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Evaluation of Iranian Standard for Assessment of Liquefaction Potential of Cohesionless Soils Based on Standard Penetration Test

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***Abstract*—**In-situ testing is preferred to evaluate the liquefaction potential in cohesionless soils due to high disturbance during sampling. Although new in-situ methods with high accuracy have been developed, standard penetration test, the simplest and the oldest in-situ test, is still used due to the profusion of the recorded data. This paper reviews the Iranian standard of evaluating liquefaction potential in soils (codes 525) and compares the liquefaction assessment methods based on standard penetration test (SPT) results on cohesionless soil in this standard with the international standards. To this, methods for assessing liquefaction potential are compared with what is presented in standard 525. It is found that although the procedure used in Iranian standard of evaluating the potential of liquefaction has not been updated according to the new findings, it is a conservative procedure.

***Keywords*—**Cohesionless soil, liquefaction, SPT, Iranian liquefaction standard.

I. Introduction

EVALUATING the potential of liquefaction in region where is exposed to earthquake is very important to prevent further problems caused by the loss of soil strength. The first attempts to investigation of liquefaction potential in cohesionless soil have been done based on standard penetration test data. Although great advancement has been occurred in methods of in-situ tests the use of SPT results is yet common because of the recorded data history. Different researchers have worked on the potential of liquefaction in cohesionless soil based on SPT data. Seed and Idriss presented a simple procedure for evaluating considering the significant factors that affect liquefaction potential of sand [12]. The further studies of Seed and Idriss, Seed et al. and Youd et al. led to a modified procedure of evaluating liquefaction potential [13]-[16]. After that, different researchers tried to present modifications on correlations between cyclic resistance ratio to standard penetration number [CRR-NSPT], and to present modified correction factors. For instance, the correction factors are presented by [1]-[6], [8], [9].

The standard that is used in Iran to evaluating the potential of liquefaction is “Standard 525” which is a kind of translated version of [16]. In other words, the final procedure agreed by National Center for Earthquake Engineering Research (NCEER) is used as the standard to evaluating the potential of liquefaction [16]. The goal of this paper is making a comparison between the standard that is used in Iran with the other procedures that are presented recently and used in the world (the methods of [3] and [1]).

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II. The Procedure of Evaluating the Potential of Liquefaction

A. Standard 525

As declared before, the Iranian standard of evaluating the potential of liquefaction based on SPT data suggests the procedure presented by NCEER [16]. Although methods of Cetin et al. [3] and other previous researchers [4], [10], [12]-[15] have been explained, the main method is NCEER’s (2001) [16]. In this method, first the cyclic stress ratio is calculated through a simple relation (1):

$$\tau_{max} = 0.65 * r_d * \gamma * h * \frac{a_{max}}{g} \tag{1}$$

where rd is stress reduction factor in depth, γ is soil specific gravity, h is depth of soil, a_{max} is maximum acceleration, and g is gravity acceleration.

Different methods of determining rd coefficient has been asserted in Standard 525, including the relation suggested by [10].

$$r_d = \begin{cases} 1 - 0.00765z & z \leq 9.15m \\ 1.174 - 0.0267z & 9.15 < z \leq 23m \end{cases} \tag{2}$$

Z indicates the depth of soil under the earth surface.

Calculation of CRR is done through the correlation between CRR and modified N-SPT presented graphically or by using the formula:

$$CRR_{7.5} = \frac{1}{34-(N_1)_{60}} + \frac{(N_1)_{60}}{135} + \frac{50}{(10*(N_1)_{60}+45)^2} - \frac{1}{200} \tag{3.1}$$

$$(N_1)_{60} = N_m.C_N.C_E.C_B.C_R.C_s \tag{3.2}$$

The corrections that are done on N-SPT are according to Table I.

For simplifying the mentioned correlation, it is presented for clean sand, but usually soil contains cohesive fines which causes an increase in resistance against liquefaction. The correction for soil’s fine content (FC) is done through (4):

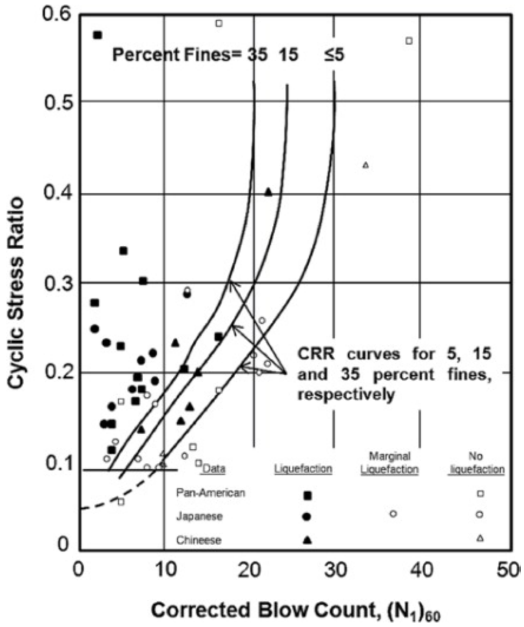

Fig. 1 Clean sand base curve for 7.5-magnitude earthquake [12]

TABLE 1
CORRECTIONS OF N-SPT PRESENTED BY [11] USED IN STANDARD 525

Factor	Equipment variable	Term	Correction
Overburden Pressure	-	CN	$C_N = (\frac{P_a}{\sigma'_{v0}})^{0.5}$, $C_N \leq 1.7$
Energy ratio	Safety Hammer	CE	0.5~1
	Donut Hammer		0.7~1.2
	Automatic Hammer		0.8~1.3
Borehole Diameter	65~115mm	CB	1
	150mm		1.05
	200mm		1.15
Rod Length	Less than3m	CR	0.75
	3~4m		0.8
	4~6m		0.85
	6~10m		0.95
	10~30m		1
Sampling Method	Standard Sampler Sampler Without Liner	CS	1.1~1.3

$$(N_1)_{60,cs} = \alpha + \beta(N_1)_{60} \tag{4.1}$$

$$\alpha \begin{cases} 0 & FC \leq 5\% \\ exp\left[1.76 - \frac{190}{FC^2}\right] & 5\% < FC < 35\% \\ 5 & FC \geq 35\% \end{cases} \tag{4.2}$$

$$\beta \begin{cases} 1 & FC \leq 5\% \\ exp\left[0.99 - \frac{FC^2}{1000}\right] & 5\% < FC < 35\% \\ 1.2 & FC \geq 35\% \end{cases} \tag{4.3}$$

Finally, the safety factor against liquefaction is calculated through (5):

$$FS = \left(\frac{CRR_{7.5}}{CSR}\right) * MSF * K_\sigma * K_\alpha \tag{5}$$

In this formula magnitude scaling factor is indicated as MSF, K_σ is effective overburden stress factor and K_α is static shear stress factor.

$$MSF = \frac{10^{2.24}}{M_W^{2.56}} \tag{6}$$

MW is the magnitude of earthquake.

$$K_\sigma = \left(\frac{\sigma'_{v0}}{P_a}\right)^{(f-1)} \tag{7}$$

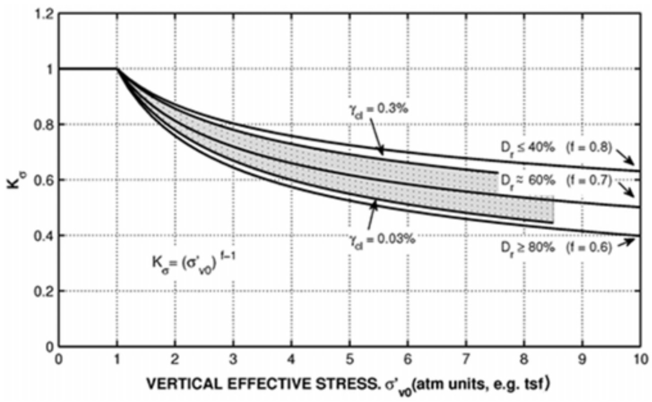

Fig. 2 Proposed curve for estimation of K_σ [11]

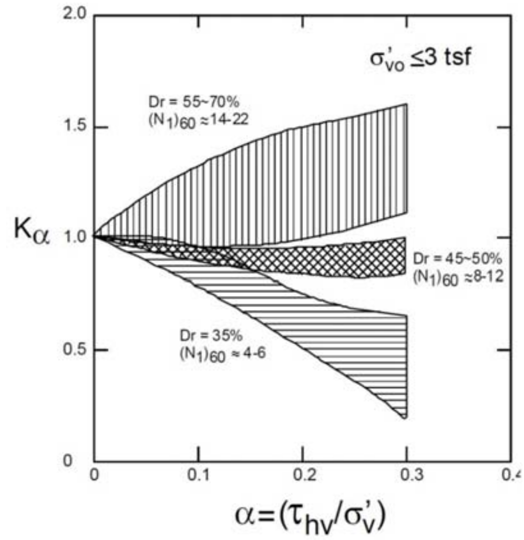

Fig. 3 Proposed curve for estimation of Kα [11]

B. The Method Proposed by Cetin et al. [4]

Some changes on the procedure have been suggested by NCEER-2001 [3]. Here the differences with the method used in standard 525 are represented. Cetin et al. [4] presented new correlation between CRR- (N1)60cs based on the new data history which were not considered in NCEER's. Also, they used new relations for considering the effect of fine content, for which the maximum increase of N-SPT was about 6.5 (in NCEER's method (standard 525) this amount was 10). The other differences of this method are the correction factors of sampling method and rod length.

$$CRR = exp\left[\frac{(N_1)_{60,CS} - 29.53Ln(M_W) - 3.70Ln\left(\frac{\sigma'_v}{P_a}\right) + 14.05}{13.32}\right] \quad (8)$$

$$(N_1)_{60,CS} = (N_1)_{60} * C_{FINES} \quad (9)$$

$$C_{FINES} = (1 + 0.004 * FC) + 0.05 * \left(\frac{FC}{(N_1)_{60}}\right), 5\% \leq FC \leq 35\% \quad (10)$$

$$C_s = 1 + \frac{(N_1)_{60}}{100} \quad (11)$$

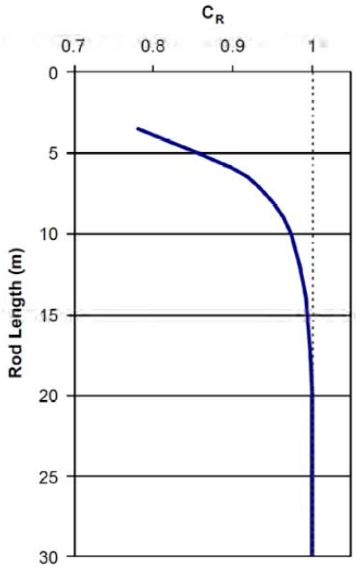

Fig. 4 Rod length correction by Cetin et al. [4]

C. The Method Proposed by Boulanger and Idriss [1]

Boulanger and Idriss made some changes on the NCEER's method of evaluating the potential of liquefaction. They have presented their last revision on 2014 [1]. The summery of their modifications on NCEER's method (standard 525) is presented here. They presented new correlation between (N1) 60, cs-CRR based on new data history. The rd parameter is calculated based on [7]. CN correction factor related to (N1)60, cs. Also the fine content correction, K_σ and MSF are different from NCEER's. The last correction on MSF is presented on 2014 [1]. In this method Kα factor is not considered. The modified relations are presented here.

$$CRR_{M=7.5,\sigma'_v=1atm} = \exp\left(\frac{(N_1)_{60CS}}{14.1} + \left(\frac{(N_1)_{60CS}}{126}\right)^2 - \left(\frac{(N_1)_{60CS}}{23.6}\right)^3 + \left(\frac{(N_1)_{60CS}}{25.4}\right)^4 - 2.8\right) \quad (12)$$

$$r_d = \exp[\alpha(z), \beta(z). M] \quad (13.1)$$

$$\alpha(z) = -1.012 - 1.126\sin\left(\frac{z}{11.73} + 5.133\right) \quad (13.2)$$

$$\beta(z) = 0.106 + 0.118\sin\left(\frac{z}{11.28} + 5.142\right) \quad (13.3)$$

$$C_N = \left(\frac{P_a}{\sigma'_v}\right)^m \leq 1.7 \quad (14.1)$$

$$m = 0.784 - 0.0768\sqrt{(N_1)_{60CS}} \quad (14.2)$$

$$(N_1)_{60CS} = (N_1)_{60} + \Delta((N_1)_{60}) \quad (15.1)$$

$$\Delta(N_1)_{60} = \exp\left(1.63 + \frac{9.7}{FC+0.01} - \left(\frac{15.7}{FC+0.01}\right)^2\right) \quad (15.2)$$

$$K_\sigma = 1 - C_\sigma Ln\left(\frac{\sigma'_v}{P_a}\right) \leq 1.1 \quad (16.1)$$

$$C_\sigma = \frac{1}{18.9 - 2.55\sqrt{(N_1)_{60Cs}}} \leq 0.3 \quad (16.2)$$

$$MSF_{max} = 1.09 + \left(\frac{(N_1)_{60cs}}{31.5}\right)^2 \leq 2.2 \quad (17)$$

III. Comparing the Potential of Liquefaction in Different Methods

Methods of Boulanger and Idriss [1] and the Cetin et al. [4] used new data history to present CRR-N correlation. They considered some modifications on correction factors and each one's allegation is to be more accurate. As a comparison between these methods and what is used in standard 525, the solved problem which is presented in standard 525, is calculated by using the two other procedures and the results are presented in Table III and Fig. 5.

TABLE II
CHARACTERISTICS OF THE SOIL LAYER

Soil Type	Depth (m)	Fine Content (%)	N_{SPT}	LL %	PI %	σ_v (Kg/cm^2)	σ_v' (Kg/cm^2)
CL	1.5	100	8	42	19	0.29	0.14
ML	3	84	7	NL	NP	0.59	0.29
ML	4.5	84	12	NL	NP	0.89	0.44
ML	6	84	13	NL	NP	1.18	0.59
ML	7.5	82	41	NL	NP	1.48	0.73
ML	9	72	85	NL	NP	1.79	0.89
CL	10.5	96	44	47	22	2.11	1.06
ML	12	73	51	NL	NP	2.43	1.23
ML	15	73	81	NL	NP	3.06	1.56
ML	18	73	94	NL	NP	3.69	1.89
ML	21	76	39	NL	NP	4.33	2.23
ML	24.5	76	66	NL	NP	5.06	2.61

Note: C_E = 0.95, a_{max}/g = 0.17, M_w = 5.93

TABLE III
THE SOLVED EXAMPLE OF EVALUATING THE POTENTIAL OF LIQUEFACTION

Depth(m)	FS-Standard 525 [11]	FS-Cetin et al.4	FS-Boulanger and Idriss [1]
3	0.41	1.85	1.20
4.5	1.79	5.00	2.87
6	4.13	5.00	3.17
7.5	4.56	5.00	5.00
9	4.36	5.00	5.00
10.5	4.56	5.00	5.00
12	3.89	5.00	5.00
15	5.00	5.00	5.00
18	4.47	5.00	5.00
21	4.33	5.00	5.00
24.5	4.94	5.00	5.00

As it can be seen in Table II in depths of 1.5 m and 10.5 m cohesive soil has been detected. Presented algorithms are used just for cohesionless soil, so the diagram for depth of 10.5 m which is a middle layer is drawn approximately (These layers are colored in pink to be distinguishable).

As it can be seen in Fig. 5 the factors of safety against liquefaction determined by standard 525 are less than what is calculated by [3] and [1]. Hence, although the procedure that is used in Iranian standard of evaluating the potential of liquefaction has not been updated according to the new findings, it is a conservative procedure.

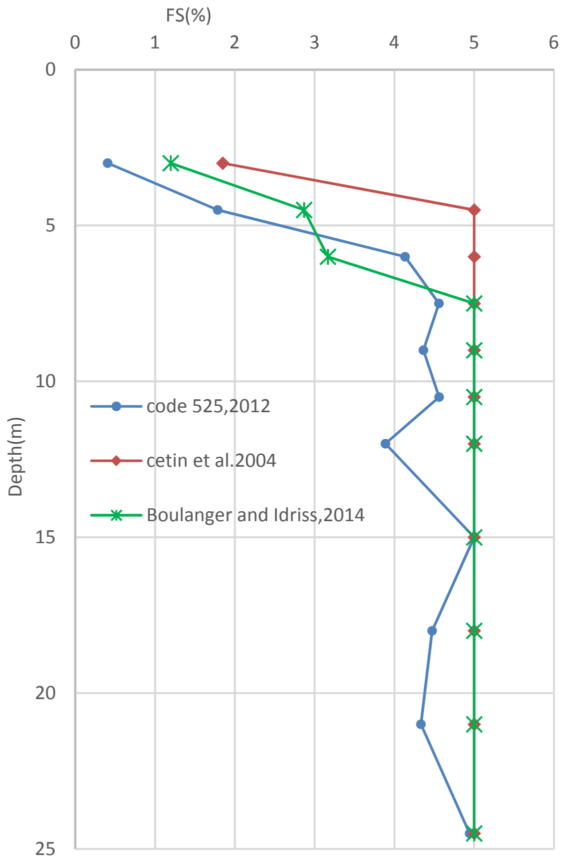

Fig. 5 Comparison of the factor of safety against liquefaction determined by Cetin et al. [4] and Boulanger and Idriss [1] with what is used in Iranian standard of evaluating liquefaction (Standard525)

IV. Conclusion

In this paper the procedure of evaluating the potential of liquefaction of cohesionless soil has been compared with the international procedures. The differences of these procedures are represented and the results of a solved problem which is presented in standard 525 are compared with the results of this standard. The results showed that the procedure which is presented in Iranian standard of evaluating the potential of liquefaction is more conservative than the compared procedures.

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