Seashore sand parameters with DMT and CPTU tests

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ABSTRACT: An extensive study was performed on the characterization of sand deposits on the Polish seashore including triaxial tests, penetration testing in-situ and calibration chamber tests. Fine to medium quartz sand from Baltic beach was used. A series of CPTU and DMT tests were performed in fresh deposits of hydraulic sand fills. Stress history of the deposits was established on the basis of CPT and DMT. There is considerable difference in strength and deformation parameters for hydraulic sand fills formed by subaerial and subaqueous placement methods. In a first case the sand is dense and often overconsolidated with high cone resistance and K_D, E_D and M values. In case of subaqueous hydraulic fills loose to medium dense sand was found in NC state. Some correlations between strength parameters from CPT and deformation moduli from DMT were established. Linear relationship between cone resistance and constrained modulus were proposed for Baltic sand.

1 INTRODUCTION

Sand fills placed with pipelines are frequently used in port and reclamation works in Poland. Two examples of hydraulic deposition are described. The first one concerns the sand fill formed by subaqueous placement method at the back of the harbour in Gdynia Port. The sand fill was placed in the period of port construction about 75 years ago. Some new construction projects are planned on this fill just behind the existing harbour. In the second example the reclamation works on The Hel peninsula are discussed. The sand fill is regularly transported with the pipeline along the coast to supply the beach material and to protect the peninsula against the erosion and material transport induced by maritime currents and waves.

Hydraulic sand fills are the unaged fresh sediments of fine to medium predominantly quartz sands. Their properties can be described with CPTU and DMT tests and the correlations elaborated on calibration chamber tests for the unaged and uncemented sands. Standard CPTU and DMT tests were performed in parallel at the harbour and at the Baltic beach at The Hel Peninsula to determine the stress state and history, relative density and modulus of deformation for different placement methods of hydraulic sand fills.

2 INTERPRETATION OF CPTU AND DMT TESTS IN SAND FILLS

Interpretation of CPTU tests was made assuming medium compressibility of the sand and relative density evaluated for normally consolidated and overconsolidated sands according to Baldi et al. (1986). Relative density of the sand can also be determined from DMT correlations based on calibration chamber tests – Reyna & Chameau (1991) and Jamiolkowski et al. (2001). These correlations were established for medium and high overburden stress exceeding 50 kPa. For small penetration depth, exceeding critical depth but not larger than 3 m, it can be considered that the effect of the overburden on the rate of increase of the cone resistance below the critical depth can be neglected Puech & Foray (2002). The quasi-stationary cone resistance at small penetration depths q_{st} can be considered as dependent only on relative density D_R. Such a correlation is presented (Fig. 1) for the laboratory sand fills - Puech & Foray (2002):

$$D_R = 0{,}209\ln(q_{st}) + 0{,}25 \qquad (1)$$

It can be used to evaluate relative density at small depth in the unaged hydraulic sand fills.

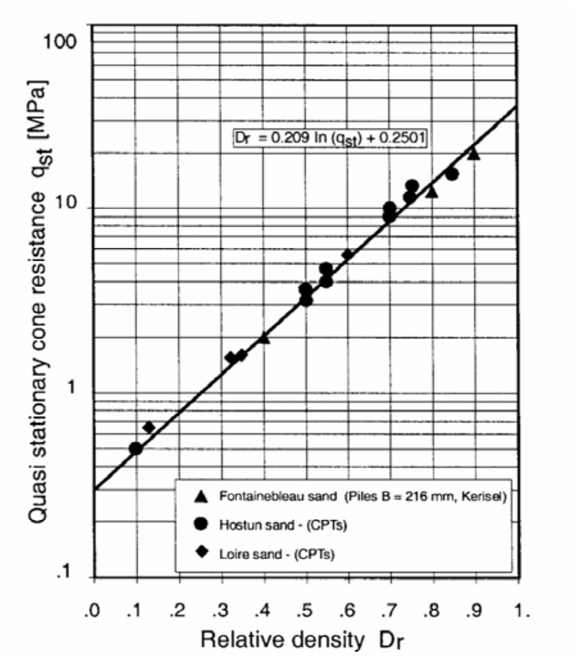

Figure 1. Correlation between quasi-stationary cone resistance and relative density

Overconsolidation ratio was determined with the formula of Mayne (2001):

$$OCR = \left[\frac{1,33}{K_{0NC}} \frac{q_T^{0,22}}{\left(\sigma'_{v0}\right)^{0,31}} \right]^{1/(\alpha - 0,27)} \tag{2}$$

where:
Corrected cone resistance q_T in MPa can be assumed equal to q_c in sands. K_{0NC}= *1-sin*ϕ*'*, α= *sin*ϕ*'* and σ'_{v0} is the effective overburden stress in kPa. The angle of internal friction was determined with DMT test according to Marchetti (1980) formula.

The earth pressure coefficient at rest K_0 was determined with the CPTU data – Mayne (2001) or CPTU/DMT data – Baldi et al. (1986) for the "seasoned" sand:

$$K_0 = 1,33(q_T)^{0,22}\left(\sigma'_{v0}\right)^{-0,31} OCR^{0,27} \tag{3}$$

$$K_0 = 0,376 + 0,095K_D - 0,0046 q_c / \sigma'_{v0} \tag{4}$$

The stress state in the sand can be also described with the ratio $\alpha = M_{DMT}/q_c$. Marchetti et al. (2001) suggest that:

α=5 to 10 for NC sand and
α=12 to 24 for OC sand.

3 ANALYSIS OF IN-SITU TESTS

3.1 *Harbour backfill*

CPTU profile in hydraulic fill at the back of the massive harbour in Gdynia port is given (Fig. 2). The water table is about 2 m below ground level. Relatively dense and overconsolidated sand (see Figs. 3 and 4) was found in the surface layer and confirmed with DMT horizontal stress index and OCR evaluated with Eq. 2. This is related to crust phenomena and densification/ overconsolidation of the superficial layers with small storage facilities and traffic. Below, a medium dense normally consolidated or lightly overconsolidated sand is found. Some loose sand with silt and mud inclusions was detected from 11 to 12 m. The roof of a very dense Pleistocene sands is located at the depth of 12 m. The properties of this layer and the surface layer are outside the scope of this paper. Relative density of the sand fill was determined (Fig. 5) from CPTU according to Baldi et al. (1986). Two methods for the determination of the earth pressure coefficient at rest give a very similar results (Fig. 6). The constrained modulus from DMT (Fig. 7) and calculated M_{DMT}/q_c ratio are presented (Fig. 8) in the profile. Values of this ratio from 2 to 8 correspond to NC sands.

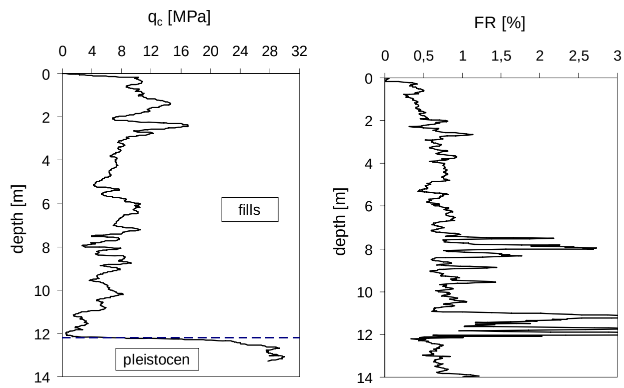

Figure 2. Profile of cone resistance and friction ratio.

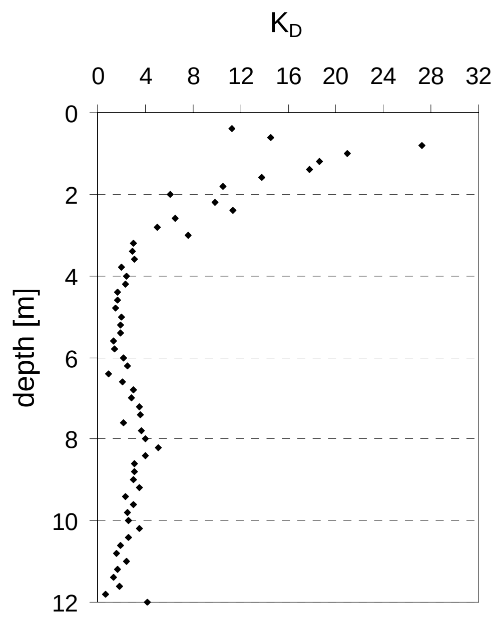

Figure 3. Profile of K_D.

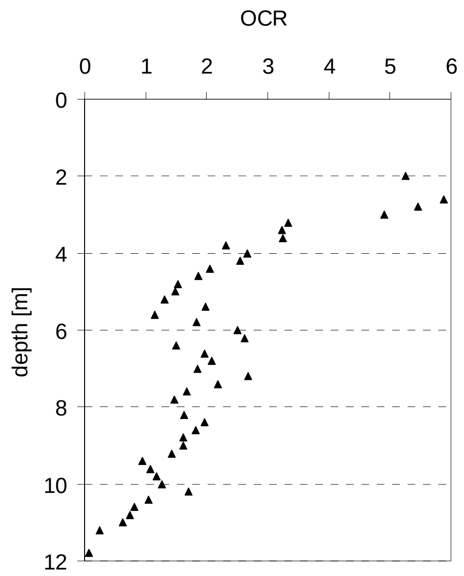

Figure 4. *OCR* profile.

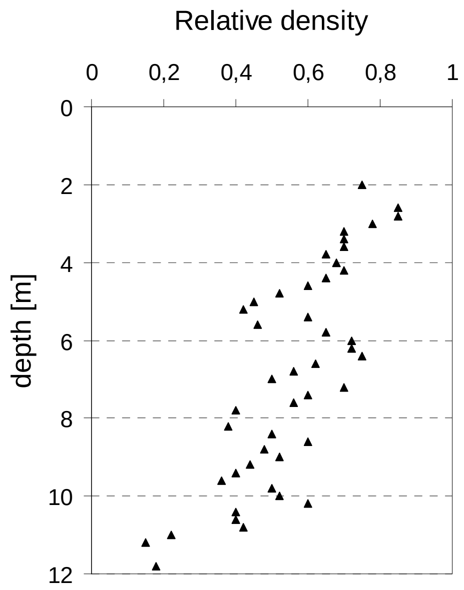

Figure 5. Relative density profile.

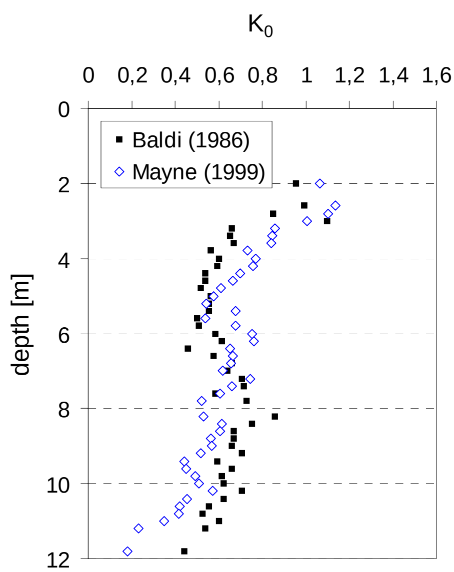

Figure 6. Earth pressure coefficient at rest.

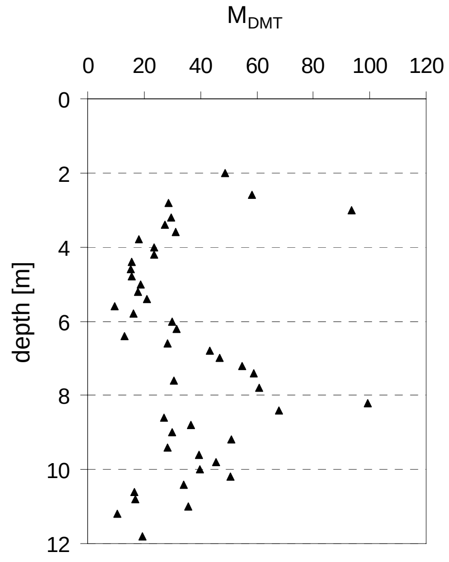

Figure 7. Constrained modulus M_{DMT}.

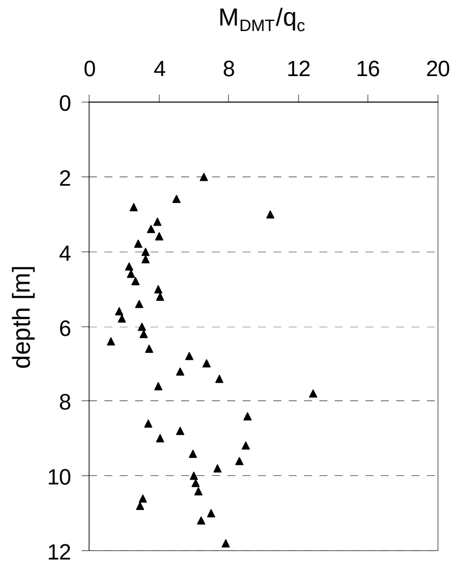

Figure 8. Profile of M_{DMT}/q_c ratio.

Linear correlation between constrained modulus from DMT and cone resistance (Fig. 9) slightly overpredicts the proposition of Lunne & Christophersen (1983).

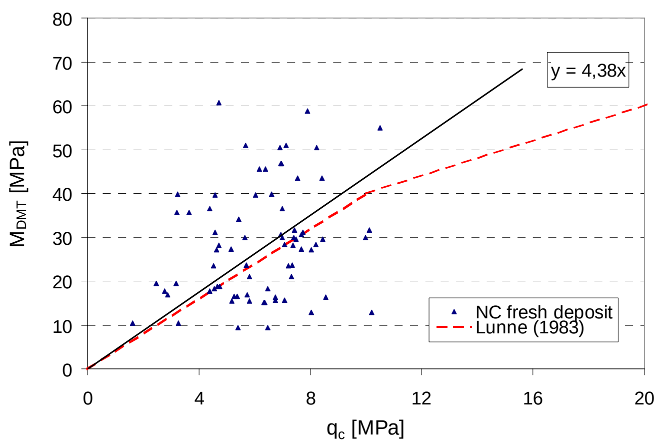

Figure 9. Constrained modulus vs. cone resistance in NC sand.

BACK

3.2 *Sand fills on the Baltic coast*

CPTU and DMT tests were performed in the fresh sand fills placed a few weeks before. These fills were discharged above sea level and densified with a flow of water. Downward seepage flow can induce overconsolidation of the sand fill. Leveling operations of bulldozer contribute to mechanical compaction and to the overconsolidation of the sand fill. Flat sandy beach (Fig. 10) has a width of about 20 to 30 m. The tests were performed with Geotech rig 220 (Fig. 11). The total thickness of the sand fills placed during a few placement periods was about 3 m (Fig. 12). A very steep mobilization of cone resistance is observed in this layer. The estimation of relative density from CPTU tests at small depths is subject to high uncertainty. A rough estimation of relative density (Eq. 1) gives D_R close to 1 in saturated sand fills. The water table is about 1,5 m under ground level. Some aged Holocene sands with a high density is found under the sand fill layer. A very high, close to 18, lateral stress index K_D is obtained in the fully saturated fills (Fig. 13). It is considerably higher than K_D which was - close to 6 at maximum relative density - found for the NC sands in the calibration chamber - Reyna & Chameau (1991). K_D values derived in partially saturated soils are even more important due to capillary forces, which will affect the effective stress state. It signifies that the sand fill is not only close to the maximum relative density, but is highly overconsolidated as well (see Fig. 14).

Figure 10. Pipeline for sand fill transport.

Figure 11. The anchoraged rig.

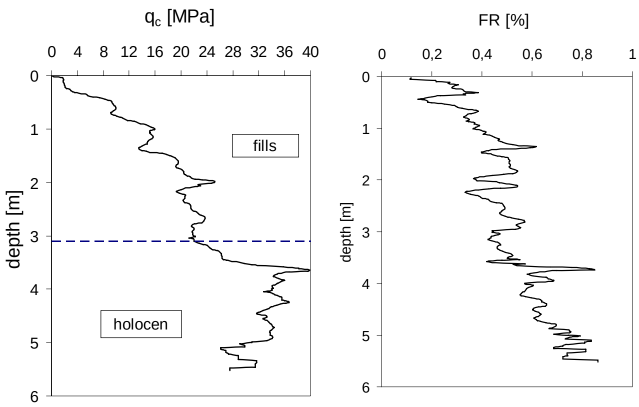

Figure 12. Profile of cone resistance and friction ratio.

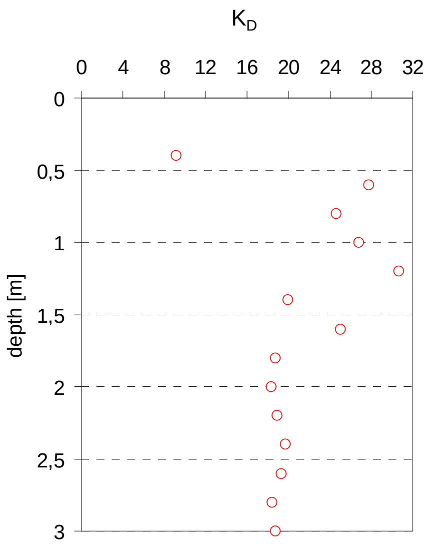

Figure 13. Profile of K_D.

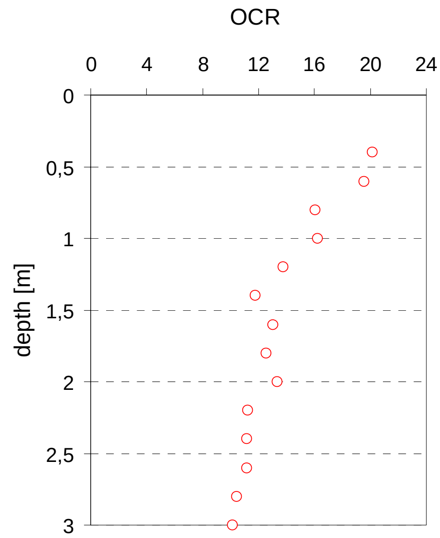

Figure 14. *OCR* profile.

To account for the overconsolidation effect in subaerial beaching by the pipeline discharge method, Lee (2001) suggests to take the coefficient of earth pressure at rest K_0 equal 1. The earth pressure coefficient at rest (Fig. 15) calculated with both methods (Eqs. 3, 4) is however considerably higher (about 2). Moreover, in partially saturated soil the capillary effect additionally increases the K_0 coefficient near the ground level.

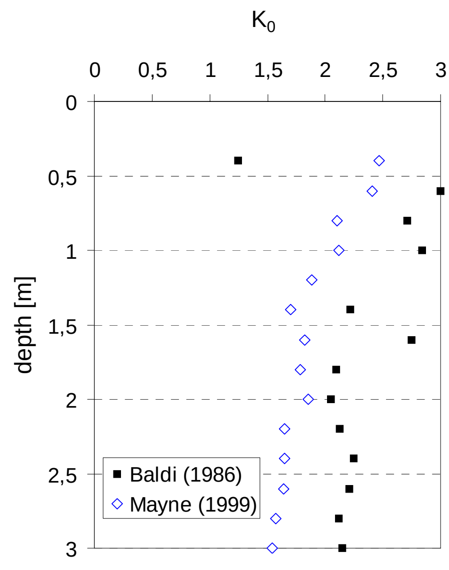

Figure 15. Earth pressure at rest coefficient.

A very high constrained modulus was found (Fig. 16) for the sand fill placed with subaerial hydraulic method. A ratio M_{DMT}/q_c from 8 to 10 was obtained in the saturated sand fills (Fig. 17). It is less than typically accepted for OC sand. Linear correlation between constrained modulus from DMT and cone resistance (Fig. 18) considerably overpredicts the Lunne & Christophersen (1983) correlation from CPTU tests. The dilatometer test is thus more sensible to stress state and history than the cone penetration test. This correlation was established for small penetration depths. Further research is necessary to expand this kind of relationship to higher depths/ confining pressures.

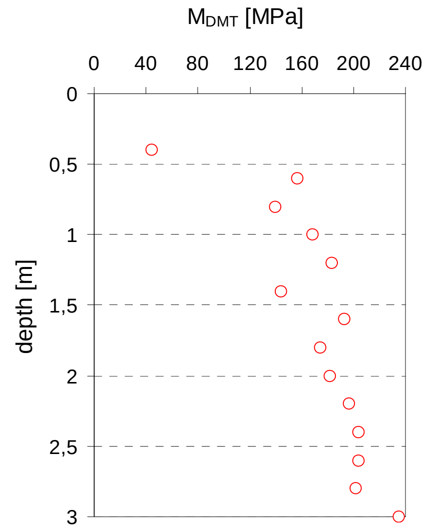

Figure 16. Constrained modulus M_{DMT}.

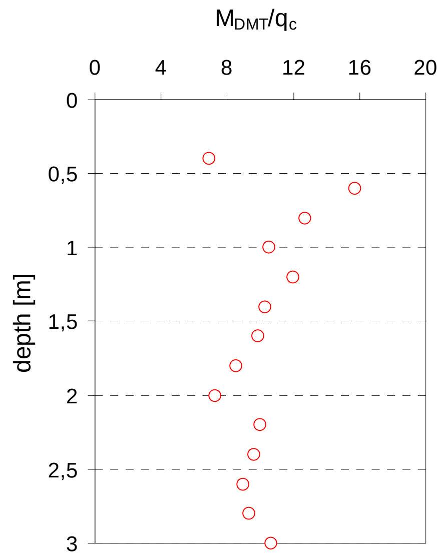

Figure 17. Profile of M_{DMT}/q_c ratio.

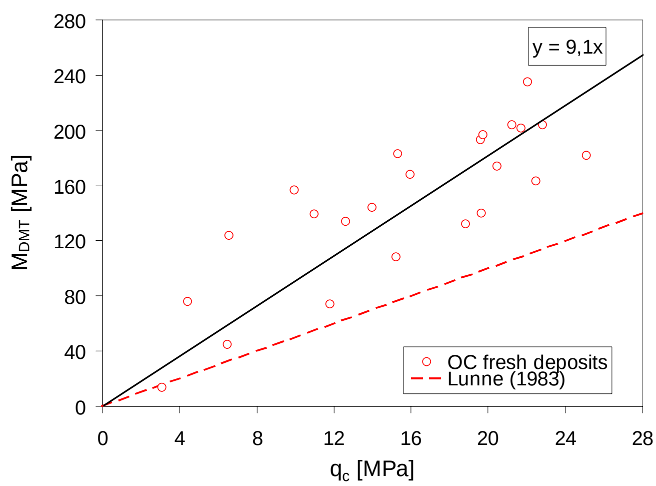

Figure 18. Constrained modulus vs. cone resistance for OC sand fills.

BACK

4 CONCLUSIONS

Strength and deformation parameters of hydraulic sand fills are essentially dependent on the placement method. Coupled CPTU and DMT tests permit a better description of sand fills including stress state and history. Sand fill at the back of harbour formed by subaqueous placement method is in normally consolidated or slightly overconsolidated state and has medium density. The constrained modulus derived from DMT tests is similar to Lunne's & Christophersen's CPTU correlation for NC sands. A very dense and overconsolidated sand was found in the hydraulically formed subaerial beach on The Hel peninsula. For OC sands the constrained modulus from DMT is significantly higher than the CPTU correlation. The dilatometer test is more sensible to stress state and history than the cone penetration test.

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BACK