Comparison 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 repeatability of the test can not be guaranteed.
- 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 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 1.5-3.0*m* 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 1.5-2*m* 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 $\pm 0.25m$ (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

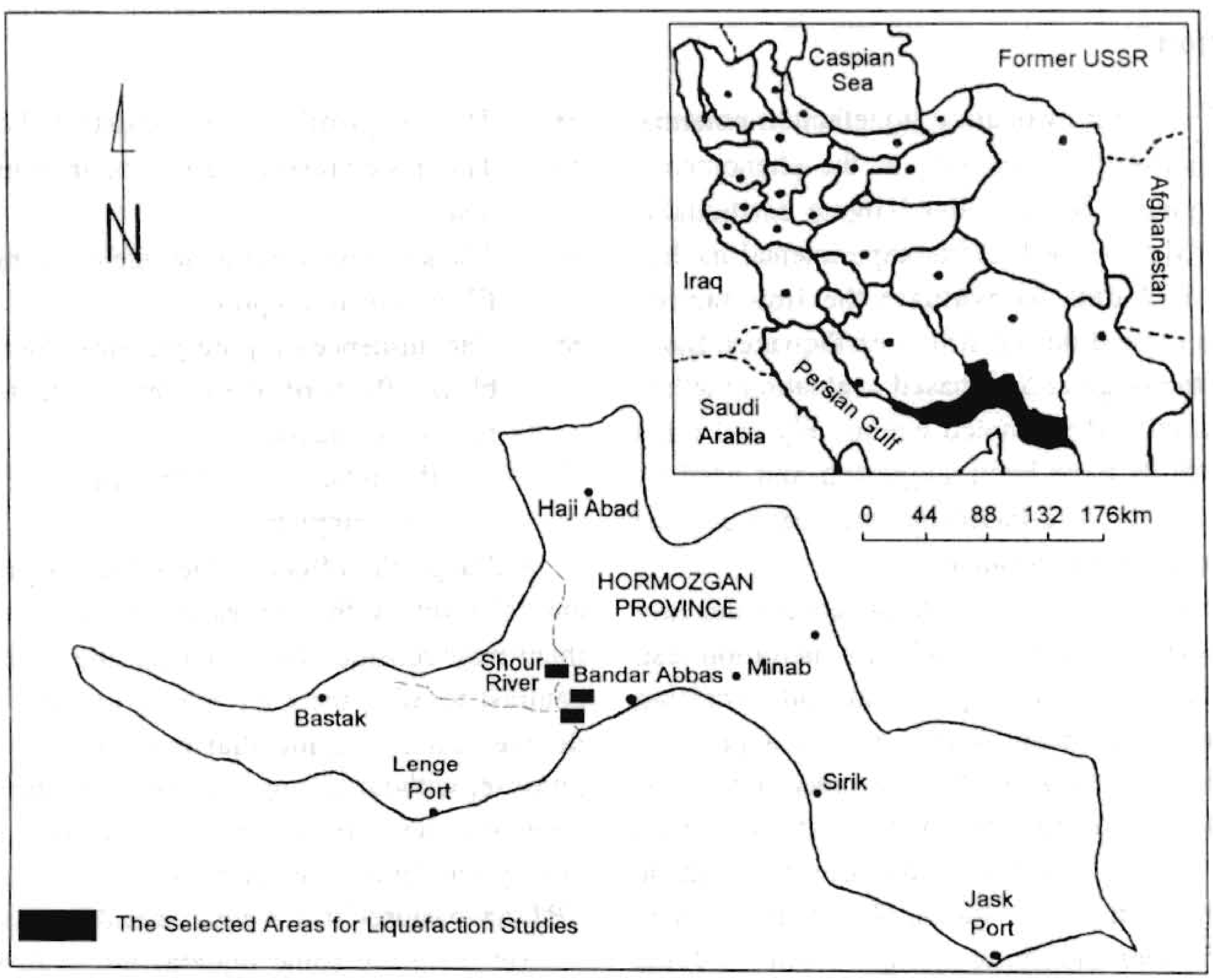


Figure 1. The general plan of the region with the selected areas for liquefaction studies.

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 *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.

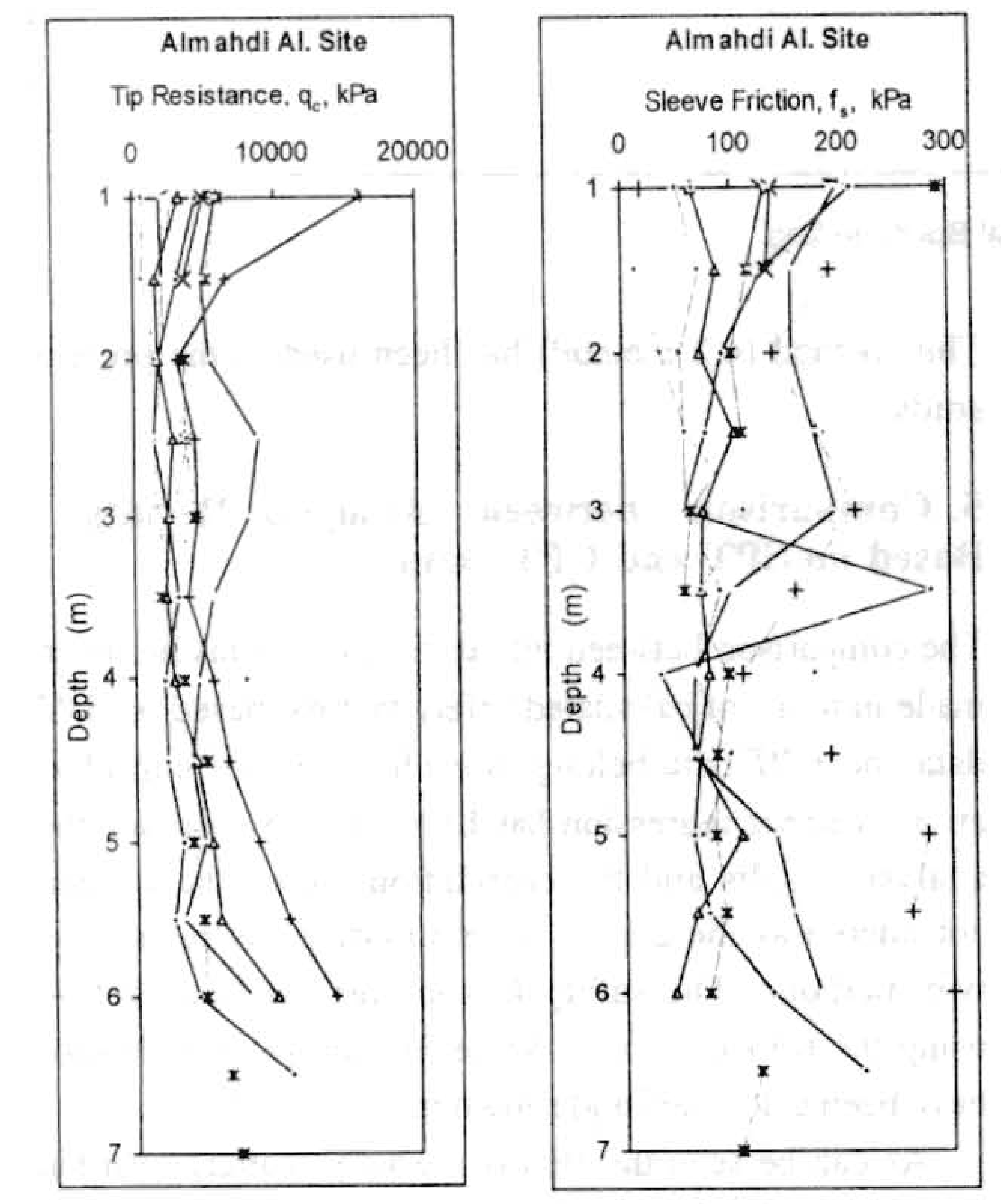


Figure 2. Typical CPT data belong to one of the sites under studies (Almahdi Al. Site).

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

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

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

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

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 α and β are coefficients determined from the following equations:

$$\alpha = 0 \quad \text{for } FC \le 5\%,$$
$$\alpha = Exp.[1.76 - (190/FC)^2] \quad \text{for } 5\% < FC < 35\%, \quad \&$$
$$\alpha = 5.0 \quad \text{for } FC \ge 35\%$$

$$\beta = 1.0 \quad \text{for } FC \le 5\%,$$
$$\beta = [0.99 - (FC^{1.5}/1000)] \quad \text{for } 5\% < FC < 35\%, \&$$
$$\beta = 1.2 \quad \text{for } FC \ge 35\%$$

Depth m	Description	Symbole	Sample and Type	Sample Depth (m)	SPT No. 15cm	15cm	15cm	Liquid Limit LL	Plastic Limit PL	Plas. Index PI	Moisture Content W%	Wet Density gr/cm³	Fine Content FC%	Clay Content CC%
	1	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										
1	Grey Loose Silty Sand (SM)		D2	1	3	2	2	NL	NP	NP			46	-
				1.45										
2	Same as above		D3		1	2	2					15	1.53	
	Green Silty Clay (CL- ML)		U1	2.45										
3	Light Brown Medium Silt with Sand (ML)			3										
			D4	3	1	2	2	NL	NP	NP	25	1.6	72	-
4	Grey Loose Sitly Sand (SM)		D5	4	1	2	2	NL	NP	NP	23	1.5		
5	Grey Loose Clayey Sand (SC)		D6	5	2	3	3	25	17	8	27	1.62	38	-
6	Green to Grey Hard Lean Clay with Sand (Marl)		D7	6	6	15	29	36	22	14				
			CB8	6.7				34	21	13				
7	Same as Above		D9	7	16	50 (11cm)								
	End of Boring at 7.26 m													

Borehole No. BH6 Location: X = 4140, Y = 7230 Level: + 1716 Water Level: 2.70m	U = Undisturbed Sample D = Disturbed Sample CB = Core Barrel Sample 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

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

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

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

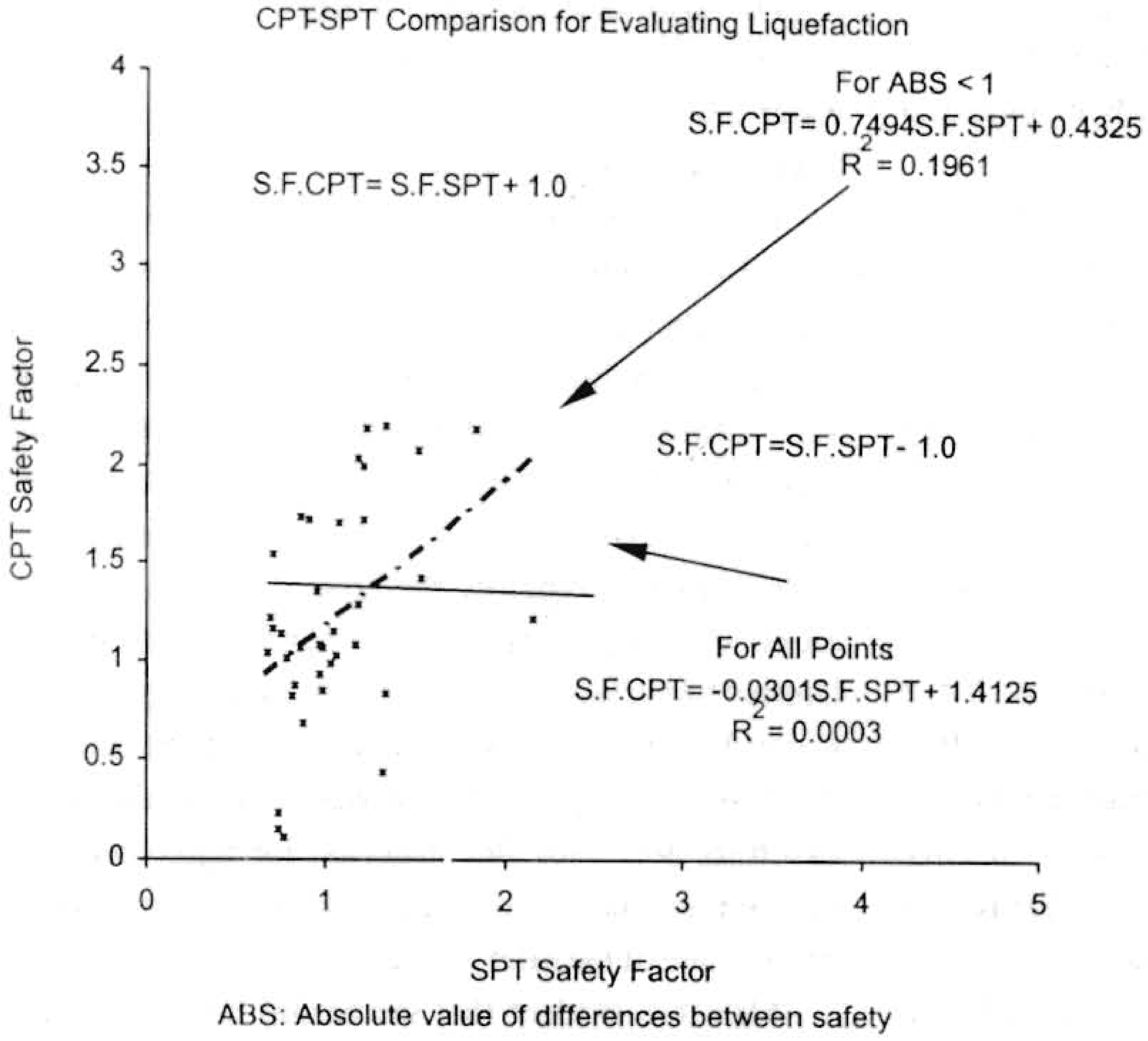
This method (4.2 method) has been used in the present study.

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, the correlation factor will increase significantly, but this factor is still very 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).



Series	Standard Deviation
All points	0.615
ABS<1	0.456

Figure 4. Comparison between safety factors against liquefaction using the method suggested by Robertson & Wride [2].

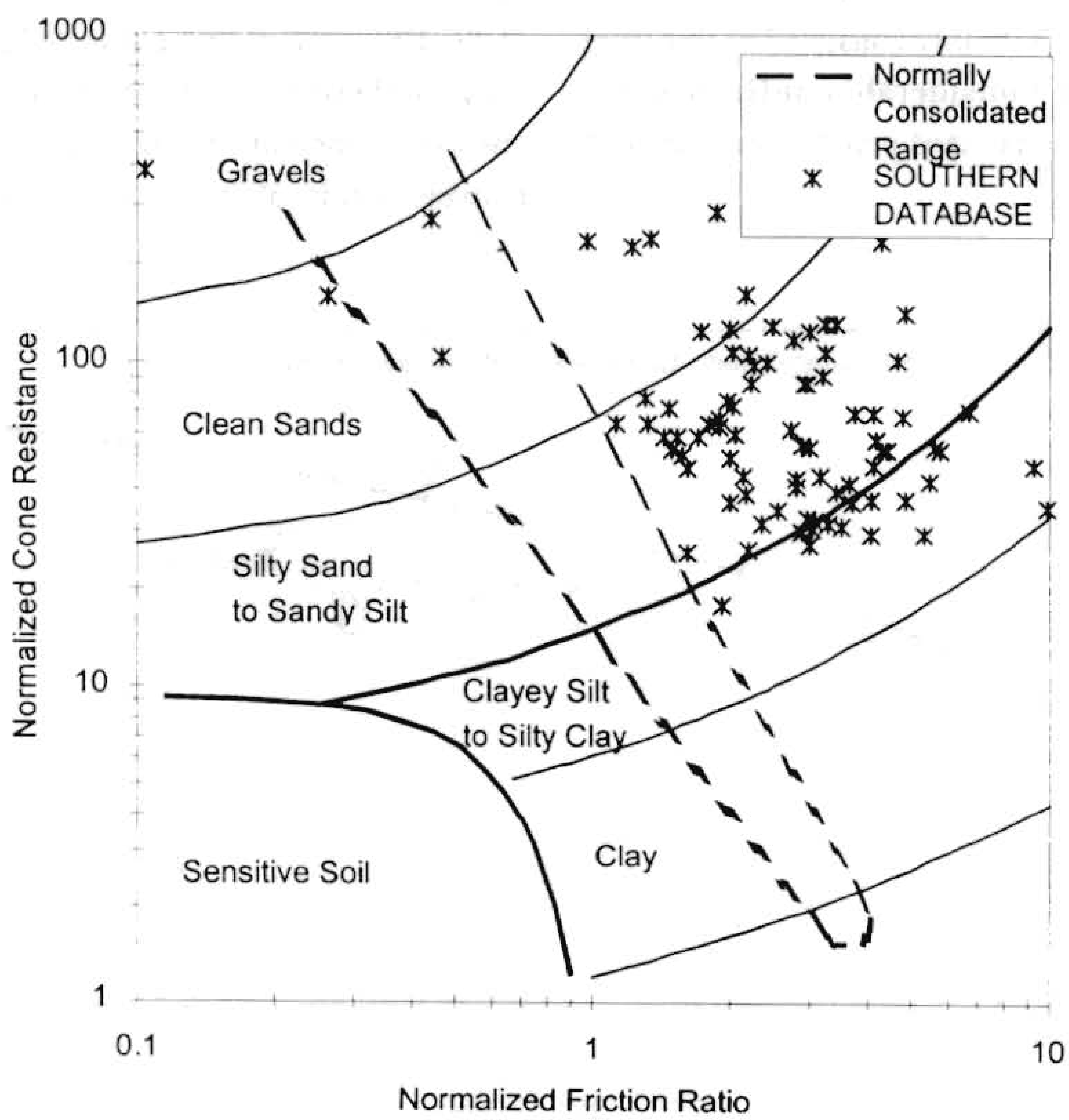


Figure 5. Soil Classification Based on CPT results.

6. Comparing the Results with other Researcher's

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).

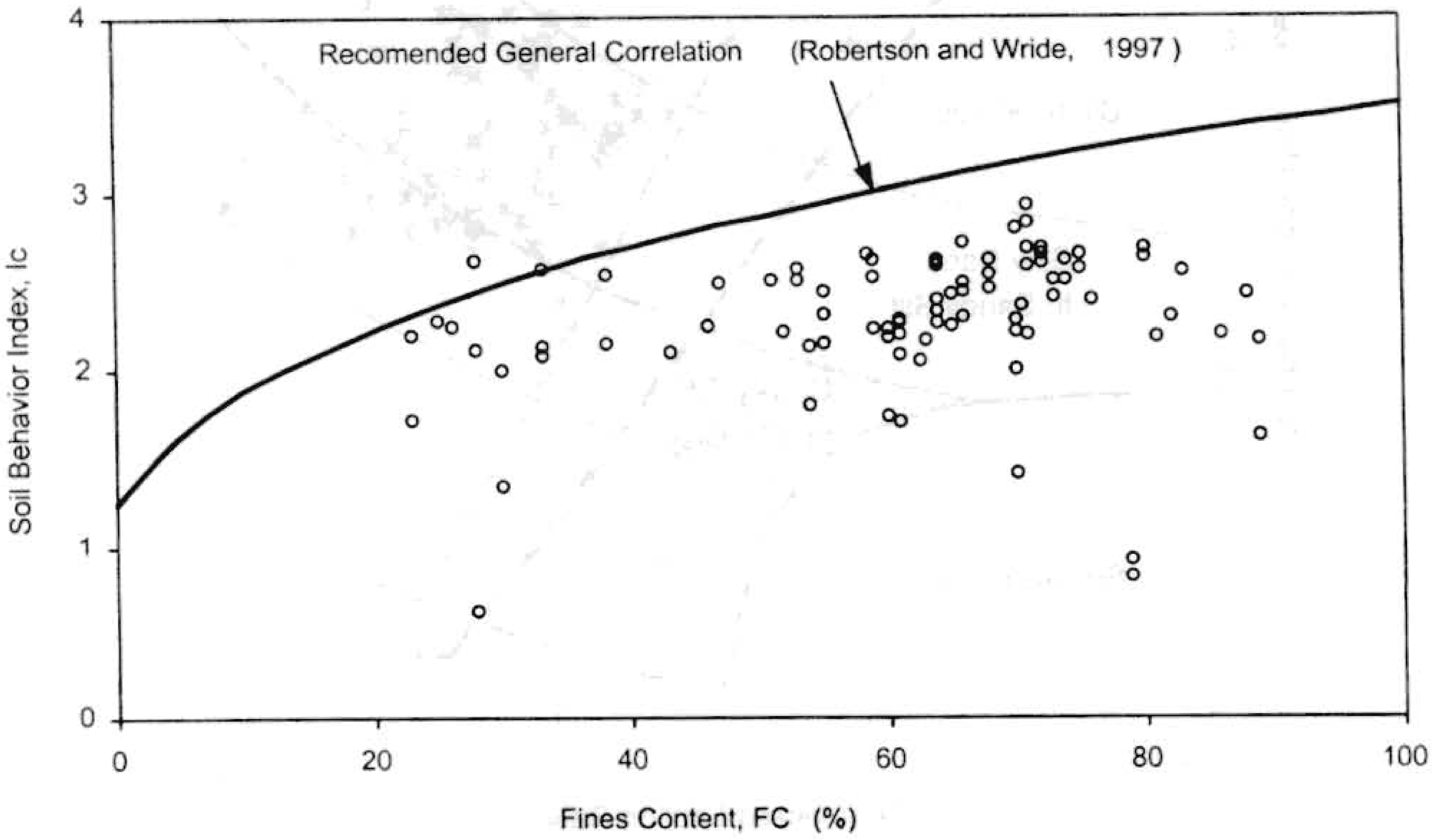


Figure 6. Correlation between fine content, Fc, of the selected sites and soil behavior index, Ic, from the Closest CPT Sounding.

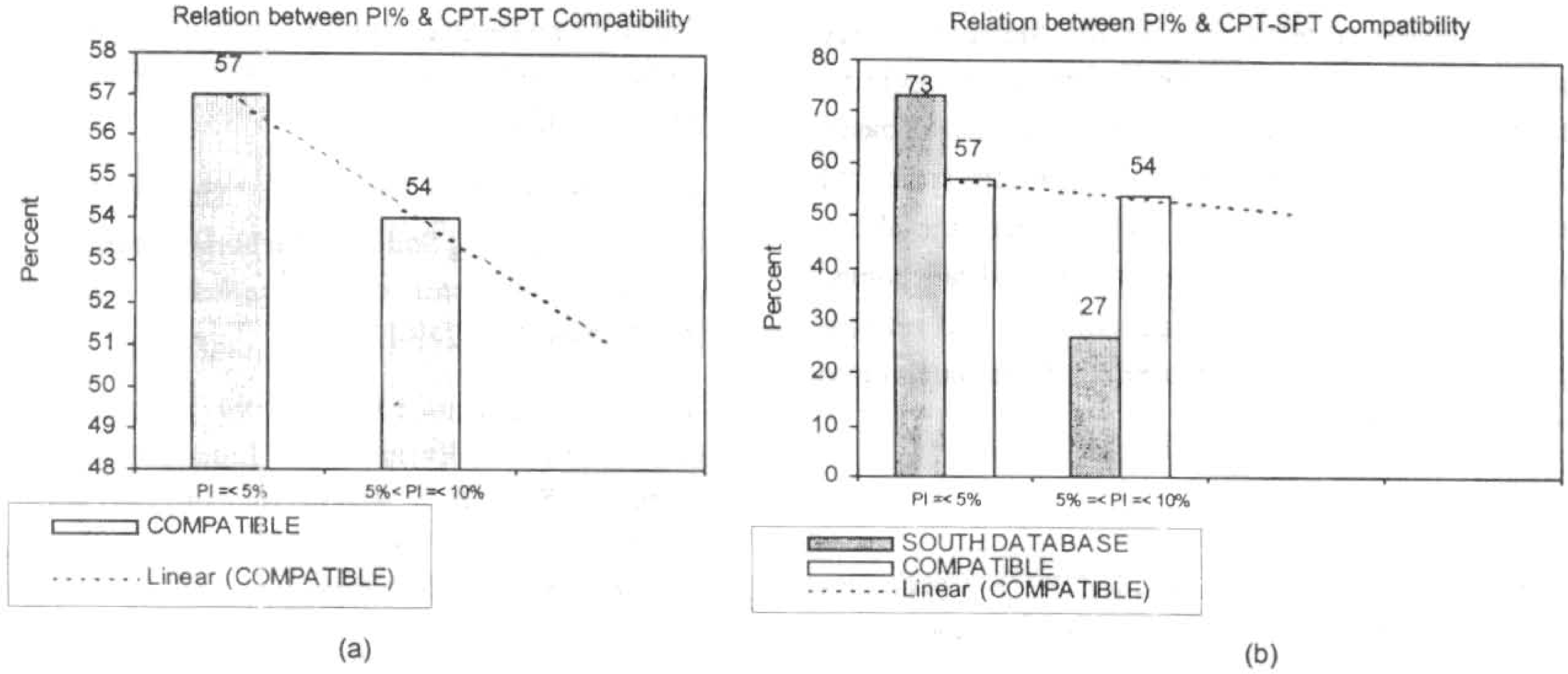


Figure 7. The plasticity index, PI, distribution in the selected points and it's effect on the compatibility between CPT-SPT analysis results. (When Both CPT and SPT show that liquefaction will occur, they are called COMPATIBLE and vice versa).

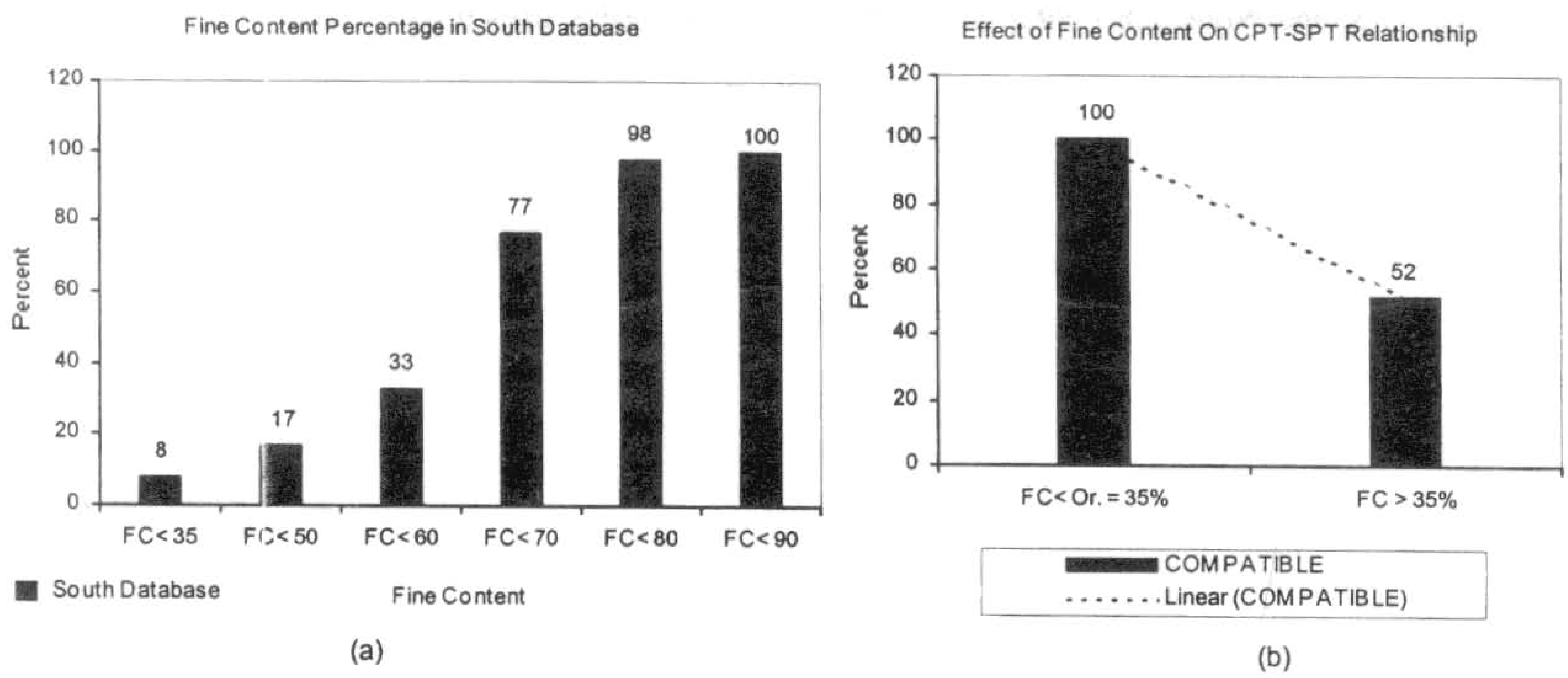


Figure 8. The fine content, Fc, distribution in the selected points and it's effect on the compatibility between CPT-SPT analysis results.

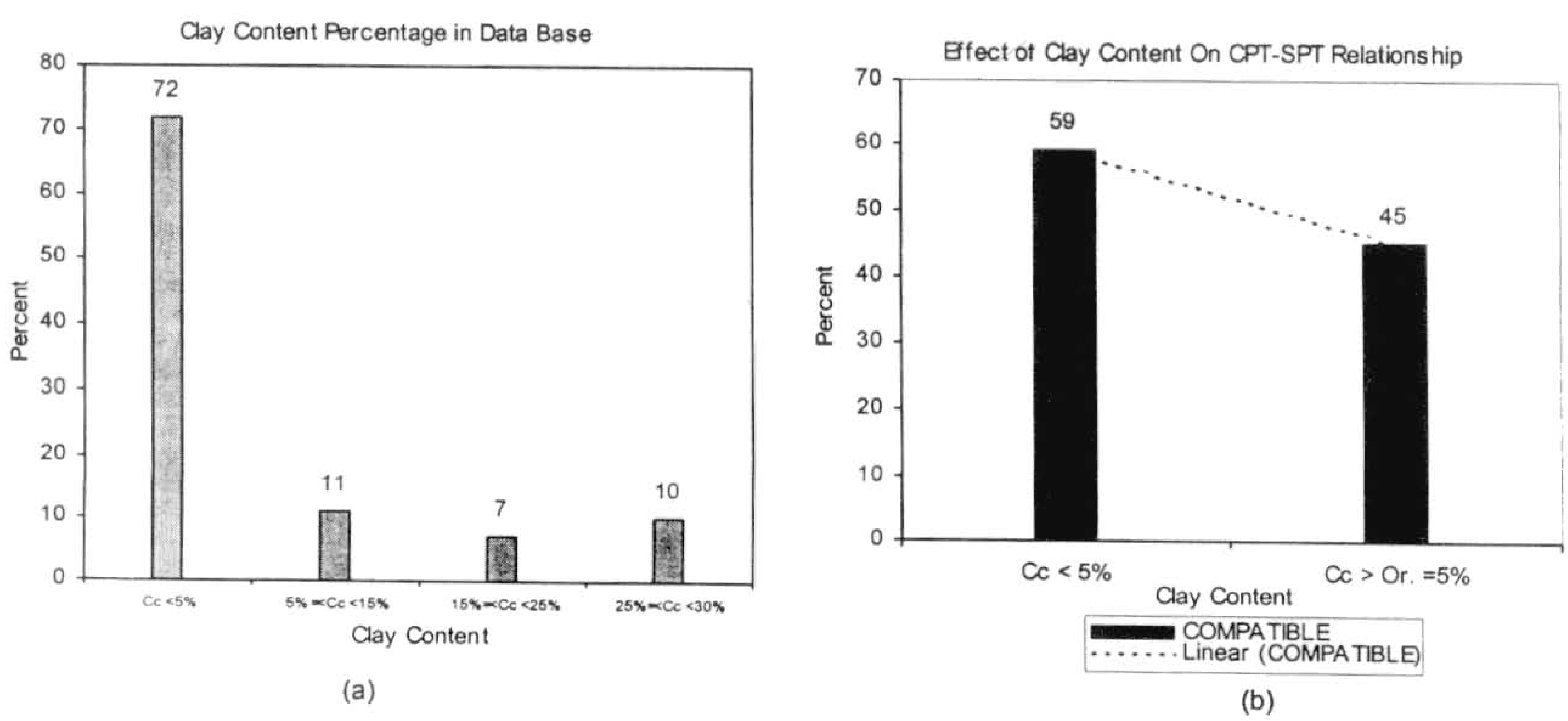


Figure 9. The clay content, Cc, distribution in the selected points and it's effect on the compatibility between CPT-SPT analysis results.

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.

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