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A glimpse into the future of site supervision: Data collection during pile installation at the Amaliahaven construction site

Un aperçu du futur de la supervision de site: Collecte de données pendant l'installation des pieux sur le chantier de construction d'Amaliahaven

J. Putteman*, P.S.F. Le Lan, C.J.F. van Marrewijk, T. Jottier
SBE Engineering Consultants, Rotterdam, The Netherlands

J.N. Bruens
Port of Rotterdam, Rotterdam, The Netherlands

A.A. Roubos
Port of Rotterdam, Rotterdam, The Netherlands/Delft University of Technology, Delft, The Netherlands

M. van der Pol
Maarten van der Pol, Utrecht, The Netherlands

**jan.putteman@sbe-engineering.nl*

ABSTRACT: The Amaliahaven project in the Port of Rotterdam involves the construction of quay walls and a back crane track. Given the enormous quantities of foundation piles and anchors included in the design, it was decided to collect and store the installation data in a uniform and structured manner. The goal was to improve quality control and support site supervision through efficient data analysis and, in addition, to acquire new knowledge. This paper presents a framework for automated data collection and validation. Despite the high level of automation, manual verifications of the data through Site Acceptance Tests remain crucial. The data of driven foundation piles can be used quite easily by site supervisors and geotechnical engineers when assessing the load-bearing capacity of these piles. In fact, the initial knowledge from the coarse-meshed CPT grid is updated with additional insights obtained from the fine-meshed pile installation grid. For grouted anchors, there is significant improvement potential to create added value based on the recorded data. The findings of this paper can play a crucial role in the quality control procedure of foundation piles and can serve as direct input for reverse engineering of quay walls, and presumably also for other types of port infrastructure.

RÉSUMÉ: Le projet Amaliahaven dans le port de Rotterdam implique la construction de quais et d'une voie de grue arrière. Compte tenu des quantités énormes de pieux et d'ancrages, il a été décidé de collecter et de stocker les données d'installation de manière uniforme et structurée. L'objectif était de soutenir la supervision du site grâce à une analyse efficace des données et, en même temps, d'acquérir de nouvelles connaissances. Un cadre pour la collecte automatisée et la validation des données est présenté. Malgré le niveau élevé d'automatisation, les vérifications manuelles des données lors des tests d'acceptation sur site restent essentielles. Les données des pieux battus peuvent être relativement facilement utilisées par les superviseurs de site et les ingénieurs géotechniciens pour évaluer la capacité portante des pieux. Il s'avère que les connaissances initiales issues de la grille CPT à mailles larges sont mises à jour avec des informations supplémentaires obtenues à partir de la grille d'installation plus fine des pieux. Pour les tirants d'ancrage, il existe un potentiel d'amélioration significatif pour créer une valeur ajoutée basée sur les données enregistrées.

Keywords: Pile; anchor; data; database.

1 INTRODUCTION

Container volumes in Rotterdam (the Netherlands) are expected to continue to grow strongly in the coming years. For this reason the Port of Rotterdam Authority invests in the further expansion of the Prinses Amaliahaven quay walls located on Maasvlakte II. The project involves the construction of:

- 1,825 metres of deep sea quay wall, with a soil retaining height of 29 metres.
- 1,825 metres of back crane track with pile foundation
- 160 meters of inland shipping quay wall
- Construction works started in 2021. A large amount of foundation elements are installed, including:

- ca. 700 open-ended tubular piles (combined wall)
- ca. 700 intermediate sheet piles (combined wall)
- ca. 2100 vibro piles (driven cast-in-situ piles)
- ca. 1300 screw injection anchors

In recent quay wall construction projects, installation data from pile and anchor installation was collected (e.g. blow count, rotations per minute, flow, pressure, torque, grout volume, …). Due to unclear agreements, this data was provided by the contractor in various file formats (handwritten, Excel files, PDFs, etc.), and there was no consistent formatting of the files. This made it very impractical to process this large amount, and as a result, this source of data was underutilized.

Given the enormous quantities of foundation piles and anchors in the Amaliahaven project, it was decided to collect and store the data in a uniform and structured manner. The goal was to improve quality control and support site supervision through efficient data analysis and, in addition, to acquire new knowledge.

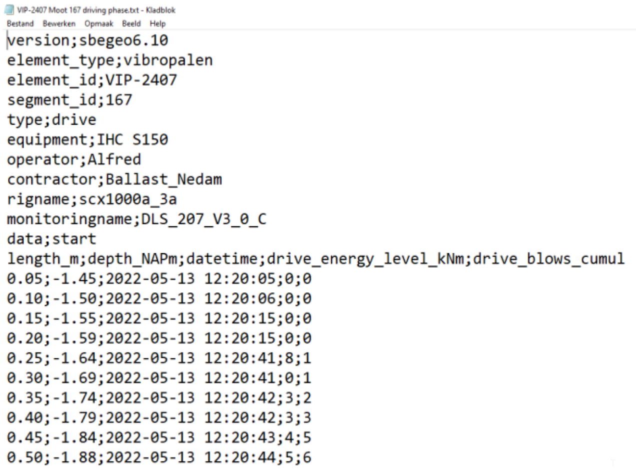
2 DATA STANDARD

The SBEGEO standard is an in-house developed general data standard to which the registrations must adhere. This data standard was included in the tender documents for the construction and consequently constituted a contractual obligation for the contractor. The corresponding SBEGEO transfer file (Figure 1) is a computer file formatted uniformly with the intention of enabling the transfer of data between different platforms in a standardized manner and allowing smooth database processing. The main characteristics of the transfer file are:

- The file is text-formatted (UTF-8)
- The extension is *.txt
- The transfer file consists of two parts. The top section includes the header data, the bottom section includes the data series.

3 COMPLIANCE CHECK AND STORAGE

The .txt transfer file is uploaded to the port's database by the contractor, according to the following process:
Step 1: Upload .txt transfer file to web application.
Step 2: Automated file compliance check.
Step 3a: If the file compliance check fails, the user receives an error message in the web application, with identification of the error (example in Figure 2 left).
Step 3b: If the file compliance check is successful, the user receives a message (example in Figure 2 right) and the .txt file is parsed to .JSON and saved to the PostgreSQL database.


VIP-2407 Moot 167 driving phase.txt - Kladblok
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0.20;-1.59;2022-05-13 12:20:15;0;0
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0.35;-1.74;2022-05-13 12:20:42;3;2
0.40;-1.79;2022-05-13 12:20:42;3;3
0.45;-1.84;2022-05-13 12:20:43;4;5
0.50;-1.88;2022-05-13 12:20:44;5;6
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Figure 1. Example of SBEGEO transfer file (.txt).

Step 4: Data transformation and visualisation in the web application, ready to be viewed by e.g. port's site supervisors, technical back-office and contractor.

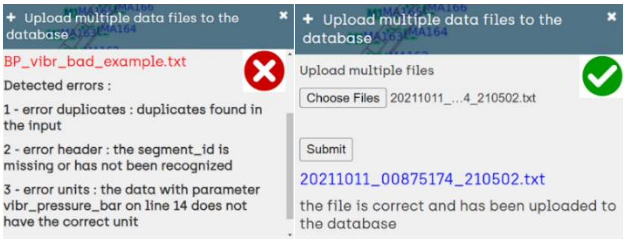

Figure 2. Automated file compliance checks: messages.

4 SITE ACCEPTANCE TESTS

In recent years, the capabilities for automated data capture during the installation of foundation piles and anchors have significantly expanded. However, it is crucial to verify the accuracy of the collected data through regular Site Acceptance Tests (SAT).

A fundamental understanding of the functioning of the monitoring equipment is of utmost importance. It is most important to know whether a parameter is measured directly or indirectly. In the latter case, the accuracy of the final parameter relies on the conversion formula provided by the manufacturer of the equipment, which is often taken for granted. An example is the indirect measurement of the energy level of a diesel hammer. Instead of measuring the actual drop height from the cylinder relative to the hammer, the energy is calculated from the drop height. The drop height is calculated from the measured number of blows per minute cfr. manufacturer's specifications. Interruptions in the driving process, e.g. due to stalling and restarting of the diesel hammer when penetrating through weak layers, result in a reduced number of blows per minute, and consequently an (incorrect) increase of energy. This is illustrated in Figure 3 and Figure 4. Drops in the blows per minute because of stalling and restarting of the hammer, or by incorrect time registration, are falsely translated into an increase of the drive energy (peaks). On the other hand, for the hydro hammer, which is shown in the same figures, the energy is directly calculated from the measured acceleration of the hammer. Figure 4 clearly shows that the energy measurement of the hydro hammer is not being influenced by the peaks in the blows per minute registration. This example shows that a fundamental understanding of the data collection process is crucial to correctly interpret installation data.

During construction, frequent Site Acceptance Tests on the registration equipment are performed to verify the accuracy of the measurements. For each installation technique (driving with diesel or hydro hammer, vibratory driving, drilling) a SAT protocol was drafted. The SAT is performed at regular time intervals. In between limited testing was performed, related to changes in the piling or registration equipment. The SAT includes e.g.:

- Comparison of visual readings of pressure gauges with the automated registrations of hydraulic pressure.
- Verification of RPM (indirectly calculated from measured flow) with manual tachometer.
- Verification of pull-down with dynamometer.
- Filling a 10 m³ water container to verify the flow rate and volume registered by anchor drilling rig.

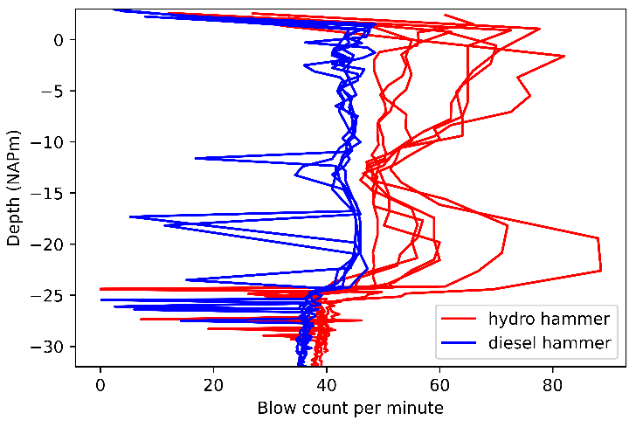

Figure 3. Comparison of blow count per minute for Delmag D-100 diesel hammer and IHC S-150 hydro hammer.

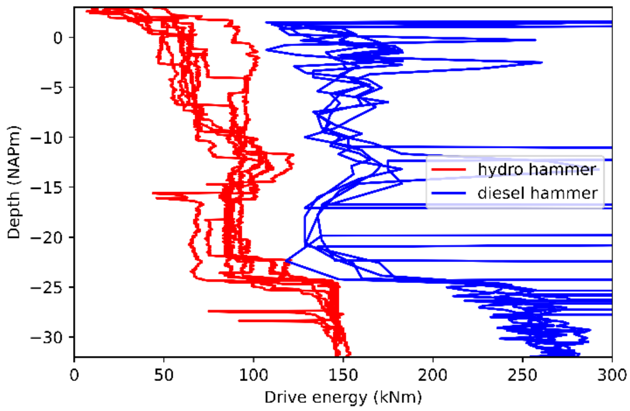

Figure 4. Comparison of drive energy for Delmag D-100 diesel hammer and IHC S-150 hydro hammer.

5 FUTURE OF SITE SUPERVISION: CASE STUDIES

5.1 Pile installation data enhance the understanding of the local geology

The pile design of the back crane track was based on CPT's available at 25m center-to-center (c.t.c.) grid distance. Figure 5 shows the plan view of a 80m stretch of the back crane track. Figure 6 shows the CPT's available for the pile design. The upper boundary of the dense Pleistocene sand layer, varies from NAP -28.50m in CPT1 to NAP -22.50m in CPT4.

Figure 7, Figure 8 and Figure 9 show the data of the driven cast-in-situ piles, installed with IHC S-150 hammer. The blow count per 25cm is influenced by the blow energy setting of the hammer. The blow energy setting is set by the operator of the piling rig, and varies with depth. The higher the blow energy, the lower the blow count per 25cm, and vice versa (for the same soil resistance). For this reason the total driving energy per 25cm is calculated. The total driving energy per 25cm is the blow count per 25cm multiplied by the blow energy setting. The total driving energy per 25cm is an unambiguous measure of the amount of energy inserted into the ground to achieve 25cm of pile settlement. The total driving energy per 25cm correlates with the local resistance of the soil. Figure 9 shows that the driving data of every single pile provides a clear indication of the exact location of the upper boundary of the dense sand layer.

For the geotechnical design of a single pile, all the surrounding CPT's are considered. One can imagine a (fictitious) situation for a pile in between CPT2 and CPT3: for the design of the pile length, CPT2 with dense sand layer at NAP -27.00m will be decisive. However, as the pile is located in between CPT2 and CPT3, at the pile's location the sand layer might be at NAP -25.00m. This results in heavier pile driving than was anticipated based on CPT2 which is decisive for geotechnical design, or even refusal. As the c.t.c. distance of the piles is 3m, the knowledge resulting from the driving data is supplementary to the initial CPT's with c.t.c. distance of 25m. This helps the site supervisor and geotechnical engineer to better understand the variation in geology and reasons for heavy pile driving or pile refusal. Assuming the data is considered accurate enough and taking into account the level of flexibility permitted by local design codes, this could ultimately aid in evaluating whether the piles possess adequate bearing capacity.

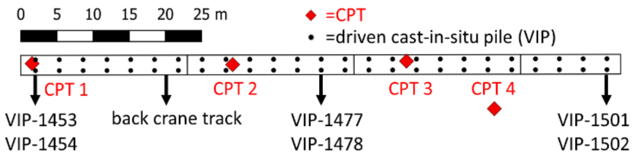

Figure 5. Plan view of 80m stretch of the back crane track.

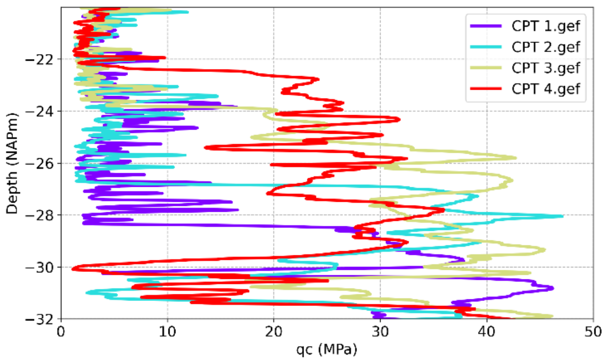

Figure 6. CPT's at back crane track location.

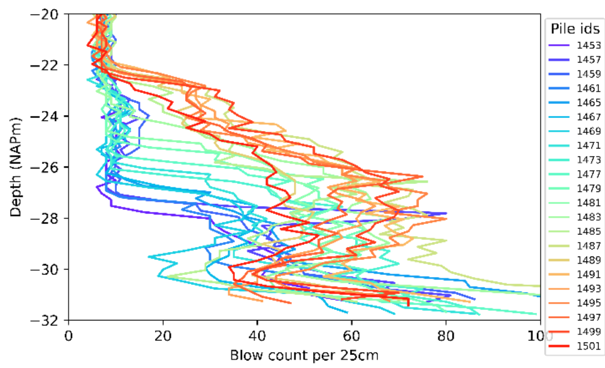

Figure 7. Blow count per 25cm.

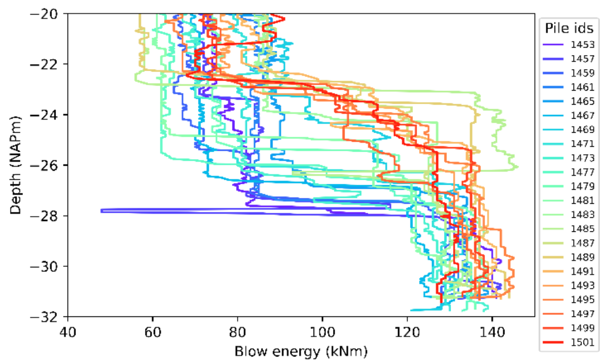

Figure 8. Drive energy.

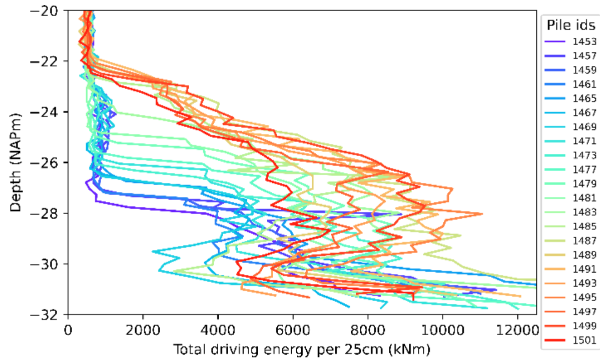

Figure 9. Total driving energy per 25cm.

5.2 Correlation between driving data and cone resistance: detecting (soft) intermediate layers

Westerbeke (2021) demonstrates the correlation between the total driving energy per 25cm and cone resistance for MV-piles. For all piles it was found that a fixed ratio of 2% between energy (kNm) and cone resistance (MPa) is valid along the entire depth of the CPT's (ca. 30m). An example from Westerbeke (2021) is shown in Figure 10. The MV-pile consists of a steel beam with a grouted cover. As the grout surrounds the pile, the shaft friction during pile driving is significantly reduced. Most of the driving energy is transferred to the pile tip to overcome the resistance of the soil. This explains the good correlation with cone resistance.

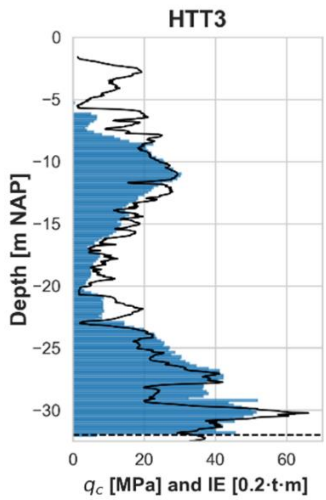

Figure 10. Cone resistance and installation energy for MV-piles (Westerbeke, 2021).

For a driven cast-in-situ pile, the shaft friction during pile driving is substantial, thus a weaker correlation is expected. However, from Figure 11 and Figure 12 it is concluded that the correlation (fixed ratio of 1%) is still fairly good. Moreover, the response of driving energy to the reduction in cone resistance at depth NAP -30.00m is observed. The drop in cone resistance in Figure 12 is caused by a silty layer with thickness of ca. 20cm. This shows that the driving data can precisely detect soft intermediate layers. The observations of the driving data can be used for quality assurance and reverse engineering of the bearing capacity of the piles.

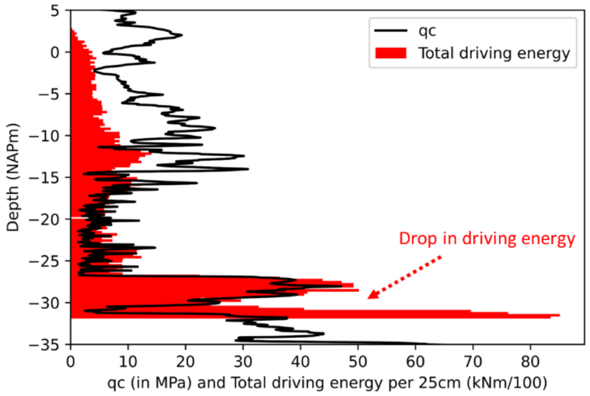

Figure 11. Cone resistance and total driving energy per 25cm with IHC S-150 hammer: example 1.

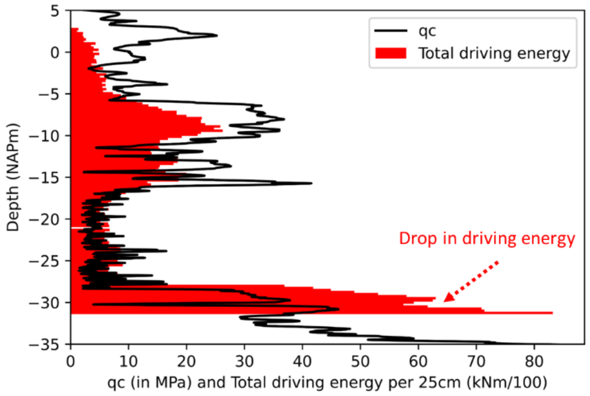

Figure 12. Cone resistance and total driving energy per 25cm with IHC S-150 hammer: example 2.

5.3 Anchor drilling parameters and measured apparent free length

Every ground anchor is subjected to a acceptance or suitability test to verify if the measured creep rate and apparent free length are within the tolerances cfr. EN-1537. The deepsea quay wall is equipped with Leeuwankers®, which are a type of self-drilling anchor with a helicoidal drill tip. The free length of this anchor is created through drilling with water. As soon as the drilling tip approaches the location of the grout body, the operator switches from water to grout.

As a tendency towards undershooting of the permissible free length has been identified, an investigation has been conducted to determine if a relationship can be found between the grout consumption and the measured apparent free length (Figure 13). To account for the variation in design length of the grout body along the length of the quay wall, both X and Y axis are normalised by dividing them by the design length of the grout body. The obtained linear trend line is included in the graph. Although the trendline suggests that an increase in grout consumption is associated with a decrease in free length, the scatter between the data points is very large. This could be partially explained by the registration method of the time at which the operator switches from water to grout. The registration of this moment in time is done manually. It is advisable to eliminate any human influence in the registration process by exploring options for complete automation. This indicates that there are still opportunities for improvement in both measuring and interpreting the installation data of this type of anchor.

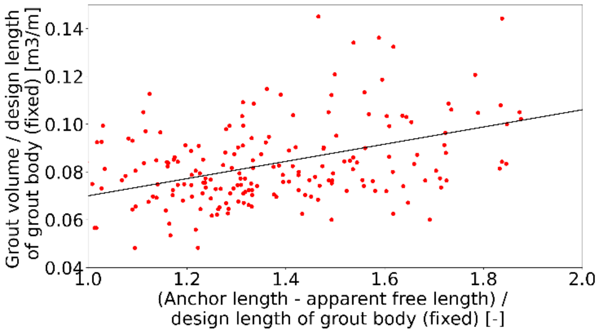

Figure 13. Normalised grout consumption vs. anchor length – apparent free length. Linear trendline in black.

6 CONCLUSIONS

A framework for automated data collection during foundation pile and anchor installation is presented. The main challenge in building a reliable database is the verification of the data through Site Acceptance Tests. The data of driven piles can be used quite easily by site supervisors and geotechnical engineers in assessing the load-bearing capacity of the piles. In fact, the initial knowledge from the coarse-meshed CPT grid is updated with additional insights obtained from the fine-meshed pile installation grid. For grouted anchors, there is significant improvement potential to create added value based on the recorded data. The findings of this paper can play a crucial role in the quality control procedure of foundation piles and can serve as direct input for reverse engineering of quay walls, and presumably also for other types of port infrastructure.

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Westerbeke, F.Y.H. (2021). *Geotechnical bearing capacity of MV-piles. Improving the design based on full scale load tests in the Port of Rotterdam.* Master thesis, Delft University of Technology, the Netherlands.