Ground improvement tank terminal Amsterdam - The Netherlands

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ABSTRACT

In the western part of the Port of Amsterdam a new storage terminal of oil products is being built. The site investigation revealed that underneath a single tank the thickness of the compressible layers could differ up to 3 meters. It was concluded by the client that ground improvement was required to avoid excessive differential settlements of the storage tanks and associated maintenance costs. The initial ground improvement design proposed by the client consisted of the application of dynamic replacement (DR). A trial showed that the traditional DR method as well as the CDC technique did not achieve sufficient improvement. Therefore, a full ground improvement was made, with large excavations up to a depth of 8 meters below the surface, removing more than 1,000,000m3 of material. The excavations were backfilled with sand. This very loose sand was compacted in one phase using the CDC technique. This paper presents an overview of the initial trial results and the final work method with a focus on the method of compaction and the compaction results.

1. INTRODUCTION

In the western part of the Port of Amsterdam a large new storage terminal for gasoline and related products is being built. An impression of the terminal is given in Figure 1. Before the storage tanks could be built, a large ground improvement was required. The ground improvement was required because of the large risk of differential settlements underneath the storage tanks and the high direct and indirect costs involved with the jacking and backfilling of differentially settled tanks. During the ground improvement, the highly compressible layers were removed within the zone of influence of the tanks and replaced by sand. This sand was compacted in one phase from the surface using the world largest rapid impact compaction hammers. This paper presents an overview of the ground improvement works with a focus on the method of compaction and the results obtained.

Figure 1: Artist impression terminal

2. GEOLOGY

The extensive site investigation data at the location of the terminal, with numerous CPT tests underneath one single tank, revealed compressible Holocene deposits with varying thicknesses underneath a continuous sand layer of 3 to 5 meters in thickness. The sand layer was placed in the 1960s during a large scale reclamation of the port of Amsterdam and was placed on top of the agricultural areas. The area was raised further during the dredging operations of the new ‘Afrika’ harbor at the beginning of this century, adding about 1 meter to the sand thickness. Underneath a single tank, the layer thickness of the compressible material, consisting of a distinct layer of peat on top of a clay layer, could differ a couple of meters. The local thickening of the layer is contributed to an infilled channel, which presumably formed in the underlying clayey sand deposits on top of the Pleistocene sands. Figure 2 presents the interpolated bottom of the compressible layers. The creek is recognizable through the red coloring.

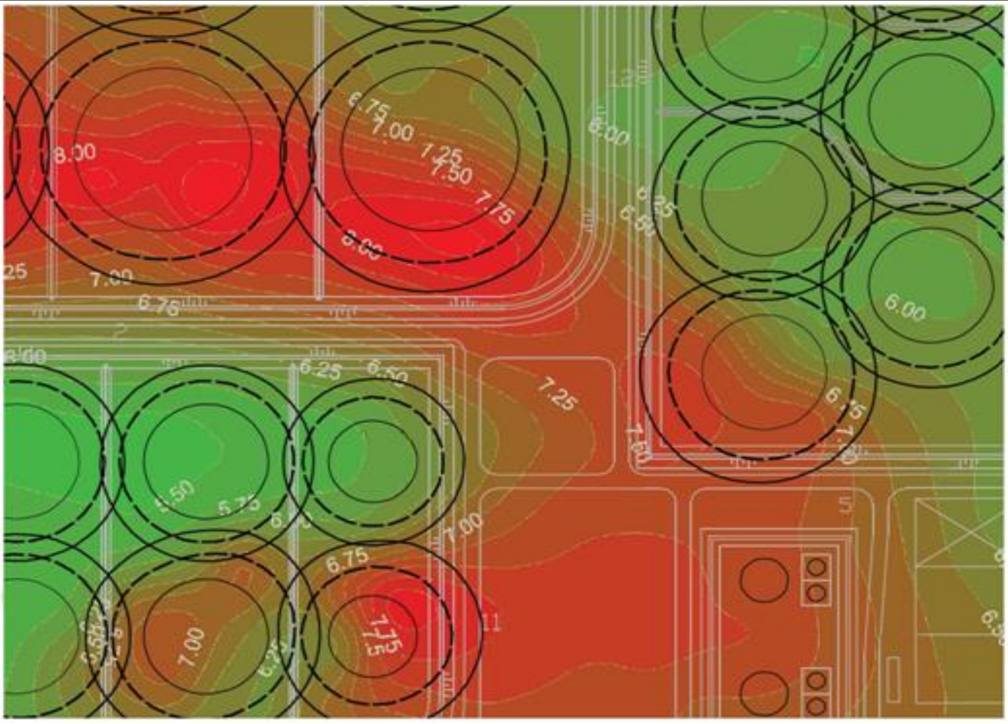

Figure 2: Interpolated bottom of the compressible peat and clay layer from the CPT information

3. INITIAL DESIGN

The large differences in the thickness of the compressible layer made that, without any ground improvement, the design did not comply with the PG29 guideline. The filling of the tanks, founded on raft foundations, would initiate differential settlements exceeding the maximal allowable 2.5% skew.
As a solution, the client proposed to use dynamic compaction to create sand columns inside the soft deposits, which is also known as Dynamic Replacement (DR). Through the installation of the sand columns it was anticipated to create shorter drainage paths, thereby allowing the excess pore water pressures to dissipate quickly during the loading of the tanks. The accompanying design made by the client consisted of dropping a 12.5 ton weight 4 times from a height of 6m in a grid of 3.5m by 3.5m. A compaction trial was initiated by the client and two contractors were invited to demonstrate their technique. Next to the design solution (DR) requested by the client, an alternative dynamic compaction technique was proposed by Cofra B.V. This was the CDC method.

4. CDC METHOD

The CDC method is a relative simple but effective compaction method. A weight of 9 or 16 tonnes is hydraulically accelerated within a frame. It drops from a height of 1.2 meters, with a frequency of minimal 40 times a minute, onto a foot which remains in contact with the ground. The foot is hammered into the ground till the stop criterion is met or when the maximum stroke of 1 meter is reached. Because the used feet have a large diameter ranging from 1.5m to 2.6m, they experience enough resistance in the granular soil to transfer the kinetic energy into compression and shear waves. The energy of the waves exceeds, in the non saturated zone, the shear resistance between the particles, making them rearrange into a denser structure. In the saturated zone, the compaction is achieved by the combination of the compression and shear waves. The pore pressures are momentarily raised during the passage of the compression wave. This results in a temporary lowering of the effective stresses and contact forces between the sand particles. When the shear waves passes, the excess pressures have not yet dissipated completely and the particles are moved into a denser structure. As a result of the dense compaction grid used during the compaction operations, with overlapping zones of influence, a single location is repeatedly vibrated, leading to homogeneous and effective compaction.

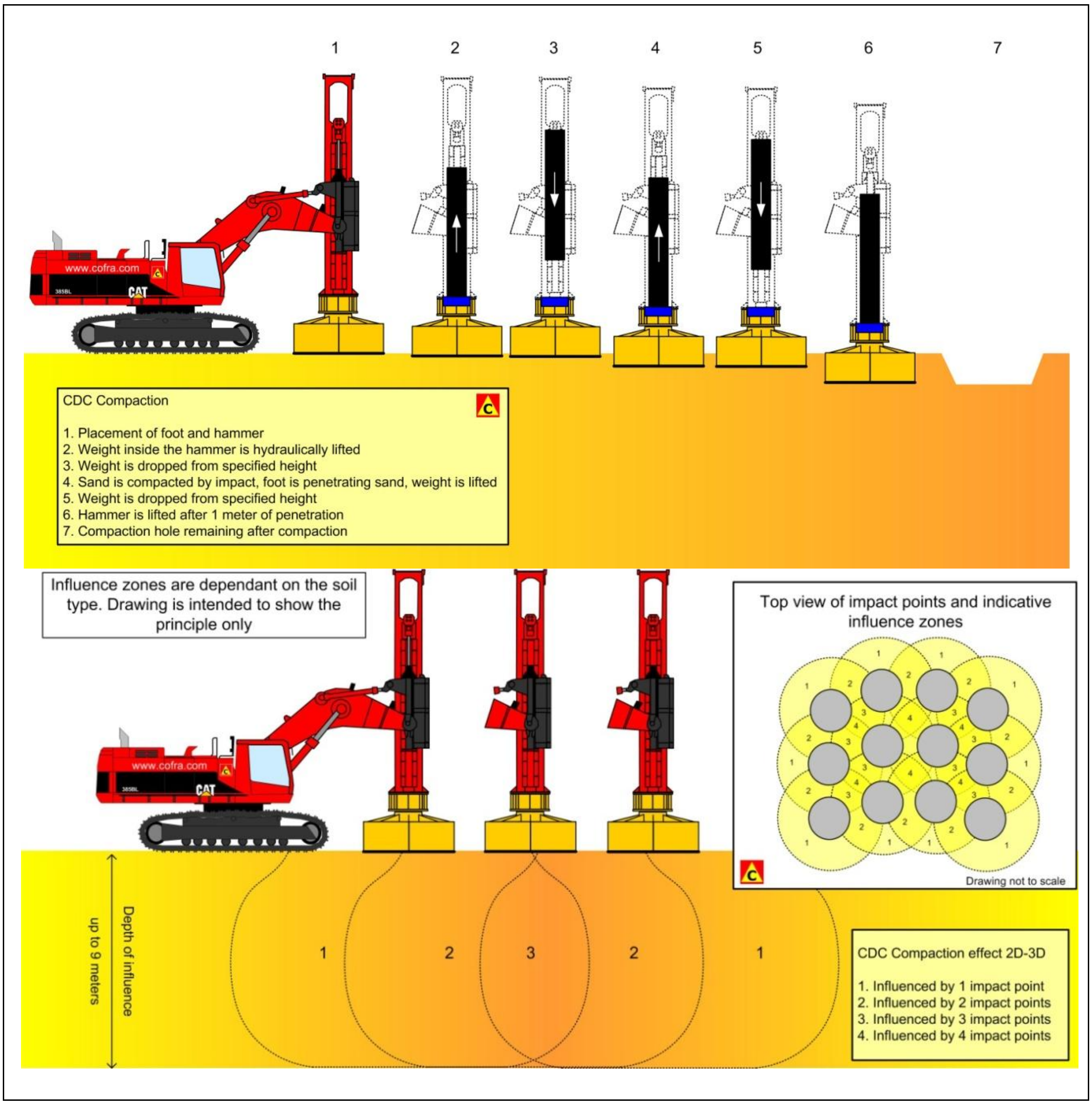

Figure 3: CDC principle

5. GROUND IMPROVEMENT TRIAL

The testing of DR and CDC techniques was performed during a compaction trial. The compaction trial was executed in march 2009. Before the trial was commenced a detailed method statement was made discussing the tests to be performed and how the alternative CDC method would be able to accomplish the same effect as the proposed Dynamic Compaction, as the CDC method is not capable to produce the same amount of energy per blow compared to the falling weight method.

It was proposed to test two compaction methods using the CDC hammers. The first method was similar to conventional dynamic replacement: a column of sand is pounded into the softer layer creating a stiff column transferring the load to the bearing layers below the soft layer. It was anticipated that in total 4 compaction runs were required to be able to create the column of sand.

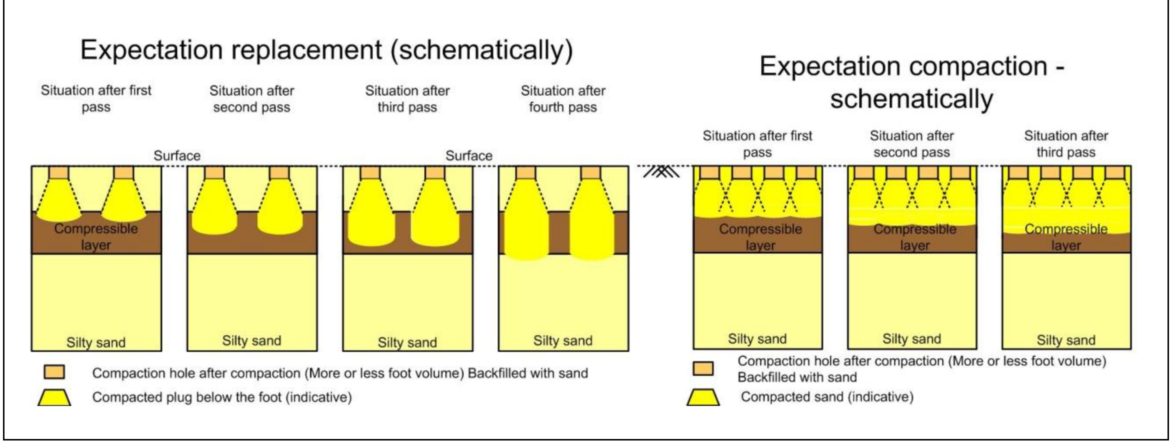

Figure 4: Principle of creating sand columns in the compressible peat and clay layer (left) and compaction on top of the peat and clay layers (right).

The second method tested was the regular CDC compaction method, where the complete surface area is treated in an overlapping grid. This was brought forward in order to accommodate the clients wish to “crack the peat and allow for a fast consolidation upon loading”. Both principles are depicted in Figure 4.

The dynamic replacement operations were executed using 9 compaction locations in a square grid of 3.5m. Each phase of the compaction consisted of the compaction of all 9 locations and the compaction of each location till the compaction foot with a diameter of 1.5m was fully penetrated into the ground, i.e. 1m of displacement. After each phase CPT tests were performed to monitor the compaction levels and possible penetration of sand into the peat layer. Photo 1 shows the execution of the trial. During the trial massive amounts of water were forced to the surface, inundating the trial area.

Photo 1: Compaction of a trial location. Note the subsidence on the surface and the water in the previously compacted location

The second stage of the trial, compacting the area using a standardized grid, was performed by downsizing the diameter of the foot and grid spacing in every following compaction phase. The following compaction method was used:

- The first phase was executed using a 2.0m diameter foot with a grid spacing of 2.5m by 2.5m.
- The second phase was executed using a 1.5m diameter foot with a grid spacing of 2.0m by 2.0m.
- The last phase was executed using a 1.0m diameter foot and a grid spacing of 1.6m by 1.6m.

The changes were made to the grid and the foot diameter as the CPT testing of each previous phase showed no clear reduction of the thickness of the peat layer and compaction of the overlying sand layer. With the reduction of the foot diameter it was tested if the compaction of the top layer could be "broken" by the higher energy-surface ratio of the smaller diameter foot.

During the execution of the trial it became clear that for both trial methods:

- tremendous amounts of water were forced to the surface inundating the trial area,
- the top layer showed clear increases in cone resistance,
- no sand was forced into the peat layer.

The reason for the results became only apparent in the next stage of the project and will be discussed in a following section. It should however be noted that, even with a peat layer underneath, a clear increase in cone resistance was measured in the sand layer overlying the peat, as shown in Figure 6.

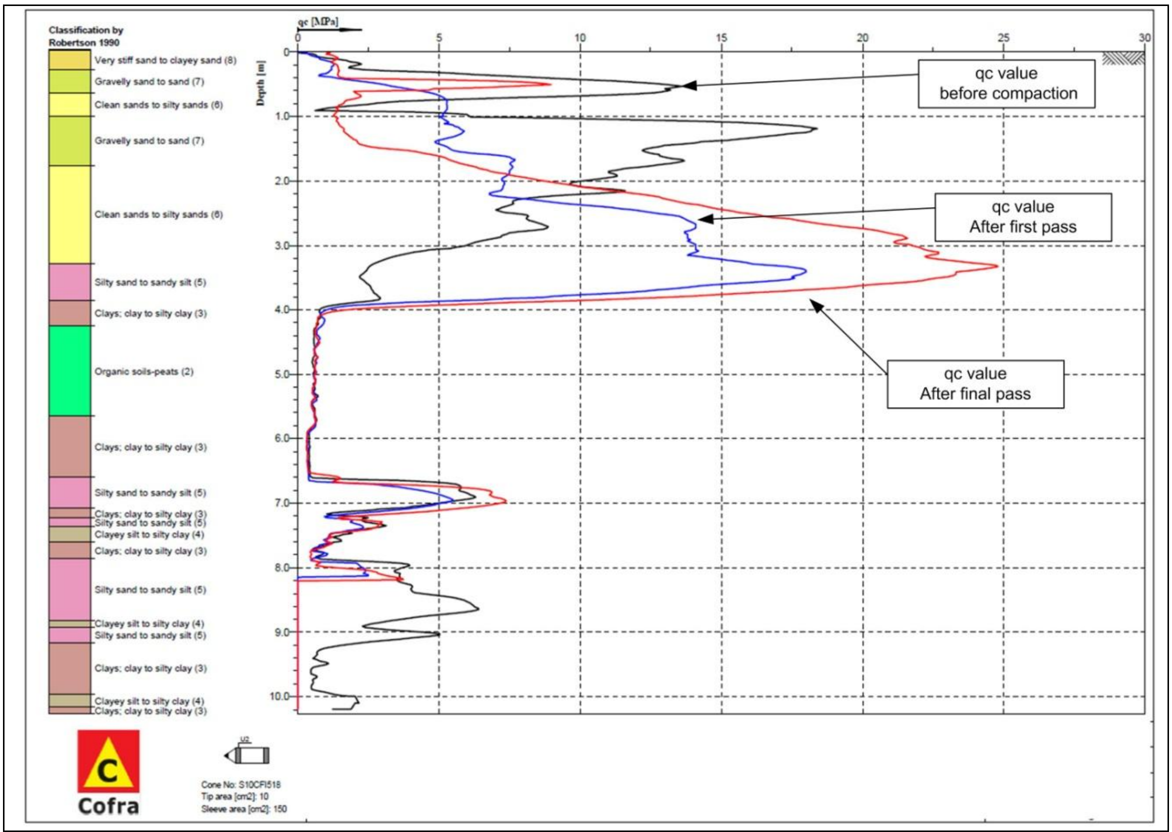

Figure 6: CPT results after the different compaction stages. The compaction after the first phase shows a clear change in the CPT profile, a clear increase in cone resistance in the zone 2-4m below the surface. The top section is disturbed by the penetration of the foot and reworking of material into previously compacted locations. The compaction of the final phase shows a further increase in cone resistance in the section from 2-4m below the surface. The low cone resistance in the top 1.4m is due to the backfilling of the compaction location.

6. NEW DESIGN

As the trial with the traditional DR method was also not successful, the client requested the contractors involvement in the design. After several consultations between the client, advisor and contractor, in which several ground improvement solutions were reviewed and priced within given boundary conditions, a simple solution was chosen to reduce the risk of the differential settlement: the removal of the compressible layers and their replacement with sand. This solution was economically most attractive, as right next to the new terminal, a new dock was required to be built providing a source of sand.

After the award of contract, a detailed operational plan was made in cooperation with the dredging company Boskalis to allow for a fast excavation and backfill. The sand was compacted from the surface after backfilling only. In total an area of 125,000m2 was compacted with a production of 2,000m2 per working day. The complete work, including excavations from 5 up to 8 meters deep, backfilling and compaction, was executed within 4 months time. Photo 2 and 3 give an impression of the project.

Photo 2: Photograph of the excavation of the compressible layers underneath the sand layer

Photo 3: aerial overview of the project with the different phases

7. EXCAVATION

During the excavation of the material it became clear why the replacement of the peat had not worked during the initial trial. The peat and clay layers were found to be very compact and almost dry. The peat could be excavated in large dry lumps. This was however of major advantage to the excavation process as the peat was strong enough for vertical excavation, as can be seen in Photo2. With the considerable strength of the peat, it is clear that the penetration of material into the peat was not possible.

8. COMPACTION REQUIREMENTS

The compaction requirements of the backfill material were set by the client, and required a cone resistance of minimal 5 MPa throughout the newly placed fill. Newly placed dry fill is generally compacted using vibratory rollers together with a slow filling process in layers. In this project it was chosen to abandon this principle and compact the placed material, with a maximum thickness of 8 meters, in one phase from the final surface using the CDC method. This was of major benefit to the speed of execution of the project and frequency of testing. Moreover the pumping period to lower the water table was reduced to only the excavation period, which also reduced the impact on the surrounding of the works. During the filling and compaction the pumps were not operational.

Photo 4: excess pore water escaping to the surface during the compaction

9. EXECUTION

The required compaction energy and compaction method was determined during a compaction trial, executed at the start of the project. In the trial two regularly used grid spacings were used, a 3.3m and a 2.5m center to center distance with a two meter foot diameter. Each grid spacing was used on a single tank footprint to incorporate the lateral variability in the fill in the trial and be sure the chosen method would be able to compact the sand in one pass. The compaction results were reviewed on the basis of CPT testing. The results indicated that the 2 meter diameter foot and a grid spacing of 2.5m was the most optimal configuration of the compaction with regards to the production and the requirement of reaching 5 MPa over the complete height of the fill. An example of a CPT test performed during the trial is given in Figure 7. The shown CPT was performed on the section compacted using the 3.3m grid. This specific CPT did not comply with the specification at 6 meter below the surface and required recompaction. The CPT result after recompaction is also shown in the figure.

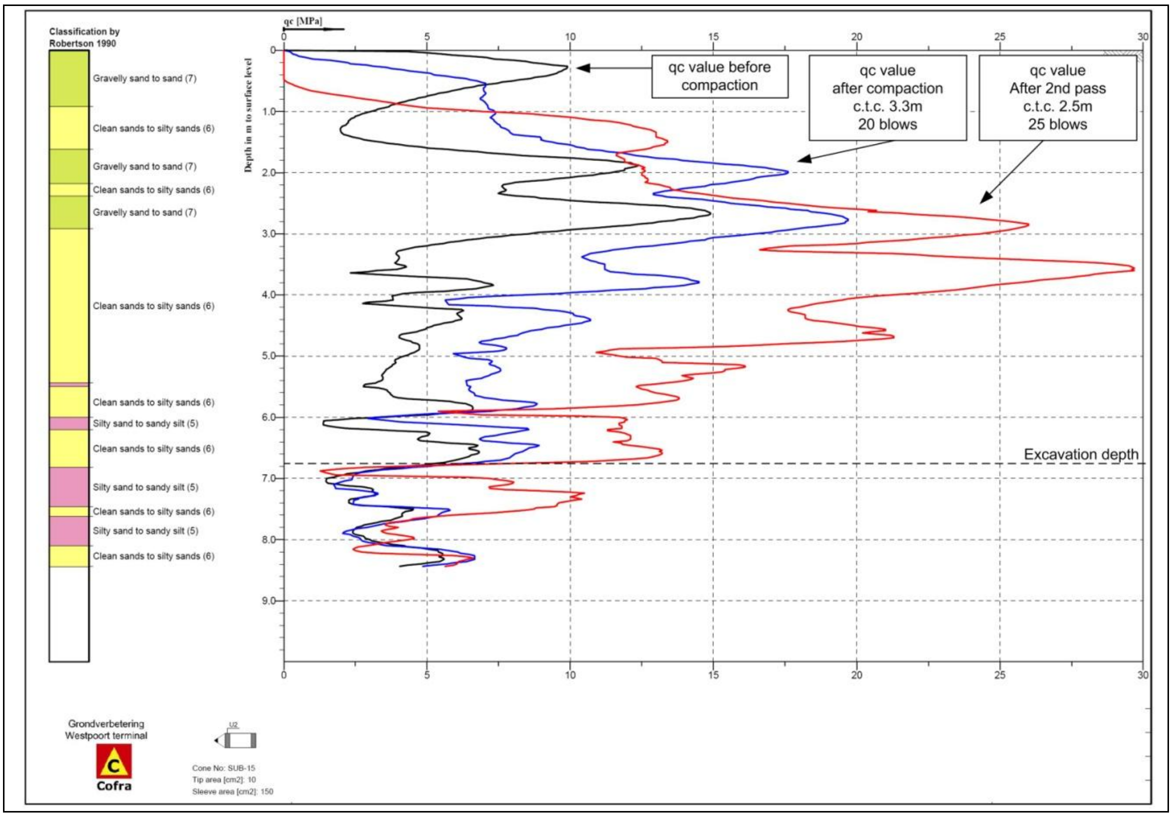

Figure 7: CPT test of initial trial area where the grid spacing was determined before and after compaction and after recompaction with the final grid.

10. QUALITY AND EFFECT OF PLACEMENT OF THE SAND

Due to the varying quality of the sand and the different methods of filling (in smaller layers and in lifts of several meters thick) the initially determined fixed number of blows per grid point was not a practical method to achieve homogeneous compaction. It was therefore chosen to change the work method to a more advanced system using the induced settlement as a stopping criterion. The induced settlement is measured during the compaction operations and displayed on the GPS guided loggers. This method was, after a statistical analysis of the performed handover CPT tests, able to deal with the varying filling methods and deliver a more homogeneous terrain after compaction. The used criterion was a settlement of the foot of 23mm per blow. When the criterion was met, the chance that the subsoil was compacted to the specification was more than 95%. The average surface level drop after compaction was, depending on the filling method and depth of excavation, after one pass, between 0.25m and 0.50m. Figure 8 presents a part of the obtained loggerdata. In the example a section of the compaction data is shown. The example shows the effect of the filling method. The left side of the compacted area was filled in one stage, the right side in multiple stages. The one stage filling results in much higher settlements before the criterion is met and hence a lower relative density before compaction.

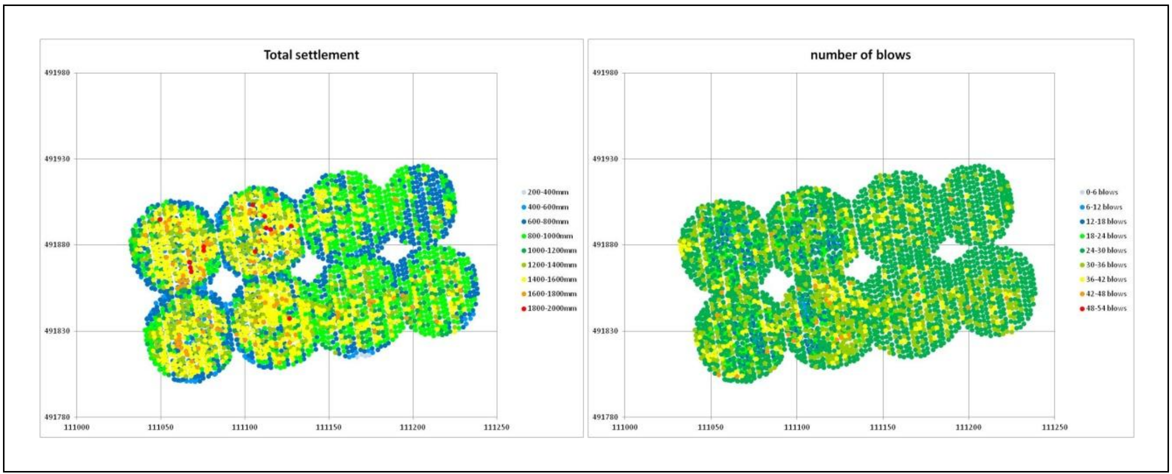

Figure 8: Logger data from one of the tank pits showing the effect of the placement method of the sand, where the left hand tank sites have been filled in one stage and hence show more settlement upon compaction

As described above, the method of filling and the quality of the sand had a large influence on the results of the compaction. This was especially noticeable during the compaction of the tank excavations backfilled with dredged North Sea sand. This sand, with a fines content of about 0%, compacted much better than the local sand with fines content above 10% using similar compaction energy. An example of a CPT taken after before and after compaction in the North Sea sand is given in Figure 9. In the silty sand CPT profiles where reached similar to Figure 9 but with cone resistances ranging between 10 and 15 MPa. Maximum cone resistance values above 30MPa were reached at sections with higher initial relative densities.

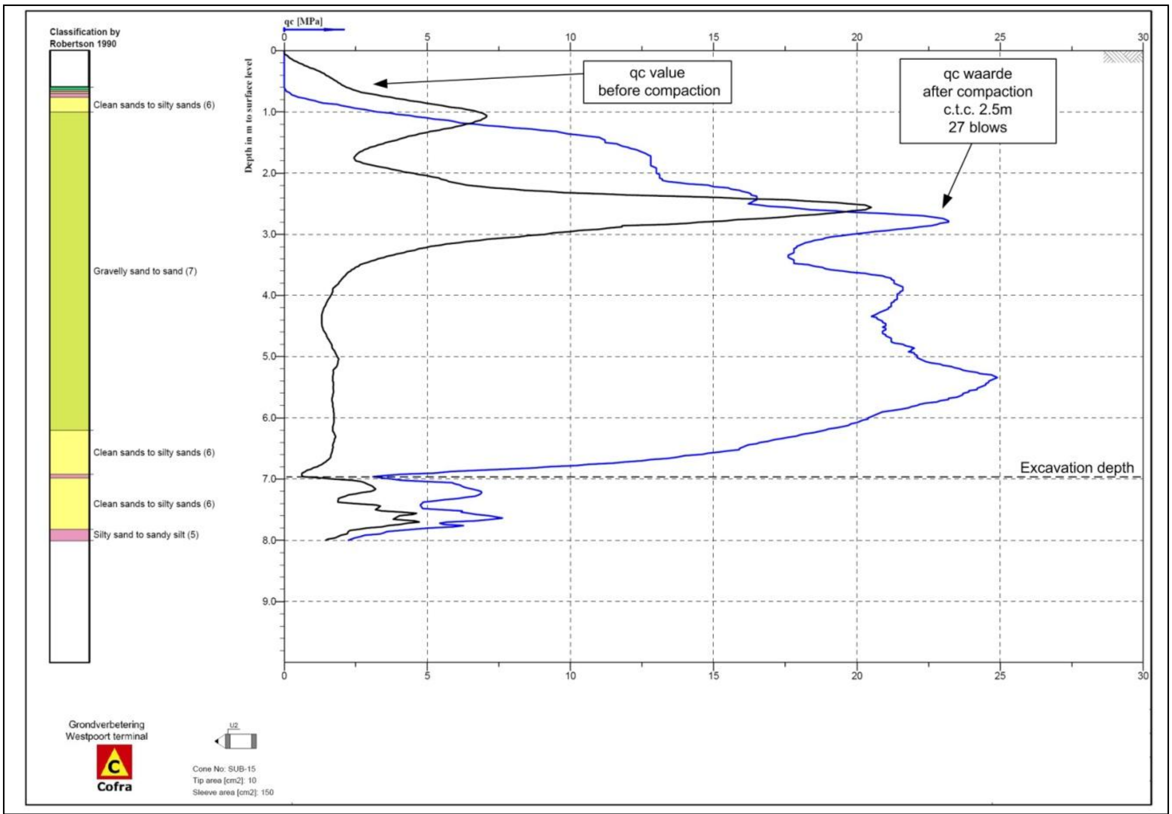

Figure 9: CPT test of area where North sea sand was used as fill material.

The surface settlement after compaction was in-between 30 and 50cm depending on the location and excavation depth.

11. QUALITY CONTROL TESTING

After the compaction and an analysis of the logger data, the compaction results were checked using CPT tests. CPTs results from before and after compaction were analyzed, where it should be noted that many more tests were available from after the compaction than from before the compaction. The compaction was checked with 17 cone penetration tests within each tank, equaling a CPT every 225m2 The CPT's were also used to check the excavation dimensions and the removal of all the compressible material. All CPT's were compliant to the contractual criterion.

The water load testing, i.e. the filling of a finished tank with water to simulate the loading conditions and test the integrity of the tanks, recently performed after the construction of the tanks, showed a compliance to the PG29 guideline.

12. INFLUENCE ON SURROUNDING STRUCTURES

Next to the area 4 windmills were located. As they were within the zone of influence of the compaction works, with minimal distances to the compaction front of 16 to 25m. They were actively monitored during the excavation and during the compaction operations. The displacement and the vibrations remained within the tolerances requested. Figure 10 gives the vibrations measured on the foundation of the windmill closest to the compaction operations. The vibrations were very low due to the large weight of the slab and the special working method, with compaction towards the windmill leaving always a section of very loose sand between the compaction and the windmill, reducing the vibrations.

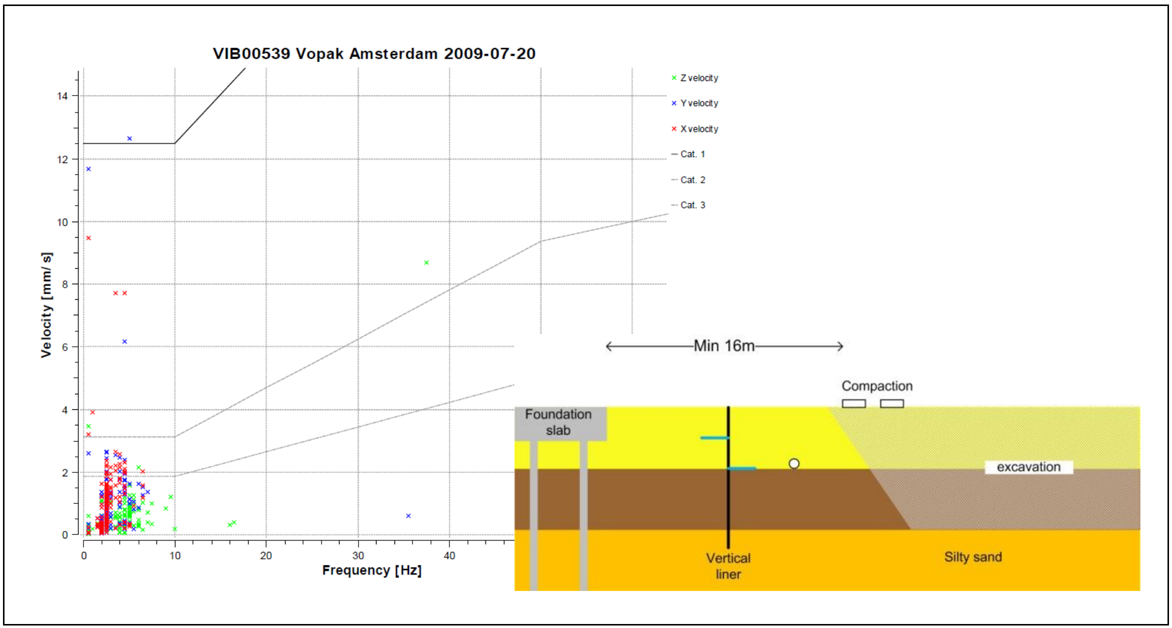

Figure 10: Vibration measurements on the foundation of the windmill

13. CONCLUSION

The CDC method was successfully applied at a large ground improvement project in the Western part of the harbor of Amsterdam. Due to the stiff characteristics of the peat and clay layer at a depth of 4 to 5 meter below the surface, the execution of DR using both CDC as well as the traditional method were not successful. This lead to the excavation of the compressible peat and clay layers within the influence zones of the tanks. After the backfilling of the excavations, with a depth up to 8 meters deep, the CDC compaction reached the required minimal cone resistance 5MPa over the full depth of the excavation. After compaction the CPT profile reached in general between 10 and 15 MPa. Maximum peak values of over 30 MPa were reached in sections with an initial higher cone resistance using a grid spacing with center to center distances of 2.5m.

The surrounding structures were not influenced by the excavation and compaction works with vibration velocities in general below 3mm/s.

REFERENCES

P. Meijers et al, 2009, Gedrag van zand onder cyclische belasting, Geotechniek nr 1 p30-35 (Dutch)
H.J.A. Berendsen, 2004, De vorming van het land, Gorcum b.v., Koninklijke Van
PGS 29 guideline, 2008, Vloeibare aardolieproducten - bovengrondse opslag in verticale cilindrische installaties, Ministerie van VROM, Den Haag (Dutch)
Lunne et al, 1997, Cone penetration testing in geotechnical practice