Drawing up of a geotechnical dossier for the stabilization of historical quay walls along the river Scheldt in Antwerp

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ABSTRACT

Within the context of the Scheldt Quays Masterplan, the stabilization of the dilapidated historical quay walls was put to study. For drawing up the geotechnical dossier all available geological and geotechnical information along the quay wall section was collected; beneficial use could be made of the Regional Database of the subsoil of Flanders (DOV). Based on this inventarisation an extensive program of in situ tests and complementary monitoring and laboratory tests was elaborated.

Analysis of the investigation data resulted in a characterisation of the soil layering and corresponding soil parameters.
The schematic geotechnical profile consists of an upper layer of fill material, overlaying a dense tertiary sand layer (Berchem Formation) and the very stiff overconsolidated Boom clay.
The foundation level of the quay wall is situated just above or in the Boom clay. The excavation works for the foundation resulted therefore in a stress relief of the upper part of the clay layer. Quite rapidly after construction important horizontal deformations of the quay wall as a whole appeared. Due to this movements, design of stabilized walls should be performed on basis of residual shear strength parameters derived from direct shear tests.
To determine the water pressure distribution along the quay wall open standpipes (in the sand layers) and closed piezometers (in the Boom clay) were continually monitored and tidal variations were noted. Furthermore a long time CPTU dissipation test was performed in the Boom clay.
The extensive geotechnical design resulted in an economic and sustainable design for the stabilized quay walls.

Keywords: geotechnical investigation, Boom clay, monitoring, residual shear strength, dissipation test

1 INTRODUCTION

The historical quay walls along the river Scheldt in Antwerp were built late 19th century and consist of gravity walls in brickwork construction built upon steel caissons filled with concrete. Figure 1 shows a cross section of the wall.

Quite rapidly after construction important horizontal deformations of the quay wall as a whole appeared (as a result being referred to as the walking quay walls). Prop boxes placed at the toe of the gravity wall were intended to resolve the stability problems, but didn't prove to be satisfactory.

The Scheldt Quays Masterplan generates an overall vision for the future use of these quays, also resolving specific questions of mobility and parking, with respect for the historical heritage. Within this context the stabilization of the dilapidated historical quay walls was put to study.

The total trajectory of the quay walls has a length of about 5,5 km and is divided into 6 different zones. This paper gives a description of the in situ and laboratory testing and monitoring program for determination of the geotechnical design conditions for the stabilization study. This paper will further focus on zone 4 (Figure 2).

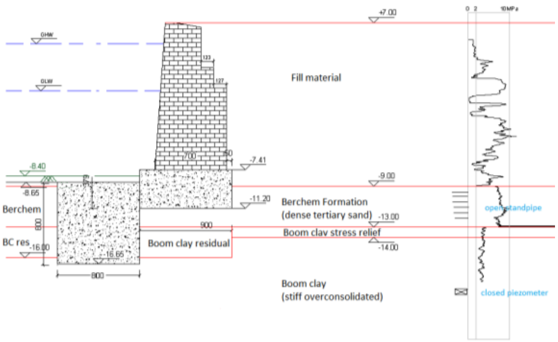

Figure 1. Cross section quay wall.

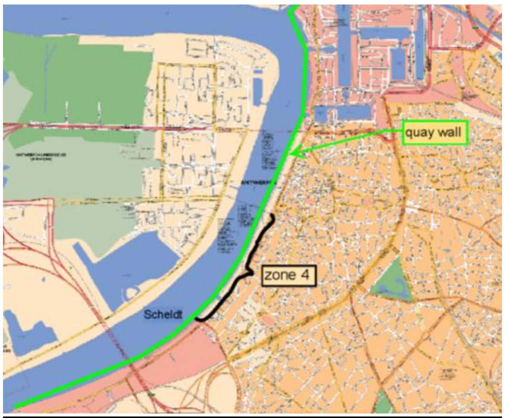

Figure 2. Trajectory quay walls- zone 4.

2 AVAILABLE GEOLOGICAL AND GEOTECHNICAL INFORMATION

For drawing up the geotechnical dossier all available geological and geotechnical information along the quay wall section was collected.

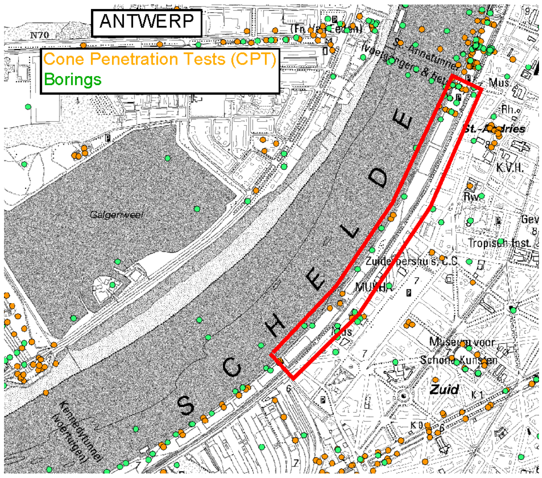

Figure 3. DOV- output zone 4

Beneficial use could be made of the Regional Database of the subsoil of Flanders (DOV). Figure 3 shows the DOV-output of zone 4 with all available cone penetration tests (CPT) and borings. Based on this inventarisation an extensive program of in situ tests and complementary monitoring and laboratory tests was performed [1].

3 GEOTECHNICAL INVESTIGATION

3.1 Field testing

Electrical CPT's were performed every 50m along the quay wall trajectory. Figure 4 shows a typical CPT plot. The upper layer consists of fill material (refill during the construction of the wall), overlaying a dense tertiary glauconite sand layer (Berchem Formation) and the very stiff overconsolidated Boom clay.

CPT's were also performed in cross sections perpendicular to the quay wall to determine the expanse of the fill.

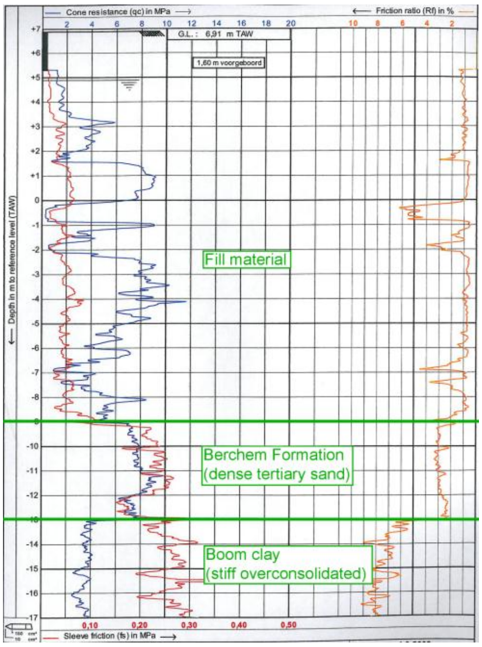

Figure 4. CPT soil profile.

The foundation level of the quay wall is situated just above or in the Boom clay (see also figure 1). The excavation works for the foundation resulted therefore in a stress relief of the upper part of the clay layer. Furthermore, due to the instability problems, the design of the stabilization should be performed on basis of residual shear strength parameters of the Boom clay. Therefore borings with discontinuous sampling were performed and undisturbed samples were taken for laboratory testing.

To determine the water pressure distribution along the quay wall, open standpipes were placed in the sand layers and closed piezometers in the Boom clay. Tidal variations became clear.

Also a long time CPTU dissipation test was performed in the Boom clay.

The results are discussed further in this paper.

3.2 *Laboratory testing*

The laboratory investigation program on the undisturbed samples focused on the determination of the geotechnical parameters of the Boom clay.

The standard laboratory tests (soil identification tests, oedometer tests, CU and UU triaxial tests were performed on all samples.

For the Boom clay samples, additional direct shear tests, Bender element tests and falling head permeability tests were performed.

4 EVALUATION GEOTECHNICAL DATA

4.1 *Geotechnical parameters Boom clay*

4.1.1 *Shear strength*

For deriving the peak values of the shear strength characteristics of the Boom clay, CU-triaxial tests were performed as follows: after applying a back-pressure of 100 kPa (for saturation), isotropic consolidation is performed with consolidation stresses calculated on the basis of a geological overburden of 90m sediment. Consolidation stresses of ½, 1 and 2 times the spherical effective stress are applied. Then vertical stresses are applied until failure. In figure 5 an example of a stress path is given.

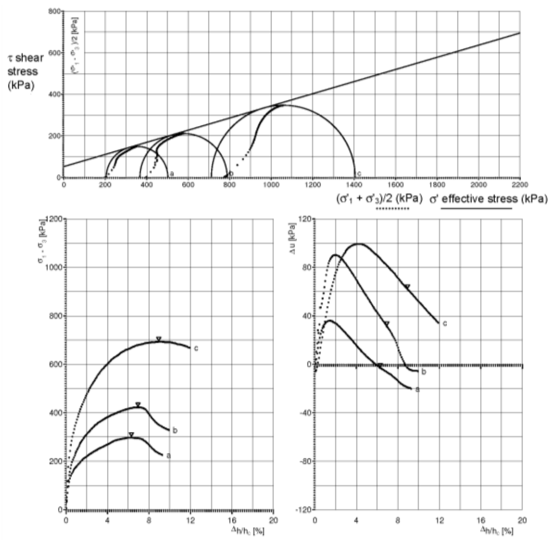

Figure 5. CU-triaxial test Boom clay.

A statistical regression analysis is performed on the CU-triaxial tests (at 95% confidence for the mean value). Figure 6 shows the p-q data plot of the Boom clay samples of zone 4 at maximum deviatoric stress. Only the samples in the relevant stress area were considered.

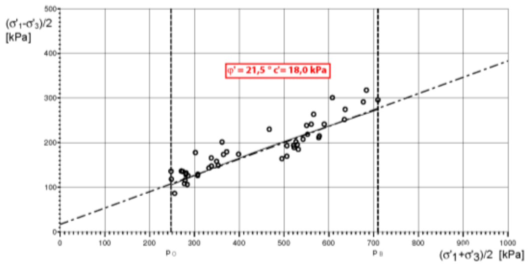

Figure 6. Regression analysis peak Boom clay

The upper part of the clay layer was subjected to a stress relief due to the excavation works for the foundation of the quay wall. In the CPT profiles, this stress relief is indicated by the lower cone resistances in the upper first meter of the Boom clay. Due to the limited thickness of this upper layer not enough samples were available to perform a regression analysis. Therefore, a rule of thumb was used to set the shear strength parameters, namely a halving of the cohesion value with unchanging shearing angle.

To determine the residual shear strength parameters, direct shear tests were performed. Figure 7 shows a typical graph. Residual shear stress was derived at a horizontal displacement of 7 mm (where the curve stays flat behind the peak in all direct shear tests).

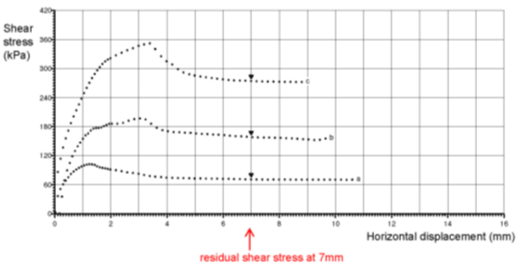

Figure 7. Direct shear test Boom clay.

In figure 8 the residual shear stress was plotted against the vertical confining stress. The value ϕ' = 15° proposed by De Beer seems to be a good assumption for the friction angle of residual Boom clay [2]. Because of the large number of tests, a mean value is acceptable.

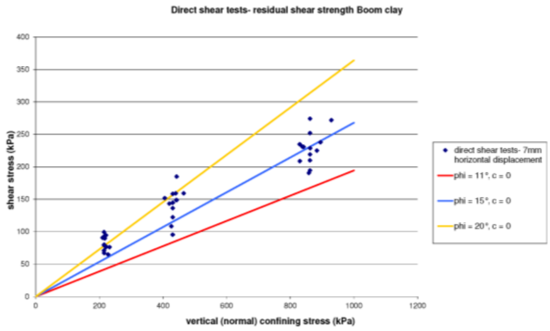

Figure 8. Shear strength parameters Boom clay.

4.1.2 *Stiffness moduli*

The small strain shear modulus G_0 was derived from Bender element tests. In figure 9 G_0 is plotted against the confining stress.

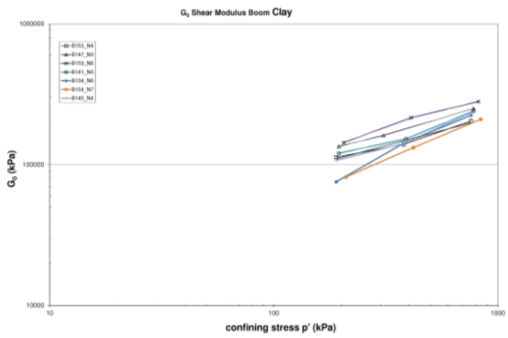

Figure 9. G_0-values from Bender element tests Boom clay.

The oedometer modulus E_{oed} was derived from the consolidation tests. In figure 10 the results are plotted against the depth (mTAW). Via the Poisson's ratio ν, the Young's modulus can be calculated. In the finite element calculations (Plaxis) the following values were used:

E_{ref} = 9000 kN/m² ; E_{inc}= 400 kN/m²/m.

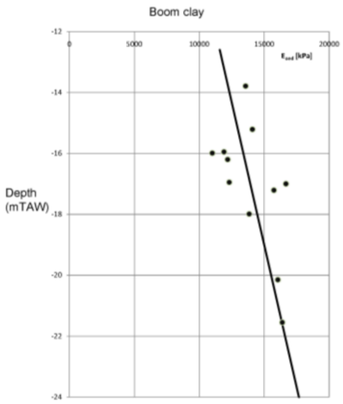

Figure 10. E_{oed} from compression test Boom clay.

4.2 *Waterpressure distribution*

The waterpressure distribution around the quay wall is depending on the tidal variations in the river Scheldt. Because of the importance of importing the right water pressures in the calculations of the stabilization design, an extensive monitoring program was executed.

In the boreholes, performed just behind the quay wall, closed piezometers were installed in the Boom clay.

In different boreholes open standpipes were placed, equipped with divers (data logger for automatic continuous measurement of water pressure). Open standpipes were placed in the tertiary sand layer and in the upper fill material. A diver data logger on the riverside of the quay wall was to monitor the water level in the river Scheldt at the same location.

Figure 11 shows the diurnal variation of measured water levels.

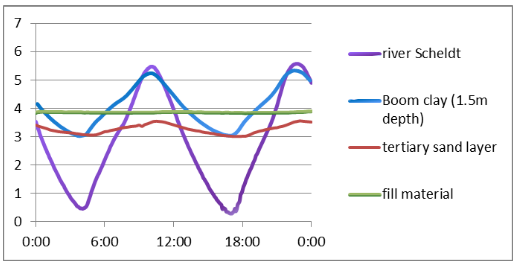

Figure 11. Measured water levels (just behind the quay wall).

The following conclusions can be drawn concerning the water levels just behind the quay wall:

- The phreatic level in the fill material shows little variations due to the tide in the river Scheldt
- The tidal variations in the tertiary sand layer amount to about 1m max
- The closed piezometers in the Boom clay show tidal variations up to 2m.

Furthermore a long time CPTU dissipation test was performed (just behind the quay wall) at different depths in the Boom clay. Figure 12 shows pore pressure against time in the Boom clay. The river level was also plotted in the graph and we can conclude that there is no time delay between high tide and rise in the pore water pressure of the Boom clay. The tidal variations are like an overburden for the nearly impermeable Boom clay. Due to the short time span, all tidal variations are transferred to the pore water pressure.

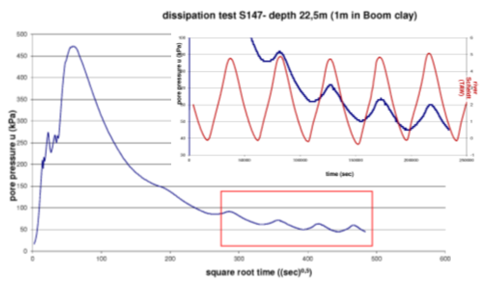

Figure 12. Long term CPTU dissipation test Boom clay.

To determine the water pressure distribution in front of and under the quay wall, a fully coupled stress/pore pressure analysis using Sigma/w-modeling was performed and the calculated water levels behind the quay wall were checked with the measured values [3]. Figure 13 shows the calculated water level. A good correspondence was found (compare to figure 11).

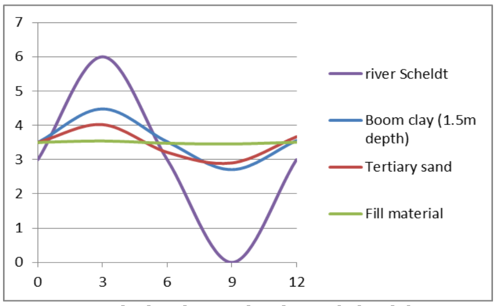

Figure 13. Calculated water levels just behind the quay wall.

Thanks to the monitoring and the Sigma/W-modeling, a clear understanding of the water pressure distribution in the different soil layers was obtained. Figure 14 and 15 show the distribution at high water, respectively low water level.

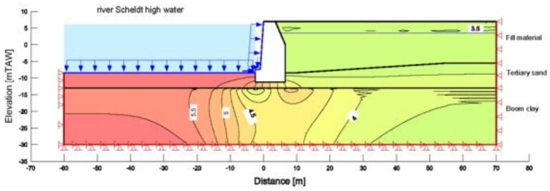

Figure 14. Sigma/W model high water.

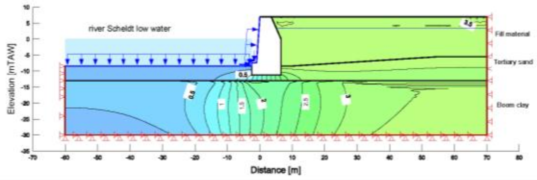

Figure 15. Sigma/W model low water.

5 STABILIZATION DESIGN

The stabilization calculations are finished for zone 4. Stabilization of the quay walls will be accomplished by injection of the cavities in the masonry, placing cross screens underneath the foundation caisson by VHP-grouting and drilling grout anchors (see figure 16).

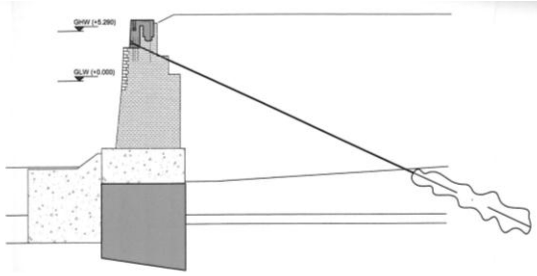
Figure 16. Stabilization design.

The stabilisation of a first section of the quay walls will start soon.

6 CONCLUSIONS

An extensive geotechnical investigation program (which includes in situ tests, laboratory tests and monitoring) was elaborated with emphasis on the geotechnical parameters of the Boom clay and the water pressure distribution around the quay wall.

This resulted in an economic and sustainable design for the stabilized quay walls.

ACKNOWLEDGEMENT

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[3] Feremans G. & Laemont A, 2010 *Rekennota D1-004-C Verificatieberekeningen technische deelstudie stabilisering kaaimuren en ontwerp bijkomende waterkering voor de Scheldekaaien te Antwerpen*, 2010.