A Study on the Effect of Field Procedure Corrections of SPT- N Values on the Liquefaction Resistance of the Subsoil Strata along the Coastline of Visakhapatnam

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ABSTRACT: The effects of liquefaction are often catastrophic, so evaluating the liquefaction potential of the subsoil strata is necessary to characterize their behaviour under dynamic loading, particularly earthquakes. Several laboratory tests are in use to evaluate the liquefaction potential of the soils. However, for improved accuracy, data from field tests are extensively being used to determine the liquefaction resistance of the ground. Over the years, several SPT- N-based methods were developed to assess the liquefaction resistance of sub-soils. Nevertheless, several studies reported the liquefaction potential of the soils without taking into consideration the field procedure corrections of standard penetration resistance (N), which may have a significant influence on the liquefaction evaluation. Hence, in the present study, the effect of SPT N field procedure corrections on the liquefaction resistance of the subsoil at the ten study areas selected along the coastline of Visakhapatnam is investigated. The Factor of Safety (FoS) against liquefaction is evaluated as per IS 1893 part 1(2016) and Idriss & Boulanger (2008) methods based on corrected and uncorrected standard penetration resistances and different input ground motions. The corresponding liquefaction potential indices (LPI) are determined from the Iwasaki *et al.* (1978) method to analyse the damage potential of the liquefaction. The study indicated that the field procedure corrections substantially affect the liquefaction resistance, as upon applying corrections to SPT N, the subsoil profiles at most study areas showed susceptibility to liquefaction, which are otherwise non-liquefiable.

KEYWORDS: Liquefaction, SPT N, Field procedure corrections, Factor of safety, and Liquefaction Potential Index.

1. INTRODUCTION

Earthquakes are the most unpredictable natural disasters that can cause enormous societal and economic devastation. Along with having severe repercussions, the enormous energy released by an earthquake spread as wavefronts and seriously harms civil engineering structures. Unquestionably, one of the most anticipated aftermaths of an earthquake is liquefaction, particularly at sites where silty sands and fine sands prevail with water table close to the ground surface, which poses real difficulties for civil engineers, particularly geotechnical engineers. Therefore, assessing the liquefaction potential of the subsoil will help in mitigating the detrimental effects of the liquefaction. Traditionally, laboratory tests such as cyclic shear and cyclic triaxial tests are used for evaluating the liquefaction potential. However, Casagrande (1976) emphasised that the radial redistribution of water content which results in the built-up of cyclic pore pressures and softening in test specimens of various cyclic tests and cyclic liquefaction in a cyclic triaxial test, is generated by a passive in-situ mechanism. Further, it is unlikely that a laboratory test can simulate the uniform stress distribution of cyclic loading in the test specimen. Peck (1979) also reported that laboratory tests fail to consider several factors that are likely to exist in the field. These drawbacks of the laboratory-based analysis have led to utilization of field data for a more precise evaluation of liquefaction potential. SPT has been in use since a long time and is regarded as one of the dependable methods for determining the liquefaction resistance of the soil. Standard penetration resistance is an indicative of the soil strength. Factors such as density, seismic loading and strain histories, over-consolidation ratio, lateral earth pressures etc., tend to directly or indirectly influence the standard penetration resistance and subsequently liquefaction resistance. However, the fines content allegedly have a direct effect on the liquefaction resistance and, therefore, must be accounted for.

After the Alaska and Niigata Earthquakes in 1964, engineers began to correlate SPT data with liquefaction resistance of the soils. Various empirical and semi empirical approaches based on N were developed for aiding the liquefaction studies. Seed (1978) developed the concept of cyclic stress ratio (CSR) to compensate for site conditions different from those in Niigata. Seed *et al.* (1983) compared the corrected SPT resistance and cyclic stress ratio for clean sand and silty sand sites at which liquefaction was observed due to earthquakes of magnitude 7.5 to determine the minimum cyclic stress ratio in clean sand. Chang *et al.* (2011) assessed the accuracy of several SPT N-based methods of evaluation of the liquefaction potential during the 1999 Chi-Chi earthquake in Taiwan. Seed *et al.* (1985) developed curves for determining the liquefaction resistance of the sand based on the SPT N value corrected for hammer energy. They reported that the developed curves produced more precise estimates of liquefaction potential compared to earlier methods. In recent times, studies on liquefaction potential of soils were carried out in parts of Thailand, Indonesia, Japan and Myanmar by Thay *et al.* (2013), Mase *et al.* (2018, 2019, 2020, 2022, 2023), and Sukkarak *et al*. (2021) through Cyclic Simple shear test, cyclic triaxial test, seismic down hole tests etc.

Since SPT being a widely used test in Visakhapatnam for subsurface investigation, the study intends to quantitively evaluate the liquefaction susceptibility of few selected areas along the coastal Visakhapatnam utilising the SPT data in SPT-N based liquefaction evaluation methods, the cyclic resistance ratio (CRR) or the liquefaction resistance of the subsoil is a function of N. Hence, any variation in the N value will affect the Factor of Safety (FoS) and Liquefaction Potential Index (LPI), thereby resulting in erroneous estimation of the liquefaction potential. Several inconsistencies may arise during the execution of SPT in the field. The corrections to incorporate these combined effects to the recorded N values are necessary to avoid any discrepancy in the evaluation of liquefaction potential. Hence, in the present study, the factor of safety and LPI are also evaluated by applying several filed procedure corrections, such as hammer energy, borehole diameter, sampler liner, rod length, etc., to the observed N values.

2. SUBSOIL PROFILE OF THE STUDY AREAS

In the present study, the liquefaction vulnerability of the ten study areas selected from the coastal Visakhapatnam, as shown in Figure 1, is evaluated. The study areas are specifically chosen as the predominance of saturated fine sand and silty sand at shallow depths in these areas makes them highly susceptible to liquefaction in events of dynamic loading. Hence, assessing the safety factor against liquefaction can help safeguard the infrastructure in these areas.

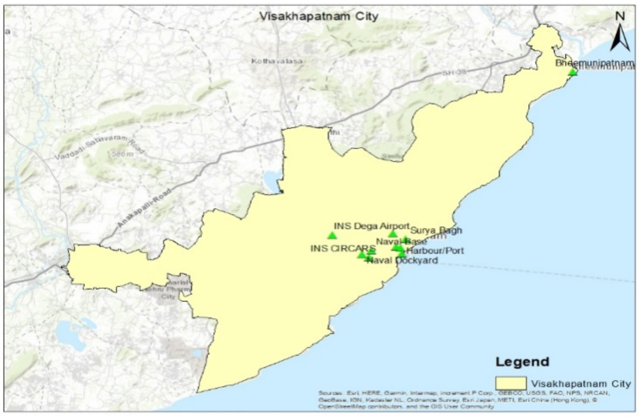

Figure 1 Typical borehole locations of the study areas in Visakhapatnam

The subsoil profile at the areas considered under study is briefly summarized below.

Study Area 1 (Naval Base): The site's subsoil is characterised by a thick deposit of potentially liquefiable fine to medium silty sand extending to a depth of 12m and underlain with medium to stiff clay supported over soft disintegrated Rock (SDR). The average observed N vary from 1 to 16 along the depth. The groundwater table is observed at the ground level.

Study Area 2 (Naval dock yard): Filled-up soil, medium to fine sand prevailing over clay with very soft to medium consistency, and soft disintegrated rock (SDR) form the subsoil profile of the area. The average SPT N along the depth ranges from 6 to 19. The water table at the location is 1.2m below the natural ground level.

Study Area 3 (Harbour port): The subsoil in the area has an average SPT N value between 2 and 10 and primarily comprises filled-up soil, silty sand, soft marine clay and SDR with water table at the ground surface.

Study Area 4 (Sea Horse Junction-Port Area): The area has a predominant prevalence of filled-up soil, silty sand and soft marine clay with N values ranging from 2 to 12m and groundwater table at 2.2m.

Study Area 5 (AKP Crossing- Convent Junction): The SA 5 has a 3.5 m thick medium dense silty fine sand deposit with recorded N values of 13 and 15 at depths of 3 and 4.5 m, respectively. Hard rock with high core recovery and fairly good RQD occurs at a shallow depth of 6.5 m and extends to a greater depth. The borelog is terminated at a depth of 9.5 m, and the water table at the location is encountered at 4 m.

Study Area 6 (Town Kotha Road-Jagadamba): 3m thick loose fine sand with low SPT N values, overlain by 1m thick clayey sand, 3.5m thick soft marine clay, and silty fine sand, constitute the subsoil profile of the area. The borehole is terminated in a silty fine sand stratum at 12.5m depth, and the water table is present at 2.1m below the ground level.

Study Area 7 (INS Dega Airport-NAD): The subsoil profile comprises of filled-up soil, silty sand, sandy clay/silty clay, silty fine sands, and soft clay, with N values ranging from 2 to 5, and a ground water table at 0.5m below ground level.

Study Area 8 (Bheemunipatnam): Filled-up soils, silty sand, coarse sand, and stiff brown sandy clay characterize the general subsoil strata at the location. The groundwater table lies 1.8 meters below ground level, and the N values along the profile vary from 7 to 18.

Study Area 9 (Suryabagh): The subsoil strata of the area is composed of filled-up material, fine sand, soft clay, silty sand, clayey gravel and SDR. The N values along the strata range between 3 and 19. The groundwater table is encountered at 2.2 m below ground level.

Study Area 10 (INS Circar): The subsoil profile consisted of filled-up material, fine sand, soft to medium clay, stiff clay, clayey gravel and SDR. The N values range from 6 to 16 along the profile, and the groundwater table is encountered at 0.5m below ground level.

The index properties of the liquefaction susceptible stratum at the considered study areas are tabulated in Table 1.

Table 1 Geotechnical properties of the liquefiable layers at the study areas

Property	SA-1	SA-2	SA-3	SA-4	SA-5	SA-6	SA-7	SA-8	SA-9	SA-10
Grainsize distribution										
Gravel (%)	1	0	0	0	0	3	0	0	0	0
Sand (%)	96	95	85	83	85	87	85	77	94	92
Fines (%)	3	5	15	17	15	10	15	23	6	8
Bulk density (g/cc)	1.83	1.98	2.03	1.75	1.74	1.92	1.75	1.96	1.73	1.92
Natural Moisture content (%)	9.2	8.5	15.2	10	9	20	8.5	24	11.8	17.2
IS classification	SP	SP	SM	SM	SM	SM	SM	SM	SP	SP-SM

3. SPT N - FIELD PROCEDURE CORRECTIONS

In order to account the discrepancy in the N value contributed from various factors that hamper the accurate execution of the Standard penetration tests in the field, the observed N value is subjected to several corrections. IS 2131 (1981) recommends only overburden correction and dilatancy corrections. However, IS 1893 Part 1 (2016) and Idriss & Boulanger (2008) methods recommends the following formula for computing the corrected N value for evaluating the cyclic resistance ratio.

$$N_{60} = N\,C_{60} \tag{1}$$

$$C_{60} = C_N\,C_{HT}\,C_{HW}\,C_{ss}\,C_{RL}C_{BH}$$

where,

C_{HT} = Correction for Hammer energy
C_{HW} = Correction for fall of the hammer
C_{ss} = Correction for sampler tube or liner
C_{RL} = Correction for Rod length
C_{BH} = borehole diameter correction factor
C_N = Overburden correction factor
N = Observed standard penetration resistance

By far the most important correction to be made to N is for the energy delivered to the drill rods. The energy delivered from the hammer depends on the way the hammer is lifted and released, and on the design of the hammer. The energy imparted to the SPT sampler through the drill rods was considered 60% of the theoretical free fall energy. The SPT test in India is conducted considering the energy transfer to the drill rod is about 60% and hence, C_{60} is taken as 1.0. As per the SPT test requirements given in IS 1893 part-1, 2016, two wraps of rope around the pulley and blow count rates of 30–40 blows per minute are recommended which is not adopted in most parts of India. Normally, SPT is carried out manually using unskilled labours with more wraps of rope and also, the rate of low count is less than 15 blows per minute and so, adoption of C_{60} as unity is incorrect. Hence, it is required to apply the correction factors for non-standard SPT procedures and equipment individually as mentioned in C_{60}. The energy available to drive the sampling tube into the ground is reduced when drill rods with shorter lengths are employed; as a result, the N values must be adjusted for the short lengths of the rods. The friction developed inside the sampling tube will be lowered when samplers without liners are used in SPT, resulting in a reduction in the measured N values. According to the literature, the lack of liners might cause N values to drop by 10% to 30%. Further, it is envisaged that the observed SPT N values require a correction if the tests are performed in boreholes of larger diameter.

The standard penetration tests at all the study areas are performed using a doughnut hammer weighing 63.5kg whose free fall is operated by a rope and pulley mechanism. The tests are conducted at every 1.5m depth in a borehole of 150mm diameter using an SPT sampler without a liner. Therefore, the recorded N values are accordingly corrected using the IS 1893 (2016) recommended correction factors listed in Table 2. The values of the various correction factors used in the study and the corresponding corrected values of N are presented in Table 3.

Table 2 Correction factors for Non-Standard Procedures and Equipment as per IS 1893 part 1 (2016)

SI No. (1)	Correction parameter (2)	Value (3)
i)	Non-standard hammer weight or height of fall	C_{HT} = 0.75 (for Donut hammer with rope and pulley) 1.33(for Donut hammer with trip/auto) and Energy Ratio = 80
ii)	Non-standard hammer weight or height of fall	$C_{HW}=\frac{HW}{48387}$ Where, H = height of fall (mm), and W = hammer weight (kg)
iii)	Non-standard sampler setup (standard samples with room for liners, but used without liners)	C_{SS} = 1.1 (for loose sand) 1.2 (for dense sand)
iv)	Non-standard sampler setup (standard samples with room for liners, but liners are used)	C_{SS} = 0.9 (for loose sand) 0.8 (for dense sand)
v)	Short rod length	C_{RL} = 0.75 (for rod length 0-3 m) = 0.80 (for rod length 3-4 m) = 0.85 (for rod length 4-6 m) = 0.95 (for rod length 6-10 m) = 1.0 (for rod length 10-30 m)
vi)	Non-standard bore hole diameter	C_{BD} = 1.00 (for bore hole diameter of 65-115 mm) = 1.05 (for bore hole diameter of 150 mm) = 1.15 (for bore hole diameter of 200 mm)

Table 3 Field procedure corrections and the corresponding corrected N values of the study areas

Study Area	Type of soil	Depth (m)	N	C_{HT}	C_{HW}	C_{SS}	C_{RL}	C_{BD}	C_{60}	$N_{60} = N*C_{60}$
SA-1	Silty fine sand	3	**5**	0.75	0.984	1.1	0.75	1.05	0.639	**3**
	Silty fine sand	4.5	**7**	0.75	0.984	1.1	0.85	1.05	0.725	**5**
	Silty fine sand	6	**14**	0.75	0.984	1.1	0.85	1.05	0.725	**10**
	Silty fine sand	7.5	**12**	0.75	0.984	1.1	0.95	1.05	0.810	**9**
	Silty fine sand	9	**12**	0.75	0.984	1.1	0.95	1.05	0.810	**9**
	Silty fine sand	10.5	**11**	0.75	0.984	1.1	1	1.05	0.852	**9**
	Silty fine sand	12	**14**	0.75	0.984	1.1	1	1.05	0.852	**11**
SA-2	Fine to medium sand	3	**9**	0.75	0.984	1.1	0.75	1.05	0.639	**6**
	Fine to medium sand	4.5	**10**	0.75	0.984	1.1	0.85	1.05	0.725	**7**
	Fine to medium sand	6	**15**	0.75	0.984	1.1	0.85	1.05	0.725	**11**
SA-3	Silty sand	2	**8**	0.75	0.984	1.1	0.75	1.05	0.639	**5**
	Silty sand	3.5	**10**	0.75	0.984	1.1	0.8	1.05	0.682	**7**
SA-4	Silty fine sand	3.5	**8**	0.75	0.984	1.1	0.8	1.05	0.682	**5**
	Silty fine sand	5	**11**	0.75	0.984	1.1	0.85	1.05	0.725	**8**
	Silty fine sand	6.5	**12**	0.75	0.984	1.1	0.95	1.05	0.810	**10**
SA-5	Silty fine sand	3.5	**8**	0.75	0.984	1.1	0.8	1.05	0.682	**5**
	Silty fine sand	5	**11**	0.75	0.984	1.1	0.85	1.05	0.725	**8**
	Silty fine sand	6.5	**12**	0.75	0.984	1.1	0.95	1.05	0.810	**10**
SA-6	Silty fine sand	3	**13**	0.75	0.984	1.1	0.75	1.05	0.639	**8**
	Silty fine sand	4.5	**15**	0.75	0.984	1.1	0.85	1.05	0.725	**11**
SA-7	Silty sand	1.5	**2**	0.75	0.984	1.1	0.75	1.05	0.639	**1**
	Silty sand	2.5	**4**	0.75	0.984	1.1	0.75	1.05	0.639	**3**
	Silty sand	4.5	**4**	0.75	0.984	1.1	0.85	1.05	0.725	**3**
SA-8	Silty sand	3	**11**	0.75	0.984	1.1	0.75	1.05	0.639	**7**
	Silty sand	4.5	**10**	0.75	0.984	1.1	0.85	1.05	0.725	**7**
	Silty sand	6	**7**	0.75	0.984	1.1	0.85	1.05	0.725	**5**
	Coarse sand	8	**9**	0.75	0.984	1.1	0.95	1.05	0.810	**7**
	Coarse sand	10	**12**	0.75	0.984	1.1	0.95	1.05	0.810	**10**
SA-9	Fine sand	1.5	**12**	0.75	0.984	1.1	0.75	1.05	0.639	**8**
	Fine sand	3	**18**	0.75	0.984	1.1	0.75	1.05	0.639	**12**
	Fine sand	4	**3**	0.75	0.984	1.1	0.8	1.05	0.682	**2**
	Silty sand	6	**19**	0.75	0.984	1.1	0.85	1.05	0.725	**14**
SA-10	Fine sand	1.5	**7**	0.75	0.984	1.1	0.75	1.05	0.639	**4**
	Fine sand	3	**6**	0.75	0.984	1.1	0.75	1.05	0.639	**4**
	Fine sand	4.5	**7**	0.75	0.984	1.1	0.85	1.05	0.725	**5**
	Fine sand	6	**7**	0.75	0.984	1.1	0.85	1.05	0.725	**5**
	Fine sand	7.5	**8**	0.75	0.984	1.1	0.95	1.05	0.810	**6**

4. EVALUATION OF LIQUEFACTION ANALYSIS OF THE SUBSOIL AT THE STUDY AREAS

The liquefaction potential of the subsoil can be evaluated from several cyclic strain, cyclic stress and energy-based methods, standard blasting tests and ground response analysis. Each method has advantages and limitations, and the choice of the method of analysis to use depends on the site conditions, available data and accuracy required. However, the most widely used method is stress-based analysis using the empirical correlations developed from field data case histories such as SPT N. These empirical correlations estimate the soil's cyclic resistance ratio (CRR) and cyclic stress ratio (CSR). The CRR is a measure of the resistance of the ground to liquefaction under cyclic loading, while the CSR is a measure of the cyclic loading induced by an earthquake.

The liquefaction potential of the soil is indicated in terms of a factor of safety (FoS) defined as the ratio of CRR to CSR.

$$FOS = \frac{CRR}{CSR} \quad (2)$$

The subsoil will be most likely to liquefy if the FoS is less than one. If the safety factor equals one, it represents the limit state, and further analysis or investigation is required. This method of analysis is relatively simple, fast and economical compared to other methods.

Visakhapatnam, located on the eastern coast of peninsular India, lies in Zone II of the seismic zoning map of India. The city could experience low to moderate earthquakes. The city has a history of experiencing tremors due to earthquakes of magnitude 5.0 that resulted in noticeable damage to the structures. (ASC, 2023). The seismicity of Visakhapatnam is governed by the geology of the city. Mainly, with the coastal parts of the city having expanses of saturated silty sands and fine sands, they are likely to be susceptible to liquefaction under the dynamic loading that can result in a considerable loss of life and property. Therefore, it is necessary to assess the liquefaction potential to mitigate the losses. In the present study, the factors of safety against liquefaction are evaluated using IS 1893 part 1 (2016) and Idriss & Boulanger (2008) methods. The liquefaction potential is also evaluated for seismic loadings corresponding to higher seismic zones (i.e., for Zone III, IV and VX, as the study can serve as a reference to assess the liquefaction susceptibility of similar subsoil profiles in highly seismically active regions.

4.1 IS 1893 Part 1 (2016) Method

The IS method is based on the studies performed by Seed and Idriss (1971). The method assumes that the soil layer is homogeneous and isotropic and renders the liquefaction potential based on standard penetration resistance (N). The cyclic stress ratio (CSR) represents the imposed loading due to the earthquake and is directly proportional to the surface peak ground acceleration. In the non-availability of acceleration data, IS 1893 recommends the use of zone factors as peak ground acceleration in the computation of CSR. The present study utilizes the corresponding zone factors as the input ground motion. The CSR for each soil layer is calculated using the following formula:

$$CSR = 0.65\left({a_{max}}/{g}\right) \times \left({\sigma_v}/{\sigma_v'}\right) \times r_d \quad (3)$$

where,

r_d = Stress reduction factor

= 1-0.00765Z for $0 < Z < 9.75$

= 1.174 – 0.0267 Z for $9.75 < Z < 20$

The dimensionless reduction factor r_d accounts for the non-rigid response of the subsoil strata to the input ground motion.

The Cyclic Resistance Ratio (CRR) is calculated based on the standard penetration resistance values obtained after adjusting the field values for various corrections. The CRR for a magnitude of 7.5 corresponding to different N values and percentage of fines is obtained from Figure 2. The cyclic resistance ratio for magnitudes other than 7.5 is calculated by multiplying the CRR at 7.5 by magnitude scaling factor (MSF). The following equations are used in computing the resistance of the soil against liquefaction.

$$(N_1)_{60} = C_N C_{60} N \quad (4)$$

$C_N = (Pa/\ \sigma_v')^{0.5} \leq 1.7$

σ_v' is the effective overburden pressure.
Corresponding to the value of $(N_1)_{60}$, the value of $CRR_{7.5}$ is obtained.

$$CRR = CRR_{7.5} \times MSF \times K_\sigma K_{\sigma'} \quad (5)$$

where,

$$CRR_{7.5} = \frac{1}{34 - (N_1)_{60}CS} - \frac{(N_1)_{60}CS}{135} + \frac{50}{[10 \times (N_1)_{60}CS + 45]^2} - \frac{1}{200}$$

$(N_1)_{60}CS = \alpha + \beta(N_1)_{60}$ (α and β are based on % fines and which is given in IS1893 Part-1, 2016)

MSF = Magnitude scaling factor
= $10^{2.24} / M_w^{2.56}$
K_σ is the correction for high overburden pressure, required for depths greater than 15m.
$K_\sigma = (\sigma_v'/ P_a)^{(f-1)}$, f is a factor which depends on the relative density of the soil.
K_α is the correction for static shear stresses and required only for sloping grounds. For plain grounds, its value is taken as one. Since the terrain of the selected study areas is almost plain, K_α is considered as one in the present analysis.

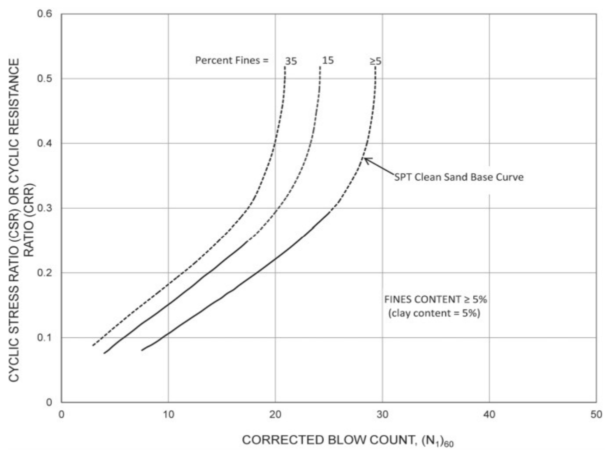

Figure 2 Relation between CRR and $(N_1)_{60}$ for an earthquake of magnitude 7.5 (IS1893 Part 1 2016)

4.2 Idriss & Boulanger (2008) Method

This method is a modified version of the seed and Idriss (1971) method in which the soil stratum is considered to be homogeneous and isotropic. This method incorporates the affects of various factors influencing the liquefaction potential of the soil such as earthquake magnitude and duration, soil properties and profile, overburden pressure, depth of water table, fines content and age of the deposit. The Idriss & Boulanger (2008) method is a semi empirical procedure that utilises the standard penetration resistances for evaluating the liquefaction potential of the ground. In this method the CSR varies with the magnitude of the earthquake as the stress reduction factor is a function of earthquake magnitude. Because the case histories in the database were predominantly located in shallow crustal active tectonic regimes, r_d is generally expressed as a function of depth and magnitude. The CSR from Idriss & Boulanger (2008) method is evaluated as

$$CSR = 0.65\left({a_{max}}/{g}\right) \times \left({\sigma_v}/{\sigma_v'}\right) \times r_d \quad (6)$$

where,

$r_d = \text{Exp}\ [\ \alpha(Z) + \beta(Z)\ M]$

$\alpha(Z) = -1.012 - 1.126 \sin\left[\ \frac{Z}{11.73} + 5.133\ \right]$

$\beta(Z) = 0.106 + 0.118 \sin\left[\frac{Z}{11.73} + 5.142\ \right]$

The cyclic resistance ratio (CRR) is determined for each soil layer using the SPT N based empirical correlation derived from the database of case histories. The following equations proposed by Idriss & Boulanger (2008) are used for the evaluation of factors of safety.

$$(N_1)_{60}CS = C_N C_{60} (N_1)_{60} \quad (7)$$

$C_N = (P_a/\ \sigma_v')^m \leq 1.7$

where,

$m = 0.784 - 0.076\sqrt{(N_1)_{60}}$

$$CRR_{M} = 7.5, \sigma_v' = 1\ \text{atm} = \exp\left[\frac{(N1)60cs}{14.1} + \left(\frac{(N1)60cs}{126}\right)^2 - \left(\frac{(N1)60cs}{23.6}\right)^3 + \left(\frac{(N1)60cs}{25.4}\right)^4 - 2.8\right] \quad (8)$$

$MSF = 6.9 \exp(-M/4) - 0.058 \leq 1.8$

where,

$(N_1)_{60cs}$ is the corrected standard penetration resistance.

4.3 Liquefaction Potential Index (LPI) using Iwasaki *et al.* (1978) Method

The liquefaction susceptibility of the subsoil at a site can be estimated using the factor of safety against liquefaction. However, the damage potential of liquefaction cannot be assessed solely on the basis of FoS. Hence liquefaction potential index is evaluated for assessing extent of hazard that is likely to result from liquefaction of subsoil. Liquefaction potential index (LPI) is a parameter that measures the severity of liquefaction in a soil layer due to an earthquake. LPI is calculated by summing the product of three factors: the thickness of the soil layer, the depth factor, and the liquefaction factor. The thickness of the soil layer is the vertical distance between two consecutive sampling points. The depth factor is a function of the depth from the ground surface to the mid-point of the soil layer. The liquefaction factor is a function of the factor of safety (FoS) or the probability of liquefaction of the soil layer.

LPI can be calculated using the data from shear wave velocities, standard penetration tests and cone penetration tests. LPI can be used to assess the severity of the liquefaction at a site by comparing it with some threshold values. Iwasaki *et al.* (1978) who introduced the concept of liquefaction potential index proposed that the liquefaction risk is very low if LPI = 0; low if $0 < LPI \leq 5$; high if $5 < LPI \leq 15$; and very high if $LPI > 15$. The following formula proposed by Iwasaki *et al.* has been used for evaluating the liquefaction potential indices of the study areas.

$$LPI = \int_0^{20} F(Z)W(Z)dz \quad (9)$$

where, $F(Z) = 1 - FOS$ for $FOS < 1$

$F(Z) = 0$ for $FOS > 1$

$W(Z) = 10 - 0.5Z$ for $Z < 20$ m

$W(Z) = 0$ for $Z > 20$m

5. RESULTS AND DISCUSSIONS

The factors of safety against liquefaction of the sub soil profile at the study areas calculated from IS 1893 part 1 (2016) and Idriss & Boulanger (2008) methods using uncorrected and corrected penetration resistances are tabulated in Tables 4 to 7. From the tables, it is observed that for the most of the study areas, the factor of safety obtained from the Idriss & Boulanger method (2008) are comparatively higher than those determined from IS 1893-part 1 (2016) method**.** The FoS against liquefaction obtained from the deterministic analysis based on uncorrected SPT values indicate that all the study areas are safe against liquefaction under an earthquake of magnitude five and PGA 0.1g. This suggests that the regions considered in the study are non-liquefiable under an earthquake magnitude of 5. This complements the fact that the city despite experiencing earthquakes of magnitude 5, hasn't reported any case histories of liquefaction. However, for a PGA of 0.36g, all the study areas indicated risk against liquefaction even under an earthquake of magnitude 5. This indirectly presumes that the similar subsoil profiles, if exist in zone V of India, would liquefy even under a magnitude of 5. Study areas 7 and 9 yielded FoS of less than one under earthquake of magnitude greater than five and PGA higher than 0.1g. Areas in zone IV with subsoil profiles similar to those prevailing in the considered study areas are anticipated to liquefy under earthquakes of magnitude ≥ 5.5. The factor of safety obtained using corrected SPT N values also indicated that all the considered study areas are safe against liquefaction under earthquakes of magnitude 5 and PGA 0.1g, while are considered liquefiable for PGA ≥ 0.36g. The values obtained from the uncorrected SPT N values are found to be approximately 30-40% higher than those obtained from N corrected for field procedures. Further it is noticed that upon using corrected N values, the subsoil profiles at most study areas exhibited susceptibility to liquefaction, which are otherwise non-liquefiable. This clearly indicates the influence of the SPT N corrections for field procedures on the liquefaction potential of the selected study areas.

Liquefaction Potential Indices of the ten study areas evaluated from Iwasaki *et al.* (1978) method using uncorrected and corrected SPT N values are presented in Tables 8 to 11. The probable liquefiable stratum at the ten study areas under study indicated low and high damage potential due to liquefaction under seismic loading corresponding to zone II and zones III respectively. However, for higher seismic loading (i.e., for seismic zones IV and V) and earthquake of magnitudes higher than 6, the subsoil stratum at the study areas is found to show very high damage potential due to liquefaction**.** Further, the use of SPT N correction factors is found to result in large variations of Liquefaction Potential Indices when compared with the LPI evaluated from uncorrected N. The present study has compared with some other studies at different regions across the world. S. Thay *et al.* (2013). Mase *et al.* (2018) Qodri *et al.* (2021) and Likitlersuang *et al.* (2020) have conducted liquefaction evaluation studies in south East Asian regions and concluded that field studies data plays pivotal role in evaluating the liquefaction potential of soils.

The variations of factor of safety (FS) with depth for all study areas under earthquake magnitude of 5 and for Zone 2 condition is plotted and are presented in Figure 3 to 12, for better understanding of the effect of field procedure corrections of SPT-N value on liquefaction evaluation.

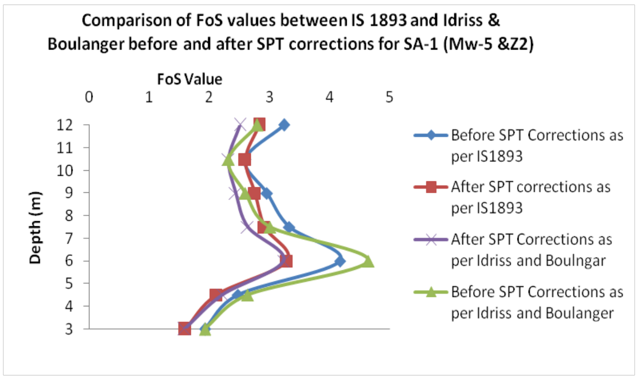

Figure 3 Variations of FoS with depth for SA-1

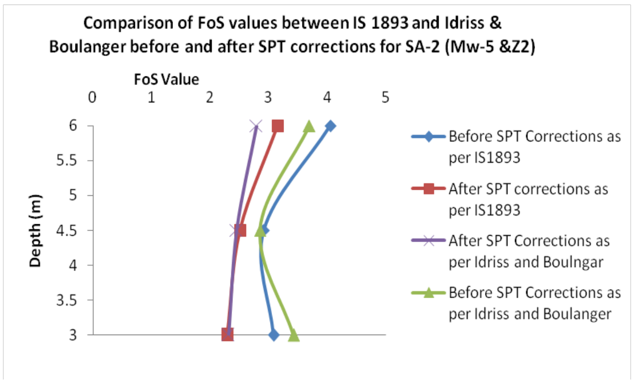

Figure 4 Variations of FoS with depth for SA-2

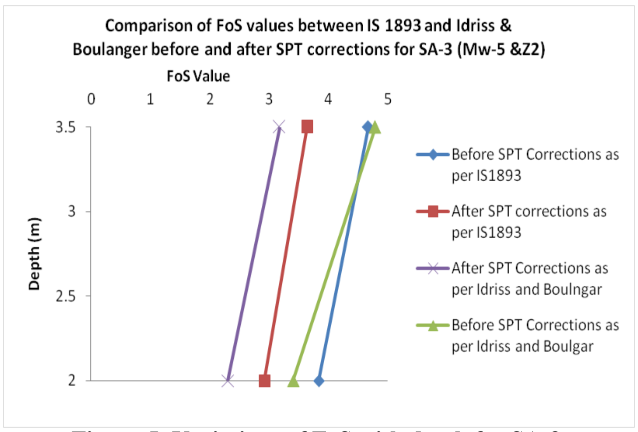

Figure 5 Variations of FoS with depth for SA-3

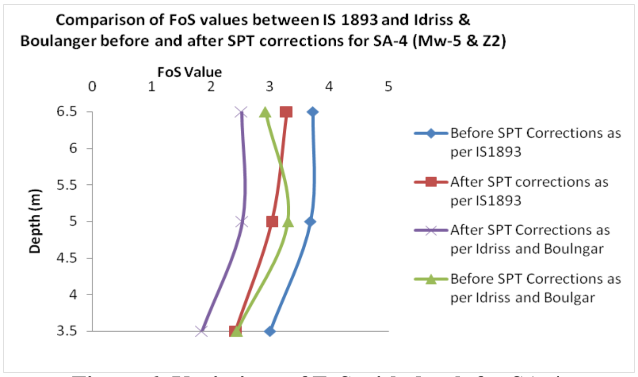

Figure 6 Variations of FoS with depth for SA-4

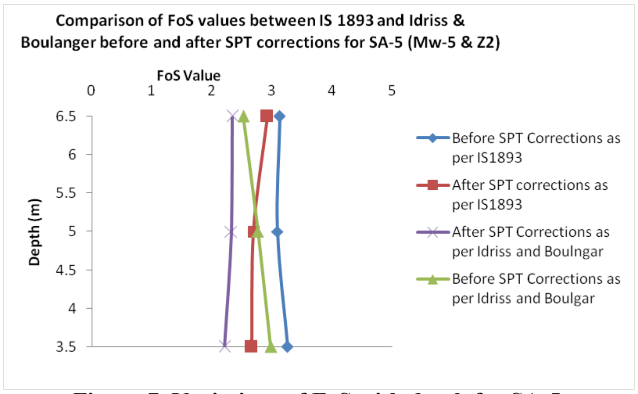

Figure 7 Variations of FoS with depth for SA-5

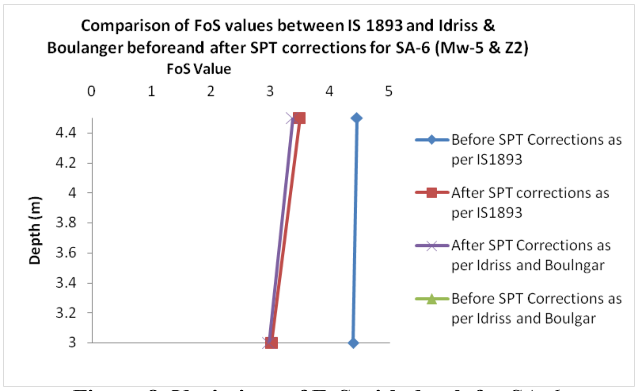

Figure 8 Variations of FoS with depth for SA-6

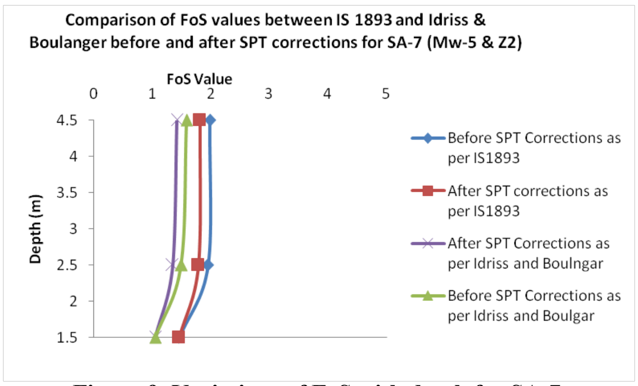

Figure 9 Variations of FoS with depth for SA-7

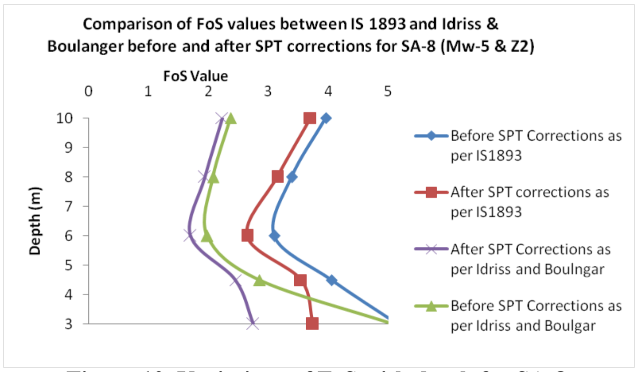

Figure 10 Variations of FoS with depth for SA-8

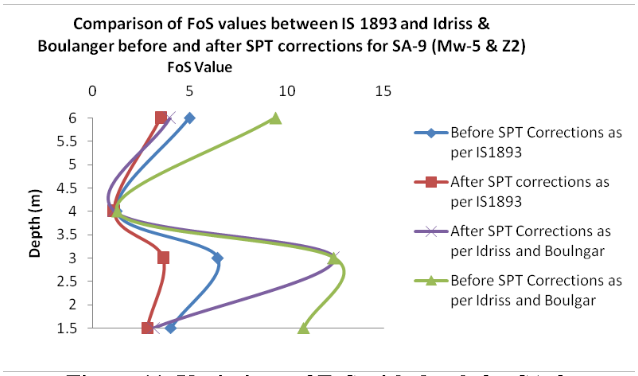

Figure 11 Variations of FoS with depth for SA-9

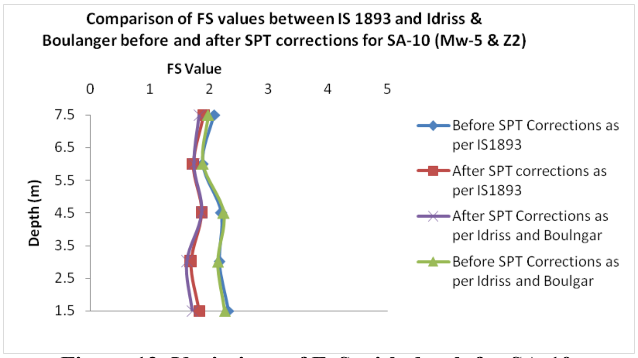

Figure 12 Variations of FoS with depth for SA-10

6. CONCLUSIONS

Based on the analysis of the liquefaction potential and the liquefaction potential indices determined from the respective deterministic approaches based on corrected and uncorrected N values and different input ground motions, the following conclusions are drawn.

1. The FoS against liquefaction determined using N values corrected for field procedures are lower by 30 – 40% compared to the FoS evaluated from uncorrected N values.
2. The factors of safety obtained from Idriss & Boulanger's (2008) method are higher than those obtained from IS 1893 part 1 (2016). Hence, Idriss & Boulanger's (2008) method is more conservative.
3. The study areas considered along the coastline of Visakhapatnam are safe against liquefaction under the present seismic loading corresponding to zone 2 for earthquakes of magnitude 5.
4. The subsoil profiles of the study areas, if present in seismic Zones V, are vulnerable to liquefaction even under earthquakes of magnitude 5.
5. The variation of results with and without field procedure corrections of SPT N values at study area 7 is almost negligible due to lesser values of measured SPT N values. Hence, the influence of correction factors on factor of safety and LPI are not remarkable if measured SPT N values are less than 5.
6. Sub soil profiles of all study areas, if present in seismic Zone 4 and 5 will be at very high risks of liquefaction under earthquakes of magnitudes up to 6.5while those in seismic Zones 3 and 2 will have moderate/high to low risk respectively.
7. LPI values based on N values corrected for field procedures are determined to be moderate to very high for all the study areas, signifying very high damage potential of liquefaction in higher seismic zones.

Hence For more precise evaluation of the liquefaction potential based on SPT, it is necessary to apply all the field procedure corrections to the observed N values.

7. APPLICATION AND LIMITATION OF THE STUDY

As the liquefaction potential evaluation of the soil is generally carried out based on SPT-N values, the present study highlighted the need for use of field procedure corrected N values for better evaluation of liquefaction potential of sub soil strata. Non application of the field procedure corrections underestimates the liquefaction potential of subsoil.

However, the measured standard penetration resistances values are affected by the degree of the disturbance caused at the bottom of the borehole during the boring operations and rate of application of blows. Therefore, the values of FoS and LPI at a site may be marginally affected based on boring method and the type of hammer employed during the execution of the test in the field.

Table 4 Factors of Safety against Liquefaction from IS 1893 Part 1 2016 method based on uncorrected N values

Earthquake Magnitude			**5**				**5.5**				**6**				**6.5**			
Study Area	**Depth**	**(N1)60**	**Z2**	**Z3**	**Z4**	**Z5**	**Z2**	**Z3**	**Z4**	**Z5**	**Z2**	**Z3**	**Z4**	**Z5**	**Z2**	**Z3**	**Z4**	**Z5**
SA-1	3	**8**	1.93	1.20	0.80	0.54	1.51	0.94	0.63	0.42	1.21	0.76	0.50	0.34	0.98	0.62	0.41	0.27
	4.5	**11**	2.48	1.55	1.03	0.69	1.94	1.21	0.81	0.54	1.55	0.97	0.65	0.43	1.27	0.79	0.53	0.35
	6	**19**	4.17	2.61	1.74	1.16	3.27	2.04	1.36	0.91	2.62	1.64	1.09	0.73	2.13	1.33	0.89	0.59
	7.5	**15**	3.33	2.08	1.39	0.92	2.61	1.63	1.09	0.72	2.09	1.30	0.87	0.58	1.70	1.06	0.71	0.47
	9	**13**	2.96	1.85	1.23	0.82	2.32	1.45	0.97	0.64	1.86	1.16	0.77	0.52	1.51	0.95	0.63	0.42
	10.5	**11**	2.60	1.63	1.08	0.72	2.04	1.27	0.85	0.57	1.63	1.02	0.68	0.45	1.33	0.83	0.55	0.37
	12	**14**	3.24	2.03	1.35	0.90	2.54	1.59	1.06	0.71	2.03	1.27	0.85	0.56	1.66	1.04	0.69	0.46
SA-2	3	**13**	3.08	1.92	1.28	0.86	2.41	1.51	1.01	0.67	1.93	1.21	0.80	0.54	1.57	0.98	0.66	0.44
	4.5	**12**	2.91	1.82	1.21	0.81	2.28	1.42	0.95	0.63	1.82	1.14	0.76	0.51	1.49	0.93	0.62	0.41
	6	**17**	4.05	2.53	1.69	1.13	3.18	1.99	1.32	0.88	2.54	1.59	1.06	0.71	2.07	1.29	0.86	0.58
SA-3	2	**13**	3.84	2.40	1.60	1.07	3.01	1.88	1.25	0.84	2.41	1.50	1.00	0.67	1.96	1.23	0.82	0.54
	3.5	**16**	4.67	2.92	1.95	1.30	3.66	2.29	1.53	1.02	2.93	1.83	1.22	0.81	2.39	1.49	1.00	0.66
SA -4	3.5	**11**	3.00	1.87	1.25	0.83	2.35	1.47	0.98	0.65	1.88	1.17	0.78	0.52	1.53	0.96	0.64	0.43
	5	**14**	3.68	2.30	1.53	1.02	2.88	1.80	1.20	0.80	2.31	1.44	0.96	0.64	1.88	1.17	0.78	0.52
	6.5	**14**	3.72	2.33	1.55	1.03	2.92	1.82	1.22	0.81	2.34	1.46	0.97	0.65	1.90	1.19	0.79	0.53
SA-5	3.5	**13**	3.26	2.03	1.36	0.90	2.55	1.59	1.06	0.71	2.04	1.28	0.85	0.57	1.66	1.04	0.69	0.46
	5	**12**	3.09	1.93	1.29	0.86	2.42	1.51	1.01	0.67	1.94	1.21	0.81	0.54	1.58	0.99	0.66	0.44
	6.5	**12**	3.13	1.95	1.30	0.87	2.45	1.53	1.02	0.68	1.96	1.22	0.82	0.54	1.60	1.00	0.67	0.44
SA-6	3	**18**	4.39	2.75	1.83	1.22	3.44	2.15	1.43	0.96	2.76	1.72	1.15	0.77	2.25	1.40	0.94	0.62
	4.5	**18**	4.45	2.78	1.85	1.24	3.48	2.18	1.45	0.97	2.79	1.74	1.16	0.77	2.27	1.42	0.95	0.63
SA-7	1.5	**3**	1.45	0.91	0.60	0.40	1.13	0.71	0.47	0.32	0.91	0.57	0.38	0.25	0.74	0.46	0.31	0.21
	2.5	**6**	1.95	1.22	0.81	0.54	1.52	0.95	0.64	0.42	1.22	0.76	0.51	0.34	0.99	0.62	0.41	0.28
	4.5	**6**	1.98	1.24	0.82	0.55	1.55	0.97	0.65	0.43	1.24	0.77	0.52	0.34	1.01	0.63	0.42	0.28
SA-8	3	**16**	5.16	3.23	2.15	1.43	4.05	2.53	1.69	1.12	3.24	2.02	1.35	0.90	2.64	1.65	1.10	0.73
	4.5	**12**	4.05	2.53	1.69	1.12	3.17	1.98	1.32	0.88	2.54	1.59	1.06	0.70	2.07	1.29	0.86	0.57
	6	**8**	3.10	1.94	1.29	0.86	2.43	1.52	1.01	0.68	1.95	1.22	0.81	0.54	1.59	0.99	0.66	0.44
	8	**9**	3.39	2.12	1.41	0.94	2.66	1.66	1.11	0.74	2.13	1.33	0.89	0.59	1.73	1.08	0.72	0.48
	10	**11**	3.96	2.48	1.65	1.10	3.10	1.94	1.29	0.86	2.48	1.55	1.03	0.69	2.02	1.26	0.84	0.56
SA-9	1.5	**20**	4.02	2.51	1.68	1.12	3.15	1.97	1.31	0.88	2.52	1.58	1.05	0.70	2.05	1.28	0.86	0.57
	3	**27**	6.43	4.02	2.68	1.79	5.04	3.15	2.10	1.40	4.03	2.52	1.68	1.12	3.28	2.05	1.37	0.91
	4	**4**	1.23	0.77	0.51	0.34	0.97	0.60	0.40	0.27	0.77	0.48	0.32	0.21	0.63	0.39	0.26	0.17
	6	**23**	4.98	3.11	2.07	1.38	3.90	2.44	1.62	1.08	3.12	1.95	1.30	0.87	2.54	1.59	1.06	0.71
SA-10	1.5	**11**	2.32	1.45	0.97	0.64	1.82	1.13	0.76	0.50	1.45	0.91	0.61	0.40	1.18	0.74	0.49	0.33
	3	**10**	2.17	1.36	0.91	0.60	1.70	1.06	0.71	0.47	1.36	0.85	0.57	0.38	1.11	0.69	0.46	0.31
	4.5	**10**	2.20	1.38	0.92	0.61	1.72	1.08	0.72	0.48	1.38	0.86	0.57	0.38	1.12	0.70	0.47	0.31
	6	**8**	1.89	1.18	0.79	0.53	1.48	0.93	0.62	0.41	1.19	0.74	0.49	0.33	0.97	0.60	0.40	0.27
	7.5	**9**	2.08	1.30	0.87	0.58	1.63	1.02	0.68	0.45	1.31	0.82	0.54	0.36	1.06	0.66	0.44	0.30

Table 5 Factors of Safety against Liquefaction from IS 1893 Part 1 (2016) method based on N values corrected for non-standard field procedures

Earthquake Magnitude			**5**				**5.5**				**6**				**6.5**			
Study Area	**Depth**	**(N1)60**	**Z2**	**Z3**	**Z4**	**Z5**	**Z2**	**Z3**	**Z4**	**Z5**	**Z2**	**Z3**	**Z4**	**Z5**	**Z2**	**Z3**	**Z4**	**Z5**
SA-1	3	**6**	1.60	1.00	0.67	0.44	1.26	0.78	0.52	0.35	1.00	0.63	0.42	0.28	0.82	0.51	0.34	0.23
	4.5	**9**	2.12	1.33	0.88	0.59	1.66	1.04	0.69	0.46	1.33	0.83	0.55	0.37	1.08	0.68	0.45	0.30
	6	**15**	3.29	2.06	1.37	0.91	2.58	1.61	1.07	0.72	2.06	1.29	0.86	0.57	1.68	1.05	0.70	0.47
	7.5	**13**	2.92	1.83	1.22	0.81	2.29	1.43	0.95	0.64	1.83	1.15	0.76	0.51	1.49	0.93	0.62	0.41
	9	**12**	2.76	1.73	1.15	0.77	2.17	1.35	0.90	0.60	1.73	1.08	0.72	0.48	1.41	0.88	0.59	0.39
	10.5	**11**	2.60	1.63	1.08	0.72	2.04	1.27	0.85	0.57	1.63	1.02	0.68	0.45	1.33	0.83	0.55	0.37
	12	**12**	2.83	1.77	1.18	0.79	2.22	1.39	0.92	0.62	1.78	1.11	0.74	0.49	1.45	0.90	0.60	0.40
SA-2	3	**9**	2.29	1.43	0.95	0.64	1.79	1.12	0.75	0.50	1.44	0.90	0.60	0.40	1.17	0.73	0.49	0.32
	4.5	**10**	2.51	1.57	1.05	0.70	1.97	1.23	0.82	0.55	1.57	0.98	0.66	0.44	1.28	0.80	0.53	0.36
	6	**13**	3.15	1.97	1.31	0.88	2.47	1.54	1.03	0.69	1.98	1.24	0.82	0.55	1.61	1.01	0.67	0.45
SA-3	2	**9**	2.92	1.83	1.22	0.81	2.29	1.43	0.95	0.64	1.83	1.14	0.76	0.51	1.49	0.93	0.62	0.41
	3.5	**12**	3.64	2.28	1.52	1.01	2.85	1.78	1.19	0.79	2.28	1.43	0.95	0.63	1.86	1.16	0.77	0.52
SA -4	3.5	**8**	2.42	1.51	1.01	0.67	1.90	1.18	0.79	0.53	1.52	0.95	0.63	0.42	1.24	0.77	0.51	0.34
	5	**11**	3.03	1.90	1.26	0.84	2.38	1.49	0.99	0.66	1.90	1.19	0.79	0.53	1.55	0.97	0.65	0.43
	6.5	**12**	3.28	2.05	1.37	0.91	2.57	1.61	1.07	0.71	2.06	1.29	0.86	0.57	1.68	1.05	0.70	0.47
SA-5	3.5	**10**	2.66	1.66	1.11	0.74	2.09	1.30	0.87	0.58	1.67	1.04	0.70	0.46	1.36	0.85	0.57	0.38
	5	**10**	2.69	1.68	1.12	0.75	2.11	1.32	0.88	0.59	1.69	1.06	0.70	0.47	1.38	0.86	0.57	0.38
	6.5	**11**	2.92	1.83	1.22	0.81	2.29	1.43	0.95	0.64	1.83	1.15	0.76	0.51	1.49	0.93	0.62	0.41
SA-6	3	**12**	3.02	1.89	1.26	0.84	2.37	1.48	0.99	0.66	1.89	1.18	0.79	0.53	1.54	0.96	0.64	0.43
	4.5	**14**	3.49	2.18	1.45	0.97	2.73	1.71	1.14	0.76	2.19	1.37	0.91	0.61	1.78	1.11	0.74	0.49
SA-7	1.5	**3**	1.45	0.91	0.60	0.40	1.13	0.71	0.47	0.32	0.91	0.57	0.38	0.25	0.74	0.46	0.31	0.21
	2.5	**5**	1.78	1.11	0.74	0.49	1.39	0.87	0.58	0.39	1.12	0.70	0.46	0.31	0.91	0.57	0.38	0.25
	4.5	**5**	1.81	1.13	0.75	0.50	1.42	0.88	0.59	0.39	1.13	0.71	0.47	0.31	0.92	0.58	0.38	0.26
SA-8	3	**11**	3.74	2.34	1.56	1.04	2.93	1.83	1.22	0.81	2.35	1.47	0.98	0.65	1.91	1.20	0.80	0.53
	4.5	**10**	3.54	2.21	1.47	0.98	2.77	1.73	1.16	0.77	2.22	1.39	0.92	0.62	1.81	1.13	0.75	0.50
	6	**6**	2.65	1.66	1.11	0.74	2.08	1.30	0.87	0.58	1.66	1.04	0.69	0.46	1.36	0.85	0.56	0.38
	8	**8**	3.15	1.97	1.31	0.88	2.47	1.54	1.03	0.69	1.98	1.24	0.82	0.55	1.61	1.01	0.67	0.45
	10	**10**	3.70	2.31	1.54	1.03	2.90	1.81	1.21	0.81	2.32	1.45	0.97	0.64	1.89	1.18	0.79	0.53
SA-9	1.5	**14**	2.80	1.75	1.17	0.78	2.19	1.37	0.91	0.61	1.76	1.10	0.73	0.49	1.43	0.89	0.60	0.40
	3	**18**	3.62	2.26	1.51	1.01	2.84	1.77	1.18	0.79	2.27	1.42	0.95	0.63	1.85	1.16	0.77	0.51
	4	**3**	1.11	0.69	0.46	0.31	0.87	0.54	0.36	0.24	0.69	0.43	0.29	0.19	0.57	0.35	0.24	0.16
	6	**17**	3.50	2.18	1.46	0.97	2.74	1.71	1.14	0.76	2.19	1.37	0.91	0.61	1.79	1.12	0.74	0.50
SA-10	1.5	**8**	1.83	1.14	0.76	0.51	1.43	0.89	0.60	0.40	1.14	0.72	0.48	0.32	0.93	0.58	0.39	0.26
	3	**7**	1.69	1.06	0.70	0.47	1.32	0.83	0.55	0.37	1.06	0.66	0.44	0.29	0.86	0.54	0.36	0.24
	4.5	**8**	1.87	1.17	0.78	0.52	1.46	0.92	0.61	0.41	1.17	0.73	0.49	0.33	0.95	0.60	0.40	0.27
	6	**7**	1.73	1.08	0.72	0.48	1.36	0.85	0.56	0.38	1.09	0.68	0.45	0.30	0.88	0.55	0.37	0.25
	7.5	**8**	1.91	1.20	0.80	0.53	1.50	0.94	0.63	0.42	1.20	0.75	0.50	0.33	0.98	0.61	0.41	0.27

Table 6 Factor of Safety against Liquefaction from Idriss & Boulanger (2008) method based on uncorrected N values

Earthquake Magnitude			**5**				**5.5**				**6**				**6.5**			
Study Area	**Depth**	**(N1)60**	**Z2**	**Z3**	**Z4**	**Z5**	**Z2**	**Z3**	**Z4**	**Z5**	**Z2**	**Z3**	**Z4**	**Z5**	**Z2**	**Z3**	**Z4**	**Z5**
SA-1	3	**8**	1.93	1.21	0.80	0.54	1.80	1.12	0.75	0.50	1.57	0.98	0.65	0.44	1.37	0.85	0.57	0.38
	4.5	**11**	2.64	1.65	1.10	0.73	2.45	1.53	1.02	0.68	2.12	1.33	0.88	0.59	1.84	1.15	0.77	0.51
	6	**19**	4.64	2.90	1.93	1.29	4.27	2.67	1.78	1.19	3.68	2.30	1.53	1.02	3.17	1.98	1.32	0.88
	7.5	**15**	3.01	1.88	1.25	0.84	2.75	1.72	1.15	0.76	2.36	1.47	0.98	0.65	2.02	1.26	0.84	0.56
	9	**13**	2.60	1.62	1.08	0.72	2.36	1.47	0.98	0.65	2.01	1.25	0.84	0.56	1.71	1.07	0.71	0.47
	10.5	**11**	2.32	1.45	0.97	0.64	2.09	1.31	0.87	0.58	1.77	1.10	0.74	0.49	1.49	0.93	0.62	0.41
	12	**14**	2.80	1.75	1.17	0.78	2.51	1.57	1.04	0.70	2.10	1.31	0.88	0.58	1.76	1.10	0.73	0.49
SA-2	3	**13**	3.42	2.14	1.42	0.95	3.18	1.99	1.32	0.88	2.77	1.73	1.15	0.77	2.42	1.51	1.01	0.67
	4.5	**12**	2.85	1.78	1.19	0.79	2.64	1.65	1.10	0.73	2.29	1.43	0.95	0.64	1.99	1.24	0.83	0.55
	6	**17**	3.69	2.31	1.54	1.03	3.40	2.12	1.41	0.94	2.93	1.83	1.22	0.81	2.52	1.58	1.05	0.70
SA-3	2	**13**	3.41	2.13	1.42	0.96	3.18	1.99	1.33	0.88	2.78	1.74	1.16	0.77	2.43	1.52	1.01	0.68
	3.5	**16**	4.79	3.00	2.00	1.33	4.45	2.78	1.85	1.24	3.88	2.42	1.61	1.08	3.37	2.11	1.41	0.94
SA-4	3.5	**11**	2.44	1.53	1.02	0.68	2.27	1.42	0.95	0.63	1.98	1.23	0.82	0.55	1.72	1.07	0.72	0.48
	5	**14**	3.30	2.06	1.37	0.92	3.05	1.90	1.27	0.85	2.64	1.65	1.10	0.73	2.28	1.43	0.95	0.63
	6.5	**14**	2.92	1.82	1.21	0.81	2.68	1.67	1.12	0.74	2.30	1.44	0.96	0.64	1.98	1.24	0.83	0.55
SA-5	3.5	**13**	2.98	1.86	1.24	0.83	2.77	1.73	1.15	0.77	2.41	1.51	1.00	0.67	2.10	1.31	0.87	0.58
	5	**12**	2.76	1.72	1.15	0.77	2.54	1.59	1.06	0.71	2.20	1.38	0.92	0.61	1.91	1.19	0.79	0.53
	6.5	**12**	2.52	1.57	1.05	0.70	2.31	1.44	0.96	0.64	1.99	1.24	0.83	0.55	1.71	1.07	0.71	0.48
SA-6	3	**18**	7.40	4.63	3.08	2.06	6.89	4.30	2.87	1.91	6.00	3.75	2.50	1.67	5.23	3.27	2.18	1.45
	4.5	**18**	5.09	3.18	2.12	1.42	4.71	2.95	1.96	1.31	4.09	2.56	1.70	1.14	3.55	2.22	1.48	0.99
SA-7	1.5	**3**	1.05	0.66	0.44	0.29	0.98	0.61	0.41	0.27	0.86	0.54	0.36	0.24	0.75	0.47	0.31	0.21
	2.5	**6**	1.49	0.93	0.62	0.41	1.38	0.87	0.58	0.38	1.21	0.76	0.50	0.34	1.06	0.66	0.44	0.29
	4.5	**6**	1.58	0.99	0.66	0.44	1.46	0.91	0.61	0.41	1.27	0.79	0.53	0.35	1.10	0.69	0.46	0.30
SA-8	3	**16**	5.09	3.18	2.12	1.41	4.74	2.96	1.97	1.32	4.13	2.58	1.72	1.15	3.60	2.25	1.50	1.00
	4.5	**12**	2.85	1.78	1.19	0.79	2.64	1.65	1.10	0.73	2.29	1.43	0.96	0.64	1.99	1.24	0.83	0.55
	6	**8**	1.98	1.24	0.83	0.55	1.82	1.14	0.76	0.51	1.57	0.98	0.66	0.44	1.36	0.85	0.56	0.38
	8	**9**	2.08	1.30	0.87	0.58	1.89	1.18	0.79	0.53	1.62	1.01	0.67	0.45	1.38	0.87	0.58	0.38
	10	**11**	2.37	1.48	0.99	0.66	2.14	1.34	0.89	0.59	1.81	1.13	0.76	0.50	1.54	0.96	0.64	0.43
SA-9	1.5	**20**	10.86	6.78	4.52	3.02	10.14	6.34	4.23	2.82	8.88	5.55	3.70	2.47	7.78	4.86	3.24	2.16
	3	**27**	12.42	7.76	5.17	3.45	11.55	7.22	4.81	3.21	10.07	6.29	4.20	2.80	8.78	5.49	3.66	2.44
	4	**4**	1.24	0.78	0.52	0.34	1.15	0.72	0.48	0.32	1.00	0.62	0.42	0.28	0.87	0.54	0.36	0.24
	6	**23**	9.42	5.89	3.93	2.62	8.67	5.42	3.61	2.41	7.48	4.67	3.12	2.08	6.45	4.03	2.69	1.79
SA-10	1.5	**11**	2.26	1.41	0.94	0.63	2.11	1.32	0.88	0.59	1.85	1.16	0.77	0.51	1.62	1.01	0.68	0.45
	3	**10**	2.14	1.34	0.89	0.60	1.99	1.25	0.83	0.55	1.74	1.09	0.72	0.48	1.51	0.95	0.63	0.42
	4.5	**10**	2.24	1.40	0.93	0.62	2.07	1.30	0.86	0.58	1.80	1.13	0.75	0.50	1.56	0.98	0.65	0.43
	6	**8**	1.89	1.18	0.79	0.52	1.74	1.09	0.72	0.48	1.50	0.94	0.62	0.42	1.29	0.81	0.54	0.36
	7.5	**9**	1.98	1.23	0.82	0.55	1.81	1.13	0.75	0.50	1.55	0.97	0.65	0.43	1.33	0.83	0.55	0.37

Table 7 Factor of Safety against Liquefaction from Idriss & Boulanger (2008) method based on N values corrected for non-standard field procedures

Earthquake Magnitude			**5**				**5.5**				**6**				**6.5**			
Study Area	**Depth**	**(N1)60**	**Z2**	**Z3**	**Z4**	**Z5**	**Z2**	**Z3**	**Z4**	**Z5**	**Z2**	**Z3**	**Z4**	**Z5**	**Z2**	**Z3**	**Z4**	**Z5**
SA-1	3	**6**	1.59	1.00	0.66	0.44	1.48	0.93	0.62	0.41	1.29	0.81	0.54	0.36	1.13	0.70	0.47	0.31
	4.5	**9**	2.22	1.39	0.92	0.62	2.05	1.28	0.85	0.57	1.78	1.11	0.74	0.49	1.54	0.96	0.64	0.43
	6	**15**	3.23	2.02	1.35	0.90	2.97	1.86	1.24	0.83	2.56	1.60	1.07	0.71	2.21	1.38	0.92	0.61
	7.5	**13**	2.64	1.65	1.10	0.73	2.41	1.51	1.01	0.67	2.07	1.29	0.86	0.57	1.77	1.11	0.74	0.49
	9	**12**	2.44	1.53	1.02	0.68	2.22	1.39	0.92	0.62	1.89	1.18	0.79	0.52	1.61	1.00	0.67	0.45
	10.5	**11**	2.32	1.45	0.97	0.64	2.09	1.31	0.87	0.58	1.77	1.10	0.74	0.49	1.49	0.93	0.62	0.41
	12	**12**	2.51	1.57	1.04	0.70	2.24	1.40	0.93	0.62	1.88	1.18	0.78	0.52	1.58	0.99	0.66	0.44
SA-2	3	**9**	2.31	1.44	0.96	0.64	2.15	1.34	0.90	0.60	1.87	1.17	0.78	0.52	1.63	1.02	0.68	0.45
	4.5	**10**	2.45	1.53	1.02	0.68	2.27	1.42	0.95	0.63	1.97	1.23	0.82	0.55	1.71	1.07	0.71	0.47
	6	**13**	2.79	1.75	1.16	0.78	2.57	1.61	1.07	0.71	2.22	1.39	0.92	0.62	1.91	1.19	0.80	0.53
SA-3	2	**9**	2.31	1.44	0.96	0.64	2.15	1.34	0.90	0.60	1.88	1.18	0.78	0.52	1.65	1.03	0.69	0.46
	3.5	**12**	3.18	1.99	1.33	0.88	2.96	1.85	1.23	0.82	2.57	1.61	1.07	0.72	2.24	1.40	0.93	0.62
SA -4	3.5	**8**	1.85	1.16	0.77	0.51	1.72	1.07	0.72	0.48	1.50	0.94	0.62	0.42	1.30	0.81	0.54	0.36
	5	**11**	2.53	1.58	1.06	0.70	2.34	1.46	0.97	0.65	2.03	1.27	0.84	0.56	1.75	1.10	0.73	0.49
	6.5	**12**	2.52	1.57	1.05	0.70	2.31	1.45	0.96	0.64	1.99	1.24	0.83	0.55	1.71	1.07	0.71	0.48
SA-5	3.5	**10**	2.21	1.38	0.92	0.61	2.05	1.28	0.85	0.57	1.79	1.12	0.74	0.50	1.55	0.97	0.65	0.43
	5	**10**	2.32	1.45	0.97	0.64	2.14	1.34	0.89	0.59	1.85	1.16	0.77	0.51	1.60	1.00	0.67	0.45
	6.5	**11**	2.34	1.46	0.98	0.65	2.15	1.34	0.90	0.60	1.85	1.16	0.77	0.51	1.59	0.99	0.66	0.44
SA-6	3	**12**	2.97	1.86	1.24	0.83	2.76	1.73	1.15	0.77	2.41	1.51	1.00	0.67	2.10	1.31	0.88	0.58
	4.5	**14**	3.37	2.11	1.40	0.94	3.12	1.95	1.30	0.87	2.71	1.69	1.13	0.75	2.35	1.47	0.98	0.65
SA-7	1.5	**3**	1.05	0.66	0.44	0.29	0.98	0.61	0.41	0.27	0.86	0.54	0.36	0.24	0.75	0.47	0.31	0.21
	2.5	**5**	1.34	0.84	0.56	0.37	1.25	0.78	0.52	0.35	1.09	0.68	0.45	0.30	0.95	0.60	0.40	0.26
	4.5	**5**	1.42	0.89	0.59	0.40	1.32	0.82	0.55	0.37	1.14	0.71	0.48	0.32	0.99	0.62	0.41	0.28
SA-8	3	**11**	2.75	1.72	1.15	0.76	2.56	1.60	1.07	0.71	2.23	1.40	0.93	0.62	1.95	1.22	0.81	0.54
	4.5	**10**	2.45	1.53	1.02	0.68	2.27	1.42	0.95	0.63	1.97	1.23	0.82	0.55	1.71	1.07	0.71	0.47
	6	**6**	1.70	1.06	0.71	0.47	1.56	0.98	0.65	0.43	1.35	0.84	0.56	0.37	1.16	0.73	0.48	0.32
	8	**8**	1.94	1.21	0.81	0.54	1.77	1.11	0.74	0.49	1.52	0.95	0.63	0.42	1.30	0.81	0.54	0.36
	10	**10**	2.23	1.40	0.93	0.62	2.02	1.26	0.84	0.56	1.71	1.07	0.71	0.48	1.45	0.91	0.60	0.40
SA-9	1.5	**14**	3.16	1.97	1.31	0.88	2.95	1.84	1.23	0.82	2.58	1.61	1.08	0.72	2.26	1.41	0.94	0.63
	3	**18**	12.42	7.76	5.17	3.45	11.55	7.22	4.81	3.21	10.07	6.29	4.20	2.80	8.78	5.49	3.66	2.44
	4	**3**	1.11	0.69	0.46	0.31	1.03	0.64	0.43	0.29	0.89	0.56	0.37	0.25	0.78	0.49	0.32	0.22
	6	**17**	3.97	2.48	1.65	1.10	3.65	2.28	1.52	1.01	3.15	1.97	1.31	0.88	2.72	1.70	1.13	0.75
SA-10	1.5	**8**	1.71	1.07	0.71	0.48	1.60	1.00	0.67	0.44	1.40	0.88	0.58	0.39	1.23	0.77	0.51	0.34
	3	**7**	1.62	1.01	0.68	0.45	1.51	0.94	0.63	0.42	1.32	0.82	0.55	0.37	1.15	0.72	0.48	0.32
	4.5	**8**	1.87	1.17	0.78	0.52	1.73	1.08	0.72	0.48	1.50	0.94	0.62	0.42	1.30	0.81	0.54	0.36
	6	**7**	1.74	1.09	0.72	0.48	1.60	1.00	0.67	0.44	1.38	0.86	0.57	0.38	1.19	0.74	0.50	0.33
	7.5	**8**	1.83	1.15	0.76	0.51	1.68	1.05	0.70	0.47	1.44	0.90	0.60	0.40	1.23	0.77	0.51	0.34

Table 8 Liquefaction potential indices corresponding to factors of safety obtained from IS 1893 Part-I 2016 method based on uncorrected N Values

Earthquake Magnitude			**5**				**5.5**				**6**				**6.5**			
Study Area	**Depth**	**(N1)60**	**Z2**	**Z3**	**Z4**	**Z5**	**Z2**	**Z3**	**Z4**	**Z5**	**Z2**	**Z3**	**Z4**	**Z5**	**Z2**	**Z3**	**Z4**	**Z5**
SA-1	3	**8**	0	0	33	77	0	9	61	96	0	40	82	110	3	63	97	120
	4.5	**11**	0	0	0	47	0	0	29	69	0	4	53	85	0	31	71	97
	6	**19**	0	0	0	0	0	0	0	12	0	0	0	37	0	0	15	55
	7.5	**15**	0	0	0	12	0	0	0	45	0	0	21	69	0	0	48	87
	9	**13**	0	0	0	27	0	0	5	53	0	0	34	73	0	8	55	87
	10.5	**11**	0	0	0	37	0	0	20	59	0	0	43	74	0	23	60	85
	12	**14**	0	0	0	17	0	0	0	50	0	0	26	74	0	0	53	92
SA-2	3	**13**	0	0	0	22	0	0	0	51	0	0	30	72	0	3	53	87
	4.5	**12**	0	0	0	36	0	0	9	68	0	0	44	91	0	13	70	109
	6	**17**	0	0	0	0	0	0	0	21	0	0	0	51	0	0	24	74
SA-3	2	**13**	0	0	0	0	0	0	0	26	0	0	0	51	0	0	28	71
	3.5	**16**	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	57
SA -4	3.5	**11**	0	0	0	26	0	0	3	54	0	0	34	74	0	7	56	89
	5	**14**	0	0	0	0	0	0	0	28	0	0	5	50	0	0	30	67
	6.5	**14**	0	0	0	0	0	0	0	23	0	0	3	42	0	0	25	57
SA-5	3.5	**13**	0	0	0	10	0	0	0	29	0	0	15	43	0	0	31	54
	5	**12**	0	0	0	28	0	0	0	66	0	0	39	92	0	3	69	112
	6.5	**12**	0	0	0	26	0	0	0	64	0	0	37	91	0	0	67	111
SA-6	3	**18**	0	0	0	0	0	0	0	9	0	0	0	47	0	0	13	75
	4.5	**18**	0	0	0	0	0	0	0	6	0	0	0	45	0	0	11	74
SA-7	1.5	**3**	0	19	79	120	0	58	105	137	18	86	124	150	52	108	138	159
	2.5	**6**	0	0	38	92	0	9	73	115	0	47	98	132	1	76	117	145
	4.5	**6**	0	0	35	90	0	6	71	114	0	45	97	131	0	74	116	144
SA-8	3	**16**	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	53
	4.5	**12**	0	0	0	0	0	0	0	24	0	0	0	59	0	0	28	85
	6	**8**	0	0	0	28	0	0	0	65	0	0	38	92	0	2	68	112
	8	**9**	0	0	0	11	0	0	0	52	0	0	23	82	0	0	56	104
	10	**11**	0	0	0	0	0	0	0	28	0	0	0	62	0	0	31	88
SA-9	1.5	**20**	0	0	0	0	0	0	0	25	0	0	0	60	0	0	29	86
	3	**27**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18
	4	**4**	0	46	97	132	7	79	120	146	45	103	136	157	74	121	148	165
	6	**23**	0	0	0	0	0	0	0	0	0	0	0	27	0	0	0	59
SA-10	1.5	**11**	0	0	7	71	0	0	49	99	0	18	79	119	0	52	101	134
	3	**10**	0	0	19	79	0	0	58	105	0	30	86	124	0	61	107	138
	4.5	**10**	0	0	17	78	0	0	56	104	0	28	85	123	0	59	106	138
	6	**8**	0	0	42	95	0	15	76	118	0	52	101	134	7	79	119	146
	7.5	**9**	0	0	26	84	0	0	64	109	0	37	91	127	0	67	111	141

Table 9 Liquefaction potential indices corresponding to factors of Safety obtained from IS 1893 Part-I 2016 method based on on N values corrected for non-standard field procedures

Earthquake Magnitude			**5**				**5.5**				**6**				**6.5**			
Study Area	**Depth**	**(N1)60**	**Z2**	**Z3**	**Z4**	**Z5**	**Z2**	**Z3**	**Z4**	**Z5**	**Z2**	**Z3**	**Z4**	**Z5**	**Z2**	**Z3**	**Z4**	**Z5**
SA-1	3	**6**	0	0	55	92	0	36	79	107	0	61	96	119	30	81	109	127
	4.5	**9**	0	0	17	62	0	0	46	81	0	25	67	95	0	48	82	105
	6	**15**	0	0	0	12	0	0	0	38	0	0	19	58	0	0	40	72
	7.5	**13**	0	0	0	31	0	0	7	60	0	0	39	81	0	11	62	97
	9	**12**	0	0	0	35	0	0	15	60	0	0	42	78	0	18	62	91
	10.5	**11**	0	0	0	37	0	0	20	59	0	0	43	74	0	23	60	85
	12	**12**	0	0	0	36	0	0	13	65	0	0	44	86	0	16	67	102
SA-2	3	**9**	0	0	7	56	0	0	39	78	0	16	62	93	0	42	79	105
	4.5	**10**	0	0	0	56	0	0	34	84	0	3	64	104	0	37	86	119
	6	**13**	0	0	0	22	0	0	0	55	0	0	31	79	0	0	58	97
SA-3	2	**9**	0	0	0	29	0	0	7	56	0	0	37	76	0	10	59	91
	3.5	**12**	0	0	0	0	0	0	0	35	0	0	8	62	0	0	38	82
SA -4	3.5	**8**	0	0	0	51	0	0	33	73	0	8	57	90	0	35	75	102
	5	**11**	0	0	0	22	0	0	1	48	0	0	29	66	0	4	50	80
	6.5	**12**	0	0	0	11	0	0	0	34	0	0	17	51	0	0	36	64
SA-5	3.5	**10**	0	0	0	26	0	0	13	42	0	0	30	54	0	15	43	62
	5	**10**	0	0	0	50	0	0	24	83	0	0	59	106	0	28	85	124
	6.5	**11**	0	0	0	38	0	0	9	73	0	0	47	98	0	13	76	117
SA-6	3	**12**	0	0	0	32	0	0	3	69	0	0	42	95	0	7	71	114
	4.5	**14**	0	0	0	6	0	0	0	48	0	0	18	79	0	0	52	101
SA-7	1.5	**3**	0	19	79	120	0	58	105	137	18	86	124	150	52	108	138	159
	2.5	**5**	0	0	52	101	0	26	84	123	0	61	107	138	18	86	124	150
	4.5	**5**	0	0	49	100	0	23	82	121	0	58	106	137	15	85	123	149
SA-8	3	**11**	0	0	0	0	0	0	0	37	0	0	4	70	0	0	41	94
	4.5	**10**	0	0	0	3	0	0	0	46	0	0	15	77	0	0	49	100
	6	**6**	0	0	0	53	0	0	27	85	0	0	61	108	0	31	87	125
	8	**8**	0	0	0	25	0	0	0	63	0	0	35	90	0	0	66	110
	10	**10**	0	0	0	0	0	0	0	39	0	0	7	71	0	0	42	95
SA-9	1.5	**14**	0	0	0	44	0	0	17	78	0	0	54	102	0	21	81	121
	3	**18**	0	0	0	0	0	0	0	42	0	0	11	74	0	0	46	97
	4	**3**	0	61	108	138	26	91	128	152	61	113	142	161	87	129	153	169
	6	**17**	0	0	0	6	0	0	0	48	0	0	17	78	0	0	51	101
SA-10	1.5	**8**	0	0	48	99	0	21	81	121	0	57	105	136	13	83	122	148
	3	**7**	0	0	59	106	0	35	90	126	0	68	112	141	27	92	128	152
	4.5	**8**	0	0	44	96	0	17	78	119	0	54	102	135	9	81	120	147
	6	**7**	0	0	56	104	0	31	87	125	0	64	110	140	23	89	126	151
	7.5	**8**	0	0	40	94	0	12	75	117	0	50	100	133	4	78	118	146

Table 10 Liquefaction potential indices corresponding to factors of Safety obtained from Idriss& Boulanger (2008) method based on uncorrected N Values

Earthquake Magnitude			**5**				**5.5**				**6**				**6.5**			
Study Area	**Depth**	**(N1)60**	**Z2**	**Z3**	**Z4**	**Z5**	**Z2**	**Z3**	**Z4**	**Z5**	**Z2**	**Z3**	**Z4**	**Z5**	**Z2**	**Z3**	**Z4**	**Z5**
SA-1	3	**8**	0	0	32	76	0	0	41	83	0	3	57	93	0	24	71	102
	4.5	**11**	0	0	0	40	0	0	0	48	0	0	17	62	0	0	35	73
	6	**19**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16
	7.5	**15**	0	0	0	27	0	0	0	39	0	0	3	57	0	0	26	72
	9	**13**	0	0	0	42	0	0	3	52	0	0	25	66	0	0	43	79
	10.5	**11**	0	0	5	48	0	0	17	57	0	0	36	69	0	9	51	79
	12	**14**	0	0	0	38	0	0	0	52	0	0	21	71	0	0	45	87
SA-2	3	**13**	0	0	0	8	0	0	0	18	0	0	0	36	0	0	0	51
	4.5	**12**	0	0	0	38	0	0	0	49	0	0	8	67	0	0	32	83
	6	**17**	0	0	0	0	0	0	0	10	0	0	0	33	0	0	0	52
SA-3	2	**13**	0	0	0	8	0	0	0	18	0	0	0	35	0	0	0	50
	3.5	**16**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11
SA-4	3.5	**11**	0	0	0	50	0	0	8	57	0	0	27	70	0	0	44	81
	5	**14**	0	0	0	12	0	0	0	22	0	0	0	37	0	0	7	51
	6.5	**14**	0	0	0	23	0	0	0	31	0	0	5	43	0	0	21	54
SA-5	3.5	**13**	0	0	0	17	0	0	0	23	0	0	0	33	0	0	13	42
	5	**12**	0	0	0	47	0	0	0	59	0	0	16	78	0	0	41	94
	6.5	**12**	0	0	0	60	0	0	8	72	0	0	34	90	0	0	57	105
SA-6	3	**18**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4.5	**18**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
SA-7	1.5	**3**	0	69	112	142	3	77	118	145	28	92	128	152	49	106	137	158
	2.5	**6**	0	14	76	117	0	27	85	123	0	49	99	133	0	68	112	141
	4.5	**6**	0	3	69	112	0	18	78	119	0	42	95	130	0	63	109	139
SA-8	3	**16**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4.5	**12**	0	0	0	41	0	0	0	53	0	0	9	73	0	0	34	90
	6	**8**	0	0	35	90	0	0	48	99	0	3	69	113	0	31	87	125
	8	**9**	0	0	27	85	0	0	42	95	0	0	65	110	0	27	85	123
	10	**11**	0	0	3	68	0	0	22	81	0	0	49	99	0	8	72	115
SA-9	1.5	**20**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	**27**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4	**4**	0	45	97	131	0	56	104	136	0	75	117	144	26	92	128	152
	6	**23**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SA-10	1.5	**11**	0	0	11	74	0	0	24	83	0	0	46	97	0	0	65	110
	3	**10**	0	0	21	81	0	0	34	89	0	0	55	103	0	11	74	116
	4.5	**10**	0	0	13	75	0	0	27	85	0	0	50	100	0	5	70	113
	6	**8**	0	0	43	95	0	0	55	103	0	13	75	117	0	39	92	128
	7.5	**9**	0	0	35	90	0	0	49	100	0	6	71	114	0	34	90	126

Table 11 Liquefaction potential indices corresponding to factors of Safety obtained from Idriss & Boulanger (2008) method based on N values collected for non-standard field procedures

Earthquake Magnitude			**5**				**5.5**				**6**				**6.5**			
Study Area	**Depth**	**(N1)60**	**Z2**	**Z3**	**Z4**	**Z5**	**Z2**	**Z3**	**Z4**	**Z5**	**Z2**	**Z3**	**Z4**	**Z5**	**Z2**	**Z3**	**Z4**	**Z5**
SA-1	3	**6**	0	0	55	92	0	12	63	97	0	32	76	106	0	49	88	113
	4.5	**9**	0	0	11	58	0	0	22	65	0	0	39	76	0	5	54	86
	6	**15**	0	0	0	14	0	0	0	24	0	0	0	39	0	0	11	52
	7.5	**13**	0	0	0	44	0	0	0	54	0	0	23	70	0	0	43	84
	9	**12**	0	0	0	48	0	0	11	58	0	0	32	71	0	0	50	83
	10.5	**11**	0	0	5	48	0	0	17	57	0	0	36	69	0	9	51	79
	12	**12**	0	0	0	52	0	0	11	64	0	0	37	81	0	2	58	95
SA-2	3	**9**	0	0	6	56	0	0	16	62	0	0	34	74	0	0	50	85
	4.5	**10**	0	0	0	59	0	0	10	68	0	0	33	84	0	0	53	97
	6	**13**	0	0	0	39	0	0	0	50	0	0	13	67	0	0	36	82
SA-3	2	**9**	0	0	6	56	0	0	16	62	0	0	33	74	0	0	49	84
	3.5	**12**	0	0	0	20	0	0	0	30	0	0	0	48	0	0	11	64
SA-4	3.5	**8**	0	0	35	75	0	0	44	81	0	0	58	91	0	29	71	99
	5	**11**	0	0	0	41	0	0	4	49	0	0	22	61	0	0	38	72
	6.5	**12**	0	0	0	36	0	0	4	43	0	0	20	54	0	0	34	63
SA-5	3.5	**10**	0	0	8	39	0	0	15	43	0	0	26	50	0	3	35	57
	5	**10**	0	0	7	71	0	0	22	81	0	0	46	97	0	0	66	111
	6.5	**11**	0	0	5	70	0	0	21	81	0	0	46	97	0	1	67	112
SA-6	3	**12**	0	0	0	35	0	0	0	46	0	0	0	66	0	0	25	83
	4.5	**14**	0	0	0	13	0	0	0	27	0	0	0	50	0	0	4	70
SA-7	1.5	**3**	0	69	112	142	3	77	118	145	28	92	128	152	49	106	137	158
	2.5	**5**	0	32	88	125	0	44	96	131	0	64	109	139	9	81	121	147
	4.5	**5**	0	22	81	121	0	35	90	127	0	57	105	136	2	76	117	145
SA-8	3	**11**	0	0	0	47	0	0	0	58	0	0	14	76	0	0	38	92
	4.5	**10**	0	0	0	64	0	0	11	74	0	0	36	91	0	0	58	105
	6	**6**	0	0	59	106	0	5	70	113	0	32	88	125	0	55	103	136
	8	**8**	0	0	38	92	0	0	52	102	0	11	74	116	0	38	92	128
	10	**10**	0	0	14	76	0	0	32	88	0	0	57	105	0	19	79	120
SA-9	1.5	**14**	0	0	0	25	0	0	0	36	0	0	0	57	0	0	12	74
	3	**18**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4	**3**	0	61	108	138	0	71	114	143	21	88	126	150	45	103	135	157
	6	**17**	0	0	0	0	0	0	0	0	0	0	0	25	0	0	0	49
SA-10	1.5	**8**	0	0	57	105	0	0	67	111	0	25	83	122	0	46	98	132
	3	**7**	0	0	65	110	0	11	74	116	0	36	90	127	0	57	104	136
	4.5	**8**	0	0	45	96	0	0	56	104	0	13	75	117	0	38	92	128
	6	**7**	0	0	55	103	0	0	67	111	0	28	85	123	0	51	101	134
	7.5	**8**	0	0	47	98	0	0	60	107	0	20	80	120	0	46	97	132

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