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Pressuremeter Test as the Only Characterization Tool for Very Dense Sands

L'Essai Pressiom®trique comme seul outil de caractérisation de sables très denses

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ABSTRACT : Making pressuremeter tests in sands is – except France – not very popular. Static or dynamic penetrometers are quicker, simpler and less expensive as well as accurate enough to estimate mechanical parameters of non-cohesive soils. There are, however, some exceptions. Very dense soils are one of them. Penetrometers, even the heaviest ones, usually meet refusal in such soils. Their parameters are often underestimated as higher values would surely be obtained below the refusal level. Normally attention is paid on weaker soils of a structure substratum, not on the strongest ones and such a situation does not create any problem. But not always. Difficulties were met while driving piles for LNG external harbour breakwater in Swinoujscie (Poland) at depths deeper than 15 m. Geological report presented there only one geotechnical layer of dense sands. No wonder. Simple statistics used normally in such a case invites placing all soils of relative density $I_D > 0,65$ into one layer. Characteristic relative density value is usually taken as $I_D \approx 0,7$ because continuous penetrometers meet their refusal somewhere close to $I_D = 0,8$ and the results of SPT are in many cases underestimated. To recognize a real changeability of strength of dense and very dense soils Ménard Pressuremeter Tests were carried out. The aim was to establish a local correlation between relative density and pressuremeter limit pressure. It succeeded. Then it was possible to divide these soils into two different geotechnical layers. It helped to understand the reasons of difficulties in pile driving.

RÉSUMÉ : A l'exception de la France, les essais pressiometriques dans les sables sont rarement utilisés. Les essais de pénétration dynamique ou statique sont plus rapides, simples à réaliser et économiques tout en garantissant une précision suffisante dans l'estimation des caractéristiques mécaniques des sols frottants. Il y a toutefois des exceptions. Les sols très denses en font partie. Les pénétromètres même les plus lourds présentent généralement le refus dans de tels sols. Leurs caractéristiques sont souvent sous-estimées et des valeurs plus élevées auraient été mesurées sous le niveau de refus. Une attention particulière est habituellement portée sur les sols les plus faibles de l'assise d'une structure, et non sur les plus résistants, sans que cette situation ne crée de problème. Mais pas toujours. Des difficultés furent rencontrées durant le battage des pieux de la digue du terminal GNL à Swinoujscie en Pologne, à des profondeurs supérieures à 15 m. Le rapport géologique ne signalait la présence que d'une passée de sable dense. Ce constat n'est pas très étonnant. En effet, l'approche statistique habituellement adoptée dans ce type de situation amène à rassembler les faciès présentant une densité relative supérieure à 65%. La valeur caractéristique retenue sera 70%, en considérant que les pénétromètres atteignent le refus vers 80% et que les résultats des essais SPT sont généralement sous-estimés. Pour différencier les sables denses et très denses il a donc été réalisé une campagne d'essais Pressiometriques. L'objectif était d'établir, une corrélation locale entre pression limite et densité relative. Le succès fut assuré. Il fut alors possible de subdiviser ces sols en deux couches géotechniques.

Les difficultés de battage des pieux purent ainsi être surmontées.

KEYWORDS : dense sands, relative density, penetrometer interpretation, pressuremeter limit pressure, correlation.

MOTS CLES : sable dense, densité relative, interprétation du pénétromètre, pression limite Ménard, corrélation.

1 INTRODUCTION.

Geological Company "Geoprojekt Szczecin" Ltd. carried out a wide scope of tests of non-cohesive soils being a substratum of a new breakwater for the External Harbour ("Gazoport") in Świnoujście, Poland. A static CPT penetrometer (anchored, of nominal pressure 200 kN, with electronic test result record; manufacturer: „Geomil", the Netherlands, a super heavy dynamic penetrometer DPSH (hammer weight Q = 63,5 kg, free fall height h = 75 cm, manufacturer: "Borro", Sweden) and Ménard pressuremeter (manufacturer: "Apageo", France) were used there among the others. A comparative analysis of some test results is presented below.

2 PENETROMETER TEST RESULTS

In some places both dynamic and static penetrometers were carried out. Their results gave a linear relationship between the values of CPT cone resistance q_c and number of blows per 20 cm of DPSH penetration N_{20}. It is presented on Fig 1. This relationship, with determination coefficient as high as $R^2 = 0,86$, is expressed by the formula:

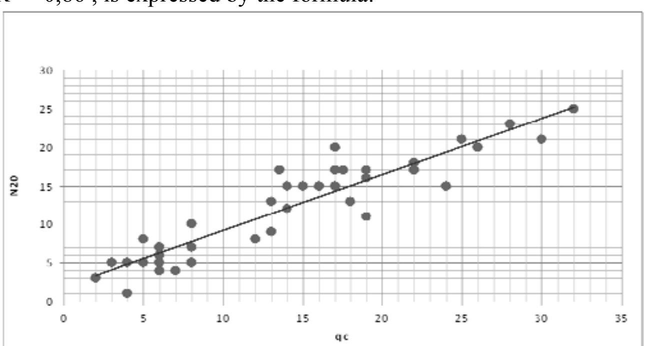

Figure 1. Correlation between the values of q_c (CPT penetrometer) and N_{20} (DPSH).

The obtained relationship (1) was used to assess correctness of the latest interpretations of static and dynamic penetrometers proposed in one of the Polish Standards [PN-B-04452:2002].

A comparable graph was created (Fig. 2) where the curves showing dependence of relative density I_D and both penetrometer results were confronted. The curves intersect and spread apart (in both directions). Coming from the same standard they are not compatible. The greatest divergences are observed in the domain of low N_{20} and q_c values [Ura and Tarnawski 2012].

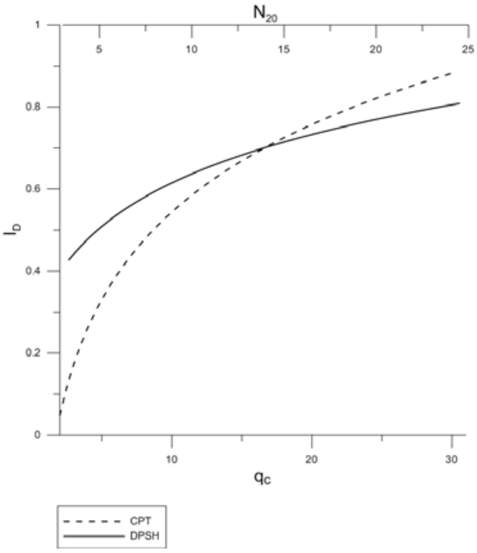

Figure 2. Discordant CPT and DPSH interpretations of relative density in PN-B-04452:2002 Standard.

Considering previous CPT and DPSH interpretations [M. Borowczyk and Z. Frankowski 1981, 1985, D. Dudycz 1981, M. Tarnawski 1983, P. Milancej 1997] and comparing the results of both types of penetrometers new regional correlations $I_D = f(N_{20};q_c)$ were constructed. They are presented in brief in $I_D = f(N_k)$Table 1.

Table 1. A proposed CPT and DPSH interpretation in Świnoujście sands.

Cone resistance q_c (MPa)	Relative density I_D	Number of blows per 20 cm of penetration N_{20}
0,8	0,1	2
1,8	0,2	3
3,0	0,3	4
4,8	0,4	5,5
8,0	0,5	8
13,0	0,6	11
21,0	0,7	17
30 – 31	0,8	26
	0,9	47 – 49

3 PROBLEMS WITH VERY DENSE SANDS

The aim of the tests carried out for the breakwater of External Harbour in Świnoujście was to determine the state (relative density) of non-cohesive soils, also the ones that occurred deeper. However it turned out that deeper than 15 m (bgl) it was not possible, due to remarkable soil resistance. The anchored CPTs meet their refusal quicker than super heavy dynamic penetrometers. Their "spring effect", which threatens with equipment damage, starts around 50 blows per 20 cm of DPSH penetration (N_{20}). Further penetration is not advisable.

Driving "Gazoport" piles also met serious difficulties at such depths (>15,0 m). But geological report presented only one geotechnical layer there: the layer of dense sands. No wonder. The authors of geological – engineering reports usually follow the recommendations of the most popular Polish Standard [PN-81/B-03020]. They compute an average value of a parameter (relative density in this case) according to so-called "A" method. The standard [PN-81/B-03020] allows to consider soils of any layer as homogenous, if variability index γ_m is not further from unity than γ_m = 0,80 or γ_m = 1,25. Unfortunately, the fulfillment of this condition strongly depends on numerical values of the analyzed parameter. For example: if we disposed an even number of results of relatively density $I_D = 0{,}70$, $I_D = 0{,}85$ and $I_D = 1{,}00$ (an example which covers almost the whole range of dense and very dense soils, exaggerated purposely as the values as high as $I_D = 1{,}0$ are not met in practice) we would obtain the layer characterized by γ_m = 0,86. The standard sees it as homogenous although it contains soils of relative density differing by as much as 0,3. The same experiment with the values of $I_D = 0{,}10$, $I_D = 0{,}25$ and $I_D = 0{,}40$ (the same absolute difference = 0,3; the soils from very loose to medium dense) would give γ_m = 0,51. This means the necessity of separation of at least two or even three geotechnical layers.

4 PRESSUREMETER CAMPAIGN

Regardless of the will to separate many geotechnical layers of dense and very dense soils we may end up without any data points with $I_D >> 0{,}8$ values, because continuous penetrometers (both static and dynamic) meet their refusal near $I_D = 0{,}8$ while on the other hand SPT measurements often give underestimated results caused by loosening of saturated soil under influence of hydrostatic pressure. Under such circumstances pressuremeter tests were proposed to assess the variability among the dense and very dense sands. Three slurry boreholes were made to the depth of 20,7 – 24,0 m which was 5 – 10 m below the range of penetrometers carried out before. Forty six pressuremeter tests were performed in these boreholes, more than half of them in direct neighborhood of earlier penetrometers' data points, in order to assess local correlation between relative density I_D and pressuremeter limit pressure p_l. Relations between pressuremeter parameters (pressuremeter limit pressure p_l, pressuremeter modulus E_M) with the state (relatively density) of non-cohesive soils were obviously investigated before [J.-L. Briaud 1992, M. Tarnawski 2007]: see Table 2 as an example.

Table 2. Approximate, typical pressuremeter parameters [J.-L. Briaud 1992].

Type of soil:	Non–cohesive soils			
State of soil:	loose	medium dense	dense	very dense
p_l (kPa)	0 - 500	500 - 1500	1500 - 2500	> 2500
E_M (kPa)	0 - 3500	3500 - 12000	12000 - 22500	> 22500

The resulting correlation between the values of pressuremeter limit pressure p_l and relative density I_D obtained from DPSH and CPT is shown on Fig. 3. It looks quite courageous in spite of the fact that neither age, origin nor granulation of tested soils were taken into account.

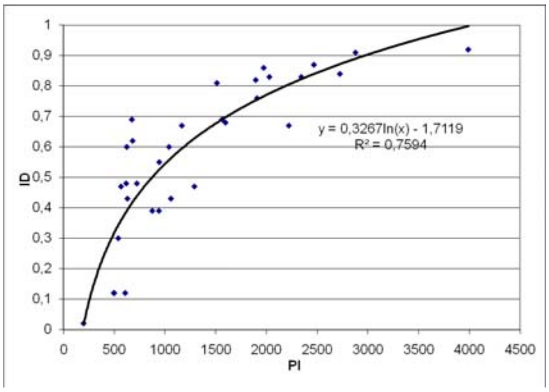

Figure 3. Correlation between pressuremeter limit pressure p_l and relative density I_D.

The pressuremeter test results prove the presence of soils (medium sands, in fact) of limit pressure $p_l \approx 2900 - 4000$ kPa at the depths of 13 – 17 m. Their relative density (see the graph on Fig. 3) may be estimated to be as high as $I_D = 0{,}9$ or more. Such dense soils cannot usually by penetrated through, without damage to equipment, by any kind of known penetrometers. These very soils made the pile driving so difficult. The values of both limit pressure and relative density went back down (to $p_l \approx 1900 - 2700$ kPa i.e. to $I_D \approx 0{,}75 – 0{,}85$; see Fig. 4 as an example) at deeper depths in two of three tested profiles.

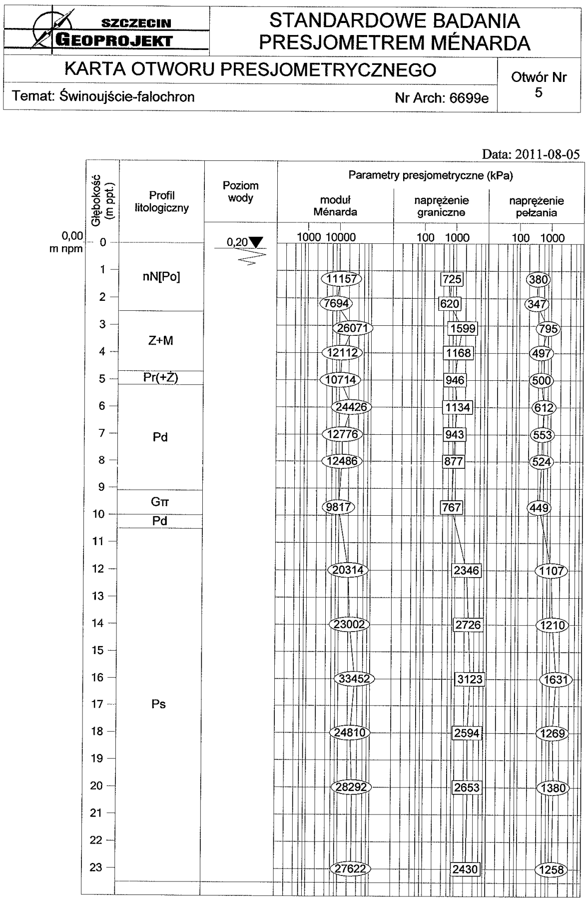

Figure 4. A card of pressuremeter borehole. Very dense soil at the depth of 16 m.

Pressuremeter test carried out solved the problem of dividing up "strong" non-cohesive soils into dense and very dense ones. Limit pressure values assigned to very dense sand layer varied between $p_l = 2900$ and $p_l = 4000$ kPa. This wide range corresponded to $I_D > 0{,}9$. The question arises: is $I_D = 1{,}0$ really the highest possible value? It is worth to remind now that although in practice relative density is determined by means of field tests, especially penetrometers [PN-EN ISO 14688-2], the actual definition of this parameter comes from a laboratory procedure. Following it, relative density is computed disposing the values void ratios: maximum e_{max}, minimum e_{min} and natural ones e_n, following the formula:

$$I_D = \frac{e_{max} - e_n}{e_{max} - e_{min}} \quad (2)$$

It is likely that nature (or very heavy human equipment) is able to compact non-cohesive soil better than a light laboratory device. Then it is possible that defined this way relative density of very dense soils may reach in extreme cases values higher than unity (as for instance it is the case with Proctor's degree of compaction I_S). The problem of a proper definition of relative density remains open.

4 CONCLUSION

Comparative analysis of CPT and DPSH results performed for a new breakwater of the External Harbour in Świnoujście, Poland enabled to find incompatibility in standard interpretation of these penetrometer results and for establishing a new regional correlations $I_D = f(N_{20};q_c)$.

Even these heaviest penetrometer devices have limited abilities of penetration. It is reached at $q_c \approx 30$ MPa in the case of 20t CPT or – for DPSH penetrometer – when $N_{20} \approx 50$. This means they cannot penetrate extremely dense sands and their presence is the reason of driven pile refusal. Pressuremeter tests were used to distinguish very dense sands from dense ones. As they were performed nearby penetrometers, relative density I_D and pressuremeter limit pressure p_l values could be successfully correlated. It has appeared that a wide range of p_l values, namely $p_l \approx 2900 - 4000$ kPa, corresponds to a very narrow zone of $I_D = 0{,}9 – 1{,}0$. This is another reason to put a question: is $I_D = 1{,}0$ really the highest possible value?

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