LIQUEFACTION ANALYSIS OF ASH EMBANKMENTS USING SPT AND CPT DATA

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By

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CERTIFICATE

This is to certify that the thesis entitled "**Liquefaction Analysis of Ash Embankments using SPT and CPT Data**'' submitted by Raj Kumar Roy in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Civil Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

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ABSTRACT

Among the various effects of earthquakes on embankments, the most critical issue that arises is whether Liquefaction of the embankment foundation may occur and, if so, what will be the consequences. Liquefaction analysis of earth and rock fill dams is a complex one and the complexity is further multiplied when it is applied to ash embankments because many features of ash behavior during earthquake loading are unknown. This project analyses the Liquefaction Potential of Ash Embankments using Standard penetration test (SPT) and Cone penetration test (CPT) values.

The method (IITK-GSMDA) used for the analysis of Dams has been extended for evaluating liquefaction potential of ash embankments in this project. The validity of (IITK-GSMDA) method has been made with certain case studies available in literature for flat ground. Then this method has been extended to ash embankments. For application to ash embankments, two sites in India have been analyzed where SPT and CPT data are available. The first case of application in ash embankment is located at Korba Super Thermal Power Station (KSTPS), Korba, CG, where eleven SPT bore hole test results are available. Second case histories relate to ash embankment located at Badarpur Thermal Power Station (BTPS), New Delhi, where six SPT bore hole test results and three CPT bore hole test results are available.

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Chapter 1

INTRODUCTION

In India the vast alluvial Gangetic basin constitutes a major area of influence of the Himalayan Earthquakes, and in this terrain liquefaction has been frequently reported in the past earthquakes. On 15th January 1934, the plains of northern Bihar and adjoining Nepal were severely jolted by a devastating earthquake (Ms>8). The tremor was felt beyond Kashmir and China. Then the Bhuj, Gujrat earthquake on 26th January 2001 caught the eyes of the whole world. A magnitude of 7.7 earthquakes devastated this area, killing 20,000 people and destroying buildings, dams and port facilities.

So, we see that in India earthquake causing liquefaction poses a major threat to life and work of man. Failure of embankment under seismic loading may occur due to liquefaction of embankment and/or foundation material (Seed and Idriss, 1971). This project works on determining the Liquefaction Potential of Ash Embankments located in two different sites in India. The first Ash dyke is located in Korba Super Thermal power Station(KSTPS), Korba, CG and the second one is located in Badarpur Thermal Power Station(BTPS), Badarpur, New Delhi.

Cone Penetration Test (CPT) and Standard Penetration Test (SPT) data is widely accepted as the best option for subsurface investigation in determining sequence of subsurface strata, groundwater conditions, and mechanical properties of subsurface strata. Both SPT and CPT values are used in this project report for determining the liquefaction potential of the two embankments. Due to the difficulties in obtaining and laboratory testing of undisturbed representative samples from most potentially liquefiable sites, in-situ testing is often relied upon for assessing the liquefaction potential of cohesion less soils.

Generally the procedure used in engineering practice for the assessment of liquefaction potential of sands and silts is the **Simplified Procedure**. This is the procedure used in the project for determining the Liquefaction Potential. The Procedure may be used with either SPT blow count or CPT tip resistance. The validation of this procedure is then done using certain CPT results obtained from Chi-Chi, Taiwan Earthquake. Then this procedure is extended to determine the Liquefaction Potential of the two Ash Embankments using both SPT and CPT methods. Here the whole embankment is divided into various stages and then the SPT and CPT tests are conducted on the crest of each stage using bore holes. The results obtained provide us knowledge of the liquefaction potential at various depths under each bore hole.

Chapter 2

LITERATURE REVIEW

2.1 Liquefaction of Soil: An Overview

Soil liquefaction describes the behavior of soils that, when loaded, suddenly suffer a transition from a solid state to a liquefied state, or having the consistency of a heavy liquid. A more precise definition of soil liquefaction is given by Sladen et al. (1985):

"Liquefaction is a phenomenon wherein a mass of soil loses a large percentage of its shear resistance, when subjected to monotonic, cyclic, or shock loading, and flows in a manner resembling a liquid until the shear stresses acting on the mass are as low as the reduced shear resistance"

Ground failures attributed to soil liquefaction.

Soil Liquefaction results from the tendency of are more correctly ascribed to "cyclic mobility" which results in limited soil deformations without liquid-like flow. Proper definition of soil liquefaction is yet a mystery soils to decrease in volume when subjected to shearing stresses. When loose, saturated soils are sheared, the soil grains tend to rearrange into a more dense packing, with less space in the voids, as water in the pore spaces is forced out. If drainage of pore water is impeded, pore water pressure increases progressively with the shear load. This leads to the transfer of stress from the soil skeleton to the pore water precipitating a decrease in effective stress and shear resistance of the soil. If the shear resistance of the soil becomes less than the static, driving shear stress, the soil can undergo large deformations and is said to liquefy (Martin et al. 1975; Seed and Idriss 1982).

Dense sands when monotonically sheared, the soil skeleton may first compress and then dilate as the sand particles move up and over one another. For dense, saturated sands sheared without pore water drainage, the tendency for dilation or volume increase results in a decrease in pore water pressure and an increase in the effective stress and shear strength. When a dense sand sample is subjected to cycles of small shear strains under undrained conditions, excess pore pressure may be generated in each load cycle leading to softening and the accumulation of deformations. However, at larger shear strains, dilation relives the excess pore pressure resulting in an increased shear resistance.

Few investigators used the term “limited liquefaction” for conditions where large deformations after initial liquefaction are prevented by an increase in the undrained shear strength (Finn 1990). The propensity of dense, saturated sands to progressively soften in undrained cyclic shear, but achieve limiting strains under subsequent static loading, is more precisely described as cyclic mobility (Castro 1975: Castro and Poulos 1977). Cyclic mobility is distinguished from liquefaction by the fact that a liquefied soil exhibits no appreciable increase in shear resistance regardless of the magnitude of deformation (Seed 1979).

As pointed out by Selig and Chang (1981) and Robertson (1994), it is possible for a dilative soil to reach a temporary condition of zero effective stress and shear resistance. When the initial static shear stress is low, cyclic loads may produce a reversal in the shear stress direction. That is the stress path passes through a state of zero shear stress. Under these conditions, a dilative soil may accumulate sufficient pore pressures to reach a condition of zero effective stress and large deformation may develop. However, deformations stabilize when cyclic loading ends because the tendency to dilate with further shearing increases the effective stress and shear resistance. Robertson (1994) termed this behavior as “cyclic liquefaction”. Unlike cyclic mobility, cyclic liquefaction involves at least some deformation occurring while static shear stress exceeds the shear resistance. However, deformations do not continue after cyclic loading ends as the tendency to dilate quickly results in strain hardening. Again, this type of failure in saturated, dense cohesion less deposits is usually identified as “liquefaction” but with limited deformations.

According to the latest version of classification of soil liquefaction, given by Robertson et al. (1994), it can be summarized as:

(1) Flow liquefaction: Undrained flow of saturated, contractive soil when the static shear stress exceeds the residual strength of the soil. Failure may be triggered by cyclic or monotonic shear loading.

(2) Cyclic softening: Large deformations occurring during cyclic shear due to pore pressure build-up in soils that would tend to dilate in undrained, monotonic shear. Cyclic softening, in which deformations do not continue after cyclic loading ceases, can be further classified as:

- Cyclic liquefaction—occurs when cyclic shear stresses exceed the initial, static shear stress to produce a stress reversal. A condition of zero effective stress may be achieved during which large deformations may occur.
- Cyclic mobility—here cyclic loads do not yield a shear stress reversal and a condition of zero effective stress does not develop.

Substantive efforts can be spent in devising nomenclature to clearly define the failure response of saturated soils in earthquakes. However, no definition or classification system appears to be entirely satisfactory for all possible failure mechanisms.

2.2 Field Experimentations

2.2.1 Standard Penetration Test (SPT)

Standard Penetration Test (SPT) has been the most commonly used in-situ test in geotechnical subsurface investigation (Decourt et al. ,1988).The test obtains both a numerical resistance (N-value) for the soil, as well as a disturbed drive sample for classification and index testing. “Undisturbed” sampling of sands would require expensive and advanced techniques such as ground freezing (Sego et al. ,1999). Because frozen samples are very difficult to obtain, and only then in limited quantity, alternative methods based on in-situ methods are preferred.

Standard Penetration Test (SPT) method consists of repeatedly dropping a 63.5-kg mass from a height of 760 mm to drive a split-spoon sampler into the ground (ASTM D-1586). Figure 2.1 displays SPT equipment and procedure.

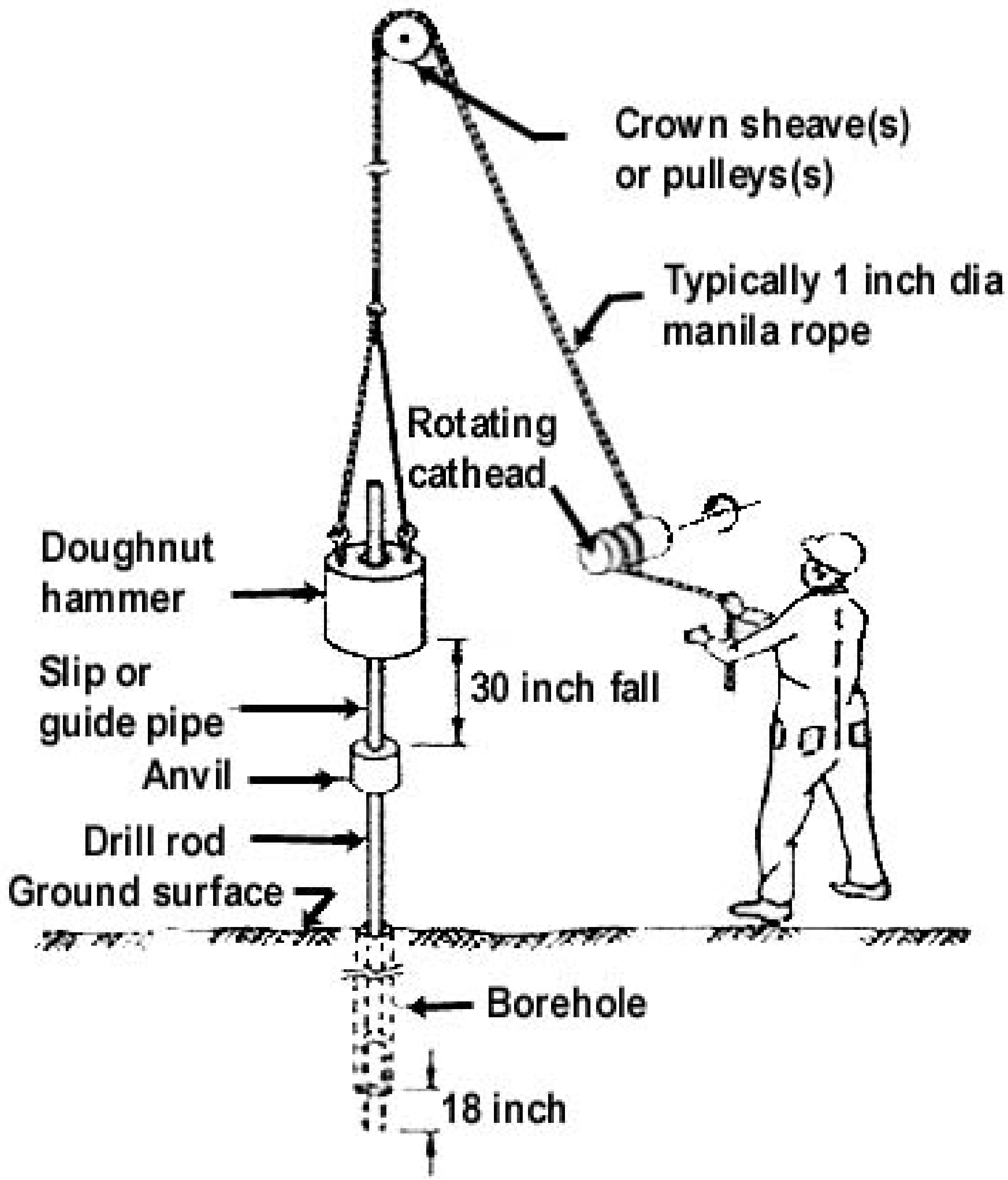


Figure 2.1 SPT Equipment and Procedure

A theoretical free-fall energy of 474.5 J would be delivered under ideal conditions, but frictional losses and operator variability results in a delivered energy which is much lower (Skempton,1986). The numbers of blows are recorded for three increments of 152 mm each. The initial 152 mm is a “seating” and is neglected. The blows from the second and third intervals are totaled as the N-values over 304-mm of penetration.

Various correction factors are applied to the measured N-value, this is necessary because of energy inefficiencies and procedural variation in practice. When all factors are applied to the field recorded N-values (Nmeans), the corrected and normalized (N1)60 can be determined by:

(N1)60 = Nmeans CN CE CB CS CR

Where CN—Correction due to stress level

CE—Correction due to Energy

CB—Correction due to Borehole diameter

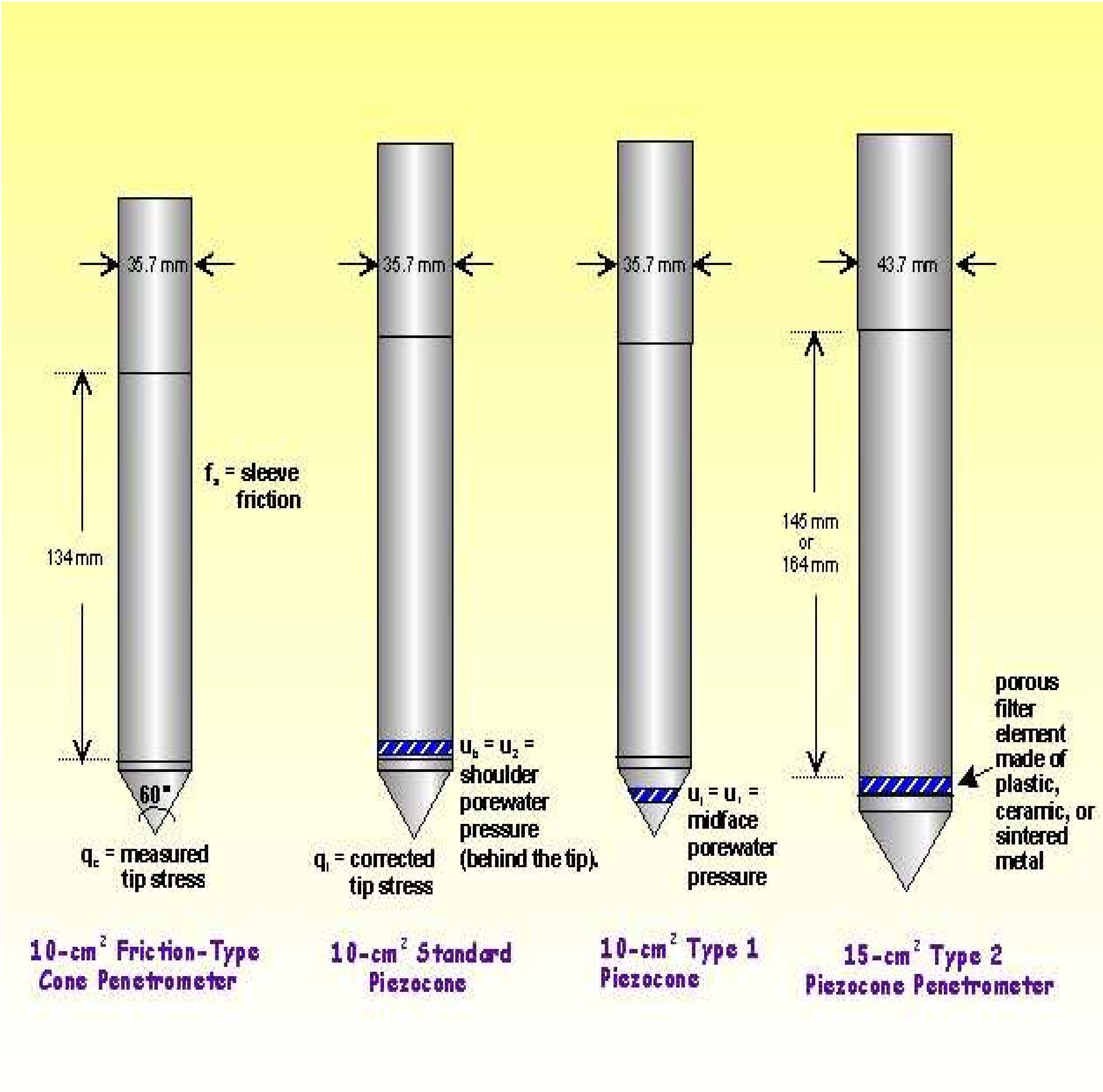
CS—Correction due to sampling method

CR—Correction due to rod length

Overall effect of having so many corrections, each with its own great uncertainty, is that little confidence can be assigned to the SPT as a reliable means for assessing the liquefaction potential of soils.

2.2.2 Cone Penetration Test (CPT)

Earlier, a cone penetrometer was a mechanical device that produced tip stress measurements with depths, with later adaption for sleeve resistance (Broms and Flodin, 1988). The probe is hydraulically pushed into the ground without the need for a soil boring. The test equipment has evolved to its current state of electric and electronic cone penetrometers with standard readings of tip resistance (qc) and sleeve friction (f_s), as shown in Fig 2.2.



(a) (b) (c) (d)

Figure 2.2 Types of Cone Penetrometer

The readings are collected by computerized data acquisition system coverting analog signals from strain gauge to digital data. New sensors have been added to cone penetrometers including pore pressure transducers with porous filters located at shoulder (Fig. 2.2.b.) or midface (Fig.2.2.c.) in order to measure penetration porewater pressure (u_2 or u_1 respectively).

Standard cone penetrometers have a 60° apex at the tip, 10-cm² projected tip area, 35.7 mm diameter, and 150 cm² sleeve surface area. Cone penetrometers may also have a 60° apex at the tip, 15 cm² projected tip area, 44 mm diameter, and either 200 or 225 cm² sleeve surface area. The maximum capacity of the load cells may carry, with lower capacity load cells providing high resolution necessary for investigations in low resistance soils, such as soft clays. The location of piezocone filters for pore pressure measurement may be at mid-face (u_1) and/or behind the shoulder (u_2), as seen in Figure 2.2.

The test consists of hydraulically pushing the cone at a rate of 2 m/s using either a standard drill rig or specialized cone truck. The advance of the probe requires the successive addition of rods at approximately 1m or 1.5 m intervals. Readings of tip resistance (q_c), sleeve friction (f_s), inclination (i), and pore pressure(u_m) are taken every 5 cm (2.5 sec.). Depending upon limitations of the data acquisition system, the readings may be recorded at higher sampling rates to distinguish variations in soil strata, fabric, and layering.

2.3 Liquefaction analysis of Ash Embankments: An Overview

Various methods have been developed for designing of conventional earth and rock fill dams when subjected to high seismic loading causing liquefaction. However, very little study has been done to understand the behavior of Ash Embankments under earthquake loading. The need for seismic analysis of ash embankments has not been seriously considered because ash ponds are generally located near coal belts, which are generally low earthquake hazard zones. Also, the ash disposal dams are of low heights (about 10m) of earthen material constructed over the original firm foundation soil. In India, many of the ash ponds are being raised over the settled ash slurry, which is likely to be very susceptible to earthquake loading. Therefore, this issue also requires very serious consideration, especially if the ash ponds are located in high earthquake zones or if a number of raisings have been planned by upstream construction.

Stability analysis of an ash embankment under low seismic loading conditions can generally be analyzed using stability analysis. However, in areas where risk is high, or for very important embankments, a site specific Liquefaction analysis must be performed for the proposed design and subsequent staging's.

Chapter 3

MEHODOLOGY

3.1 Simplified Procedure (IITK-GSDMA guidelines for Seismic Design of Earth Dams and Embankments)

The simplified procedure based on IITK-GSDMA guidelines for liquefaction analysis of earth dams and embankments has been extended for liquefaction analysis of ash embankment in thermal power plants. The project utilizes the Simplified Procedure for Evaluation of Liquefaction Potential of Ash Embankments. The procedure will be used with either SPT blow count or CPT tip resistance measured within the deposits.

The following steps are followed to determine the Liquefaction Potential of Cohesion less Soils using Simplified Procedure:

Step 1:

The subsurface data used to assess liquefaction susceptibility included the location of the water table, either SPT blow count (N), or tip resistance of a standard CPT cone (q_c), mean grain size (D_{50}), unit weight, and fines content of the soil (percent by weight passing the IS Standard Sieve No. 76μ).

Step 2:

The total vertical stress (σ_v) and effective vertical stress (σ'_v) for all potentially liquefiable layers within the deposit were evaluated.

Step 3:

The following equation can be used to evaluate the stress reduction factor r_d :

$r_d = 1 – 0.00765z$ for $z \leq 9.15$m and

$r_d = 1.174 – 0.0267z$ for $9.15 < z \leq 23$m where z is the depth below the ground surface in meters.

Step 4:

The Critical stress ratio induced by the design earthquake, CSR was calculated as:

$CSR = 0.65\ (\alpha_{max} / g)\ r_d\ (\sigma_v / \sigma'_v)$

where σ_v and σ'_v are the total and effective vertical stresses, respectively, at depth z, α_{max} is the peak horizontal ground acceleration (PHGA), and g is the acceleration due to gravity. For assessing liquefaction of soil layers underneath free standing water column, the height of free standing water is neglected and the water table is assumed at the soil surface.

Now for assessing liquefaction susceptibility using the SPT we use Step 5a and for CPT we use Step 5b, to compute cyclic resistance ratio ($CRR_{7.5}$) for Mw = 7.5 earthquakes. Cyclic resistance ratio, CRR for sites for earthquakes of other magnitudes or for sites underlain by non-horizontal soil layers or where vertical effective stress exceeds 1 atmospheric pressure is estimated by multiplying $CRR_{7.5}$ by three correction factors, K_m, K_α and K_σ respectively. These correction factors are obtained from figures A-1, A-2 and A-3.

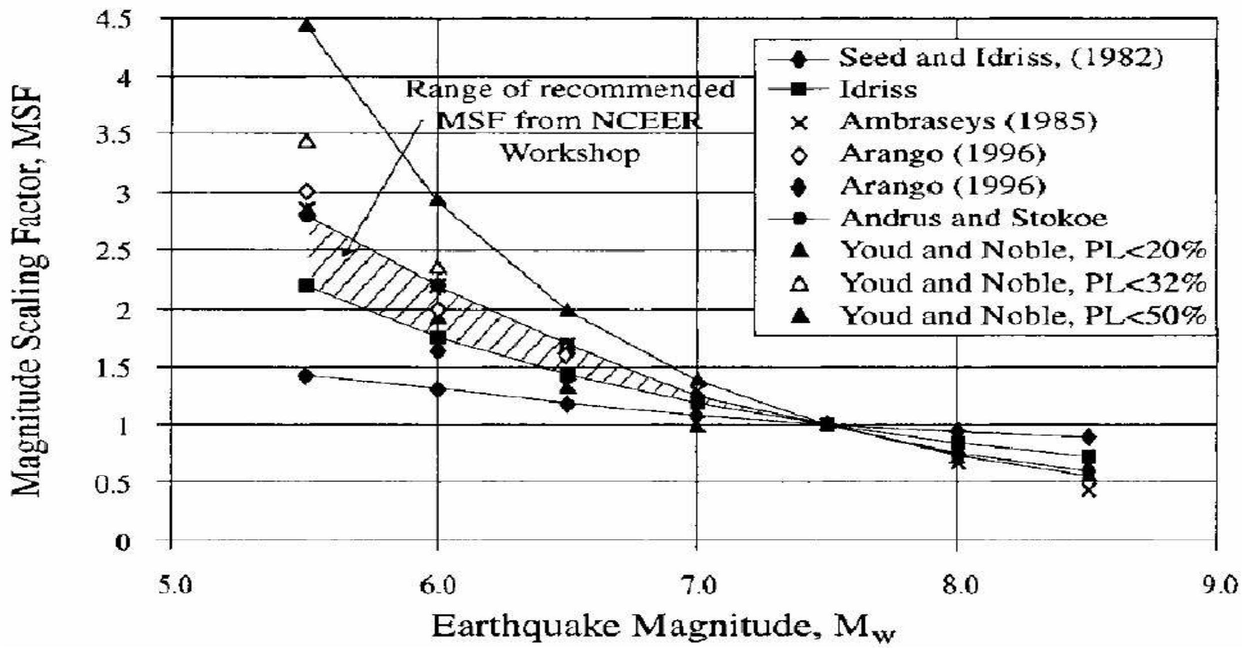


Figure A-1 Magnitude Correction factor

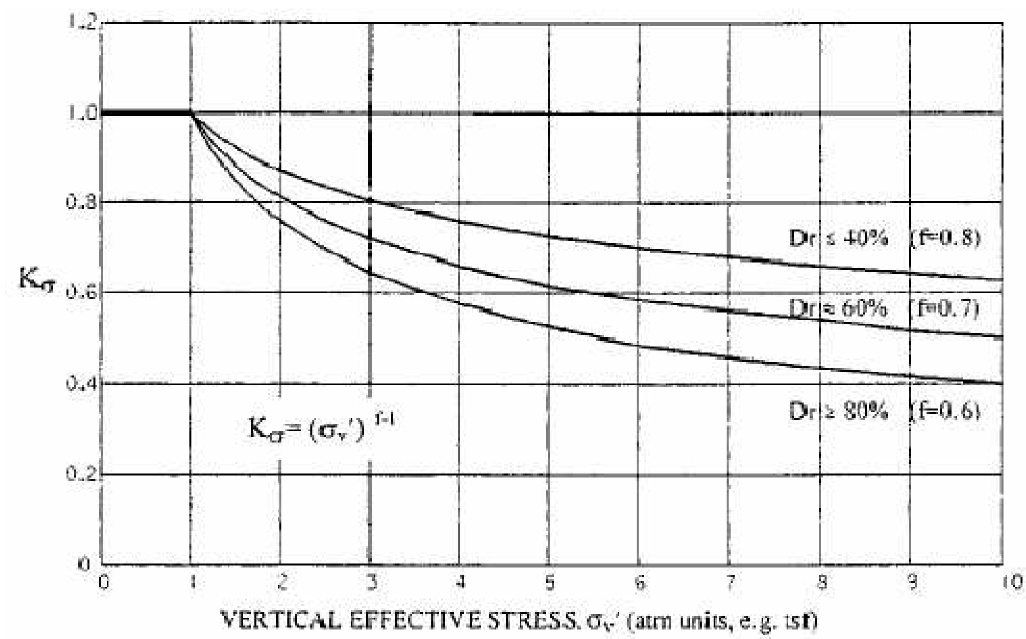


Figure A-2 Stress Correction factor

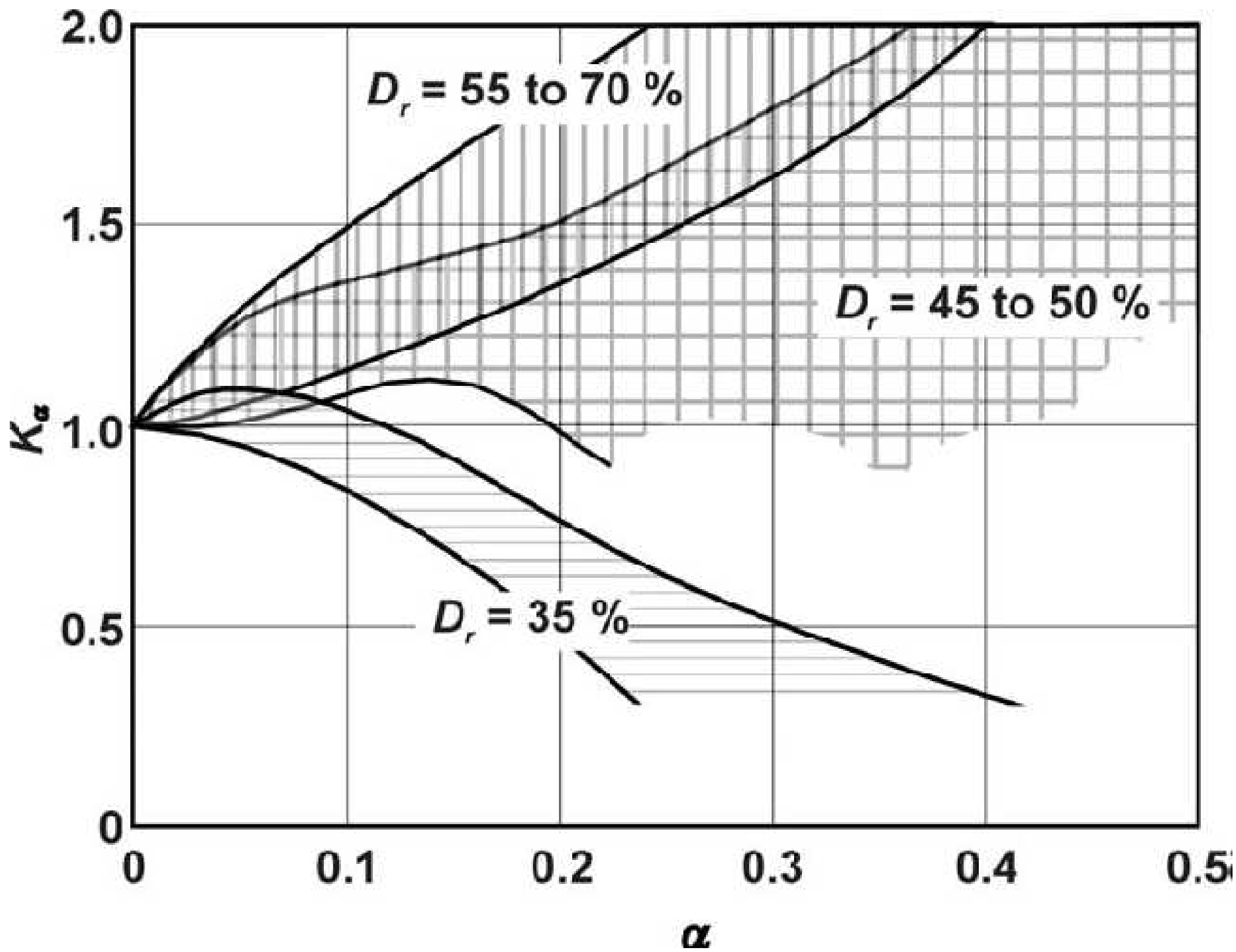


Figure A-3 Correction for initial static shear

Step 5a:

The standardized SPT blow count (N_{60}) which is the standard penetration blow count for a hammer with an efficiency of 60 percent is now evaluated. The standardized SPT blow count is obtained from the equation:

$N_{60} = N.C_{60}$

where C_{60} is the product of various correction factors.

Now the normalized standardized SPT blow count, $(N_1)_{60}$ are calculated using $(N_1)_{60} = C_N N_{60}$, where Stress normalization factor C_N is calculated from the following expression:

$C_N = (P_a / \sigma'_v)^{0.5}$

Subjected to $C_N \leq 2$, where Pa is the atmospheric pressure. However the closed-form expression proposed by Liao and Whitman (1986) may also be used:

$C_N = 9.79(1 / \sigma'_v)^{0.5}$

The CRR or the resistance of a soil against liquefaction is estimated from Figure 3.1.1 for representative $(N_1)_{60}$ values of the deposit.

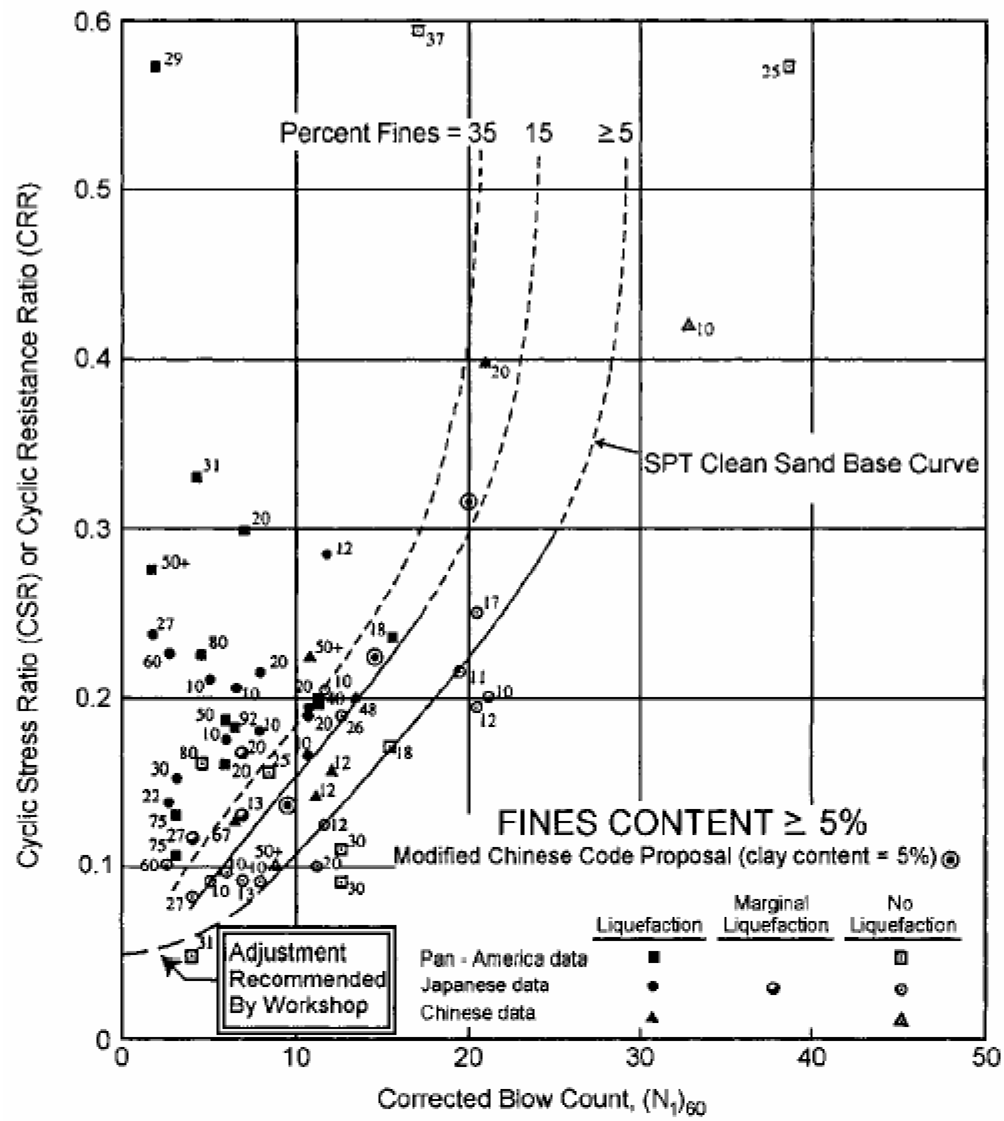


Figure 3.1.1 Relationship between *CRR* and $(N_1)_{60}$ for *Mw, 7.5* earthquakes

Step 5b:

Normalized cone tip resistance $(q_{c1N})_{cs}$ is calculated using,

$$(q_{c1N})_{cs} = K_c (P_a / \sigma'_v)^n (q_c / P_a)$$

where q_c is the measured cone tip resistance corrected for thin layers, exponent n has a value of 0.5 for sand and 1 for clay, and K_c is the correction factor for grain characteristics estimated as follows.

$K_c = 1$ for $I_c \leq 1.64$ and

$K_c = -0.403I_c^4 + 5.58I_c^3 - 21.63I_c^2 + 33.75I_c - 17.88$ for $I_c > 1.64$

The soil behavior type index, I_c, is given by

$$I_c = \sqrt{(3.47 - \log Q)^2 + (1.22 + \log F)^2}$$

where $Q = [(q_c - \sigma_v) / P_a](P_a / \sigma'_v)^n$

$F = [f / (q_c - \sigma_v)]*100$, f is the measured sleeve friction and n has the same values as earlier.

The CRR for a soil is estimated from Figure 3.1.2 using the $(q_{c1N})_{cs}$ value representative of the layer.

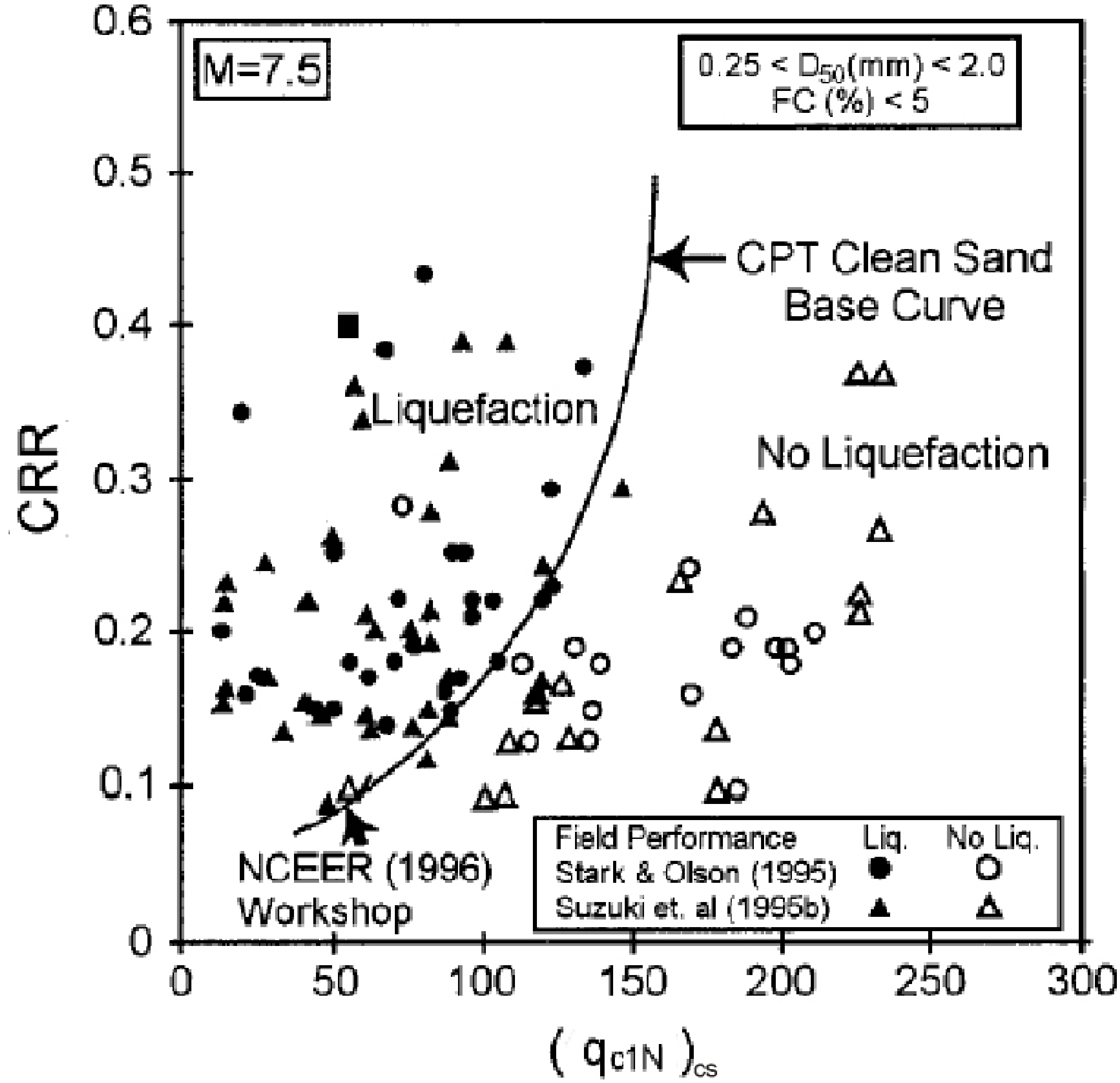


Figure 3.1.2 Relationship between *CRR* and (*qc*1*N*)cs for *Mw, 7.5* earthquakes

Step 6:

$CRR_{7.5}$ was corrected for earthquake magnitude(M_w), stress level and for initial static shear using correction factors k_m,k_σ and k_α respectively, according to:

$CRR = CRR_{7.5}.k_m.k_\sigma.k_\alpha$

where k_m, k_σ and k_α are correction factors, respectively for magnitude correctio, effective overburden correction and sloping ground correction.

Step 7:

The factor of safety against initial liquefaction, FS, is calculated as:

FS = CRR / CSR

where CSR is as estimated in step 4. When the design ground motion is conservative, earthquake-related permanent ground deformation is generally small if FS $\geq$ 1.1.

Chapter 4

APPLICATION OF SIMPLIFIED PROCEDURE TO ASH EMBANKMENTS

4.1 Ash Embankment in Korba Super Thermal Power Station (KSTPS)

At KSTPS the Ash Dyke is being raised by upstream method of construction. At Eleven test borehole location, SPT was carried out (B1 through B6 and BH7 through BH11) at KSTPS ash dyke. The bore holes B1, B2, B3, B4 and B5 are located at the crest of stage 1 (starter dyke), stage 2, stage 3, stage 4 and the ash pond respectively. The boreholes BH1 and BH2 are located at the crest of stage 5 and stage 6, respectively on the western dyke and BH3 and BH6 are located at the crest of stage 4 and stage 3 on the eastern dyke. The borehole BH5 is located at the crest of starter dyke (stage 1) and BH4 is located on settled ash bed. Tests covered the entire alignment of all four stages of embankment.

Bore hole Number 1(BH1)

Bore hole number 1(BH1) is situated on the crest of Stage 5 on the Western Dykes. The SPT test Results of BH1 are shown in table 4.1.1and the Graph of Depth vs. FS against Liquefaction is shown in Fig 4.1.1.

Table 4.1.1 SPT test Results of BH1

Dep Rn	Depth	%Fine	γ_{sat}	σ_o	u_0	σ_o'	Av.N_{60}	C_N	C_{60}	$(N_I)_{60}$	r_d	K_m	K_α	K_σ	CSR	$CRR_{7.5}$	CRR	FS_{liq}	Remarks
0-1.5	0.75	15.00	1.85	1.39	0.74	0.65	7.00	2.00	1.00	29.87	0.99	1.00	1.00	1.20	0.33	0.32	0.38	1.16	NL
1.5-3	2.25	14.00	1.85	4.16	2.21	1.96	13.50	2.21	1.00	30	0.98	1.00	1.00	1.13	0.33	0.33	0.37	1.14	NL
3-4.5	3.75	9.00	1.85	6.94	3.68	3.26	11.00	1.71	1.00	19	0.97	1.00	1.00	1.05	0.32	0.24	0.25	0.78	L
4.5-6	5.25	8.00	1.85	9.71	5.15	4.57	9.00	1.45	1.00	13	0.96	1.00	1.00	0.97	0.32	0.14	0.14	0.43	L
6-7.5	6.75	7.00	1.85	12.49	6.62	5.87	10.00	1.28	1.00	13	0.95	1.00	1.00	0.94	0.31	0.16	0.15	0.48	L
7.5-9	8.25	6.00	1.85	15.26	8.09	7.18	8.00	1.16	1.00	9	0.94	1.00	1.00	0.93	0.31	0.09	0.08	0.27	L
9-10.5	9.75	5.00	1.85	18.04	9.56	8.48	5.00	1.06	1.00	5	0.93	1.00	1.00	0.92	0.31	0.07	0.06	0.21	L
10.5-12	11.25	5.00	1.85	20.81	11.03	9.79	6.00	0.99	1.00	6	0.70	1.00	1.00	0.91	0.23	0.07	0.06	0.27	L
12-13.5	12.75	5	1.85	23.59	12.50	11.09	6.00	0.93	1.00	6	0.66	1.00	1.00	0.88	0.22	0.07	0.06	0.282	L
13.5-15	14.25	5	1.85	26.36	13.97	12.40	7.00	0.88	1.00	6	0.62	1.00	1.00	0.83	0.21	0.07	0.06	**0.283**	L
15-16.5	15.75	7	1.85	29.14	15.44	13.70	8.00	0.84	1.00	7	0.58	1.00	1.00	0.81	0.19	0.08	0.06	0.32	L
16.5-18	17.25	6	1.85	31.91	16.91	15.01	6.00	0.80	1.00	5	0.54	1.00	1.00	0.80	0.18	0.06	0.05	0.26	L

Depth vs. FS Graph for BH1

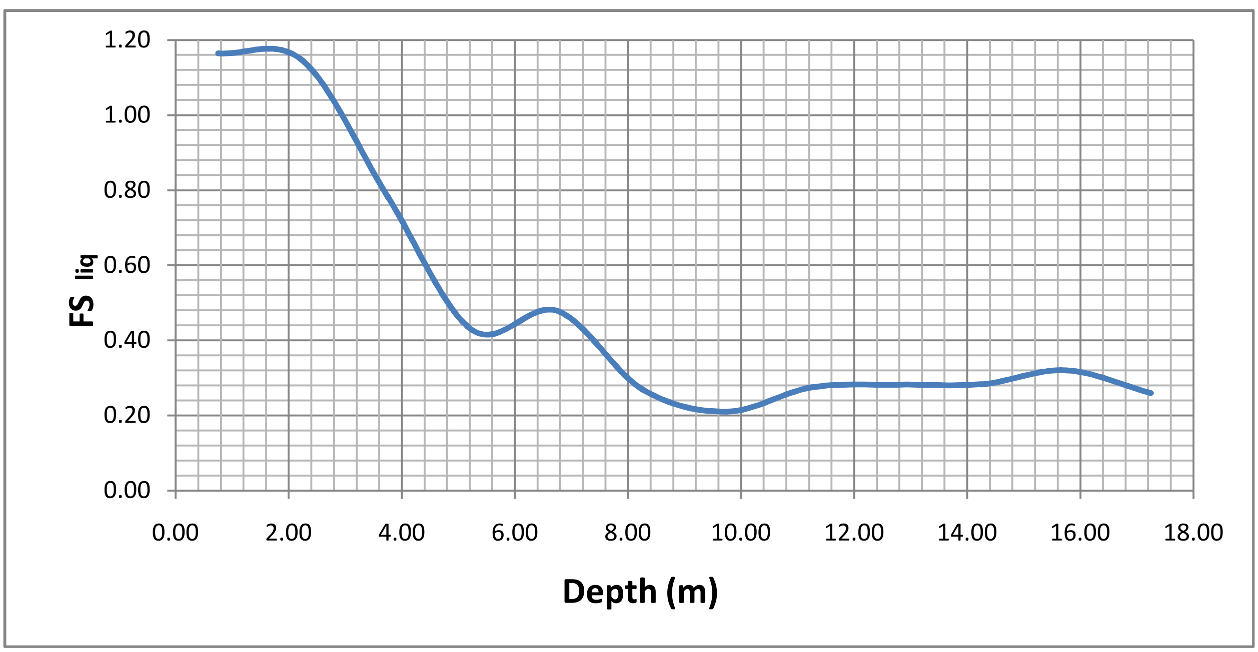


Figure 4.1.1

Bore Hole Number 2(BH2)

Bore hole number 2(BH2) is situated on the crest of Stage 4 on the Western Dykes.

The SPT test Results of BH2 are shown in table 4.1.2. and the Graph of Depth vs. FS against Liquefaction is shown in Fig. 4.1.2.

Table 4.1.2 SPT test Results of BH2

Dep Rn	Depth	%Fine	γ_{sat}	σ_o	u_0	σ_o'	Av.N_{60}	C_N	C_{60}	$(N_I)_{60}$	r_d	K_m	K_α	K_σ	CSR	$CRR_{7.5}$	CRR	FS_{liq}	Remarks
0-1.5	0.75	13.00	1.85	1.39	0.74	0.65	15.00	2.00	1.00	30.00	0.99	1.00	1.00	1.20	0.33	0.37	0.44	1.35	NL
1.5-3	2.25	15.00	1.85	4.16	2.21	1.96	21.00	2.21	1.00	46	0.98	1.00	1.00	1.13	0.33	0.50	0.57	1.73	NL
3-4.5	3.75	9.00	1.85	6.94	3.68	3.26	11.00	1.71	1.00	19	0.97	1.00	1.00	1.05	0.32	0.24	0.25	0.78	L
4.5-6	5.25	6.00	1.85	9.71	5.15	4.57	9.00	1.45	1.00	13	0.96	1.00	1.00	0.97	0.32	0.14	0.14	0.43	L
6-7.5	6.75	7.00	1.85	12.49	6.62	5.87	10.00	1.28	1.00	13	0.95	1.00	1.00	0.94	0.31	0.16	0.15	0.48	L
7.5-9	8.25	5.00	1.85	15.26	8.09	7.18	6.60	1.16	1.00	8	0.94	1.00	1.00	0.93	0.31	0.09	0.08	0.26	L
9-10.5	9.75	5.00	1.85	18.04	9.56	8.48	7.60	1.06	1.00	8	0.93	1.00	1.00	0.92	0.31	0.09	0.08	0.26	L
10.5-12	11.25	8.00	1.85	20.81	11.03	9.79	10.00	0.99	1.00	10	0.70	1.00	1.00	0.91	0.23	0.11	0.10	0.43	L

Depth vs. FS Graph for BH2

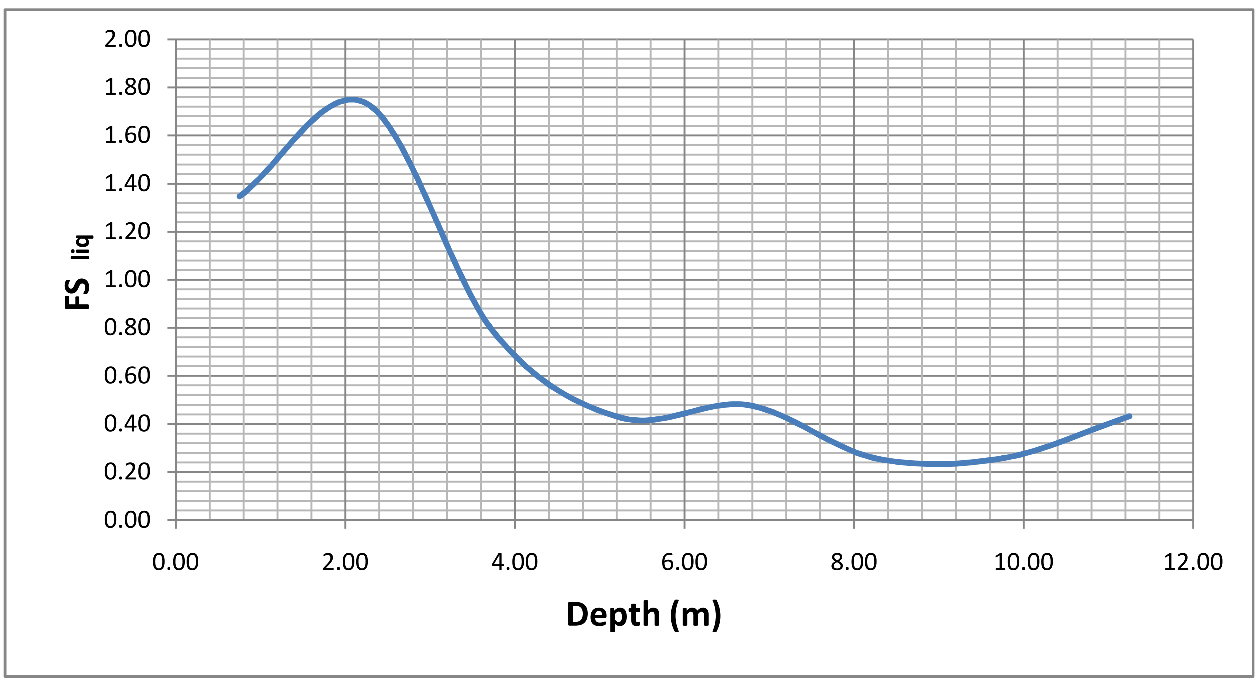


Figure 4.1.2

Bore Hole Number 3(BH3)

Bore hole number 3(BH3) is situated on the crest of Stage 4 on the Eastern Dykes.

The SPT test Results of BH3 are shown in table 4.1.3. And the Graph of Depth vs. FS against Liquefaction is shown in Fig. 4.1.3.

Table 4.1.3 SPT test Results of BH3

Dep Rn	Depth	%Fine	γ_{sat}	σ_o	u_0	σ_o'	Av.N_{60}	C_N	C_{60}	$(N_I)_{60}$	r_d	K_m	K_α	K_σ	CSR	$CRR_{7.5}$	CRR	FS_{liq}	Remarks
0-1.5	0.75	12.00	1.85	1.39	0.74	0.65	17.00	2.00	1.00	34.00	0.99	1.00	1.00	1.20	0.33	0.40	0.48	1.46	NL
1.5-3	2.25	13.00	1.85	4.16	2.21	1.96	20.00	2.21	1.00	44	0.98	1.00	1.00	1.13	0.33	0.50	0.57	1.73	NL
3-4.5	3.75	8.00	1.85	6.94	3.68	3.26	10.00	1.71	1.00	17	0.97	1.00	1.00	1.05	0.32	0.41	0.43	1.34	NL
4.5-6	5.25	7.00	1.85	9.71	5.15	4.57	10.00	1.45	1.00	14	0.96	1.00	1.00	0.97	0.32	0.17	0.16	0.52	L
6-7.5	6.75	6.00	1.85	12.49	6.62	5.87	8.00	1.28	1.00	10	0.95	1.00	1.00	0.94	0.31	0.12	0.11	0.36	L
7.5-9	8.25	7.00	1.85	15.26	8.09	7.18	8.00	1.16	1.00	9	0.94	1.00	1.00	0.93	0.31	0.11	0.10	0.33	L
9-10.5	9.75	7.00	1.85	18.04	9.56	8.48	9.00	1.06	1.00	10	0.93	1.00	1.00	0.92	0.31	0.11	0.10	0.33	L
10.5-12	11.25	5.00	1.85	20.81	11.03	9.79	6.00	0.99	1.00	6	0.70	1.00	1.00	0.91	0.23	0.07	0.06	0.27	L
12-13.5	12.75	6	1.85	23.59	12.50	11.09	7.00	0.93	1.00	6.51	0.66	1.00	1.00	0.88	0.22	0.07	0.06	0.29	L

Depth vs. FS Graph for BH3

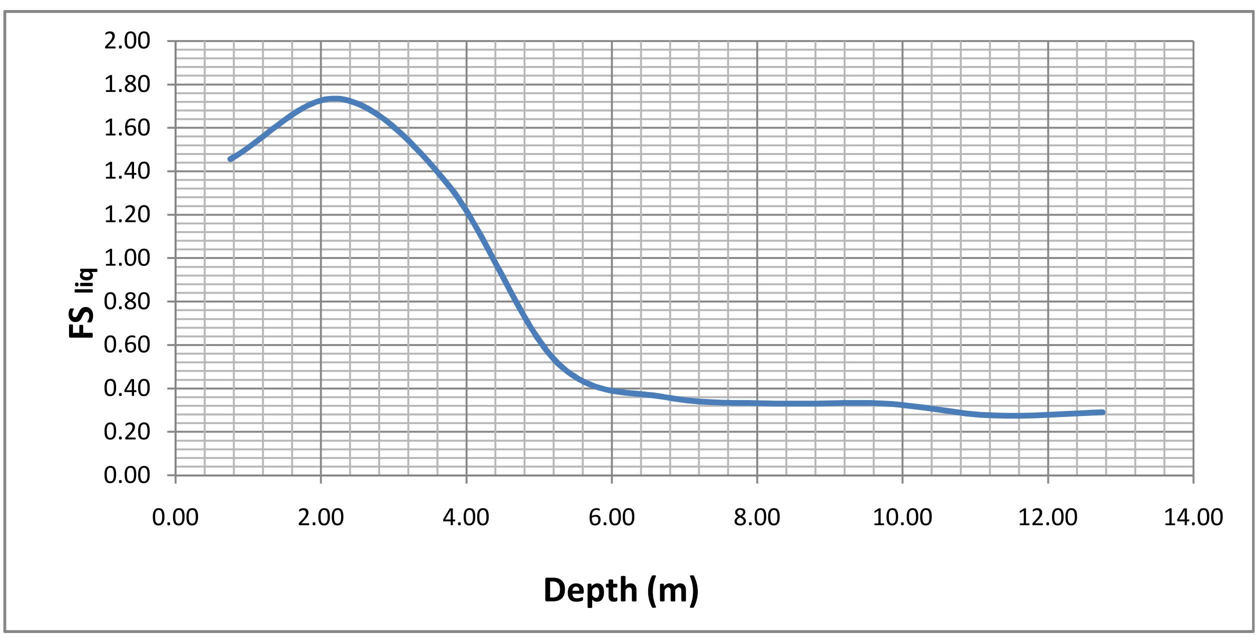


Figure 4.1.3

Bore Hole Number 4(BH4)

Bore hole number 4(BH4) is situated on the crest of settled ash bed.

The SPT test Results of BH4 are shown in table 4.1.4. And the Graph of Depth vs. FS against Liquefaction is shown in Fig. 4.1.4.

Table 4.1.4 SPT test Results of BH4

Dep Rn	Depth	%Fine	γ_{sat}	σ_o	u_0	σ_o'	Av. N_{60}	C_N	C_{60}	$(N_l)_{60}$	r_d	K_m	K_α	K_σ	CSR	$CRR_{7.5}$	CRR	FS_{liq}	Remarks
0-1.5	0.75	10.00	1.85	1.39	0.74	0.65	9.00	2.00	1.00	18.00	0.99	1.00	1.00	1.20	0.33	0.35	0.42	1.27	NL
1.5-3	2.25	9.00	1.85	4.16	2.21	1.96	11.00	2.21	1.00	24	0.98	1.00	1.00	1.13	0.33	0.38	0.43	1.32	NL
3-4.5	3.75	5.00	1.85	6.94	3.68	3.26	9.00	1.71	1.00	15	0.97	1.00	1.00	1.05	0.32	0.33	0.35	1.08	NL
4.5-6	5.25	6.00	1.85	9.71	5.15	4.57	10.00	1.45	1.00	14	0.96	1.00	1.00	0.97	0.32	0.33	0.32	1.01	NL
6-7.5	6.75	7.00	1.85	12.49	6.62	5.87	10.00	1.28	1.00	13	0.95	1.00	1.00	0.94	0.31	0.14	0.13	0.42	L
7.5-9	8.25	9.00	1.85	15.26	8.09	7.18	10.00	1.16	1.00	12	0.94	1.00	1.00	0.93	0.31	0.13	0.12	0.39	L
9-10.5	9.75	7.00	1.85	18.04	9.56	8.48	10.00	1.06	1.00	11	0.93	1.00	1.00	0.92	0.31	0.10	0.09	0.30	L
10.5-12	11.25	6.00	1.85	20.81	11.03	9.79	8.00	0.99	1.00	8	0.70	1.00	1.00	0.91	0.23	0.07	0.06	0.27	L

Depth vs. FS Graph for BH4

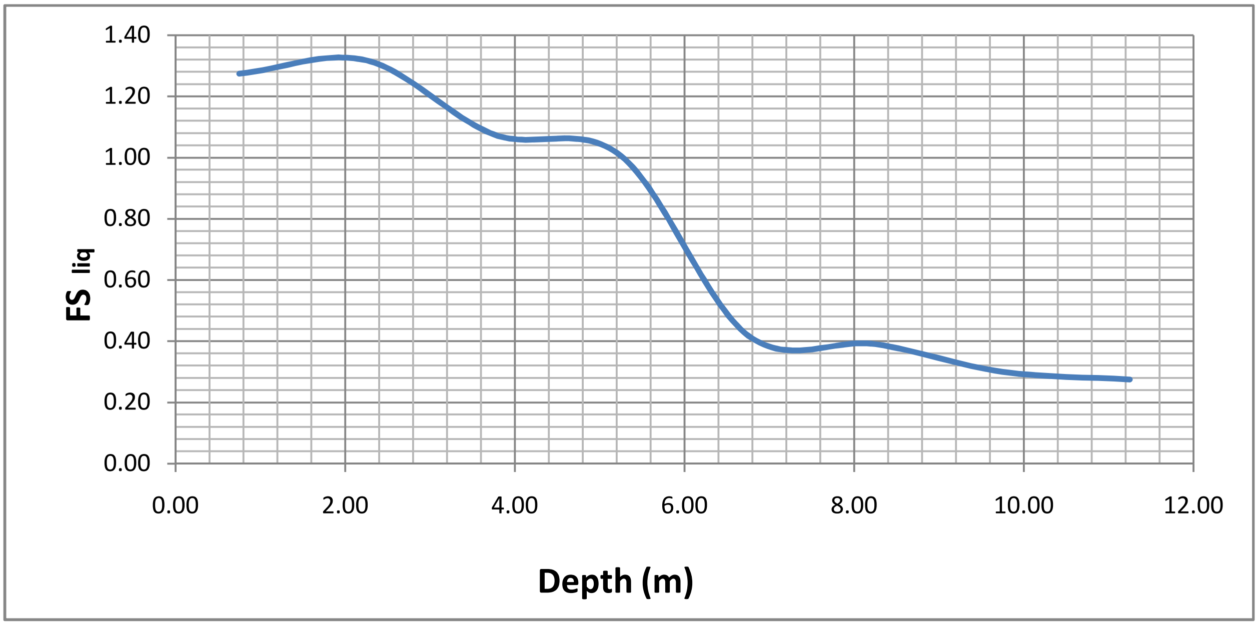


Figure 4.1.4

Bore Hole Number 5(BH5)

Bore hole number 5(BH5) is situated on the crest of starter dyke (Stage 1) on the Eastern Dykes.

The SPT test Results of BH5 are shown in table 4.1.5. And the Graph of Depth vs. FS against Liquefaction is shown in Fig. 4.1.5.

Table 4.1.5 SPT test Results of BH5

Dep Rn	Depth	%Fine	γ_{sat}	σ_o	u_0	σ_o'	Av.N_{60}	C_N	C_{60}	$(N_I)_{60}$	r_d	K_m	K_α	K_σ	CSR	$CRR_{7.5}$	CRR	FS_{liq}	Remarks
0-1.5	0.75	12.00	1.85	1.39	0.74	0.65	9.00	2.00	1.00	18.00	0.99	1.00	1.00	1.20	0.33	0.28	0.34	1.02	NL
1.5-3	2.25	8.00	1.85	4.16	2.21	1.96	11.00	2.21	1.00	24	0.98	1.00	1.00	1.13	0.33	0.30	0.34	1.04	NL
3-4.5	3.75	7.00	1.85	6.94	3.68	3.26	10.00	1.71	1.00	17	0.97	1.00	1.00	1.05	0.32	0.23	0.24	0.75	L
4.5-6	5.25	5.00	1.85	9.71	5.15	4.57	7.00	1.45	1.00	10	0.96	1.00	1.00	0.97	0.32	0.13	0.13	0.40	L
6-7.5	6.75	12.00	1.85	12.49	6.62	5.87	15.00	1.28	1.00	19	0.95	1.00	1.00	0.94	0.31	0.23	0.22	0.69	L
7.5-9	8.25	16.00	1.85	15.26	8.09	7.18	19.00	1.16	1.00	22	0.94	1.00	1.00	0.93	0.31	0.29	0.27	0.87	L
9-10.5	9.75	18.00	1.85	18.04	9.56	8.48	19.00	1.06	1.00	20	0.93	1.00	1.00	0.92	0.31	0.24	0.22	0.72	L
10.5-12	11.25	19.00	1.85	20.81	11.03	9.79	19.00	0.99	1.00	19	0.70	1.00	1.00	0.91	0.23	0.23	0.21	0.90	L

Depth vs. FS Graph for BH5

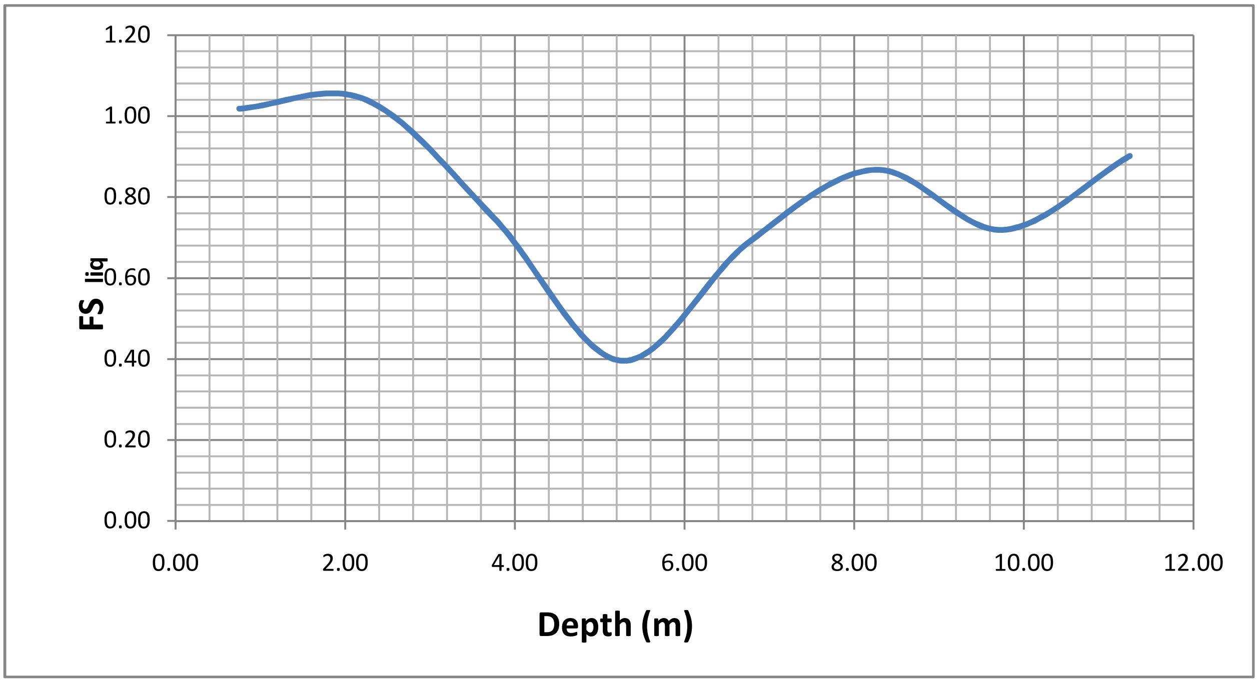


Figure 4.1.5

Bore Hole Number 6(BH6)

Bore hole number 6(BH6) is situated on the crest of Stage 3 on the Eastern Dykes.

The SPT test Results of BH6 are shown in table 4.1.6. And the Graph of Depth vs. FS against Liquefaction is shown in Fig. 4.1.6.

Table 4.1.6 SPT test Results of BH6

Dep Rn	Depth	%Fine	γ_{sat}	σ_o	u_0	σ_o'	Av.N_{60}	C_N	C_{60}	$(N_l)_{60}$	r_d	K_m	K_α	K_σ	CSR	$CRR_{7.5}$	CRR	FS_{liq}	Remarks
0-1.5	0.75	8.00	1.85	1.39	0.74	0.65	10.00	2.00	1.00	20.00	0.99	1.00	1.00	1.20	0.33	0.30	0.36	1.09	NL
1.5-3	2.25	11.00	1.85	4.16	2.21	1.96	15.40	2.21	1.00	34	0.98	1.00	1.00	1.13	0.33	0.38	0.43	1.32	NL
3-4.5	3.75	11.00	1.85	6.94	3.68	3.26	14.00	1.71	1.00	24	0.97	1.00	1.00	1.05	0.32	0.32	0.34	1.04	NL
4.5-6	5.25	6.00	1.85	9.71	5.15	4.57	9.00	1.45	1.00	13	0.96	1.00	1.00	0.97	0.32	0.19	0.18	0.58	L
6-7.5	6.75	7.00	1.85	12.49	6.62	5.87	10.00	1.28	1.00	13	0.95	1.00	1.00	0.94	0.31	0.20	0.19	0.60	L
7.5-9	8.25	6.00	1.85	15.26	8.09	7.18	8.00	1.16	1.00	9	0.94	1.00	1.00	0.93	0.31	0.11	0.10	0.33	L
9-10.5	9.75	5.00	1.85	18.04	9.56	8.48	6.40	1.06	1.00	7	0.93	1.00	1.00	0.92	0.31	0.09	0.08	0.27	L
10.5-12	11.25	6.00	1.85	20.81	11.03	9.79	7.40	0.99	1.00	7	0.70	1.00	1.00	0.91	0.23	0.09	0.08	0.35	L
12-13.5	12.75	7	1.85	23.59	12.50	11.09	8.00	0.93	1.00	7.44	0.66	1.00	1.00	0.88	0.22	0.10	0.09	0.40	L
13.5-15	14.25	9	2	26.36	13.97	12.40	10.40	0.9	1	9.14	0.62	1.00	1.00	0.82	0.21	0.12	0.10	0.48	L
15-16.5	15.75	8	1.85	29.14	15.44	13.70	9.00	0.8	1	7.53	0.58	1.00	1.00	0.81	0.19	0.10	0.08	0.42	L
16.5-18	17.25	6	1.85	31.91	16.91	15.01	6.00	0.8	1	4.79	0.54	1	1.00	0.80	0.18	0.05	0.04	0.22	L
18-19.5	18.8	9	1.9	34.7	18.4	16.3	9	0.8	1	6.9	0.5	1	1	0.8	0.17	0.1	0.08	0.48	L

Depth vs. FS Graph for BH6

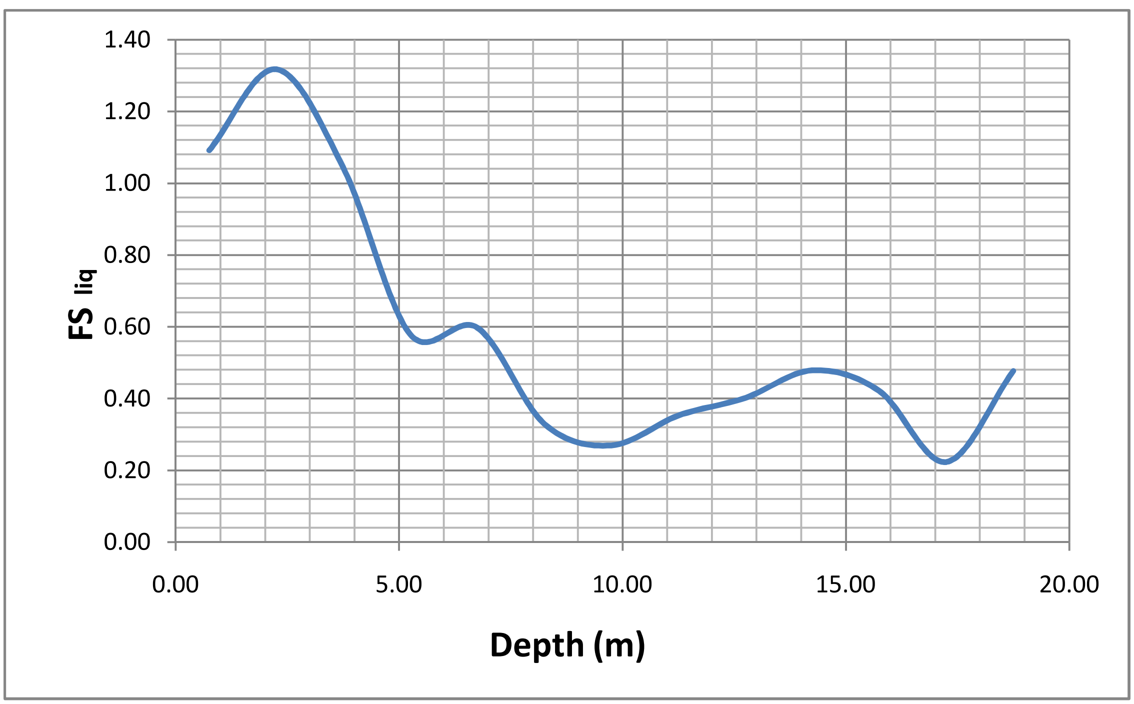


Figure 4.1.6

Bore Hole Number 7(BH7)

Bore hole number 7(BH7) is situated on the crest of Stage 5 on the Western Dykes of Lagoon 2.

The SPT test Results of BH7 are shown in table 4.1.7. And the Graph of Depth vs. FS against Liquefaction is shown in Fig. 4.1.7.

Table 4.1.7 SPT test Results of BH7

Dep Rn	Depth	%Fine	γ_{sat}	σ_o	u_0	σ_o'	Av.N_{60}	C_N	C_{60}	$(N_I)_{60}$	r_d	K_m	K_α	K_σ	CSR	$CRR_{7.5}$	CRR	FS_{liq}	Remarks
0-1.5	0.75	13.00	1.85	1.39	0.74	0.65	3.00	2.00	1.00	6.00	0.99	1.00	1.00	1.20	0.33	0.08	0.10	0.29	L
1.5-3	2.25	17.00	1.85	4.16	2.21	1.96	6.00	2.21	1.00	13	0.98	1.00	1.00	1.13	0.33	0.15	0.17	0.52	L
3-4.5	3.75	8.00	1.85	6.94	3.68	3.26	12.00	1.71	1.00	21	0.97	1.00	1.00	1.05	0.32	0.32	0.34	1.04	NL
4.5-6	5.25	8.00	1.85	9.71	5.15	4.57	3.00	1.45	1.00	4	0.96	1.00	1.00	0.97	0.32	0.05	0.05	0.15	L
6-7.5	6.75	7.00	1.85	12.49	6.62	5.87	3.00	1.28	1.00	4	0.95	1.00	1.00	0.94	0.31	0.05	0.05	0.15	L
7.5-9	8.25	6.00	1.85	15.26	8.09	7.18	4.00	1.16	1.00	5	0.94	1.00	1.00	0.93	0.31	0.06	0.06	0.18	L
9-10.5	9.75	5.00	1.85	18.04	9.56	8.48	5.00	1.06	1.00	5	0.93	1.00	1.00	0.92	0.31	0.06	0.06	0.18	L
10.5-12	11.25	5.00	1.85	20.81	11.03	9.79	6.00	0.99	1.00	6	0.70	1.00	1.00	0.91	0.23	0.07	0.06	0.27	L
12-13.5	12.75	6	1.85	23.59	12.50	11.09	9.00	0.93	1.00	8	0.66	1.00	1.00	0.88	0.22	0.09	0.08	0.36	L
13.5-15	14.25	9	1.85	26.36	13.97	12.40	20.00	0.88	1.00	18	0.62	1.00	1.00	0.83	0.21	0.28	0.23	1.13	NL

Depth vs. FS Graph for BH7

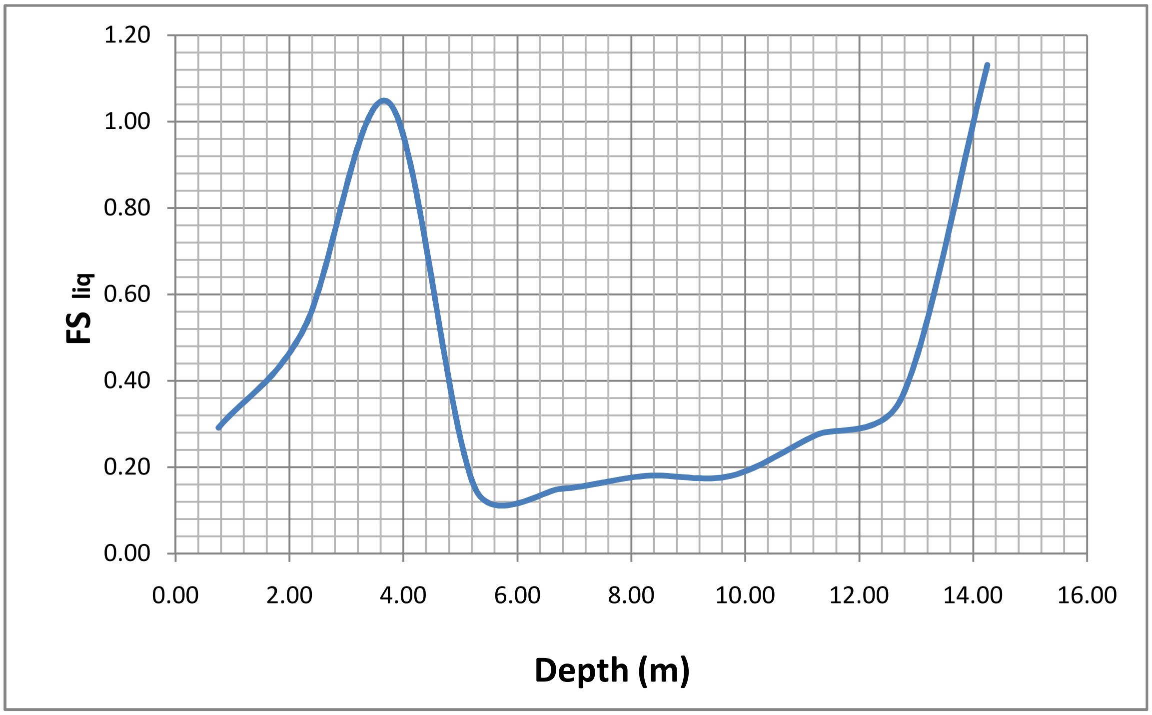


Figure 4.1.7

Bore Hole Number 8(BH8)

Bore hole number 8(BH8) is situated on the crest of Stage 4 on the Western Dykes of Lagoon 2.

The SPT test Results of BH8 are shown in table 4.1.8. And the Graph of Depth vs. FS against Liquefaction is shown in Fig. 4.1.8.

Table 4.1.8 SPT test Results of BH8

Dep Rn	Depth	%Fine	γ_{sat}	σ_o	u_0	σ_o'	Av.N_{60}	C_N	C_{60}	$(N_l)_{60}$	r_d	K_m	K_α	K_σ	CSR	$CRR_{7.5}$	CRR	FS_{liq}	Remarks
0-1.5	0.75	17.00	1.85	1.39	0.74	0.65	21.00	2.00	1.00	42.00	0.99	1.00	1.00	1.20	0.33	0.43	0.52	1.56	NL
1.5-3	2.25	12.00	1.85	4.16	2.21	1.96	17.00	2.21	1.00	38	0.98	1.00	1.00	1.13	0.33	0.39	0.44	1.35	NL
3-4.5	3.75	11.00	1.85	6.94	3.68	3.26	28.00	1.71	1.00	48	0.97	1.00	1.00	1.05	0.32	0.52	0.55	1.69	NL
4.5-6	5.25	8.00	1.85	9.71	5.15	4.57	12.00	1.45	1.00	17	0.96	1.00	1.00	0.97	0.32	0.26	0.25	0.79	L
6-7.5	6.75	7.00	1.85	12.49	6.62	5.87	12.00	1.28	1.00	15	0.95	1.00	1.00	0.94	0.31	0.19	0.18	0.57	L
7.5-9	8.25	6.00	1.85	15.26	8.09	7.18	13.00	1.16	1.00	15	0.94	1.00	1.00	0.93	0.31	0.19	0.18	0.57	L
9-10.5	9.75	5.00	1.85	18.04	9.56	8.48	14.00	1.06	1.00	15	0.93	1.00	1.00	0.92	0.31	0.20	0.18	0.60	L
10.5-12	11.25	4.00	1.85	20.81	11.03	9.79	18.00	0.99	1.00	18	0.70	1.00	1.00	0.91	0.23	0.28	0.25	1.10	NL
12-13.5	12.75	5	1.85	23.59	12.50	11.09	17.00	0.93	1.00	16	0.66	1.00	1.00	0.88	0.22	0.25	0.22	1.01	NL
13.5-15	14.25	5	1.85	26.36	13.97	12.40	19.00	0.88	1.00	17	0.62	1.00	1.00	0.83	0.21	0.26	0.22	1.05	NL

Depth vs. FS Graph for BH8

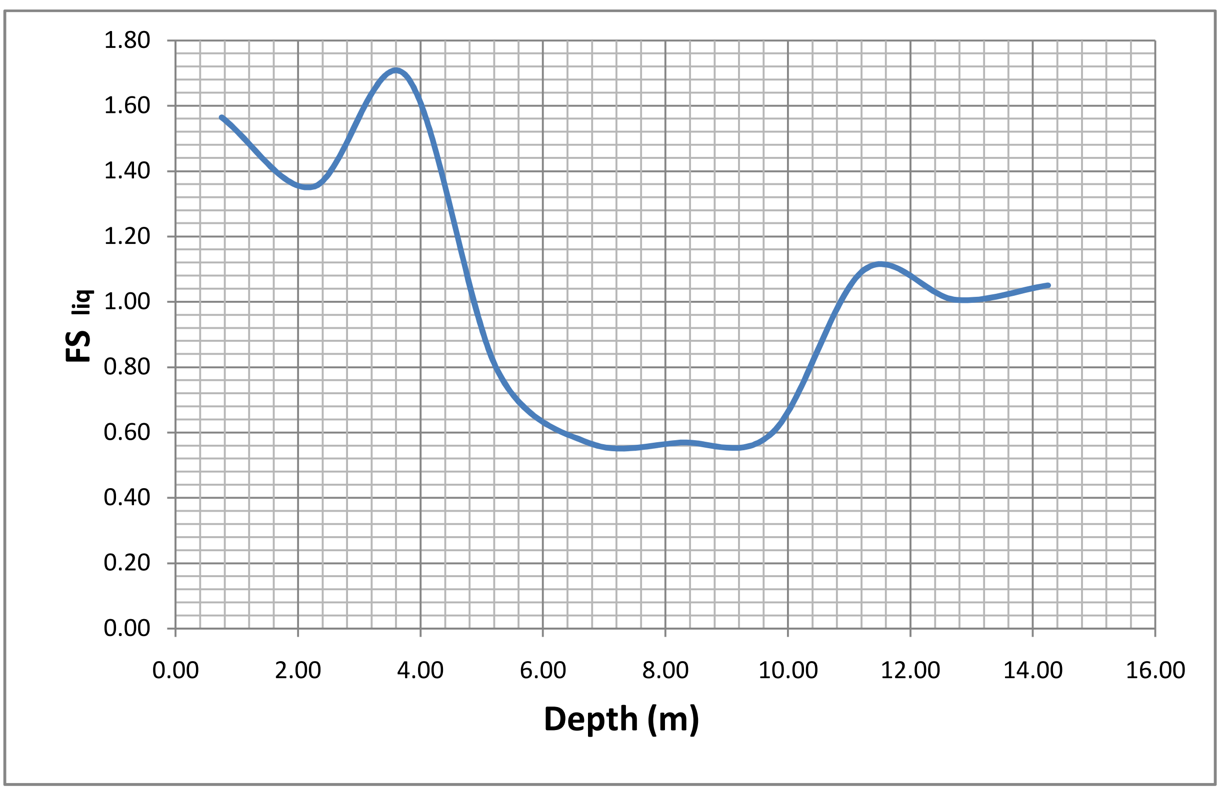


Figure 4.1.8

Bore Hole Number 9(BH9)

Bore hole number 9(BH9) is situated on the crest of Stage 3 on the Western Dykes of Lagoon 2.

The SPT test Results of BH9 are shown in table 4.1.9. And the Graph of Depth vs. FS against Liquefaction is shown in Fig. 4.1.9.

Table 4.1.9 SPT test Results of BH9

Dep Rn	Depth	%Fine	γ_{sat}	σ_o	u_0	σ_o'	$Av.N_{60}$	C_N	C_{60}	$(N_I)_{60}$	r_d	K_m	K_α	K_σ	CSR	$CRR_{7.5}$	CRR	FS_{liq}	Remarks
0-1.5	0.75	13.00	1.85	1.39	0.74	0.65	8.00	2.00	1.00	16.00	0.99	1.00	1.00	1.20	0.33	0.28	0.34	1.02	NL
1.5-3	2.25	45.00	1.85	4.16	2.21	1.96	14.00	2.21	1.00	31	0.98	1.00	1.00	1.13	0.33	0.36	0.41	1.25	NL
3-4.5	3.75	23.00	1.85	6.94	3.68	3.26	11.00	1.71	1.00	19	0.97	1.00	1.00	1.05	0.32	0.29	0.30	0.95	L
4.5-6	5.25	14.00	1.85	9.71	5.15	4.57	9.00	1.45	1.00	13	0.96	1.00	1.00	0.97	0.32	0.22	0.21	0.67	L
6-7.5	6.75	16.00	1.85	12.49	6.62	5.87	23.00	1.28	1.00	29	0.95	1.00	1.00	0.94	0.31	0.34	0.32	1.02	NL
7.5-9	8.25	7.00	1.85	15.26	8.09	7.18	15.00	1.16	1.00	17	0.94	1.00	1.00	0.93	0.31	0.28	0.26	0.84	L
9-10.5	9.75	6.00	1.85	18.04	9.56	8.48	24.00	1.06	1.00	26	0.93	1.00	1.00	0.92	0.31	0.31	0.29	0.93	L
10.5-12	11.25	7.00	1.85	20.81	11.03	9.79	24.00	0.99	1.00	24	0.70	1.00	1.00	0.91	0.23	0.30	0.27	1.18	NL

Depth vs. FS Graph for BH9

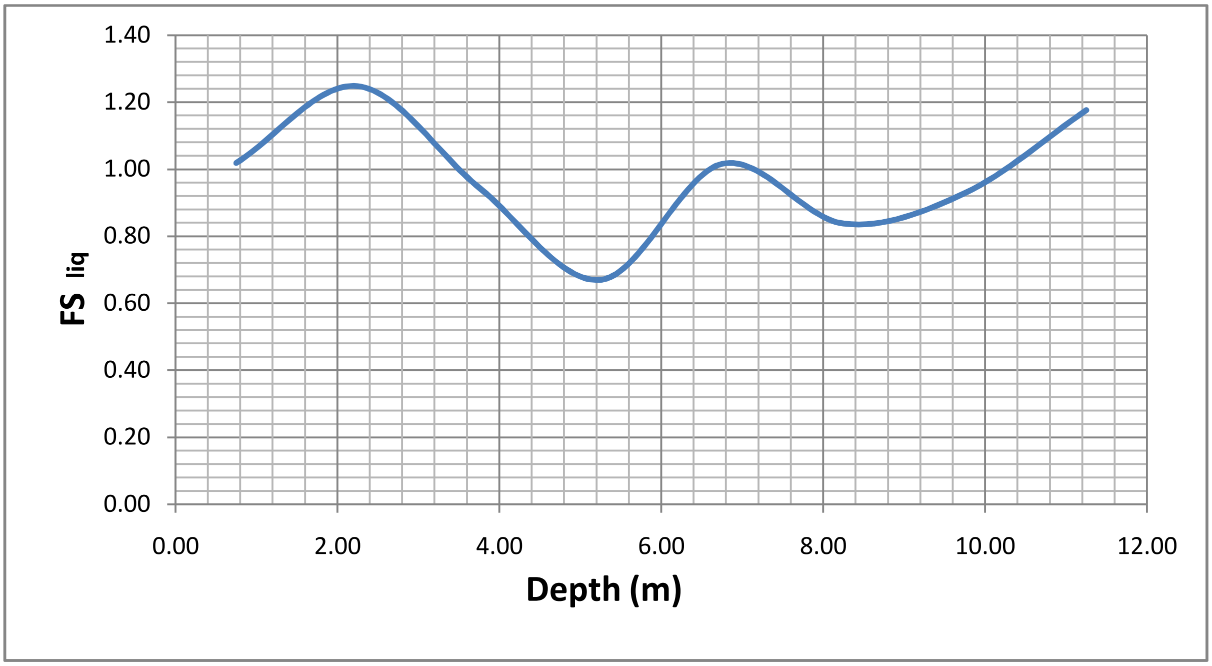


Figure 4.1.9

Bore Hole Number 10(BH10)

Bore hole number 10(BH10) is situated on the crest of Stage 2 on the Western Dykes of Lagoon 2.

The SPT test Results of BH10 are shown in table 4.1.10. And the Graph of Depth vs FS against Liquefaction is shown in Fig. 4.1.10.

Table 4.1.10 SPT test Results of BH10

Dep Rn	Depth	%Fine	γ_{sat}	σ_o	u_0	σ_o'	Av.N_{60}	C_N	C_{60}	$(N_l)_{60}$	r_d	K_m	K_α	K_σ	CSR	$CRR_{7.5}$	CRR	FS_{liq}	Remarks
0-1.5	0.75	17.00	1.85	1.39	0.74	0.65	7.00	2.00	1.00	14.00	0.99	1.00	1.00	1.20	0.33	0.20	0.24	0.73	L
1.5-3	2.25	8.00	1.85	4.16	2.21	1.96	11.00	2.21	1.00	24	0.98	1.00	1.00	1.13	0.33	0.29	0.33	1.01	NL
3-4.5	3.75	10.00	1.85	6.94	3.68	3.26	11.00	1.71	1.00	19	0.97	1.00	1.00	1.05	0.32	0.22	0.23	0.72	L
4.5-6	5.25	43.00	1.85	9.71	5.15	4.57	13.00	1.45	1.00	19	0.96	1.00	1.00	0.97	0.32	0.22	0.21	0.67	L
6-7.5	6.75	23.00	1.85	12.49	6.62	5.87	21.00	1.28	1.00	27	0.95	1.00	1.00	0.94	0.31	0.30	0.28	0.90	L

Depth vs. FS Graph for BH10

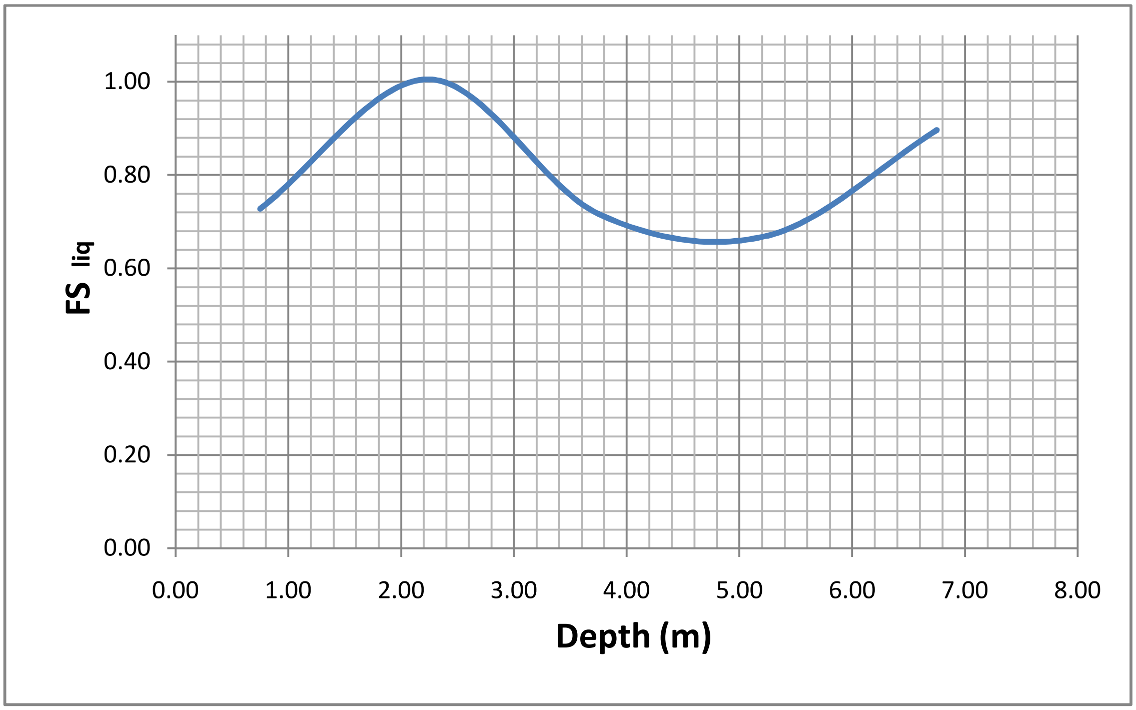


Figure 4.1.10

Bore Hole Number 11(BH11)

Bore hole number 11(BH11) is situated on the crest of Stage 1 on the Western Dykes of Lagoon 2.

The SPT test Results of BH11 are shown in table 4.1.11. And the Graph of Depth vs. FS against Liquefaction is shown in Fig. 4.1.11.

Table 4.1.11 SPT test Results of BH11

Dep Rn	Depth	%Fine	γ_{sat}	σ_o	u_0	σ_o'	Av.N_{60}	C_N	C_{60}	$(N_I)_{60}$	r_d	K_m	K_α	K_σ	CSR	$CRR_{7.5}$	CRR	FS_{liq}	Remarks
0-1.5	0.75	76.00	1.85	1.39	0.74	0.65	7.00	2.00	1.00	14.00	0.99	1.00	1.00	1.20	0.33	0.20	0.20	0.61	L
1.5-3	2.25	23.00	1.85	4.16	2.21	1.96	15.00	2.21	1.00	33	0.98	1.00	1.00	1.13	0.33	0.29	0.36	1.10	NL
3-4.5	3.75	12.00	1.85	6.94	3.68	3.26	18.00	1.71	1.00	31	0.97	1.00	1.00	1.05	0.32	0.22	0.33	1.02	NL
4.5-6	5.25	8.00	1.85	9.71	5.15	4.57	20.00	1.45	1.00	29	0.96	1.00	1.00	0.97	0.32	0.22	0.28	0.88	L

Depth vs. FS Graph for BH11

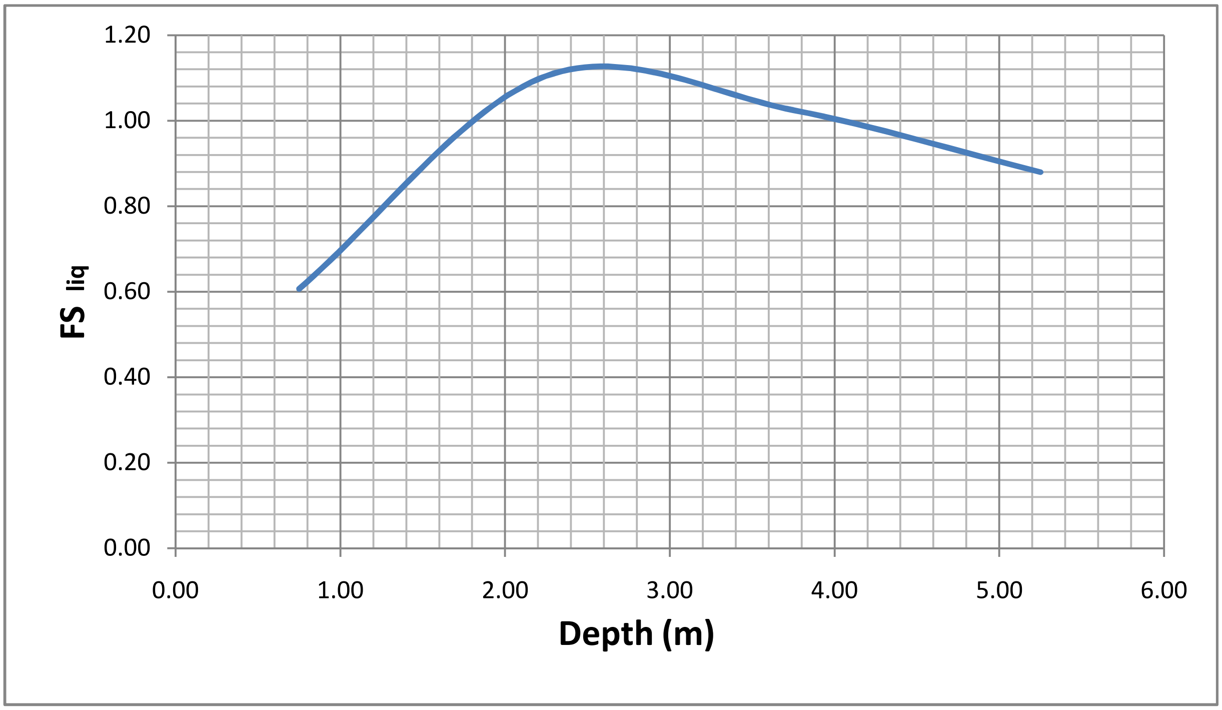


Figure 4.1.11

4.2 Ash Embankment in Badarpur Thermal Power Station (BTPS)

BTPS ash dyke site is located at the out skirts of Delhi at Badarpur, having divided into several lagoons. The starter dyke was constructed with earthen material. At the time of field testing, some ponds, one and in others two raisings have been completed at this site by upstream method of construction.

4.2.1 SPT Results

Badarpur Bore Hole Number 1(BBH1)

Bore hole number 1(BBH1) is situated on the crest of Stage 1 containing silty sand material.

The SPT test Results of BBH1 are shown in table 4.2.1. And the Graph of Depth vs. FS against Liquefaction is shown in Fig. 4.2.1.

Table 4.2.1 SPT test Results of BBH1

Dep Rn	Depth	%Fine	γ_{sat}	σ_o	u_0	σ_o'	Av.N_{60}	C_N	C_{60}	$(N_I)_{60}$	r_d	K_m	K_α	K_σ	CSR	$CRR_{7.5}$	CRR	FS_{liq}	Remarks
0-1.5	0.75	12.00	1.85	1.39	0.74	0.65	10.00	2.00	1.00	20.00	0.99	1.00	1.00	1.20	0.33	0.30	0.36	1.09	NL
1.5-3	2.25	15.00	1.85	4.16	2.21	1.96	21.00	2.21	1.00	46	0.98	1.00	1.00	1.13	0.33	0.48	0.54	1.66	NL
3-4.5	3.75	7.00	1.85	6.94	3.68	3.26	25.00	1.71	1.00	43	0.97	1.00	1.00	1.05	0.32	0.44	0.46	1.43	NL
4.5-6	5.25	43.00	1.85	9.71	5.15	4.57	17.50	1.45	1.00	25	0.96	1.00	1.00	0.97	0.32	0.35	0.34	1.07	NL
6-7.5	6.75	24.00	1.85	12.49	6.62	5.87	25.00	1.28	1.00	32	0.95	1.00	1.00	0.94	0.31	0.36	0.34	1.08	NL
7.5-9	8.25	7.00	1.85	15.26	8.09	7.18	15.00	1.16	1.00	17	0.94	1.00	1.00	0.93	0.31	0.17	0.16	0.51	L

Depth vs. FS Graph for BBH1

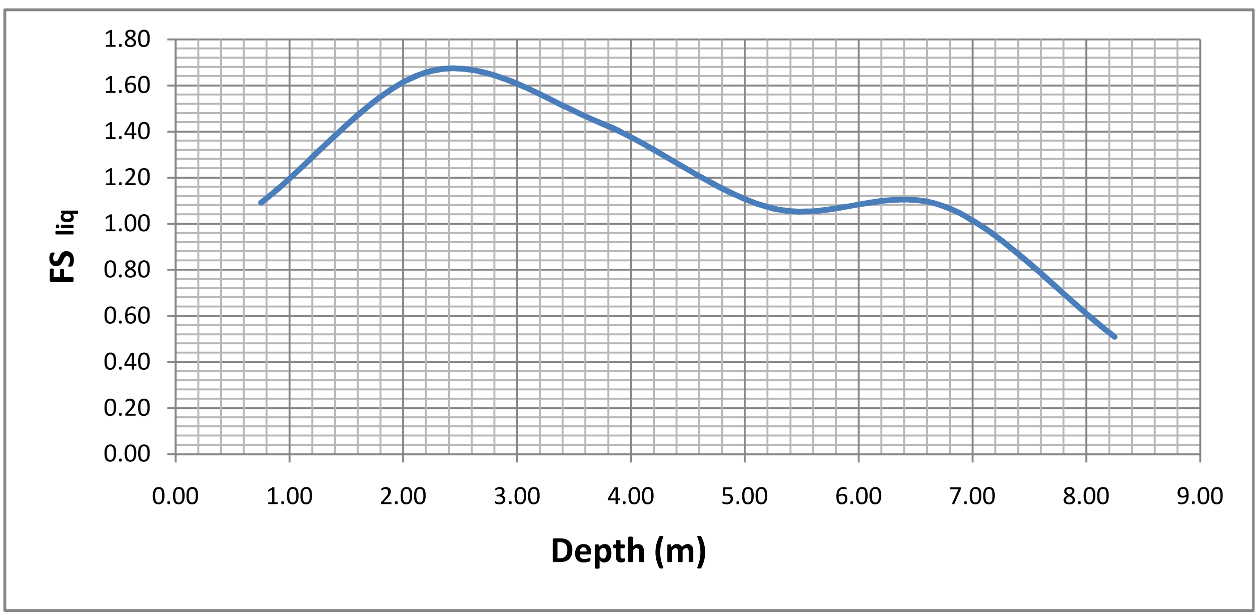


Figure 4.2.1

Badarpur Bore Hole Number 2(BBH2)

Bore hole number 2(BBH2) is situated on the crest of Stage 2 containing compacted ash upto a depth of 5 m and rest settled ash as material.

The SPT test Results of BBH2 are shown in table 4.2.2. And the Graph of Depth vs. FS against Liquefaction is shown in Fig. 4.2.2.

Table 4.2.2 SPT test Results of BBH2

Dep Rn	Depth	%Fine	γ_{sat}	σ_o	u_0	σ_o'	Av.N_{60}	C_N	C_{60}	$(N_I)_{60}$	r_d	K_m	K_α	K_σ	CSR	$CRR_{7.5}$	CRR	FS_{liq}	Remarks
0-1.5	0.75	12.00	1.85	1.39	0.74	0.65	4.00	2.00	1.00	8.00	0.99	1.00	1.00	1.20	0.33	0.10	0.12	0.36	L
1.5-3	2.25	15.00	1.85	4.16	2.21	1.96	13.00	2.21	1.00	29	0.98	1.00	1.00	1.13	0.33	0.34	0.38	1.18	NL
3-4.5	3.75	7.00	1.85	6.94	3.68	3.26	14.00	1.71	1.00	24	0.97	1.00	1.00	1.05	0.32	0.31	0.33	1.01	NL
4.5-6	5.25	43.00	1.85	9.71	5.15	4.57	20.00	1.45	1.00	29	0.96	1.00	1.00	0.97	0.32	0.36	0.35	1.10	NL
6-7.5	6.75	24.00	1.85	12.49	6.62	5.87	17.00	1.28	1.00	22	0.95	1.00	1.00	0.94	0.31	0.30	0.28	0.90	L
7.5-9	8.25	7.00	1.85	15.26	8.09	7.18	10.00	1.16	1.00	12	0.94	1.00	1.00	0.93	0.31	0.13	0.12	0.39	L
9-10.5	9.75	8.00	1.85	18.04	9.56	8.48	6.00	1.06	1.00	6	0.93	1.00	1.00	0.92	0.31	0.07	0.06	0.21	L
10.5-12	11.25	19.00	1.85	20.81	11.03	9.79	5.00	0.99	1.00	5	0.70	1.00	1.00	0.91	0.23	0.05	0.05	0.20	L

Depth vs. FS Graph for BBH2

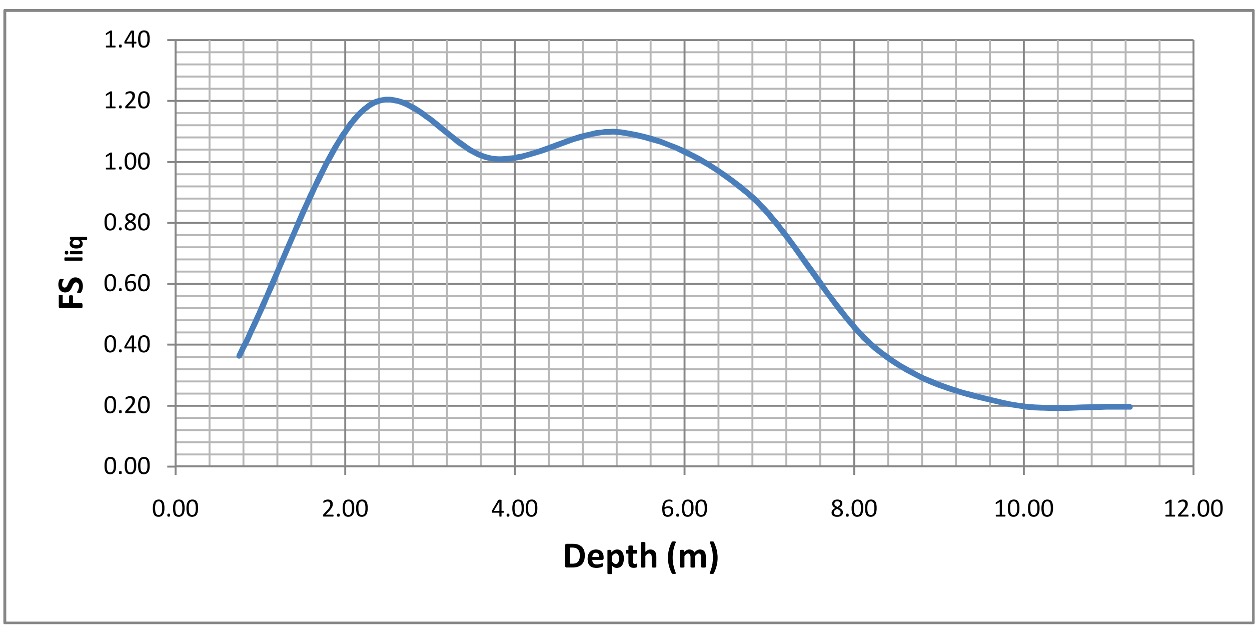


Figure 4.2.2

Badarpur Bore Hole Number 3(BBH3)

Bore hole number 3(BBH3) is situated on the crest of Stage 3 containing settled ash as material.

The SPT test Results of BBH3 are shown in table 4.2.3. And the Graph of Depth vs. FS against Liquefaction is shown in Fig. 4.2.3.

Table 4.2.3 SPT test Results of BBH3

Dep Rn	Depth	%Fine	γ_{sat}	σ_o	u_0	σ_o'	Av.N_{60}	C_N	C_{60}	$(N_1)_{60}$	r_d	K_m	K_α	K_σ	CSR	$CRR_{7.5}$	CRR	FS_{liq}	Remarks
0-1.5	0.75	12.00	1.85	1.39	0.74	0.65	2.00	2.00	1.00	4.00	0.99	1.00	1.00	1.20	0.33	0.04	0.05	0.15	L
1.5-3	2.25	15.00	1.85	4.16	2.21	1.96	4.00	2.21	1.00	9	0.98	1.00	1.00	1.13	0.33	0.10	0.11	0.35	L
3-4.5	3.75	7.00	1.85	6.94	3.68	3.26	4.00	1.71	1.00	7	0.97	1.00	1.00	1.05	0.32	0.07	0.07	0.23	L
4.5-6	5.25	43.00	1.85	9.71	5.15	4.57	6.00	1.45	1.00	9	0.96	1.00	1.00	0.97	0.32	0.10	0.10	0.30	L
6-7.5	6.75	24.00	1.85	12.49	6.62	5.87	7.00	1.28	1.00	9	0.95	1.00	1.00	0.94	0.31	0.11	0.10	0.33	L
7.5-9	8.25	7.00	1.85	15.26	8.09	7.18	4.00	1.16	1.00	5	0.94	1.00	1.00	0.93	0.31	0.05	0.05	0.15	L
9-10.5	9.75	8.00	1.85	18.04	9.56	8.48	2.00	1.06	1.00	2	0.93	1.00	1.00	0.92	0.31	0.03	0.03	0.09	L
10.5-12	11.25	19.00	1.85	20.81	11.03	9.79	2.00	0.99	1.00	2	0.70	1.00	1.00	0.91	0.23	0.02	0.02	0.08	L

Depth vs. FS Graph for BBH3

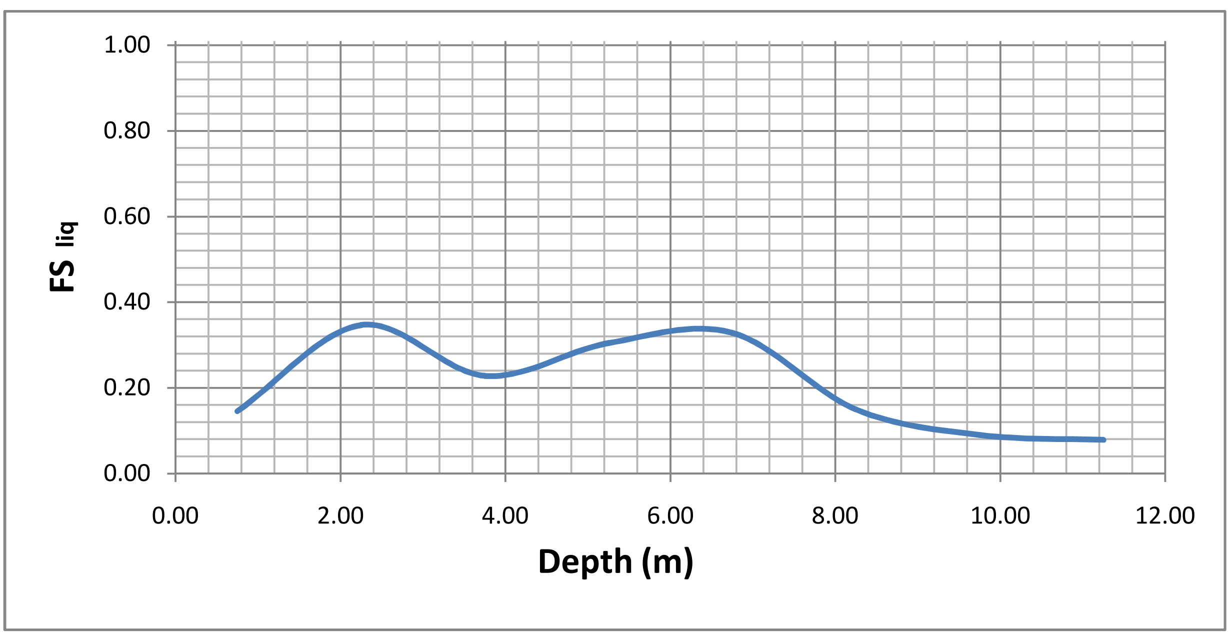


Figure 4.2.3

Badarpur Bore Hole Number 4(BBH4)

Bore hole number 4(BBH4) is situated on the crest of Stage 4 containing settled ash as material. The SPT test Results of BBH4 are shown in table 4.2.4. And the Graph of Depth vs. FS against Liquefaction is shown in Fig. 4.2.4.

Table 4.2.4 SPT test Results of BBH4

Dep Rn	Depth	%Fine	γ_{sat}	σ_o	u_0	σ_o'	Av.N_{60}	C_N	C_{60}	$(N_I)_{60}$	r_d	K_m	K_α	K_σ	CSR	$CRR_{7.5}$	CRR	FS_{liq}	Remarks
0-1.5	0.75	12.00	1.85	1.39	0.74	0.65	3.00	2.00	1.00	6.00	0.99	1.00	1.00	1.20	0.33	0.08	0.10	0.29	L
1.5-3	2.25	15.00	1.85	4.16	2.21	1.96	3.00	2.21	1.00	7	0.98	1.00	1.00	1.13	0.33	0.08	0.09	0.28	L
3-4.5	3.75	7.00	1.85	6.94	3.68	3.26	5.00	1.71	1.00	9	0.97	1.00	1.00	1.05	0.32	0.09	0.09	0.29	L
4.5-6	5.25	43.00	1.85	9.71	5.15	4.57	6.00	1.45	1.00	9	0.96	1.00	1.00	0.97	0.32	0.12	0.12	0.37	L
6-7.5	6.75	24.00	1.85	12.49	6.62	5.87	7.00	1.28	1.00	9	0.95	1.00	1.00	0.94	0.31	0.09	0.08	0.27	L
7.5-9	8.25	7.00	1.85	15.26	8.09	7.18	6.00	1.16	1.00	7	0.94	1.00	1.00	0.93	0.31	0.06	0.06	0.18	L
9-10.5	9.75	8.00	1.85	18.04	9.56	8.48	4.00	1.06	1.00	4	0.93	1.00	1.00	0.92	0.31	0.04	0.04	0.12	L
10.5-12	11.25	19.00	1.85	20.81	11.03	9.79	3.00	0.99	1.00	3	0.70	1.00	1.00	0.91	0.23	0.02	0.02	0.08	L

Depth vs. FS Graph for BBH4

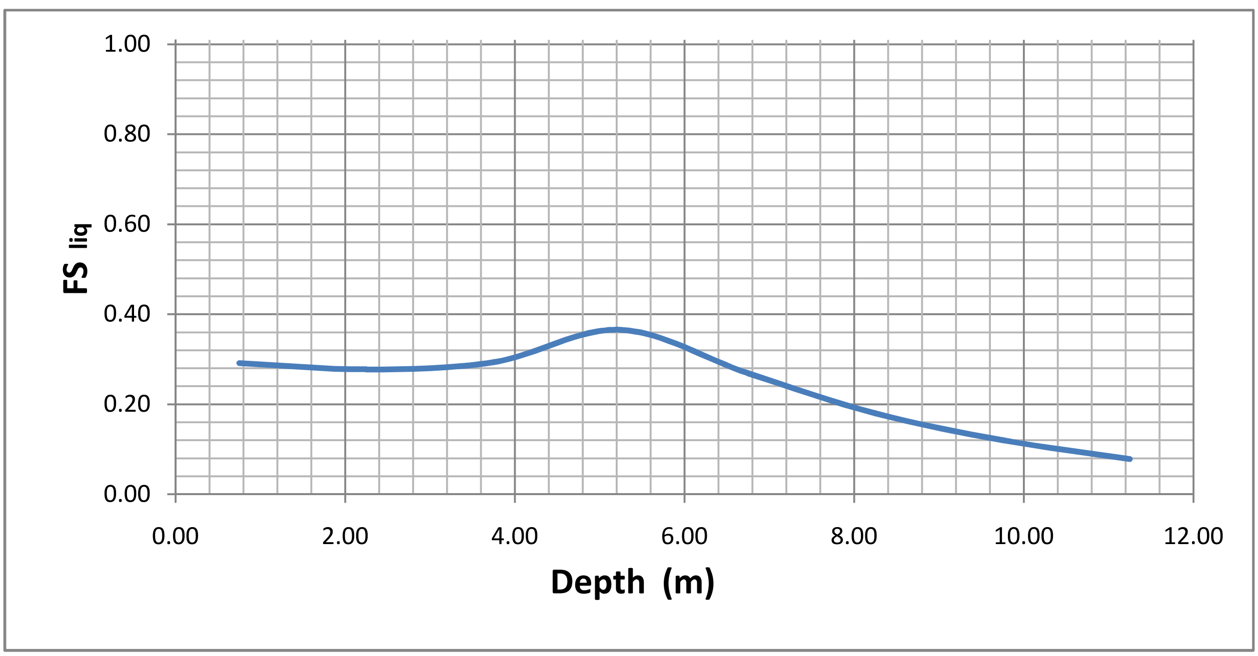


Figure 4.2.

Badarpur Bore Hole Number 5(BBH5)

Bore hole number 5(BBH5) is situated on the crest of Stage 5 containing settled ash as material.

The SPT test Results of BBH5 are shown in table 4.2.5. And the Graph of Depth vs. FS against Liquefaction is shown in Fig. 4.2.5.

Table 4.2.5 SPT test Results of BBH5

Dep Rn	Depth	%Fine	γ_{sat}	σ_o	u_0	σ_o'	Av.N_{60}	C_N	C_{60}	$(N_I)_{60}$	r_d	K_m	K_α	K_σ	CSR	$CRR_{7.5}$	CRR	FS_{liq}	Remarks
0-1.5	0.75	12.00	1.85	1.39	0.74	0.65	4.00	2.00	1.00	8.00	0.99	1.00	1.00	1.20	0.33	0.09	0.11	0.33	L
1.5-3	2.25	15.00	1.85	4.16	2.21	1.96	4.00	2.21	1.00	9	0.98	1.00	1.00	1.13	0.33	0.11	0.12	0.38	L
3-4.5	3.75	7.00	1.85	6.94	3.68	3.26	5.00	1.71	1.00	9	0.97	1.00	1.00	1.05	0.32	0.10	0.11	0.33	L
4.5-6	5.25	43.00	1.85	9.71	5.15	4.57	5.00	1.45	1.00	7	0.96	1.00	1.00	0.97	0.32	0.07	0.07	0.21	L
6-7.5	6.75	24.00	1.85	12.49	6.62	5.87	3.00	1.28	1.00	4	0.95	1.00	1.00	0.94	0.31	0.05	0.05	0.15	L
7.5-9	8.25	7.00	1.85	15.26	8.09	7.18	3.00	1.16	1.00	3	0.94	1.00	1.00	0.93	0.31	0.04	0.04	0.12	L
9-10.5	9.75	8.00	1.85	18.04	9.56	8.48	2.00	1.06	1.00	2	0.93	1.00	1.00	0.92	0.31	0.03	0.03	0.09	L
10.5-12	11.25	19.00	1.85	20.81	11.03	9.79	2.00	0.99	1.00	2	0.70	1.00	1.00	0.91	0.23	0.02	0.02	0.08	L

Depth vs. FS Graph for BBH5

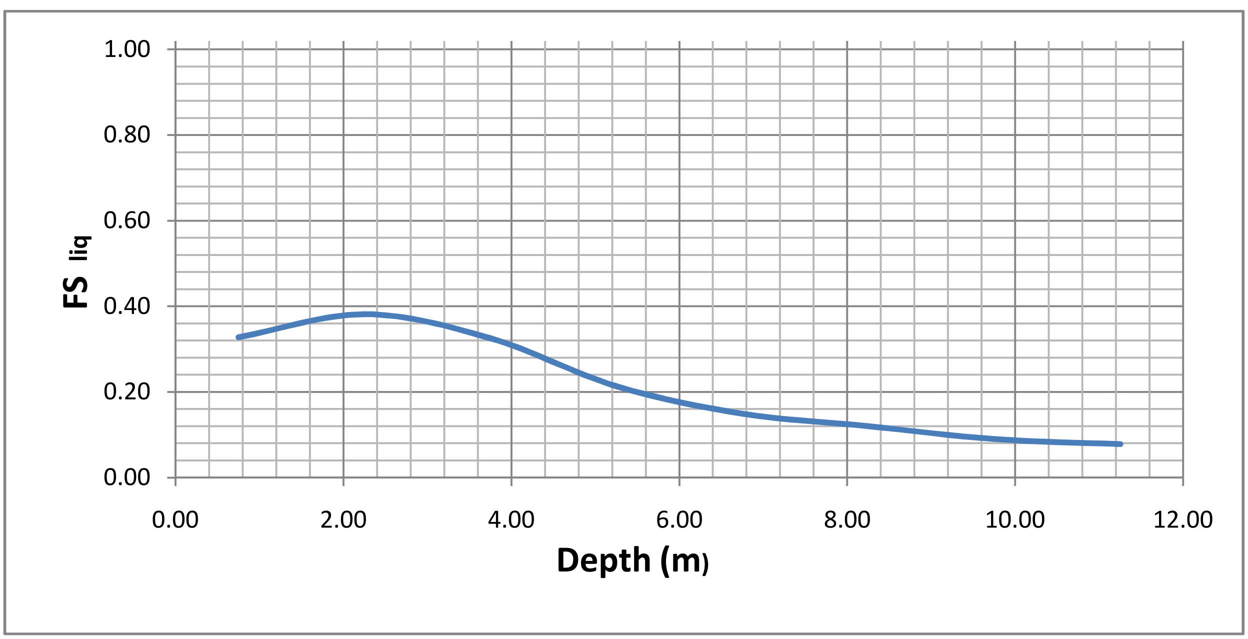


Figure 4.2.5

Badarpur Bore Hole Number 6 (BBH6)

Bore hole number 6(BBH6) is situated on the crest of Stage 6 containing compacted ash upto a depth of 5m and rest settled ash as material.

The SPT test Results of BBH6 are shown in table 4.2.6. And the Graph of Depth vs. FS against Liquefaction is shown in Fig. 4.2.6.

Table 4.2.6 SPT test Results of BBH6

Dep Rn	Depth	%Fine	γ_{sat}	σ_o	u_0	σ_o'	Av.N_{60}	C_N	C_{60}	$(N_l)_{60}$	r_d	K_m	K_α	K_σ	CSR	$CRR_{7.5}$	CRR	FS_{liq}	Remarks
0-1.5	0.75	76.00	1.85	1.39	0.74	0.65	5.00	2.00	1.00	10.00	0.99	1.00	1.00	1.20	0.33	0.18	0.22	0.65	L
1.5-3	2.25	34.00	1.85	4.16	2.21	1.96	10.00	2.21	1.00	22	0.98	1.00	1.00	1.13	0.33	0.29	0.33	1.01	NL
3-4.5	3.75	6.00	1.85	6.94	3.68	3.26	9.00	1.71	1.00	15	0.97	1.00	1.00	1.05	0.32	0.22	0.23	0.72	L
4.5-6	5.25	7.00	1.85	9.71	5.15	4.57	7.50	1.45	1.00	11	0.96	1.00	1.00	0.97	0.32	0.18	0.17	0.55	L
6-7.5	6.75	12.00	1.85	12.49	6.62	5.87	6.00	1.28	1.00	8	0.95	1.00	1.00	0.94	0.31	0.09	0.08	0.27	L
7.5-9	8.25	6.00	1.85	15.26	8.09	7.18	4.00	1.16	1.00	5	0.94	1.00	1.00	0.93	0.31	0.06	0.06	0.18	L
9-10.5	9.75	10.00	1.85	18.04	9.56	8.48	4.00	1.06	1.00	4	0.93	1.00	1.00	0.92	0.31	0.04	0.04	0.12	L
10.5-12	11.25	7.00	1.85	20.81	11.03	9.79	3.00	0.99	1.00	3	0.70	1.00	1.00	0.91	0.23	0.03	0.03	0.12	L

Depth vs. FS Graph for BBH6

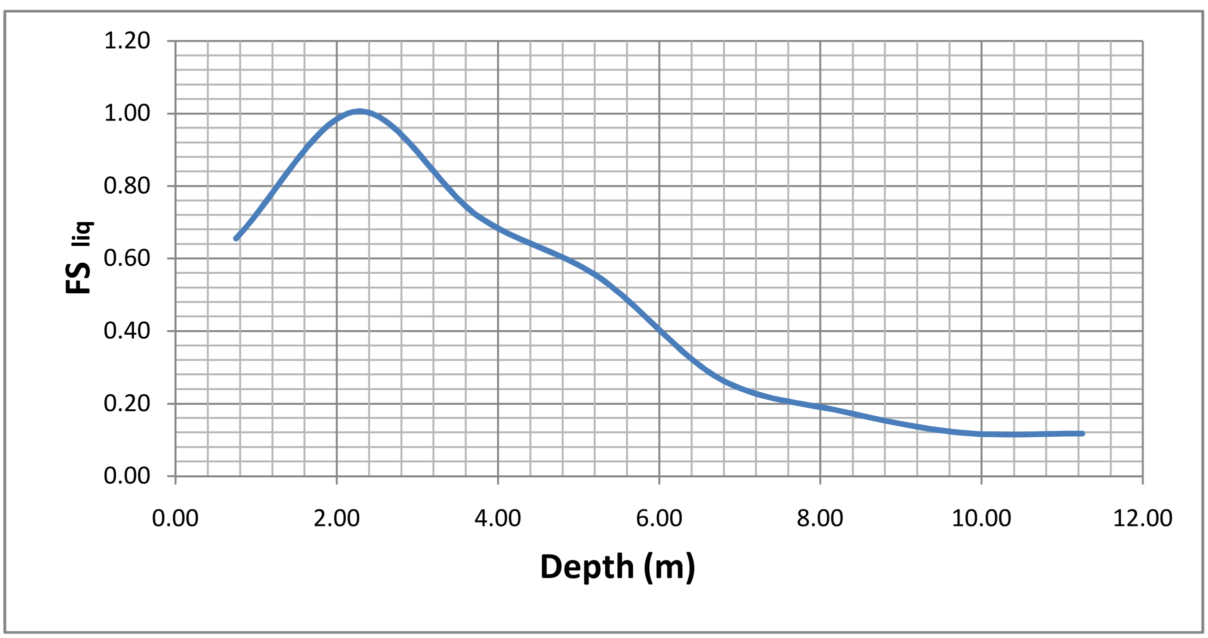


Figure 4.2.6

4.2.2 CPT Results

Badarpur Bore Hole Number 7 (BBH7)

Bore hole number 7(BBH7) is situated on the crest of Stage 7 containing compacted ash upto a depth of 5m, settled ash between depths 5-10.5 m and rest soil as material. The CPT test Results of BBH7 are shown in table 4.2.7. And the Graph of Depth vs. FS against Liquefaction is shown in Fig. 4.2.7.

Table 4.2.7 SPT test Results of BBH7

Depth (m)	Material	q_c(MPa)	f_s (kPa)	CSR	$(q_{c1N})_{cs}$	CRR	FS liq	Remark
2.5	Compacte-d ash	7.5	27.80	0.10	111.06	0.21	2.13	No-Liquefaction
7.5	Settled ash	3.0	60.20	0.15	91.28	0.15	0.97	Liquefaction
12.5	Settled ash	2.5	28.10	0.17	65.02	0.11	0.61	Liquefaction
17.5	Soil	4.0	21.90	0.18	55.27	0.10	0.53	Liquefaction

Depth vs. FS Graph for BBH7

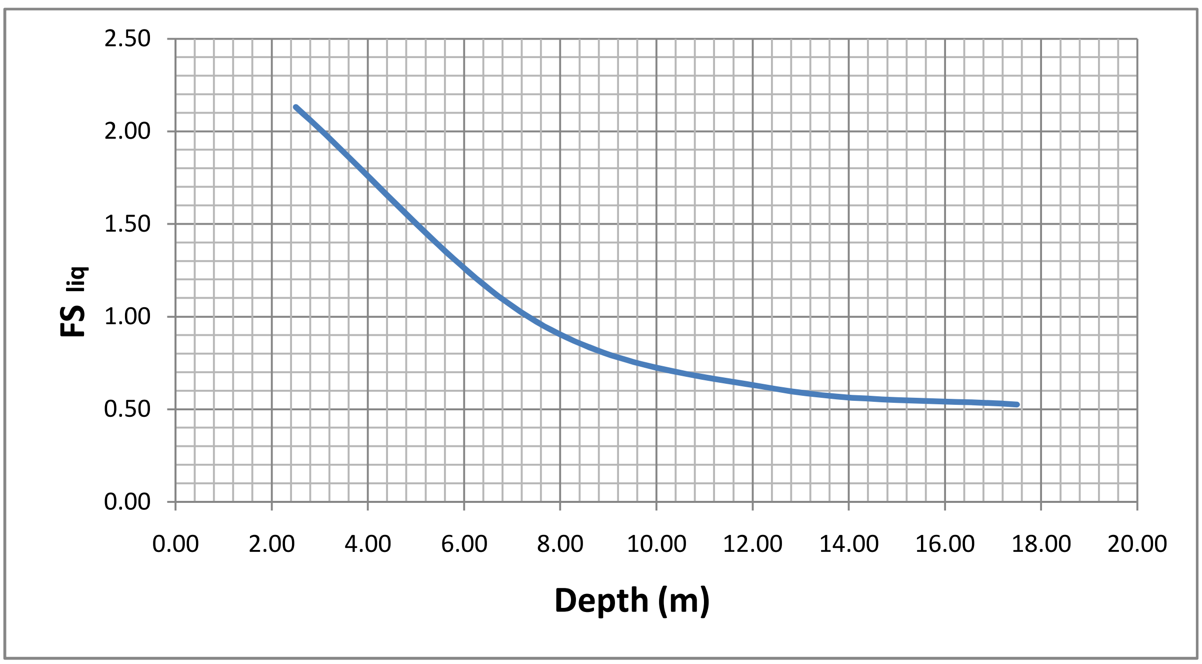


Figure 4.2.7

Badarpur Bore Hole Number 8 (BBH8)

Bore hole number 8(BBH8) is situated on the crest of Stage 7 containing compacted ash upto a depth of 5m, settled ash between depths 5-11.5 m and rest soil as material.

The CPT test Results of BBH8 are shown in table 4.2.8. And the Graph of Depth vs. FS against Liquefaction is shown in Fig. 4.2.8.

Table 4.2.8 SPT test Results of BBH8

Depth (m)	Material	q_c(MPa)	f_s (kPa)	CSR	$(q_{c1N})_{cs}$	CRR	FS_{liq}	Remark
2.5	Compacte-d ash	5	60	0.10	103.50	0.18	1.88	No-Liquefaction
7.5	Settled ash	2	103	0.15	127.94	0.27	1.77	No-Liquefaction
12.5	Settled ash	1	36	0.17	86.97	0.14	0.82	Liquefaction
17.5	Soil	7.5	14	0.18	63.92	0.10	0.57	Liquefaction

Depth vs. FS Graph for BBH8

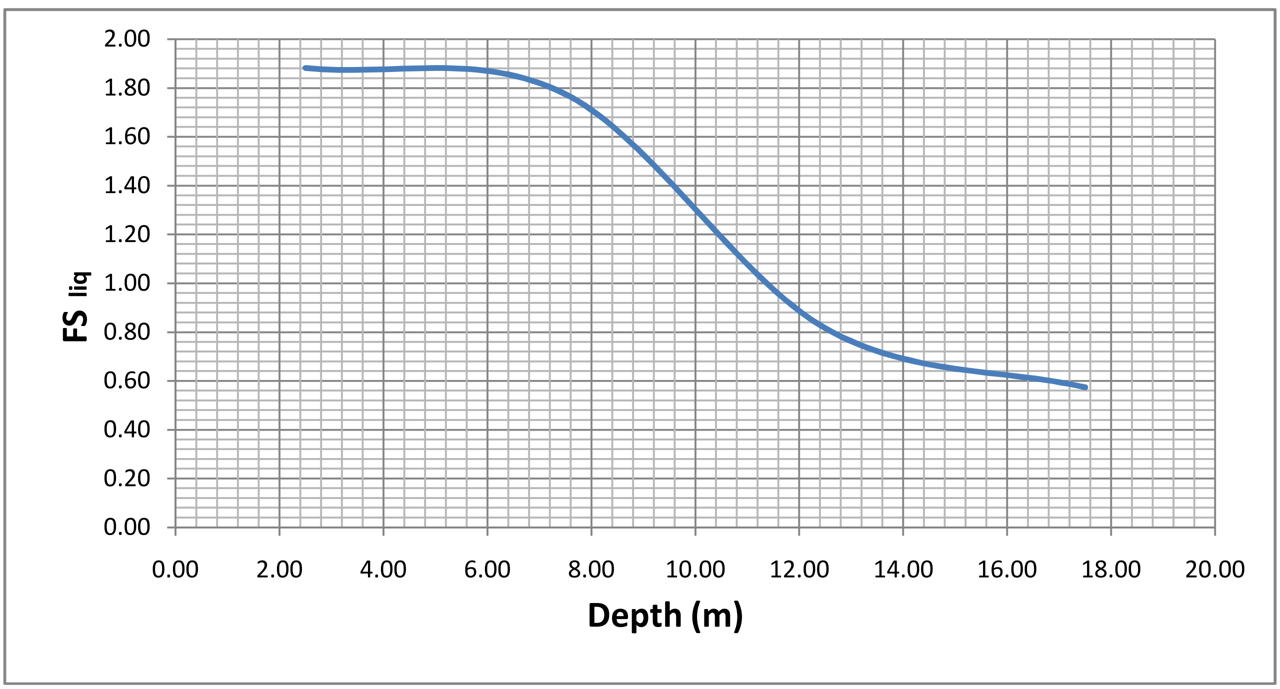


Figure 4.2.8

Badarpur Bore Hole Number 9 (BBH9)

Bore hole number 9 (BBH9) is situated on the crest of Stage 9 containing compacted ash upto a depth of 3m, settled ash between depths 3-12.5 m and the rest soil as material. The CPT test Results of BBH9 are shown in table 4.2.9. And the Graph of Depth vs. FS against Liquefaction is shown in Fig. 4.2.9.

Table 4.2.9 SPT test Results of BBH9

Depth (m)	Material	q_c(MPa)	f_s (kPa)	CSR	$(q_{c1N})_{cs}$	CRR	FS_{liq}	Remark
2.5	Compacte-d ash	1.5	24	0.10	70.58	0.11	1.16	No-Liquefaction
7.5	Settled ash	2.5	23	0.15	61.39	0.10	0.66	Liquefaction
12.5	Settled ash	4	29	0.17	62.55	0.10	0.59	Liquefaction
17.5	Soil	5	18	0.18	54.33	0.10	0.52	Liquefaction

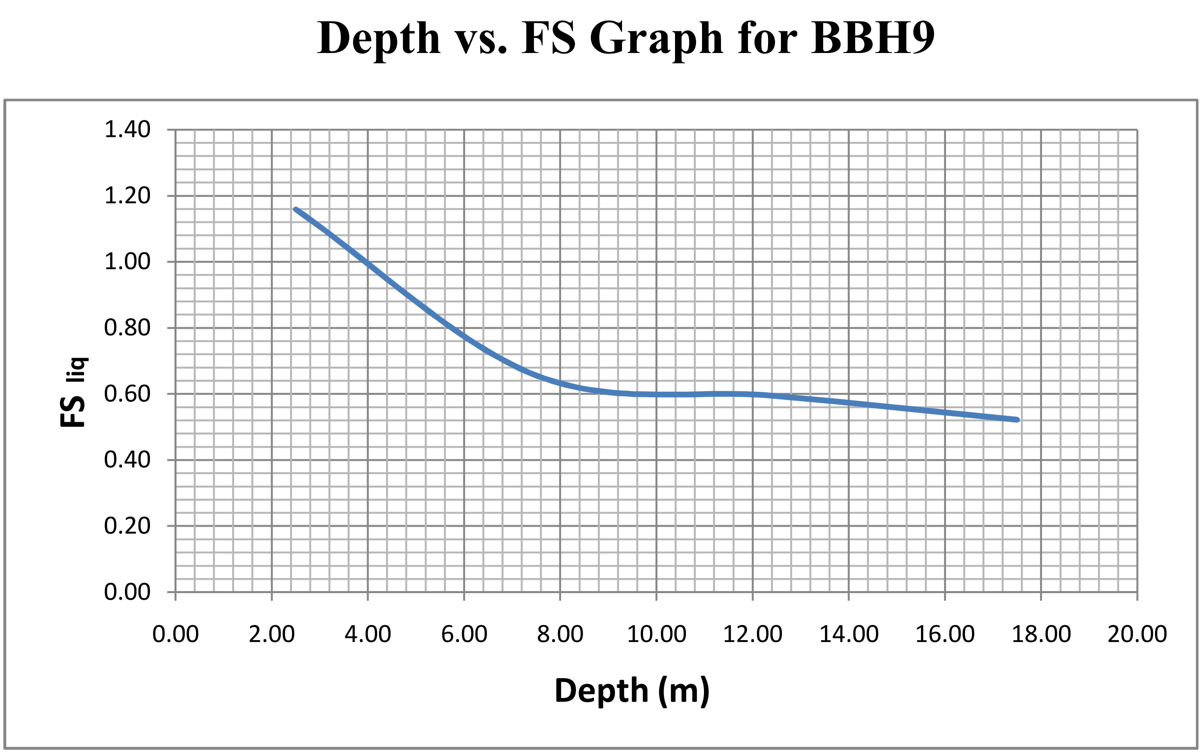


Figure 4.2.9

Chapter 5

ANALYSIS OF RESULTS

5.1 Validation of the Simplified procedure

In this project the validation of the Simplified Procedure is done using the CPT results obtained from various sites after the Chi-Chi, Taiwan Earthquake by Chih-Sheng Ku et al. (2004).

The National Centre for Research on Earthquake Engineering (NCREE), Taiwan conducted an extensive investigation in the areas of Yualin, Nantou and Wefeng which suffered the most severe liquefaction during the 1999 Chi-Chi earthquake. CPT values reported in the paper were derived from the sites in the inland plain covering Yualin, Nantou and Wufeng, as well as from the sites in the Chang-Bin industrial park. The CPT exploration in Yualin, Nantou and Wefeng were conducted by Moh and Associates for NCREE, shortly after the 1999 Chi-Chi earthquake. The CPT soundings in the Chang-Bin industrial park were performed by the writers.

5.1.1 Validation of the results from the Site in Wufeng

The actual results obtained from the literature for the site in Wufeng is shown in table 5.1.1(a) and the results obtained using the Simplified procedure is shown in table 5.1.1(b) along with Depth vs. FS against Liquefaction graph shown in fig 5.1.1.

Table 5.1.1(a) Actual results for the site in Wufeng

Depth (m)	q_c(MPa)	f_s (kPa)	q_{c1N}	$CSR_{7.5}$	Remark
2.5	1.27	1.24	21.01	0.643	Liquefaction
2.5	1.97	28.52	31.54	0.665	Liquefaction
2.5	0.72	13.90	11.46	0.665	Liquefaction
3.5	1.79	45.14	26.82	0.749	Liquefaction
4.5	1.35	15.57	18.56	0.802	Liquefaction
6.5	11.66	176.54	139.14	0.836	No-Liquefaction
7.5	13.89	153.90	156.47	0.853	No-Liquefaction
12.15	14.45	358.56	132.88	0.829	No-Liquefaction
13.8	20.05	279.14	174.30	0.826	No-Liquefaction

Table 5.1.1(b) Simplified Procedure results for the site in Wufeng

Depth (m)	q_c(MPa)	f_s(kPa)	CSR	$(q_{c1N})_{cs}$	CRR	FS_{liq}	Remarks
2.5	1.27	1.24	0.10	32.50	0.08	0.79	Liquefaction
2.5	1.97	28.52	0.10	72.50	0.12	1.19	No-Liquefaction
2.5	0.72	13.90	0.10	54.22	0.09	0.97	Liquefaction
3.5	1.79	45.14	0.10	77.17	0.12	1.26	No-Liquefaction
4.5	1.35	15.57	0.13	68.70	0.11	0.84	Liquefaction
6.5	11.66	176.54	0.15	168.46	100.00	672.47	No-Liquefaction.
7.5	13.89	153.90	0.15	157.61	0.44	2.87	No-Liquefaction
12.15	14.45	358.56	0.17	212.75	100.00	580.64	No-Liquefaction
13.8	20.05	279.14	0.18	192.56	100.00	568.33	No-Liquefaction

Depth vs. FS graph for Wufeng site

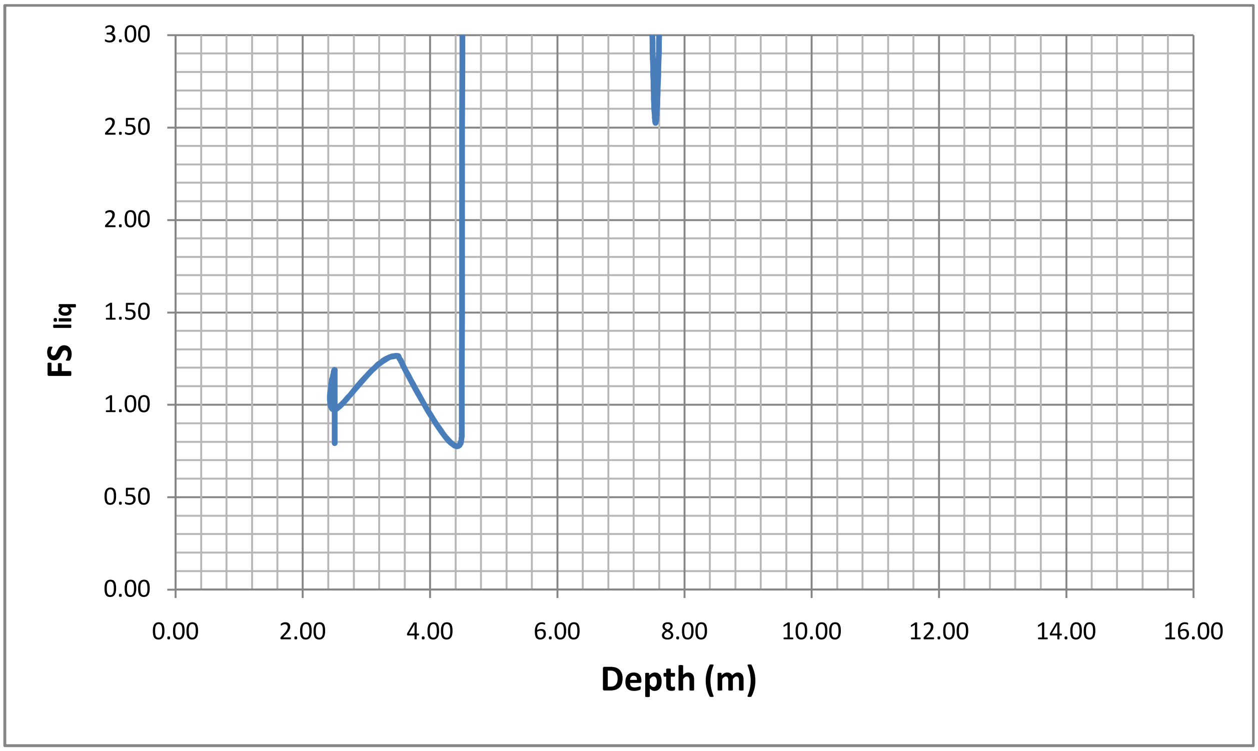


Figure 5.1.1

From the remarks section in the Table 5.1.1(a) and 5.1.1(b), it is observed that the results obtained in the literature are quite similar to the results obtained using simplified procedure for the site in Wufeng, with exceptions like for depth 2.5 and 3.5 m.

5.1.2 Validation of the results from the Site in Nantou

The actual results obtained from the literature for the site in Nantou is shown in table 5.1.2(a) and the results obtained using the Simplified procedure is shown in table 5.1.2(b) along with Depth vs. FS against Liquefaction graph shown in fig 5.1.2.

Table 5.1.1(a) Actual results for the site in Nantou

Depth (m)	q_c(MPa)	f_s (kPa)	q_{c1N}	$CSR_{7.5}$	Remark
2.5	0.94	22.4	14.6	0.34	Liquefaction
3.5	1.47	24.6	20.9	0.37	Liquefaction
10.35	11.32	114.0	108.9	0.46	No-Liquefaction

Table 5.1.2(b) Simplified Procedure results for the site in Nantou

Depth (m)	q_c(MPa)	f_s(kPa)	CSR	$(q_{c1N})_{cs}$	CRR	FS_{liq}	Remarks
2.5	0.94	22.4	0.10	59.90	0.10	1.03	Liquefaction
3.5	1.47	24.6	0.10	65.60	0.11	1.09	Liquefaction
10.35	11.32	114.0	0.10	115.50	0.22	2.31	No-Liquefaction

Depth vs FS graph for Nantou site

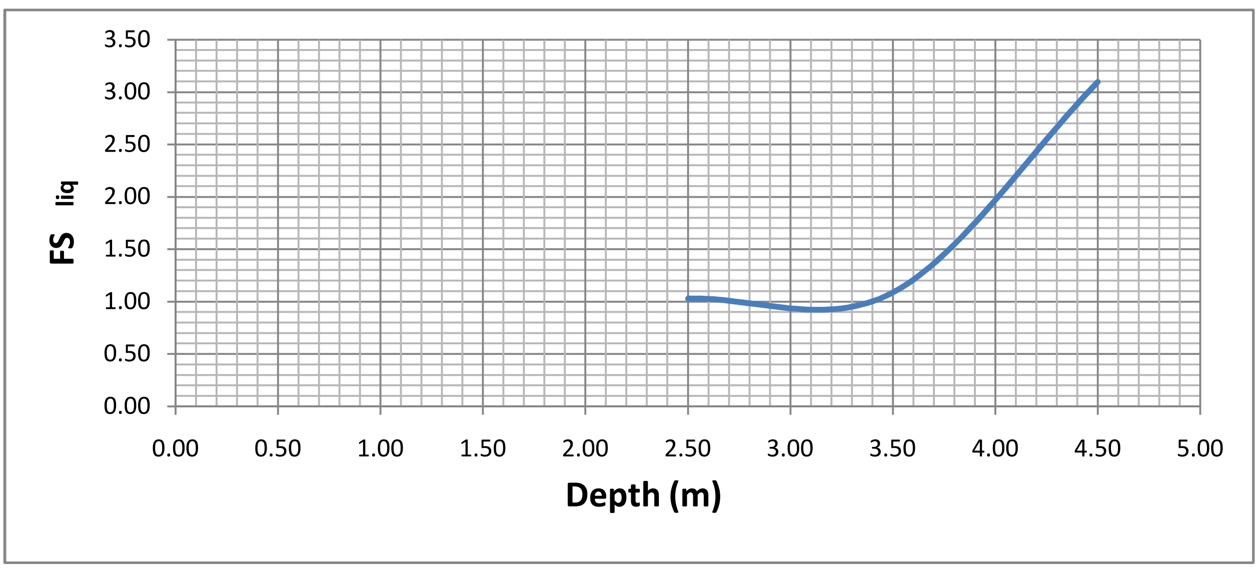


Figure 5.1.2

From the remarks section in the Table 5.1.2(a) and 5.1.2(b) it is observed that the results obtained in the literature are same as the results obtained using simplified procedure for the site in Nantou.

5.1.3 Validation of the results from the Site in Yuanlin

The actual results obtained from the literature for the site in Yuanlin is shown in table 5.1.3(a) and the results obtained using the Simplified procedure is shown in table 5.1.3(b) along with Depth vs. FS against Liquefaction graph shown in fig 5.1.3.

Table 5.1.3(a) Actual results for the site in Yuanlin

Depth (m)	q_c(MPa)	f_s (kPa)	q_{c1N}	$CSR_{7.5}$	Remark
2.5	3	7.4	53.6	0.18	Liquefaction
3.5	2.09	8.2	33.1	0.20	Liquefaction
4.5	2.78	20.7	40.0	0.24	Liquefaction
6.5	2.69	28.8	33.4	0.22	Liquefaction
7.5	3.05	32.5	35.5	0.22	Liquefaction
13.5	14.67	9.8	131.4	0.20	No-Liquefaction
14.5	10.61	19.2	91.9	0.20	No-Liquefaction
15.5	14.74	26.2	123.8	0.19	No-Liquefaction
16.5	13.65	17.6	111.4	0.19	No-Liquefaction

Table 5.1.3(b) Simplified Procedure results for the site in Yuanlin

Depth (m)	q_c(MPa)	f_s(kPa)	CSR	$(q_{c1N})_{cs}$	CRR	FS_{liq}	Remarks
2.5	3	7.4	0.10	50.87	0.09	0.95	Liquefaction
3.5	2.09	8.2	0.10	50.86	0.09	0.95	Liquefaction
4.5	2.78	20.7	0.10	65.79	0.11	1.10	No-Liquefaction
6.5	2.69	28.8	0.10	72.27	0.12	1.19	No-Liquefaction
7.5	3.05	32.5	0.15	88.22	0.14	0.93	Liquefaction
13.5	14.67	9.8	0.18	49.78	0.09	0.52	Liquefaction.
14.5	10.61	19.2	0.18	69.25	0.11	0.63	Liquefaction
15.5	14.74	26.2	0.18	72.10	0.11	0.64	Liquefaction
16.5	13.65	17.6	0.18	63.74	0.10	0.58	Liquefaction

Depth vs. FS graph for Yuanlin site

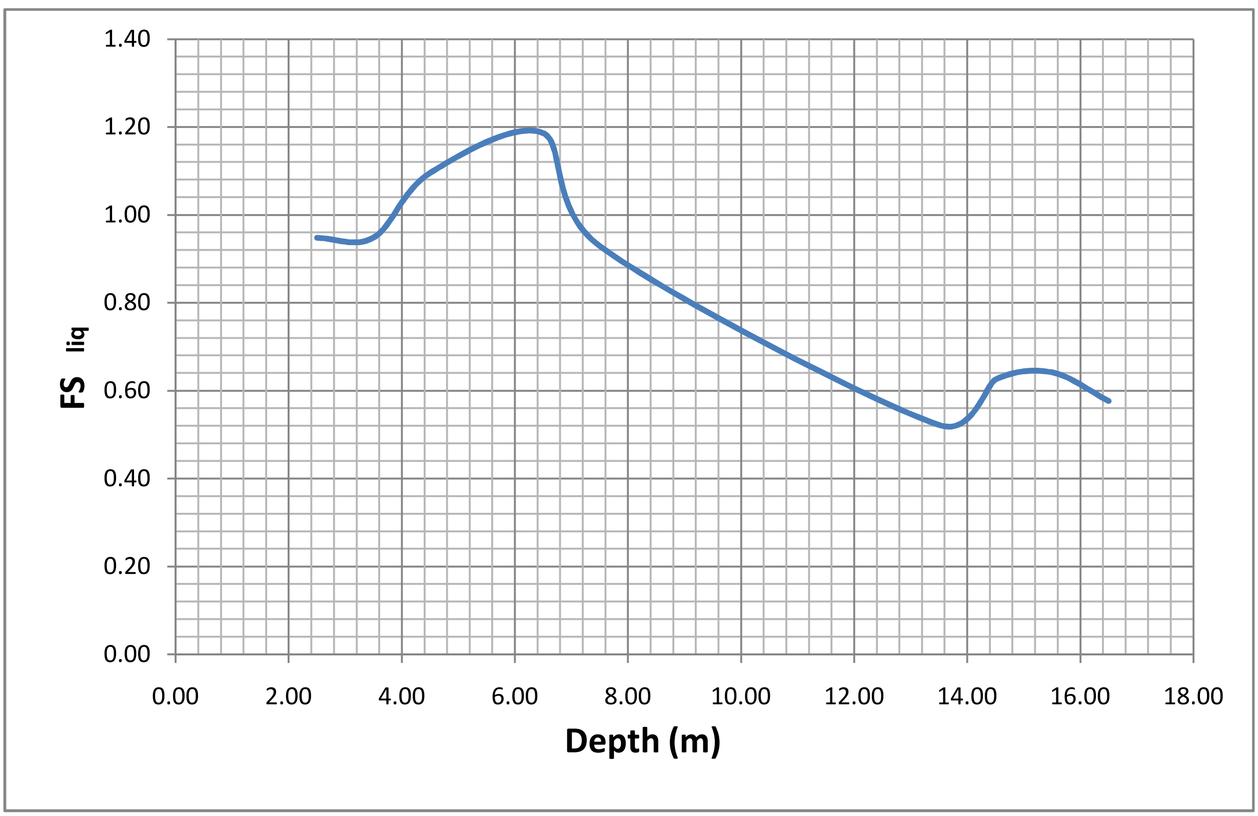


Figure 5.1.3

From the remarks section in tables 5.1.3(a) and 5.1.3(b), it is observed that the results obtained in the literature are not quite similar to the results obtained using simplified procedure for the site in Yuanlin.

5.1.4 Validation of the results from the Site in Chang-Bin industrial park

The actual results obtained from the literature for the site in Chang-Bin industrial park is shown in table 5.1.4(a) and the results obtained using the Simplified procedure is shown in table 5.1.4(b) along with Depth vs. FS against Liquefaction graph shown in fig 5.1.4.

Table 5.1.4(a) Actual results for the site in Chang-Bin industrial park

Depth (m)	q_c(MPa)	f_s (kPa)	q_{c1N}	$CSR_{7.5}$	Remark
3.5	2.49	10	37.2	0.12	Liquefaction
4.5	2.01	5.1	27.6	0.13	Liquefaction
5.5	1.89	6.7	24.1	0.14	Liquefaction
6.5	1.54	5.8	18.3	0.14	Liquefaction
9.5	7.43	57.7	75.9	0.14	No-Liquefaction
11.6	7.72	62.6	72.5	0.14	No-Liquefaction

Table 5.1.4(b) Simplified Procedure results for the site in Chang-Bin industrial park

Depth (m)	q_c(MPa)	f_s (kPa)	CSR	$(q_{c1N})_{cs}$	CRR	FS_{liq}	Remark
3.5	2.49	10	0.10	53.95	0.09	0.97	Liquefaction
4.5	2.01	5.1	0.10	46.14	0.09	0.91	Liquefaction
5.5	1.89	6.7	0.10	51.78	0.09	0.96	Liquefaction
6.5	1.54	5.8	0.10	60.99	0.10	1.04	Liquefaction
9.5	7.43	57.7	0.16	105.04	0.19	1.15	No-Liquefaction
11.6	7.72	62.6	0.17	108.66	0.20	1.17	No-Liquefaction

Depth vs. FS graph for Chang-Bin industrial park site

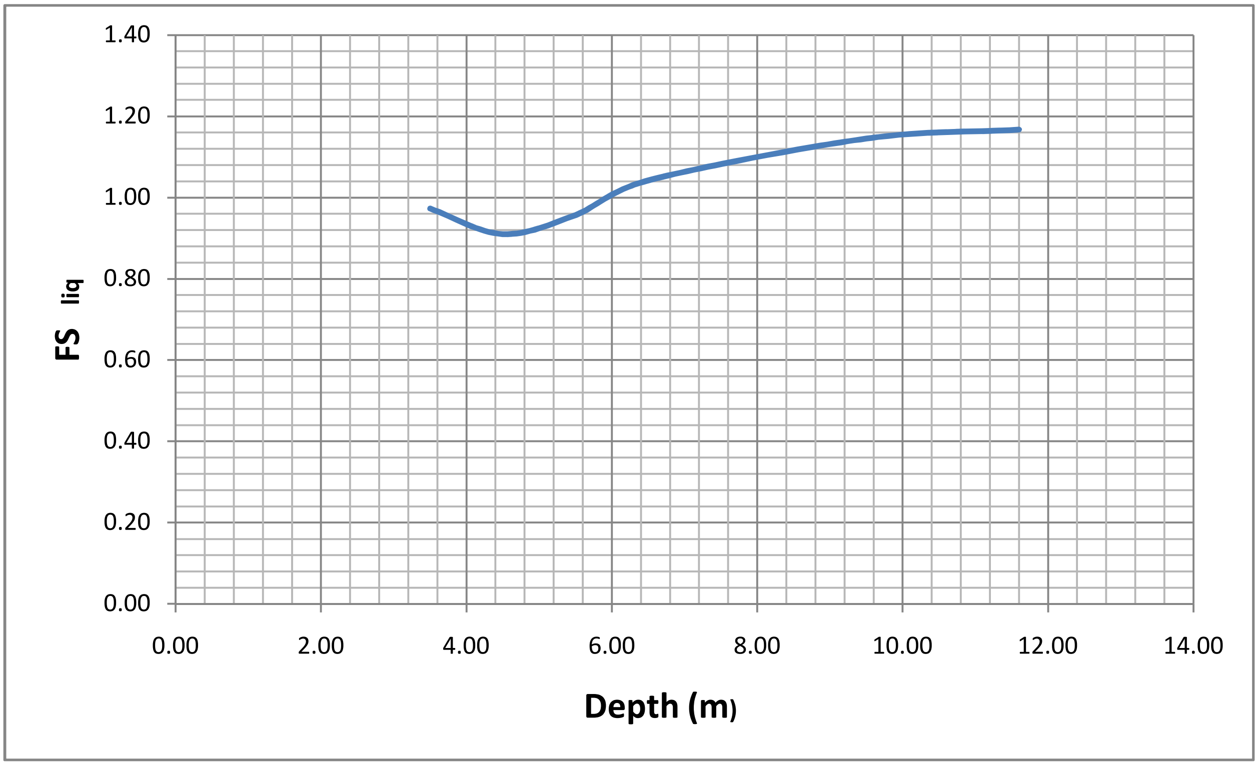


Figure 5.1.4

From the Remarks section in tables 5.1.4(a) and 5.1.4(b), it is observed that the results obtained in the literature are same as the results obtained using simplified procedure for the site in Chang-Bin industrial park.

5.2 Analysis of results for the Ash Embankment at Korba Super Thermal Power Station (KSTPS)

Bore hole Number 1 (BH1)

The analysis of SPT results at Bore hole number 1(BH1) shows that the strata between depths 0-3 m are Non-Liquefiable, and the strata between 3-18 m are liable to liquefy under earthquake shaking corresponding to peak horizontal ground acceleration of 0.24g.

Bore hole Number 2 (BH2)

The analysis of SPT results at Bore hole number 2(BH2) shows that the strata between depths 0-3.4 m are Non-Liquefiable, and the strata between 3.4-12 m are liable to liquefy under earthquake shaking corresponding to peak horizontal ground acceleration of 0.24g.

Bore hole Number 3 (BH3)

The analysis of SPT results at Bore hole number 3(BH3) shows that the strata between depths 0-4.3 m are Non-Liquefiable, and the strata between 4.3-13.5 m are liable to liquefy under earthquake shaking corresponding to peak horizontal ground acceleration of 0.24g.

Bore hole Number 4 (BH4)

The analysis of SPT results at Bore hole number 4(BH4) shows that the strata between depths 0-5.25 m are Non-Liquefiable, and the strata between 5.25-12 m are liable to liquefy under earthquake shaking corresponding to peak horizontal ground acceleration of 0.24g.

Bore hole Number 5 (BH5)

The analysis of SPT results at Bore hole number 5(BH5) shows that the strata between depths 0-2.6 m are Non-Liquefiable, and the strata between 2.6-12 m are liable to liquefy under earthquake shaking corresponding to peak horizontal ground acceleration of 0.24g.

Bore hole Number 6 (BH6)

The analysis of SPT results at Bore hole number 6(BH6) shows that the strata between depths 0-4 m are Non-Liquefiable, and the strata between 4-19.5 m are liable to liquefy under earthquake shaking corresponding to peak horizontal ground acceleration of 0.24g.

Bore hole Number 7 (BH7)

The analysis of SPT results at Bore hole number 7(BH7) shows that the strata between depths 3.4-4 m and 14-15 m are Non-Liquefiable, and the strata between

0-3.4 m and 4-14 m are liable to liquefy under earthquake shaking corresponding to peak horizontal ground acceleration of 0.24g

Bore hole Number 8 (BH8)

The analysis of SPT results at Bore hole number 8(BH8) shows that the strata between depths 0-4.9 m and 10.9-15 m are Non-Liquefiable, and the strata between 4.9-10.9 m are liable to liquefy under earthquake shaking corresponding to peak horizontal ground acceleration of 0.24g.

Bore hole Number 9 (BH9)

The analysis of SPT results at Bore hole number 9(BH9) shows that the strata between depths 0-3.5 m, 6.6-7.2 m and 10.2-12 m are Non-Liquefiable, and the strata between 3.5-6.6 m and 7.2-10.2 m are liable to liquefy under earthquake shaking corresponding to peak horizontal ground acceleration of 0.24g.

Bore hole Number 10 (BH10)

The analysis of SPT results at Bore hole number 10(BH10) shows that the strata between depths 2.2-2.8 m are Non-Liquefiable, and the strata between 0-2.2 m and 2.8-7.5 m are liable to liquefy under earthquake shaking corresponding to peak horizontal ground acceleration of 0.24g.

Bore hole Number 11 (BH11)

The analysis of SPT results at Bore hole number 11(BH11) shows that the strata between depths 1.8-4.1 m are Non-Liquefiable, and the strata between 0-1.8 m and 4.1-6 m are liable to liquefy under earthquake shaking corresponding to peak horizontal ground acceleration of 0.24g

5.3 Analysis of results for the Ash Embankment at Badarpur Thermal Power Station (BTPS)

5.3.1 Analysis of SPT Results

Badarpur Bore Hole Number 1 (BBH1)

The analysis of SPT results at Badarpur Bore hole number 1(BBH1) shows that the strata between depths 0-7.5 m are Non-Liquefiable, and the strata between 7.5-9m and are liable to liquefy under earthquake shaking corresponding to peak horizontal ground acceleration of 0.24g.

Badarpur Bore Hole Number 2 (BBH2)

The analysis of SPT results at Badarpur Bore hole number 2(BBH2) shows that the strata between depths 1.8-6.2 m are Non-Liquefiable, and the strata between 0-1.8 m and 6.2-12 m are liable to liquefy under earthquake shaking corresponding to peak horizontal ground acceleration of 0.24g.

Badarpur Bore Hole Number 3 (BBH3)

The analysis of SPT results at Badarpur Bore hole number 3(BBH3) shows that the whole strata between depths 0-12 m are liable to liquefy under earthquake shaking corresponding to peak horizontal ground acceleration of 0.24g.

Badarpur Bore Hole Number 4 (BBH4)

The analysis of SPT results at Badarpur Bore hole number 4(BBH4) shows that the whole strata between depths 0-12 m are liable to liquefy under earthquake shaking corresponding to peak horizontal ground acceleration of 0.24g.

Badarpur Bore Hole Number 5 (BBH5)

The analysis of SPT results at Badarpur Bore hole number 5(BBH5) shows that the whole strata between depths 0-12 m are liable to liquefy under earthquake shaking corresponding to peak horizontal ground acceleration of 0.24g.

Badarpur Bore Hole Number 6 (BBH6)

The analysis of SPT results at Badarpur Bore hole number 6(BBH6) shows that the strata between depths 2.2-2.4 m are Non-Liquefiable, and the strata between 0-2.2 m and 2.4-12 m are liable to liquefy under earthquake shaking corresponding to peak horizontal ground acceleration of 0.24g.

5.3.2 Analysis of CPT Results

Badarpur Bore Hole Number 7 (BBH7)

The analysis of CPT results at Badarpur Bore hole number 7(BBH7) shows that the strata between depths 0-6.8 m are Non-Liquefiable, and the strata between 6.8-18 m are liable to liquefy under earthquake shaking corresponding to peak horizontal ground acceleration of 0.24g.

Badarpur Bore Hole Number 8 (BBH8)

The analysis of CPT results at Badarpur Bore hole number 8(BBH8) shows that the strata between depths 0-10.8 m are Non-Liquefiable, and the strata between 10.8-18 m are liable to liquefy under earthquake shaking corresponding to peak horizontal ground acceleration of 0.24g.

Badarpur Bore Hole Number 9 (BBH9)

The analysis of CPT results at Badarpur Bore hole number 9(BBH9) shows that the strata between depths 0-3 m are Non-Liquefiable, and the strata between 3-18 m are liable to liquefy under earthquake shaking corresponding to peak horizontal ground acceleration of 0.24g.

Chapter 6

CONCLUSION

The subsurface characteristics at the liquefied layer of the ash embankment at KSTPS site is consist of settled ash which is generally below the depth 3 m. Here the average SPT blow count is in the range of 3 to 24 blows, with liquefied layers generally below 3 m depth which consists of settled ash. The most liquefiable layer is found below bore hole number 10 situated on the western dyke of the embankment on lagoon 2, where almost the entire depth below the bore hole is liquefiable. At the BTPS site the subsurface characteristics at the liquefied layer below the embankment also consists of settled ash. Here the average SPT blow count is in the range of 2 to 25 blows and the average CPT cone tip resistance varies from 10 to 75 kg/cm^2. Liquefaction occurs for the entire depth in case of BTPS for bore hole number 3, 4 and 5. Subsurface below bore hole number 1 is the strongest with non-liquefies layer upto a depth of 7.5 m, consisting of silty sand in BTPS.

Based upon the Simplified Procedure, 63 liquefaction case histories and 31 non-liquefaction case histories are obtained from the embankment at KSTPS site, along with that 45 liquefaction case histories and 13 non-liquefaction case histories are obtained from the embankment at BTPS site. It is found from the above case histories that strength of settled ash remains low generally when subjected to earthquake loading. Compacted ash has a larger liquefaction resistance potential than settled ash.

The Liquefaction potential can be computed by extending Simplified procedure (IITK-GSDMA) to Ash embankments using SPT and CPT values.

Chapter 7

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