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Assessment of Liquefaction Potential Index for Approach Road of Padma Multipurpose Bridge

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Abstract: *Seismic soil liquefaction is evaluated for ongoing approach road project of Padma Multipurpose Bridge in terms of the factors of safety against liquefaction (FS) along the depths of soil profiles for different magnitude of earthquakes and peak ground acceleration by using standard penetration test (SPT) based on simplified empirical procedure. This liquefaction potential is evaluated in the approach road using the borehole records from standard penetration tests. Liquefaction potential index (LPI) is evaluated at borehole locations from the obtained factors of safety (FS) to predict the potential of liquefaction to cause damage at the surface level at the site of interest. For each location, soil liquefaction potential is presented in the form of contour plot of matrix of LPI values by using MATLAB numerical tool. As the soils at the site are predominantly alluvial deposits, the vulnerability of liquefaction is observed to be very high at many locations.*
Keywords – *Borehole Log, Liquefaction, LPI, MATLAB, Site Investigation, SPT*

I. Introduction

Liquefactions and associated ground failures have been widely observed during numerous devastating earthquakes. Liquefaction occurs due to rapid loading during seismic events where there is not sufficient time for dissipation of excess pore-water pressures by natural drainage. Rapid loading situation increases pore-water pressures resulting in cyclic softening in fine-grained materials. The increased pore water pressure transforms granular materials from a solid to a liquefied state thus shear strength and stiffness of the soil deposit are reduced. Liquefaction is observed in loose, saturated, and clean to silty sands. The soil liquefaction depends on the magnitude of earthquake, peak ground acceleration, intensity and duration of ground motion, the distance from the source of the earthquake, type of soil and thickness of the soil deposit, relative density, grain size distribution, fines content, plasticity of fines, degree of saturation, confining pressure, hydraulic conductivity of soil layer, position and fluctuations of the groundwater table, reduction of effective stress, and shear modulus degradation [1]. Liquefaction-induced ground failure is influenced by the thickness of non-liquefied and liquefied soil layers. Measures to mitigate the damages caused by liquefaction require accurate evaluation of liquefaction potential of soils.

The potential for liquefaction to occur at certain depth at a site is quantified in terms of the factors of safety against liquefaction (FS). Seed and Idriss (1971) proposed a simplified procedure to evaluate the liquefaction resistance of soils in terms of factors of safety (FS) by taking the ratio of capacity of a soil element to resist liquefaction to the seismic demand imposed on it. Capacity to resist liquefaction is computed as the cyclic resistance ratio (CRR), and seismic demand is computed as the cyclic stress ratio (CSR). FS of a soil layer can be calculated with the help of several in-situ tests such as standard penetration test (SPT), cone penetration test (CPT), shear wave velocity (Vs) test etc. SPT-based simplified empirical procedure is widely used for evaluating liquefaction resistance of soils. Factors of safety (FS) along the depth of soil profile are generally evaluated using the surface level peak ground acceleration (PGA), earthquake magnitude (Mw), and SPT data, namely SPT blow counts (N), overburden pressure (σ_v), fines content (FC), clay content, liquid limits and grain size distribution. A soil layer with FS<1 is generally classified as liquefiable and with FS>1 is classified as nonliquefiable [2].

A layer may liquefy during an earthquake, even for FS>1.0. A factor of safety of 1.2 at a particular depth is considered as the threshold value for the layer to be categorized as non-liquefiable. Seed and Idriss (1982) considered the soil layer with FS value between 1.25 and 1.5 as non-liquefiable. Soil layers with FS greater than 1.2 and FS between 1.0 and 1.2 are defined as non-liquefiable and marginally liquefiable layers, respectively. Although FS shows the liquefaction potential of a soil layer at a particular depth in the subsurface, it does not show the degree of liquefaction severity at a liquefaction-prone site. Iwasaki et al. (1978) proposed liquefaction potential index (LPI) to overcome this limitation of FS [9]. Liquefaction potential index (LPI) provides an integration of liquefaction potential over the depth of a soil profile and predicts the performance of the whole soil column as opposed to a single soil layer at particular depth and depends on the magnitude of the peak horizontal ground acceleration [3]. LPI combines depth, thickness, and factor of safety against liquefaction (FS) of soil layers and predicts the potential of liquefaction to cause damage at the surface level at the site of interest. A seismic map of Bangladesh and surrounding area is presented in Fig 1 with Peak Ground Acceleration (PGA in cm/s^2) for a 10% probability of exceedance in an economic life of 50 year based on the attenuation law of Duggal [7].

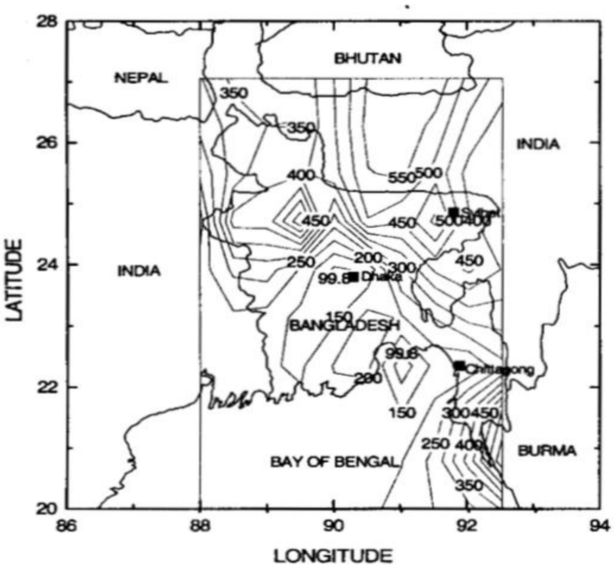

Figure 1. Seismic map of Bangladesh and surrounding area

II. Study Area

Bangladesh Geological Survey indicates that the project site Jajira of Madaripur district, in general, is underlain by recent alluvium. The Padma superficial alluvial river deposits typically comprise normally-consolidated, low strength compressible clays, or silts and fine sands of low density. The thickness of these deposits is usually quite variable and can exhibit considerable changes over short distances depending on the profile of the former river channel in which they were deposited. The underlying deposit is predominantly dense sand. The Jajira approach road length is 10.579 km. The project site and the borehole locations are shown in Fig 2, 3 and 4. Locations where LPI is determined is marked with red color in Fig 3 and 4.

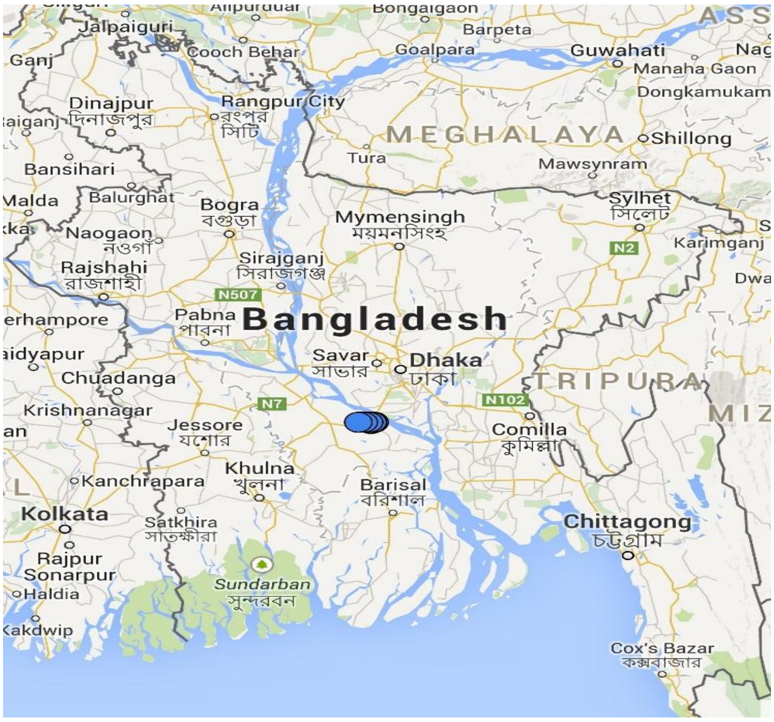

Figure 2. Site location (Jajira Approach Road Project of Padma Multipurpose Bridge)

(a) Map View (b) Sattelite view

Figure 3. Jajira Approach Road (7 Boreholes within chainage 17600 to 21600)

(a) Map View (b) Sattelite view

Figure 4. Jajira Approach Road (8 Boreholes within chainage 24100 to 27600)

III. Assessment of Liquefaction Potential Index

The liquefaction potential index (LPI) quantifies the severity of liquefaction and predicts surface manifestations of liquefaction, liquefaction damage or failure potential of a liquefaction-prone area [3]. LPI is computed by taking integration of one minus the liquefaction factors of safety along the entire depth of soil column limited to the depths ranging from 0 to 20m below the ground surface at a specific location. The level of liquefaction severity with respect to LPI as per Iwasaki et al. (1982), Luna and Frost (1998), and MERM (2003) is given in Table **1** . The factors of safety against liquefaction (FS) and the corresponding liquefaction potential index (LPI) are determined by comparing the seismic demand expressed in terms of cyclic stress ratio (CSR) to the capacity of liquefaction resistance of the soil expressed in terms of cyclic resistance ratio (CRR).

Table 1. The level of liquefaction severity

LPI	Iwasaki et al. (1982)	Luna and Frost (1998)	MERM(2003)
LPI=0	Very low	Little to none	None
0<LPI<5	Low	Minor	Low
5<LPI<15	High	Moderate	Medium
15<LPI	Very high	Major	High

A. Determination of Cyclic Stress Ratio

To Cyclic stress ratio (CSR) characterizes the seismic demand induced by a given earthquake, and it can be determined from peak ground surface acceleration that depends upon site-specific ground motions. The expression for CSR induced by earthquake ground motions formulated by Idriss and Boulanger (2006) is as follows [4]:

$$CSR = 0.65\frac{a_{max}}{g}\frac{\sigma_v}{\sigma_v'}r_d\frac{1}{MSF}\frac{1}{K_\sigma}$$

0.65 is a weighing factor to calculate the equivalent uniform stress cycles required to generate same pore water pressure during an earthquake; a_{max} is the peak horizontal ground acceleration; g is acceleration of gravity; σ_v and σ_v' are total vertical overburden stress and effective vertical overburden stress, respectively, at a given depth below the ground surface; r_d is depth-dependent stress reduction factor; MSF is the magnitude scaling factor, and K_σ is the overburden correction factor.

This stress reduction factor(r_d), can be calculated by-

$$r_d = 1 - 0.015\,z$$

Where,
z is the depth (in m)

The values of CSR that pertain to the equivalent uniform shear stress induced by an earthquake of magnitude, Mw, are adjusted to an equivalent CSR for an earthquake of magnitude Mw =7.5 through introduction of magnitude scaling factor (MSF). MSF accounts for the duration effect of ground motions. MSF for Mw < 7.5 is expressed as follows:

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

Hybes and Olson derived the $K_\sigma$correction factor to be

$$K_\sigma = \left(\frac{\sigma_v'}{p_a}\right)^{f-1}$$

Where σ_v' is the effective overburden stress, p_a is atmospheric pressure in the same units, and f is a function of site conditions. Youd et al. recommended f values between 0.6 and 0.8, depending on the relatively density of the soil. For this study assumed a conservative estimate for f of 0.8.

B. Determination of Cyclic Resistance Ratio

Determination of cyclic resistance ratio (CRR) requires fines content (FC) of the soil to correct updated SPT blow count $(N_1)_{60}$ to an equivalent clean sand standard penetration resistance value $(N_1)_{60cs}$. Idriss and Boulanger (2006) determined CRR value for cohesionless soil with any fines content using the following expression[4]:

$$CRR = \exp\left\{\frac{(N_1)_{60cs}}{14.1} + \left(\frac{(N_1)_{60cs}}{126}\right)^2 - \left(\frac{(N_1)_{60cs}}{23.6}\right)^3 + \left(\frac{(N_1)_{60cs}}{25.4}\right)^4 - 2.8\right\}$$

$$(N_1)_{60cs} = (N_1)_{60} + \Delta(N_1)_{60}$$

Where $\Delta(N_1)_{60}$ the correction for fines is content in percent (FC) present in the soil and is expressed as-

$$\Delta(N_1)_{60} = \exp\left(1.63 + \frac{9.7}{FC+0.1} - \left(\frac{15.7}{FC+0.1}\right)^2\right)$$

C. Determination of Factor of Safety

The factor of safety against liquefaction (FS) is commonly used to quantify liquefaction potential. The factor of safety against liquefaction (FS) can be defined by

$$FS = \frac{(CRR)_{M_W=7.5}}{(CSR)_{M_W=7.5,\sigma_v'=1}} MSF$$

Both CSR and CRR vary with depth, and therefore the liquefaction potential is evaluated at corresponding depths within the soil profile.

D. Determination of Liquefaction Potential Index

To Liquefaction potential index (LPI) is a single-valued parameter to evaluate regional liquefaction potential. LPI at a site is computed by integrating the factors of safety (FS) along the soil column up to 20m depth. A weighting function is added to give more weight to the layers closer to the ground surface. The liquefaction potential index (LPI) proposed by Iwasaki (1978) is expressed as follows [9]:

$$LPI = \int_0^{20} F(z).w(z)dz$$

Where, z is depth of the midpoint of the soil layer (0 to 20m) and dz is differential increment of depth. The weighting factor, w(z), and the severity factor, F(z), are calculated as per the following expressions:
$F(z)=1-FS$ for $FS < 1.0$
$F(z)=0$ for $FS \geq 1.0$
$w(z)=10-0.5z$ for $z < 20$ m

w(z)=0 for z > 20 m
For the soil profiles with the depth less than 20m, LPI is calculated using the following expression [3]:

$$LPI = \sum_{i=1}^{n} w_i F_i H_i$$

with
$F_i = 1 - FS_i$ for FSi < 1.0
$F_i = 0$ for $FS_i \geq 1.0$
Where, H_i is thickness of the discretized soil layers; n is number of layers; F_i is liquefaction severity for i-th layer; FS_i is the factor of safety for i-th layer; w_i is the weighting factor ($=10–0.5z_i$); and z_i is the depth of i-th layer (m) [5][6].

IV. Results and Conclusion

The site is at Jajira approach road of Padma Multipurpose Bridge Project which lies in Madaripur district. From Fig 5, it was understood that our site is located in flood prone area. So, considering worst case scenario, to analyze seismic soil liquefaction and liquefaction potential index, ground water table is assumed to be at ground level. The liquefaction potential was estimated using borehole data. Contour matrix plot outputs, which is developed by MATLAB - are presented in Fig 6 and Fig 7 [8]. A typical calculation sheet is presented in Table 2.

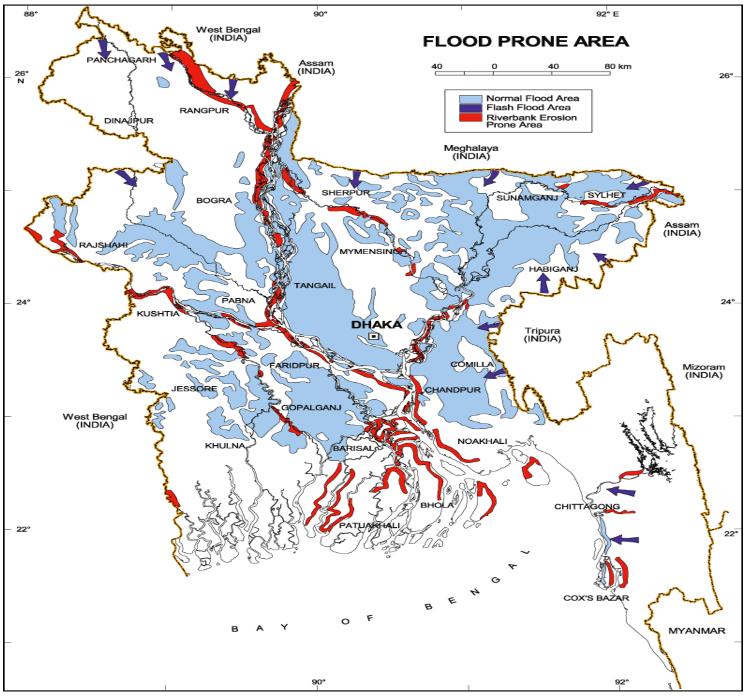

Figure 5. Flood prone area of Bangladesh

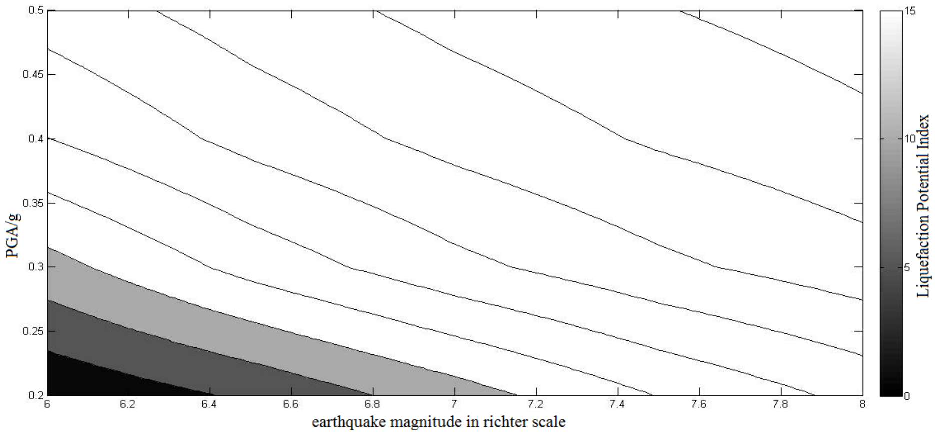

Figure 6. Liquefaction Potential Index for different Peak Ground Acceleration & Earthquake Magnitude at chainage 21100

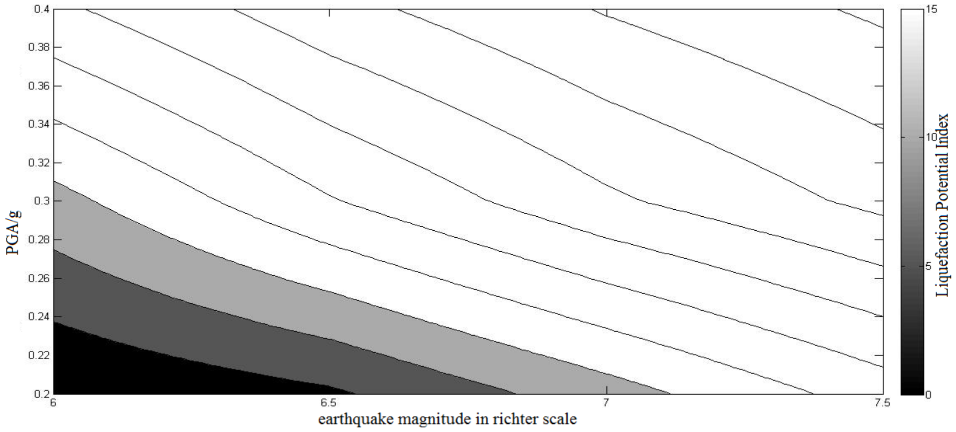

Figure 7. Liquefaction Potential Index for different Peak Ground Acceleration & Earthquake Magnitude at chainage 26100.

This study attempts to evaluate the factors of safety against liquefaction (FS) and corresponding liquefaction potential indices (LPI) for the variable seismic scenario for the site using SPT-based semiempirical procedure. The borehole log at chainage 26100 is shown in Fig 8 and FS values for this location is shown in Table 2. This study reveals that the higher susceptibility of liquefaction at a particular location can be attributed to the higher thickness of soft soil deposits (in this case alluvium deposits) and ground water table at shallow depths. It can be observed from the LPI contour maps that a high degree of liquefaction damages is likely to occur at a particular location for higher magnitude of earthquake and peak ground acceleration. These LPI contour plots will help the geotechnical engineers to make decisions regarding ground improvement and the structural designers and city planners to check the vulnerability of the area against liquefaction. These contour plots can also be used efficiently for seismic safety plans and in the seismic hazard mitigation programs.

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References

[1]. Youd, T. L. and Perkins, D. M.: Mapping liquefaction-induced ground failure potential, J. Geotech. Eng. Division, 104, 443– 446, 1978.
[2]. Seed, H. B. and Idriss, I. M.: Simplified procedure for evaluating soil liquefaction potential, J. Soil Mech. Foundation Division, 97, 1249–1273, 1971
[3]. Luna, R. and Frost, J. D.: Spatial liquefaction analysis system, J. Comput. Civil Eng., 12, 48–56, 1998
[4]. Idriss, I. M. and Boulanger, R. W.: Semi-empirical procedures for evaluating liquefaction potential during earthquakes, Soil Dynam. Earthq. Eng., 26, 115–130, 2006
[5]. Dixit, J., Dewaikar, D. & Jangid, R.: Assessment of liquefaction potential index for Mumbai city. Natural Hazards and Earth System Sciences, 2012
[6]. Lenz, J. A. & Baise, L. G.: Spatial variability of liquefaction potential in regional mapping using CPT and SPT data. SOIL DYNAMICS AND EARTHQUAKE ENGINEERING, 2007.
[7]. Ansary, M. A. & Sharfuddin, M.: PROPOSAL FOR A NEW SEISMIC ZONING MAP FOR BANGLADESH. Journal of Civil Engineering, pp. Vol. CE 30, No. 2, 2002.
[8]. Hanselman, D. & Littlefield, B. Mastering MATLAB 7. 1st ed. s.l.: Pearson Education, 2007.
[9]. Iwasaki, T., Tokida, K., Tatsuko, F., and Yasuda, S.: A practical method for assessing soil liquefaction potential based on case studies at various sites in Japan, Proceedings of 2nd International Conference on Microzonation, San Francisco, 885–896, 1978

APPENDIX

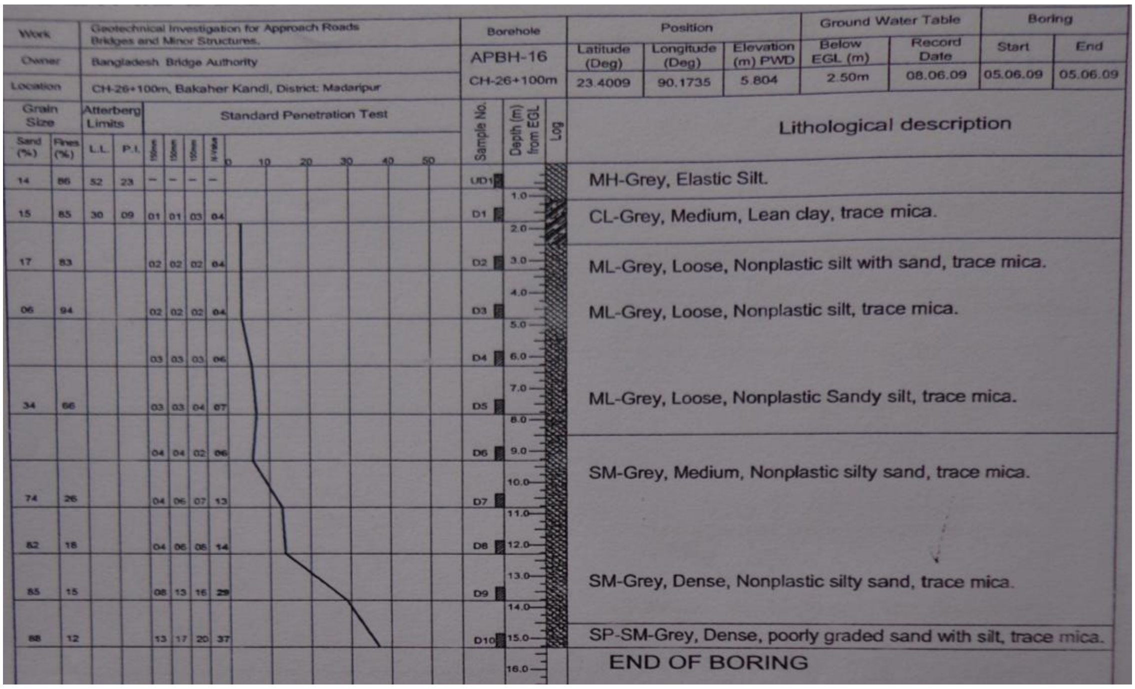

Figure 8. Borehole log at chainage 26100

Table 2. Calculation of Liquefaction Potential Index (at chainage 26100)

Chainage	depth of water table (in m)	Dry unit weight of soil (γ)	Saturated unit weight of soil(γ')	a_{max}/g	Magnitude of EQ ,M
26100	0	15	18	0.3	6.5

magnitude scaling factor, MSF	1.441922

Depth (m)	Soil type	Grain Size		SPT-N		percent finer correction	Total stress	Effective overburden stress			cyclic resistance ratio		cyclic stress ratio		FS= (CRR/CSR)* MSF*Kσ				Liquefaction Potential Index
		% Sand	%Fines	in-situ	corrected	Δ (N1) 60	σv (KN/m^2)	σ'v (KN/m^2)	σ'v (Kgf/cm^2)	(N1)60cs	CRR	rd	CSR	Kσ	FL=R/L	wi	Hi	Fi	∑wi * Fi * Hi
0	Cohesive	0	0	0	0	0.00	0	0.0	0.00	0	0.06	1.00	0.00	0.00	0.00	10	0	1.00	0
1.5	Cohesive	15	85	4	11	5.53	27	12.3	0.12	17	0.17	0.98	0.42	1.52	0.89	9.25	1.5	0.11	2
3	Cohesive	17	83	4	8	5.53	54	24.6	0.25	14	0.14	0.96	0.41	1.32	0.67	8.5	1.5	0.33	4
4.5	Cohesionless	7	93	4	6	5.51	81	36.9	0.37	12	0.13	0.93	0.40	1.22	0.57	7.75	1.5	0.43	5
6	Cohesionless	15	85	6	8	5.53	108	49.1	0.49	14	0.14	0.91	0.39	1.15	0.61	7	1.5	0.39	4
7.5	Cohesionless	33	67	7	9	5.58	135	61.4	0.61	15	0.15	0.89	0.38	1.10	0.64	6.25	1.5	0.36	3
9	Cohesionless	54	46	6	7	5.61	162	73.7	0.74	13	0.14	0.87	0.37	1.06	0.57	5.5	1.5	0.43	4
10.5	Cohesionless	73	27	13	14	5.22	189	86.0	0.86	19	0.20	0.84	0.36	1.03	0.81	4.75	1.5	0.19	1
12	Cohesionless	82	18	14	14	4.11	216	98.3	0.98	18	0.18	0.82	0.35	1.00	0.76	4	1.5	0.24	1
13.5	Cohesionless	85	15	29	27	3.29	243	110.6	1.11	30	0.50	0.80	0.34	0.98	2.08	3.25	1.5	0.00	0
15	Cohesionless	88	12	37	33	2.11	270	122.9	1.23	35	1.13	0.78	0.33	0.96	4.73	2.5	1.5	0.00	0
16.5		91	9																
18		94	6																
19.5		97	3																
																		LPI	25