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Research Article

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Liquefaction Hazards on the Western Bank of Jamuna River, Bangladesh

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Abstract Liquefaction can occur in sandy and silty saturated soils due to major earthquakes resulting in serious damages to infrastructures. In this research, liquefaction potential in some parts of the western bank of the river Jamuna has been calculated using corrected SPT (Standard Penetration Test) data using Liquefy pro, version 5 (2005) software at different earthquake magnitudes (M) like 7.5, 7.0, 6.5, 6.0, 5.5 and 5.0. During analyses, many parameters including CSR (Cyclic Stress Ratio), CRR (Cyclic Resistance Ratio) & F_s (Factor of Safety) are calculated at different locations with respect to depths. Shear stress ratio versus depth curves, factor of safety versus depth curves and settlement versus depth curves are produced to identify the potential zone of liquefaction. Most sand grains of the upper part of the investigated area lie within range of 0.05 mm. to 1 mm. and are highly potential to liquefy at very high magnitude of earthquake (M = 6 or greater). It is established that at earthquake magnitude, M =6 or above having maximum acceleration of 0.28 might causing liquefaction hazards up to a depth of 10 m. (SPT value varies from 1 to 18) below ground surface in the investigated area. Below this depth soil can be classified as non-liquefiable except at some depths where SPT values are low due to loose fabric & lithology. It is also observed that very loose nature of sandy soils, low SPT values, fine contents, uniformity of soil, pore water pressure, thickness of sand layer properties are very much consistent to the criteria of a liquefiable soil.

Keywords Liquefaction, Factor of safety, Jamuna, magnitude, CSR

Introduction

From historical seismic data and recent seismic activities for example earthquake and so on in Bangladesh and adjoining areas we can clearly understand that Bangladesh is in seismic risk. Bangladesh is one of the world's most densely populated countries and any future earthquake shall affect more people per unit area than other seismically active regions of the world. Liquefaction may occur when water saturated sandy soils are subjected to earthquake ground shaking. When soil liquefies, it loses strength and behave as a viscous liquid (like quick sand) rather than as a solid. This can cause building or engineering structure sink into the ground or tilts slope failures, nearly level ground to shift laterally tens of feet, surface subsidence, ground shaking and sand blows. The character of ground motion, soil type, and in situ stress conditions are the three primary factors controlling the development of cyclic mobility or liquefaction. According to Rao & Anubhav, (2001) [1] two conditions must exist for liquefaction to occur.

1) The soil must be loose, water saturated sandy soil typically located in between 0-30m depth.
2) Ground shaking must be strong to liquefy.

Numerous methods have been proposed for evaluating the liquefaction potential of soil deposits including in-situ and laboratory tests which can be divided into stress based, strain based and energy based methods. In-situ tests (the standard penetration test (SPT), the cone penetration test CPT), shear-wave velocity measurements (Vs), and the Becker penetration test (BPT)) can often be accepted to laboratory tests because of important advantages such as cost, time effectiveness, the ability of soil assessment in its natural environment and its possibility to estimate the spatial variability of deposits. A few researches have been conducted to estimate liquefaction possibilities at local levels in Bangladesh. Ansary and Rashid (2000) [2], generated liquefaction potential map for Dhaka city.

It has long been recognized that relatively "clean" sandy soils, with few fines, are potentially vulnerable to seismically induced liquefaction [3]. The floodplain deposit within the study area is characterized by Grey dense to very dense medium to fine sand trace mica at the bottom layer which is underlain by medium dense to dense silty fine sand trace mica and medium stiff to stiff clayey silt with fine sand are present at the top layer. Soil of Sirajganj area shows a consistency with Seed et al (2002) [3].

Study Area

The study area in lies between 89°40´to 89°46´ E longitudes and from 24°34´to 24°39´ N lattitude and is bounded by Kazipur Upazilza in north, Belkuchiupazila in south, Bangabandhu Multipurpose Bridge in east and Kamarkhondupazila in west. Total four boreholes were drilled among them three boreholes (BH-1, 2, 3) were drilled using light cable percussion drilling rig near to Simla-spur 2 and one borehole (BH-4) were drilled in Meghai with the technical assistance of "Delta Soil Engineers" to collect samples. SPT numbers were recorded in the log sheets to interpret the ground condition.

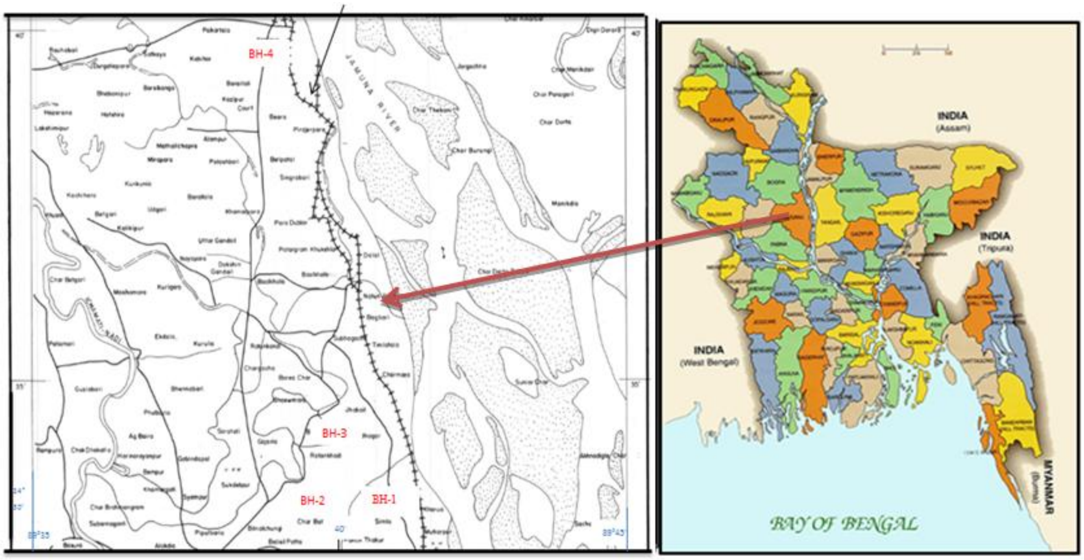

Figure 1: Location map of study area with location of Boreholes of Sirajganj district.

Materials &Methods

The geo-engineering and strength properties of soil were determined according to BS 1377 (1990) [4]. Liquefaction hazard potential has been estimated using corrected SPT data as obtained during Site investigation using Liquefypro, version 5 (2005) software. This sophisticated software is capable of calculating many parameters including CSR, CRR, Fs. Lithology can also be incorporated in the software and corresponding outputs in terms of graphical presentations can be made as an output. The average earthquake-induced cyclic shear stress is estimated either from the simplified empirical equation as given below according to Seed et al (1985) [5].

(1) Computing the cyclic stress ratio, CSR, which is related to the peak acceleration at ground surface during the design earthquake:

$CSR = \frac{\zeta av}{\partial o'}$ = 0.65(amax/g) (∂o/∂o') rd (according to Seed et al, 1985) [5].

where: ζav = average cyclic shear stress induced by design ground motion, ∂o = initial static effective overburden stress on sand layer under consideration, ∂o= initial total overburden stress on sand layer under consideration, a_{max}= peak horizontal acceleration in g's, rd = a stress reduction factor varying from a value of 1.0 at ground surface to a value of 0.9 at a depth of about 30 feet. If stresses and accelerations are computed directly in an amplification analysis, rd is ignored or set to 1.0.

(2) The empirical chart published by Seed et al. (1985) [5] is based on a standardized SPT blow counts, $(N_1)_{60,}$ and to get $(N_1)_{60,}$ measured N_{SPT} is corrected for the energy delivered by different hammer system and normalized with respect to overburden stress. American Naval Academy (MIL-HDBK-1007/3) [6] used Seed et al. (1985) [5] to calculate the CSR value. To get the converted SPT value, a conversion is required for overburden stress. Correction of SPT values: For SPT values, correct N for overburden by following equation using Figure 2.

N1 = CN × N, Where, N_1= Effective overburden stress tons/sq. ft., CN= Correction factor based on the effective overburden stress, N= Field SPT value, this is the value of N that would have been measured if the effective overburden stress had been 1.0 tons/sq. ft. Since N is also sensitive to the energy supplied by the equipment, N1 is further corrected to the value at 60 percent of the input energy, (N1)60. The combined correction is:

(N1)60 = CN ERm N/60, Where: ERm = corresponding energy ratio in percent, N/60= N1 is further corrected to the value at 60 percent of the input energy, (N1)60.

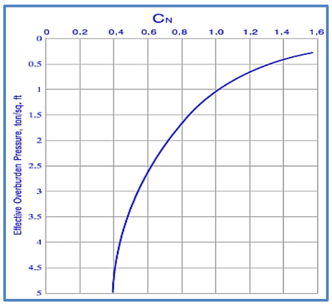

Figure 2: Correlation between CN and Effective Overburden Pressure

(3) Knowing the normalized blow count, (N1)60, from Figure 3 estimate the cyclic resistance ratio (CRR) required to cause liquefaction for clean sands under level ground conditions based on SPT values. Note that this curve applies for earthquake magnitudes 7.5.

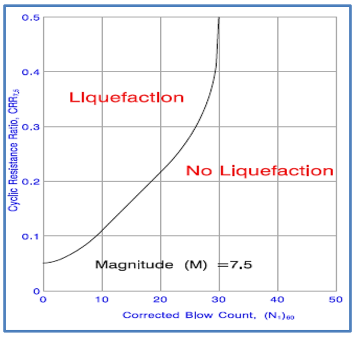

Figure 3 Cyclic Resistance Ratio (CRR) for Clean Sands Under Level Ground Conditions Based on SPT (After Robertson and Fear, 1996) [7].

(4) Correction for Different Earthquake Magnitudes

To adjust CRR to magnitudes other than 7.5, the calculated CRR7.5 is multiplied by the magnitude scaling factor for the particular magnitude required. The same magnitude scaling factors are used with cone penetration data as for standard penetration data. Figure 4 can be used for the correction of different earthquake magnitudes.

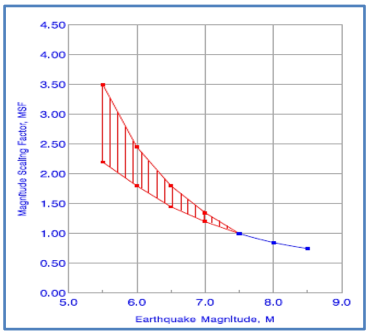

Figure 4: Range of Magnitude Scaling Factors for Correction of Earthquake Magnitudes

(5) Calculate the factor of safety (Fs) against liquefaction for each layer or for specific depth, to obtain an appropriate factor of safety compatible with the type of structure.

$$\mathrm{Fs} = \frac{\mathrm{CRR}}{\mathrm{CSR}}$$

Where: CRR = Cyclic resistance ratio required to cause liquefaction (obtained from figure 3 & 4), CSR = Cyclic stress ratio generated by the design earthquake, Fs= Factor of Safety.

Results and Discussion

Tsuchida (1970) [8] summarized the results of sieve analyses performed on a number of alluvial and diluvial soils that were known to have liquefied or not to have liquefied during earthquakes (Figure 5). The grain size distribution curve of sand samples (Figure 6) shows that all of the samples in Sirajganj area are lie within the range of 0.05 mm to 4mm and most of the samples are lie within 0.05 to 1mm range which grain size of soil directly indicate that the top soil of Sirajganj area are highly potential to liquefy at very high Magnitude of Earthquake (M ≥ 6) according to Tsuchida (1970) [8]. Liquefaction probability of soil of the study area was analyzed by Liquefypro, version 5, (2005) [9] software using SPT data with maximum acceleration 0.28g at different earthquake magnitude like 7.5, 7.0, 6.5, 6.0, 5.5 and 5.0 because in general earthquake below magnitude 5.0 (M=5) is not significant for any damages or losses and magnitude above 7 may results severe damage during earthquake.. According to BNBC (2012), investigated area Sirajganj is located in Seismic Zones 3 [10] having maximum acceleration (z) = 0.28. This value is used in any Liquefaction analysis. The intensity of earthquake indicated in this code belongs to earthquake with 2% probability of exceedance in 50 years. This means earthquake with 2500 years return period. The liquefaction analysis of the study area is carried out using Liquefypro, version 5, (2005) [9] software where four (4) boreholes are shown in Figure 7 to 22.

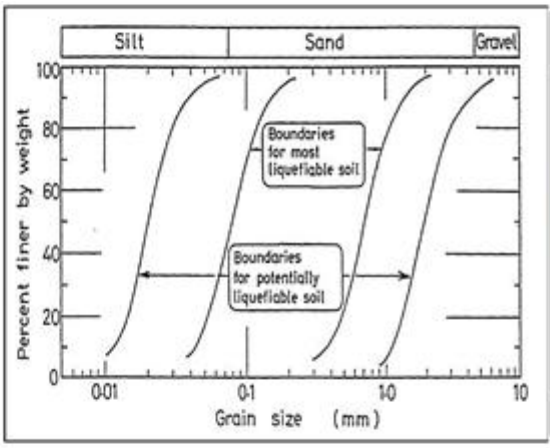

Figure 5: Limits in the gradation curves separating liquefiable and nonliquefiable soils [8]

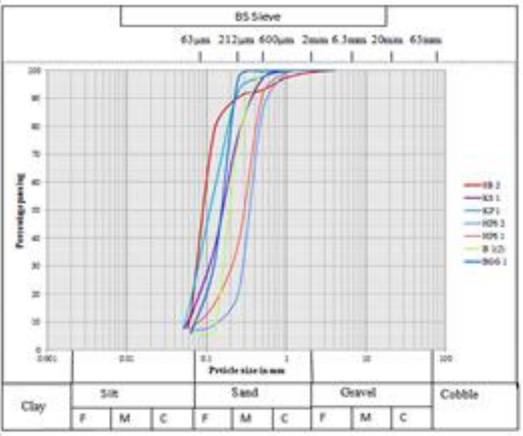

Figure 6: Grain size distribution curves of the analyzed sand samples of Srajganj

From analyzed results it is also established that at soils near to Simla Spur-2 are highly susceptible to liquefy from ground surface up to seven (7) meters depth below the ground (Figure 7) with earthquake magnitude M=7.5 and low SPT value, theoretically known as a liquefaction potential zone and shown by red shaded area in Figure 7. With Magnitudes 6 and 5.5 (Figures 8 & 9) soils are also susceptible to liquefy but in lesser extent than M = 7.5. Soils from the same area did not show any potential to liquefaction with M = 5 (Figure 10). Using borehole data (borehole 2), it is observed that soils near Balighugri (close to Simla) is vulnerable to liquefaction from 6 m up to greater depth (19 m) below ground with magnitude of 7.5 and 7.0 (Figure 11 & 12) showing Factor of Safety values are below 1.0. Settlement may also occur up to a depth of 27cm. With earthquake magnitudes 5.5 & 5.0 (M = 5, 5.5) soils are non-liquefiable (Figure 13 & 14). At Bahuka, a Factor of safety value <1.0 up to a depth of 10.5 m indicates liquefaction probability with earthquake magnitude 6 and above (Figures 15, 16 & 17). But at M = 5, soils are not liquefiable in this area. It is also understand that soils at Meghai area (Borehole 4) are highly potential to liquefy with M = 6 or above up to a depth of 10 m. (Figures 19, 20 & 21). The obtained Factor of Safety values below 1.0 indicate unstable ground condition with possibility of large settlement rate up to 50 cm. This area is also vulnerable to liquefaction up to 7.0 m depth with earthquake magnitudes M = 5.0 (Figure 22). Again an attempt has been made to draw a vertical distribution of soil liquefaction zone in study area by using four boreholes data for earthquake magnitudes 7.5, 6.0 and 5.0 It is established that from ground surface up to 10 m depth soils are more vulnerable for liquefaction with magnitude M = 7.5 shown in red shaded zone in Figure 23. This depth is also vulnerable with magnitude 6.0 at Simla, Bahuka and Meghai area from ground surface up to 8 m depth (Figure 24). At Bahuka and Meghai areas (Figure 25) even with M = 5, some degrees of liquefaction potentials are encountered which can be justified by its very loose lithology and SPT values. Below this depth (up to 18 m) with magnitude 7 and above shows few criteria of liquefaction as shown by pink shaded zone in Figure 23. With earthquake magnitude 6 or below the area can be considered as non-liquefiable zone and marked by green shaded zone below 10 m depth except in some areas because of very loose nature of sandy soils.

Seed et al. (2002) [3] stated that, well-graded soils have lesser void ratios than uniformly-graded or gap-graded soils, and so require lesser fines contents to fill the remaining available void space and thus separate (or "float") the coarser particles in a matrix of the fines. From grain size analysis and from the value of D_{10}, D_{30} and D_{60} we observed that soils of our investigated area are mainly uniformly graded soil. From bore log sheets it is also observed that in case of most of the boreholes loose silty sand or clayey silt covers 1.5-2.0 m depth form surface layer and below this depth highly liquefiable loose fine sand covers up to 8 m depth.

Pore Water Pressure in each depth was also calculated using Empirical Formula. A pore water pressure ranges from 15000 N/m³ to 90000 N/m³ for 1.5 m to 10.5 m depth below ground surface is encountered for these soils. The effects of pore pressure generation consist of strength reduction/degradation as a result of seismic-induced shear stress and strain and post-seismic settlement as a result of pore pressure dissipation which is also a criterion of liquefaction hazard . Marcuson et al, (1990) [11] suggested an SPT value of [(N1)60] less than 30 as the threshold to use for suspecting liquefaction potential. From SPT record of bore log sheets it is clearly established that most of the SPT values up to 10-15 m depth below ground surface is less than 30 except somewhere lithology is denser. Our field SPT values are also consistent with Marcuson et al, (1990) [11] for liquefiable soils. From empirical formula we found CSR value 0.364 and software calculates a range of CSR value from 0.18 to 0.35 with earthquake magnitude 7.5 (M = 7.5). In most of the cases liquefaction occurs with CSR value 0.28 to 0.35 but at a very low CSR value 0.18 is also responsible for triggering soil liquefaction.

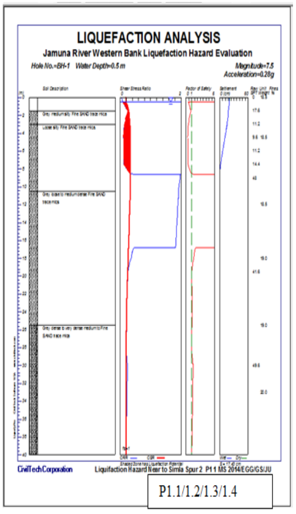

Figure 7: Liquefaction analysis of BH-1 with M=7.5

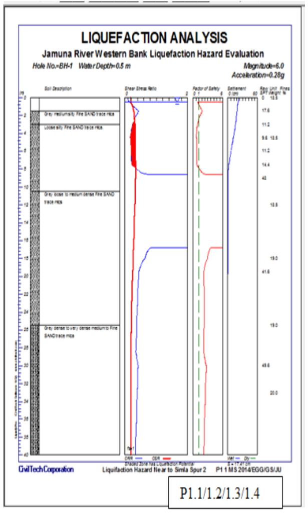

Figure 8: Liquefaction analysis of BH-1 with M=6.0

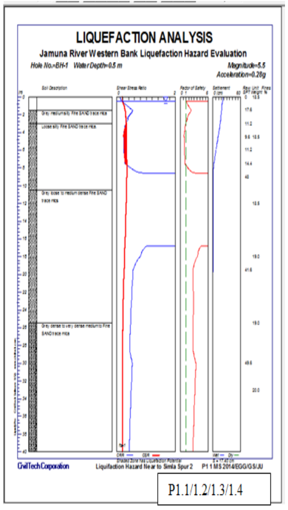

Figure 9: Liquefaction analysis of BH-1 with M=5.5

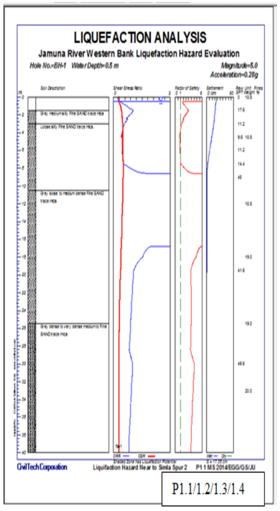

Figure 10: Liquefaction analysis of BH-1

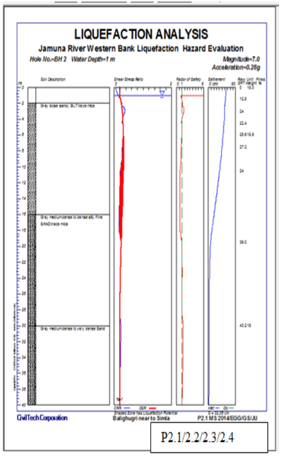

Figure 11: Liquefaction analysis of BH-2 with M=7.5

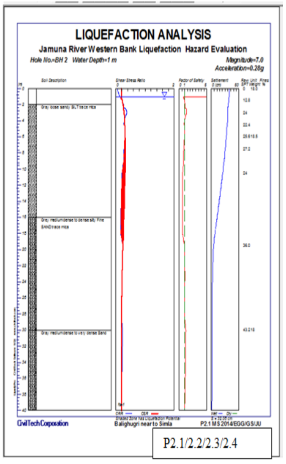

Figure 12: Liquefaction analysis of BH-2 with M=7.0

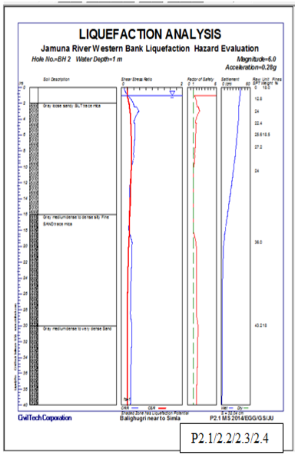

Figure 13: Liquefaction analysis of BH-2 with M=5.5

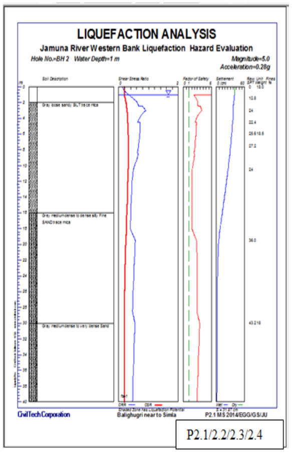

Figure 14: Liquefaction analysis of BH-2 with M=5.0

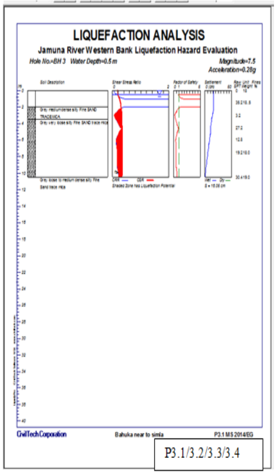

Figure 15: Liquefaction analysis of BH-3

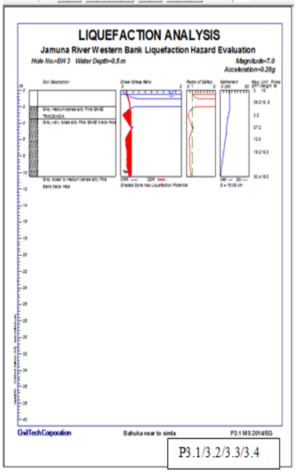

Figure 16: Liquefaction analysis of BH-3

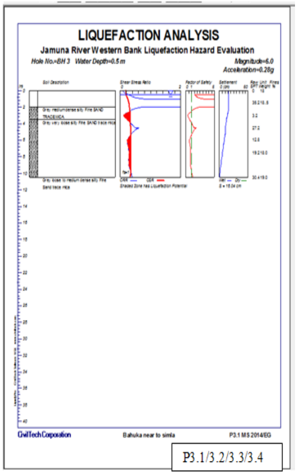

Figure 17: Liquefaction analysis of BH-3 with M=6.0

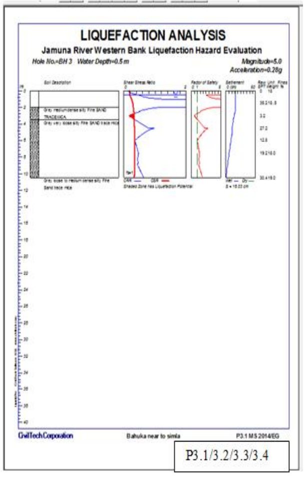

Figure 18: Liquefaction analysis of BH-3

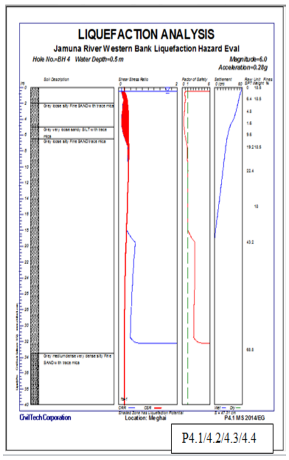

Figure 19: Liquefaction analysis of BH-4

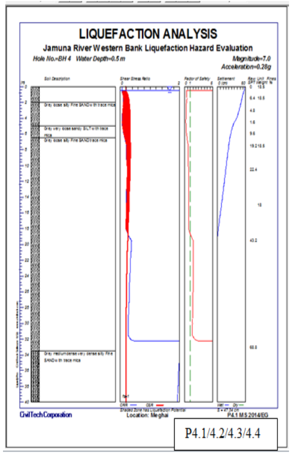

Figure 20: Liquefaction analysis of BH-4 with M=7.0

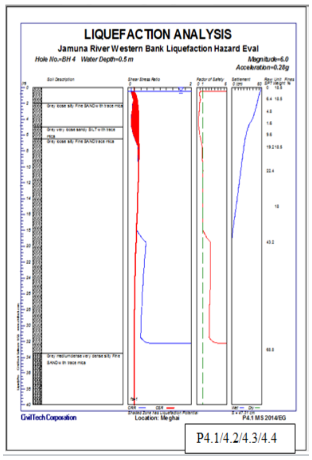

Figure 21: Liquefaction analysis of BH-4 with M=6.0

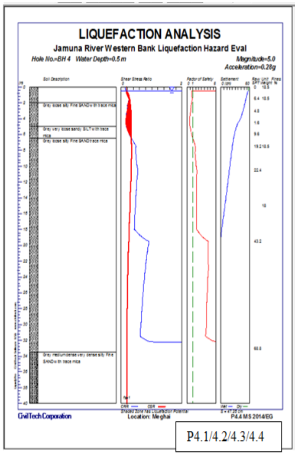

Figure 22: Liquefaction analysis of BH-4 with M=5

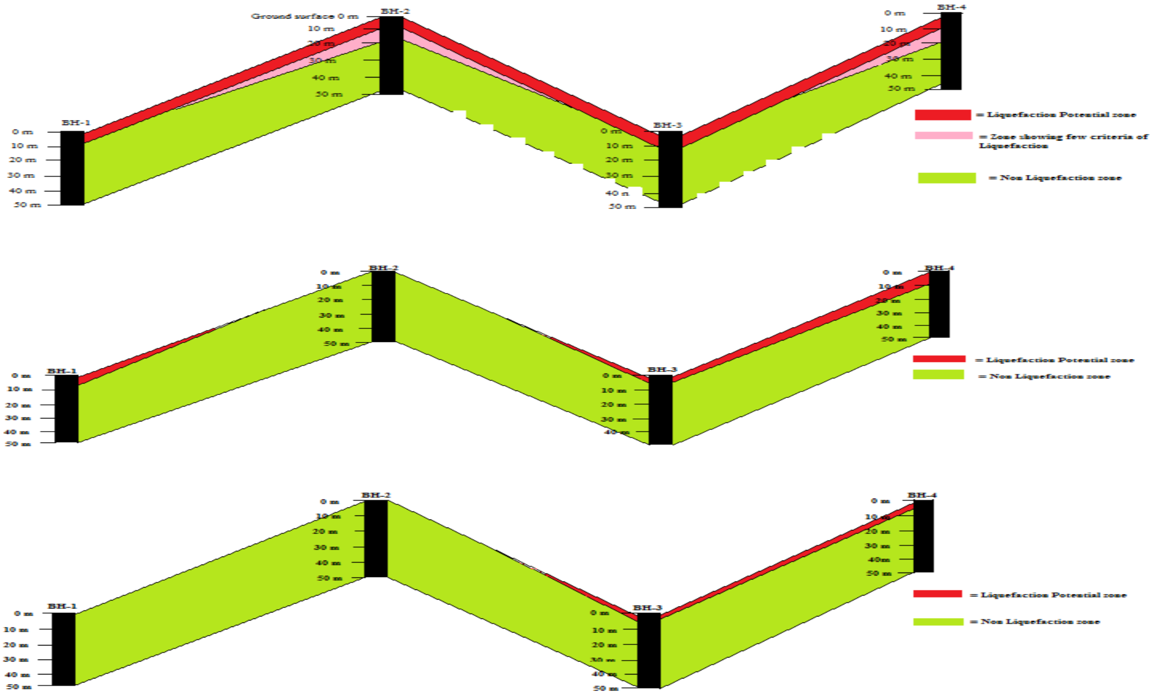

Figure 23: Vertical distribution of the potential soil liquefaction hazard zone with earthquake magnitude 7.5 (M=7.5).

Conclusion

From these analyses it is established that soils of the investigated area are highly liquefiable with earthquake magnitude 6 to 7.5 or above and a factor of safety of less than one (Fs< 1.0). Very low CSR value is sometime responsible for liquefaction at shallow depths. Very loose sand, low SPT values, fine contents, uniformity of soil, pore water pressure, thickness of sand layer of study area etc. are very much consistent to the criteria of a liquefiable soil. If this type of soil occurs in region with higher seismic activity zone (earthquake magnitude more than 7), the soil can be categorized as highly liquefiable up to certain depth which is reflected in the present study.

From the overall observations it is also established that up to 10 m depth below the ground surface in the investigated area is categorized by liquefaction potential zone. Earthquake magnitude 6.0 and above 7 (having maximum acceleration 0.28) might causes liquefaction hazards in the investigated area, Below this zone at greater depth (≥ 10 m.) a non-liquefiable zone is also identified. River bank erosion might also occur in this area due to this liquefaction hazard. It is also clearly observed that dense sandy soils below 10 m depth are safe and non-liquefiable.

In this research, the probability of liquefaction is presented for some certain depths, from shallow to deep, on software analysis results. So, one can get information about the risk level for a definite construction site for his desired foundation depth or one can choose suitable, out of risk site location for engineering construction. A layer of fine sand with sufficient thickness is present below the top clay layer in Sirajganj area which is identified as liquefaction potential zone with an earthquake magnitude above 5.5 (M >5.5). This liquefaction hazard can be minimized by using some ground improvement technique to protect the slope from erosion. The main goal of most soil improvement techniques used for reducing liquefaction hazards is to avoid large increases in pore water pressure during earthquake shaking. This can be achieved by densification of the soil and/or improvement of its drainage capacity. Some ground improvement techniques for reducing liquefaction hazards viz. vibroflotation, Dynamic compaction, compaction piles, Compaction grouting, Drainage techniques can be considered in this case. Liquefaction hazards are evaluated by using limited borehole data in and around

Sirajganj district. A detail liquefaction study from Sirajganj to Rangpur is strongly recommended to interpret the ground condition due to liquefaction.

Acknowledgement

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