Terminal DCT2 w Gdańsku

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Effectiveness of Impulse Compaction (IC): A case study of Deepwater Container Terminal extension in Gdansk (Poland)

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Introduction

The Port of Gdansk (Poland) is situated on the southern coastline of the Baltic Sea enabling connection to the high seas through the Danish Straights. The extension of Deepwater Container Terminal (DCT) concerning brand new 2nd terminal (T2) was a major step giving DCT the position of the largest container terminal in the Baltic Sea and strengthening the role of the Port of Gdansk as a key port in this part of Europe. Now it has an opportunity to meet the growing demand for the deepwater services, by the increased capacity of the containers in the port and the ability to handle the largest Ultra Large Container Vessels (ULCVs).

The industrial region of Gdansk is known for its difficult ground and water conditions, with a significant presence of marine and alluvial deposits. The geotechnical part of the design and build process of T2 project concerned the new quay and adjacent container stacking yards – platform area.

The area of 25 ha of the investment has been divided into two major parts: heavy foundation of the STS (Ship-To-Share) gantry crane beam and deep soil improvement of the platform and quay area with connecting transition zone (Figure 1).

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The soil improvement in the quay area consisted of the land part (onshore) with its origin soil layers and deep hydraulic fill of the marine part (offshore). Deep soil improvement elements, such as stone and concrete stone columns, were adopted in variable grids and lengths to ensure the allowable settlements.

In the platform area the aim of the soil improvement was to compact loose fill and upper layer of loose sands by Impulse Compaction (IC) to reduce differential settlements and offer sufficient stiffness to the pavement structure. The improved upper layer function was to uniform the loads and distribute them to the deeper silty layer, that governed the global settlements. To meet the settlement requirements of the project the soil profiles, geological origin, loading conditions and design requirements were analyzed in details (Buca and Mitrosz, 2016).

Geological conditions

![Figure 2. Typical geotechnical profile in the platform area.](image)

Basing on the results of the soil investigation (BAGEO soil investigation campaign, 2014), the ground-water conditions in the area were determined as varied and difficult. Soil sedimentation due to transport by the Vistula river was the main phenomenon creating the geological formations such as sand layers and soft organic silts with very low strength and deformation parameters. The typical geological cross section (Figure 2) consists of an upper layer of fine sands (stratum II) with wide range of cone resistance, \( q_c = 2 \pm 12 \) MPa. The results of soil investigation showed low value of non-uniformity coefficient, what indicates the presence of single-grained soils. Samples
of natural fine sand from upper layer showed $C_u$ (U) coefficient in range from 1.5 to 1.7, which unambiguously proves the mono-fraction of the tested soils. Those types of non-cohesive soils are very difficult for compaction. The layer occurs down to 3÷4 m from the existing level and is highly diversified in its parameters. Therefore, it needed some special geotechnical treatment adjusted to the designed structure.

**Soil Improvement**

In order to compact the upper loose sand layer and uniform the settlements throughout the whole platform area, IC technology was introduced. The allowable settlements in the platform area, according to Client’s requirements, were 240 mm. Due to the required settlements, the upper sand layer had to be compacted. Its purpose was to improve and uniform the parameters to avoid differential settlements, that were crucial in this part.

**Implemented method**

The Impulse Compaction technology is performed by means of a 9 tonne heavy hammer. The effectiveness and range of compaction is dependent on the soil type and the groundwater level relative to the working platform level. The depth of compaction reaches approximately 5÷7 m. During IC a high level of soil compaction is obtained due to the reduction of porosity. The compaction works are performed with a frequency of 40÷60 blows per minute on a specially placed foot that transfers the energy deep into the ground, which results in soil improvement (Figure 3). As a result of ground compaction technological craters appear, that need to be filled with material and levelled after each pass.

![Figure 3. Sequence of Impulse Compaction performance.](image)

**Field Trials**

The Impulse Compaction trial was performed on the testing site in order to specify: the improvement factor after each pass of compaction (measured by CPT tests), the IC points spacing, grid and number of passes and the number of drops to obtain the total penetration of the hammer approximately 40÷50 cm.

The minimum design criteria for the ground compaction was to achieve at least 8 MPa of the cone resistance ($q_c$) over the depth of 4 m below working level (Figure 4).
Obtaining the high values of compaction ($q_c > 12.0$ MPa) to the assumed level of 4-5 m from the working level was proved by performed CPT tests (Figure 5).

In addition, all the CPT tests regardless of their position (in or between the executed IC points) showed an equal improvement factor of the treated soil, hence proving the volumetric character of the soil improvement. When comparing the performance of the various compaction methods outlined above, it has been determined that Sweep&Track provides the most effective and efficient method of compaction. Therefore it was implemented for the execution.

Figure 4. Impulse Compaction acceptance criteria.

Figure 5. Results of CPT tests and Sweep&Track grid diagram.
Embankment test

To confirm the validity of the settlement calculations, a monitored embankment test was performed. It was assumed that 3 m high overload of the embankment will be an equivalent weight that will occur during the pavement construction and as a surcharge load. The ground in the area of the embankment was previously improved with the Impulse Compaction technology.

One can observe the development of settlements on all of the settlement gauges, showing a similar type and pace of deformation. The measurements after ~1 month of monitoring showed approximately 3 cm of settlement. Above 80% of the settlement was observed in the first 2 days of the measurements. The curves showed fast stabilization of the settlements and proved that observed settlement values are in line with the calculated values (Figure 6).

![Figure 6. Calculated settlements of test embankment: 3.17 cm after 1 month; Measured settlements of test embankment showed: 3.00 cm after 1 month.](image-url)
Conclusions

The presented case was just a part of the complex geotechnical engineering that was implemented at the DCT site.

Before choosing any geotechnical solution, the designer has to consider a variety of components: the applicability of certain technology and its limits, type of structure, type of applied loads, structure sensitivity to settlements and type of foundation. It is also highly recommended to perform field tests prior to the commencement of works, to set appropriate QA/QC procedures and monitor the real life of the structure in order to verify the implemented solution, maintain the high quality of work and mitigate any potential risk. The applied solution also needs to fit the construction timetable and finally has to be economically viable. Thus, geotechnical engineering has to face many challenging demands.

The presented Impulse Compaction technology was very successful on DCT T2 project. All of the test results met the design assumptions. The soils were compacted quickly and economically, providing uniform parameters and required stiffness to the platform. It proved to be efficient and effective way of ground improvement, regardless difficult ground conditions with low non-uniformity coefficient values of upper sand layer and lack of compaction features.

Moreover, significant improvement of parameters was observed during first compaction pass with the “Sweep & Track” method. Equal improvement factor of the treated soil was achieved, what proved the volumetric character of the soil improvement. The measured settlements were in line with the calculations as well.

However, it also has to be noted that IC technology has its limits and restrictions in terms of execution, which have to be considered, due to significant vibrations caused by IC works.

However, the solution should always be specified on the base of the existing ground conditions and like the other parameters, adjusted to the characteristics, requirements and constrains of a particular project.

Bibliography

[5] PN-85/B-02170 Evaluation of the harmfulness of the vibrations transmitted through the ground to the buildings.
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