Set-up in Heavy Tamping Compaction of Sands

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**Keywords:** dynamic compaction, dilatometer test, cone penetration test

**ABSTRACT:** Heavy tamping compaction method in cohesionless alluvial soil was controlled 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 $M_{DMT}/q_c$ ratio. Changes in the soil classification induced by set-up are also considered. For a given relative density lateral stress index was insensitive to compaction just after the work completion. Net increase of $K_{DMT}$ 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.

2 **TRIAL FIELD**

2.1 **Type of soil**

The trial field was made in Gdańsk as a part of control tests after dynamic compaction of cohesionless soils. To the depth of 18 m below ground level (BGL) 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 ground profile there are sands with different grain size with interbedings of organic deposits (delta formation) and curonian-marine sandy sediments (Fig. 1). Organic soils are located under sandy soils with thickness of 8.5 – 16m. The soil to 6 m depth are developed as a fine to a medium sands that are affected and loosened during the illegal exploitation of the amber (layer IIa). Below, the sand in medium compacted state (layer IIb and IIc) are placed. According to Lukas (1995) nomogram, sands (IIa, IIb and IIc) from trial area is confined within zone 1, it means that the soils are very well compactable using dynamic compaction technology (Fig. 2).

![Fig. 1. Geological section – trial field in Gdańsk (Kurek 2013).](image-url)
Uniformity coefficient of this sand is equal 2.6 and the fine grain content (< 75 µm) is about 6%, which indicates the potential effectiveness of dynamic compaction technology.

Fig. 2. Grain size distribution curve – trial field in Gdańsk (Kurek 2103).

2.2 The process and control of compaction

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 18 m. The compaction was made in two phases. In first phase the square grid of compaction with space 7,5m was used (Fig. 3). After 8 days the compaction in middle of basic grid (second phase) was made. In each phase 13 impacts were done in a given grid node.

As main tools of compaction control the cone penetration test CPTU and the dilatometer test DMT were used. These tests were made at the trial field in a few steps:
- before compaction,
- after I phase,
- after II phase,
- 14 days after II phase.

Amount of energy generated during dynamic compaction according to Lukas (1995) equals about 1500kJ/m². It means that the soil should be densified to the depth of 6 m.

2.3 Results of pre- and post- compaction

Results of pre- and post-compaction CPTU test are shown in figure 4. The tests were made between the compaction points. It must be noted that dynamic compaction increases the registered values of the cone resistance $q_c$ and the sleeve friction $f_s$.

![Fig. 4. Pre- and Post-compaction CPTU results – trial field in Gdańsk (Kurek 2013).](image)

The comparison of the pre- and post- compaction results of dilatometer tests DMT are shown on figure 5. The dynamic compaction technology influences all three indexes: horizontal stress index $K_{DMT}$, material index $I_{DMT}$ and dilatometer modulus $E_{DMT}$. The increase of $K_{DMT}$ and $E_{DMT}$ was observed.

Particular attention should be paid to material index $I_{DMT}$, which decreases after the dynamic compaction. This might suggest that after compaction the material was changed, which 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 the dynamic compaction the increase of contact pressure $p_0$ is much greater than pressure $p_1$. The large increase of $p_0$ pressure may be caused by increase of lateral earth pressure $K$. The material index $I_{DMT}$ describes the soil behavior type, which probably also conceals
the effect of overconsolidation. The analysis of CPTU results using Robertson (1990) soil classification chart (Fig. 6) shows that the dynamic compaction process moves the CTPU results in zone of the soils presenting the overconsolidated or cemented behavior. In case of dynamic compaction the cement bonds are destroyed so we are dealing only with overconsolidation. It should be noted that Robertson’s (1990) chart should not be used to evaluate the type of the soil after compaction but as the tool to evaluate the changes of the soil behavior made by the dynamic compaction process.

![Fig. 5. Pre- and Post-compaction DMT results – trial field in Gdańsk (Kurek 2013).](image)

![Fig. 6. Robertson (1990) soil classification of Pre- and Post-compaction CPTU results – trial field in Gdańsk (Kurek 2013).](image)

2.4 State and history stress

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 but the Mayne (2001) proposal is based on CPTU test and 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 both proposals show increase of lateral earth pressure but obtained values are significantly different. The distribution of the lateral earth pressure is proportional to horizontal stress index $K_{DMT}$ according to Baldi et al. (1986) proposal which means that at high values of horizontal stress index $K_{DMT}$ the estimated values of lateral earth pressure are unnaturally high. This effect is not observed for the interpretation according to Mayne (2001) proposal. This proposal seems to be more appropriate for the analysis of lateral earth pressure $K$ after dynamic compaction.

![Fig. 7. Lateral earth pressure – trial field in Gdańsk (Kurek 2013).](image)

The analysis of stress history using Mayne (2001) and Marchetti (1997) proposals were made. The increase of OCR ratio after dynamic compaction is given (Fig. 8) according to Mayne (2001) proposal.

![Fig. 8. OCR ratio – trial field in Gdańsk (Kurek 2013).](image)
Marchetti (1997) proposal, based on the $M_{DMT}/q_c$ ratio, is another measure of overconsolidation. This ratio increase after dynamic compaction is rather slight (Fig. 9). The reason could be related to quite small increase of the horizontal stress index $K_{DMT}$, which is one of the principal parameters governing the constrained modulus $M_{DMT}$. The obtained ratio after compaction is smaller than suggested by Marchetti (1997).

The relationship between the horizontal stress index $K_{DMT}$ and OCR ratio is shown on figure 10. In case of the dynamic compaction the energy is applied mainly in vertical direction. The dynamic contact stress $\sigma_{0,dyn}$, thus induced, makes an immediate temporary increase of the vertical stress, which is comparable to classical overconsolidation of the soil.

2.5 Aging effect

Aging effect in sand 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 observation of Massarsch et al. (2005) it can attest the increase of the lateral earth pressure $K$.

The results of DMT tests 14 days after completion densification works were made (Fig. 12). During this time the increase of horizontal stress index $K_{DMT}$ and dilatometer modulus $E_{DMT}$ was observed. The material index $I_{DMT}$ continues to decrease with time, which indicates further increase of lateral earth pressure.
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), as no significant increase of lateral stress was induced during heavy tamping. $K_{DMT}$ is therefore not only a sensitive measure of stress state changes in soil, but it also takes into account the aging effect. This should be taken into account when the control criterion is defined.

Aging effect significantly increase the value of $M_{DMT}$ modulus (Fig. 14). This increase is however less pronounced than in case of $K_{DMT}$ index. One should notice the limitations of traditional criterion of compaction control as a fixed value of relative density. The constrained modulus $M_{DMT}$ is much better measure of compaction, as it includes not only the lateral stress increase but the aging effect as well.

Aging effect after dynamic compaction in a period of 14 days is mainly due to mechanical aging. Mesri et al. (1990) and Schmertmann (1991) explained the mechanical aging as increasing grain blocking, micro interlocking at rough surface of grain, which leads to higher frictional resistance and rearrangement of grains. Densification of sand by heavy tamping can be also explained by this theory. Further studies using CPTU and DMT tests should be done.

3 CONCLUSIONS

Dynamic compaction causes changes in parameters measured by CPTU and DMT tests. At the trial field the increase of cone resistance $q_c$, sleeve friction $f_s$, horizontal stress index $K_{DMT}$ and dilatometer modulus $E_{DMT}$ were observed. The decrease of material index $I_{DMT}$ was recorded which may indicate an increase in lateral earth pressure. The same tendency is observed in the tests performed 14 days after the heavy tamping completion. $K_{DMT}$ is a sensitive measure of stress state changes in the soil, but also takes into account the aging effect.

The study confirms the limitations of fixed value of relative density as a criterion of compaction control, as it does not take into consideration the lateral stress increase and set-up effect. These are registered by the lateral stress index and constrained modulus from DMT.
The study confirms the existence of set-up effect after heavy tamping of sands and the necessity of certain delay to perform compaction control tests. This delay should be also defined in the list of compaction control criterion.

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

Mayne (2001) proposal for the lateral earth pressure coefficient seems to be appropriate methods in case of dynamic compaction. Here, the overconsolidation plays a dominant role.

4 REFERENCES


