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ABSTRACT

The lowlands of India are vulnerable to possible future large earthquakes. The liquefaction strength is estimated using in-situ tests and the factor of safety against liquefaction by comparing the liquefaction strength with cyclic shear stress ratio developed in the deposit during an earthquake. Standard Penetration test (SPT) and Cone Penetration test(CPT) have been most commonly used in-situ tests for characterization of liquefaction resistance. In this study, liquefaction potential is evaluated based on SPT as well as CPT data obtained from the three different locations situated in alluvial lowlands. A large difference in factor of safety against liquefaction is found based on SPT and CPT data. It is observed that CPT data is more reliable for liquefaction potential evaluation because there is no concrete method available in India to convert measured SPT N-value to $(N_1)_{60}$.

INTRODUCTION

Lands affected by fluctuating surface water levels e.g. by tides, floods etc. are classified as lowlands. Large tracts of coastal lands which are below mean sea level exist all over the world notably in the Netherlands, Japan, Bangladesh, India, Thailand etc. Lowlands of India, normally consist of soft fine grained soil (ML) in the upper horizon (1.0 – 3.0 m) overlying sand (SM/SP). Lowlands near the foothills of Himalayas are situated in the high seismic hazard zone which is vulnerable to possible future large earthquake. Often, the delicate balance of project costs, schedules and long term success is hinged on the geotechnical engineer's ability to predict, assess and deal with liquefaction susceptibility effectively (Gupta et al. 2008). Data from Standard Penetration tests (SPT) and Cone Penetration tests (CPT) show the sign of potential liquefaction. SPT and CPT datas from three locations were obtained and the "simplified procedure" developed by Seed and Idriss (1971) is used to evaluate the liquefaction potential for the comparison.

LITERATURE REVIEW

Liquefaction is defined as the transformation of granular material from solid to a liquefied state as a consequence of increased pore-water pressure and reduced effective stress (Marcuson 1978). Loose soils also compact during liquefaction and reconsolidate, leading to ground settlement, Soil boils may also erupt as excess pore-water pressure dissipate (Youd and Idriss, 2001). The "simplified procedure" developed by Seed and Idriss (1971) is most commonly used method to evaluate the liquefaction potential of a site. The simplied procedure is reproduced below:

The factor of safety against liquefaction is defined as

$$\text{F.S.} = \frac{\text{CRR}}{\text{CSR}} \qquad (1)$$

where CSR = cyclic stress ratio and CRR = cyclic resistance ratio of in-situ soil.

<u>Cyclic Stress Ratio (CSR)</u>

Seed and Idriss (1971) proposed the following equation for calculating the cyclic stress ratio

$$\text{CSR} = \frac{\tau_{av}}{\sigma_0'} = 0.65\, r_d \left(\frac{\sigma_{v0}}{\sigma_{v0}'}\right)\left(\frac{a_{\max}}{g}\right) \qquad (2)$$

where

a_{max}	peak horizontal ground acceleration
g	acceleration due to gravity.
σ_{v0}'	total effective overburden stresses
σ_{v0}	Effective vertical overburden stresses
r_d	Stress reduction coefficient

Lio and Whiteman (1986) proposed the following equation for determining stress reduction coefficient(r_d)

$$r_d = 1.0 - 0.00765\, z \text{ for } z \leq 9.15 \text{ m} \quad (3)$$
$$r_d = 1.174 - 0.0267\, z \text{ for } 9.15 < z \leq 23.0 \text{ m} \quad (4)$$

where z is the depth below ground surface in meters.

Alternatively, for ease of computation, r_d may be calculated from the following equation (Youd and Idriss, 2001)

$$r_d = \frac{1.000 - 0.4113\, z^{0.5} + 0.04052\, z + 0.001753\, z^{1.5}}{(1.00 - 0.4177\, z^{0.5} + 0.05729\, z - 0.006205\, z^{1.5} + 0.001210\, z^2)} \quad (5)$$

Cyclic Resistance Ratio (CRR)

A credible method for evaluating CRR is to obtain and test undisturbed soil specimens. Specimens should be obtained through specialized sampling techniques, such as ground freezing. To avoid difficulty in obtaining undisturbed specimen, field tests have become the state of art practice for routine liquefaction resistance evaluation (Youd and Idriss, 2001). Standard Penetration Test (SPT) and Cone Penetration test (CPT) have gained the popularity for evaluation of CRR.

CRR from SPT: Based on the SPT and field performance data, Seed et al. (1985) defined three potential damage ranges that can be defined as

$(N_1)_{60}$	Potential damage
0 - 20	High
20 - 30	Intermediate
> 30	No significant

Based on the investigation of numerous sites that had liquefied or did not liquefy during earthquakes, Seed et al. (1985) had developed a chart(Fig. 1) that can be used to determine CRR of in-situ soil.

Rauch (1998) proposed the following equation for determining CRR based on SPT N-value $(N_1)_{60}$ for an earthquake of magnitude 7.5.

$$CRR = \frac{1}{34 - (N_1)_{60}} + \frac{(N_1)_{60}}{135} + \frac{50}{[10(N_1)_{60} + 45]^2} - \frac{1}{200} \quad (6)$$

where $(N_1)_{60}$ refers to SPT blow count normalized to an overburden pressure of approximately 100 kPa and a hammer efficiency of 60%.

$(N_1)_{60}$ must also be corrected for fines as per the following equation proposed by Seed and Idriss(1971):

$$(N_1)_{60} \text{ corrected} = \alpha + \beta\, (N_1)_{60} \quad (7)$$

where α and β are coefficients determined from the following relationships:

$$\alpha = 0 \text{ for } FC \leq 5\% \quad (8)$$
$$\alpha = \exp\,[\,1.76 - (190/FC^2)] \text{ for } 5\% < FC < 35 \quad (9)$$
$$\alpha = 5.0 \text{ for } FC \geq 35\% \quad (10)$$
$$\beta = 1.0 \text{ for } FC \leq 5\% \quad (11)$$
$$\beta = [\,0.99 - (FC^{1.5}/1000)] \text{ for } 5\% < FC < 35 \quad (12)$$
$$\beta = 1.2 \text{ for } FC \geq 35\% \quad (13)$$

Other correction factors such as overburden pressure, borehole diameter, rod length and samples with or without liners have also to be taken as proposed by Youd and Idriss (2001).

Also, an energy ratio(ER) of 60% is accepted as the approximate average for U.S. testing practice and as a reference value for energy correction. ER depends on the type and weight of SPT hammer, anvil, lifting mechanism and method of hammer release. If N-value is measured in any other country using different weight, fall and lifting mechanism etc, the correction should be made to SPT N-value for difference in energy efficiency using the following equation (JGS, 1998):

$$(N_1)_{60} = \left(\frac{ER_m}{ER_c}\right) N_m \quad (14)$$

where N_m and ER_m are the measured N-value and corresponding energy efficiency. $(N_1)_{60}$ and ER_c are the N-value at an energy ratio of 60% and energy efficiency equal to 60%.Since hammer efficiency and hammer used in India is different from one used in USA, hence it is necessary to normalize the measured N-value to get $(N_1)_{60}$. Seed et. al. (1985) compiled the energy ratio (ER_m/ER_c) for different countries and the same is reproduced in Table 1.

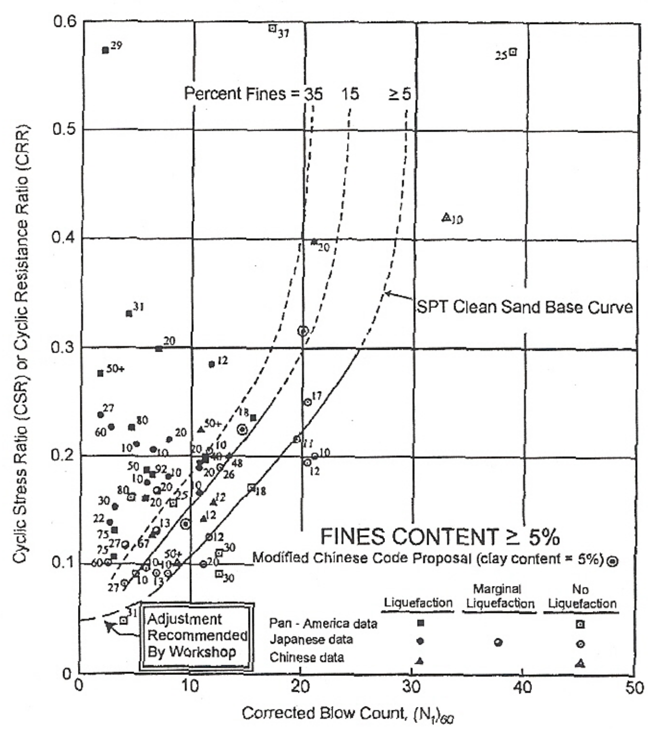

Fig. 1. SPT clean sand base curve for magnitude 7.5 earthquake (courtesy Seed et. al. 1985)

Table 1. Summary of Energy Ratios for SPT Procedures

Country	Hammer Type	Hammer Release	Estimated Rod Energy, %	Correction Factor for 60% Rod Energy
Japan	Donut	Free-fall	78	1.30
	Donut	Rope and Pulley with special throw release	67	1.12
United States	Safety	Rope and Pulley	60	1.00
	Donut	Rope and Pulley	45	0.75
Argentina	Donut	Rope and Pulley	45	0.75
China	Donut	Free-fall	60	1.00
	Donut	Rope and Pulley	50	0.83

(After Seed et al. 1985)

CRR from CPT: Robertson and Wride(1998) provide curves for determination of CRR for clean sand (FC ≤ 5%) from CPT data (Fig. 2). This curve was approximated by the following equation (Robertson and Wride 1998)

If $(q_{c1N})_{cs} < 50$, $CRR_{7.5} = 0.833[(q_{c1N})_{cs}/1000] + 0.05$ (15)
If $50 \leq (q_{c1N})_{cs} \leq 160$, $CRR7.5 = 93.0[(q_{c1N})_{cs}/1000]^3 + 0.08$ (16)

Where $(q_{c1N})_{cs}$ = clean sand cone penetration resistance normalized to approximately 100 kPa.

SITE INVESTIGATION AND GENERAL SITE CONDITION

Both SPT and CPT tests were carried out at three locations in alluvial lowlands of eastern Uttar Pradesh province of India. The locations of sites are given below:

Designation	Location
Site A	Village Khotahi, District Kushinagar
Site B	Village Khajuri, District Kushinagar
Site C	Village Rahsu Junebee Patti, District Kushinagar

The borehole logs of these sites are shown in Fig. 3. The corrected SPT and CPT data were plotted and appended here as Fig. 4 and 5 respectively.

The borehole log of Site A shows that inorganic silt (ML) is available up to a depth of 1.50 m below existing ground level. It is followed by silty sand(SM) up to the depth of 3.0 m below G.L. Again, inorganic silt(ML) is available up to the depth of 4.60 m. Poorly graded sand(SP) is found below ML layer and it extends up to the depth of boring i.e. 10.0 m.

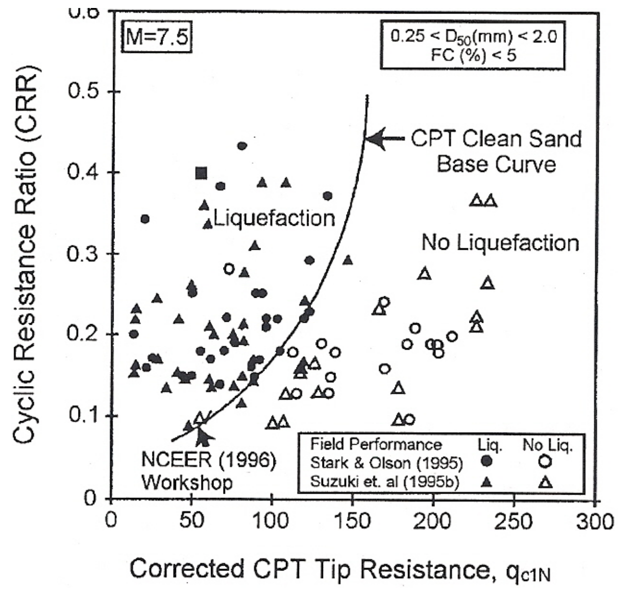

Fig. 2. Curve recommended for calculation of CRR fromCPT data (Courtesy Robertson and Wride 1998)

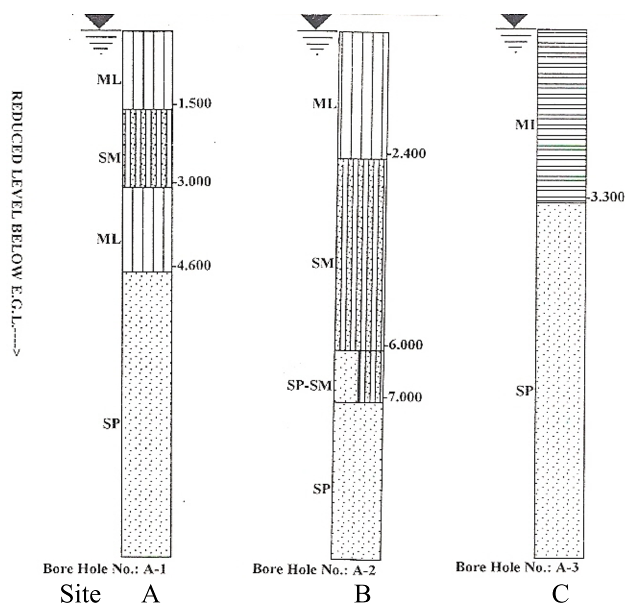

Fig. 3. Borehole logs

Site B consists of inorganic silt (ML) up to the depth of 2.40 m followed by silty sand(SM) up to the depth of 6.00 m below G.L. Poorly graded sand-silty sand mixture (SP-SM) is found below SM layer. Poorly graded sand (SP) is available from a depth of 7.00 m and continued up to the depth of boring i.e. 10.0 m.

Site C consists of inorganic silt (ML) up to the depth of 3.30 m followed by poorly graded sand (SP) up to the depth of boring i.e. 10.0 m below G.L.

The water table in all sites were with in top 0.30 m depth below G.L. at the time of boring, which usually rises up to the G.L.

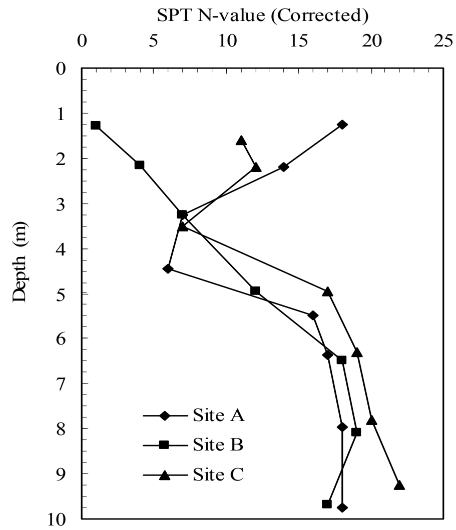

Fig. 4. SPT curves

RESULT AND DISCUSSION

The region under consideration lies in seismic zone III of India. A peak horizontal ground acceleration of 0.24 g was adopted for calculating CSR. The liquefaction susceptibility for an earthquake of magnitude 7.5 was evaluated for all the three sites using both the SPT as well as CPT data.

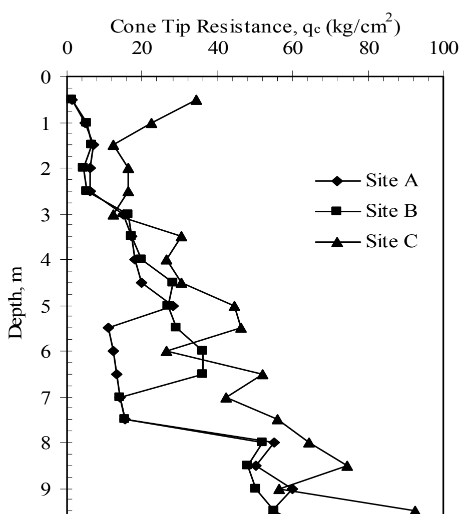

Fig. 5. CPT curves

Since the SPT hammer used in India is different in weight and release mechanism etc. than one used in USA, it is necessary to determine and standardize energy ratio (ER_m/ER_c). Unfortunately, such ratio is not available for Indian SPT hammer. Gupta et al.(2008) had proposed energy ratio (the correction factor for 60% rod energy) of 0.75 however, some researchers proposed an energy ratio of 1.0(Swami Saran, 2006). In Table 1, the maximum correction factor for 60% rod energy is given as 1.3 for free fall hammer used in Japan. In the absence of any standardized correction factor for 60% rod energy, the two correction factors 0.75 and 1.3 were used in calculating CRR in this study. The factor of safety against liquefaction using SPT data with correction factor 0.75 and 1.3 are plotted in Fig. 6 and 7 respectively. It is evident from Figs. 6 and 7 that F.S. against liquefaction is less than 1.0 when correction factor for 60% rod energy is taken as 0.75. However, factor of safety is more than 1.0 for soil strata below a depth of 7.5 m in case of Site A and C and 6.5 in case of Site B. It shows the importance of correction factor for liquefaction susceptibility evaluation.

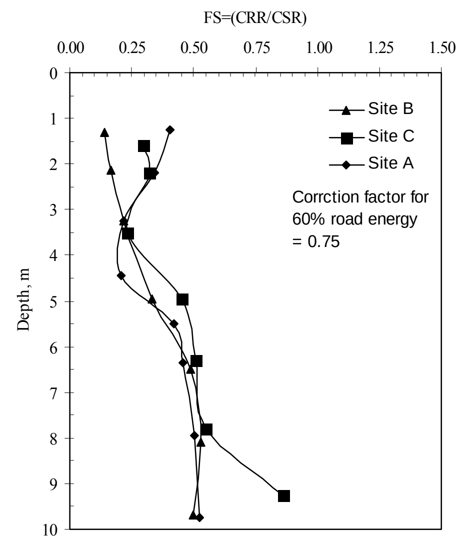

Fig. 6. Factor of safety against Liquefaction vs depth curve with SPT correction factor 0.75.

The factor of safety against liquefaction using SPT data with correction factor 1.3 and CPT data is plotted in Fig. 8. It is found that factor of safety is more than 1.0 for soil strata below a depth of 7.5 m in case of Site A and C and 6.5 in case of Site B. The F.S. evaluated using CPT data and SPT data (with correction factor for 60% rod energy =1.3) are in close agreement. However, it need further study. It is the need of time to develop an appropriate standardized correction factor for Indian Standard SPT hammer.

CONCLUSIONS

Two field tests such as standard penetration test(SPT) and cone penetration test(CPT) were considered and factor of safety against liquefaction is evaluated in this study. It is found that the evaluation of factor of safety against liquefaction using SPT very much depends on correction factor for 60% of rod energy. However, the standard energy correction factor is not available for India. On comparing the factor safety obtained from CPT as well as SPT data with energy correction factor 1.3, it is found that both are in close agreement. In the absence of standard energy correction factor for India, it is more appropriate to use the CPT data for the liquefaction susceptibility evaluation.

A major thrust is required from academia and testing agencies alike to standardize the energy correction factor, so that SPT data may be effectively used for the determination of liquefaction susceptibility.

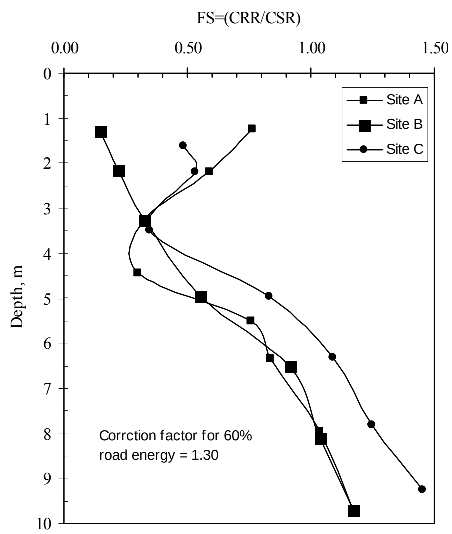

Fig. 7. Factor of safety against liquefaction vs depth curve with SPT Correction Factor 1.3.

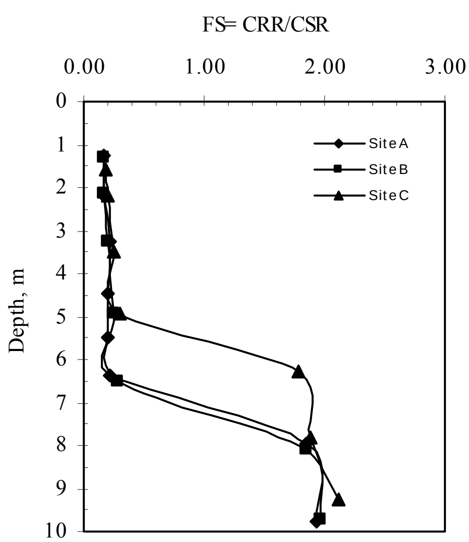

Fig. 8. Factor of Safety against Liquefaction vs Depth Curve with CPT data.

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