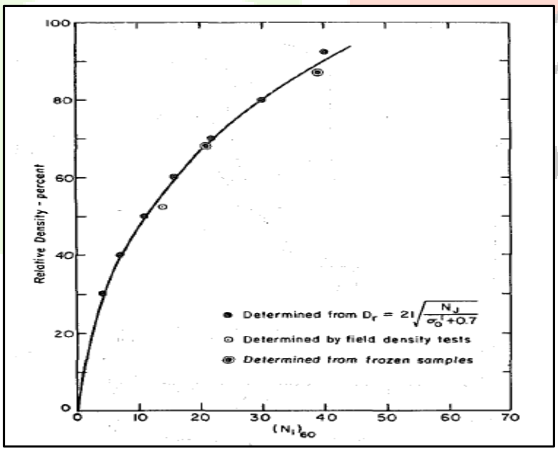

Figure 2. Relationship between Relative Density and $(N_1)_{60}$, Tokimatsu and Seed, (1987)

The above Figure 2 is obtained by recent studies on natural deposits of sand where the relative density obtained from in situ freezing soil samples Yoshimi 1984[20]; Yoshimi et. al. 1984[20]; Katayama, et al. 1984[4].

was obtained using undisturbed soil samples procured from in situ freezing samples by Yoshimi et. al. 1984[20] and Katayama, et al. 1984[4] which shows good agreement and are hence adopted in the present study. The relationship is different since it takes into the effect of aging on the SPT N-value of sands, given by Mitchell (1984)[7]. The Relative density expression by Mayerhof (1957)[6] shows good average relationships with the SPT N value as given by Tatsuoka, et al. 1978[15]; Tokimatsu and Yoshimi, 1983[18].

$$D_r = 21\sqrt{\frac{N_J}{\sigma'_o+0.7}} \qquad (1)$$

Where which N_J = SPT N-value measured by Japanese standards; and σ'_o= effective overburden pressure, in ksc.

III. CALCULATION OF VOLUMETRIC STRAIN

Figure 2 gives an approximate relationship between SPT N-values in $(N_1)_{60}$ and volumetric strain after liquefaction. Figure 3 and 4 depicts volumetric strain combinations vs $(N_1)_{60}$ for different stress combinations. The volumetric strains after liquefaction may be as high as 2-3% for loose to medium sands and even higher for very loose sands.

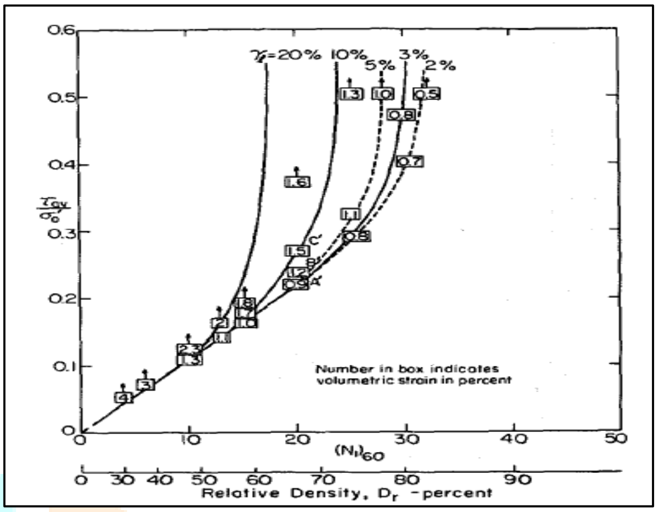

Figure 3. Cyclic Stress Ratio relationship with Volumetric Strain, and $(N_1)_{60}$, Tokimatsu and Seed, (1987)

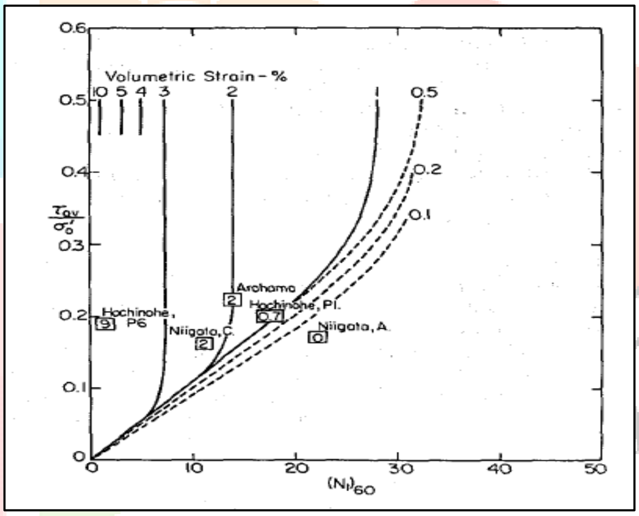

Figure 4. Cyclic Stress Ratio, $(N_1)_{60}$ relationship with Volumetric Strain for Saturated Clean Sands, Tokimatsu and Seed, (1987)

IV. LOCATION OF THE STUDY AREA

The present study is done across 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. After analyzing the liquefaction susceptibility of the soils of the borehole location are the seismic settlement is calculated on the basis of cyclic stress ratio and the $(N_1)_{60}$ value at that location. The number of boreholes locations used for conducting the study is 807. Intervals of 1.5 m depths are chosen for carrying out the study.

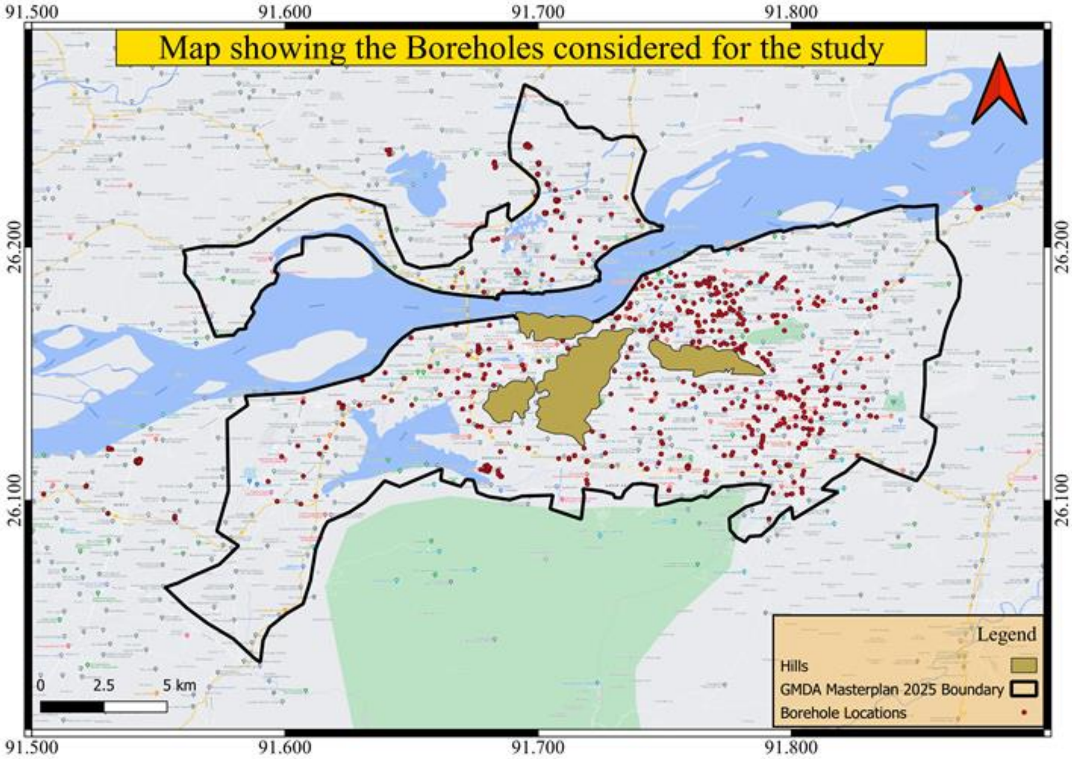

Figure 5. Map showing the borehole locations considered for the study

V. RESULTS AND DISCUSSIONS

Out of these 807 locations, 250 locations are found to have layers of sand where settlement could occur. The settlement is calculated on these 250 borehole locations and a map is prepared showing the amount of settlement based on the methodology presented above. The figure 3 and figure 4 is used to plot the $(N_1)_{60}$ value and the Cyclic shear stress in the respective graphs and the volumetric stain is calculated in the layer and the settlement is calculated by multiplying the depth of the layer of influence and the corresponding volumetric strain in that layer. The calculated results are plotted in a map and the settlements are shown. The highest settlement recorded in a particular borehole location is 385 mm. The map shows the total settlement of a particular borehole and not the amount of settlement at a particular depth in a borehole location. The maps are shown below.

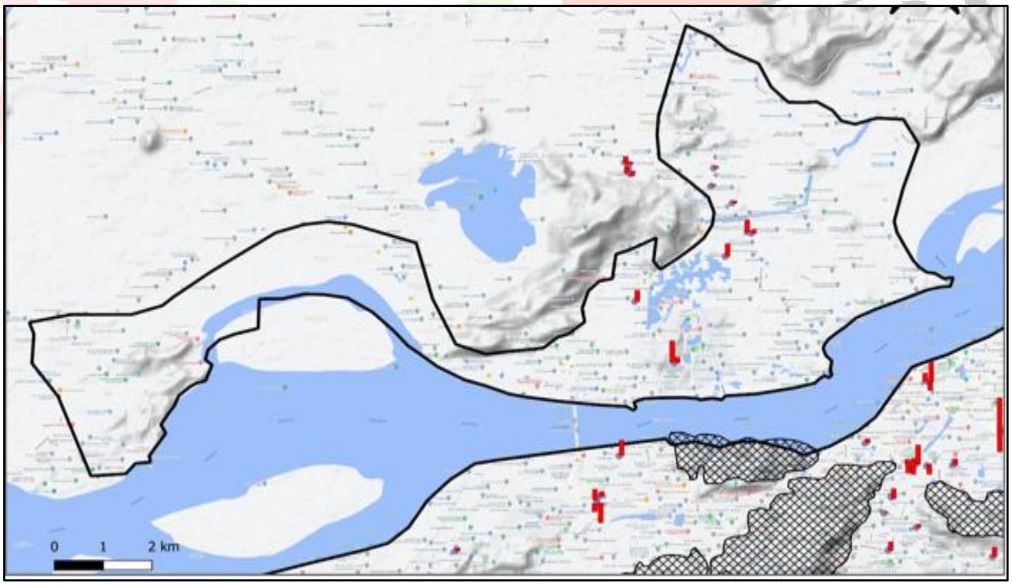

Figure 6. Map showing the amount of settlement of the locations of North Guwahati

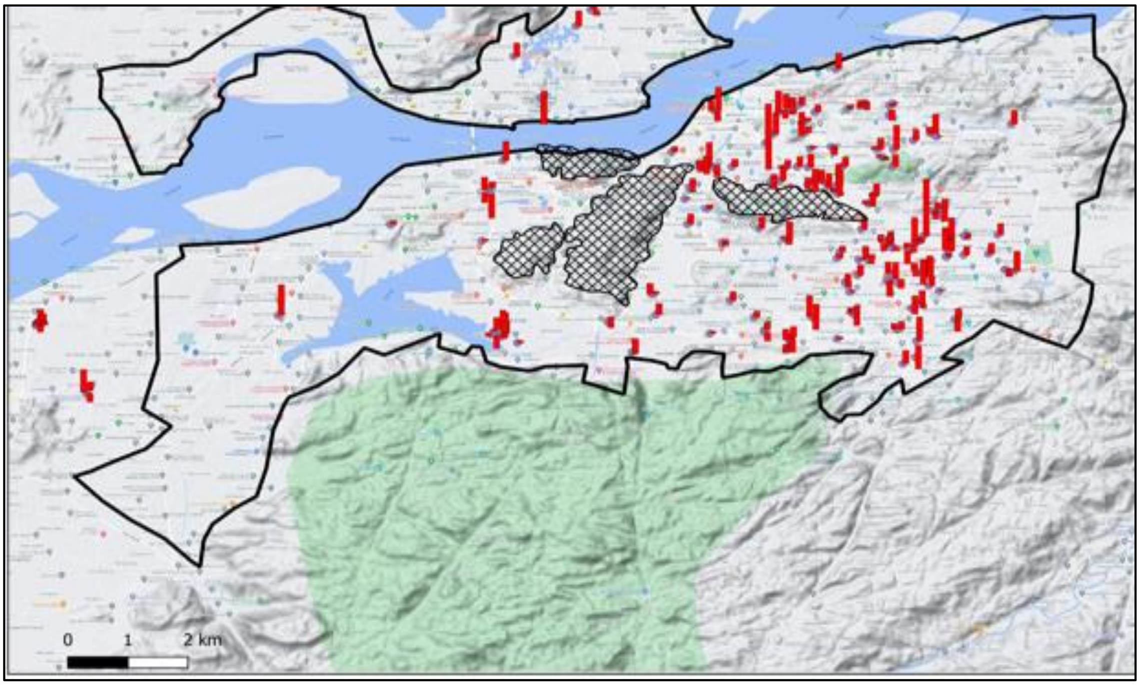

Figure 7. Map showing the amount of settlement of the locations of South Guwahati

The height of the red columns shown on both the maps indicates the magnitude of the settlement at that particular borehole location of the city. The column with more height indicates higher settlement and smaller height columns give smaller amount of settlement.

VI. CONCLUSIONS

The paper attempt to provide the locations where liquefaction induced settlements can occur, and in turn provide the total settlement in that location across all depths of the sand layer. It was found that the maximum settlement to be 385 mm in a particular location and as low as 1 mm in other locations. The average settlement in the sand layers is found to 63 mm.

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