## Comparisons Between Liquefaction Potential Estimated Based on the SPT and CPT Data in Southern Parts of Iran

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ABSTRACT: The geotechnical characteristics of the soil layers is one of the main factors influencing liquefaction potential of the ground. The standard penetration test (SPT) had been extensively used to measure the in-situ soil properties due to its simplicity and availability all over the world in the majority of the liquefaction studies. Nevertheless, it suffers from some shortcomings in comparison with another in-situ test called cone penetration test (CPT). In order to compare the liquefaction potentials based on the SPT data with those based on the CPT data, some sites in the southern parts of Iran have been selected and studied. The geotechnical characteristics of these sites have been measured both from SPT and CPT methods, and for the same seismicity condition, the liquefaction potential were estimated using the SPT and CPT based evaluation methods. At the end some correlations were derived between the obtained results and their validities were discussed and justified. Although the correlation factor was found to be very small and the results were highly scattered, it could be concluded that the liquefaction evaluation methods based on the SPT data show more conservative results compared with those based on the CPT data.

Keywords: Liquefaction; CPT; SPT; Relationship; Potential; Seismicity

## 1. Introduction

Using the SPT data for evaluating liquefaction potential of the soil layers is nearly as long as the phenomenon was first recognized during 1964 Niigata earthquake. Seed and Idriss [3] developed the first experimental method based on the SPT data to evaluate the liquefaction potential of the ground during strong earthquakes. Since then, although the original SPT based evaluation method has been modified and promoted extensively and other evaluation methods have been suggested and used by many researchers, the SPT-based methods have become increasingly common and popular.

One of the main reasons is the simple device and easy technique associated with the standard penetration test. Also the availability of the equipment and operating system is another factor making it more routine in practice. Furthermore the vast majority of geotechnical investigation carried out in site projects in the past, have been involved with the *SPT*, and considerable data can be collected and used in these regions. Nevertheless, there are some deficiencies and shortcomings with the *SPT*, the most important of which can be summarized as follows:

- The soil profile cannot be detected continuously.
- The pore pressure cannot be measured during the test.
- The sensitivity of the device to changing soil profile is sometimes poor.
- The influence of pore pressure fluctuations due to blow effects of the system on the test results can not be considered.
- The theoretical interpretations about the test results cannot be implemented.

Although the effect of these factors on the accuracy and reliability of the test results are not the same, some of them may considerably influence the measured data. In contrast to SPT, the CPT is also another in situ testing device and technique that can be used for the same purpose, without having the above mentioned problems. However the complexity of the system and the more energy and time consuming of operation relative to the SPT, have caused it less popular and common in practice.

Yet there are some liquefaction evaluation methods based on the CPT data, in which the geotechnical characteristics of soil obtained from tip resistance and WWW.SID.W

The repeatability of the test can not be guaranteed.

sleeve friction of the device can be used more accurately. Since extensive efforts still are being done for microzoning different cities against liquefaction using the existing SPT data all over the country, in this study some different sites have been selected to compare the liquefaction potential estimated by using SPT and CPT data. This may clarify the level of reliability and accuracy of the SPT based methods. The specifications of the selected sites and liquefaction potential evaluation methods used in this study are described in the following sections.

### 2. The Selected Sites for Study

There are some initial requirements for each site to be under consideration in this study. The results of the *SPT* and *CPT* studies must have been available and the points at which these tests are carried out cannot be far from each other. Also there must have been some liquefaction potential observed in the site at least according to one or more methods based on the *SPT* and *CPT* data. Furthermore the test should have been done in the site by an acceptable degree of accuracy and satisfactory.

Considering these facts, some different sites in the southern parts of Iran have been selected. These sites were located on the Hormozgan province near the coastal region of the Persian Gulf. The ground in these areas is usually consisted of deposits belonging to Testiary and Quaternary geological periods. The soil layers in these sites are between sandy silts to silty sands and can be classified as fine granular soils ( $PI \leq 5\%$ ). The water

table in these sites are between 1.5-3.0m depths and the densification of the top layers can be categorized between medium to loose. The seismicity of the regions is relatively high compared with other areas of the country. The positions of the studies sites are shown in Figure (1).

## 3. The Collected SPT and CPT Data in the Sites

In all sites the existing SPT and CPT data belonging to different depths and layers were collected. The SPT data have been taken nearly every 1.5-2m and also at changing the soil profiles. The position of the water table and some physical properties of the layers were also recorded and used in the studies. Some main assumptions in connection with SPT and CPT data were made, the important of which are as follows:

- Since there has not been definite information about the exact position of the SPT data along the soil profile, a kind of moment in the ± 0.25m (in each layer separately) depth interval has been estimated, and used as an average SPT value for the whole distance.
  - The average of the tip resistance and sleeve friction of the *CPT* data have been calculated also in  $\pm 0.25m$ depth interval. As a result, the continuous *CPT* data can be compared with the sporadic point data of *SPT*. In fact the depth interval selection has been done so that, within the relevant distance, the diagram area of qc-depth or fs-depth to have equal amounts on both sides (i.e. a kind of weight



Figure 1. The general plan of the region with the selected areas for liquefaction studies.

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averaging has been made).

- Since the ground characteristics vary with depth gradually, for points whose soil characteristics, such as the fine content or the clay percent, were not available, a linear interpolation between two adjacent points has been done. For the *SPT* data the same interpolation have also been made in case of necessity.
- The plasticity index for all selected points were in the range of  $0\% \le PI \le 10\%$ , the cyclic resistance ratios (*CRR*) for points having  $5\% \le PI \le 10\%$  have been considered to increase linearly from 0 to 5% (According to the comments of Youd & Idriss in the *NCEER* workshop in 1997) [4].
- Since the suggested method by Robertson & Wride [1] for points having  $q_{C1N} < 1$  (where  $q_{C1N} = C_Q$   $(q_c / P_a)$  and  $C_Q$  is a normalizing factor for cone penetration resistance) and or  $(N_1)_{60} < 5$  can not be valid, in this study 15 points [having  $(N_1)_{60} < 5$ ] and 6 points [Having  $q_{C1N} < 1$ ] were ignored [5].

The total points having acceptable *CPT* and *SPT* data in these sites were 87. A typical *CPT* records belong to one of the site under studies is presented in Figure (2). *SPT* records is presented in Figure (3).

## 4. The Liquefaction Evaluation Method Used in the Study

Although there are different methods for evaluating liquefaction potential of the sand layers using SPT and



 Figure 2. Typical CPT data belong to one of the sites under studies (Almahdi Al. Site).

*CPT* data, in order to avoid scattering the results, one of them which proven to be the most appropriate one, and has been used in many cases by different researchers, has been selected and used as below.

### 4.1. Robertson and Wride Method [1, 2]

This method is in fact based on the method, originally suggested by Seed and Idriss [3]. In this method the values of tip resistance of the *CPT* and also the number of *SPT* blows, are corrected in terms of the fine content according to one of the two following ways:

$$(N_1)_{60Cs} = Ks (N_1)_{60}$$

In which

$$K_s = 0.025 \text{ FC} + 0.875$$
 for  $\% \le FC \le 35\%$ ,  $PI \le 5\%$ , & $K_s = 1$  for  $FC \le 5\%$ ,  $PI \le 5\%$ 

where FC is the fines content measured from laboratory gradation tests on retrieved soil samples and PI is Plasticity Index of the soil.  $(N_1)_{60}$  is SPT blow counts corrected for overburden stress.

The tip resistance of the *CPT* can be corrected by these equations:

$$(q_{c1N})_{cs} = K_c q_{c1N}$$

In which

 $Kc = 1.0 for Ic \le 1.64, \& Kc = -0.403 Ic^4 + 5.581 Ic^3 - 21.63 Ic^2 + 33.57 Ic - 17.88 for Ic > 1.64$ 

 $I_c$  is the soil behavior type index obtained by using an Iterative Method [2] and  $q_{c1N}$  is the cone penetration resistance corrected for overburden stress.

In the second way, which has been developed in 1997, the following equations can be used to correct the *SPT* numbers and also the *CPT* tip resistance, respectively.

#### 4.2. Seed and Idriss Method

The following equations, developed by I.M. Idriss with assistance from H.B. Seed are recommended for correcting standard penetration resistance determined for silty sands to an equivalent clean sand penetration resistance:

$$(N_1)_{60Cs} = \alpha + \beta (N_1)_{60}$$

where  $\alpha$  and  $\beta$  are coefficients determined from the following equations:

$\alpha = 0$	for $FC \leq 5\%$ ,
$\alpha = Exp. [1.76 - (190/FC)^2]$	for 5% < FC < 35%, &
$\alpha = 5.0$	for $FC \ge 35\%$
$\beta = 1.0$	for $FC \leq 5\%$ , $0 = 0.3$
$\beta = [0.99 - (FC^{1.5}/1000)]$	for 5% < FC < 35%, &
$\beta = 1.2$	for FC ≥ 35% D.ir

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hm	Archive of SID Description	SAMIB	Sample	Sample	SPT No.			Light	Plastic	Plas: 100	Moisture	Density	Conten	Clay
Dept	ees by different resourchers).	010	Spe	(I) II	15cm	15cm	15cm	1 this	PLAN	AJ+	Wooth	ang s	*Co	Colo
Ē	have been lielectowold a	2	3	4	5	6	7	8	9	10	11	12	13	14
0-	Light Brown very Stiff Sandy		D1	0.3	12	13	10	24	17	7	11	1.75	56	18
-	Sitly Clay (CL - ML)			0.75		300	1500 5265	de in	cities en roa		heen den on have a	tadati polati	et peu me inte	estes a
1-	Grey Loose Silty Sand (SM)		D2	1	3	2	2	NL	NP	NP	PT and C	PT de	46	gn <del>5</del> 10
-	the OP-Vand steer the mumber		dan q	1.45	oley	<sup>a</sup>	Were	anto	6.56	ofsi	tex for all	el vits	ie plast	T data
2-	Same as above		D3	wold gnib	1	2	2	TP 24			TH 2 TA	15	1.53	a some
-	Green Silty Clay (CL-ML)		UI	2.45		1988	010	mon	Vins	11.52	to more	Stall	en con	igd and.
3-	Light Brown Medium Silt with Sand (ML)			3		viii		and a	PTd			iner gr		Zwhich
-	17% transferra and addition		D4	3	1	2	2	NL	NP	NP	25	1.6	72	8 <u>*</u> \$
4-	Grey Loose Sitly Sand (SM)		D5	4	1	2	2	NL	NP	NP	23	1.5		a soil
-	Rend more hour to the			3-6-		50	forth			196	an a a AFGhi	1251 14		in each
5-	Grey Loose Clayey Sand (SC)		D6	5	2	3	3	25	17	8	27	1.62	38	giotado giotado giotado
6-	Green to Grey Hard Lean Clay		D7	6	6	15	29	36	22	14	SIGUR.	18 515		50570°m
-	with Sand (Mari)		CB8	6.7	ups			34	21	13				
7-	Same as Above		D9	7	16	50 (1	1cm)	n be e Kauta	onpe M	ed a		ibinod See the	point.	data of
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B	orehole No. BH6 ocation: X = 4140, Y = 7230	U = U D = I	Undistur Disturbe	bed Sam	mple ple									
I	Level: + 1716 CB = Core Barrel Sample													
1	Water Level: 2.70m DE = Denison Sample													

Figure 3. A Typical Boerhole Log.

And for CPT:

 $(q_{C1N})_{CS} = q_{C1N} + \Delta (q_{C1N})$ 

in which

 $\Delta(q_{C1N}) = K_{CPT} (q_{C1N})_{CS}$ 

$$\Delta(q_{C1N}) = [K_{CPT} / (1 - K_{CPT})](q_{C1N})$$

where

 $\begin{array}{ll} K_{CPT} = 0 & \mbox{for} & AFC \leq 5\%, \\ K_{CPT} = 0.0267 \, (AFC \ -5) & \mbox{for} & \%5 < AFC < 35\%, \& \\ K_{CPT} = 0.8 & \mbox{for} & AFC \geq 35\% \end{array}$ 

Where the *AFC* is Apparent Fine Content, to be determined as follows: [1]

AFC = 0	for	<i>Ic</i> < 1.26,
$AFC(\%) = 1.75 Ic^{3.25} - 3.7$	for 1.2	$26 < Ic \le 3.5, \&$
AFC (%) = 100	for	<i>Ic</i> > 3.5

This method (4.2 method) has been used in the present study.

## 5. Comparison between Analysis Results Based on SPT and CPT Data

The comparison between the results of analysis has been made in terms of calculated safety factors, based on SPT data and CPT data belong to each site under consideration. A linear regression has been used to correlate the analysis results and the correlation factors have been considered as the degree of relationship between these two methods. The safety factors against liquefaction using the Robertson and Wride method [1] for all sites have been calculated and shown in Figure (4).

As can be seen the results are very scattered. In ten points the absolute differences between their safety factors are more than 1.0 (ABS > 1.0). If they are ignored,

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the correlation factor will increase significantly, but this factor As still yery small. The above points only cover 20% of all information points, see Figure (4).

According to the general results of this study, as far as the fine non-cohesive soils are concerned, in spite of highly scattered results, an overall conclusion can be derived, in the way that the liquefaction potential evaluation of the ground by *SPT* data would be more conservative (Pessimistic) than that obtained by *CPT* data (Optimistic), see Figure (4). As it was observed in this study, all sites selected were in the sandy silt to silty sand ranges, thus the results can be valid only for these fine granular soils. This classification can be also confirmed by *CPT* data belonging to the sites, see Figure (5).







Figure 5. Soil Classification Based on CPT results.

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# 6. Comparing the Results with other Resea-

Different researchers have focused on liquefaction potentials of susceptible soils in a comparative study by using both *SPT* and *CPT* of the ground layers. Among them Youd and Gilstrap [5] carried out extensive investigations to correlate between liquefaction safety factors based on CPT and SPT data of several sites. They used Robertson-Wride [1] method and obtained important results in their studies. The information points used, mainly belonged to the sites of clean sand to silty sands.

It can be seen that, see Figure (6), for AFC > 50%, the suggested graphs by Robertson and Wride give the predicted AFC values less than its real value in term of  $I_c$ . This is clear in Youd and Gilsrap studies as well. It has to be noted that the suggested AFC-  $I_c$  relation by Robertson-Wride is an average curve, which has been, fitted to an extensive range of many informations points.

In the comparison made between liquefaction safety factors estimated based on the *CPT* and *SPT* data by Youd and Gilstrap, show also a large scattering ( $R^2 = 0.5864$ ), nevertheless, ignoring the points of having ABS > 0.4 and concentrating to the 77% of the remaining points, the correlation factor would be of high value ( $R^2 = 0.914$ ).

The main cause of this difference between the results of Gilstrap and Youd and the results of the current study may be attributed to the quite fine nature of the selected sites in this piece of research. As noted earlier the soil layers involved in this study belonged to the southern region of Iran, and the surfacial layers which are susceptible to liquefaction's mainly consisted of fine sand to silty material which considerably influence the penetration strength in the standard penetration and cone penetration tests.

#### 7. Summary and Conclusions

In order to find a correlation between liquefaction evaluation results based on the *SPT* data and *CPT* data, some different sites were selected. The sites were all belonged to the southern part of Iran, and their geotechnical characteristics were measured using both in-situ tests; SPT and *CPT* up to about 25*m* depths separately.

The soil fabrics were mainly non-cohesive fine materials ranging from silty sands to sandy silts. The water table was relatively high and the seismicity of the region was classified as the high-risk area in the country.

The liquefaction potential of each site was evaluated, using Robertson and Wride [1] method. The safety factors of each site against liquefaction were estimated using the mentioned method for *SPT* data and *CPT* data separately. The results were plotted against each other and the correlation between the safety factors calculated based on the *SPT* data and the *CPT* data were obtained.

As mentioned before the ground soils in the selected areas were sandy silts to silty sands, according to the Unified Soil Classification System. Referring to Figure (7) it can be seen that as the plasticity of the fine grains increases, the agreement between the results from the two tests decreases (the criterion for agreement is only similar predictability of liquefaction by *CPT* and *SPT* data, irrespective of the safety margins of each test, Figure (7a)).

Also it is evident that increasing the fine content of the soils leads to decreasing the agreement between the results of two tests. This fact is shown for two ranges of FC < 35% and FC > 35% in Figure (8a). The distribution of the fine content in the selected sites is given in Figure (8b). Furthermore, it may be seen that increasing the clay content of the soil, results in decreasing the agreement between results of the two tests, see Figures (9a) and (9b).



Figure 6. Correlation between fine content, Fc, of the selected sites and soil behavior index, Ic, from the Closest GPT Sounding.



Figure 7. The plasticity index, PI, distribution in the selected points and it's effect on the compatibility between CPT-SPT analysis results. (When Both CPT and SPT show that liquefaction will occur, they are called COMPATIBLE and vice versa).



Figure 8. The fine content, Fc, distribution in the selected points and it's effect on the compatibility between CPT-SPT analysis results.



Figure 9. The clay content, Cc, distribution in the selected points and it's effect on the compatibility between CPT-SPT analysis results.

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Although the correlation factor was found to be very small and the results were highly scattered, it could be concluded that the liquefaction evaluation methods based on the SPT data show more conservative results compared with those based on the CPT data. Indeed, the above results are obtained according to some limited data points. To achieve more accurate, comprehensive and reliable results, some more information points from much more sites are required.

#### References

- Robertson, P.K. and Wride, C.E. (1997). "Cyclic Liquefaction and its Evaluation Based on SPT and, CPT", *Final Contribution to the Proceedings of the 1996* NCEER Workshop on Evaluation of Liquefaction Resistance (T.L Youd, Chair).
- 2. Robertson, P.K. and Wride, C.E. (1998). "Evaluating

Cyclic Liquefaction Potential Using the Cone Penetration Test", *Canadian Geotechnical Journal*, 35(3),442-459.

- Seed, H.B. and Idriss, I.M. (1971). "Simplified Procedure for Evaluating Soil Liquefaction Potential", J. of the Soil Mechanics and Foundations Division, ASCE, 97(SM9), 1249-1273.
- Youd, T.L. and Idriss, I.M., eds (1997). "Proceedings of the NCEER on Evaluation of Liquefaction Resistances of Soils Tech. Report NCEER-1997-0022", Multidisciplinary Center for Earthquake Engineering Research, Buffalo, New York.
- Youd, T.L. and Gilstrap, S.D. (1999). "Liquefaction and Deformation of Silty and Fine Grained Soils", Proceedings 2<sup>nd</sup> International Conference on Earthquake Geotechnical Engineering, Lisbon, Portugal, 3, 1013-1020.

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