Proceedings of the 16th International Conference on Soil Mechanics and Geotechnical Engineering

doi:10.3233/978-1-61499-656-9-739

The Dynamic Penetration Cone Index as an alternative for the control of a subgrade surface

Le Cône de Penetration Dinamique comme une alternative par le control de la surface d'une sous-couche de chaussée

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ABSTRACT
The purpose of the paper is to demonstrate the usefulness of the Dynamic Penetration Cone Index (DPCI) as an alternative for the control of sub grade surface. Correlating its results with other in place parameters such as load tests and the Penetration Index, the geotechnical characteristics of the sub grade surface can be estimated with great accuracy. The DPCI, gives consistent relationship when it is plotted against depth. Previous research concentrated on the relationship of the DCP with the CBR and SPT and the water content. This paper goes one step further introducing an index that better represent the geotechnical engineering properties of the subgrade surface. An extension of the use of the method for hard soils, such as the cemented sands of Asuncion, Paraguay, is also presented as an alternative to penetrability determinations with SPT equipment.

RÉSUMÉ
Le but de cette communication est de montrer l'intérêt de l'indice de pénétration du pénétromètre dynamique (DPCI) comme variante pour le contrôle des couches de sol superficielles. En corrélant les résultats ainsi obtenus avec d'autres paramètres in situ tels que ceux des essais de chargement et la résistance en pointe au pénétromètre, les caractéristiques du sol peuvent être estimées avec beaucoup de précision. Le DPCI, définie comme l'inverse de la pénétration dans mm par coup du cône léger multiplié par une échelle facteur, donne une relation compatible avec ces autres essais quand il est donné en fonction de la profondeur. Les précédentes recherches ont été concentrées sur les relations entre la résistance en pointe et les CBR, SPT et teneur en eau. Cette communication fait un pas de plus en introduisant un indice qui représente mieux les propriétés géotechniques des sols superficiels. Une extension de l'utilisation de cette méthode aux sols raides, comme les sables cimentés d'Asuncion au Paraguay est aussi présentée comme une variante vis à vis des résultats obtenus au SPT.

1. INTRODUCTION

The Dynamic Penetration Cone (DPC) provides a large quantity of on site data. Comparing its results with SPT, load test and laboratory determinations from undisturbed samples taken from pits, the parameters necessary for the surface compressibility of the soil can be obtained with reasonable accuracy. The principal advantages of the DCP are that it is a very practical "in situ" test, it may be executed either above or below water table, it gives a good quantity of low cost information about the subsurface conditions and its usefulness is constantly being proven for the estimation of the ultimate capacity for shallow foundations. Furthermore, it does not need qualified personnel.

An extension of its use, for hard soils, such as the cemented sands of Asuncion, Paraguay, is also presented as an alternative to penetrability determinations with the SPT equipment for the control of the quality of the soil mass below the bottom of excavations for spread footing.

2. CASE STUDY 1. THE DPCI FOR THE CONTROL OF A COMPACTED FILL

2.1 The Dynamic Penetration Cone Index (DPCI)

The Dynamic Penetration Cone (DCP) has mainly been used in the field of geotechnics applied to transportation Engineering as an alternative for executing CBR test for expeditious evaluation of airfields and has also been used in others geotechnical applications. The PCASE Institute has an official site on the web that promotes DCP use. In this case, it has been demonstrated its usefulness for the control of the geotechnical characteristics of a compacted fill, in the case of the collapse of the formwork of a huge concrete slab of a public building, while it was being filled with concrete. This disaster resulted various death and serious injuries, as well as a great deal of material damage. The DCP used for this investigation was the light one which was developed by the Unites States Army Corps of Engineers (USACE). The device is used with a 60º lost cone of 20 mm diameter. The energy penetration is given by a light hammer of 8 kg which is dropped from 574 mm. The penetration in millimeter was carefully recorded.

The Dynamic Penetration Cone Index (DPCI) is defined here as the inverse of the penetration in millimeters of the cone in the soil for each blow of the hammer multiply by a scale factor of 100 (1). For very soft and very hard soils, this index varies between 0 and 1000.

DPCI= 100 x Number of blows / penetration in mm (1)

The problem was to determine whether the collapse was due to the soil condition or to the failure of the structural formwork. The formwork transmitted its load to the soil through wooden shores resting on small pieces of wood between 10 and 20 cm in width. All of the bases of the shores lie on a compacted clayey sand (SC) fill specially constructed for this propose. Before the formwork was put in place, the perimeter of the fill had been excavated to place the foundation of the columns of the final concrete structure of the building. In spite of testimony that these excavations had been filled and properly compacted, the investigators decided to test the validity of this information, in which the use of the DCP was of fundamental importance.

2.2 Correlation between load tests and DPCI

The stress-strain characteristics of the fill were investigated by means of load tests. In order to establish a correlation between load tests and DPCI, four tests and the corresponding DCP tests were made in the clayey sand fill . Two of them (LT_3 and LT_4), were located in places where the fill had not been affected by the excavations of the foundation columns, and the other two (LT_1 and LT_2), in places where the excavation for the foundations were made.

Circular bearing plates of 11.5 cm and 17.0 cm were used in harder soils, and 15.0 cm and 27.0 cm in softer soils. The tests were made at depths of 15 cm (LT_3 and LT_1) and 30 cm (LT_4 and LT_2). In Figure 1, a consistent linear relationship between the two values can be observed. This linear relation is defined by equation (2), which was used to obtain the bearing capacities on the other sites of the fill where the DCPI were determined.

$$\sigma_f = 0.09 \text{ DPCI} \qquad (2)$$

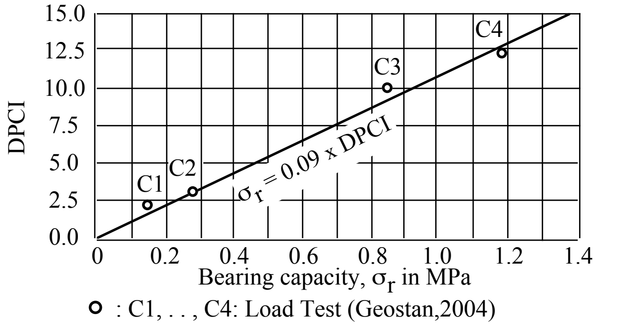

Figure 1. Bearing capacity vs DCPI

Obs.: The equation shows a direct relationship between the bearing capacity and the DCPI for clayey sands soils. Its validity must be proven in other fill material.

In Figure 2, the numbers in parenthesis for each DCP test location are the bearing capacity of the fill in MPa obtained by equation (2). A remarkable difference amongst values in places where the fill was not affected by the excavations for the structural columns and in places where these excavations were made can be noted.

3. CASE STUDY 2. THE DPCI USED TO CONFIRM THE BEARING CAPACITY FOR OPEN PITS.

In the project of a great convention hall for the South American Confederation of Soccer, exploratory borings with SPT test indicated the presence of a firm strata of clayey sands and hard clays to the depth of 10 m. Because of the heterogeneity of the profile, the client requested the execution of five open pits up to the recommended depth for the construction of the foundations.

The definition of an alternative test to confirm the results of the SPT in the bottom of the pits to assure the bearing capacity of the foundations was required. The execution of load tests would be very expensive due to the depth of the pits as well as the presence of water.

The experience obtained in the previous historical case, suggested the execution of DPC test with determination of the DPCI. The results confirmed the high bearing capacity of the soil below the bottom of the pit. The tests were limited by the maximum capacity of the device (120mm). The same Formation was confirmed by previous SPT determinations below this depth. Figure 3, shows the evolution of the DPCI values with depth, and the theoretical SPT refusal and precast/steel driven piles refusal criterion.

In this case, DPCI values higher than 12.5 were found immediately after the surface an up to the end of test. With the use of the graph, it was possible to confirm the recommended bearing capacity of 0.3 MPa, estimated from the SPT determination.

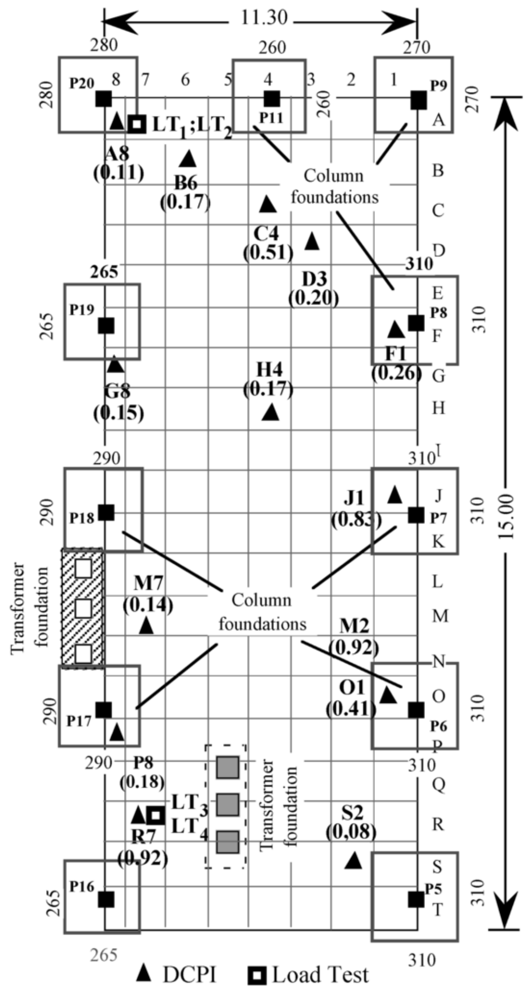

Figure. 2 Bearing capacity of the clayey sand fill

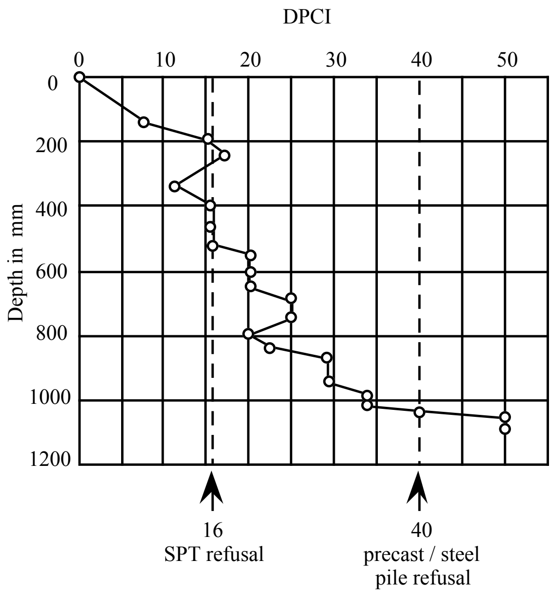

Figure 3. DPCI vs Depth

The required minimum safety factor of 3.0 was confirmed. The execution time of the test required for this confirmation was only one hour while the execution of a load test would have required a much greater effort and cost.

4. CASE STUDY 2. THE DCP FOR THE CONTROL OF SHALLOW FOUNDATIONS ON CEMENTED SANDS

The bedrock of Asuncion and its surroundings is formed by cemented sands and very soft weathered sandstones. Both materials have rounded and sub-rounded particles with fine to medium gradation. The 20m criterion was established for the limit between fine matrix and skeletal grains (Barton and others, 1993). The matrix content for the cemented sands varies from 0 to 5 % and for the weathered sandstones from 7 to 10 %, being its principal components the kaolinitic clay (>95%), iron oxide (limonite) (< 1%) and traces of secondary quartz.

Cemented sands and very soft sandstones are located at surface levels or at a depth of less than twenty meters. These materials are generally covered by loose sandy sediments coming from colluviums or transported soils. These cemented sands and the very soft sandstones are easily detected by a sudden increase of the SPT penetration resistance (N>50) when the top of the stratum is reached. Despite its great resistance, small penetrations of the split tube sampler can be obtained with the same equipment and energy utilized for SPT determinations.

4.1 Penetration Indexes: Np and N_B

After the penetrability limit of the normal SPT has been reached (N_{SPT}=50) the test is continued in a modify form. Instead of counting the necessary number of blows to obtain a length of penetration of 30 cm, as it is done in the SPT, a series of 50 blows is applied, measuring the length of penetration obtained every 10 blows (Bosio, 1991). Plotting these values in a semi-logarithmical graph of the number of blows versus accumulated penetration, it is observed that the curves have convex shapes up to 30 blows. From this point to the end of the test (50 blows), the curves turn practically straight lines.

The slope of this straight line is correlated to the properties of the tested materials. The numerical value of the slope were denominated "Penetration Index, Np" and are easily obtained from (Fig.4).

$$Np = \frac{P50 - P30}{\log 50 - \log 30} \sim 4.5\,(P50 - P30) \tag{3}$$

In order to have a direct correlation between the resistance of the material and the Penetration Index, Decourt, has suggested the use of the inverse value of equation (3) introducing a new Index, which he named "Bosio's Penetration Index, N_B recommending its use for hard soils and soft rocks (Decourt, L, 2002).

$$N_B = 100 / Np \tag{4}$$

The top of the cemented sand and residual sandstone soil strata show several singularities due to their maturity degree or weathering. Both materials have excellent bearing capacities for direct foundations. The knowledge of the foundation depth from the top of the strata is of great importance for engineers.

The main singularities observed are, cavities with or without fills, small conduits formed by root relict structures and the presence of very hard laterite crusts that give the soil/rock mass a high degree of heterogeneity.

These singularities usually observed in the first meters from the top, gradually disappear with depth.

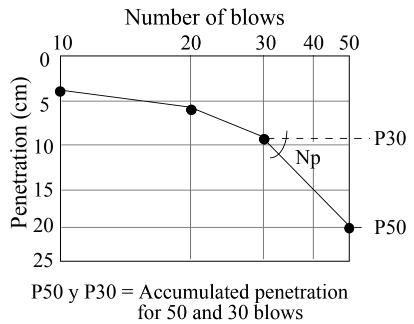

Figure 4. The Penetration Index, Np

The penetration measurements make it possible to detect shear strength variations in materials that present the same physical appearance. These variations are mainly due to the erosive action of the water that circulate through their pores.

4.2 Correlation between DPCI and N_B

In order to establish a correlation between DCPI and N_B, several tests were made in two sites located in downtown Asuncion, Paraguay. Both sites had cemented sands from the surface of the soil. In each place, four tests were carry out measuring the length of penetration of the SPT sampler and the Dynamic Cone every 10 blows of a series of 50 blows. The Dynamic Penetration Cone Index (DPCI), defined as the penetration in millimeters of the cone in the soil for each blow of the hammer (mm/blow) was determined. In order to obtain comparables values, the same procedure employed for the determination of Np and N_B was used for the DPCI. The average values for the last 20 blows of a series of 50 blows is shown by a dashed line (Fig 5).

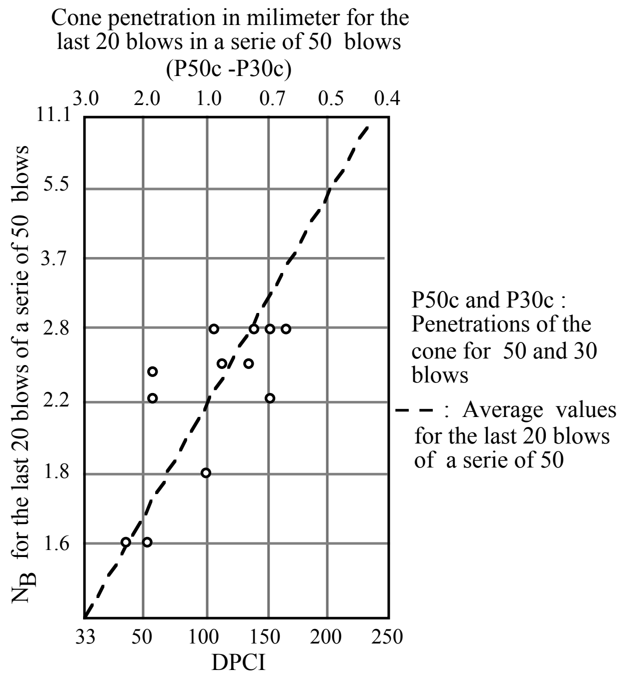

Figure 5: DPCI vs "Bosio's Penetration Index,N_B

In figure 6, on the classification of the cemented sands and sandstones of Asuncion proposed by Bosio (1997), the values of

N_B and DPCI are represented. This graph was of great usefulness for correlating both values with the average unconfined compression strength of these materials

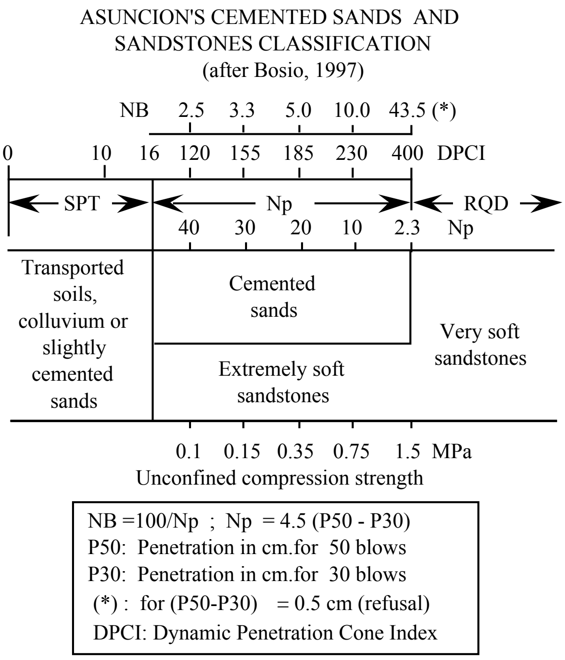

Figure 6 Cemented sands and Soft Sandstones Classification of Asuncion

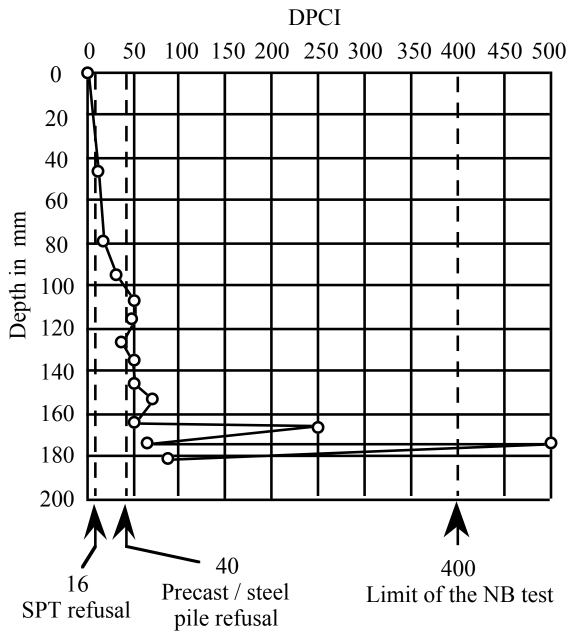

Figure 7. DPCI vs Depth for Cemented Sands

The following features out from figure 7 can be highlighted:

- The values for soils below the N_{SPT} corresponds to DPCI less than 16.
- DPCI=400 correspond to the value NB=43.5. The penetration of the sampler for the NB determination is 5 mm and for the light cone is 0.25 mm
- Values of DPCI up to 1000 which represents penetration of 0.1 mm of the cone in the cemented sands can be determined.
- The use of the light cone penetration test is more sensible than the SPT sampler and therefore determination of DPCI can detect singularities within the cemented sands more accurately.

5. CONCLUSIONS

5.1 The use of the light DPC and the DCPI, is a simple form for gathering information that can be used to correlate different geotechnical parameters.

5.2 The application of the light DPC for the control of fills and subgrade for shallow foundations, can be readily executed and obtained very dense information at low cost.

5.3 The DPCI scale range of variation between 0 and 1000 (where 0 represents no resistance and 1000 refusal), is easy to apply. Values from 0 to 16 represent the range of soft to medium dense and compacted soils. 16 to 100 is the range for very dense soils and 100 to 400 is for cemented soils.

5.4 The relationship between the DPCI for the last 20 blows of a series of 50 has been demonstrated to be proportional to the penetration obtained for the same interval with SPT equipment and energy. The ratio between these values was very consistent.

5.5 The execution of on site and laboratory comparison tests is advisable to intensify to obtain better relationships and more reliable results.

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