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Study the Significance and Possibilities of Liquefaction in Dhaka City and Proposed Some Remedies to Liquefaction Induced Soil

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Abstract: *Population of Dhaka city is increasing day by day as it is the center of i.e. capital of Bangladesh. With the increasing population the demand of residence is also increasing which leads to construction of new apartment and houses. Though the soil of Dhaka city is quite good to sustain any hazards like earthquake but with the passage of time the soil layer has been disturbed a great length which makes it vulnerable. So the risk of any hazards should be checked with cautious in case of original soil and reclaimed soil. This study will help to understand the soil condition and its vulnerability to liquefaction due to earthquake loading.*

Keywords: *liquefaction, earthquake, site investigation, soil improvement, Dhaka soil*

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I. INTRODUCTION

Soil liquefaction has been a frequently observed disaster phenomenon, which can cause lateral spreading, settlement and sand boils, and then brings extensive damages to buildings and infrastructures during many earthquakes. Soil liquefaction occurs due to large earthquakes and it is also termed as a ground failure (for flow liquefaction) and sometimes it is termed as lateral spreading (cyclic mobility) [1]. Generally, soil liquefaction occurs due to less strength of soil. If a saturated sand is subjected to ground vibrations, it tends to compact and decrease in volume; if drainage is unable to occur, the tendency to decrease in volume results in an increase in pore water pressure. If the pore water pressure builds up to the point at which it is equal to the overburden pressure, the effective stress becomes zero. At this condition, the sand loses its strength completely and it develops a liquefied state. [2]. Several case histories, field and laboratory studies revealed that silty sands are also prone to liquefaction [3,4]. It is seen that the soil texture observed in Dhaka is most likely to susceptible to liquefaction. So on the basis of seismological and geotechnical characteristics; it is necessary to assess liquefaction susceptibility at Dhaka city. The objective of this study is to:

1. Understanding soil liquefaction.
2. Understand the soil condition of Dhaka city.
2. Assess the possibility of liquefaction due to earthquake in Dhaka city.
3. Suggest some most suitable ground improvement technique to mitigate soil liquefaction.

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II. SOIL LIQUEFACTION:

2.1 Mechanism of soil liquefaction:

Figure 1 represents a section of ground having a sand layer of depth z from ground level (GL) where ground water table. (GWT) lies at a depth h_w from ground level where the unit weight of sand is γ and γ_{sub} are saturated unit weight of sand. The shear strength of sand is primarily due to internal friction (cohesion, c = 0). In the saturated state it may be expressed as follows:

$$\sigma = \sigma'_n \tan \phi \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where,
σ= Shear strength.
σ'_n = Effective normal pressure on any plane.
ϕ = Angle of internal friction

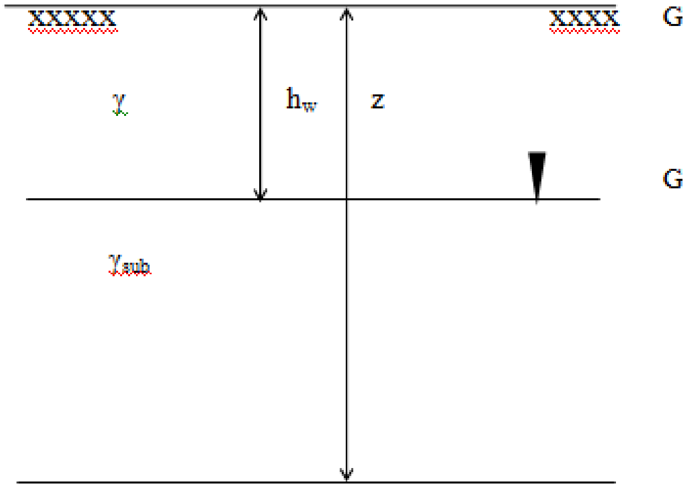


Figure 1: Section of ground showing the position of ground water table.

Due to ground vibrations, saturated sand tends to compact in volume. As the earthquake load acts suddenly for a very short period of time the pore water pressure cannot be dissipated as a result it becomes in undrained condition. The shear strength of sand can be expressed as:

$\sigma_{dyn} = (\sigma'_n - u_{dyn}) \tan \phi_{dyn}$……………….. (2)

Where,
σ_{dyn} = Shear strength of soil under vibrations.
u_{dyn} = Excess pore water pressure due to ground vibrations.
ϕ_{dyn} = Angle of internal friction under dynamic condition.

It is seen that with the development of additional positive pore water pressure, the strength of sand is reduced. In sands, ϕ_{dyn} is almost equal to ϕ, i.e. angle of internal friction in static condition.
For complete loss of strength, i.e. σ_{dyn} is zero.

Thus, $\sigma'_n - u_{dyn} = 0$
Or, $\sigma_n = u_{dyn}$
Or, $u_{dyn} / \sigma'_n = 1$

It is seen that due to increase in pore water pressure the effective stress reduces, resulting in loss of strength. Intergranular stress gets transferred from soil grains to pore water. When this transfer is complete, there is a complete loss of strength, resulting in what is known as complete liquefaction. In the case of complete liquefaction, the effective stress is lost and the sand – water mixture behaves like a viscous material and process of consolidation start, followed by surface settlement, resulting in closer packing of sand grains. Thus the structures resting on such the material start sinking. The rate of sinking of structures depends upon the time for which the sand remains in the liquefied state. Liquefaction may develop in any zone of a deposit, where the necessary combination in situ density, surcharge conditions, and vibration characteristics occur.

Thus, an important feature of the phenomenon of liquefaction is the fact that, its onset in one zone of deposit may lead to liquefaction of other zones, which would have remained stable otherwise.

2.2 Soil liquefaction during an earthquake:

The pressures generated during large earthquakes with many cycles of shaking can cause the liquefied sand and excess water to force its way to the ground surface from several meters below the ground. This is often observed as "sand boils" also called "sand blows" or "sand volcanoes" (as they appear to form small volcanic craters) at the ground surface. The phenomenon may incorporate both flow of already liquefied sand from a layer below ground, and a quicksand effect whereby the upward flow of water initiates liquefaction in overlying non-liquefied sandy deposits due to buoyancy.

The other common observation is land instability – cracking and movement of the ground downslope or towards unsupported margins of rivers, streams, or the coast. The failure of ground in this manner is called 'lateral spreading' and may occur on very shallow slopes of angles of only 1 or 2 degrees from the horizontal.
Soil liquefaction induced by earthquake shaking is also a major contributor to urban seismic risk.

2.3 Types of soil failure in liquefaction:

There are three basic types of ground failure that commonly result from liquefaction. They are as follows:

1. Flow Failures:

Very large scale landslides can be referred as flow failures occur in sloping areas, inclined at 5 percent or greater. The most damaging type of ground failure caused by liquefaction is flow failure. Example: Liquefaction failure of Sheffield Dam (Santa Barbara Earthquake, 1925)

2. Lateral Spreading:

The most common type of ground failure occurred by liquefaction is lateral spreading. As a result of liquefaction in underline layers, there is a lateral displacement of a large box of intact, surficial soil. Lateral spreading generally develops on a 3 degrees flat gentle slopes and move toward a free phase. Example: Lateral spreading of very flat ground toward the Motagua River (Guatemala Earthquake, 1976)

3. Ground Oscillation:

By decoupling of overlying soil blocks, liquefaction at the depth may create separation at the surface. When the ground is too flat to permit lateral movement, it allows the blocks to jostle back and forth on the liquefied layer.

2.4 Factors affecting liquefaction susceptibility of soil:

The composition of the soil mass:

Coarse grained soils mainly sand are most prone to liquefaction. Liquefaction of nonplastic silts has been observed [5] indicating that plasticity of soil rather than grain size alone influenced the liquefaction susceptibility in the case of fine- grained soils. Soil satisfying each of the following four Chinese criteria [6] may be considered susceptible to liquefaction:

Fraction of soil particles finer than 0.005mm ≤ 15 %
Liquid limit, LL ≤ 35 %
Natural water content ≥ 0.9 Liquid limit
Liquidity index ≤ 0.75

Grain-Size Distribution and Soil Types:

Friction between particles mobilizes the resistance to deformation of the type of soil most susceptible to liquefaction. The frictional resistance of the cohesion less soil decreases as the grain size of soil becomes smaller if other factors such as grain shape, uniformity coefficient, and relative density are equal. The uniformly graded soil is more susceptible to liquefaction than well-graded soil.

Relative Density:

The most important factors controlling liquefaction for a given soil are the initial void ratio or relative density. Liquefaction occurs principally in the silty sand and saturated clean sand heaving a relative density less than 50 percent.

Earthquake Loading Characteristics:

The magnitude and number of cycles of stresses or strains induced in it by earthquake shaking controls the vulnerability of any cohesion less soil to liquefaction. Duration of ground shaking, predominant frequency and intensity are related to it.

Vertical Effective Stress and Over-consolidation ratio:

Since an increase in the effective vertical stress increases the bearing capacity and shear strength of soil, thereby increases the shear stress required to cause liquefaction thus decreases the potential for liquefaction. Saturated sands located deeper than 50 to 60 ft. are not likely to liquefy.

Age and Origin of the Soils:

Generally, soil grains in the state of loose packing are present in natural deposition and fluvial origin. Due to cementation and aging these deposits are young, weak and free from added strength.

Seismic Strain History:

Prior seismic strain history can significantly affect the resistance of soils to liquefaction; Series of previous shaking producing low levels of excess pore pressure can significantly increase soil resistance to pore pressure build-up during subsequent cyclic loading is a result of low levels of prior seismic strain history. Large pore pressure generation and conditions of full liquefaction can develop weak zone in the soil due to uneven densification and redistribution of water content [7]

The degree of Saturation:

In dry soils, liquefaction does not occur. Partially saturated sands are little susceptible to liquefaction. The sand samples with a low degree of saturation can become liquefied only under the severe and long duration of earthquake shaking which shows liquefaction resistance for soil increases with decreasing degree of saturation [8].

The thickness of Sand Layer:

The liquefied soil layer must be thick enough so that the resulting uplift pressure and the amount of water expelled from the liquefied layer can result in ground ruptures such as sand boiling and fissuring, in order to induce extensive damage at the level ground surface from liquefaction.

Previous Strain History:

Some strain history reveals are subjected by previously similar deposits which are studied on liquefaction characteristics of freshly deposited sand, the strain history reveal is though the prior strain history caused no significant change in the density of the sand, it increased the stress that causes liquefaction by a factor of 1.5.

III. SOIL CONDITION OF DHAKA CITY

3.1 Analysis of liquefaction map in Dhaka:

It can be seen that Madhupur clay formed terraces and inliers in and around Dhaka, although most part of Dhaka is covered by an old natural levee, flood plain and gully fill, active natural levee, abandoned channel, depressions, and other channels.

The study area (Dhaka) is located between the Megna and Brahmaputra Flood Plains [9]. The soil deposits mainly consist of the following types of soil.

Alluvial Silt and Clay: Medium to dark gray silt to clay; and organic-rich clay in sag ponds and large depressions. Some depressions contain peat. Large areas underlain by this unit remain dry only a few months of the year; the deeper part of the depressions and bils contain water throughout the year.

Madhupur Clay Residuum: Light yellowish grey, orange, light to brick red and greyish white, micaceous silty clay to sandy clay; sand fraction dominantly quartz, minor feldspar, and mica. **Marsh Clay and Peat:** gray or bluish-gray clay, black herbaceous peat, and yellowish gray silt. Alternating beds of peat and peaty clay is common in bils and large structurally controlled depressions; peat is thickest in the deeper parts.

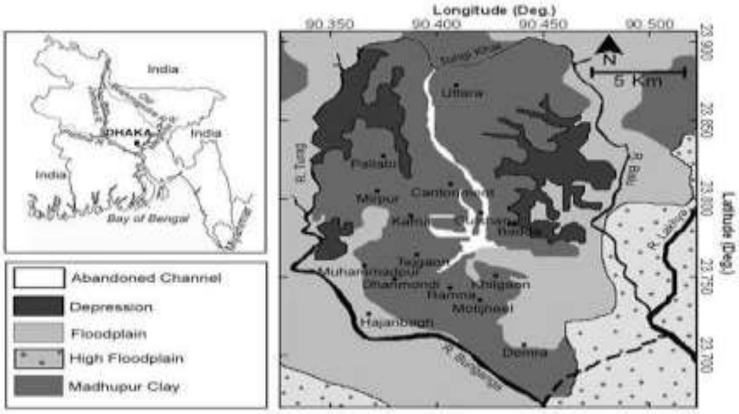


Figure 2: Soil condition of Dhaka city.

The general soil condition of Bangladesh can be clearly visualized by the following figure.

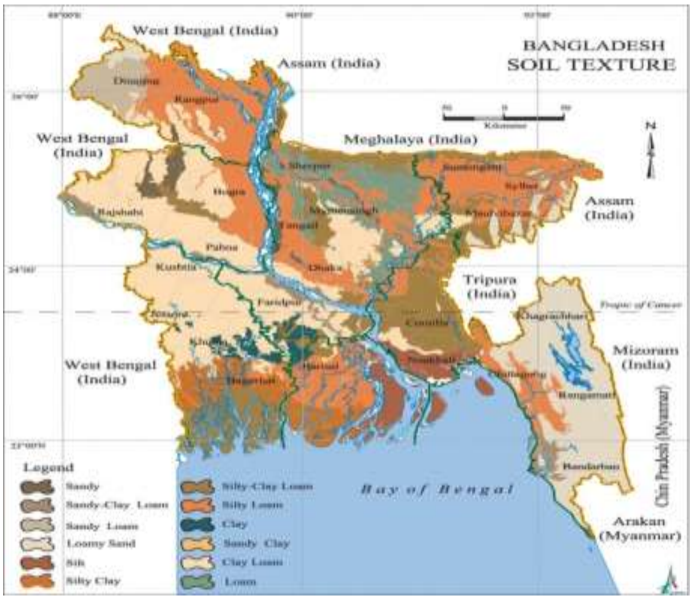


Figure 3: Soil texture of Dhaka City.

Criteria for the liquefaction potential of different zones, is presented in Table 1, in accordance with the past liquefaction behavior of such zones, and with the levels and aerial extent of the causal ground motions.

Table 1: Microzonation procedure based on topographical information

Topography	**Liquefaction Potential**
Present river bed, Old river bed, Swamp, Reclaimed land, Interdune lowland, Fan, Natural levee, Sand dune, Floodplain, Beach, other plains	Liquefiable
Terrace, Hill, Mountain	Non-liquefiable

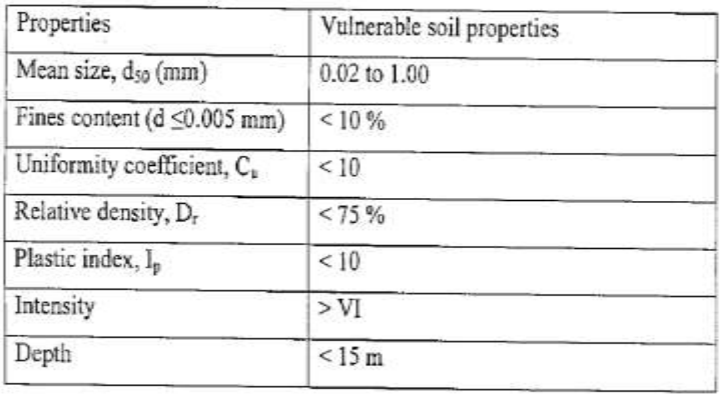
IV. ASSES THE POSSIBILITY OF LIQUEFACTION IN DHAKA CITY:

4.1 Assessing the probability of liquefaction of some areas of Dhaka city:

According to Seed and Idriss (1983) outlined criteria, derived from case histories in China (Wang, 1979), which provided a basis for partitioning clayey soils vulnerable to sever strength loss as a result of earthquake shaking. Seed et at (1983) evaluated liquefaction potential using field test data. The clayey soils vulnerable to sever strength loss appeared to have the following characteristics:

Clay content (defined as % finer than 0.005 mm):	< 15 %
Liquid limit (LL, liquid limit):	<35 %
Water content (Wn):	> 0.9 LL

As a general guide, the characteristics of liquefiable soils are presented in figure. The liquefaction susceptibility can be estimated based on the soil properties given in Table 2.7 by comparing existing soil properties.



Properties	Vulnerable soil properties
Mean size, d_{50} (mm)	0.02 to 1.00
Fines content (d ≤0.005 mm)	< 10 %
Uniformity coefficient, C_u	< 10
Relative density, D_r	< 75 %
Plastic index, I_p	< 10
Intensity	> VI
Depth	< 15 m

Fig: Properties of vulnerable soil (Rao, 2003)

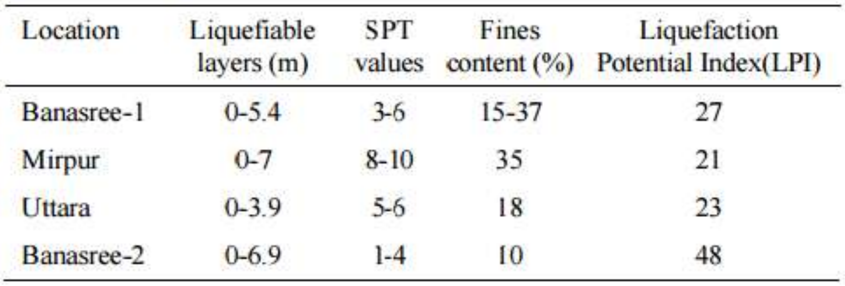
Hossain et aI. (2003) evaluated sub-soil characteristics and liquefaction potential of Mirpur DOHS area. To characterize soil deposit eight bore holes were drilled at the project site. Moisture content, specific gravity, Atterberg limits, grain size distribution, unconfined compressive strength, density and shear strength parameters of the collected samples were determined in the laboratory. It was observed that geotechnical properties of the soil in the study area varied with depth and location. It was observed that loose soil exits from 4.7 to 14.0 m depth below existing ground level (EGL). From the study, the possibility of the liquefaction was found to be zero. However, more detailed study have been conducted in these study of these area based on these data and other data collected from different agencies

A detailed understanding of site conditions, the soil stratification, dynamic soil properties, their variability, and the areal extension of potential critical layers should be developed. Simplified field tests like CPT, shear wave velocity test, SPT etc. are widely used in practice to characterize the soil stratum to obtain cyclic resistance ratio (CRR). Corrections of the data should be applied as necessary, e.g. the normalized SPT blow counts $[(N1)_{60}]$ or the normalized CPT value. Designed earthquake should be calculated by multiplying CRR value with earthquake magnitude scaling factor (MSF).Calculation of the stress for the liquefaction of critical zones is necessary, depending on the characteristics of the critical zone(s) (e.g., normalized standardized blow count, fine content, overburden stresses, the level of saturation).Mainly to cyclic stress ratio (CSR) or $\tau av / \sigma_{v0}'$ where τ_{av} means developed shear stress during earthquake and τ_h, the shear stress required to cause liquefaction. For each liquefaction susceptible critical layer, computation of the factor of safety against liquefaction is to be done.

The maximum ground surface acceleration is considered from the historic earthquake. The peak ground surface acceleration value for a 200 year return period for Dhaka is around 0.15g. The average liquefaction potential index of different locations of Dhaka city varies from 0.11 to 8.71.

We know that a soil layer is said to liquefiable if the liquefaction potential index, IL≥1.0. The liquefaction potential index for non-liquefiable layers varies from 0.11 to 0.94 and for liquefiable layers 1.0 to 8.71.

Liquefaction Potential Index (LPI) calculated according to the procedures proposed by (Sonmez,2003) [11]. Liquefaction susceptibility has been categorized as non-liquefiable for LPI = 0; low for 0<LPI≤5; high for 5<LPI≤15 and very high for LPI>15.

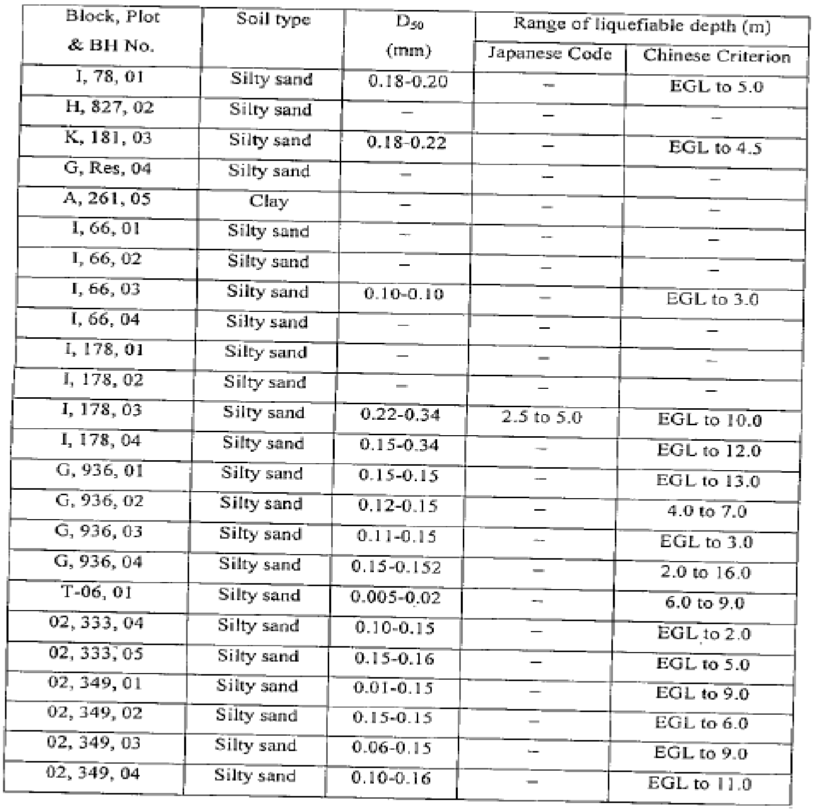


Location	Liquefiable layers (m)	SPT values	Fines content (%)	Liquefaction Potential Index(LPI)
Banasree-1	0-5.4	3-6	15-37	27
Mirpur	0-7	8-10	35	21
Uttara	0-3.9	5-6	18	23
Banasree-2	0-6.9	1-4	10	48

Figure 4: Liquefaction potential index at different locations. [12]

According to these criteria, the soils in some residential areas of Dhaka city are characterized as high to very high susceptibility to liquefaction as shown in figure due to an earthquake of moment magnitude of 7.5. Among these location Mirpur and Uttara are the most densely populated area with a population of 500,373 within 7.4 km^2 179,907 within 5.4 km^2 respectively [13]. So the risk to lose many lives is more in those areas.

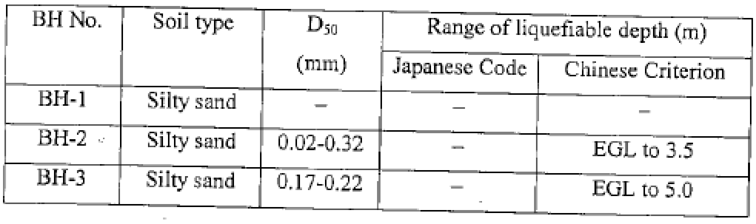
It is to be mentioned here that Standard Penetration Test (SPT) values have been used to determine the Cyclic Resistance Ratio (CRR) for these soils. So, it is essential to give deep concentration for the foundation design of any structures in the Dhaka city. According to another research conducted by the M.Sc. students of BUET following data has been gathered for the calculation of liquefaction susceptibility [14].



Block, Plot & BH No.	Soil type	D_{50} (mm)	Range of liquefiable depth (m)	
			Japanese Code	Chinese Criterion
I, 78, 01	Silty sand	0.18-0.20	–	EGL to 5.0
H, 827, 02	Silty sand	–	–	–
K, 181, 03	Silty sand	0.18-0.22	–	EGL to 4.5
G, Res, 04	Silty sand	–	–	–
A, 261, 05	Clay	–	–	–
I, 66, 01	Silty sand	–	–	–
I, 66, 02	Silty sand	–	–	–
I, 66, 03	Silty sand	0.10-0.10	–	EGL to 3.0
I, 66, 04	Silty sand	–	–	–
I, 178, 01	Silty sand	–	–	–
I, 178, 02	Silty sand	–	–	–
I, 178, 03	Silty sand	0.22-0.34	2.5 to 5.0	EGL to 10.0
I, 178, 04	Silty sand	0.15-0.34	–	EGL to 12.0
G, 936, 01	Silty sand	0.15-0.15	–	EGL to 13.0
G, 936, 02	Silty sand	0.12-0.15	–	4.0 to 7.0
G, 936, 03	Silty sand	0.11-0.15	–	EGL to 3.0
G, 936, 04	Silty sand	0.15-0.152	–	2.0 to 16.0
T-06, 01	Silty sand	0.005-0.02	–	6.0 to 9.0
02, 333, 04	Silty sand	0.10-0.15	–	EGL to 2.0
02, 333, 05	Silty sand	0.15-0.16	–	EGL to 5.0
02, 349, 01	Silty sand	0.01-0.15	–	EGL to 9.0
02, 349, 02	Silty sand	0.15-0.15	–	EGL to 6.0
02, 349, 03	Silty sand	0.06-0.15	–	EGL to 9.0
02, 349, 04	Silty sand	0.10-0.16	–	EGL to 11.0

Fig: 7: Presence of liquefiable soil strata at Bashundhara site.

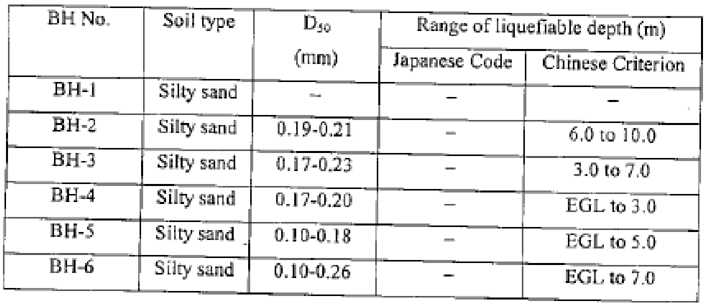
According to Japanese Code of Bridge Design, among these 18 locations, there is only one liquefiable depth (i.e., 2.5 to 5.0 m) at one location. According to Chinese Criterion, there are 10 locations where liquefaction may occur. Among these, at seven locations the liquefaction depth varies from 3 to 13 m from EGL. In other cases, the liquefiable depth is 2 to 16 m, 4 to 7 m and 6 to 9 m.



BH No.	Soil type	D_{50} (mm)	Range of liquefiable depth (m)	
			Japanese Code	Chinese Criterion
BH-1	Silty sand	–	–	–
BH-2	Silty sand	0.02-0.32	–	EGL to 3.5
BH-3	Silty sand	0.17-0.22	–	EGL to 5.0

Fig: Presence of liquefiable soil strata at Purbachal New Model Town site

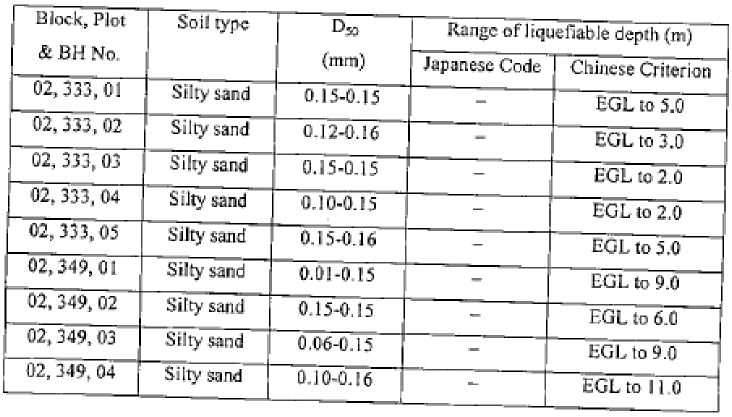
According to Japanese Code of Bridge Design, there is no liquefiable depth for 3 locations at Purbachal New Model Town. According to Chinese Criterion, there are 2 locations where liquefaction may occur. Liquefaction depth varies from 3.5 to 5 m from EGL at these two locations.



BH No.	Soil type	D_{50} (mm)	Range of liquefiable depth (m)	
			Japanese Code	Chinese Criterion
BH-1	Silty sand	–	–	–
BH-2	Silty sand	0.19-0.21	–	6.0 to 10.0
BH-3	Silty sand	0.17-0.23	–	3.0 to 7.0
BH-4	Silty sand	0.17-0.20	–	EGL to 3.0
BH-5	Silty sand	0.10-0.18	–	EGL to 5.0
BH-6	Silty sand	0.10-0.26	–	EGL to 7.0

Fig: Presence of liquefiable soil strata at Uttara Model Town (Third Phase) site

According to Japanese Code of Bridge Design, there is no liquefiable depth for 6 locations at Uttara Model Town (Third Phase). According to Chinese Criterion, there are 5 locations where liquefaction may occur. The liquefiable depth varies from 3 to 7 m from EGL at 3 locations. For other two locations, the liquefiable depth is 3 to 7 m and 6 to 10m.



Block, Plot & BH No.	Soil type	D_{50} (mm)	Range of liquefiable depth (m)	
			Japanese Code	Chinese Criterion
02, 333, 01	Silty sand	0.15-0.15	–	EGL to 5.0
02, 333, 02	Silty sand	0.12-0.16	–	EGL to 3.0
02, 333, 03	Silty sand	0.15-0.15	–	EGL to 2.0
02, 333, 04	Silty sand	0.10-0.15	–	EGL to 2.0
02, 333, 05	Silty sand	0.15-0.16	–	EGL to 5.0
02, 349, 01	Silty sand	0.01-0.15	–	EGL to 9.0
02, 349, 02	Silty sand	0.15-0.15	–	EGL to 6.0
02, 349, 03	Silty sand	0.06-0.15	–	EGL to 9.0
02, 349, 04	Silty sand	0.10-0.16	–	EGL to 11.0

Fig: Presence of liquefiable soil strata at Mirpur DOHS site

According to Japanese Code of Bridge Design, there is no liquefiable depth for 9 locations among these 23 locations, at Mirpur DOHS site. According to Chinese Criterion, there are 9 *locations* where liquefaction may occur. The liquefiable depth varies from 2 to 11 m from EGL for all locations.
Finally the probability of liquefaction can be summarized by the following table

Area	Probability
Banasree	High
Bashundhara	Low
Uttara	Low
Mirpur	Low
Purbachal	Low

V. ANTI-LIQUEFACTION MEASURES:

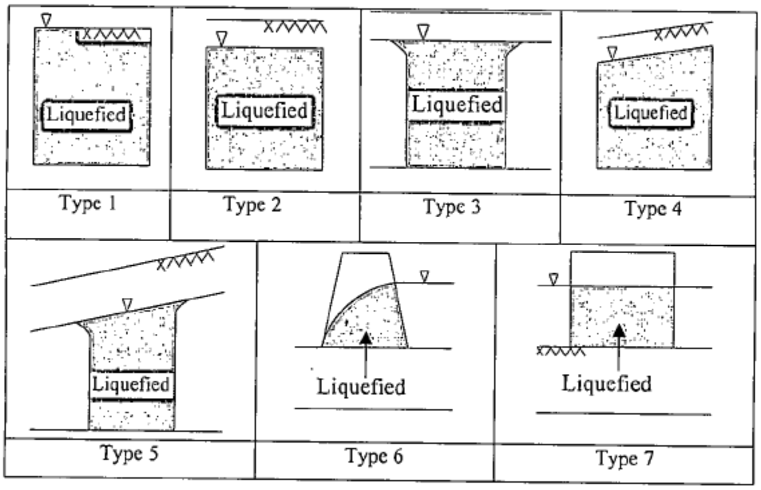


Fig 4: Classification of liquefiable ground types (JGS, 1998),

To find out various possible measures to prevent liquefaction a comprehensive study is required. It depends on several numbers of factors; however, few can be controlled in the field. To some extent, liquefaction resistance can be improved by:

Compaction of Loose Sands: Loose saturated sands are more prone to liquefaction than dense saturated sand. Therefore, by compacting the sand deposit before any structure is constructed, the liquefaction potential can be reduced. Various methods for compaction of loose sands can be suggested as:

A. **Rolling with rubber tyre rollers:** By excavating some depth it may be accomplished, then carefully backfilling in controlled lift thickness and compacting the soil. Lifts are commonly 150mm – 200mm when rubber tyres are used. However, this method cannot be used for compacting deep sand deposit.

B. **Compaction with vibratory plates and vibratory rollers:** By using smooth wheel rollers commonly with a vibratory device inside, the compaction of cohesion less soil can be achieved. With this equipment, lift depths up to about 1.5m – 2 m can be compacted. Also, vibratory assembly can be used with plates mounted; however, the small thickness of soil can be compacted by these methods and they cannot be used for large deposits.

C. **Driving of piles:** When piles are driven in loose deposits, they compact the sand within an area covered by 8 times around it in the sight having a loose sand deposit. The overall stiffness of the soil stratum increases substantially since pile remains in the sand.

D. **Vibrofloatation:** To densify cohesion less deposit of sands and gravel with having not more than 20 percent silt or 10 percent clay, this method is commonly used. Its upper half is stationary part and the lower half is vibrator at the top and bottom the device has water jets. With bottom jet on which induces the quick sand condition, Vibrofloat in lower under its own weight when it reaches the desired depth, the flow of water is diverted to upper jet and Vibrofloat is pulling out slowly.Top jet aids the compaction process. A crater is formed when the Vibrofloat is pulled. To the crater formed sand or gravel is added.

E. **Blasting:** The explosion of buried charges induces liquefaction of the soil mass followed by escape of excess pore water pressure which acts as a lubricant to facilitate rearrangement and thus leading the sand to a more compacted state.

Grouting and Chemical Stabilization:

The technique of inserting some kind of a stabilizing agent into the soil mass under pressure is known as grouting. Into the solid voids in limited space around the injection tube, the pressure processes the agent. To from a stable mass, the agent reacts with the soil or itself. A mixture of cement and water, with or without sand, is the most common grout.

Sand Drain:
For radial consolidation, which increases the rate of drainage in the rate of drainage in the embankment by driving a casing into the embankment and making vertical bore holes, the process of the sand drain is needed. With a suitable grade of sand, these holes are backfilled.

Stone Column:
Vibro replacement is a ground improvement, By means of a crane suspended down hole vibrator, to reinforce all soils and densify granular soils vibro replacement that constructs dense aggregate columns (stone column).

VI. CONCLUSION

In conclusion it can be said that though the possibility of liquefaction in Dhaka city is not severe but it cannot be denied because the casualties will be humongous compare to any other cities. So, the possibilities cannot be denied so engineers should take account the probability of liquefaction during construction process.

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