Geotechnical monitoring of a trial pit excavation toward the Boom clay in Antwerp (Belgium)

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Abstract. In order to relieve the busy traffic arteries of Antwerp (Belgium), the closing of the ring around Antwerp was put to study by BAM (Beheersmaatschappij Antwerpen Mobiel). The design of this construction requires detailed insight in the behaviour of the overconsolidated Boom clay layer during and after dewatering and removal of the covering soil layers. For this purpose a fully monitored excavation test was performed in order to assess soil behaviour and specific techniques to be used in anticipated projects in the Antwerp area. This paper will specifically present and evaluate the results regarding swell and pore pressures recorded in the Boom clay. From the monitoring results it can be derived that the Boom clay shows a quick response to a fluctuation in water level in the overlaying aquifer. The Boom clay also shows a severe pore pressure reduction as a result from loss on effective stress during excavation. These two effects should be considered separately. The underpressure is caused by swell hindered by a very low permeability of the Boom clay. Up to 50% of the effective stress reduction can be transferred into a pore pressure reduction. This condition results in a long term dissipation and swell process towards a gradient of approximately 25 kPa pressure increase per m depth increase. This effect intersects with the original hydraustatic pressure in the Boom clay.

Keywords. Full scale trial pit installation, excavation and monitoring, D-wall, overconsolidated clay, pore pressures, swell

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. This construction is also known as the Oosterweel link.

Available geotechnical data, although being quite abundant in the Antwerp region, showed a lack of information up to greater depths. Additional geotechnical investigation had to focus on the dense glauconite sands and the very stiff overconsolidated Boom clay.

As a part of the study a field test was initiated. The construction of the trial pit started in January 2014 in order to define a proof of concept, a cost effective design, calibrated soil parameters and a reduction on risks.

The 20 x 20 m trial pit has an anticipated final depth of 25 m. Purpose of this fully monitored excavation was to assess:

- Driveability of sheetpiles with a length of 30 m, of which 7 m in Boom clay.
- Installation of slurry walls in anthropogenic loosely packed sand.
- Strains and deformations of the sheetpiles and five layers of struts during excavation.
- Time and depth dependent strength, stiffness and swelling of the Boom clay and corresponding pore water pressures.

The trial pit was installed at a specific test site at the Noordkasteel area, Antwerp. The site was selected given the specific high top level of the Boom clay at this location, therefore allowing the trial pit to be formed with maximum length sheetpiles. This was a critical aspect in the design of the trial pit, since the test required at least 4 m penetration in the Boom clay in order to monitor pore pressure fluctuation over the height of the sheetpile wall in the Boom clay.

2. Test Geometry and monitoring program

In **Figure 1** an overview is presented of the trial pit. A total of 52 sheetpiles type AZ36-700N with a length of 29.65 m were installed in an octagonal shape on a 2 m pre-excavated site. Before sheetpile installation with tip level at local reference level TAW -24.65 m, three horizontal inclinotubes were installed on the Eastside as well as the Southside. The tubes were combined with a grid of manual levelling points, so called Feno markers. At the centre of the pit three extensometer systems were placed to monitor vertical displacements at various depths. The anchor positions were placed at a constant interval in the boom clay, see the red marked positions in Figure 3. At three positions a set of piezometers were installed in the boom clay. The first position in the centre, the other two positons were selected on either side of the sheetpiles. All piezo sensors were installed in the boom clay at corresponding depths with the extensometer anchors.

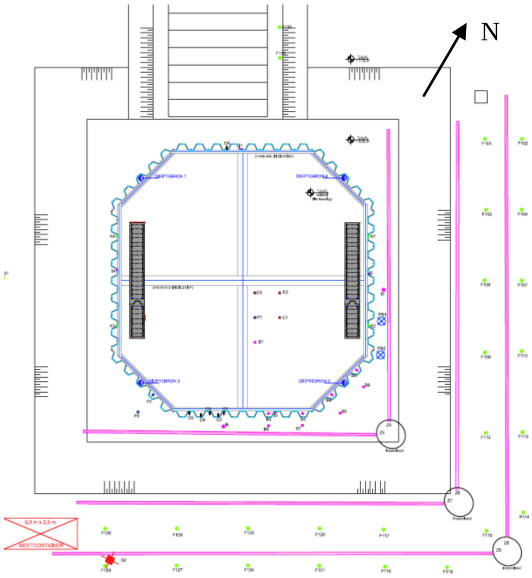

Figure 1. Overview trial pit with pre excavation.

A more detailed overview of the sensor locations related to the sheetpiles is presented in Figure 2. The sensors marked B1 to B9 are so called piezo cone BAT sensors. The sensors have one filter per position and are installed by cone penetration. The position marked P1 indicates sensors placed in a borehole at five depths. The installation depths of the BAT and borehole piezo sensors are presented in Figure **3.** An optical fibre extenso system was installed at position E2 (blue markers). The mechanical extenso rods were installed at positions E1 and E3. The anchor positions of the extenso systems are presented in Figure 3 (red markers).

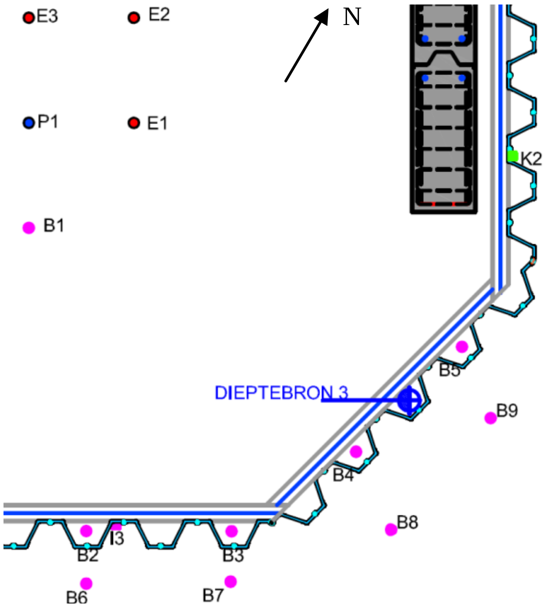

Figure 2. Detailed overview South / East corner

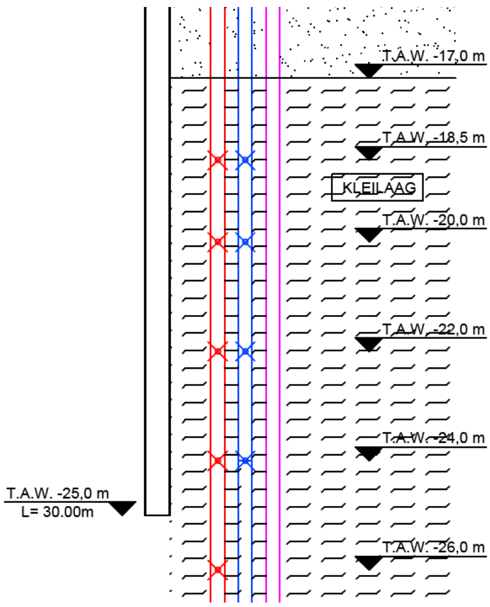

Figure 3. Cross section installation depth sensors.

At the test site, marked in Figure 4, the Boom clay was encountered at a level of TAW -17.3 m. The sandlayer of the Berchem formation with its characteristic high friction ratio was not present at the trial pit location, allowing sheetpile installation without pre drilling (Nijs, de et al. 2015). From TAW -17.3 m to TAW -5 m, the sandlayers from the Kattendijk formation are overlaying the Boom formation. The Lillo formation has been encountered from TAW -5 m to TAW -1.0 m. Within this formation the impermeable layer of Kruisschans has been identified from TAW -1.6 m tot TAW -4.1 m. A pleistoceen sand layer was covered by Holocene layers from TAW 0.0 to surface level.

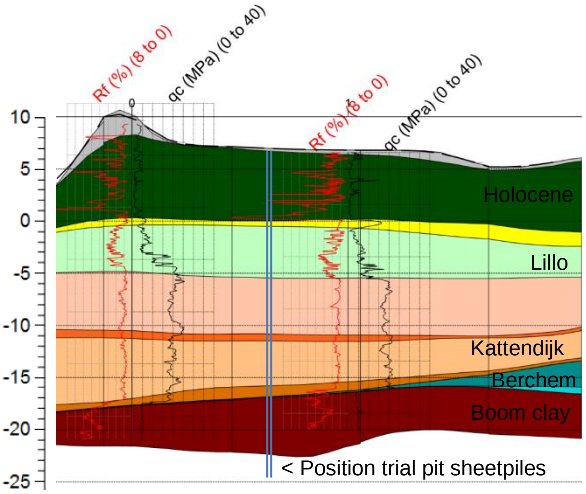

Figure 4. Soil strata at the trial pit location

3. Construction program

The construction program is presented in Table 1.

Table 1. Trial pit construction program

date 2014	program status
jan	installation sheetpiles by vibratory hammer
feb	7 m Boom clay trajectory by diesel hammer
mrt	start installation monitoring systems
apr	installation completed, base reading period
may 4th	start pumping test, lowered in stages per 5 m
may 26th	pumping test to TAW -9.5 m
june 12th	pumping test to lowest level TAW-11.8 m
july 11th	D wall construction completed
aug	excavation TAW -1.7 m, water TAW -9.5 m
sept	excavation TAW -6.7 m, water TAW -11.8 m
nov	excavation TAW -11.7 m, water TAW -12 m
jan 2015	excavation TAW -14 m, water TAW -15 m

The site was pre excavated to TAW +5.0 m prior to sheetpile installation. After completion of the sheetpile wall and monitoring installation, a pumping test was initiated in order to check on functionality of the systems and water tightness of the sheetpile wall. The test was also held in order to detect the pore pressure response of the Boom clay on a fluctuation in the overlaying Kattendijk sandlayer and to obtain early results. After the pumping test the pit was excavated to TAW -1.7 m and backfilled, in order to create an anthropogenic top layer to test trench stability of the diaphragm wall excavation. After completion of the diaphragm walls, the trial pit was dewatered and excavated in stages of 5 m. Struts were placed at every stage. An example of a stage of the program is presented in Figure 5.

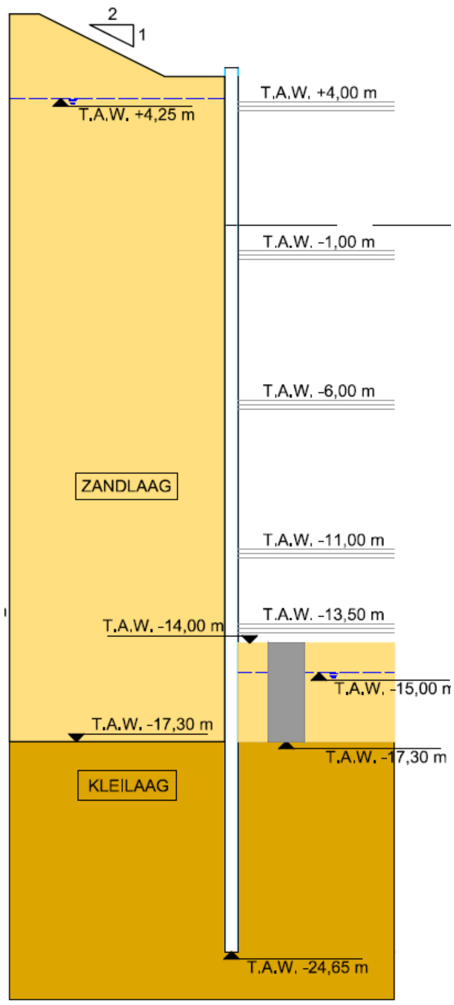

Figure 5. Cross-section trial pit at TAW -14 m excavation

4. Monitoring results

In order to understand the response of the Boom clay, the driving forces in the trial pit were recorded, see Figure 6. The level of excavation was recorded by manual levelling in the trial pit. The water level results were obtained from standpipes in the trial pit with the filter in the Kattendijk formation, the aquifer above the Boom clay. The automatically obtained recordings (series PB4 and 6) were confirmed by occasional manual readings (HPB 4 and 6).

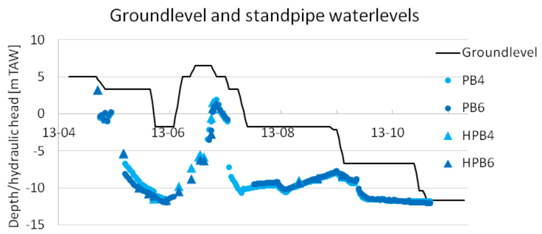

Figure 6. Evolution of ground- and waterlevels in the trial pit

The results from the driving forces are combined with the pore pressure recordings obtained at position P1, see Figure 7. The position P1 is at the center of the trial pit.

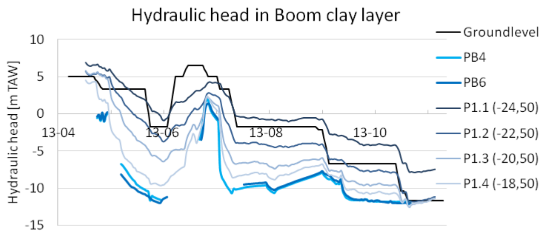

Figure 7. Pore pressure at various depths in the Boom clay

The results from the driving forces are combined with the swell recorded at position E2, see Figure 8

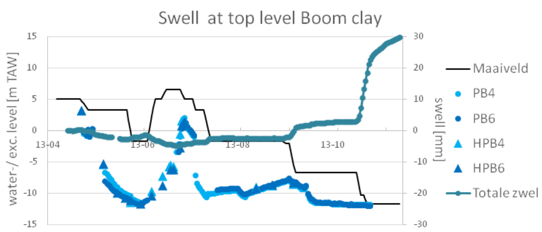

Figure 8. Swell at the top of the boom clay layer

5. Analysis

From Figure 7 the particular response over time at various depths in the Boom clay can be recognized. This response can be presented as an absolute pore pressure obtained at a specific depth in the Boom clay at a specific moment in time. Separate figures were made in order to present the effect caused by solely lowering of the water table and the effect caused by the combination of lowering of the water table and excavation. The results obtained during the pumping test are presented in Figure 9. The pore pressure results from dewatering and excavation of the trial pit are presented in Figure 10.

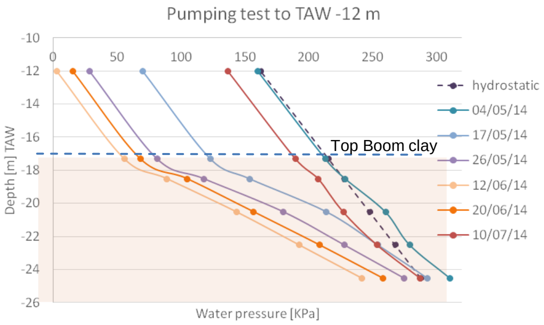

Figure 9. Pore pressures Boom clay during pumping test

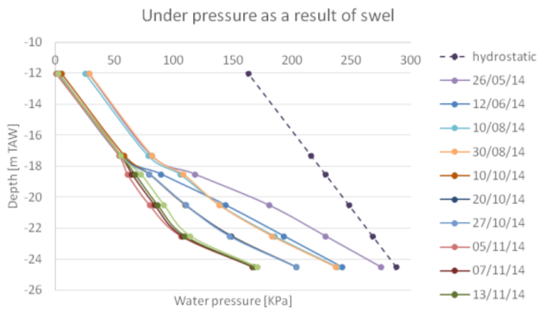

Figure 10. Pore pressures Boom clay during excavation

The swell effect during lowering of the water table and / or excavating of the trial pit was recorded by the extensometers. Separate figures were made in order to present the swell effect caused by solely lowering of the water table, see Figure 11, and the swell effect caused by the combination of lowering of the water table and excavation, see Figure 12 and Figure 13.

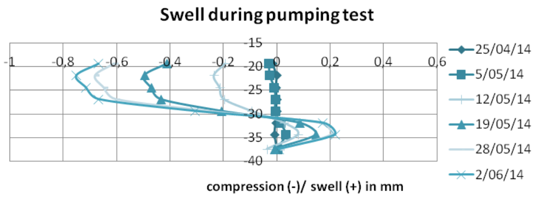

Figure 11. Vertical effect per module pumping test

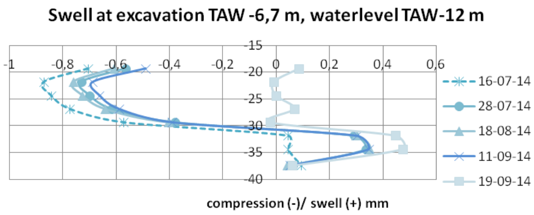

Figure 12. Vertical effect per module excavation -6.7 m

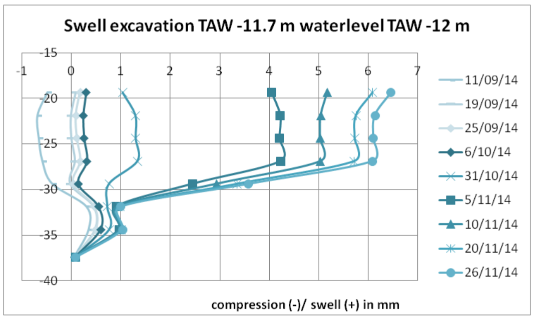

Figure 13. Vertical effect per module excavation -11.7 m

The results from Figure 9 coincide with Figure 11. The pore pressure monitoring indicates a constant gradient of approximately 25 kPa pore pressure increase per m depth increase, until the initial hydrostatic line is met. The extensometer results indicate compression up to a level of TAW -30 m, with decreasing magnitude by increasing depth. Below TAW -30 m a reduction on effective stress occurs, given the weight of the water that has been pumped out of the soil.

From Figure 12 it can be derived that the loss on effective stress due to the excavation to TAW -6.7 m is compensated by the increase on effective stress due to lowering of the water table to TAW -11.7 m.

From Figure 10 and Figure 13 it can be derived that the excavation is causing a loss on effective stress, resulting in swell on all modules. This swell requires an inflow of pore water, which is hindered by the low permeability of the Boom clay (Vincke et al. 2015), resulting in an under pressure on all sensors at P1. Figure 14 illustrates the effects.

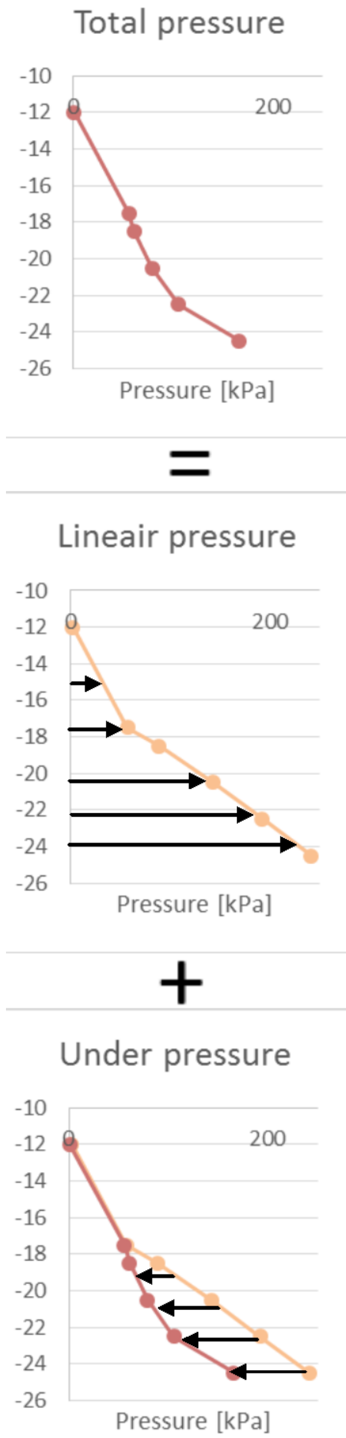

Figure 14. Combination of pore pressure effects

The resulting pore pressure (top graph in Figure 14) can be derived from the lowering of the water table which causes a gradient in the Boom clay. The excavation causes a reduction of effective stress which is transferred into an decreasing pore water pressure. The ratio at which this transformation occurs is presented in Figure 15.

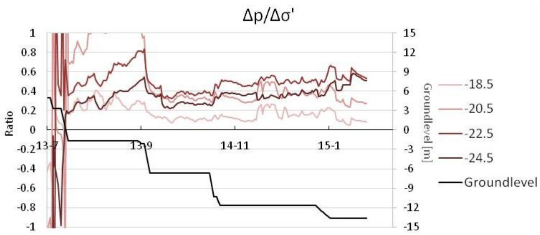

Figure 15. Transfer ratio pore pressure / effective stress

At the start of the excavation the ratio does not appear to be constant. At the deeper excavation levels, TAW -6.7 m and further, a more constant value occurs, driven by the bigger swell effect. In Table 2 an overview is presented on the ratio's as derived from the progress on excavation, soil unit weight and recorded pore pressures at P1.

Table 2. Average Δp/Δσ' ratio at excavation TAW -13.7 m

piezo sensor	Δp/Δσ'
P1.4(-18.5)	0.09
P1.3(-20.5)	0.28
P1.2(-22.5)	0.54
P1.1(-24.5)	0.51

From Figure 15 it can be learned that the ratio is increasing to 0.5 for the sensor at TAW -22.5 m at the excavation towards TAW -11.7 m and TAW -13.7 m.

The results from the sensors at TAW -18.5 m and TAW -20.5 m demonstrate that the top three metres of the Boom clay show a much bigger dissipation over time, therefore indicating a higher permeability. This coincides with the weathered top layer of the Boom clay.

The results also indicate a very long term dissipation effect.

6. Conclusions

- The monitoring results generated by the piezometers at position P1 prove to be consistent within the profile.
- The monitoring results generated by the optical fibre extensometer at position E2 prove to be consistent within the profile.
- The monitoring results generated by P1 coincide with the results generated by E2
- The pore pressure in the Boom clay responds very quickly to a reduction in water level in the overlaying aquifer. A gradient of approximately 25 kPa per m depth has been recorded. The lineair behaviour continues until the initial phreatic pore pressure has been met.
- The pore pressure in the Boom clay responds very quickly to a loss on effective stress due to excavation. The loss on effective stress results in a loss on pore pressure. A ratio of 0,5 has been derived.
- The total effect on the pore pressure in the Boom clay can be separated into the effect of lowering of the water table and the effect of excavation.
- The piezometer recordings of the top two meter of the Boom clay indicates a much higher permeability.
- The piezometer recordings several meters in the Boom clay indicate a very low permeability.

Acknowledgements

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