CPTU/DMT Control of Heavy Tamping Compaction of Sands

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ABSTRACT: Heavy tamping compaction method in cohesionless alluvial soil was evaluated with CPTU and DMT tests. Some examples of interpretation of soundings in pre-treated and compacted sands are given. The compaction work was performed in two stages. Compaction control was performed after each stage of tamping. Additional tests were performed two weeks after the compaction works completion to study the set-up effect. While typical increase of cone resistance and sleeve friction in time was observed for CPTU tests, more complex phenomena was noted for DMT tests. If lateral stress index and dilatometer modulus increase with time, a decrease of material index of the compacted soil was observed. The effect of densification and set-up was analysed for angle of internal friction and M_d/q_c ratio. Changes in the soil classification induced by set-up are also considered. For a given relative density the lateral stress index was insensitive to compaction just after the work completion. Net increase of K_d in time was however recorded.

1 INTRODUCTION

Technologies of deep compaction of non-cohesive soils can be divided into dynamic or vibration methods. Dynamic methods use external energies that are generated by falling mass or explosion of charge. Depending on the applied energy or equipment to be used one should recognize: dynamic compaction, rapid impact compaction, square impact roller compaction and microblasting. Compaction of non-cohesive soils using vibration methods consists on insertion into soil the probe that generates the vibration. Depending on vibrating device type, its location and the direction of vibration one have to distinguish several techniques: vibroflotation/ vibroompaction, H- probe and more sophisticated forms as Terra-probe or Y-probe, Jendeby 1992.

The dynamic compaction method was used in the present study. The soil strength and deformability parameters increase with time after completion of sand fills compaction, as it was detected in CPTU (Mesri et al. 1990, Massarsch et al. 2005) or using CPTU/DMT control tests (Schmertmann et al. 1986) and this set-up process can take even several weeks. The dynamic compaction control of sandy soils using coupled CPTU and DMT tests was studied in this paper with special attention paid to the influence of soil aging.

2 TRIAL FIELD

2.1 *Subsoil*

The trial field was made in Gdańsk as a part of control tests after dynamic compaction of cohesionless soils. To the depth of 18m below ground level the postglacial and holocene soils associated with development of the Vistula Delta were found. This area is characterized by the geological structures typical for Żuławy Wiślane (Vistula Marshland). In the profile there are sands with different grain size with interbeddings of organic deposits (delta formation) and curonian-marine sandy sediments (Fig. 1). Organic soils are located under sandy soils with variable thickness from 8,5 to 16m. The soil up to 6 m depth are fine to a medium sands that are affected and loosened during the illegal exploitation of amber (layer IIa). Below, the medium dense sands (layer IIb and IIc) are placed. According to Lukas (1995) nomogram, sands (IIa, IIb and IIc) from trial area are confined within zone 1 (Fig. 2), which means a good soils compactibility. Moreover, the uniformity coefficient of this sand equal 2,6 and the small fines content (<75 μm) about 6% indicate the soil suitability for dynamic compaction.

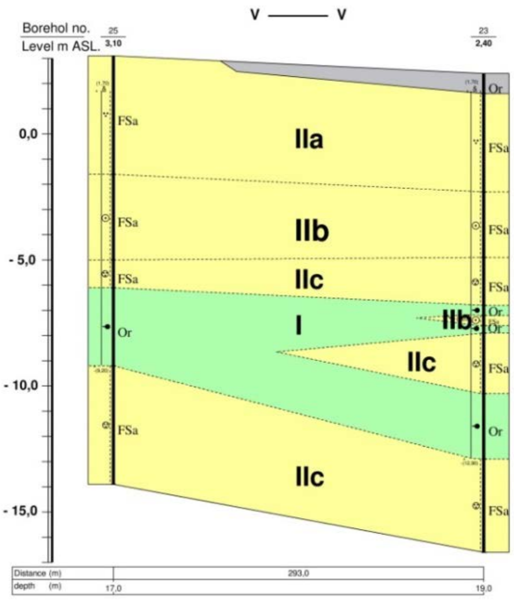

Fig. 1. Geological cross-section– trial field in Gdańsk (Kurek 2013).

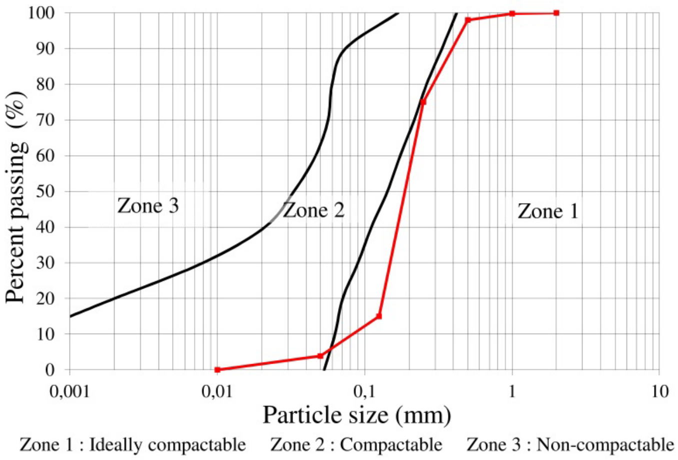

Fig. 2. Grain size distribution curve – trial field in Gdańsk (Kurek 2013).

2.2 *The process of compaction and its control*

The square shape pounder (1,6x1,6 m) was used for dynamic compaction. The rammer with a mass of 18 tons was dropped from a height of 18m. Amount of energy generated during dynamic compaction approaches 1500 kJ/m^2 and the densification depth up to 6m according to Lukas (1995). The compaction was made in two phases. In the first phase the square grid of compaction 7,5mx7,5m was used (Fig. 3). After 8 days the compaction in the middle of basic grid (second phase) was made. In each phase 13 impacts were done in a given grid node. The cone penetration test CPTU and the dilatometer test DMT were used as main tools of compaction control.

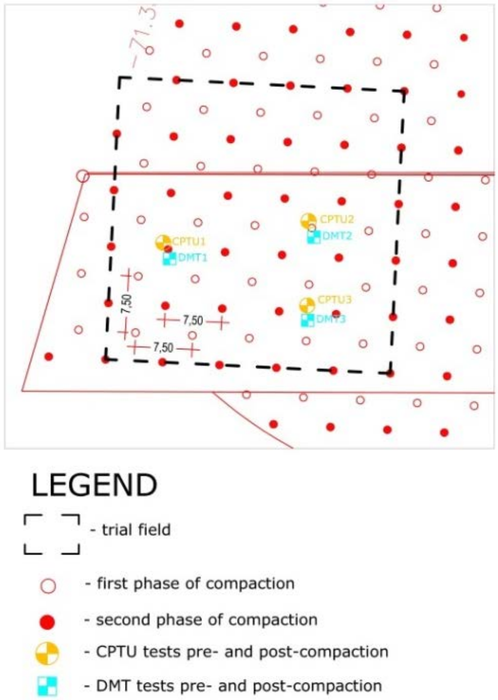

Fig. 3. Shape of trial field in Gdańsk (Kurek 2013).

The CPTU/DMT tests were made at the trial field in the following steps:

- before compaction,
- after I phase,
- after II phase,
- 14 days after II phase.

2.3 *Results of pre- and post- compaction*

Results of pre- and post-compaction CPTU test are shown in Fig. 4. The tests were made between the compaction points. The registered values of the cone resistance q_c and the sleeve friction f_s considerably increased after II phase of dynamic compaction.

The comparison of the pre- and post- compaction results of dilatometer tests DMT (Marchetti et al. 2001) is shown on Fig. 5. Net increase of K_d and M_d was observed. Particular attention should be paid to the material index I_d, which decreases after the dynamic compaction. This might suggest that after compaction the material has changed but is not true. To explain this phenomena we should look at the measured pressures p_0 and p_1. The analysis of this results showed that after dynamic compaction the increase of contact pressure p_0 is much higher than pressure p_1. The large increase of p_0 pressure may be related to lateral earth pressure increase and stiffening effect of compaction. The material index I_d describes the soil behaviour type, which probably also conceals the effect of overconsolidation.

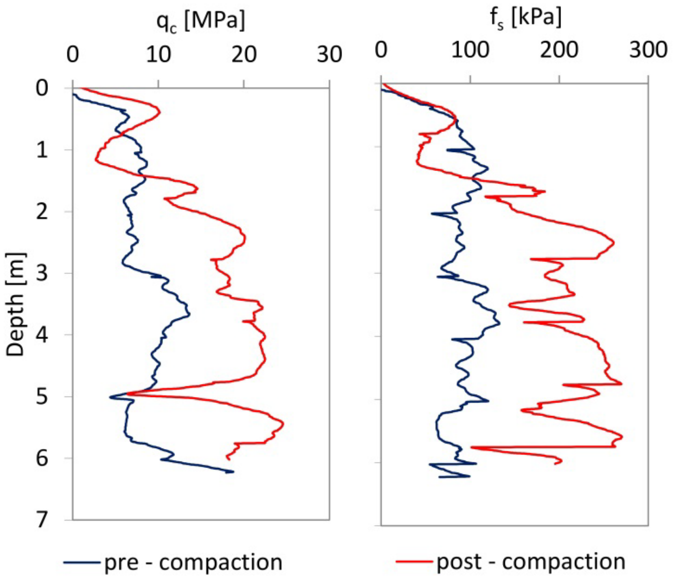

Fig. 4. Pre- and post-compaction CPTU results – trial field in Gdańsk (Kurek 2013).

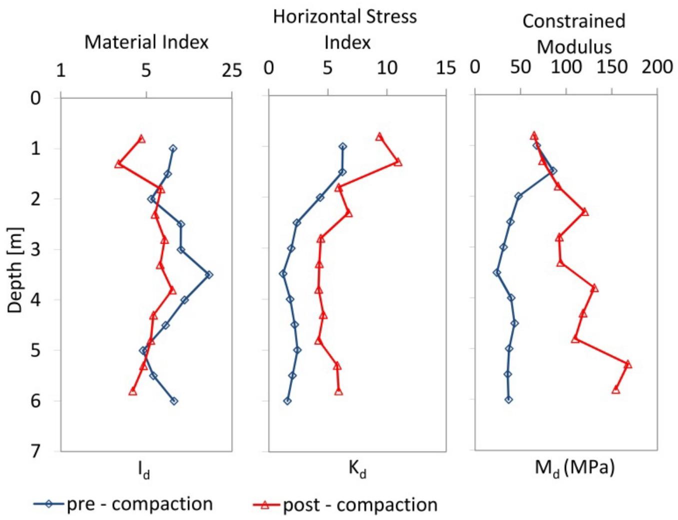

Fig. 5. Pre- and post-compaction DMT results – trial field in Gdańsk (Kurek 2013).

The analysis of CPTU results using Robertson (1990) soil classification chart (Fig. 6) shows that the dynamic compaction process moves the CTPU results into the zone of the soils presenting the overconslidated or cemented behaviour. In case of dynamic compaction the eventual cement bonds are destroyed so only the overconsolidation can be concerned. One should remember that Robertson's (1990) chart can't be used to evaluate the type of the soil after compaction, but as a tool to evaluate the changes in the soil behaviour induced by the dynamic compaction process.

2.4 *State and stress history*

The analysis of the lateral earth pressure K using Baldi et al. (1986) and Mayne (2001) proposals were done. The Baldi et al. (1986) proposal takes into account the CPTU and DMT result while the Mayne (2001) proposal is based only on CPTU test but takes into account the stress history and effective angle of internal friction. The Baldi et al. (1986) and Mayne (2001) proposals show similar distribution of lateral earth pressure with depth before compaction (Fig. 7). After dynamic compaction the lateral earth pressure coefficient calculated according to Mayne 2001 is significantly higher. One should notice that the distribution of the lateral earth pressure calculated according to Baldi et al. (1986) proposal, is proportional to horizontal stress index K_d. It means that for high values of horizontal stress index K_d the estimated lateral earth pressure coefficient K is unusually high. This effect is not observed for the interpretation according to Mayne (2001), where earth pressure coefficient tends to stabilize for higher OCR. The use of Mayne (2001) proposal seems to be thus more appropriate for the analysis of the lateral earth pressure coefficient K after dynamic compaction.

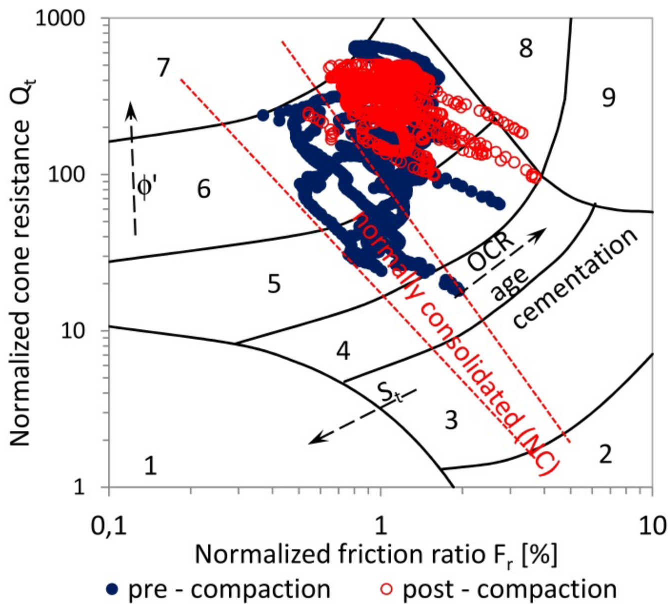

Fig. 6. Robertson (1990) soil classification of pre- and post-compaction CPTU results – trial field in Gdańsk (Kurek 2013).

The analysis of stress history using Mayne (2001) and Marchetti (1997) proposals were performed. The increase of OCR ratio after dynamic compaction is given (Fig. 8) according to Mayne (2001) proposal. Marchetti (1997) proposal, based on the M_d/q_c ratio, is another measure of overconsolidation. Only slight increase of this ratio after dynamic compaction is observed (Fig. 9). The obtained ratio after compaction is smaller than suggested by Marchetti 1997 and observed by Jendeby 1992.

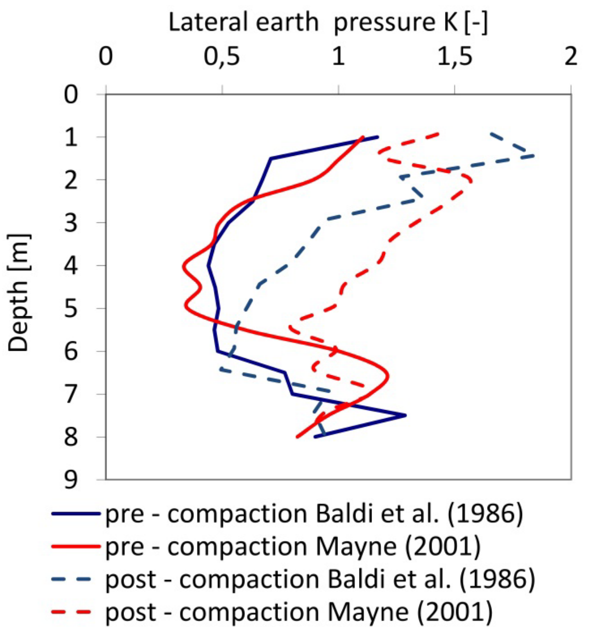

Fig. 7. Lateral earth pressure – trial field in Gdańsk (Kurek 2013).

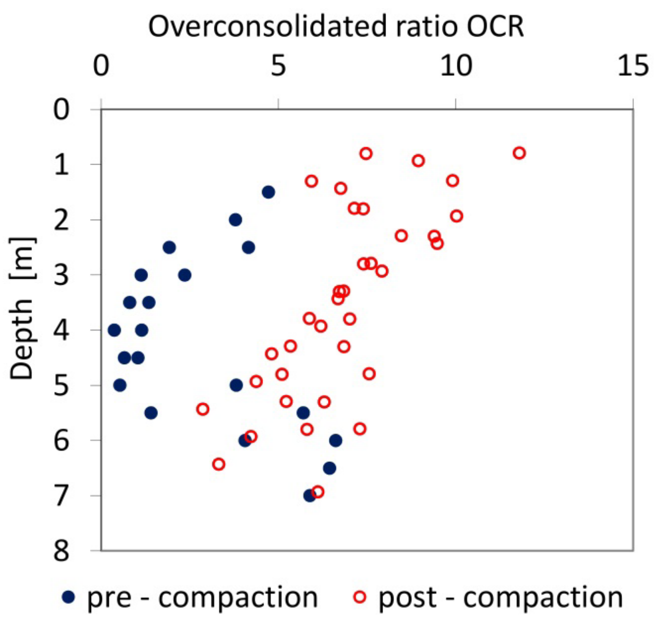

Fig. 8. OCR ratio using Mayne (2001) proposal – trial field in Gdańsk (Kurek 2013).

The relationship between the horizontal stress index K_d and OCR ratio estimated with Mayne (2001) proposal is shown on Fig. 10. In case of dynamic compaction the energy is applied mainly in vertical direction. The dynamic contact stress $\sigma_{0,dyn}$, is thus induced and the temporary vertical stress immediately increases. This process seems to be produce a comparable effect to classic soil overconsolidation (see Fig. 6).

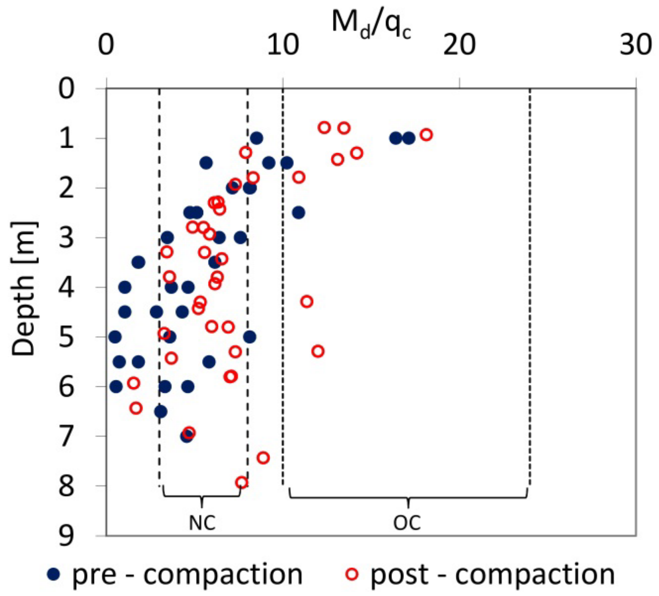

Fig. 9. M_d/q_c ratio compared to to Marchetti (1997) proposal – trial field in Gdańsk (Kurek 2013).

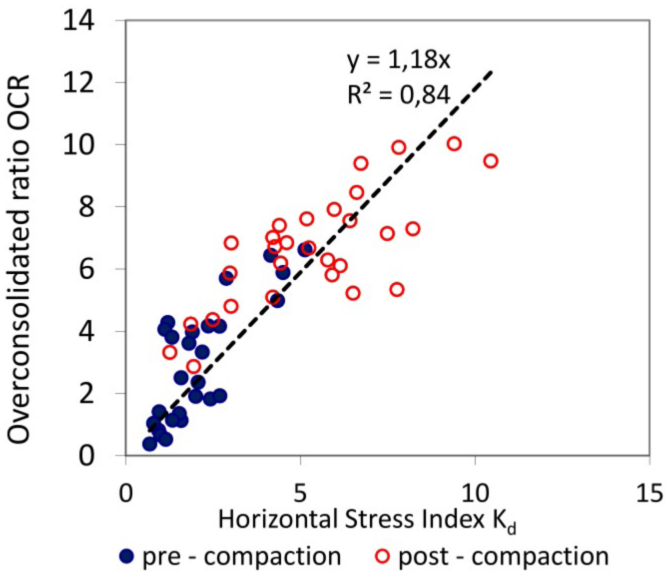

Fig. 10. OCR vs K_d for dynamic compaction – trial field in Gdańsk (Kurek 2013).

2.5 *Aging effect*

Set-up in sands is define as time-dependent increase in the strength and the stiffness in recently densified or deposited sands. In order to analyze the aging effect, CTPU and DMT tests 14 days after completion of dynamic compaction were done. The increase of cone resistance q_c and sleeve friction f_s with time was observed (Fig. 11). According to observations of Massarsch et al. 2005 it may suggest the increase of lateral earth pressure coefficient K.

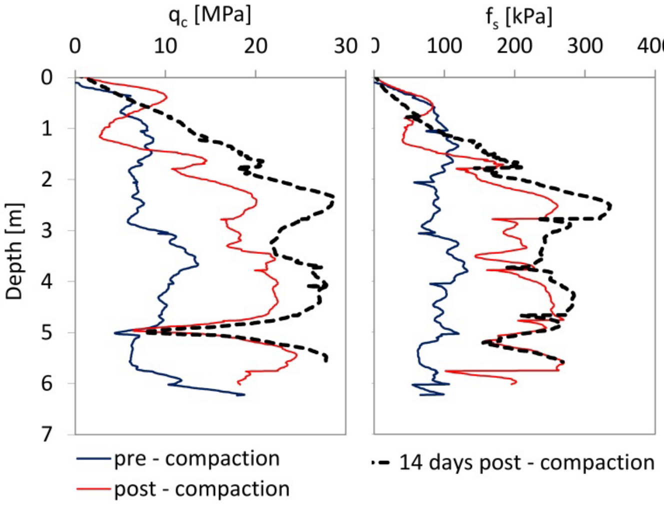

Fig. 11. Aging effect on q_c and f_s – trial field in Gdańsk (Kurek 2013).

The results of DMT tests 14 days after completion of densification works are given (Fig. 12). During this time further increase of horizontal stress index K_d and constrained modulus M_d was observed. The material index I_d continues to decrease with time, which may indicate a further increase of lateral earth pressure.

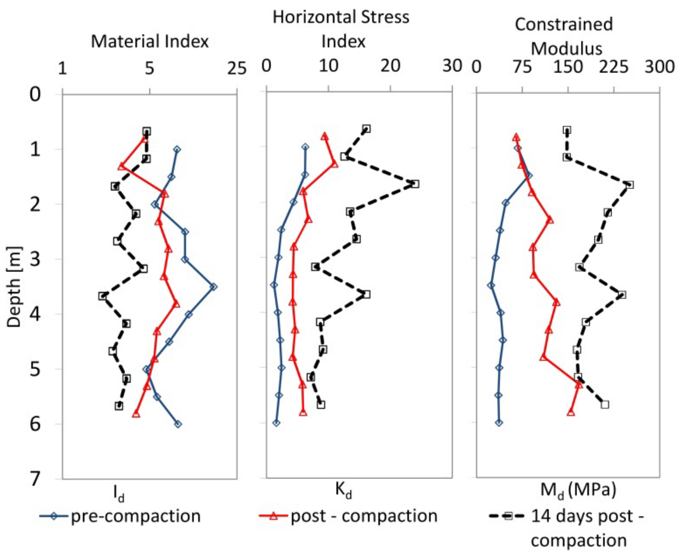

Fig. 12. Aging effect for DMT parameters – trial field in Gdańsk (Kurek 2013).

Aging effect is particularly evident when horizontal stress index vs. relative density D_R is shown (Fig. 13). The data before and after the second phase of compaction are located in the vicinity of the line proposed for NC sands (Reyna and Chameau, 1991). K_d is therefore not only a sensitive measure of stress state changes in soil, but it also takes into account the aging effect. The similar aging effect is observed for M_d modulus (Fig. 14).

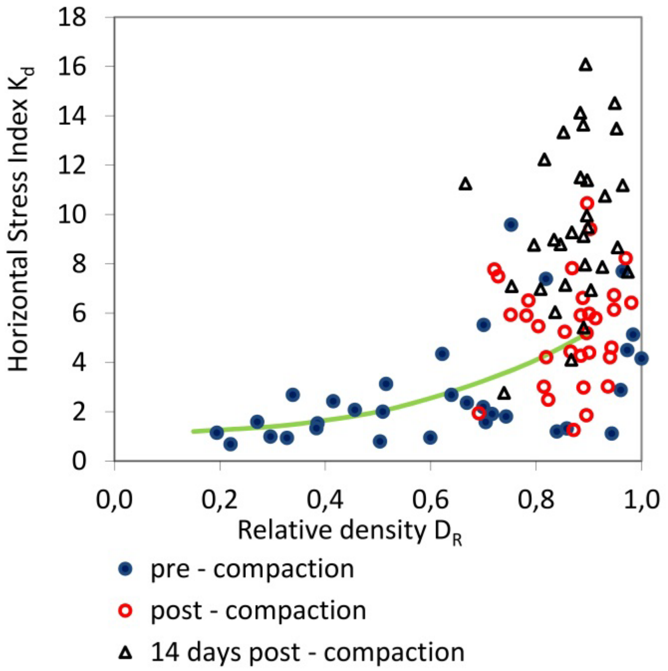

Fig. 13. Aging effect – K_d vs. D_R – trial field in Gdańsk (Kurek 2013).

Set-up effect after dynamic compaction within a short period of 14 days can be attributed mainly to mechanical aging. Mesri et al. (1990) and Schmertmann (1991) explained the mechanical aging as an increasing grain blocking, micro interlocking at rough surface of grain, which leads to higher frictional resistance and rearrangement of grains. Further research using CPTU and DMT tests should be performed to study this effect including larger time span.

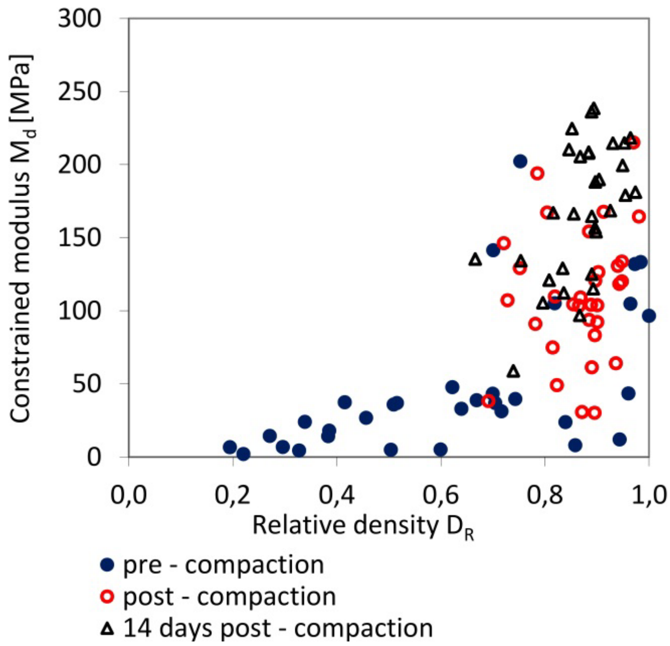

Fig. 14. Aging effect – M_d vs. D_R – trial field in Gdańsk (Kurek 2013).

3 CONCLUSIONS

Heavy tamping compaction can be evaluated by the parameters measured with CPTU and DMT tests and the soil behaviour charts. At the trial field the increase of cone resistance q_c, sleeve friction f_s, horizontal stress index K_d and constrained modulus M_d was observed. A decrease of material index I_d after compaction was however noticed. The same tendency was observed in the tests performed 14 days after completion of dynamic compaction.

The study confirms that K_d is not only a sensitive measure of stress state changes in the soil, but it takes into account the aging effect as well.

Finally, one should notice the limitations of traditional criterion of compaction control as a fixed value of relative density, as it does not take into consideration the lateral stress increase and set-up effect. The constrained modulus M_d is much better measure of compaction, as it includes not only the lateral stress increase or overconsolidation (see the compagnon paper), but the aging effect as well. This should be taken into account when the compaction control criteria are defined.

Set-up effect after heavy tamping of sands imposes a certain delay for the compaction control tests. This delay should be also defined in the list of compaction control criteria.

Robertson (1990) chart could be used to evaluate the changes in the soil behaviour induced by heavy tamping, but not as a tool to estimate the type of the soil after compaction.

Mayne (2001) proposal seems to be the appropriate estimation method for lateral earth pressure coefficient after dynamic compaction, as it limits K values at high OCR.

4 REFERENCES

Baldi, G., Bellotti, R., Jamiolkowski, M., Pasqualini, E. (1986). "Interpretation of CPT's and CPTU's. Part 2: Drained penetration of sand." *Proc. 4th International Geotechnical Seminar on Field Instrumentation and In-Situ Measurements*, Singapore, 143–156.

Jendeby, L. (1992) Deep Compaction by Vibrowing. *Proc. Nordic Geotechnical Meeting NGM -92*, Vol. 1: 19-24.

Kurek, N. (2013). "Quality control of deep compaction of non-cohesive soils." *PhD Thesis, Gdansk University of Technology*.

Lukas, R.G. (1995). "Geotechnical Engineering Circular No.1 Dynamic Compaction. Technical report." *Federal Highway Administration Office of Technology Applications*.

Marchetti, S., Monaco, P., Totani, G. and Calabrese, M. (2001) "The flat dilatometer test (DMT) in soil investigations". A report by the ISSMGE Committee TC16. *Proc. In-situ 2001*, Bali, May 21, 41 pages.

Marchetti, S. (1997). "The flat dilatometer design applications." *Proc. 3rd Geotechnical Engineering Conference*, Cairo University, 421–448.

Massarsch, K.R, Fellenius, B.H. (2005). "Deep vibratory compaction of granular soils." *Elsevier*, 633–658.

Mayne, P. W. (2001). "Stress - strain - strength - flow parameters from enhanced in-situ tests." *International Conference on In-Situ Measurement of soil Properties and Case Histories*, Bali, Indonesia, 27-48.

Mesri, G., Feng, T.W., Benak, J.M. (1990). "Postdensification Penetration Resistance of Clean Sands." *J. Geotech. Eng.*, 116(7), 1095–1115.

Reyna, F., Chameau, J.L. (1991). "Dilatometer Based Liquefaction Potential of Sites in the Imperial Valley." *Proc. 2nd International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics*, St. Louis, Missouri, vol. 3.13, 385–392.

Robertson, P.K. (1990). "Soil classification using the cone penetration test." *Canadian Geotechnical Journal*, 27(1), 151–158.

Schmertmann, J., Baker, W., Gupta, R. and Kessler, M. (1986). "CPT/DMT QC of ground modification at a power plant." *Proceedings of In Situ '86 GT Div., ASCE*, June 23-25, Blacksburg, VA, 985-1001.

Schmertmann, J.H. (1991). "The Mechanical Aging of Soils." *J. Geotech. Eng.*, 117(9), 1288–1330.