Assessment of Liquefaction potential - Deterministic and Probabilistic Approach

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

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Structural Engineering

By

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CANDIDATE'S DECLARATION

I hereby declare that the project work entitled **"Assessment of Liquefaction potential - Deterministic and Probabilistic Approach"** submitted to Department of Civil Engineering, DTU is a record of an original work done by **Rahul Verma** under the guidance of **Mr. G.P.Awadhiya**, Associate Professor, Department of Civil Engineering, DTU, and this project work has not performed the basis for the award of any Degree or diploma/fellowship and similar project, if any.

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CERTIFICATE

It is certified that the thesis titled "**Assessment of Liquefaction potential - Deterministic and Probabilistic Approach"** Presented by **RAHUL VERMA** in partial fulfillment of the requirement for the award Of the Master of technology in **Civil Engineering** with specialization in Structural Engineering At the **DELHI TECHNOLOGICAL UNIVERSITY, DELHI** is an authentic record of the Research work carried out under my supervision. The content of this thesis, in whole or in Part, has not been submitted to any other institute or university for the award of a degree or Diploma.

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ABSTRACT

Seismic soil liquefaction continues to be a challenging problem, and attracts considerable attention from researchers all around the world. The term liquefaction has been used to define various different aspects of shear strength reduction, such as flow failure or cyclic softening.

The studies presented herein are directed towards the development of improved SPT-based correlations for both probabilistic and deterministic evaluation of potential for “triggering” or initiation of seismically-induced soil liquefaction.

This studies presents new correlations for assessment of the likelihood of initiation (or “triggering”) of soil liquefaction and provide greatly reduced overall uncertainty and variance. Key elements in the development of these new correlations are:(1) accumulation of a significant database of field performance case histories (2) use of improved knowledge and understanding of factors affecting interpretation of standard penetration test data.(3) determining whether the soil is susceptible to liquefaction or not, at whereas depths up to 35m below ground level. (4) use of reliability method and Bayesian approach to determine the probability of liquefaction.

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CHAPTER 1

INTRODUCTION

1.1 General

Liquefaction is the phenomena when there is loss of strength in saturated and cohesion-less soils because of increased pore water pressures and hence reduced effective stresses due to dynamic loading. It is a phenomenon in which the strength and stiffness of a soil is reduced by earthquake shaking or other rapid loading.

Liquefaction occurs in saturated soils and saturated soils are the soils in which the space between individual particles is completely filled with water. This water exerts a pressure on the soil particles that. The water pressure is however relatively low before the occurrence of earthquake. But earthquake shaking can cause the water pressure to increase to the point at which the soil particles can readily move with respect to one another.

Although earthquakes often triggers this increase in water pressure, but activities such as blasting can also cause an increase in water pressure. When liquefaction occurs, the strength of the soil decreases and the ability of a soil deposit to support the construction above it.

Soil liquefaction can also exert higher pressure on retaining walls, which can cause them to slide or tilt. This movement can cause destruction of structures on the ground surface and settlement of the retained soil. Accordingly, the use of in situ "index" testing is the dominant approach in common practice. As summarized in the recent state of-the-art paper (Youd et al. 2001), four in situ test methods have now reached a level of sufficient maturity as to represent viable tools for this purpose, and these are: (1) the standard penetration test (SPT); (2) the cone penetration test; (3) measurement of in situ shear wave velocity Vs; and (4) the Becker penetration test. The oldest, and still the most widely used of these, is the SPT, and this will be the focus of this study.

1.2 OBJECTIVE OF THE PRESENT STUDY

The objectives of the research are as follows:

a) To determine the liquefaction potential by deterministic approach.

b) To determine the liquefaction potential by probabilistic approach.

c) to compare the results of the above two approaches.

d) to apply necessary corrections to get more precise results.

1.3 METHODOLOGY OF THE STUDY

This includes the thorough study of two methods to determine probability of liquefaction.

(i) ***Deterministic Approach*** : The most common procedure used in engineering practice for the assessment of liquefaction potential of sands and silts is the Simplified Procedure. The procedure may be used with either SPT blow count, CPT tip resistance or shear wave velocity. In this report SPT data is obtained of 10 bore holes and detailed calculation is performed using *Sixth Revision of IS 1893 (Part 1) February 2016.* The results are obtained whether the soil is liquefiable or not using factor of safety.

(ii) ***Probabilistic Approach*** : The above simplified methods for assessing soil liquefaction potential using a deterministic safety factor in order to judge whether liquefaction will occur or not. However, these methods are unable to determine the liquefaction probability related to a safety factor. An answer to this problem can be found by reliability analysis. This study presents a reliability analysis method based on the popular Seed'85 liquefaction analysis method. This reliability method uses the empirical acceleration attenuation law to derive the probability density distribution function (PDF) and the statistics for the earthquake-induced cyclic shear stress ratio (CSR). The CSR and CRR statistics are used in conjunction with the first order and second moment method, to calculate the relation between the liquefaction probability, the safety factor and the reliability index. Based on the proposed method, the liquefaction probability related to a safety factor can be easily calculated.

1.4 ORGANIZATION OF THE STUDY

The study is organized according to the stages followed for the determination of the liquefaction potential by deterministic and probabilistic approach. Thus,

Chapter 1 introduces a general statement of the liquefaction, objective and methodology of this research.

Chapter 2 reviews the available literature that is required to understand the background theories of various aspects of liquefaction. This chapter also includes a literature survey on the different techniques used for determining the liquefaction potential like deterministic method using empirical relationships and probabilistic method using reliability function, normal distribution, probability function, etc.

Chapter 3 describes soil liquefaction and liquefaction hazard assessment

Chapter 4 describes the methodology of the project. Which include detailed analysis of deterministic approach followed by deterministic sample calculations and detailed probabilistic approach followed by probabilistic sample calculations.

Chapter 5 draws conclusions and results of the current work. Most of the results are in tabular form and are shown in appendix A and B.

CHAPTER 2

LITERATURE REVIEW

Armen Der Kiureghian; K. Onder Cetin; Raymond B. Seed; Kohji Tokimatsu4 ; Leslie F. Harder Jr; Robert E. Kayen; and Robert E. S. Moss [1] has presented the development of recommended new probabilistic and deterministic relationships for assessment of likelihood of initiation of liquefaction. Stochastic models for assessment of seismic soil liquefaction initiation risk have been developed within a Bayesian framework. In the course of developing the proposed stochastic models, the relevant uncertainties including (1) measurement/estimation errors, (2) model imperfection, (3) statistical uncertainty, and (4) those arising from inherent variables were addressed. Improved treatment of r_d in "simplified" assessment of in situ CSR results in triggering relationships that are unbiased with respect to use in conjunction with either (1) direct seismic response analyses for evaluation of in situ CSR, or (2) improved "simplified" assessment of in situ CSR. This is an important step forward, as these studies also show that all previous, widely used correlations are unconservatively biased when used in conjunction with direct response analyses for assessment of CSR, as a result of bias in previous "simplified" r_d recommendations. The new models provide a significantly improved basis for engineering assessment of the likelihood of liquefaction initiation, relative to previously available models. The new models presented and described in this paper deal explicitly with the issues of: (1) FC, (2) magnitude-correlated, and (3) effective overburden stress (K_σ effects), and they provide both: (1) an unbiased basis for evaluation of liquefaction initiation hazard and (2) significantly reduced overall model uncertainty. Indeed, model uncertainty will be reduced sufficiently that overall uncertainty in application of these new correlations to field problems is now driven strongly by the difficulties/uncertainties associated with project-specific engineering assessment of the necessary "loading" and "resistance" variables, rather than uncertainty associated with the correlations themselves. This represents a significant overall improvement in our ability to accurately and reliably assess liquefaction hazard.

J.H. Hwang*, C.W. Yang, D.S. Juang [2] presents a practical reliability-based method for liquefaction analysis. The proposed method is simple and clear. Based on the popular Seed'85 method, we use the empirical acceleration attenuation law to derive the probability density distribution function (PDF) and the statistics for the earthquake-induced cyclic shear stress ratio (CSR). He also collected liquefaction and non-liquefaction data from Chi-Chi earthquake and others around the world. The logistic model modified from Liao et al. is then used to derive the PDF and the statistics for cyclic resistance ratio (CRR). With these statistics, the first order and second moment method can be used to calculate the relation between the liquefaction probability with the safety factors and the reliability index. The whole proposed computation procedure is summarized in a flow chart, to facilitate its use by engineers. Finally, an analysis assessing the liquefaction potential at a real construction site is presented, to demonstrate the use and the feasibility of the method.. The probability may seem a little high at first glance, but it should be noted that the derived liquefaction probability does not include the probability that an earthquake of the given magnitude will occur. It only gives the liquefaction probability for one soil layer and for the given earthquake event. The real liquefaction probability would be the probability that liquefaction would occur during an earthquake considered jointly with the probability that an earthquake of such a magnitude will occur. Based on seismic hazard analysis, the probability that the specified earthquake will occur is about 0.002 annually, or, in other words, this size earthquake has a return period of 475 years. Thus, a comprehensive probabilistic liquefaction analysis method is considered the uncertainties in the CSR and the CRR, as well as the probability that an earthquake will occur. Based on the proposed method, the liquefaction probability related to a safety factor can be easily calculated. The influence of some of the soil parameters on the liquefaction probability can be quantitatively evaluated.

K. Onder Cetina, Armen Der Kiureghian, Raymond B. Seed [3] A Bayesian framework for probabilistic assessment of the initiation of seismic soil liquefaction is described. A database, consisting of post-earthquake field observations of soil performance, in conjunction with in situ ‘‘index’’ test results is used for the development of probabilistically-based seismic soil liquefaction initiation correlations. The proposed stochastic model allows full and consistent representation of all relevant uncertainties. including (a) measurement/estimation errors, (b) model imperfection, (c) statistical uncertainty, and (d) inherent variability. Different sets of probabilistic liquefaction boundary curves are developed for the seismic soil liquefaction initiation hazard problem, representing various sources of uncertainty that are intrinsic to the problem. The resulting correlations represented a significant improvement over prior efforts, producing predictive relationships with enhanced accuracy and greatly reduced overall model uncertainty.

K. Onder CETIN , Raymond B SEED And Armen DER KIUREGHIAN [4] presents the results to date of ongoing studies to develop improved, probabilisticallybased correlations for the use of SPT data for evaluation of resistance to "triggering" or initiation of cyclic liquefaction. Although these studies are ongoing, the relationships developed at this stage are considered to represent a sufficient advance over previously available, similar relationships as to merit their exposition at this time. The relationships presented herein have a number of significant advantages over previous probabilistic and "deterministic" relationships currently available. These include:

- Previously available field case history data have been re-evaluated, taking advantage of recent developments/insights regarding (a) factors affecting "correction" of SPT data for energy, equipment, procedure, and rod-length effects, and (b) factors affecting evaluation of in-situ equivalent uniform cyclic stress ratio including source mechanism effects, local site effects, etc.
- A large number of "new" field case history data were collected and similarly evaluated.
- With this greatly enhanced database, higher standards were set for acceptability of case history data, and data not meeting these standards were deleted. The result is an enlarged database of high quality.
- The Bayesian parameter estimation method was used to develop and evaluate correlations. This method allowed for separate treatment of different sources of aleatory and epistemic uncertainty, and allowed assessment of more contributing variables/parameters than prior studies.

The resulting correlations provide a significantly improved basis for evaluation of liquefaction resistance, and also resolve a number of previously difficult issues including (a) "corrections" for fines content and effective overburden stress, and (b) magnitude-correlated duration weighting factors (for magnitudes other than MW = 7.5)

Neelima Satyam D and K. S. Rao [5] state that determination of liquefaction potential due to an earthquake is a complex geotechnical engineering problem. Many factors, including soil parameters and seismic characteristics influence this phenomenon. To assess the liquefaction hazard in an area, it is important to examine initially the liquefaction susceptibility. Before proceeding to the rigorous investigation of the liquefaction potential for Delhi region, first qualitative assessment of liquefiable soils is carried out based on the geotechnical characteristics. The percentage of silt is high in the north and eastern side of Delhi indicating that there is a great chance of soil being subjected to liquefaction. Also, the value of plasticity index in these locations is also less compared to the soils in the western side of the area indicating the probability of liquefaction to occur. According to the geological criteria also, the Holocene soils present in the trans Yamuna region are highly susceptible than the Pleistocene soils in the western side of Delhi region and there is very less chance of liquefaction to occur in the central part of Delhi because of the rock outcrop and gravelly sands. This liquefaction hazard map which is developed in this paper will help in selecting a suitable ground improvement technique and a foundation system by the engineers for future constructions in the Delhi region.

Hidenori MOGI and Hideji KAWAKAMI [6] In this study, spatial variation of peak ground accelerations (PGAs) is examined using strong motion records for a large number of events from dense accelerometer arrays at Chiba in Japan, SMART–1 in Lotung, Taiwan, and a realtime city gas network damage estimation system (SIGNAL) in Japan. We defined PGA ratios as spatial intra-event variations of PGAs and examined their probability density functions (PDFs), mean values, standard deviations and percentiles estimated using accelerometer arrays of the Chiba, SMART-1, and SIGNAL databases. Then, the relationship between these statistics and the station separation distances was analyzed. We found that there is a very large scatter of PGAs in the results. It was also revealed that the means and standard deviations have an almost linear relationship with the logarithm of the station separation distances ranging from several meters to one hundred kilometers, and this relationship can be attributed to the dependence of the correlation between intra-event PGAs on the separation distances.

Dr. Sudhir K Jain [7] Explanatory Examples are given on Indian Seismic Code IS 1893 (Part I). He measured SPT resistance and results of sieve analysis for a site in Zone IV. He determine the extent to which liquefaction is expected for 7.5 magnitude earthquake. Estimated the liquefaction potential and resulting settlement expected at Delhi.

Raghvendra Singh, Debasis Roy and Sudhir K. Jain [8] damaging effects of Bhuj Earthquake on embankment dams have been considered in this paper with particular reference to Chang Dam, Fatehgadh Dam and Kaswati Dam. Liquefaction to various extents of the foundation soils underneath these embankment dams during Bhuj Earthquake have been reported as one of the major causes of the distress within these dams. The data presented in this paper indicate that liquefaction within the shallow foundation soils would have been widespread underneath Chang Dam, while that underneath Fatehgadh Dam and Kaswati Dam were relatively localized. This assessment is in qualitative agreement with the facts that the damage to Chang Dam was near total, while those inflicted on the other two dams were relatively less pronounced. The sliding block method was then used to estimate the magnitude of observed deformations.

Shashank Burman and A. Murali Krishna [9] this study gives a better understanding of the liquefaction potential evaluation. This paper discussed the evaluation of seismically induced Liquefaction based on semi empirical field-based procedures using the Standard Penetration Test (SPT) profile of soil. This work has been carried out to initiate such studies in the region and to address the problem of seismically induced liquefaction based on deterministic as well as probabilistic approach. A case study for IIT Guwahati with 3 different borehole locations has been carried out for 3 different Earthquake Moment Magnitude of M=5, 6 and 7 respectively.. The results obtained in probabilistic approach are in good agreement with deterministic approach. This Study provides a good understanding to account for the liquefaction assessment based on two approaches.

IS 1893 (Part 1) Sixth Revision February 2016 the entire deterministic approach is performed using this code.

CHAPTER = 3

SOIL LIQUEFACTION AND LIQUEFACTION HAZARD ASSESSMENT

3.1 SOIL LIQUEFACTION : Liquefaction is the phenomena in which the strength and stiffness of a soil is reduced by earthquake shaking or other rapid loading. Loss of strength in saturated and cohesion-less soils occurs under undrained conditions, during dynamic loading, because of increased pore water pressures and hence significant reduction in effective stresses. Soil liquefaction induced by an earthquake can be a major cause of damage to structures and facilities. Damage to structure in liquefied sediments can occur as a result of bearing capacity failure of a foundation, lateral spreading or slope failure and differential settlement.

Sediments below water table temporarily lose shear strength and behave more as a viscous liquid than as a solid. The water in the soil voids exerts pressure upon the soil particles. If the pressure is low enough, the soil stays stable. However, once the water pressure exceeds a certain level, it forces the soil particles to move relative to each other, thus causing the strength of the soil to decrease and failure of the soil. The shear resistance of cohesion less soil is mainly proportional to the intergranular pressure and the co-efficient of friction between solid particles. The liquefaction phenomena that results from this process can be divided into two main groups e.g. flow liquefaction and cyclic mobility (Youd, T. L. and Perkins, 1978). Flow liquefaction can occur when the static shear stress is greater than the shear strength of the soil in its liquefied state. The deformations produced by flow liquefaction are induced by static shear stress. It occurs less frequently than cyclic mobility but can cause more severe damage. Cyclic mobility occurs when the static shear stress is less than the shear strength of the liquefied soil. It can occur in broad range of soils and site conditions. Various laboratory and field methods have been developed to assess soil resistance to liquefaction. The information regarding geomorphology, soil properties and its origin, water table depth, past seismic history is very essential in the liquefaction assessment of an area. Generally, the liquefaction process is associated with recent Holocene deposits and uncompacted fills. However, there have been a few observed cases of liquefaction of Pleistocene and even pre-Pleistocene deposits.

3.2 LIQUEFACTION HAZARD ASSESSMENT

The first step in liquefaction hazard assessment is the evaluation of liquefaction susceptibility. Liquefaction susceptibility was first coined by Youd and Perkins (1978) as a measure of inherent resistance of soil to liquefaction, and can range from not susceptible, to highly susceptible. Susceptibility can be estimated by comparing the properties of a given deposit to other soil deposits where liquefaction has been observed in the past. The primary relevant soil properties include grain size, fines content (i.e., amount of silt and /or clay), density, degree of saturation, and age of the deposit. In order to assess the preliminary liquefaction potential assessment of soil deposits over a large area in a seismically active region. Liquefaction susceptibility maps are the most basic level of liquefaction hazard mapping.

There are three different ways to predict liquefaction susceptibility of a soil deposit in a particular region i.e., Historical criteria, Geological/ Geomorphologic criteria and Compositional criteria. According to the historical criteria soils that have liquefied in the past can liquefy in future also. With the help of past earthquake records the liquefaction in future can be predicted. The liquefaction susceptibility depends strongly on the type of the geological process that created the soil deposits. River deposits, deposits formed by lakes, winds etc are highly susceptible to the process of liquefaction. Liquefaction potential also depend on the type of the soil. That is, uniform graded soils are highly susceptible than well-graded soil deposits; soils with angular particles are less susceptible than soils with rounded particles. Liquefaction potential is represented as the ratio induced to stress ratio causing liquefaction. It also refers to the probability that soil will actually liquefy at a given site, and therefore depends not only on the liquefaction susceptibility of soil, but also the level of seismic activity in the region. For example, very loose clean sand may be highly susceptible to liquefaction, however if it exists in a region of negligible seismicity, then its liquefaction potential will be low. In contrast, a denser soil may have a lower susceptibility however, a higher liquefaction potential because it is situated in an area of very strong seismic activity.

CHAPTER = 4

METHODOLOGY

4.1 DETERMINISTIC APPROACH

Evaluations of soil liquefaction potential by empirical methods and semi-empirical methods have become popular among practicing engineers. These methods use deterministic relations implying the occurrence or triggering of liquefaction. A semi-empirical method originally developed by Seed and Idriss[10,11] was based on the evaluation of soil liquefaction resistance based on the results of the standard penetration test (SPT) values. Over the past decades, these methods have been modified successively and have become more attractive and a standard of practice for many engineers around the world. Recently Idriss and Boulanger [12] have proposed an updated and improved method for the evaluation of liquefaction potential of soil deposits, which has been used in the present analysis. Although Deterministic analysis is well accepted method to evaluate the soil liquefaction, there are uncertainties left with traditional deterministic approach where factors of safety are often difficult to interpret. To overcome these uncertainties, probabilistic and statistical approaches have been employed in the literature.

Steps to calculate factor of safety of liquefaction

Step 1: The subsurface data used to assess liquefaction susceptibility should include the location of the water table, either SPT blow count N, mean grain size D50 , unit weight, and fines content of the soil (percent by weight passing the IS Standard Sieve No. 75μ).

Step 2: Evaluate total vertical stress σ_{vo} and effective vertical stress σ'_{vo} for all potentially liquefiable layers within the deposit.

Step 3: Evaluate Stress Reduction Factor r_d using:

$$r_d = \begin{cases} 1 - 0.00765z & 0 < z \leq 9.15\,m \\ 1.174 - 0.0267z & 9.15\text{ m} < z \leq 23.0\,m \end{cases}$$

where z is the depth below the ground surface in metre.

Step 4: In the deterministic approach, Cyclic Stress Ratio(CSR) induced by earthquake ground motions, at a given depth z below the ground surface is usually calculated using Seed and Idriss relation. Calculation Critical Stress Ratio *CSR*, the resistance of a soil layer against liquefaction, induced by the design earthquake using:

$$CSR = 0.65\left(\frac{a\ max}{g}\right)\left(\frac{\sigma vo}{\sigma' vo}\right) r_d$$

Where

σvo = Vertical overburden stress at depth z,

$\sigma' vo$ = Effective vertical overburden stress at depth z,

a_{max} = Peak ground acceleration,

g = Acceleration due to gravity, and

r_d = Stress Reduction Factor.

Step 5: Obtain Critical Resistance Ratio CRR by correcting standard Critical Resistance Ratio *CRR7.5* for earthquake magnitude, stress level and initial static shear using:

$$CRR = CRR_{7.5}(MSF)\ k_\sigma\ k_\alpha$$

Where :

$CRR_{7.5}$ = Standard Critical Resistance Ratio for a 7.5 magnitude earthquake obtained using values of SPT (as per Step 6),

MSF = Magnitude Scaling Factor given by following equation:

$$MSF = 10^{2.24}/M_w^{2.56}$$

This factor is required when the magnitude is different than 7.5.

k_σ = Correction for high overburden pressure is required when overburden pressure is high(depth > 15 m) and can be found using equation:

$$k_\sigma = (\sigma'vo/Pa)^{(f-1)}$$

P_a = atmospheric pressure, and

$\sigma'vo$ = effective overburden pressure, measured in same units

k_α = Correction for static shear stresses is required only for sloping ground and is not required in routine engineering practice. Therefore, in the sope of this standard , value of k_α shall be assumed unity. Hence

$$k_\alpha = 1$$

f is an exponent and its value depends on the relative density D_r

For D_r = 40% - 60%, f = 0.8 – 0.7, and

D_r = 60% - 80%, f = 0.7 – 0.6

Step 6: Obtain Critical Resistance Ratio CRR7.5

Using values of SPT: Evaluate the standardized SPT blow count N_{60} , which is the Standard Penetration Test blow count for a hammer with an efficiency of 60 percent. Specifications are given in Table F1 of the standardized equipment corresponding to an efficiency of 60 percent. If equipment used is of non-standard type, N60 shall be obtained using:

$$N_{60} = NC_{60} ,$$

where C60 = $C_{HT}C_{HW}C_{SS}C_{RL}C_{BD}$.

Table F1 Recommended Standardized SPT Equipment

Element	Standard Specification
Sampler	Standard split-spoon sampler with: Outside diameter *OD* = 51 mm, and Inside Diameter *ID* = 35 mm (constant, that is, no room for liners in the barrel)
Drill Rods	*A or AW* type for depths less than 15.2 m; *N* or *NW* type for greater depths
Hammer	Standard (safety) hammer with (a) weight = 63.5 kg; and (*b*) drop height = 762 mm (delivers 60 of theoretical free fall energy)
Rope	Two wraps of rope around the pulley
Borehole	100-130mm diameter rotary borehole with bentonite mud for borehole stability (hollow stem augers where SPT is taken through the stem)
Drill Bit	Upward deflection of drilling mud (tricone or baffled drag bit)
Blow Count Rate	30 to 40 blows per minute
Penetration Resistant Count	Measured over range of 150mm–460 mm of penetration into the ground

Table F2 Correction Factors for Non-Standard SPT Procedures and Equipment

Correction for	*Correction Factor*
Nonstandard Hammer Type	$C_{HT} = \begin{cases} 0.75 & \text{for DH with rope and pulley} \\ 1.33 & \text{for DH with trip / auto} \end{cases}$ and ER = 80, where DH= doughnut hammer, and ER = energy ratio.
Nonstandard Hammer Weight or Height of fall	$C_{HW} = \frac{HW}{48{,}387}$ where H = height of fall (mm), and W = hammer weight (kg)
Nonstandard Sampler Setup (standard samples with room for liners, but used without liners	$C_{SS} = \begin{cases} 1.1 & \text{for loose sand} \\ 1.2 & \text{for dense sand} \end{cases}$
Nonstandard Sampler Setup (standard samples with room for liners, but liners are used)	$C_{SS} = \begin{cases} 0.9 & \text{for loose sand} \\ 0.8 & \text{for dense sand} \end{cases}$
Short Rod Length	C_{RL} =0.75 for rod length 0-3 m
Nonstandard Borehole Diameter	$C_{BD} = \begin{cases} 1.00 & \text{for Bore Hole Diamter of 65 - 115 mm} \\ 1.05 & \text{for Bore Hole Diameter of 150 mm} \\ 1.15 & \text{for Bore Hole Diameter of 200 mm} \end{cases}$
Notes N = Uncorrected SPT Blow Count $C_{60} = C_{HT}C_{HW}C_{SS}C_{RL}C_{BD}$ $N_{60} = NC_{60}$ C_N = Correction factor for overburden pressure = $(N_1)_{60} = C_N C_{60} N$	

Factors C_{HT}, C_{HW}, C_{SS}, C_{RL} and C_{BD}, recommended by various investigators for some common non-standard SPT configurations are provided in Table F2. For SPT conducted as per IS 2131-1981, the energy delivered to the drill rod is 60percent and hence C60 may be assumed as 1.

Calculate the normalized standardized SPT blow count $(N_1)_{60}$ is normalized to an effective overburden pressure of approximately 100kPa using Stress resistance ratio C_N using:

$$(N_1)_{60} = C_N . N_{60}$$ where

$$C_N = \sqrt{\frac{Pa}{\sigma'vo}} \leq 1.7,$$

The effect of fines content FC (in %) can be rationally accounted for by correcting $(N_1)_{60}$ and finding $(N_1)_{60CS}$ as follows:

$$(N_1)_{60CS} = \alpha + \beta(N_1)_{60}$$

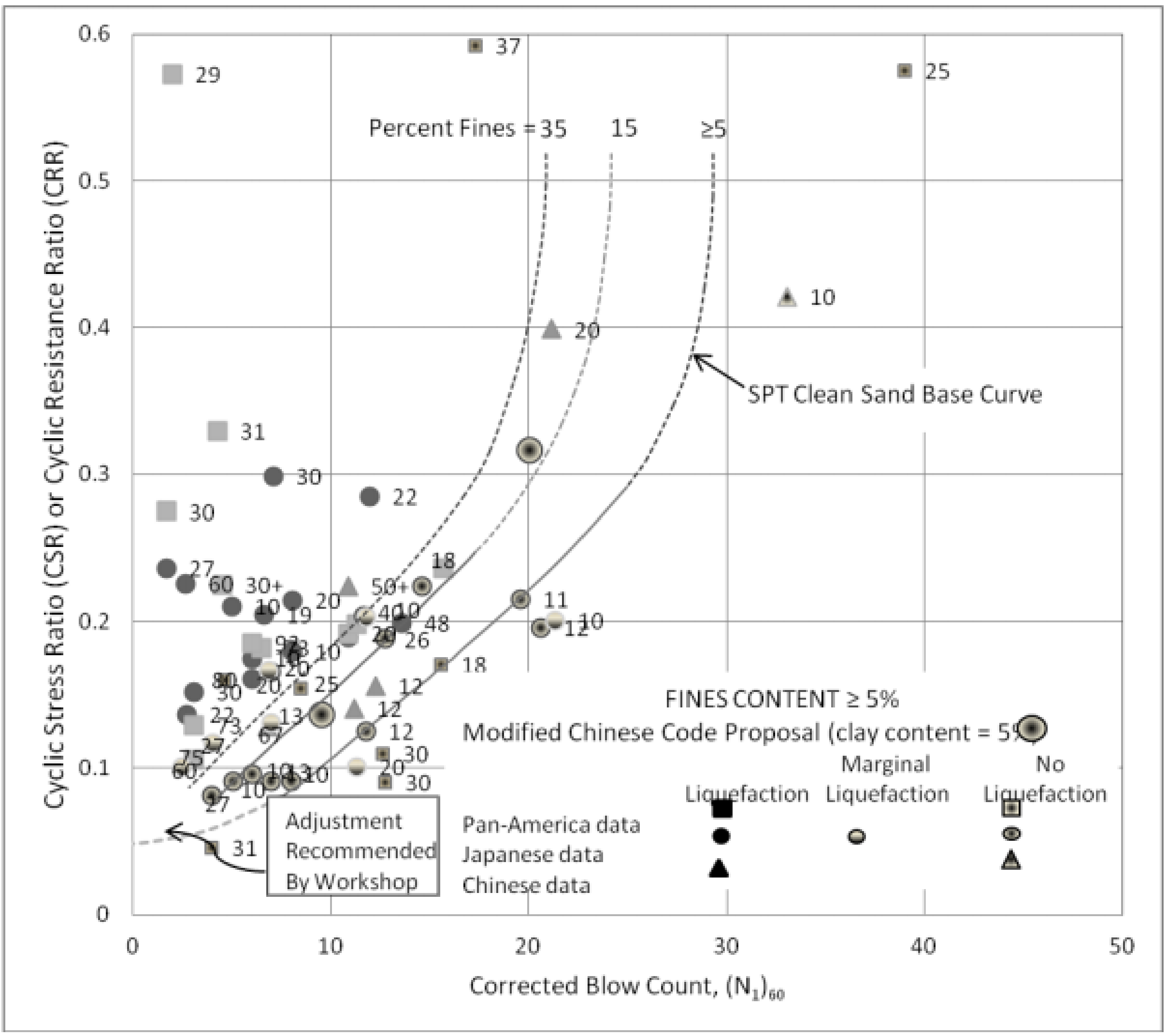
Where

$\alpha = 0$ $\beta = 1$ for $FC \leq 5\%$

$\alpha = e^{[1.76 - \left(190/FC^2\right)]}$ $\beta = 0.99 + \frac{(FC)^{1.5}}{1000}$ for $5\% < FC < 35\%$

$\alpha = 5$ $\beta = 1.2$ for $FC \geq 35\%$

Figure below can be used to estimate $CRR_{7.5}$, where $(N_1)_{60CS}$ shall be used instead of $(N_1)_{60}$ and only SPT clean sand based curve shall be used irrespective of fines contents.



RELATION BETWEEN CRR AND $(N_1)_{60}$ FOR SAND FOR Mw 7.5 EARTHQUAKES

The $CRR_{7.5}$ can be estimated using following equation, instead of figure.

$$CRR_{7.5} = \frac{1}{34-(N1)_{60CS}} + \frac{(N1)_{60CS}}{135} + \frac{50}{[10X(N1)_{60CS}+45]^2} - \frac{1}{200}$$

Step 7: Calculation of the Factor of Safety FS against initial liquefaction. Determination of earthquake induced loading expressed in terms of cyclic stress ratio (CSR), this loading is compared with the liquefaction resistance of the soil, which is expressed in terms of cyclic resistance ratio (CRR). The Factor of safety (FOS) is evaluated using CSR and CRR :

$$FS = \frac{CRR}{CSR}$$

where CSR is as estimated in Step 5 and CRR in Step 6. When the design ground motion is conservative, earthquake-related permanent ground deformation is generally small, if 1.2.≥FS

4.2 Deterministic calculations

Determination of the extent to which liquefaction is expected for 7.5 magnitude earthquake

The measured SPT resistance and results of sieve analysis for a site in New delhi (Zone IV) are indicated in Table below.

Table 10.1: A portion of Result of the Standard penetration Test and Sieve Analysis

Depth	Type of Strata	Observed SPT value	Saturated Density (t/m3)	Fine Content (%)
1.5	CL	6	1.92	64
3	CL	5	1.92	49
4.5	CL	8	1.92	49
6	CH	18	1.88	95
7.5	ML	21	1.88	64
9	ML	25	1.88	91
10.5	ML	27	2	91
12	ML	34	2.01	65
13.5	SM	38	2.01	39
15	CL	76	2.03	88
16.5	CL	75	2.03	88

Site Characterization:

1. This site consists of loose to dense poorly graded sand to inorganic clay. The SPT values ranges from 6 at 1.5m depth to 197 at a depth of 35m.
2. The site is located in New Delhi (zone IV).
3. The peak horizontal ground acceleration value for the site will be taken as 0.24g corresponding to zone factor Z = 0.24
4. Actual water table depth = 6.10m
5. Water table assumed for calculation = 0.0m
6. Borehole diameter = 150mm

Liquefaction Potential of Underlying Soil

Step by step calculation for the depth of 3m is given below. Detailed calculations for all the depths are given in Table 10.2. This table provides the factor of safety against liquefaction (FS) and maximum depth of liquefaction below the ground surface.

Step 1:

1. $\frac{a\,max}{g} = 0.24$
2. $M_w = 7.5$
3. $\gamma_{sat} = 1.92$ t/m^3
4. $\gamma_w = 1$ t/m^3
5. Depth at which liquefaction potential is to be evaluated = 3 m

Step 2: Initial stresses:

σ_{vo} = (1.92 x 1.5)+(1.92x1.5) = 5.76 t/m^2

u_o = 3 x 1 = 3 t/m^2

$\sigma'_{vo} = (\sigma_{vo} - u_o)$ = 5.76 – 3 = 2.76 t/m^2

Step 3: Stress reduction factor:

$$r_d = \begin{cases} 1 - 0.00765z & 0 < z \leq 9.15\,m \\ 1.174 - 0.0267z & 9.15\text{ m} < z \leq 23.0\,m \end{cases}$$

r_d = 1 – 0.00765x3 = 0.97705

Step 4: Calculation Critical Stress Ratio *CSR*

$$CSR = 0.65\left(\frac{a\,max}{g}\right)\left(\frac{\sigma vo}{\sigma' vo}\right)r_d$$

$CSR = 0.65 \text{ x } (0.24) \text{ x } (\frac{5.76}{2.76}) \text{ x } 0.97705$

CSR = 0.31809

Step 5: Obtain Critical Resistance Ratio CRR7.5

1. $C60 = C_{HT}C_{HW}C_{SS}C_{RL}C_{BD}$

   [C_{HT} =1, C_{HW} =1, C_{SS} =1] (assumed)

   C_{RL}= 0.8 (from Table F2)

   C_{BD}= 1.05 (from Table F2) (Borehole diameter = 150mm)

   C60 = 1x1x1x0.8x1.05 =0.84

2. $N_{60} = NC_{60}$

   = 5 x 0.84 = 4.2

3. $C_N = \sqrt{\frac{Pa}{\sigma'vo}} \leq 1.7$

   $= \sqrt{\frac{10.33}{2.76}} =$ 1.934 (> 1.7) therefore

   C_N= 1.7

4. Calculate the normalized standardized SPT blow count

   $(N_1)_{60} = C_N . N_{60}$

   = 1.7 x 4.2 = 7.14

5. The effect of fines content FC (in %) can be rationally accounted for by correcting $(N_1)_{60}$ and finding $(N_1)_{60CS}$

   FC = 49% at depth of 3 m

$\alpha = 5$ $\beta = 1.2$ for FC $\geq$ 35%

$$(N_1)_{60CS} = \alpha + \beta(N_1)_{60}$$

$$= 5 + 1.2 \text{ x } 7.14 = 13.568$$

$$CRR_{7.5} = \frac{1}{34-(N1)60CS} + \frac{(N1)60CS}{135} + \frac{50}{[10X(N1)60CS+45]^\wedge 2} - \frac{1}{200}$$

$$= \frac{1}{34-13.568} + \frac{13.568}{135} + \frac{50}{[10X13.568+45]^\wedge 2} - \frac{1}{200}$$

$$CRR_{7.5} = 0.14598$$

Step 6 : Obtain Critical Resistance Ratio CRR by correcting standard Critical Resistance Ratio *CRR7.5* for earthquake magnitude, stress level and initial static shear using:

1 k_σ = 1 Correction for high overburden pressure is required when overburden pressure is high(depth > 15 m)
2 k_α = 1 Assumed (not required in routine engineering practice)
3 MSF = 1 (This factor is required when the magnitude is different than 7.5)

$$CRR = CRR_{7.5}(MSF)\, k_\sigma\, k_\alpha$$

CRR = 0.14598 x 1 x 1 x1 = 0.14598

Step 7: Calculate the Factor of Safety FS against initial liquefaction using:

$$FS = \frac{CRR}{CSR} = \frac{0.14598}{0.31809} = 0.45892 \text{ (< 1 Hence liquefiable)}$$

Similarly, calculation is being performed for each layer of soil in MS excel. And results shown in table below.

4.3 PROBABILISTIC APPROACH

Civil engineers usually use a factor of safety (FS) to evaluate the safety of a structure. The safety factor is defined as the strength of a member divided by the load applied to it. Most design codes require that a member's calculated safety factor should be greater than a specified safety factor, a value at least larger than one, to ensure the safety of the designed structure. The specified safety factor is largely determined by experience, there has been no rational way to determine such a factor up to now. Because the safety factor-based design method does not consider the variability of the member strength or the applied loading, the probability that the structure will fail cannot be known. Engineering design methods based on reliability analysis have been born against this background.

The reliability method requires a detailed investigation of the member strength and the applied loading data, from which statistical indices, such as the mean value and the coefficient of variation, can be derived. Then, using the first order and second moment method, the relationships between the failure probability, the reliability index and the safety factor can be deduced. As science and technology progress, more data about member strength and loading are collected, making engineering reliability analysis more feasible. These developments have led to the gradual evolution of design codes in various countries, from safety factor-based methods to reliability-based ones. There has been some research on reliability analysis in liquefaction areas. They used the same linear first order and second moment method to assess the variability of the major parameters that influence soil liquefaction and to set up probability models for liquefaction evaluation. However, these models have adopted the early simplified methods for liquefaction evaluation; the soil parameters they used are rarely used now. Moreover, the rationality of the reliability analysis results largely depends on the amount and quality of the collected data used to deduce the statistics of earthquake-induced cyclic stress and cyclic soil strength. Liao et al.[13] collected data for 289 liquefaction and non liquefaction cases around the world, then employed the logistic regression model to establish probabilistic cyclic strength curves. Since that effort, this methodology has attracted much attention. Similar probabilistic cyclic strength curves, based on the SPT-N, CPT-qc, and Vs parameters have been proposed [14-16]. These models only consider the variability of the soil cyclic strength, but do not take into consideration the variability of the earthquake induced cyclic shear stress.

Juang et al. [17,18] proposed a limit state curve, which separates the states of liquefaction and non-liquefaction by using an artificial neural network. They developed a reliability-based method for assessing the liquefaction potential by introducing the Bayes' mapping theorem. Their work also contains a useful discussion on the relation of the safety factor and the liquefaction probability, which has led to a notable advancement in the state of the art for liquefaction evaluation. Nevertheless, the use of an artificial neural network, with its hidden variables, does not have a clear physical meaning, which may explain why practicing engineers have not much familiarized themselves with this technique. In this study, a practical reliability-based method is developed for assessing the soil liquefaction potential. The proposed approach, based on conventional probability theory, enables the earthquake-induced cyclic stress ratio (CSR) and the soil cyclic resistance ratio (CRR) statistics to be clearly derived.

On the basis of the simplified SPT-N method proposed by Seed et al. [19], the probability density function (PDF) can be deduced for the earthquake-induced cyclic stress ratio, by means of the empirical peak ground acceleration attenuation law and its statistics. We used a revised version of the logistic model proposed by Liao et al. [13] to regress the probabilistic cyclic strength curves with cases of liquefaction and non-liquefaction. The PDF of the soil cyclic resistance ratio is then derived from these curves. With the CSR and CRR statistics, it becomes very simple to calculate the relationship between the liquefaction probability, the reliability index and the safety factor by way of the first order and second moment method.

The first step in engineering reliability analysis is to define the performance function of a structure. If the performance function values of some parts of the whole structure exceed a specified value under a given load, it is thought that the structure will fail to satisfy the required function. This specified value (state) is called the limit state of the performance function of the structure. In the simplified liquefaction potential assessment methods, if the CSR is denoted as S; and the CRR is denoted as R; we can define the performance function for liquefaction as $Z = R - S$. If $Z = R - S < 0$; the performance state is designated as 'failed', i.e. liquefaction occurs. If $Z = R - S > 0$; the performance state is designated as 'safe', i.e. no liquefaction occurs. If $Z = R - S = 0$; the performance state is designated as a 'limit state', i.e. on the boundary between liquefaction and non-liquefaction states. Since there are some inherent uncertainties involved in the estimation of the CSR and the CRR, we can treat R and S as random variables, hence the liquefaction performance function will also be a random variable. Therefore, the above three performance states can only be assessed as having some probability of occurrence.

The liquefaction probability is defined as the probability that $Z = R - S \leq 0$. However, an exact calculation of this probability is not easy. In reality, it is difficult to accurately find the PDFs of random variables, such as R and S. Moreover, the calculation of the probability of $Z = R - S \leq 0$ needs multiple integration over the R and S domains, which is a complicated and tedious process. A simplified calculation method, the first order and second moment method, has been developed to meet this need. The method uses the statistics of the basic independent random variables, such as R and S; to calculate the approximate statistics of the performance function variable, in this case $Z = R - S$; so as to bypass the complicated integration process. According to the principle of statistics, the performance function $Z = R - S$ is also a normally distributed random variable, if both R and S are independent random variables under normal distribution. If the probability density function (PDF) and the cumulative probability function (CPF) of Z are denoted as $f_z(z)$ and $F_z(z)$ respectively, the liquefaction probability P_f then equals the probability of $Z = R - S \leq 0$. Hence

$$P_f = P(z \leq 0) = \int_{-\infty}^{0} f z(z) dz = F_z(z) \qquad \text{.............................(1)}$$

If the mean values and standard deviations of R and S are μ_r, μ_s and σ_r, σ_s according to the first order and second moment method, the mean value μ_z the standard deviation σ_z and the coefficient of variation δ_z of Z; can be derived as follows :

$$\mu_z = \mu_r - \mu_s \qquad \text{............................(2)}$$

$$\sigma_z = \sqrt{\sigma_R{}^2 + \sigma_S{}^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

$$\delta_z = \frac{\sigma_z}{\mu_z} = \frac{\sqrt{\sigma_R{}^2+\sigma_S{}^2}}{\mu_R - \mu_S} \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

The statistics for the performance function Z can be simply calculated by Eqs. (2)–(4), using statistics for the basic variables R and S. This shows the advantage of the first order and second moment method. **The reliability index** β is defined as the inverse of the coefficient of variation δ_Z and is used to measure the reliability of the liquefaction evaluation results. β is expressed as:

$$\beta = \frac{1}{\delta z} = \frac{\mu_R - \mu_S}{\sqrt{\sigma_R{}^2+\sigma_S{}^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

$$\mu_z = \beta.\ \sigma_z \quad \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

In Fig. 1 the liquefaction probability is indicated by the shaded tail areas of the PDF $f_z(z)$ of the performance function Z, Since $\mu_Z = \beta.\ \sigma_Z$, the larger the β; the greater the mean value μ_Z, and the smaller the shaded area and the liquefaction probability P_f, This means that β has a unique relation with P_f and can be used as an index to measure the reliability of the liquefaction evaluation. Since the normal distribution is the most important and the simplest probability distribution, we first assume that R and S are independent variables with a normal distribution to demonstrate the process of the reliability analysis. Based on this assumption, the performance function Z = R - S is also in a normal distribution of $Z\tilde{}(\mu_Z, \sigma_Z{}^2)$ By placing the PDF of Z into Eq. (1), we obtain the following liquefaction probability P_f :

$$P_f = \int_{-\infty}^{0} fz(z)dz = \int_{-\infty}^{0} \frac{1}{\sqrt{2\Pi}\,\sigma_Z} e^{-1/2(z-\mu_Z/\sigma_Z)^2}$$

The above equation can be rewritten as

$$P_f = \frac{1}{\sqrt{2\Pi}} \int_{-\infty}^{-\mu_z/\sigma_z} e^{-t^2/2}\, dz = \Phi(-\frac{\mu_z}{\sigma_z})$$

Where, $t = (\frac{z-\mu_z}{\sigma_z})$

where Φ is the cumulative probability function for a standard normal distribution. Since

$\beta = \mu_z/\sigma_z$ then

$$P_f = \Phi(-\beta) = 1 - \Phi(\beta)$$

The probability distribution of the basic engineering variables are usually slightly skewed, so they cannot be reasonably modeled by a normal distribution function. It has been found that most of the basic variables in engineering areas can be described more accurately by a log-normal distribution model, such as that proposed by Rosenblueth and Estra [20]. In this research, we also found that the CRR and the CSR data are more close to log-normal distributions, therefore, assumed that R (CRR) and S (CSR) are log– normal distributions. Based on this assumption, the liquefaction performance function is defined as Z = ln(R/S) = ln(R) - ln(S) since the state of ln(R/S) = ln(1) = 0 is equivalent to the state of (R/S) = 1 or (R – S) = 0, the limit state of liquefaction. Then, the reliability index β and the liquefaction probability P_f can be expressed as

$$\beta = \frac{1}{\delta z} = \frac{\mu_R - \mu_S}{\sqrt{\sigma_R{}^2+\sigma_S{}^2}} = \frac{\ln\left[\frac{\mu_R}{\mu_S}\left(\frac{\delta_S^2+1}{\delta_R^2+1}\right)^{1/2}\right]}{\left[\ln\left(\delta_{S+1}^2\right)(\delta_R^2+1)\right]^{1/2}}$$

$$P_f = \Phi(-\beta) = 1 - \Phi(\beta)$$

According to the safety factor-based design method, the safety factor FS for liquefaction is defined as the ratio of the mean values of R and S. Hence

$$FS = \frac{\mu_R}{\mu_S}$$

4.4 PROBABILISTIC CALCULATIONS

Step by step calculation for the depth of 3m is given below. Detailed calculations for all the depths are given in Table 10.2. This table provides the Reliabilty function (β) and probability of liquefaction (P_f) for different depths.

$\frac{a\ max}{g} = 0.24$

$M_w = 7.5$

$\gamma_{sat} = 1.92\ t/m^3$

$\gamma_w = 1\ t/m^3$

Depth at which liquefaction potential is to be evaluated = 3 m

$CSR = 0.31809$

$CRR_{7.5} = 0.14598$

$CRR = 0.14598$

$FS = \frac{CRR}{CSR} = 0.4589$

Deterministic result = liquefiable

$\mu_R = 0.31809$

$\mu_s = 0.14598$

$\sigma_R = 0.44101$

$\sigma_S = 0.08194$

Coefficient of variation δ_R of R :

$$\boldsymbol{\delta_R} = \frac{\sigma_R}{\mu_R} = \frac{0.44101}{0.31809} = 1.3864$$

Coefficient of variation δ_S of S :

$$\boldsymbol{\delta_S} = \frac{\sigma_S}{\mu_S} = \frac{0.08194}{0.14598} = 0.5613$$

The reliability index β :

$$\beta = \frac{\ln\left[\frac{\mu_R}{\mu_S}\left(\frac{\delta_S^2+1}{\delta_R^2+1}\right)^{1/2}\right]}{\left[\ln(\delta_S^2+1)(\delta_R^2+1)\right]^{1/2}}$$

on putting the values mentioned above, we get

$\beta = -1.23456$

mean value μ_z of Z:

$\mu_z = \mu_r - \mu_s$

$= 0.14598 - 0.31809 = -0.17212$

Standard deviation σ_z of Z :

$$\sigma_z = \sqrt{\sigma_R{}^2 + \sigma_S{}^2}$$

$$= \sqrt{0.44101^2 + 0.08194^2} = 0.44856$$

Probability function for a standard normal distribution:

$\Phi(\beta)$ = this value can be obtained using MS Excel software directly, by applying Normal Distribution function.

$\Phi(\beta) = 0.00893$

Liquefaction probability P_f :

$P_f = \Phi(-\beta) = 1 - \Phi(\beta)$

$= 1 - 0.00893 = 0.99107$

$P_f = 0.99107$

Hence, this layer has a high probability of liquefaction.

And the results of Probabilistic approach is similar to Deterministic approach.

CHAPTER 5

Results and Conclusions:

Determination of liquefaction potential due to an earthquake is a complex geotechnical engineering problem. Many factors, including soil parameters and seismic characteristics influence this phenomenon. Several methods developed for the assessment of the liquefaction potential. This study we used IS code method for deterministic approach and reliability method for probabilistic approach and have been discussed in detail. To assess the liquefaction hazard in an area, it is important to examine initially the liquefaction susceptibility. Before proceeding to the rigorous investigation of the liquefaction potential for Delhi region, first qualitative assessment of liquefiable soils is carried out based on the geotechnical characteristics. The percentage of silt is high in the north and eastern side of Delhi indicating that there is a great chance of soil being subjected to liquefaction.

Liquefaction potential over the study area was evaluated using the simplified procedure based on the available SPT profile of soil. The analysis involved two approaches, Deterministic and Probabilistic respectively.

SPT results of 10 bore hole were obtained, each at a interval of 200m. And using the soil characteristics like fine content, saturated unit weight, etc, each layer of soil of 1.5m depth is checked whether liquefiable or not. SPT test gave the no. of blow count (N) at each interval of 1.5m up to the depth of 35m below ground level. The analysis is performed on the software called MS EXCEL. The data is analyzed in tabular form. A number of corrections were applied to obtain the most precise results.

- Both the approaches used obtained almost same results as shown in Table 1.
- Table 2 to Table 11 shows the results of deterministic approach and
- Table 12 to Table 21 shows the results of probabilistic approach.
- Under probabilistic approach probability of liquefaction is obtained between 0 to 1. As we can see the values near to 1 are liquefiable and values near to 0 are non liquefiable.

- The results obtained shows that the soil is susceptible to liquefaction maximum up to the depth of 9m.
- The present analysis highlights the advantage of probabilistic analysis for liquefaction evaluation and also the need to consider various soil profiles in same area at different depths..

TABLE 1: probability of liquefaction and factor of safety (comparative) results.

Depth	BORE HOLE 1	BORE HOLE 2	BORE HOLE 3	BORE HOLE 4	BORE HOLE 5	BORE HOLE 6	BORE HOLE 7	BORE HOLE 8	BORE HOLE 9	BORE HOLE 10
1.5	P = 0.99 & FOS = 0.49	P = 0.98 & FOS = 0.51	P = 0.99 & FOS = 0.54	P = 1.00 & FOS = 0.45	P = 1.00 & FOS = 0.37	P = 1.00 & FOS = 0.58	P = 1.00 & FOS = 0.52	P = 1.00 & FOS = 0.58	P = 1.00 & FOS = 0.58	P = 1.00 & FOS = 0.42
3	P = 0.99 & FOS = 0.46	P = 0.96 & FOS = 0.64	P = 0.97 & FOS = 0.67	P = 1.00 & FOS = 0.63	P = 1.00 & FOS = 0.47	P = 0.01 & FOS = 1.32	P = 1.00 & FOS = 0.66	P = 1.00 & FOS = 0.75	P = 1.00 & FOS = 0.45	P = 0.99 & FOS = 0.46
4.5	P = 0.97 & FOS = 0.63	P = 0.93 & FOS = 0.77	P = 0.00 & FOS = 0.66	P = 1.00 & FOS = 0.70	P = 0.95 & FOS = 0.77	P = 0.59 & FOS = 1.06	P = 1.00 & FOS = 0.76	P = 0.98 & FOS = 0.85	P = 1.00 & FOS = 0.49	P = 0.99 & FOS = 0.57
6	P = 0.18 & FOS = 1.96	P = 0.96 & FOS = 0.63	P = 0.00 & FOS = 2.73	P = 0.89 & FOS = 0.97	P = 0.99 & FOS = 0.53	P = 0.00 & FOS = 1.41	P = 1.00 & FOS = 0.81	P = 1.00 & FOS = 0.57	P = 0.37 & FOS = 1.31	P = 0.99 & FOS = 0.57
7.5	Can't be determined	P = 0.94 & FOS = 0.75	P = 0.96 & FOS = 0.75	P = 0.00 & FOS = 1.78	P = 0.94 & FOS = 0.79	P = 0.00 & FOS = 1.77	P = 0.27 & FOS = 1.13	P = 0.01 & FOS = 1.48	P = 0.99 & FOS = 0.66	P = 0.80 & FOS = 1.10
9	P = 1.00 & FOS = 0.22	P = 0.26 & FOS = 2.03	P = 0.65 & FOS = 1.31	P = 0.64 & FOS = 1.05	P = 1.00 & FOS = 0.46	P = 0.01 & FOS = 1.31	P = 0.07 & FOS = 1.22	P = 0.99 & FOS = 0.82	P = 1.00 & FOS = 0.44	P = 0.83 & FOS = 1.06
10.5	P = 1.00 & FOS = 0.24	P = 0.99 & FOS = 0.47	P = 0.98 & FOS = 0.67	P = 0.02 & FOS = 1.32	P = 0.92 & FOS = 0.80	Can't be determined	P = 0.00 & FOS = 1.60	P = 0.88 & FOS = 0.99	P = 1.00 & FOS = 0.53	P = 0.76 & FOS = 1.18
12	P = 0.90 & FOS = 0.93	P = 0.15 & FOS = 2.36	P = 0.78 & FOS = 1.17	P = 0.57 & FOS = 1.08	P = 0.70 & FOS = 1.05	P = 0.00 & FOS = 2.16	P = 1.00 & FOS = 0.53	P = 0.90 & FOS = 0.98	P = 0.85 & FOS = 0.95	P = 0.03 & FOS = 2.36
13.5	P = 0.84 & FOS = 1.08	P = 0.21 & FOS = 2.25	P = 0.73 & FOS = 1.26	P = 0.29 & FOS = 1.17	P = 0.46 & FOS = 1.20	P = 0.00 & FOS = 2.33	P = 0.39 & FOS = 1.13	P = 0.30 & FOS = 1.27	P = 0.48 & FOS = 1.14	P = 0.03 & FOS = 2.46

- Pink = liquefiable
- white = Non-liquefiable
- yellow = cannot be determined

22.5	P = 0.89 & FOS = 1.07	P = 0.66 & FOS = 1.61	P = 0.66 & FOS = 1.50	P = 0.60 & FOS = 1.14	P = 0.98 & FOS = 0.63	P = 0.05 & FOS = 1.38	P = 0.00 & FOS = 5.30	P = 0.00 & FOS = 2.70	P = 0.07 & FOS = 1.38	P = 0.27 & FOS = 2.08
24	P = 0.01 & FOS = 3.69	P = 0.03 & FOS = 3.71	P = 0.34 & FOS = 2.00	P = 0.00 & FOS = 2.52	P = 0.94 & FOS = 0.77	P = 0.00 & FOS = 2.24	P = 0.00 & FOS = 2.38	P = 0.00 & FOS = 3.21	P = 0.38 & FOS = 1.19	Can't be determined
25.5	P = 0.00 & FOS = 4.22	P = 0.01 & FOS = 4.23	P = 0.17 & FOS = 2.42	P = 0.00 & FOS = 3.26	P = 0.98 & FOS = 0.62	P = 0.00 & FOS = 2.87	P = 0.00 & FOS = 3.53	P = 0.00 & FOS = 3.58	P = 0.13 & FOS = 1.33	P = 0.86 & FOS = 1.17
27	P = 0.01 & FOS = 3.86	P = 0.04 & FOS = 3.87	P = 0.05 & FOS = 2.96	P = 0.00 & FOS = 2.58	P = 0.24 & FOS = 1.36	P = 0.00 & FOS = 4.97	P = 0.00 & FOS = 1.15	P = 0.00 & FOS = 2.53	P = 0.01 & FOS = 1.56	P = 0.43 & FOS = 1.95
28.5	P = 0.00 & FOS = 4.51	P = 0.02 & FOS = 4.52	P = 0.00 & FOS = 4.11	P = 0.00 & FOS = 3.42	P = 0.00 & FOS = 2.03	P = 0.00 & FOS = 3.34	P = 0.00 & FOS = 3.16	P = 0.00 & FOS = 3.07	P = 0.88 & FOS = 0.92	P = 0.02 & FOS = 3.50
30	P = 0.00 & FOS = 11.08	P = 0.00 & FOS = 9.15	P = 0.02 & FOS = 3.70	Can't be determined	P = 0.00 & FOS = 2.09	P = 0.00 & FOS = 4.15	P = 0.00 & FOS = 3.78	P = 0.00 & FOS = 7.55	P = 0.32 & FOS = 1.26	P = 0.00 & FOS = 2.70
31.5	P = 0.00 & FOS = 11.22	P = 0.00 & FOS = 10.45	P = 0.00 & FOS = 4.84	Can't be determined	P = 0.00 & FOS = 2.31	P = 0.00 & FOS = 5.47	P = 0.00 & FOS = 4.25	P = 0.00 & FOS = 5.29	P = 0.00 & FOS = 2.42	P = 0.25 & FOS = 7.32
33	P = 0.00 & FOS = 14.70	P = 0.00 & FOS = 13.10	P = 0.00 & FOS = 6.88	P = 0.00 & FOS = 4.33	P = 0.00 & FOS = 2.73	P = 0.00 & FOS = 6.23	P = 0.00 & FOS = 9.93	P = 0.00 & FOS = 7.06	P = 0.00 & FOS = 2.80	P = 0.00 & FOS = 2.53
35	P = 0.00 & FOS = 17.22	P = 0.00 & FOS = 17.69	P = 0.00 & FOS = 8.78	P = 0.00 & FOS = 8.10	P = 0.00 & FOS = 3.69	P = 0.00 & FOS = 9.77	P = 0.00 & FOS = 7.95	P = 0.00 & FOS = 10.78	P = 0.00 & FOS = 3.48	P = 0.00 & FOS = 26.76

- Pink = liquefiable
- white = Non-liquefiable
- yellow = cannot be determined

CONCLUSIONS

The comparative results shown in the above table 1 describe the almost same results for liquefaction.

- Factor of safety less than 1 describe the soil layer is liquefiable
- Probability of liquefaction close to 1 describe the soil is liquefiable
- Probability of liquefaction close to 0 describe the soil is non- liquefiable

Hence both the studies (deterministic and probabilistic)shows the similar results.

RESULTS

TABLE 2: Deterministic analysis of bore hole no.1

Depth	Type of Strata	Observed SPT value	Saturated Density (t/m3)	Fine Content (%)	Reduction factor (rd)	Total virtical overburden pressure (t/m2)	Effective virtical overburden pressure (t/m2)	CSR	C(ht)	C(hw)	C(bd)	C(ss)	C(rl)	C(60)	N60	C(N)	(N1)60	α	β	(N1)60,cs	CRR(M=7.5)	MSF	Kσ	Kα	CRR	FS	Conclusion
1.5	CL	6	1.92	64	0.9885	2.88	1.38	0.3218	1	1	1.05	1	0.75	0.7875	4.725	1.7	8.0325	5	1.2	14.639	0.1565	1	1	1	0.1565	0.4861	Liquefiable
3	CL	5	1.92	49	0.9771	5.76	2.76	0.3181	1	1	1.05	1	0.8	0.84	4.2	1.7	7.14	5	1.2	13.568	0.146	1	1	1	0.146	0.4589	Liquefiable
4.5	CL	8	1.92	49	0.9656	8.64	4.14	0.3144	1	1	1.05	1	0.85	0.8925	7.14	1.5796	11.278	5	1.2	18.534	0.1979	1	1	1	0.1979	0.6295	Liquefiable
6	CH	18	1.88	95	0.9541	11.52	5.52	0.3106	1	1	1.05	1	0.85	0.8925	16.065	1.368	21.977	5	1.2	31.372	0.6083	1	1	1	0.6083	1.9583	Non-Liquefiable
7.5	ML	21	1.88	64	0.9426	14.34	6.84	0.3083	1	1	1.05	1	0.95	0.9975	20.948	1.2289	25.743	5	1.2	35.891	-0.268	1	1	1	-0.268	-0.868	
9	ML	25	1.88	91	0.9312	17.16	8.16	0.3055	1	1	1.05	1	0.95	0.9975	24.938	1.1251	28.058	5	1.2	38.67	0.0676	1	1	1	0.0676	0.2212	Liquefiable
10.5	ML	27	2	91	0.8937	19.98	9.48	0.2938	1	1	1.05	1	0.95	0.9975	26.933	1.0439	28.114	5	1.2	38.737	0.0711	1	1	1	0.0711	0.242	Liquefiable
12	ML	34	2.01	65	0.8536	22.98	10.98	0.2787	1	1	1.05	1	1	1.05	35.7	0.9699	34.627	5	1.2	46.553	0.2604	1	1	1	0.2604	0.9342	Liquefiable
13.5	SM	38	2.01	39	0.8136	25.995	12.495	0.264	1	1	1.05	1	1	1.05	39.9	0.9092	36.279	5	1.2	48.535	0.2859	1	1	1	0.2859	1.0828	Non-Liquefiable
15	CL	76	2.03	88	0.7735	29.01	14.01	0.2499	1	1	1.05	1	1	1.05	79.8	0.8587	68.523	5	1.2	87.227	0.6224	1	1	1	0.6224	2.491	Non-Liquefiable
16.5	CL	75	2.03	88	0.7335	32.055	15.555	0.2358	1	1	1.05	1	1	1.05	78.75	0.8149	64.175	5	1.2	82.01	0.5817	1	1.1307	1	0.6577	2.7895	Non-Liquefiable
18	CL	42	2.03	80	0.6934	35.1	17.1	0.222	1	1	1.05	1	1	1.05	44.1	0.7772	34.276	5	1.2	46.131	0.2545	1	1.1632	1	0.296	1.3332	Non-Liquefiable
19.5	CL	44	2.03	80	0.6534	38.145	18.645	0.2085	1	1	1.05	1	1	1.05	46.2	0.7443	34.388	5	1.2	46.266	0.2564	1	1.1938	1	0.3061	1.4678	Non-Liquefiable
21	SM	40	2	31	0.6133	41.19	20.19	0.1952	1	1	1.05	1	1	1.05	42	0.7153	30.042	4.7697	1.1626	39.697	0.1138	1	1.2227	1	0.1391	0.7126	Liquefiable
22.5	SM	43	2	31	0.5733	44.19	21.69	0.1822	1	1	1.05	1	1	1.05	45.15	0.6901	31.159	4.7697	1.1626	40.995	0.1559	1	1.2492	1	0.1948	1.0692	Non-Liquefiable
24	SM	78	2.04	41	0.5332	47.19	23.19	0.1693	1	1	1.05	1	1	1.05	81.9	0.6674	54.662	5	1.2	70.594	0.4907	1	1.2746	1	0.6254	3.6948	Non-Liquefiable
25.5	SM	83	2.04	41	0.4932	50.25	24.75	0.1562	1	1	1.05	1	1	1.05	87.15	0.646	56.303	5	1.2	72.563	0.5067	1	1.2997	1	0.6585	4.2159	Non-Liquefiable
27	CL	72	2.05	79	0.4531	53.31	26.31	0.1432	1	1	1.05	1	1	1.05	75.6	0.6266	47.371	5	1.2	61.845	0.4173	1	1.3238	1	0.5524	3.8571	Non-Liquefiable
28.5	CL	77	2.05	79	0.4131	56.385	27.885	0.1303	1	1	1.05	1	1	1.05	80.85	0.6086	49.209	5	1.2	64.051	0.4363	1	1.347	1	0.5877	4.5105	Non-Liquefiable
30	SM	168	2.06	35	0.373	59.46	29.46	0.1174	1	1	1.05	1	1	1.05	176.4	0.5922	104.46	5	1.2	130.35	0.9502	1	1.3694	1	1.3012	11.08	Non-Liquefiable
31.5	SM	153	2.06	35	0.333	62.55	31.05	0.1046	1	1	1.05	1	1	1.05	160.65	0.5768	92.662	5	1.2	116.19	0.8436	1	1.3912	1	1.1736	11.216	Non-Liquefiable
33	CL	178	2.06	90	0.2929	65.64	32.64	0.0919	1	1	1.05	1	1	1.05	186.9	0.5626	105.14	5	1.2	131.17	0.9564	1	1.4122	1	1.3506	14.698	Non-Liquefiable
35	SM	197	2.06	19	0.2395	68.73	33.73	0.0761	1	1	1.05	1	1	1.05	206.85	0.5534	114.47	3.4336	1.0728	126.24	0.9193	1	1.4262	1	1.3111	17.221	Non-Liquefiable

TABLE 3: Deterministic analysis of bore hole no.2

Depth	Type of Strata	Observed SPT value	Saturated Density (t/m3)	Fine Content (%)	Reduction factor (rd)	Total virtical overburden pressure (t/m2)	Effective virtical overburden pressure (t/m2)	CSR	C(ht)	C(hw)	C(bd)	C(ss)	C(rl)	C(60)	N60	C(N)	(N1)60	α	β	(N1)60_cs	CRR(M=7.5)	MSF	Kσ	Kα	CRR	FS	Conclusion
1.5	SM	7	1.94	28	0.9885	2.91	1.41	0.3183	1	1	1.05	1	0.75	0.7875	5.5125	1.7	9.3713	4.561	1.138	15.225	0.1623	1	1	1	0.1623	0.5101	Liquefiable
3	SM	8	1.94	35	0.9771	5.82	2.82	0.3146	1	1	1.05	1	0.8	0.84	6.72	1.7	11.424	5	1.2	18.709	0.1999	1	1	1	0.1999	0.6355	Liquefiable
4.5	SM	10	1.94	35	0.9656	8.73	4.23	0.3109	1	1	1.05	1	0.85	0.8925	8.925	1.5627	13.947	5	1.2	21.737	0.2383	1	1	1	0.2383	0.7665	Liquefiable
6	SM	9	1.96	39	0.9541	11.64	5.64	0.3072	1	1	1.05	1	0.85	0.8925	8.0325	1.3534	10.871	5	1.2	18.045	0.1923	1	1	1	0.1923	0.6261	Liquefiable
7.5	SM	11	1.96	39	0.9426	14.58	7.08	0.3028	1	1	1.05	1	0.95	0.9975	10.973	1.2079	13.254	5	1.2	20.905	0.227	1	1	1	0.227	0.7496	Liquefiable
9	ML-CL	20	2	91	0.9312	17.52	8.52	0.2987	1	1	1.05	1	0.95	0.9975	19.95	1.1011	21.967	5	1.2	31.361	0.6066	1	1	1	0.6066	2.0306	Non-Liquefiable
10.5	SM	29	1.98	36	0.8937	20.52	10.02	0.2855	1	1	1.05	1	0.95	0.9975	28.928	1.0154	29.372	5	1.2	40.246	0.1333	1	1	1	0.1333	0.4668	Liquefiable
12	SM	71	2.02	36	0.8536	23.49	11.49	0.2722	1	1	1.05	1	1	1.05	74.55	0.9482	70.687	5	1.2	89.824	0.6425	1	1	1	0.6425	2.3601	Non-Liquefiable
13.5	SM	74	2.02	26	0.8136	26.52	13.02	0.2585	1	1	1.05	1	1	1.05	77.7	0.8907	69.209	4.388	1.1225	82.076	0.5822	1	1	1	0.5822	2.2523	Non-Liquefiable
15	CL	75	2.06	84	0.7735	29.55	14.55	0.2451	1	1	1.05	1	1	1.05	78.75	0.8426	66.354	5	1.2	84.625	0.6022	1	1	1	0.6022	2.4572	Non-Liquefiable
16.5	CL	63	2.06	84	0.7335	32.64	16.14	0.2314	1	1	1.05	1	1	1.05	66.15	0.8	52.921	5	1.2	68.505	0.4736	1	1.1432	1	0.5414	2.3398	Non-Liquefiable
18	ML	31	1.98	53	0.6934	35.73	17.73	0.218	1	1	1.05	1	1	1.05	32.55	0.7633	24.845	5	1.2	34.815	-0.974	1	1.1759	1	-1.146	-5.257	
19.5	ML	39	1.98	53	0.6534	38.7	19.2	0.2054	1	1	1.05	1	1	1.05	40.95	0.7335	30.037	5	1.2	41.044	0.1573	1	1.2044	1	0.1895	0.9222	Liquefiable
21	ML	43	1.98	80	0.6133	41.67	20.67	0.1929	1	1	1.05	1	1	1.05	45.15	0.7069	31.918	5	1.2	43.302	0.2085	1	1.2313	1	0.2567	1.3308	Non-Liquefiable
22.5	ML	46	1.98	80	0.5733	44.64	22.14	0.1803	1	1	1.05	1	1	1.05	48.3	0.6831	32.992	5	1.2	44.59	0.2311	1	1.257	1	0.2905	1.6109	Non-Liquefiable
24	SM	78	2.03	38	0.5332	47.61	23.61	0.1677	1	1	1.05	1	1	1.05	81.9	0.6615	54.173	5	1.2	70.008	0.4859	1	1.2814	1	0.6226	3.7122	Non-Liquefiable
25.5	SM	83	2.03	38	0.4932	50.655	25.155	0.1549	1	1	1.05	1	1	1.05	87.15	0.6408	55.848	5	1.2	72.017	0.5022	1	1.306	1	0.656	4.2342	Non-Liquefiable
27	CL	72	2.05	87	0.4531	53.7	26.7	0.1422	1	1	1.05	1	1	1.05	75.6	0.622	47.024	5	1.2	61.428	0.4137	1	1.3296	1	0.55	3.8691	Non-Liquefiable
28.5	CL	77	2.05	87	0.4131	56.775	28.275	0.1294	1	1	1.05	1	1	1.05	80.85	0.6044	48.868	5	1.2	63.642	0.4328	1	1.3527	1	0.5854	4.5247	Non-Liquefiable
30	CL	138	2.05	90	0.373	59.85	29.85	0.1167	1	1	1.05	1	1	1.05	144.9	0.5883	85.241	5	1.2	107.29	0.7761	1	1.3748	1	1.0671	9.146	Non-Liquefiable
31.5	CL	142	2.05	90	0.333	62.925	31.425	0.104	1	1	1.05	1	1	1.05	149.1	0.5733	85.485	5	1.2	107.58	0.7784	1	1.3962	1	1.0867	10.449	Non-Liquefiable
33	ML	158	2.06	60	0.2929	66	33	0.0914	1	1	1.05	1	1	1.05	165.9	0.5595	92.82	5	1.2	116.38	0.845	1	1.4169	1	1.1972	13.101	Non-Liquefiable
35	SM	178	2.06	37	0.2395	69.09	34.09	0.0757	1	1	1.05	1	1	1.05	186.9	0.5505	102.88	5	1.2	128.46	0.936	1	1.4307	1	1.3392	17.685	Non-Liquefiable

TABLE 4: Deterministic analysis of bore hole no.3

Depth	Type of Strata	Observed SPT value	Saturated Density (t/m3)	Fine Content (%)	Reduction factor (rd)	Total virtical overburden pressure (t/m2)	Effective virtical overburden pressure (t/m2)	CSR	C(ht)	C(hw)	C(bd)	C(ss)	C(rl)	C(60)	N60	C(N)	(N1)60	α	β	(N1)60_cs	CRR(M=7.5)	MSF	Kσ	Kα	CRR	FS	Conclusion
1.5	SM	7	1.94	38	0.9885	2.91	1.41	0.3183	1	1	1.05	1	0.75	0.7875	5.5125	1.7	9.3713	5	1.2	16.246	0.1728	1	1	1	0.1728	0.543	Liquefiable
3	SM	9	1.94	31	0.9771	5.82	2.82	0.3146	1	1	1.05	1	0.8	0.84	7.56	1.7	12.852	4.7697	1.1626	19.711	0.2118	1	1	1	0.2118	0.6735	Liquefiable
4.5	CL	17	2	91	0.9656	8.73	4.23	0.3109	1	1	1.05	1	0.85	0.8925	15.173	1.5627	23.71	5	1.2	33.452	2.0692	1	1	1	2.0692	6.656	Non-Liquefiable
6	CL	19	2	91	0.9541	11.73	5.73	0.3047	1	1	1.05	1	0.85	0.8925	16.958	1.3427	22.769	5	1.2	32.322	0.8308	1	1	1	0.8308	2.7267	Non-Liquefiable
7.5	ML	11	1.97	71	0.9426	14.73	7.23	0.2996	1	1	1.05	1	0.95	0.9975	10.973	1.1953	13.116	5	1.2	20.739	0.2248	1	1	1	0.2248	0.7504	Liquefiable
9	ML	18	1.97	71	0.9312	17.685	8.685	0.2958	1	1	1.05	1	0.95	0.9975	17.955	1.0906	19.582	5	1.2	28.498	0.3883	1	1	1	0.3883	1.3128	Non-Liquefiable
10.5	ML	31	1.97	71	0.8937	20.64	10.14	0.2838	1	1	1.05	1	0.95	0.9975	30.923	1.0093	31.211	5	1.2	42.453	0.1914	1	1	1	0.1914	0.6745	Liquefiable
12	SM	39	2.01	37	0.8536	23.595	11.595	0.271	1	1	1.05	1	1	1.05	40.95	0.9439	38.652	5	1.2	51.382	0.3182	1	1	1	0.3182	1.1744	Non-Liquefiable
13.5	SM	42	2.01	37	0.8136	26.61	13.11	0.2576	1	1	1.05	1	1	1.05	44.1	0.8877	39.146	5	1.2	51.975	0.3245	1	1	1	0.3245	1.2598	Non-Liquefiable
15	CL	32	2.03	83	0.7735	29.625	14.625	0.2444	1	1	1.05	1	1	1.05	33.6	0.8404	28.238	5	1.2	38.886	0.0787	1	1	1	0.0787	0.3218	Liquefiable
16.5	CL	36	2.03	83	0.7335	32.67	16.17	0.2312	1	1	1.05	1	1	1.05	37.8	0.7993	30.213	5	1.2	41.255	0.163	1	1.1439	1	0.1864	0.8065	Liquefiable
18	CL	39	2.03	83	0.6934	35.715	17.715	0.2181	1	1	1.05	1	1	1.05	40.95	0.7636	31.27	5	1.2	42.524	0.1929	1	1.1756	1	0.2268	1.04	Non-Liquefiable
19.5	CL	40	2.03	83	0.6534	38.76	19.26	0.2051	1	1	1.05	1	1	1.05	42	0.7324	30.759	5	1.2	41.911	0.1793	1	1.2055	1	0.2161	1.0536	Non-Liquefiable
21	ML	42	2	83	0.6133	41.805	20.805	0.1922	1	1	1.05	1	1	1.05	44.1	0.7046	31.075	5	1.2	42.289	0.1878	1	1.2337	1	0.2318	1.2055	Non-Liquefiable
22.5	ML	45	2	83	0.5733	44.805	22.305	0.1796	1	1	1.05	1	1	1.05	47.25	0.6805	32.155	5	1.2	43.586	0.2138	1	1.2598	1	0.2693	1.4991	Non-Liquefiable
24	ML	50	2.01	63	0.5332	47.805	23.805	0.167	1	1	1.05	1	1	1.05	52.5	0.6587	34.584	5	1.2	46.501	0.2596	1	1.2846	1	0.3335	1.9968	Non-Liquefiable
25.5	ML	54	2.01	54	0.4932	50.82	25.32	0.1544	1	1	1.05	1	1	1.05	56.7	0.6387	36.216	5	1.2	48.459	0.285	1	1.3086	1	0.3729	2.4151	Non-Liquefiable
27	CL	59	2.04	81	0.4531	53.835	26.835	0.1418	1	1	1.05	1	1	1.05	61.95	0.6204	38.436	5	1.2	51.123	0.3155	1	1.3316	1	0.4201	2.9623	Non-Liquefiable
28.5	CL	71	2.04	81	0.4131	56.895	28.395	0.1291	1	1	1.05	1	1	1.05	74.55	0.6032	44.965	5	1.2	58.958	0.3918	1	1.3544	1	0.5306	4.1099	Non-Liquefiable
30	ML	62	2.02	68	0.373	59.955	29.955	0.1165	1	1	1.05	1	1	1.05	65.1	0.5872	38.229	5	1.2	50.875	0.3128	1	1.3763	1	0.4304	3.696	Non-Liquefiable
31.5	ML	70	2.02	68	0.333	62.985	31.485	0.1039	1	1	1.05	1	1	1.05	73.5	0.5728	42.1	5	1.2	55.52	0.3599	1	1.397	1	0.5028	4.8393	Non-Liquefiable
33	ML	85	2.02	68	0.2929	66.015	33.015	0.0914	1	1	1.05	1	1	1.05	89.25	0.5594	49.923	5	1.2	64.908	0.4435	1	1.417	1	0.6285	6.8794	Non-Liquefiable
35	CL	90	2.02	87	0.2395	69.045	34.045	0.0758	1	1	1.05	1	1	1.05	94.5	0.5508	52.054	5	1.2	67.465	0.465	1	1.4302	1	0.665	8.7758	Non-Liquefiable

TABLE 5: Deterministic analysis of bore hole no.4

Depth	Type of Strata	Observed SPT value	Saturated Density (t/m3)	Fine Content (%)	Reduction factor (rd)	Total virtical overburden pressure (t/m2)	Effective virtical overburden pressure (t/m2)	CSR	C(ht)	C(hw)	C(bd)	C(ss)	C(rl)	C(60)	N60	C(N)	(N1)60	α	β	(N1)60_cs	CRR(M=7.5)	MSF	Kσ	Kα	CRR	FS	Conclusion
1.5	SM	6	1.95	24	0.9885	2.925	1.425	0.3165	1	1	1.05	1	0.75	0.7875	4.725	1.7	8.0325	4.179	1.107	13.071	0.1412	1	1	1	0.1412	0.4461	Liquefiable
3	GM	8	1.95	33	0.9771	5.85	2.85	0.3129	1	1	1.05	1	0.8	0.84	6.72	1.7	11.424	4.881	1.179	18.35	0.1958	1	1	1	0.1958	0.6258	Liquefiable
4.5	ML	9	1.98	63	0.9656	8.775	4.275	0.3092	1	1	1.05	1	0.85	0.8925	8.0325	1.5545	12.486	5	1.2	19.984	0.2152	1	1	1	0.2152	0.696	Liquefiable
6	ML	14	1.98	69	0.9541	11.745	5.745	0.3043	1	1	1.05	1	0.85	0.8925	12.495	1.3409	16.755	5	1.2	25.106	0.294	1	1	1	0.294	0.9661	Liquefiable
7.5	ML	18	1.88	69	0.9426	14.715	7.215	0.2999	1	1	1.05	1	0.95	0.9975	17.955	1.1966	21.484	5	1.2	30.781	0.5341	1	1	1	0.5341	1.7807	Non-Liquefiable
9	ML	16	1.88	63	0.9312	17.535	8.535	0.2984	1	1	1.05	1	0.95	0.9975	15.96	1.1001	17.558	5	1.2	26.07	0.3147	1	1	1	0.3147	1.0547	Non-Liquefiable
10.5	ML	19	1.99	63	0.8937	20.355	9.855	0.2879	1	1	1.05	1	0.95	0.9975	18.953	1.0238	19.404	5	1.2	28.285	0.3799	1	1	1	0.3799	1.3195	Non-Liquefiable
12	ML	37	2	51	0.8536	23.34	11.34	0.2741	1	1	1.05	1	1	1.05	38.85	0.9544	37.08	5	1.2	49.495	0.2973	1	1	1	0.2973	1.0846	Non-Liquefiable
13.5	ML	40	2	51	0.8136	26.34	12.84	0.2604	1	1	1.05	1	1	1.05	42	0.8969	37.672	5	1.2	50.206	0.3054	1	1	1	0.3054	1.1729	Non-Liquefiable
15	ML	31	2	75	0.7735	29.34	14.34	0.2469	1	1	1.05	1	1	1.05	32.55	0.8487	27.627	5	1.2	38.152	0.037	1	1	1	0.037	0.15	Liquefiable
16.5	ML	36	2	75	0.7335	32.34	15.84	0.2336	1	1	1.05	1	1	1.05	37.8	0.8076	30.526	5	1.2	41.631	0.1726	1	1.1368	1	0.1962	0.8398	Liquefiable
18	CL	34	2.03	58	0.6934	35.34	17.34	0.2205	1	1	1.05	1	1	1.05	35.7	0.7718	27.555	5	1.2	38.065	0.0313	1	1.1681	1	0.0365	0.1657	Liquefiable
19.5	CL	35	2.03	58	0.6534	38.385	18.885	0.2072	1	1	1.05	1	1	1.05	36.75	0.7396	27.18	5	1.2	37.616	-0.003	1	1.1984	1	-0.003	-0.015	Liquefiable
21	ML	39	2	49	0.6133	41.43	20.43	0.194	1	1	1.05	1	1	1.05	40.95	0.7111	29.119	5	1.2	39.942	0.1228	1	1.227	1	0.1507	0.7768	Liquefiable
22.5	ML	42	2	49	0.5733	44.43	21.93	0.1812	1	1	1.05	1	1	1.05	44.1	0.6863	30.267	5	1.2	41.32	0.1647	1	1.2534	1	0.2064	1.1395	Non-Liquefiable
24	ML	57	2	52	0.5332	47.43	23.43	0.1684	1	1	1.05	1	1	1.05	59.85	0.664	39.74	5	1.2	52.688	0.3319	1	1.2785	1	0.4244	2.5203	Non-Liquefiable
25.5	SM	68	2.04	32	0.4932	50.43	24.93	0.1556	1	1	1.05	1	1	1.05	71.4	0.6437	45.961	4.828	1.171	58.648	0.389	1	1.3025	1	0.5067	3.2557	Non-Liquefiable
27	SM	56	2.04	32	0.4531	53.49	26.49	0.1427	1	1	1.05	1	1	1.05	58.8	0.6245	36.719	4.828	1.171	47.826	0.2771	1	1.3265	1	0.3676	2.5754	Non-Liquefiable
28.5	CI	62	2.07	90	0.4131	56.55	28.05	0.1299	1	1	1.05	1	1	1.05	65.1	0.6069	39.506	5	1.2	52.407	0.329	1	1.3494	1	0.444	3.4179	Non-Liquefiable
30	CI	39	2.07	90	0.373	59.655	29.655	0.1171	1	1	1.05	1	1	1.05	40.95	0.5902	24.169	5	1.2	34.003	-390.2	1	1.3721	1	-535.4	-4574	Non-Liquefiable
31.5	CI	43	2.07	90	0.333	62.76	31.26	0.1043	1	1	1.05	1	1	1.05	45.15	0.5749	25.955	5	1.2	36.145	-0.203	1	1.394	1	-0.283	-2.714	Non-Liquefiable
33	SM	61	2.01	41	0.2929	65.865	32.865	0.0916	1	1	1.05	1	1	1.05	64.05	0.5606	35.909	5	1.2	48.091	0.2804	1	1.4151	1	0.3969	4.3338	Non-Liquefiable
35	CI	84	2.07	85	0.2395	68.88	33.88	0.076	1	1	1.05	1	1	1.05	88.2	0.5522	48.702	5	1.2	63.442	0.4311	1	1.4281	1	0.6156	8.1047	Non-Liquefiable

TABLE 6: Deterministic analysis of bore hole no.5

Depth	Type of Strata	Observed SPT value	Saturated Density (t/m3)	Fine Content (%)	Reduction factor (rd)	Total virtical overburden pressure (t/m2)	Effective virtical overburden pressure (t/m2)	CSR	C(ht)	C(hw)	C(bd)	C(ss)	C(rl)	C(60)	N60	C(N)	(N1)60	α	β	(N1)60_cs	CRR(M=7.5)	MSF	Kσ	Kα	CRR	FS	Conclusion
1.5	ML	5	1.69	53	0.9885	2.535	1.035	0.3777	1	1	1.05	1	0.75	0.7875	3.9375	1.7	6.6938	5	1.2	13.033	0.1409	1	1	1	0.1409	0.3729	Liquefiable
3	ML	7	1.51	31	0.9771	5.07	2.07	0.3733	1	1	1.05	1	0.8	0.84	5.88	1.7	9.996	4.7697	1.1626	16.391	0.1744	1	1	1	0.1744	0.467	Liquefiable
4.5	CL	10	1.79	89	0.9656	7.335	2.835	0.3897	1	1	1.05	1	0.85	0.8925	8.925	1.9089	17.037	5	1.2	25.444	0.3009	1	1	1	0.3009	0.7721	Liquefiable
6	CL	22	0.99	55	0.9541	10.02	4.02	0.371	1	1	1.05	1	0.85	0.8925	19.635	1.603	31.475	5	1.2	42.77	0.198	1	1	1	0.198	0.5338	Liquefiable
7.5	SM	25	0.95	40	0.9426	11.505	4.005	0.4224	1	1	1.05	1	0.95	0.9975	24.938	1.606	40.05	5	1.2	53.06	0.3357	1	1	1	0.3357	0.7948	Liquefiable
9	SM	20	0.95	40	0.9312	12.93	3.93	0.4779	1	1	1.05	1	0.95	0.9975	19.95	1.6213	32.344	5	1.2	43.813	0.2179	1	1	1	0.2179	0.4558	Liquefiable
10.5	SM	29	1	39	0.8937	14.355	3.855	0.5191	1	1	1.05	1	0.95	0.9975	28.928	1.637	47.353	5	1.2	61.824	0.4171	1	1	1	0.4171	0.8035	Liquefiable
12	SM	37	1	40	0.8536	15.855	3.855	0.5477	1	1	1.05	1	1	1.05	38.85	1.637	63.596	5	1.2	81.315	0.5763	1	1	1	0.5763	1.0522	Non-Liquefiable
13.5	SM	44	1.01	40	0.8136	17.355	3.855	0.5714	1	1	1.05	1	1	1.05	46.2	1.637	75.628	5	1.2	95.753	0.6881	1	1	1	0.6881	1.2044	Non-Liquefiable
15	ML	53	1.01	54	0.7735	18.87	3.87	0.5884	1	1	1.05	1	1	1.05	55.65	1.6338	90.92	5	1.2	114.1	0.8278	1	1	1	0.8278	1.4069	Non-Liquefiable
16.5	ML	60	1.02	54	0.7335	20.385	3.885	0.6004	1	1	1.05	1	1	1.05	63	1.6306	102.73	5	1.2	128.28	0.9346	1	0.7457	1	0.697	1.1609	Non-Liquefiable
18	CL	25	1.02	93	0.6934	21.915	3.915	0.6055	1	1	1.05	1	1	1.05	26.25	1.6244	42.64	5	1.2	56.168	0.3661	1	0.7475	1	0.2736	0.4519	Liquefiable
19.5	CL	36	1.02	93	0.6534	23.445	3.945	0.6057	1	1	1.05	1	1	1.05	37.8	1.6182	61.167	5	1.2	78.401	0.5533	1	0.7492	1	0.4145	0.6843	Liquefiable
21	ML	53	1	59	0.6133	24.975	3.975	0.6011	1	1	1.05	1	1	1.05	55.65	1.6121	89.711	5	1.2	112.65	0.8168	1	0.7509	1	0.6133	1.0203	Non-Liquefiable
22.5	ML	33	1	59	0.5733	26.475	3.975	0.5956	1	1	1.05	1	1	1.05	34.65	1.6121	55.858	5	1.2	72.03	0.5023	1	0.7509	1	0.3772	0.6333	Liquefiable
24	SM	39	1	39	0.5332	27.975	3.975	0.5854	1	1	1.05	1	1	1.05	40.95	1.6121	66.014	5	1.2	84.217	0.599	1	0.7509	1	0.4498	0.7683	Liquefiable
25.5	SM	31	1	39	0.4932	29.475	3.975	0.5705	1	1	1.05	1	1	1.05	32.55	1.6121	52.473	5	1.2	67.967	0.4691	1	0.7509	1	0.3522	0.6175	Liquefiable
27	SM	65	1.03	40	0.4531	30.975	3.975	0.5508	1	1	1.05	1	1	1.05	68.25	1.6121	110.02	5	1.2	137.03	1.0003	1	0.7509	1	0.7511	1.3637	Non-Liquefiable
28.5	SM	92	1.03	40	0.4131	32.52	4.02	0.5213	1	1	1.05	1	1	1.05	96.6	1.603	154.85	5	1.2	190.82	1.4021	1	0.7534	1	1.0564	2.0266	Non-Liquefiable
30	ML	89	1.03	54	0.373	34.065	4.065	0.4876	1	1	1.05	1	1	1.05	93.45	1.5941	148.97	5	1.2	183.76	1.3496	1	0.7559	1	1.0202	2.0922	Non-Liquefiable
31.5	ML	91	1.03	54	0.333	35.61	4.11	0.45	1	1	1.05	1	1	1.05	95.55	1.5854	151.48	5	1.2	186.78	1.372	1	0.7584	1	1.0406	2.3123	Non-Liquefiable
33	ML	98	1.03	54	0.2929	37.155	4.155	0.4086	1	1	1.05	1	1	1.05	102.9	1.5768	162.25	5	1.2	199.7	1.4682	1	0.7609	1	1.1172	2.7343	Non-Liquefiable
35	CL	124	1.07	85	0.2395	38.7	3.7	0.3908	1	1	1.05	1	1	1.05	130.2	1.6709	217.55	5	1.2	266.06	1.9615	1	0.7349	1	1.4415	3.6888	Non-Liquefiable

TABLE 7: Deterministic analysis of bore hole no.6

Depth	Type of Strata	Observed SPT value	Saturated Density (t/m3)	Fine Content (%)	Reduction factor (rd)	Total virtical overburden pressure (t/m2)	Effective virtical overburden pressure (t/m2)	CSR	C(ht)	C(hw)	C(bd)	C(ss)	C(rl)	C(60)	N60	C(N)	(N1)60	α	β	(N1)60_cs	CRR(M=7.5)	MSF	Kσ	Kα	CRR	FS	Conclusion
1.5	SM	8	1.96	30	0.9885	2.94	1.44	0.3148	1	1	1.05	1	0.75	0.7875	6.3	1.7	10.71	4.706	1.154	17.065	0.1815	1	1	1	0.1815	0.5766	Liquefiable
3	ML-CL	14	1.96	60	0.9771	5.88	2.88	0.3112	1	1	1.05	1	0.8	0.84	11.76	1.7	19.992	5	1.2	28.99	0.4098	1	1	1	0.4098	1.3169	Non-Liquefiable
4.5	ML-CL	13	1.97	60	0.9656	8.82	4.32	0.3075	1	1	1.05	1	0.85	0.8925	11.603	1.5464	17.942	5	1.2	26.53	0.3259	1	1	1	0.3259	1.0597	Non-Liquefiable
6	ML	17	1.98	78	0.9541	11.775	5.775	0.3035	1	1	1.05	1	0.85	0.8925	15.173	1.3374	20.292	5	1.2	29.351	0.4279	1	1	1	0.4279	1.4101	Non-Liquefiable
7.5	ML	18	1.98	56	0.9426	14.745	7.245	0.2993	1	1	1.05	1	0.95	0.9975	17.955	1.1941	21.44	5	1.2	30.728	0.5286	1	1	1	0.5286	1.7662	Non-Liquefiable
9	ML	18	1.99	59	0.9312	17.715	8.715	0.2953	1	1	1.05	1	0.95	0.9975	17.955	1.0887	19.548	5	1.2	28.458	0.3867	1	1	1	0.3867	1.3096	Non-Liquefiable
10.5	SM	27	1.99	34	0.8937	20.7	10.2	0.2829	1	1	1.05	1	0.95	0.9975	26.933	1.0064	27.104	4.9315	1.188	37.131	-0.049	1	1	1	-0.049	-0.174	
12	SM	65	1.99	35	0.8536	23.685	11.685	0.2699	1	1	1.05	1	1	1.05	68.25	0.9402	64.171	5	1.2	82.005	0.5817	1	1	1	0.5817	2.1551	Non-Liquefiable
13.5	SM	71	1.99	35	0.8136	26.67	13.17	0.257	1	1	1.05	1	1	1.05	74.55	0.8856	66.024	5	1.2	84.229	0.5991	1	1	1	0.5991	2.331	Non-Liquefiable
15	CL	38	2.02	75	0.7735	29.655	14.655	0.2442	1	1	1.05	1	1	1.05	39.9	0.8396	33.499	5	1.2	45.199	0.2407	1	1	1	0.2407	0.9858	Liquefiable
16.5	CL	38	2.02	75	0.7335	32.685	16.185	0.2311	1	1	1.05	1	1	1.05	39.9	0.7989	31.876	5	1.2	43.251	0.2075	1	1.1442	1	0.2374	1.0276	Non-Liquefiable
18	SM	62	2.03	34	0.6934	35.715	17.715	0.2181	1	1	1.05	1	1	1.05	65.1	0.7636	49.712	4.9315	1.188	63.989	0.4358	1	1.1756	1	0.5123	2.3491	Non-Liquefiable
19.5	SM	62	2.03	34	0.6534	38.76	19.26	0.2051	1	1	1.05	1	1	1.05	65.1	0.7324	47.676	4.9315	1.188	61.571	0.4149	1	1.2055	1	0.5002	2.4386	Non-Liquefiable
21	ML	42	2	58	0.6133	41.805	20.805	0.1922	1	1	1.05	1	1	1.05	44.1	0.7046	31.075	5	1.2	42.289	0.1878	1	1.2337	1	0.2318	1.2055	Non-Liquefiable
22.5	ML	44	2	58	0.5733	44.805	22.305	0.1796	1	1	1.05	1	1	1.05	46.2	0.6805	31.441	5	1.2	42.729	0.1972	1	1.2598	1	0.2484	1.3827	Non-Liquefiable
24	CL	53	2.05	63	0.5332	47.805	23.805	0.167	1	1	1.05	1	1	1.05	55.65	0.6587	36.659	5	1.2	48.991	0.2914	1	1.2846	1	0.3743	2.2407	Non-Liquefiable
25.5	CL	60	2.05	63	0.4932	50.88	25.38	0.1542	1	1	1.05	1	1	1.05	63	0.638	40.192	5	1.2	53.231	0.3375	1	1.3095	1	0.4419	2.8653	Non-Liquefiable
27	CL	90	2.05	63	0.4531	53.955	26.955	0.1415	1	1	1.05	1	1	1.05	94.5	0.6191	58.501	5	1.2	75.201	0.5279	1	1.3334	1	0.7038	4.9747	Non-Liquefiable
28.5	CL	61	2.08	72	0.4131	57.03	28.53	0.1288	1	1	1.05	1	1	1.05	64.05	0.6017	38.541	5	1.2	51.249	0.3168	1	1.3563	1	0.4297	3.336	Non-Liquefiable
30	CL	67	2.08	72	0.373	60.15	30.15	0.1161	1	1	1.05	1	1	1.05	70.35	0.5853	41.179	5	1.2	54.414	0.3492	1	1.379	1	0.4816	4.1484	Non-Liquefiable
31.5	CL	77	2.08	72	0.333	63.27	31.77	0.1034	1	1	1.05	1	1	1.05	80.85	0.5702	46.102	5	1.2	60.323	0.404	1	1.4008	1	0.5659	5.4706	Non-Liquefiable
33	CL	78	2.08	71	0.2929	66.39	33.39	0.0909	1	1	1.05	1	1	1.05	81.9	0.5562	45.554	5	1.2	59.665	0.3981	1	1.4219	1	0.5661	6.2307	Non-Liquefiable
35	CL	99	2.08	71	0.2395	69.51	34.51	0.0753	1	1	1.05	1	1	1.05	103.95	0.5471	56.872	5	1.2	73.247	0.5122	1	1.436	1	0.7355	9.7732	Non-Liquefiable

TABLE 8: Deterministic analysis of bore hole no.7

Depth	Type of Strata	Observed SPT value	Saturated Density (t/m3)	Fine Content (%)	Reduction factor (rd)	Total virtical overburden pressure (t/m2)	Effective virtical overburden pressure (t/m2)	CSR	C(ht)	C(hw)	C(bd)	C(ss)	C(rl)	C(60)	N60	C(N)	(N1)60	α	β	(N1)60_cs	CRR(M=7.5)	MSF	Kσ	Kα	CRR	FS	Conclusion
1.5	SM	8	1.83	28	0.9885	2.745	1.245	0.34	1	1	1.05	1	0.75	0.7875	6.3	1.7	10.71	4.561	1.138	16.749	0.1781	1	1	1	0.1781	0.5239	Liquefiable
3	CL	9	1.83	38	0.9771	5.49	2.49	0.3361	1	1	1.05	1	0.8	0.84	7.56	1.7	12.852	5	1.2	20.422	0.2207	1	1	1	0.2207	0.6568	Liquefiable
4.5	SM	10	1.83	43	0.9656	8.235	3.735	0.3321	1	1	1.05	1	0.85	0.8925	8.925	1.663	14.843	5	1.2	22.811	0.254	1	1	1	0.254	0.7649	Liquefiable
6	SM	12	1.98	42	0.9541	10.98	4.98	0.3282	1	1	1.05	1	0.85	0.8925	10.71	1.4402	15.425	5	1.2	23.51	0.2651	1	1	1	0.2651	0.8079	Liquefiable
7.5	ML	15	1.98	52	0.9426	13.95	6.45	0.318	1	1	1.05	1	0.95	0.9975	14.963	1.2655	18.935	5	1.2	27.722	0.3601	1	1	1	0.3601	1.1324	Non-Liquefiable
9	SM	17	2	54	0.9312	16.92	7.92	0.3103	1	1	1.05	1	0.95	0.9975	16.958	1.1421	19.366	5	1.2	28.24	0.3783	1	1	1	0.3783	1.2189	Non-Liquefiable
10.5	SM	20	2	39	0.8937	19.92	9.42	0.2948	1	1	1.05	1	0.95	0.9975	19.95	1.0472	20.891	5	1.2	30.07	0.4726	1	1	1	0.4726	1.6031	Non-Liquefiable
12	SM	30	2	32	0.8536	22.92	10.92	0.2795	1	1	1.05	1	1	1.05	31.5	0.9726	30.637	4.828	1.171	40.704	0.1476	1	1	1	0.1476	0.5281	Liquefiable
13.5	SM	40	2	32	0.8136	25.92	12.42	0.2649	1	1	1.05	1	1	1.05	42	0.912	38.304	4.828	1.171	49.681	0.2994	1	1	1	0.2994	1.1304	Non-Liquefiable
15	ML	24	1.98	71	0.7735	28.92	13.92	0.2507	1	1	1.05	1	1	1.05	25.2	0.8615	21.709	5	1.2	31.05	0.5644	1	1	1	0.5644	2.2514	Non-Liquefiable
16.5	ML	29	1.98	71	0.7335	31.89	15.39	0.2371	1	1	1.05	1	1	1.05	30.45	0.8193	24.947	5	1.2	34.936	-0.814	1	1.127	1	-0.917	-3.869	
18	ML	30	1.99	78	0.6934	34.86	16.86	0.2237	1	1	1.05	1	1	1.05	31.5	0.7827	24.657	5	1.2	34.588	-1.45	1	1.1583	1	-1.679	-7.508	
19.5	ML	35	1.99	78	0.6534	37.845	18.345	0.2103	1	1	1.05	1	1	1.05	36.75	0.7504	27.577	5	1.2	38.093	0.0331	1	1.188	1	0.0393	0.187	Liquefiable
21	ML	47	2	65	0.6133	40.83	19.83	0.197	1	1	1.05	1	1	1.05	49.35	0.7218	35.619	5	1.2	47.742	0.2761	1	1.2161	1	0.3357	1.7042	Non-Liquefiable
22.5	ML	31	2	66	0.5733	43.83	21.33	0.1838	1	1	1.05	1	1	1.05	32.55	0.6959	22.652	5	1.2	32.182	0.7839	1	1.243	1	0.9744	5.3026	Non-Liquefiable
24	ML	55	2.01	68	0.5332	46.83	22.83	0.1706	1	1	1.05	1	1	1.05	57.75	0.6727	38.846	5	1.2	51.616	0.3207	1	1.2686	1	0.4069	2.3847	Non-Liquefiable
25.5	ML	71	2.01	68	0.4932	49.845	24.345	0.1575	1	1	1.05	1	1	1.05	74.55	0.6514	48.562	5	1.2	63.274	0.4296	1	1.2933	1	0.5557	3.5277	Non-Liquefiable
27	ML	44	2.01	68	0.4531	52.86	25.86	0.1445	1	1	1.05	1	1	1.05	46.2	0.632	29.2	5	1.2	40.04	0.1263	1	1.3169	1	0.1663	1.1509	Non-Liquefiable
28.5	ML	59	2.01	69	0.4131	55.875	27.375	0.1315	1	1	1.05	1	1	1.05	61.95	0.6143	38.055	5	1.2	50.666	0.3105	1	1.3396	1	0.4159	3.1623	Non-Liquefiable
30	ML	63	2.01	69	0.373	58.89	28.89	0.1186	1	1	1.05	1	1	1.05	66.15	0.598	39.555	5	1.2	52.467	0.3296	1	1.3614	1	0.4488	3.7836	Non-Liquefiable
31.5	CL	64	2.06	71	0.333	61.905	30.405	0.1058	1	1	1.05	1	1	1.05	67.2	0.5829	39.169	5	1.2	52.003	0.3248	1	1.3825	1	0.4491	4.2463	Non-Liquefiable
33	CL	121	2.06	71	0.2929	64.995	31.995	0.0928	1	1	1.05	1	1	1.05	127.05	0.5682	72.191	5	1.2	91.629	0.6564	1	1.4038	1	0.9215	9.9276	Non-Liquefiable
35	CL	83	2.06	88	0.2395	68.085	33.085	0.0769	1	1	1.05	1	1	1.05	87.15	0.5588	48.697	5	1.2	63.436	0.431	1	1.4179	1	0.6112	7.9492	Non-Liquefiable

TABLE 9: Deterministic analysis of bore hole no.8

Depth	Type of Strata	Observed SPT value	Saturated Density (t/m3)	Fine Content (%)	Reduction factor (rd)	Total virtical overburden pressure (t/m2)	Effective virtical overburden pressure (t/m2)	CSR	C(ht)	C(hw)	C(bd)	C(ss)	C(rl)	C(60)	N60	C(N)	(N1)60	α	β	(N1)60_cs	CRR(M=7.5)	MSF	Kσ	Kα	CRR	FS	Conclusion
1.5	ML	8	1.89	55	0.9885	2.835	1.335	0.3275	1	1	1.05	1	0.75	0.7875	6.3	1.7	10.71	5	1.2	17.852	0.1902	1	1	1	0.1902	0.5807	Liquefiable
3	SM-ML	10	1.93	50	0.9771	5.67	2.67	0.3237	1	1	1.05	1	0.8	0.84	8.4	1.7	14.28	5	1.2	22.136	0.244	1	1	1	0.244	0.7537	Liquefiable
4.5	SM-ML	11	1.93	50	0.9656	8.565	4.065	0.3174	1	1	1.05	1	0.85	0.8925	9.8175	1.5941	15.65	5	1.2	23.78	0.2696	1	1	1	0.2696	0.8495	Liquefiable
6	CI	25	2	52	0.9541	11.46	5.46	0.3124	1	1	1.05	1	0.85	0.8925	22.313	1.3755	30.69	5	1.2	41.828	0.1773	1	1	1	0.1773	0.5677	Liquefiable
7.5	SM	17	1.97	37	0.9426	14.46	6.96	0.3055	1	1	1.05	1	0.95	0.9975	16.958	1.2183	20.659	5	1.2	29.791	0.4537	1	1	1	0.4537	1.485	Non-Liquefiable
9	ML	13	1.97	59	0.9312	17.415	8.415	0.3006	1	1	1.05	1	0.95	0.9975	12.968	1.108	14.367	5	1.2	22.241	0.2455	1	1	1	0.2455	0.8166	Liquefiable
10.5	ML	16	1.97	59	0.8937	20.37	9.87	0.2877	1	1	1.05	1	0.95	0.9975	15.96	1.023	16.328	5	1.2	24.593	0.2841	1	1	1	0.2841	0.9873	Liquefiable
12	CL	35	2.04	83	0.8536	23.325	11.325	0.2743	1	1	1.05	1	1	1.05	36.75	0.9551	35.098	5	1.2	47.118	0.268	1	1	1	0.268	0.9771	Liquefiable
13.5	CL	42	2.04	83	0.8136	26.385	12.885	0.2599	1	1	1.05	1	1	1.05	44.1	0.8954	39.486	5	1.2	52.384	0.3288	1	1	1	0.3288	1.2651	Non-Liquefiable
15	ML	33	2	75	0.7735	29.445	14.445	0.246	1	1	1.05	1	1	1.05	34.65	0.8457	29.302	5	1.2	40.162	0.1305	1	1	1	0.1305	0.5304	Liquefiable
16.5	ML	58	2	75	0.7335	32.445	15.945	0.2328	1	1	1.05	1	1	1.05	60.9	0.8049	49.018	5	1.2	63.822	0.4343	1	1.1391	1	0.4947	2.125	Non-Liquefiable
18	CI	58	2.06	90	0.6934	35.445	17.445	0.2198	1	1	1.05	1	1	1.05	60.9	0.7695	46.863	5	1.2	61.236	0.412	1	1.1702	1	0.4821	2.1937	Non-Liquefiable
19.5	CI	41	2.06	90	0.6534	38.535	19.035	0.2063	1	1	1.05	1	1	1.05	43.05	0.7367	31.714	5	1.2	43.056	0.2037	1	1.2013	1	0.2447	1.1861	Non-Liquefiable
21	SM	41	2	30	0.6133	41.625	20.625	0.1931	1	1	1.05	1	1	1.05	43.05	0.7077	30.467	4.706	1.154	39.865	0.12	1	1.2305	1	0.1477	0.765	Liquefiable
22.5	SM	69	2.03	23	0.5733	44.625	22.125	0.1804	1	1	1.05	1	1	1.05	72.45	0.6833	49.505	4.058	1.1	58.513	0.3878	1	1.2567	1	0.4873	2.7017	Non-Liquefiable
24	SM	76	2.03	23	0.5332	47.67	23.67	0.1675	1	1	1.05	1	1	1.05	79.8	0.6606	52.717	4.058	1.1	62.047	0.4191	1	1.2824	1	0.5374	3.2081	Non-Liquefiable
25.5	SM	82	2.03	19	0.4932	50.715	25.215	0.1547	1	1	1.05	1	1	1.05	86.1	0.6401	55.109	3.433	1.073	62.565	0.4235	1	1.307	1	0.5536	3.5776	Non-Liquefiable
27	CL	54	2.06	55	0.4531	53.76	26.76	0.142	1	1	1.05	1	1	1.05	56.7	0.6213	35.228	5	1.2	47.274	0.27	1	1.3305	1	0.3593	2.5301	Non-Liquefiable
28.5	CL	58	2.06	55	0.4131	56.85	28.35	0.1292	1	1	1.05	1	1	1.05	60.9	0.6036	36.761	5	1.2	49.114	0.2928	1	1.3537	1	0.3964	3.0678	Non-Liquefiable
30	ML	114	2.03	56	0.373	59.94	29.94	0.1165	1	1	1.05	1	1	1.05	119.7	0.5874	70.31	5	1.2	89.372	0.639	1	1.3761	1	0.8793	7.5484	Non-Liquefiable
31.5	ML	75	2.03	56	0.333	62.985	31.485	0.1039	1	1	1.05	1	1	1.05	78.75	0.5728	45.108	5	1.2	59.129	0.3933	1	1.397	1	0.5495	5.2882	Non-Liquefiable
33	ML	87	2.03	72	0.2929	66.03	33.03	0.0913	1	1	1.05	1	1	1.05	91.35	0.5592	51.086	5	1.2	66.304	0.4553	1	1.4172	1	0.6452	7.0639	Non-Liquefiable
35	CI	109	2.03	81	0.2395	69.075	34.075	0.0757	1	1	1.05	1	1	1.05	114.45	0.5506	63.016	5	1.2	80.619	0.5708	1	1.4305	1	0.8165	10.781	Non-Liquefiable

TABLE 10: Deterministic analysis of bore hole no.9

Depth	Type of Strata	Observed SPT value	Saturated Density (t/m3)	Fine Content (%)	Reduction factor (rd)	Total virtical overburden pressure (t/m2)	Effective virtical overburden pressure (t/m2)	CSR	C(ht)	C(hw)	C(bd)	C(ss)	C(rl)	C(60)	N60	C(N)	(N1)60	α	β	(N1)60_cs	CRR(M=7.5)	MSF	Kσ	Kα	CRR	FS	Conclusion
1.5	SM	7	1.71	24	0.9885	2.565	1.065	0.3714	1	1	1.05	1	0.75	0.7875	5.5125	1.7	9.3713	4.179	1.107	14.553	0.1556	1	1	1	0.1556	0.4189	Liquefiable
3	SM	7	1.71	25	0.9771	5.13	2.13	0.3671	1	1	1.05	1	0.8	0.84	5.88	1.7	9.996	4.289	1.115	15.435	0.1645	1	1	1	0.1645	0.448	Liquefiable
4.5	CL	6	1.71	83	0.9656	7.695	3.195	0.3628	1	1	1.05	1	0.85	0.8925	5.355	1.7981	9.6288	5	1.2	16.555	0.1761	1	1	1	0.1761	0.4853	Liquefiable
6	ML	15	0.95	75	0.9541	10.26	4.26	0.3585	1	1	1.05	1	0.85	0.8925	13.388	1.5572	20.847	5	1.2	30.016	0.4688	1	1	1	0.4688	1.3078	Non-Liquefiable
7.5	ML	10	0.95	75	0.9426	11.685	4.185	0.4106	1	1	1.05	1	0.95	0.9975	9.975	1.5711	15.672	5	1.2	23.806	0.2701	1	1	1	0.2701	0.6578	Liquefiable
9	ML	20	0.98	85	0.9312	13.11	4.11	0.4633	1	1	1.05	1	0.95	0.9975	19.95	1.5854	31.628	5	1.2	42.954	0.2017	1	1	1	0.2017	0.4353	Liquefiable
10.5	CI	22	1.02	85	0.8937	14.58	4.08	0.4982	1	1	1.05	1	0.95	0.9975	21.945	1.5912	34.919	5	1.2	46.902	0.2651	1	1	1	0.2651	0.5321	Liquefiable
12	CI	33	1.02	95	0.8536	16.11	4.11	0.522	1	1	1.05	1	1	1.05	34.65	1.5854	54.933	5	1.2	70.919	0.4933	1	1	1	0.4933	0.9452	Liquefiable
13.5	ML	41	1.01	62	0.8136	17.64	4.14	0.5408	1	1	1.05	1	1	1.05	43.05	1.5796	68.002	5	1.2	86.603	0.6176	1	1	1	0.6176	1.142	Non-Liquefiable
15	ML	41	1.01	74	0.7735	19.155	4.155	0.5563	1	1	1.05	1	1	1.05	43.05	1.5768	67.879	5	1.2	86.455	0.6164	1	1	1	0.6164	1.1081	Non-Liquefiable
16.5	ML	46	1.01	74	0.7335	20.67	4.17	0.5672	1	1	1.05	1	1	1.05	48.3	1.5739	76.02	5	1.2	96.224	0.6918	1	0.7617	1	0.5269	0.9291	Liquefiable
18	CL	57	1.03	77	0.6934	22.185	4.185	0.5734	1	1	1.05	1	1	1.05	59.85	1.5711	94.03	5	1.2	117.84	0.856	1	0.7626	1	0.6527	1.1383	Non-Liquefiable
19.5	CL	68	1.03	77	0.6534	23.73	4.23	0.5718	1	1	1.05	1	1	1.05	71.4	1.5627	111.58	5	1.2	138.89	1.0143	1	0.765	1	0.776	1.3571	Non-Liquefiable
21	SM	66	1.03	34	0.6133	25.275	4.275	0.5657	1	1	1.05	1	1	1.05	69.3	1.5545	107.72	4.931	1.188	132.91	0.9694	1	0.7675	1	0.744	1.3153	Non-Liquefiable
22.5	SM	68	1.03	34	0.5733	26.82	4.32	0.5552	1	1	1.05	1	1	1.05	71.4	1.5464	110.41	4.931	1.188	136.1	0.9934	1	0.7699	1	0.7648	1.3775	Non-Liquefiable
24	SM	58	1.03	32	0.5332	28.365	4.365	0.5405	1	1	1.05	1	1	1.05	60.9	1.5384	93.686	4.828	1.171	114.53	0.831	1	0.7723	1	0.6418	1.1873	Non-Liquefiable
25.5	SM	63	1.03	32	0.4932	29.91	4.41	0.5218	1	1	1.05	1	1	1.05	66.15	1.5305	101.24	4.828	1.171	123.38	0.8978	1	0.7746	1	0.6955	1.3329	Non-Liquefiable
27	SM	69	1.02	38	0.4531	31.455	4.455	0.4991	1	1	1.05	1	1	1.05	72.45	1.5227	110.32	5	1.2	137.39	1.003	1	0.777	1	0.7794	1.5616	Non-Liquefiable
28.5	SM	39	1.01	38	0.4131	32.985	4.485	0.4739	1	1	1.05	1	1	1.05	40.95	1.5176	62.147	5	1.2	79.577	0.5626	1	0.7786	1	0.438	0.9243	Liquefiable
30	SM	50	1.02	36	0.373	34.5	4.5	0.4461	1	1	1.05	1	1	1.05	52.5	1.5151	79.543	5	1.2	100.45	0.7241	1	0.7794	1	0.5643	1.265	Non-Liquefiable
31.5	SM	89	1.02	36	0.333	36.03	4.53	0.4131	1	1	1.05	1	1	1.05	93.45	1.5101	141.12	5	1.2	174.34	1.2793	1	0.7809	1	0.999	2.4183	Non-Liquefiable
33	CI	94	1.09	82	0.2929	37.56	4.56	0.3764	1	1	1.05	1	1	1.05	98.7	1.5051	148.55	5	1.2	183.27	1.3458	1	0.7825	1	1.0531	2.798	Non-Liquefiable
35	SM	107	1.09	72	0.2395	39.195	4.195	0.3491	1	1	1.05	1	1	1.05	112.35	1.5692	176.3	5	1.2	216.56	1.5937	1	0.7631	1	1.2162	3.4839	Non-Liquefiable

TABLE 11: Deterministic analysis of bore hole no.10

Depth	Type of Strata	Observed SPT value	Saturated Density (t/m3)	Fine Content (%)	Reduction factor (rd)	Total virtical overburden pressure (t/m2)	Effective virtical overburden pressure (t/m2)	CSR	C(ht)	C(hw)	C(bd)	C(ss)	C(rl)	C(60)	N60	C(N)	(N1)60	α	β	(N1)60_cs	CRR(M=7.5)	MSF	Kσ	Kα	CRR	FS	Conclusion
1.5	SM	6	1.92	21	0.9885	2.88	1.38	0.3218	1	1	1.05	1	0.75	0.7875	4.725	1.7	8.0325	3.778	1.086	12.501	0.1358	1	1	1	0.1358	0.4221	Liquefiable
3	ML-CL	5	1.92	61	0.9771	5.76	2.76	0.3181	1	1	1.05	1	0.8	0.84	4.2	1.7	7.14	5	1.2	13.568	0.146	1	1	1	0.146	0.4589	Liquefiable
4.5	CL	7	1.92	83	0.9656	8.64	4.14	0.3144	1	1	1.05	1	0.85	0.8925	6.2475	1.5796	9.8686	5	1.2	16.842	0.1791	1	1	1	0.1791	0.5699	Liquefiable
6	ML	8	1.96	61	0.9541	11.52	5.52	0.3106	1	1	1.05	1	0.85	0.8925	7.14	1.368	9.7674	5	1.2	16.721	0.1778	1	1	1	0.1778	0.5725	Liquefiable
7.5	CL	15	1.96	61	0.9426	14.46	6.96	0.3055	1	1	1.05	1	0.95	0.9975	14.963	1.2183	18.228	5	1.2	26.874	0.3349	1	1	1	0.3349	1.0962	Non-Liquefiable
9	CL	16	2	92	0.9312	17.4	8.4	0.3009	1	1	1.05	1	0.95	0.9975	15.96	1.1089	17.699	5	1.2	26.239	0.3187	1	1	1	0.3187	1.0593	Non-Liquefiable
10.5	CI	18	2	92	0.8937	20.4	9.9	0.2873	1	1	1.05	1	0.95	0.9975	17.955	1.0215	18.341	5	1.2	27.009	0.3386	1	1	1	0.3386	1.1787	Non-Liquefiable
12	SM	74	2.04	30	0.8536	23.4	11.4	0.2733	1	1	1.05	1	1	1.05	77.7	0.9519	73.964	4.706	1.154	90.06	0.6443	1	1	1	0.6443	2.3573	Non-Liquefiable
13.5	SM	78	2.04	30	0.8136	26.46	12.96	0.2591	1	1	1.05	1	1	1.05	81.9	0.8928	73.119	4.706	1.154	89.086	0.6368	1	1	1	0.6368	2.4576	Non-Liquefiable
15	SM	55	2.04	30	0.7735	29.52	14.52	0.2453	1	1	1.05	1	1	1.05	57.75	0.8435	48.71	4.706	1.154	60.917	0.4092	1	1	1	0.4092	1.668	Non-Liquefiable
16.5	CI	58	2.07	82	0.7335	32.58	16.08	0.2318	1	1	1.05	1	1	1.05	60.9	0.8015	48.812	5	1.2	63.574	0.4322	1	1.142	1	0.4936	2.1291	Non-Liquefiable
18	CL	27	2.03	78	0.6934	35.685	17.685	0.2183	1	1	1.05	1	1	1.05	28.35	0.7643	21.667	5	1.2	31.001	0.5584	1	1.175	1	0.6562	3.0062	Non-Liquefiable
19.5	CL	32	2.03	78	0.6534	38.73	19.23	0.2053	1	1	1.05	1	1	1.05	33.6	0.7329	24.626	5	1.2	34.552	-1.562	1	1.2049	1	-1.882	-9.167	Non-Liquefiable
21	SM	31	2	20	0.6133	41.775	20.775	0.1924	1	1	1.05	1	1	1.05	32.55	0.7051	22.953	3.614	1.079	28.38	0.3836	1	1.2332	1	0.4731	2.459	Non-Liquefiable
22.5	SM	28	2	20	0.5733	44.775	22.275	0.1798	1	1	1.05	1	1	1.05	29.4	0.681	20.021	3.614	1.079	25.217	0.2962	1	1.2593	1	0.373	2.0751	Non-Liquefiable
24	ML-CL	37	2.05	71	0.5332	47.775	23.775	0.1671	1	1	1.05	1	1	1.05	38.85	0.6592	25.608	5	1.2	35.73	-0.318	1	1.2841	1	-0.408	-2.444	Non-Liquefiable
25.5	ML-CL	44	2.05	71	0.4932	50.85	25.35	0.1543	1	1	1.05	1	1	1.05	46.2	0.6384	29.492	5	1.2	40.39	0.1379	1	1.3091	1	0.1806	1.1702	Non-Liquefiable
27	ML	49	2.01	61	0.4531	53.925	26.925	0.1416	1	1	1.05	1	1	1.05	51.45	0.6194	31.868	5	1.2	43.242	0.2073	1	1.333	1	0.2764	1.9522	Non-Liquefiable
28.5	ML	63	2.01	61	0.4131	56.94	28.44	0.129	1	1	1.05	1	1	1.05	66.15	0.6027	39.867	5	1.2	52.841	0.3335	1	1.355	1	0.4519	3.5028	Non-Liquefiable
30	SM	124	2.04	21	0.373	59.955	29.955	0.1165	1	1	1.05	1	1	1.05	130.2	0.5872	76.459	3.778	1.086	86.812	0.6192	1	1.3763	1	0.8522	7.3171	Non-Liquefiable
31.5	SM	59	2.03	21	0.333	63.015	31.515	0.1039	1	1	1.05	1	1	1.05	61.95	0.5725	35.468	3.778	1.086	42.296	0.188	1	1.3974	1	0.2627	2.5295	Non-Liquefiable
33	SM	73	2.03	28	0.2929	66.06	33.06	0.0913	1	1	1.05	1	1	1.05	76.65	0.559	42.846	4.561	1.138	53.32	0.3384	1	1.4176	1	0.4797	5.2535	Non-Liquefiable
35	SM	286	2.03	28	0.2395	69.105	34.105	0.0757	1	1	1.05	1	1	1.05	300.3	0.5504	165.27	4.561	1.138	192.64	1.4157	1	1.4309	1	2.0257	26.758	Non-Liquefiable

TABLE 12: Probabilistic calculation for bore hole no.1**.**

Depth	Observed SPT value	CSR(eq)	CRR(M =7.5)	CRR	FS	Conclusion		β	μ_z	σ_z	Φ(β)	Pf
1.5	6	0.321829	0.156452	0.156452	0.486134	Liquefiable		-1.18925	-0.16538	0.448558	0.011227	0.988773
3	5	0.318093	0.145978	0.145978	0.458916	Liquefiable		-1.23456	-0.17212	0.448558	0.008928	0.991072
4.5	8	0.314358	0.19789	0.19789	0.629507	Liquefiable		-0.97221	-0.11647	0.448558	0.02821	0.97179
6	18	0.310622	0.608287	0.608287	1.958288	Non-Liquefiable		0.706664	0.297665	0.448558	0.819065	0.180935
7.5	21	0.308288	-0.26758	-0.26758	-0.86796			#NUM!	-0.57587	0.448558	#NUM!	#NUM!
9	25	0.305472	0.067564	0.067564	0.221179	Liquefiable		-1.71444	-0.23791	0.448558	0.000498	0.999502
10.5	27	0.293819	0.071094	0.071094	0.241965	Liquefiable		-1.66234	-0.22272	0.448558	0.000665	0.999335
12	34	0.278693	0.260361	0.260361	0.934222	Liquefiable		-0.58674	-0.01833	0.448558	0.102543	0.897457
13.5	38	0.264036	0.285894	0.285894	1.082786	Non-Liquefiable		-0.42236	0.021858	0.448558	0.161008	0.838992
15	76	0.249859	0.622399	0.622399	2.491004	Non-Liquefiable		1.065746	0.37254	0.448558	0.938877	0.061123
16.5	75	0.235788	0.581719	0.657725	2.789481	Non-Liquefiable		1.287957	0.421937	0.448558	0.973238	0.026762
18	42	0.222034	0.254476	0.296017	1.333204	Non-Liquefiable		-0.20477	0.073983	0.448558	0.267156	0.732844
19.5	44	0.208519	0.256379	0.30607	1.467827	Non-Liquefiable		-0.09439	0.097551	0.448558	0.334361	0.665639
21	40	0.195188	0.113766	0.139099	0.712642	Liquefiable		-0.91095	-0.05609	0.448558	0.028338	0.971662
22.5	43	0.182194	0.155941	0.194808	1.069238	Non-Liquefiable		-0.52875	0.012615	0.448558	0.113734	0.886266
24	78	0.169264	0.490681	0.625403	3.69484	Non-Liquefiable		1.544472	0.456139	0.448558	0.992373	0.007627
25.5	83	0.156194	0.506659	0.658504	4.215935	Non-Liquefiable		1.75546	0.50231	0.448558	0.997395	0.002605
27	72	0.143221	0.417312	0.552417	3.857099	Non-Liquefiable		1.413064	0.409196	0.448558	0.987389	0.012611
28.5	77	0.130293	0.43628	0.587688	4.510518	Non-Liquefiable		1.641519	0.457395	0.448558	0.995853	0.004147
30	168	0.117443	0.950181	1.301206	11.07951	Non-Liquefiable		3.58573	1.183763	0.448558	1	4.28E-08
31.5	153	0.104633	0.843564	1.173563	11.21598	Non-Liquefiable		3.315724	1.06893	0.448558	1	2.74E-07
33	178	0.091889	0.956386	1.350605	14.69826	Non-Liquefiable		3.536048	1.258716	0.448558	1	1.92E-07
35	197	0.076131	0.919289	1.311073	17.22133	Non-Liquefiable		3.393566	1.234942	0.448558	0.999999	7.46E-07

TABLE 13: Probabilistic calculation for bore hole no.2.

Depth	Observed SPT value	CSR	CRR(M=7.5)	CRR	FS	Conclusion	β	μ_z	σ_z	$\Phi(\beta)$	Pf
1.5	7	0.318263	0.16233	0.16233	0.51005	Liquefiable	-1.16939	-0.15593	0.502814	0.021922	0.978078
3	8	0.314569	0.199909	0.199909	0.635502	Liquefiable	-0.98669	-0.11466	0.502814	0.041432	0.958568
4.5	10	0.310874	0.238283	0.238283	0.766493	Liquefiable	-0.81232	-0.07259	0.502814	0.070622	0.929378
6	9	0.30718	0.192326	0.192326	0.626103	Liquefiable	-1.00248	-0.11485	0.502814	0.038755	0.961245
7.5	11	0.302822	0.226985	0.226985	0.749566	Liquefiable	-0.83841	-0.07584	0.502814	0.064683	0.935317
9	20	0.298702	0.606556	0.606556	2.030638	Non-Liquefiable	0.637964	0.307854	0.502814	0.744257	0.255743
10.5	29	0.285497	0.133262	0.133262	0.466772	Liquefiable	-1.24482	-0.15224	0.502814	0.014892	0.985108
12	71	0.272234	0.642506	0.642506	2.360127	Non-Liquefiable	0.897417	0.370272	0.502814	0.85277	0.14723
13.5	74	0.258506	0.582234	0.582234	2.2523	Non-Liquefiable	0.731955	0.323728	0.502814	0.791571	0.208429
15	75	0.245064	0.602163	0.602163	2.457168	Non-Liquefiable	0.876914	0.357099	0.502814	0.849388	0.150612
16.5	63	0.231388	0.473559	0.541396	2.33977	Non-Liquefiable	0.707358	0.310007	0.502814	0.78531	0.21469
18	31	0.217988	-0.97449	-1.14593	-5.25685		#NUM!	-1.36392	0.502814	#NUM!	#NUM!
19.5	39	0.205438	0.15731	0.189459	0.922223	Liquefiable	-0.70146	-0.01598	0.502814	0.086397	0.913603
21	43	0.192877	0.208466	0.256689	1.330845	Non-Liquefiable	-0.31503	0.063812	0.502814	0.225591	0.774409
22.5	46	0.180308	0.231081	0.290461	1.610916	Non-Liquefiable	-0.09346	0.110153	0.502814	0.342759	0.657241
24	78	0.167732	0.485897	0.622648	3.712153	Non-Liquefiable	1.39897	0.454916	0.502814	0.969778	0.030222
25.5	83	0.154918	0.502243	0.65595	4.234179	Non-Liquefiable	1.607763	0.501032	0.502814	0.986135	0.013865
27	72	0.142161	0.413681	0.550034	3.86908	Non-Liquefiable	1.277886	0.407872	0.502814	0.958211	0.041789
28.5	77	0.129384	0.432796	0.585428	4.52472	Non-Liquefiable	1.505225	0.456044	0.502814	0.981539	0.018461
30	138	0.116668	0.776126	1.067052	9.146025	Non-Liquefiable	3.025393	0.950384	0.502814	0.999982	1.84E-05
31.5	142	0.104004	0.778354	1.08675	10.44908	Non-Liquefiable	3.069216	0.982745	0.502814	0.999983	1.67E-05
33	158	0.091385	0.844996	1.197233	13.10101	Non-Liquefiable	3.254529	1.105848	0.502814	0.99999	9.63E-06
35	178	0.075721	0.935999	1.339163	17.68541	Non-Liquefiable	3.394224	1.263442	0.502814	0.999989	1.13E-05

TABLE 14: **Probabilistic calculation for bore hole no.3.**

Depth	Observed SPT value	CSR	CRR(M=7.5)	CRR	FS	Conclusion	β	μ_z	σ_z	Φ(β)	Pf
1.5	7	0.318263	0.172823	0.172823	0.543018	Liquefiable	-1.08934	-0.14544	0.409136	0.010526	0.989474
3	9	0.314569	0.21185	0.21185	0.673461	Liquefiable	-0.89422	-0.10272	0.409136	0.026522	0.973478
4.5	17	0.310874	2.069176	2.069176	6.655993	Non-Liquefiable	6.021538	1.758302	0.409136	1	0
6	19	0.304693	0.830817	0.830817	2.726738	Non-Liquefiable	1.773349	0.526124	0.409136	0.99885	0.00115
7.5	11	0.29959	0.224812	0.224812	0.750397	Liquefiable	-0.7911	-0.07478	0.409136	0.039988	0.960012
9	18	0.295787	0.38831	0.38831	1.312801	Non-Liquefiable	-0.06292	0.092523	0.409136	0.352003	0.647997
10.5	31	0.283768	0.191393	0.191393	0.67447	Liquefiable	-0.90322	-0.09238	0.409136	0.023748	0.976252
12	39	0.270974	0.318237	0.318237	1.174418	Non-Liquefiable	-0.26906	0.047263	0.409136	0.219717	0.780283
13.5	42	0.257603	0.324526	0.324526	1.259791	Non-Liquefiable	-0.18559	0.066923	0.409136	0.268556	0.731444
15	32	0.244426	0.078653	0.078653	0.321787	Liquefiable	-1.48205	-0.16577	0.409136	0.000647	0.999353
16.5	36	0.231171	0.162996	0.186449	0.80654	Liquefiable	-0.75418	-0.04472	0.409136	0.041456	0.958544
18	39	0.218081	0.192913	0.226795	1.039959	Non-Liquefiable	-0.48894	0.008714	0.409136	0.111924	0.888076
19.5	40	0.205115	0.179271	0.216111	1.053609	Non-Liquefiable	-0.48818	0.010996	0.409136	0.111217	0.888783
21	42	0.192246	0.187849	0.231755	1.205508	Non-Liquefiable	-0.3435	0.039508	0.409136	0.1746	0.8254
22.5	45	0.179636	0.213761	0.269289	1.499081	Non-Liquefiable	-0.0777	0.089653	0.409136	0.341253	0.658747
24	50	0.16704	0.259648	0.333546	1.996803	Non-Liquefiable	0.330295	0.166506	0.409136	0.655543	0.344457
25.5	54	0.15441	0.284976	0.372922	2.415145	Non-Liquefiable	0.613541	0.218512	0.409136	0.832858	0.167142
27	59	0.141802	0.315455	0.420066	2.962343	Non-Liquefiable	0.935709	0.278264	0.409136	0.945963	0.054037
28.5	71	0.12911	0.391785	0.530629	4.109899	Non-Liquefiable	1.531962	0.401519	0.409136	0.997136	0.002864
30	62	0.116463	0.312758	0.430446	3.695975	Non-Liquefiable	1.180915	0.313982	0.409136	0.982952	0.017048
31.5	70	0.103905	0.359934	0.502833	4.839342	Non-Liquefiable	1.597806	0.398927	0.409136	0.998307	0.001693
33	85	0.091364	0.443549	0.628528	6.879381	Non-Liquefiable	2.142033	0.537164	0.409136	0.999956	4.38E-05
35	90	0.075772	0.464955	0.664962	8.775824	Non-Liquefiable	2.325962	0.58919	0.409136	0.999989	1.09E-05

TABLE 15: Probabilistic calculation for bore hole no.4

Depth	Observed SPT value	CSR	CRR(M=7.5)	CRR	FS	Conclusion	β	μ_z	σ_z	Φ(β)	Pf
1.5	6	0.316536	0.141222	0.141222	0.446148	Liquefiable	-1.26268	-0.17531	0.178761	5.91E-10	1
3	8	0.312862	0.19578	0.19578	0.625772	Liquefiable	-0.91468	-0.11708	0.178761	4.06E-06	0.999996
4.5	9	0.309187	0.215205	0.215205	0.696034	Liquefiable	-0.77495	-0.09398	0.178761	6.97E-05	0.99993
6	14	0.304286	0.293973	0.293973	0.96611	Liquefiable	-0.22984	-0.01031	0.178761	0.109711	0.890289
7.5	18	0.299908	0.534058	0.534058	1.780741	Non-Liquefiable	1.447125	0.23415	0.178761	1	5.79E-12
9	16	0.298433	0.314747	0.314747	1.054667	Non-Liquefiable	-0.05016	0.016315	0.178761	0.355002	0.644998
10.5	19	0.287943	0.379948	0.379948	1.319526	Non-Liquefiable	0.477393	0.092005	0.178761	0.984454	0.015546
12	37	0.274073	0.29727	0.29727	1.084636	Non-Liquefiable	-0.00958	0.023196	0.178761	0.427253	0.572747
13.5	40	0.260351	0.30536	0.30536	1.172878	Non-Liquefiable	0.143619	0.045009	0.178761	0.709399	0.290601
15	31	0.246886	0.037025	0.037025	0.149968	Liquefiable	-1.90228	-0.20986	0.178761	1.43E-21	1
16.5	36	0.233604	0.172562	0.196174	0.839771	Liquefiable	-0.47599	-0.03743	0.178761	0.007077	0.992923
18	34	0.220458	0.03127	0.036527	0.165688	Liquefiable	-1.83143	-0.18393	0.178761	1.54E-20	1
19.5	35	0.207164	-0.00263	-0.00315	-0.01523	Liquefiable	#NUM!	-0.21032	0.178761	#NUM!	#NUM!
21	39	0.194019	0.122836	0.150722	0.776841	Liquefiable	-0.57873	-0.0433	0.178761	0.001371	0.998629
22.5	42	0.181178	0.164711	0.206445	1.139455	Non-Liquefiable	-0.02058	0.025266	0.178761	0.398799	0.601201
24	57	0.168382	0.331924	0.424366	2.520259	Non-Liquefiable	1.657117	0.255984	0.178761	1	2.33E-15
25.5	68	0.155622	0.388984	0.506662	3.255729	Non-Liquefiable	2.182503	0.351041	0.178761	1	0
27	56	0.142728	0.277116	0.367583	2.57541	Non-Liquefiable	1.491917	0.224855	0.178761	1	6.8E-13
28.5	62	0.129905	0.329031	0.444004	3.417904	Non-Liquefiable	1.998829	0.314099	0.178761	1	0
30	39	0.117053	-390.227	-535.447	-4574.4	Non-Liquefiable	#NUM!	-535.564	0.178761	#NUM!	#NUM!
31.5	43	0.104279	-0.20305	-0.28306	-2.71445	Non-Liquefiable	#NUM!	-0.38734	0.178761	#NUM!	#NUM!
33	61	0.091572	0.28044	0.396853	4.333755	Non-Liquefiable	1.97995	0.30528	0.178761	1	0
35	84	0.075959	0.431088	0.615628	8.104732	Non-Liquefiable	2.706204	0.539669	0.178761	1	0

.

TABLE 16: Probabilistic calculation for bore hole no.5

Depth	Observed SPT value	CSR	CRR(M=7.5)	CRR	FS	Conclusion	β	μ_z	σ_z	Φ(β)	Pf
1.5	5	0.377703	0.140857	0.140857	0.37293	Liquefiable	-1.36784	-0.23685	0.368103	0.001061	0.998939
3	7	0.373318	0.17435	0.17435	0.467028	Liquefiable	-1.19427	-0.19897	0.368103	0.003427	0.996573
4.5	10	0.389724	0.300906	0.300906	0.772099	Liquefiable	-0.69852	-0.08882	0.368103	0.048828	0.951172
6	22	0.370988	0.198018	0.198018	0.533757	Liquefiable	-1.08022	-0.17297	0.368103	0.006857	0.993143
7.5	25	0.422423	0.335721	0.335721	0.794751	Liquefiable	-0.65635	-0.0867	0.368103	0.060869	0.939131
9	20	0.477915	0.217851	0.217851	0.455836	Liquefiable	-1.22852	-0.26006	0.368103	0.004257	0.995743
10.5	29	0.519124	0.417127	0.417127	0.803522	Liquefiable	-0.6305	-0.102	0.368103	0.075537	0.924463
12	37	0.547672	0.576267	0.576267	1.052211	Non-Liquefiable	-0.16708	0.028594	0.368103	0.297508	0.702492
13.5	44	0.571359	0.688138	0.688138	1.204388	Non-Liquefiable	0.152997	0.116779	0.368103	0.539189	0.460811
15	53	0.588364	0.827767	0.827767	1.406898	Non-Liquefiable	0.607631	0.239404	0.368103	0.841426	0.158574
16.5	60	0.600364	0.934609	0.696975	1.160921	Non-Liquefiable	0.085568	0.096611	0.368103	0.488033	0.511967
18	25	0.605506	0.366081	0.273632	0.451906	Liquefiable	-1.27109	-0.33187	0.368103	0.005363	0.994637
19.5	36	0.605723	0.553296	0.414516	0.684333	Liquefiable	-0.85153	-0.19121	0.368103	0.036419	0.963581
21	53	0.601127	0.816793	0.613314	1.020274	Non-Liquefiable	-0.20611	0.012187	0.368103	0.276581	0.723419
22.5	33	0.595618	0.502342	0.377199	0.633291	Liquefiable	-0.94157	-0.21842	0.368103	0.024734	0.975266
24	39	0.585393	0.598977	0.449761	0.768305	Liquefiable	-0.69472	-0.13563	0.368103	0.064403	0.935597
25.5	31	0.570454	0.469115	0.35225	0.61749	Liquefiable	-0.96367	-0.2182	0.368103	0.021425	0.978575
27	65	0.550799	1.00034	0.751136	1.363722	Non-Liquefiable	0.461142	0.200337	0.368103	0.760686	0.239314
28.5	92	0.521257	1.402128	1.056392	2.026626	Non-Liquefiable	1.802796	0.535136	0.368103	0.999713	0.000287
30	89	0.48762	1.349553	1.020183	2.092169	Non-Liquefiable	1.810507	0.532563	0.368103	0.999741	0.000259
31.5	91	0.450022	1.372009	1.040589	2.312307	Non-Liquefiable	2.074524	0.590567	0.368103	0.999972	2.77E-05
33	98	0.408592	1.468221	1.117204	2.734276	Non-Liquefiable	2.591374	0.708612	0.368103	1	1.57E-07
35	124	0.390786	1.961518	1.441527	3.688785	Non-Liquefiable	3.931873	1.05074	0.368103	1	2.55E-15

TABLE 17: **Probabilistic calculation for bore hole no.6**

Depth	Observed SPT value	CSR	CRR(M=7.5)	CRR	FS	Conclusion		β	μ_z	σ_z	Φ(β)	Pf
1.5	8	0.314845	0.181536	0.181536	0.576587	Liquefiable		-1.01735	-0.13331	0.173703	1.8E-07	1
3	14	0.31119	0.409806	0.409806	1.316899	Non-Liquefiable		0.542911	0.098616	0.173703	0.994733	0.005267
4.5	13	0.307536	0.325903	0.325903	1.059724	Non-Liquefiable		-0.02158	0.018367	0.173703	0.409064	0.590936
6	17	0.303478	0.427938	0.427938	1.410113	Non-Liquefiable		0.726233	0.12446	0.173703	0.999734	0.000266
7.5	18	0.299275	0.528591	0.528591	1.76624	Non-Liquefiable		1.450929	0.229316	0.173703	1	1.01E-12
9	18	0.295269	0.386684	0.386684	1.309597	Non-Liquefiable		0.493841	0.091415	0.173703	0.989741	0.010259
10.5	27	0.282919	-0.0491	-0.0491	-0.17356			#NUM!	-0.33202	0.173703	#NUM!	#NUM!
12	65	0.269913	0.581681	0.581681	2.15507	Non-Liquefiable		1.994317	0.311768	0.173703	1	0
13.5	71	0.257008	0.599076	0.599076	2.330966	Non-Liquefiable		2.180171	0.342068	0.173703	1	0
15	38	0.244173	0.240711	0.240711	0.985822	Liquefiable		-0.20469	-0.00346	0.173703	0.123343	0.876657
16.5	38	0.231063	0.207509	0.237433	1.027568	Non-Liquefiable		-0.13737	0.00637	0.173703	0.203976	0.796024
18	62	0.218081	0.435756	0.51229	2.349079	Non-Liquefiable		1.897938	0.294209	0.173703	1	0
19.5	62	0.205115	0.414926	0.500193	2.438594	Non-Liquefiable		1.906577	0.295078	0.173703	1	0
21	42	0.192246	0.187849	0.231755	1.205508	Non-Liquefiable		0.112693	0.039508	0.173703	0.66324	0.33676
22.5	44	0.179636	0.197169	0.248387	1.382728	Non-Liquefiable		0.351116	0.068752	0.173703	0.947978	0.052022
24	53	0.16704	0.291363	0.374287	2.240704	Non-Liquefiable		1.381429	0.207247	0.173703	1	6.91E-12
25.5	60	0.154227	0.337454	0.441908	2.86532	Non-Liquefiable		1.879823	0.287682	0.173703	1	0
27	90	0.141485	0.527852	0.70384	4.974656	Non-Liquefiable		3.033615	0.562355	0.173703	1	0
28.5	61	0.128804	0.316806	0.429688	3.335988	Non-Liquefiable		1.959656	0.300884	0.173703	1	0
30	67	0.116087	0.349227	0.481575	4.148412	Non-Liquefiable		2.256273	0.365488	0.173703	1	0
31.5	77	0.103439	0.403963	0.56587	5.47057	Non-Liquefiable		2.591287	0.462431	0.173703	1	0
33	78	0.090851	0.398118	0.566066	6.230699	Non-Liquefiable		2.598721	0.475215	0.173703	1	0
35	99	0.075254	0.512173	0.735479	9.773224	Non-Liquefiable		2.959651	0.660225	0.173703	1	0

TABLE 18: **Probabilistic calculation for bore hole no.7**

Depth	Observed SPT value	CSR	CRR(M=7.5)	CRR	FS	Conclusion	β	μ_z	σ_z	Φ(β)	Pf
1.5	8	0.340005	0.178141	0.178141	0.523938	Liquefiable	-1.14901	-0.16186	0.173703	6.62E-09	1
3	9	0.336058	0.220733	0.220733	0.656829	Liquefiable	-0.88042	-0.11533	0.173703	5.3E-06	0.999995
4.5	10	0.332111	0.254018	0.254018	0.764858	Liquefiable	-0.65355	-0.07809	0.173703	0.000462	0.999538
6	12	0.328164	0.265114	0.265114	0.80787	Liquefiable	-0.56036	-0.06305	0.173703	0.002098	0.997902
7.5	15	0.318037	0.360132	0.360132	1.132357	Non-Liquefiable	0.146173	0.042095	0.173703	0.725471	0.274529
9	17	0.310327	0.378252	0.378252	1.218882	Non-Liquefiable	0.326725	0.067925	0.173703	0.931874	0.068126
10.5	20	0.294802	0.472589	0.472589	1.603073	Non-Liquefiable	1.101339	0.177787	0.173703	1	5.28E-08
12	30	0.279493	0.147597	0.147597	0.528087	Liquefiable	-1.07251	-0.1319	0.173703	3.06E-08	1
13.5	40	0.264864	0.299411	0.299411	1.130435	Non-Liquefiable	0.083721	0.034548	0.173703	0.611445	0.388555
15	24	0.250694	0.564412	0.564412	2.2514	Non-Liquefiable	2.009763	0.313718	0.173703	1	0
16.5	29	0.237089	-0.81382	-0.91722	-3.86866		#NUM!	-1.15431	0.173703	#NUM!	#NUM!
18	30	0.223655	-1.44963	-1.67913	-7.50767		#NUM!	-1.90278	0.173703	#NUM!	#NUM!
19.5	35	0.210262	0.033094	0.039317	0.18699	Liquefiable	-1.75759	-0.17095	0.173703	3.29E-20	1
21	47	0.196995	0.276061	0.335716	1.704188	Non-Liquefiable	0.875188	0.138721	0.173703	0.999989	1.12E-05
22.5	31	0.183759	0.78392	0.974403	5.302607	Non-Liquefiable	3.934995	0.790644	0.173703	1	0
24	55	0.170621	0.320728	0.406872	2.384653	Non-Liquefiable	1.56472	0.236251	0.173703	1	1.02E-14
25.5	71	0.157513	0.429644	0.555651	3.527658	Non-Liquefiable	2.437398	0.398138	0.173703	1	0
27	44	0.144483	0.126268	0.166284	1.150889	Non-Liquefiable	-0.04132	0.021801	0.173703	0.358167	0.641833
28.5	59	0.13152	0.310469	0.415905	3.162302	Non-Liquefiable	1.872756	0.284385	0.173703	1	0
30	63	0.118612	0.329643	0.448785	3.783647	Non-Liquefiable	2.102601	0.330173	0.173703	1	0
31.5	64	0.105751	0.324821	0.449052	4.24632	Non-Liquefiable	2.158854	0.343301	0.173703	1	0
33	121	0.09282	0.656438	0.921485	9.927645	Non-Liquefiable	3.366552	0.828664	0.173703	1	0
35	83	0.076887	0.431036	0.611185	7.949177	Non-Liquefiable	2.710387	0.534298	0.173703	1	0

TABLE 19: **Probabilistic calculation for bore hole no.8**

Depth	Observed SPT value	CSR	CRR(M=7.5)	CRR	FS	Conclusion	β	μ_z	σ_z	$\Phi(\beta)$	Pf
1.5	8	0.327479	0.190165	0.190165	0.580693	Liquefiable	-0.98512	-0.13731	0.219538	5.63E-05	0.999944
3	10	0.323678	0.243964	0.243964	0.753724	Liquefiable	-0.67062	-0.07971	0.219538	0.003556	0.996444
4.5	11	0.317378	0.269625	0.269625	0.849539	Liquefiable	-0.49553	-0.04775	0.219538	0.020693	0.979307
6	25	0.3124	0.177334	0.177334	0.567651	Liquefiable	-1.00025	-0.13507	0.219538	4.06E-05	0.999959
7.5	17	0.305508	0.453666	0.453666	1.484955	Non-Liquefiable	0.67286	0.148158	0.219538	0.991576	0.008424
9	13	0.300617	0.245488	0.245488	0.816612	Liquefiable	-0.55466	-0.05513	0.219538	0.011442	0.988558
10.5	16	0.287717	0.284069	0.284069	0.98732	Liquefiable	-0.25717	-0.00365	0.219538	0.124087	0.875913
12	35	0.27426	0.267981	0.267981	0.977106	Liquefiable	-0.28224	-0.00628	0.219538	0.104375	0.895625
13.5	42	0.259885	0.328785	0.328785	1.265115	Non-Liquefiable	0.186371	0.068899	0.219538	0.703704	0.296296
15	33	0.245968	0.130468	0.130468	0.530427	Liquefiable	-1.03482	-0.1155	0.219538	1.41E-05	0.999986
16.5	58	0.232819	0.434327	0.494736	2.124982	Non-Liquefiable	1.402813	0.261917	0.219538	1	1.01E-07
18	58	0.219782	0.411998	0.482133	2.193684	Non-Liquefiable	1.415649	0.26235	0.219538	1	7.47E-08
19.5	41	0.206335	0.203739	0.244743	1.186142	Non-Liquefiable	-0.02224	0.038408	0.219538	0.391176	0.608824
21	41	0.193089	0.120034	0.147705	0.764955	Liquefiable	-0.64577	-0.04538	0.219538	0.003121	0.996879
22.5	69	0.18037	0.387763	0.487305	2.701703	Non-Liquefiable	1.704017	0.306936	0.219538	1	9.85E-11
24	76	0.167518	0.419067	0.537419	3.208125	Non-Liquefiable	2.038972	0.369901	0.219538	1	1.45E-14
25.5	82	0.154732	0.423549	0.553568	3.577586	Non-Liquefiable	2.178599	0.398836	0.219538	1	0
27	54	0.142001	0.270027	0.359271	2.530058	Non-Liquefiable	1.239176	0.21727	0.219538	0.999998	1.62E-06
28.5	58	0.129213	0.292812	0.396392	3.067755	Non-Liquefiable	1.549097	0.26718	0.219538	1	2.62E-09
30	114	0.116493	0.639014	0.879338	7.548442	Non-Liquefiable	3.250268	0.762845	0.219538	1	0
31.5	75	0.103905	0.393322	0.549476	5.288247	Non-Liquefiable	2.351021	0.445571	0.219538	1	0
33	87	0.091343	0.455281	0.645241	7.06391	Non-Liquefiable	2.655513	0.553898	0.219538	1	0
35	109	0.075738	0.570794	0.816545	10.78115	Non-Liquefiable	2.986623	0.740807	0.219538	1	0

TABLE 20: Probabilistic calculation for bore hole no.9

Depth	Observed SPT value	CSR	CRR(M=7.5)	CRR	FS	Conclusion	β	μ_z	σ_z	Φ(β)	Pf
1.5	7	0.371407	0.155599	0.155599	0.418945	Liquefiable	-1.28059	-0.21581	0.303258	0.000223	0.999777
3	7	0.367096	0.164452	0.164452	0.44798	Liquefiable	-1.22581	-0.20264	0.303258	0.000371	0.999629
4.5	6	0.362784	0.176076	0.176076	0.485348	Liquefiable	-1.15757	-0.18671	0.303258	0.000684	0.999316
6	15	0.358473	0.468798	0.468798	1.307764	Non-Liquefiable	0.214416	0.110325	0.303258	0.634292	0.365708
7.5	10	0.410579	0.270062	0.270062	0.657758	Liquefiable	-0.86929	-0.14052	0.303258	0.008127	0.991873
9	20	0.463346	0.201711	0.201711	0.435335	Liquefiable	-1.28028	-0.26164	0.303258	0.000391	0.999609
10.5	22	0.498184	0.265107	0.265107	0.532147	Liquefiable	-1.118	-0.23308	0.303258	0.001761	0.998239
12	33	0.521955	0.493331	0.493331	0.945161	Liquefiable	-0.33842	-0.02862	0.303258	0.153493	0.846507
13.5	41	0.540763	0.617551	0.617551	1.141999	Non-Liquefiable	0.093786	0.076788	0.303258	0.52235	0.47765
15	41	0.556283	0.616406	0.616406	1.108079	Non-Liquefiable	0.028156	0.060122	0.303258	0.458026	0.541974
16.5	46	0.567152	0.691751	0.526939	0.929097	Liquefiable	-0.36449	-0.04021	0.303258	0.142463	0.857537
18	57	0.573419	0.855965	0.652731	1.138314	Non-Liquefiable	0.109981	0.079312	0.303258	0.540277	0.459723
19.5	68	0.571779	1.014331	0.775982	1.357138	Non-Liquefiable	0.639091	0.204204	0.303258	0.924221	0.075779
21	66	0.565656	0.969419	0.743982	1.315255	Non-Liquefiable	0.526899	0.178326	0.303258	0.87481	0.12519
22.5	68	0.555193	0.99336	0.764754	1.377457	Non-Liquefiable	0.663432	0.209562	0.303258	0.932758	0.067242
24	58	0.540522	0.831022	0.641767	1.18731	Non-Liquefiable	0.19613	0.101245	0.303258	0.622815	0.377185
25.5	63	0.521773	0.897786	0.695464	1.332886	Non-Liquefiable	0.507013	0.173691	0.303258	0.864146	0.135854
27	69	0.499069	1.003035	0.779364	1.561636	Non-Liquefiable	0.98938	0.280295	0.303258	0.990312	0.009688
28.5	39	0.473894	0.562588	0.438015	0.924289	Liquefiable	-0.3903	-0.03588	0.303258	0.121261	0.878739
30	50	0.446108	0.724085	0.564317	1.264978	Non-Liquefiable	0.258506	0.118209	0.303258	0.678186	0.321814
31.5	89	0.413114	1.279303	0.999017	2.418262	Non-Liquefiable	2.463585	0.585903	0.303258	1	2.98E-10
33	94	0.376361	1.345833	1.053054	2.797989	Non-Liquefiable	2.898796	0.676693	0.303258	1	1.17E-13
35	107	0.349083	1.593699	1.216174	3.48391	Non-Liquefiable	3.717297	0.867091	0.303258	1	0

TABLE 21: Probabilistic calculation for bore hole no.10

Depth	Observed SPT value	CSR	CRR(M=7.5)	CRR	FS	Conclusion	β	μ_z	σ_z	Φ(β)	Pf
1.5	6	0.321829	0.135846	0.135846	0.422107	Liquefiable	-1.28596	-0.18598	0.413865	0.003932	0.996068
3	5	0.318093	0.145978	0.145978	0.458916	Liquefiable	-1.22256	-0.17212	0.413865	0.005572	0.994428
4.5	7	0.314358	0.179139	0.179139	0.569857	Liquefiable	-1.04474	-0.13522	0.413865	0.013988	0.986012
6	8	0.310622	0.177842	0.177842	0.572535	Liquefiable	-1.04134	-0.13278	0.413865	0.014071	0.985929
7.5	15	0.305508	0.33491	0.33491	1.096238	Non-Liquefiable	-0.32592	0.029402	0.413865	0.195298	0.804702
9	16	0.300894	0.31873	0.31873	1.059277	Non-Liquefiable	-0.37804	0.017836	0.413865	0.169401	0.830599
10.5	18	0.287268	0.33861	0.33861	1.178725	Non-Liquefiable	-0.24163	0.051342	0.413865	0.239504	0.760496
12	74	0.273332	0.64433	0.64433	2.357319	Non-Liquefiable	1.130539	0.370998	0.413865	0.966765	0.033235
13.5	78	0.259116	0.636797	0.636797	2.457577	Non-Liquefiable	1.174187	0.377681	0.413865	0.972857	0.027143
15	55	0.245321	0.409206	0.409206	1.668045	Non-Liquefiable	0.253702	0.163885	0.413865	0.585903	0.414097
16.5	58	0.231825	0.432214	0.493576	2.129091	Non-Liquefiable	0.700843	0.261751	0.413865	0.855644	0.144356
18	27	0.218267	0.558421	0.656165	3.006241	Non-Liquefiable	1.48322	0.437897	0.413865	0.994228	0.005772
19.5	32	0.205276	-1.56163	-1.88167	-9.16651	Non-Liquefiable	#NUM!	-2.08694	0.413865	#NUM!	#NUM!
21	31	0.192386	0.383612	0.473069	2.458961	Non-Liquefiable	0.83643	0.280683	0.413865	0.910335	0.089665
22.5	28	0.179757	0.296211	0.373007	2.075057	Non-Liquefiable	0.445142	0.193249	0.413865	0.728616	0.271384
24	37	0.167146	-0.31807	-0.40844	-2.44361	Non-Liquefiable	#NUM!	-0.57558	0.413865	#NUM!	#NUM!
25.5	44	0.154318	0.137949	0.180585	1.170212	Non-Liquefiable	-0.42495	0.026267	0.413865	0.1378	0.8622
27	49	0.141564	0.207326	0.276357	1.952168	Non-Liquefiable	0.205922	0.134793	0.413865	0.568228	0.431772
28.5	63	0.129008	0.333487	0.451885	3.502777	Non-Liquefiable	1.168506	0.322877	0.413865	0.979486	0.020514
30	124	0.116463	0.619177	0.852169	7.317053	Non-Liquefiable	2.650898	0.735706	0.413865	0.999998	1.85E-06
31.5	59	0.103856	0.18799	0.2627	2.529469	Non-Liquefiable	0.436805	0.158844	0.413865	0.749087	0.250913
33	73	0.091302	0.338351	0.479654	5.253495	Non-Liquefiable	1.579117	0.388352	0.413865	0.997994	0.002006
35	286	0.075704	1.415667	2.025706	26.75808	Non-Liquefiable	3.983491	1.950002	0.413865	1	4.48E-07

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