

# Full scale field test (sheet)pile driveability in Antwerp (Belgium)

## Test de terrain à grande échelle de l' installation des palplanches et pieux tubulaires à Anvers (Belgique)

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**ABSTRACT** The closing of the ring around Antwerp (Belgium) was put to study by BAM. The construction of two-layer tunnels necessitate excavations up to great depth. Purpose of this unprecedented (sheet)pile driving test was to assess performance of state of the art top range (sheet)pile driving equipment, soil resistance and specific techniques to be used in the Antwerp area. A special focus was on the dense glauconite sands. The retrievability also had to be put to the test. From the tests it was learned that full length pre-drilling by means of an auger provided the best results for pile (sheet)pile driving, in terms of depth, duration and retrievability. On a larger scale, no deviation in cone resistance or friction has been encountered. At the steel surface a 3 cm thick clay plaster was visible after retrieval of the sheet-piles, caused by the manipulation of the glauconite. Vibration levels and settlements were acceptable at a 15 m distance.

**RÉSUMÉ** La finition de l'anneau périphérique autour d'Anvers (Belgique) est étudiée par BAM. La construction de tunnels à deux couches nécessite des excavations à grande profondeur. But du test inouï était d'évaluer la performance de la gamme supérieure de l'équipement de battage des pieux et palplanches, la résistance du sol et des techniques spécifiques pour être utilisés dans la région d'Anvers. Une attention particulière étaient les sables glauconite denses. La récupération des éléments devait aussi être mis à l'épreuve. D'après les tests, le préforage la longueur complète à l'aide d'une tarière a donné les meilleurs résultats pour le battage des pieux et palplanches, en termes de profondeur, la durée et la récupération. Sur une plus grande échelle, une déviation dans la cône résistance ou la friction n'a pas été remarqué. A la surface de l'acier une épaisse couche de plâtre d'argile de 3 cm était visible après la récupération des palplanches, causé par la manipulation de la glauconite. Le niveau des vibrations et les tassements étaient acceptables à une distance de 15 m.

## 1 INTRODUCTION

In order to relieve the busy traffic arteries of Antwerp (Belgium), the closing of the ring around Antwerp was put to study by BAM. At the right bank of the river Scheldt the construction of two-layer tunnels necessitate excavations up to great depth.

Purpose of this unprecedented (sheet)pile driving test was to assess performance of the equipment, soil resistance and specific techniques to be used in the Antwerp area. Previous experiences in Antwerp showed a lack of information up to greater depths and larger dimensions on elements to be installed. An important issue, since the tunnel design implies the use of (sheet) piles with large dimensions and lengths

in the range of 30 m. Also the use of state of the art top range (sheet)pile driving equipment had not yet been put to the test. Additional tests had to focus on the dense glauconite sands. The retrievability of the sheetpiles also had to be put to the test. The elements have been installed at a specific test site at the IJzerlaan, Antwerp. The site was selected given the specific high cone resistance and friction ratio at this location, indicating dense sand with a high content of glauconite. During the test a variety of equipment and measure's to improve driveability have been monitored.

The field test was held in December 2013 in order to define a proof of concept, a cost effective design, calibrated soil parameters and a reduction on risks.

## 2 TEST PROGRAM

The program, see Figure 1, consisted of the installation of a combined wall and a sheetpile wall. The combined wall consisted of 6 tubes 1420 /22 mm and length 30 m (B1 to B6, numbers increasing from the top downwards in Figure 1) and 5 double sheetpile profiles AZ36-700N with a length of 26 m (TP1 to TP5). The second phase of the program involved the installation of 16 double sheetpile profiles AZ36-700N with a length of 26 m (P1 to P16).

The vibratory hammers used in the project involved the Dieseko PVE-2319VM, PVE-2350VM and PVE-110M. The hydro hammer was a S-200 manufactured by IHC. The dieselhammer was a Delmag type D62-22. The PVE-2319VM has solely been used to pre-install the tubes, after which the PVE-2350VM would take over the pile driving. The PVE-110M has only been applied on piles B1 and B3 and on sheetpile P7. The IHC hammer has solely been used for piling on tubes B1 and B3, the diesel hammer solely for sheetpile P16.

The first pile B1 and first sheetpile P1 were installed without additional measures. At the installation of the following piles and sheetpiles several measures were introduced in order to improve driveability as explained below (see Figure 1).

Piles B3 and B6 were fitted with a so called piling shoe. It consisted of a steel plate 100 mm high, 13 mm thick and was welded close to the piletip on the inside of the tube. In case of sheetpiles waterinjection was performed at a pressure of 100-200 bar at 30 L/sec. The water was injected via openings in a tube welded at the sheetpile tip. The openings of 1,5 mm at 15 cm spacing along the tube were facing towards the installation trajectory. In case of pile B2, the injection tubes were welded just above the pile tip and fitted with two feeding pipes and two injection tubes. B5 was fitted without the perpendicular tube and was fitted with two nozzels. Given the higher number of injection openings, the pressure decreased to 50 bar.

Predrilling was performed either with (orange circle: 0,7 m<sup>3</sup> mixture added, black circle: full bentonite column, only at B6) or without bentonite (unmarked circle) over the full trajectory of the installation. The auger was 450 mm in diameter and transported an estimated volume of 2 m<sup>3</sup> of soil to the surface.

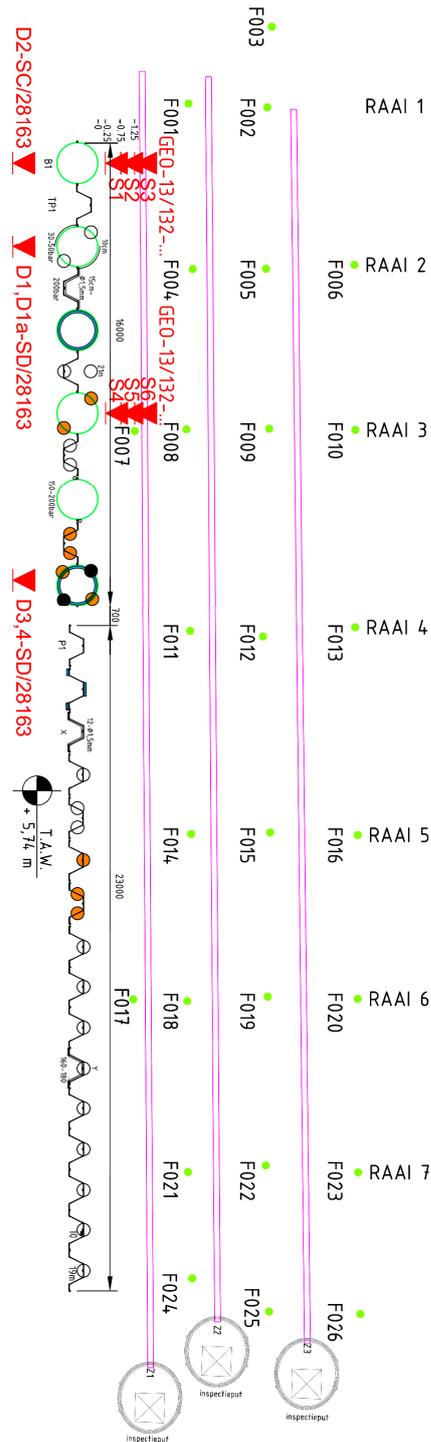


Figure 1. Test program.

### 3 MONITORING PROGRAM

The program involved various recording devices.

- Vibration monitoring was performed at four positions simultaneously throughout nearly the whole test program. The installation of sheetpiles P5, 6 and 7 was not covered by vibration monitoring.
- Surface settlement was recorded by three parallel horizontal inclination tubes in one base reading and five process readings. The recordings were taken in 0,5 m intervals. The base reading was performed five days prior to the installation of the elements, the last process reading was taken one day after retrieval of the sheetpiles.
- Surface settlement was also recorded by a grid of 26 ground points. The grid lines were placed in between the horizontal inclination tubes, thus creating a redundancy and higher level of detail in the surface recording. The recordings were taken on the same dates as the incline tubes.
- The sound level was recorded in a grid of three to seven positions on three days during the installation of the combined wall. No recordings were taken during the installation and retrieval of the 16 sheetpiles of the sheetpile wall.
- Video registration on the installation of each element as well as the retrieval of the sheetpiles P16 t/m P10.
- Pile Driving Analysis has been performed on sheetpiles P1, 2, 3 en 16 and piles B1, 3 en 6.

In the recordings after cut off of the piles, pluggin has not been encountered in any of the 6 piles. The surface level in the tubes was within 0,5 to 2,5 m meters from the original undisturbed surface level.

Prior to retrieval of the sheetpiles between the tubes, three mechanical CPT's were made at 1,5 m distance from the tubes B1, B2 en B6 (D-series in Figure 1).

The six standard CPT's (indicated as S1 to S6 in Figure 1) were performed in close proximity of piles B1 and B3. The possible installation effects of the two piles were examined with two series of three CPT's. The distance increased from 0,25 m to 0,75 m up to 1,25 m. The tests were executed two months after retrieval of the intermediate sheetpiles TP1 to TP5 and presented in Figure 4.

### 4 RESULTS AND INTERPRETATION

#### 4.1 Installation depth

The following Figure 2 to Figure 7 will demonstrate the monitoring results on achieved installation depths per item and method and installation duration per item and method. In Figure 2 the pile positions are presented, the sheetpiles TP1 to TP5 were already removed at the time the picture was taken.



Figure 2. Maximum achieved installation depth of the tubes.

In Figure 3 the maximum installation depths of the piles and sheetpiles of the combined wall are presented in a graph. Tube 1 corresponds with B1 (red, dark, and if hammered marked with rectangular blue) and sheetpile 1 with TP1 (green, light).

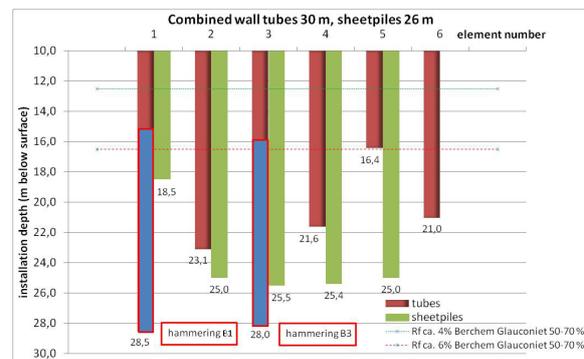


Figure 3. Installation depths and –method, combined wall.

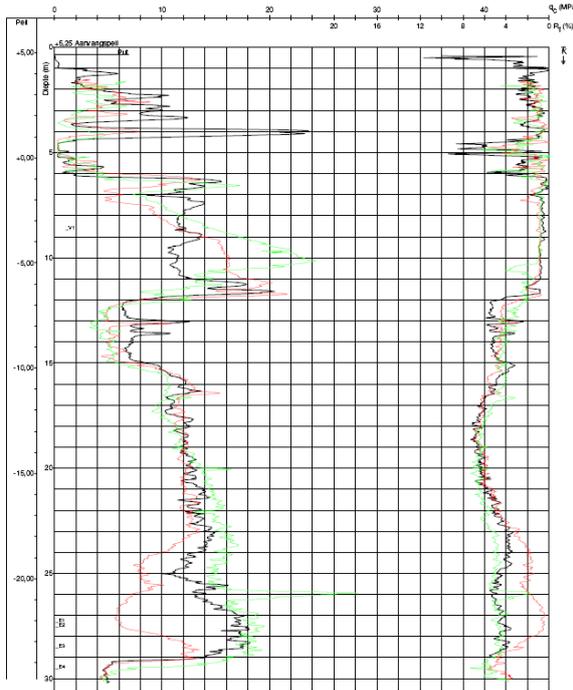


Figure 4. CPT S1 black, S2 red, S3 green at installed pile B1.

With no additional measures, the piles would penetrate by vibratory hammer up to 15 m and the sheetpiles up to 18.5 m. The piles B1 and B3 were successfully hammered to the installation depth, although with blowcounts up to 100 blows per 25 cm and higher (set up) with the S-200 hammer. In Figure 5 a summary is presented on installation results on all elements and all type of applied measures.

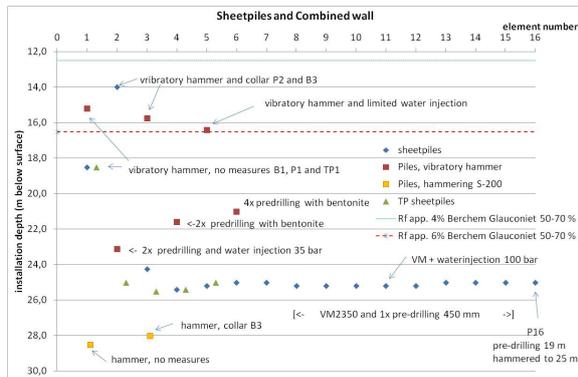


Figure 5. Summary installation results on all elements.

From Figure 5 it can be learned that in order to prevent pile refusal by vibratory hammer no measure was fully successful. Pre drilling without bentonite in combination with water injection tubes at the tip resulted in the greatest installation depth of 23,1 m at B2. Given the combined use of the two measures it is not possible to distinguish their individual effect. With no additional measures, the piles would penetrate by vibratory hammer up to 15 m and the sheetpiles up to 18.5 m. There was no explanation for the reduced depth when bentonite was applied.

#### 4.2 Installation Duration

Another criterion on successful installation is duration. In Figure 6 an overview is presented on the results on the duration of the installation of the combined wall per method. From this figure it can be learned that reaching installation depth can imply long installation durations. The hammering trajectory of app. 12 m on B1 and B3 required 90 and 60 minutes with the S-200, after the use of the vibratory hammer for 30 minutes on each pile. On the other piles the vibratory hammer was used 30 to 60 minutes, although – 28 m was not achieved. The TP sheetpiles 2 to 5 (with measures) required 10 to 20 minutes until they reached the installation depth. After 30 minutes TP 1 stranded at app. 18 m installed length. The measure pre-drilling without bentonite was the most effective, based on installation duration.

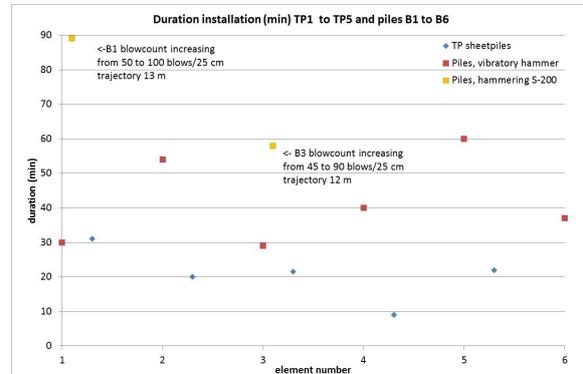


Figure 6. Installation duration per method, combined wall.

The overview on duration on sheetpile installation (P-series) is presented in Figure 7. The addition of bentonite during pre drilling (P6) or water injection

during sheetpile driving (P11) appears to increase driving time considerably. Single pre-drilling is best.

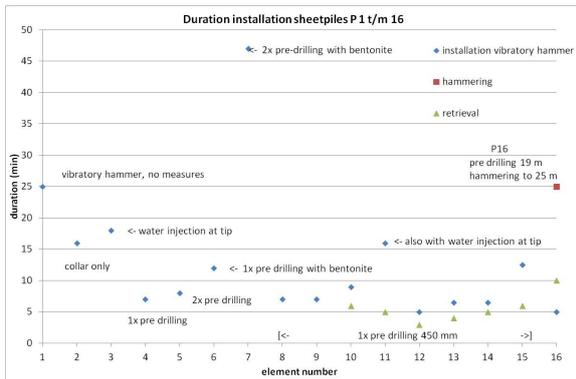


Figure 7. Installation duration per method, sheetpile wall.

The hammering of sheetpile P16 was successful over the trajectory without pre drilling. The installation duration on average took approximately 7 minutes, which is considered as a good performance. Retrieval of the sheetpiles was slightly faster. At retrieval of the TP and P series, all sheetpiles showed a 3 cm thick clay plaster on both sides over the last 10 m to the tip, the trajectory installed in the Berchem. The anticipated glauconite effect had clearly manifested itself at this site. From the grain size distribution in Figure 8 the distinction can be made between 16 non-manipulated samples and a recent soil sample obtained from a retrieved sheetpile (upper smooth red line). The mass passing the 0.1 mm sieve has doubled due to manipulation (=sheetpile installation) of the glauconite fraction. This increase in fines explains the clay like behaviour on the sheetpiles.

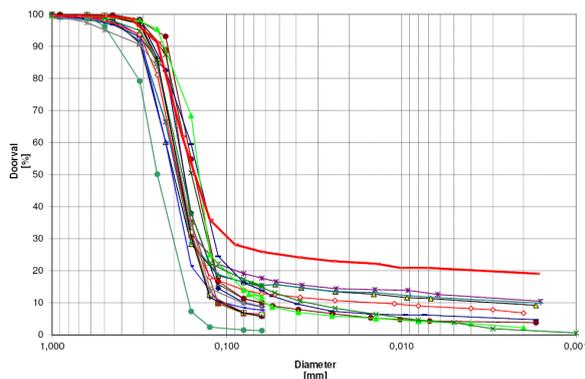


Figure 8. sieve curves on the Berchem formation samples.

### 4.3 Settlements

Apart from depth and duration, effects to the surrounding area also define drivability. Settlement induced by piledriving has been recorded by horizontal inclino tubes and markers. Based on cross sections (Raai 1 to 7) the settlements have been interpreted by postdiction (Figure 9).

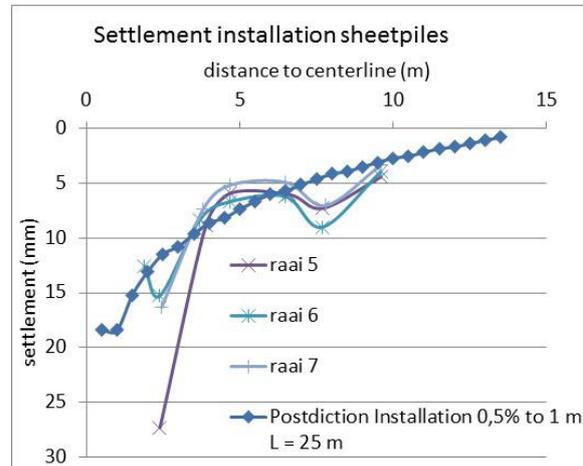


Figure 9. Settlements after installation of sheetpiles.

The estimated resulting volume loss (contraction) of 0,5% over a distance of 1 m to the sheetpile over the full length of the sheetpile shows a strong correlation with raai 5 to 7. An active wedge can be recognized.

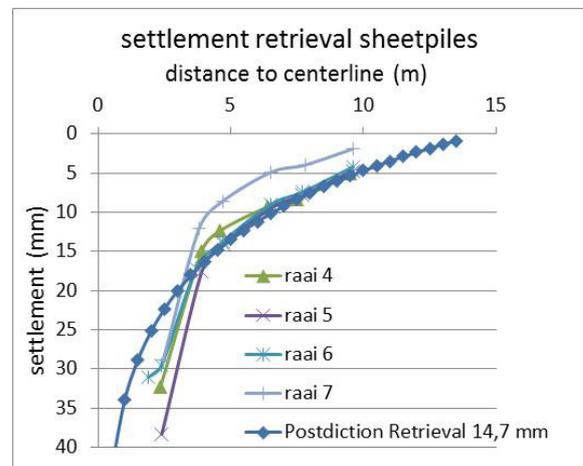


Figure 10. Settlements due to retrieval of sheetpiles.

At retrieval, three days after installation, the retrieval also caused settlements in the area. In the postdiction, see Figure 10, the equivalent thickness per m wall has been used, in order to get a comparison with the removed steel volume per metre wall. In this case it involves 14,7 mm loss on steelthickness per m over a length of 25 m. It should be noted that ignoring the 3 cm volume loss on both sides over the deepest 10 m of the sheetpile does not affect the quality of the postdiction, especially at a distance over 5 m. An explanation was not at hand.

#### 4.4 Vibrations

Another criterion to consider was the level of induced vibrations. With the equipment active at full capacity in granular soil, high levels of induced vibrations were anticipated. In Figure 11 the peak particle velocities per sheetpile during installation and retrieval have been presented as a function over distance to the monitoring point no. 2. The rpm of the vibratory hammer has been used in the postdiction. It is based on Barkan's formula, input 0,3 g at 1 m.

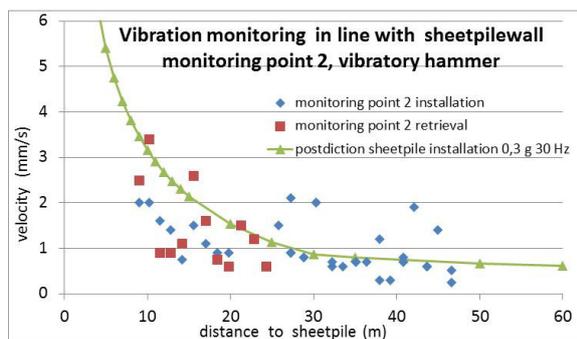


Figure 11. Results vibration monitoring point 2, sheetpiles.

In the results it can be recognized that retrieval and installation produce identical vibration levels. The monitoring position does have an effect on peak values. When monitoring perpendicular to the wall, approximately 30% higher values were recorded. The weight and the contact of the structure being monitored also played an important role. In Figure 12 the results obtained at position 1 clearly deviate from the other 3 positions and the postdiction. During hammering of B1 and B3 at 30 m distance a velocity of approximately 4 mm/s at an estimated 20 Hz has

been recorded. It should be noted that position 4 was lighter than the masonry base at positions 2 and 3.

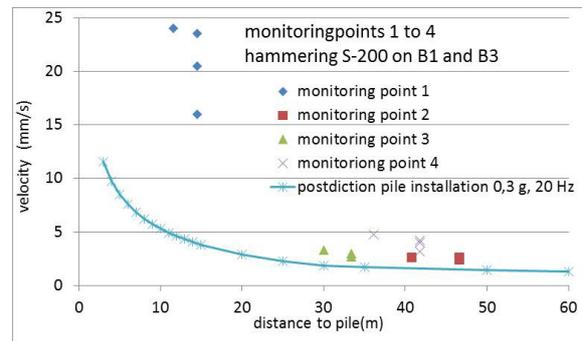


Figure 12. Results vibration monitoring points 1 to 4, piles.

## 5 CONCLUSIONS

Pile driving by vibratory hammer did not reach full depth, even with measures to improve driveability. Pile driving by hammering was successful even without measures, but time consuming given the high blowcount and considered less favorable for urban city areas. Sheetpiles were installed and retrieved successfully by vibratory hammer, although measures were required. Pre drilling is recommended. Bentonite and water injection seemed to worsen installation. Glauconite manipulation and high friction should be considered, cone resistance is unaffected. Vibration levels and settlements were acceptable from a distance of 15 m and can be estimated given the correlation with postdictions.

## ACKNOWLEDGEMENT

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