Geotechnical and Geophysical Site Characterisation 5 – Lehane, Acosta-Martínez & Kelly (Eds)

A comparative analysis of the stability of a slope in an overconsolidated clay pit based on CPT and DMT measurements

H. Peiffer
Laboratory of Geotechnics, Department of Civil Engineering, Ghent University, Ghent, Belgium

ABSTRACT: In Belgium the Boom Clay is a well know overconsolidated tertiary clay formation. In the period 2011-2014 small slidings occurred in the slopes of a pit with a depth of 30 m. Because more slidings could be expected, a monitoring was started including a series of DMT-tests and CPT-tests around the pit. In June 2014 a very large sliding (an area about 100 m by 50 m) occurred. In the present paper the results of the DMT-tests and the CPT-tests were discussed at different stages, before the sliding and after the remediation works. Although both CPT and DMT gives a clear image of the sliding surface, the measurement with the DMT gives a more pronounced result.

1 INTRODUCTION

The dilatometer as developed by Marchetti, gives the opportunity to evaluate stress changes in the soil. This opportunity resulted, besides other applications, in an experimental method for the evaluation of changes of the stress in the soil during pile installation (Peiffer, 1997). The DMT test allows also for the risk assessment for the stability of slopes (Peiffer, 2015). In this article a comparative analysis is made considering the results of the cone penetration test (CPT) and the dilatomer test (DMT) in order to evaluate the sensitivity of these test methods for the evaluation of slope stability. In order to make this evaluation, the tests were carried out in a clay pit in Flanders (Kruibeke). In the period 1963 – 2010 the pit was excavated in the Boom Clay till a depth of about 30 meters.The clay was used for the fabrication of expanded clay granulates.

In 2010, the exploitation of this pit stopped because the borders of the concession were reached. One year later, in 2011 a first (limited) instability of the slope of this pit occurred (sliding). Apparently, it became clear that more stability problems could be expected. In 2012 and 2013, new (limited) slidings occurred. In the beginning of 2014 it was decided to setup an extensive monitoring program in order to evaluate the risk of further instability of the slopes, site investigation was carried out (DMT and CPT). Besides the monitoring of the settlements and the pore water pressures in the environment, the in-situ-tests were carried out on a regular basis.

In the consecutive DMT-measurements one could clearly see an evolution towards instability (Peiffer, 2015) . After an important failure (sliding) in one zone in June 2014 (an area of 100 m by 50 m was affected), remediation works were done in the destabilized zone (October – November 2014). In 2015 and 2016 additional soil investigation was done, in order to evaluate the change in stress state after these remediation works. The results of the tests before the period of instability and after stabilization are discussed. More detailed results are presented in the general test report (Peiffer, 2015). In the future the tests will continue. Although the last measurements are about two years after the sliding, the measurements will continue in the futur, in order to monitor the evolution of the soil conditions.

2 SOIL PROFILE AND LAYOUT OF THE SITE

2.1 *Geology*

Based on the geological investigations and data maps, the upper layer consists out of a sandy silt (quaternary deposit). Under this layer the tertiary overconsolidated Boom Clay can be found. This can be seen also on the I_D-diagram as presented below. The profile confirms the results of the undisturbed sampling of the soil.

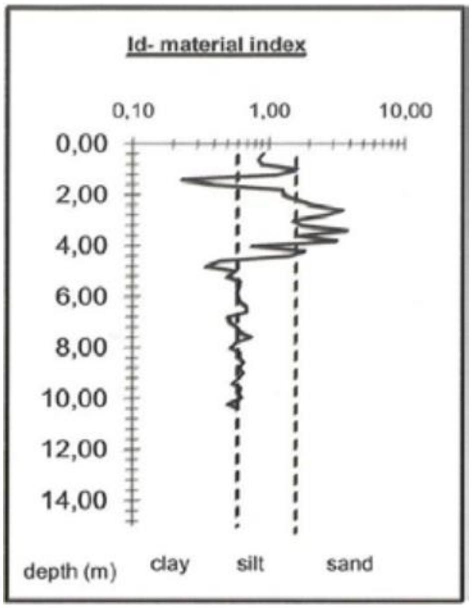

Figure 1. I_D (DMT1)

2.2 *Ground□ater*

The phreatic level is at depth of about 1,5 m (before remediation). The thickness of the clay at the bottom of the pit is about 10 m. This thickness is sufficient in order to resist the upward artesian water pressures.

2.3 *Sliding (2014)*

In the next figures a general view of the main sliding is presented. After excavation of the clay pit till a depth of about 30 meters, in the Northern part of the pit instability (small slidings) of the walls started to occur after some years. The main raison for this was the lack of a sufficient resistance against horizontal stability. During the period of excavation the pit became the central dewatering point for the region. Unfortunately the surface between the upper quaternary layer and the underlying Boom clay was slightly declining towards the pit. The upper part (quaternary layer), with a thickness of about 4 to 5 m moved towards the pit, resulting in instability. Also the underlying Boom Clay was affected by this slide.

In the figures 2 and 3 a general impression of the sliding and the soil movement is presented. A zone of 100 m by 50 m started to move resulting in a downward movement of about 9 m in the corner of the pit. After the first sliding in the northwestern part of the pit a monitoring program was set up. The monitoring consisted out of the execution of CPT-tests and DMT-test. Besides these tests, also the water pressures were measured on a regular base

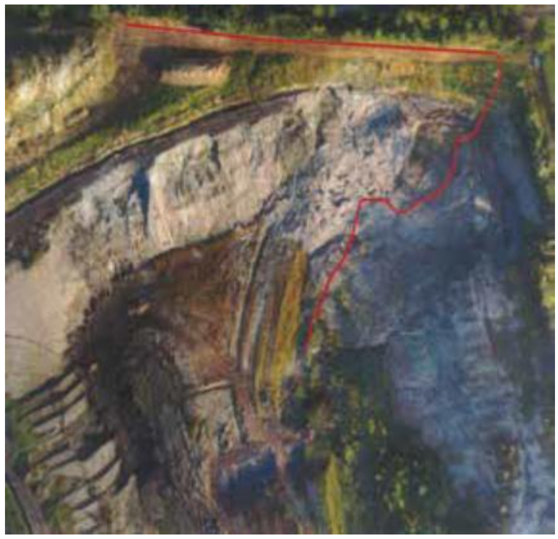
Figure 2. Photographic impression of the sliding


Figure 3. Detailed impression of the instable slope

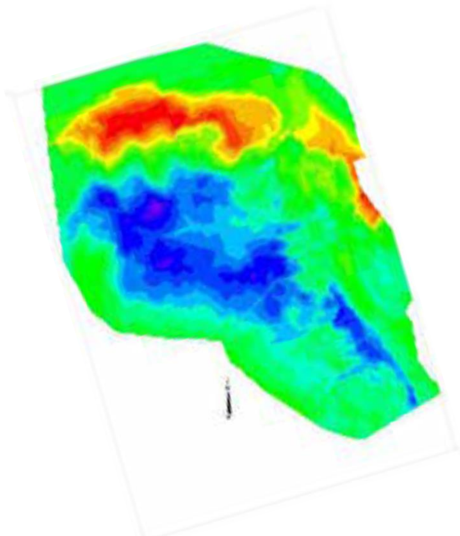
Figure 4. Topographic survey of the soil movement

An overview of the monitoring points is presented in figure 5.
Until now four campaigns were organized :

January 2014 – DMT 1 to 5 (before the important sliding)
July 2014 – DMTA to F (about 1 month after the sliding)
January 2015 – DMT I to I□ (after stabilizing)
March 2016 - DMT1□to 5□

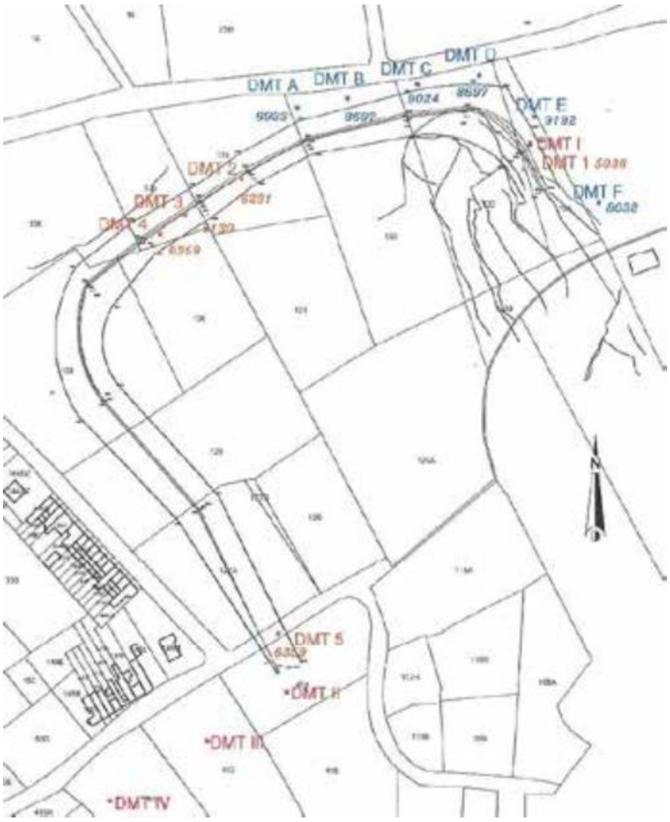

Figure 5. Overview in-situ tests

3 DMT AS A TOOL FOR THE DETECTION OF SLIP SURFACES

3.1 *DM□-K_D-method*

The principle of the DMT-K_D-method for the detection of slip surfaces can be shown as follows. (Marchetti, 1997). In many OC clay landslides, the sequence of sliding, remoulding and reconsolidation, leaves the clay in the slip zone in a normally consolidated (NC) or nearly NC state, with loss of structure, ageing or cementation effects.

Based on field data from different clay sites in various geographical areas correlations could be established (□. Totani et al., 1997, Lacassse □ Lunne,19□□).

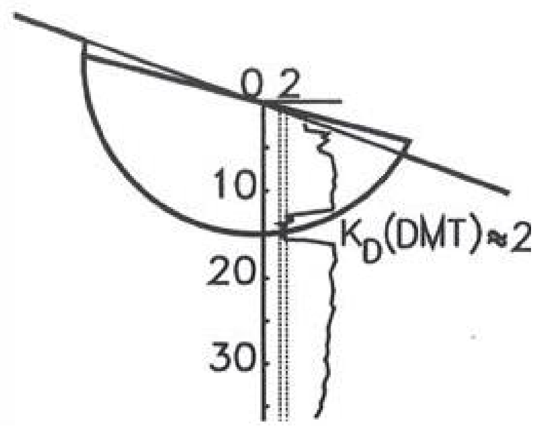

Figure 6. Principle of the DMT-K_D-method

In genuinely NC clays (no structure, ageing or cementation) the horizontal stress index K_D from the DMT is approximately equal to 2, while KD values in OC clays are considerably higher (for the Boom Clay about □).

Therefore it is known that, if and OC clay slope contains clay layers with KD ≈ 2, these layers are highly likely to be part of a slip surface (active or quiescent).

The DMT-K_D-method method consists on identifying zones of NC-clay in a slope, using KD ≈ 2 as the identifier of the NC zones.

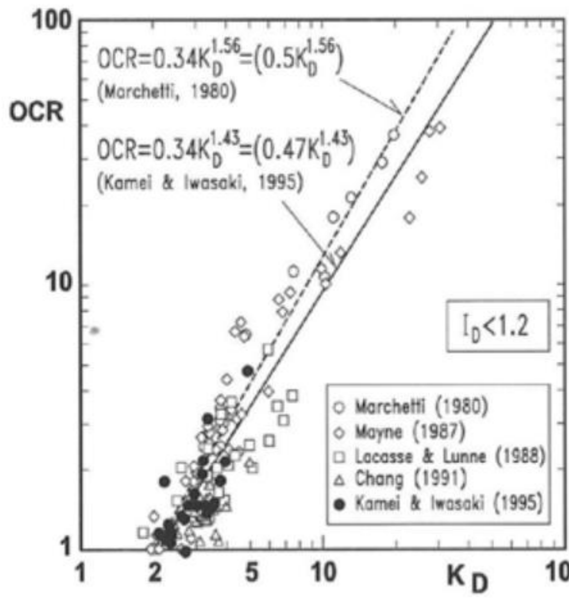

Figure 7. Correlation KD – OCR for cohesive soils (after Kamei □ Iwasaki, 1995)

4 FIRST SLIDIN□S

4.1 *□eriod 2011 and 2012*

The first instability occurred in 2011. The size of the sliding was limited. No DMT-measurements were done before or after this sliding.

In the second half of 2013 a more important slide occurred in the neighborhood of point 5 on figure 5. The number 5 refers to DMT 5 executed in the beginning of 2014 at a distance of 5 m from the top of the slope.

In the figure □a photo of the slide is presented. The sliding occurred in the quaternary layer until a depth of about 1.5 m in the Boom clay.

Figure □. Photo of the unstable zone after sliding

5 MORE PRONOUNCED INSTABILITY OF THE SLOPE (2014)

5.1 *Instability problems in 2014 (period □une-□uly)*

As discussed in 4.1., after the more pronounced sliding in 2013, a monitoring program was elaborated for different points at the top of the slope around the pit. Besides topographic surveys and the measurement of the phreatic waterlevel, DMT-tests were carried out. In this article the top of the slope in section □□□□□d□□□□□d□□□□□□□□□ itself is given in the figure 9. The reference level in the figures 1 and 9 corresponds with the national reference (TA□) □-□□m TA□.

5.2 *Discussion of the results*

In the figure 10, the results are presented for the tests before (January 2014), immediately after (July 2014)

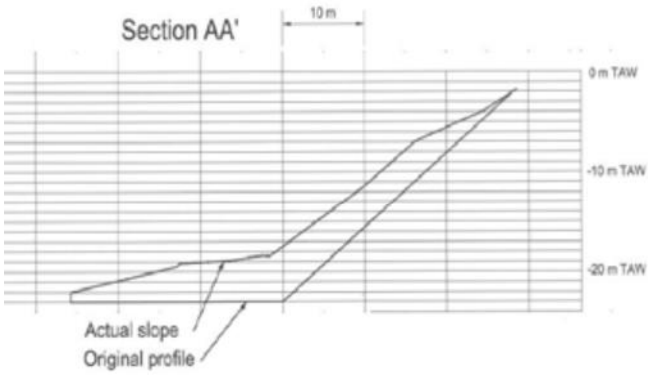

Figure 9□□□□□□□ □ □□□□□□)

and about two years after the sliding in point of sec-□□□□□ □ □□□rr□□□□d□□□□ □□□M□□□□□□□□□r□□□

In the test diagrams one can distinguish the upper quaternary sandy silt layer. In the K_D-graph one can see that two points (one in a weaker point in the quaternary deposit and one at the interface between the quaternary layer) show a lower value of K_D. The CPT diagram shows also the presence of a weaker layer at depth of about 2m. The DMT-results show a decrease in horizontal stress at these point.

The layer between these two points became unstable in June 2014, resulting in an important sliding. One can see on the diagrams of figure 10 (July 2014) that the K_D-value became lower than 1.□, referring to unstable soil conditions. The failure occurred in this zone and affected a slip layer with a thickness of about 1.5 m. Although the cone resistance decreased with a factor about 2, and a significant decrease of qc between 2 and 4 meter can be seen in this layer, the CPT-d□□r□□d□□□□□□□□□□□□□□r□r□□□□□□□□□ the sliding. It is also important to notice that the KD-values below the sliding zone decreased till a depth of about 5 m below the sliding surface. It is interesting to see which way the stresses changed after the sliding. In the last column of figure 10, the results are presented for the measurements carried out in March 2016. Remediation works were done in October-November 2014 (see 6.).

The q_c-value did not change in an important way. Out of the K_D-diagram it become clear that the K_D-values exceeded the critical value 1.□ For the clayey layer the measurement reflects actually a normally consolidated soil. For the intermediate sandy silt layer, one can see a slightly overconsolidated soil condition. The difference between the measurements of July 2014 and March 2016 can be explained by the presence of excessive pore pressures, resulting in lower values of K_D in the sandy silt layer in the sliding layer.

After consolidation a residual part of the original overconsolidation did appear again. The soil conditions after sliding and reconsolidation can be measured more clearly using the dilatometer.

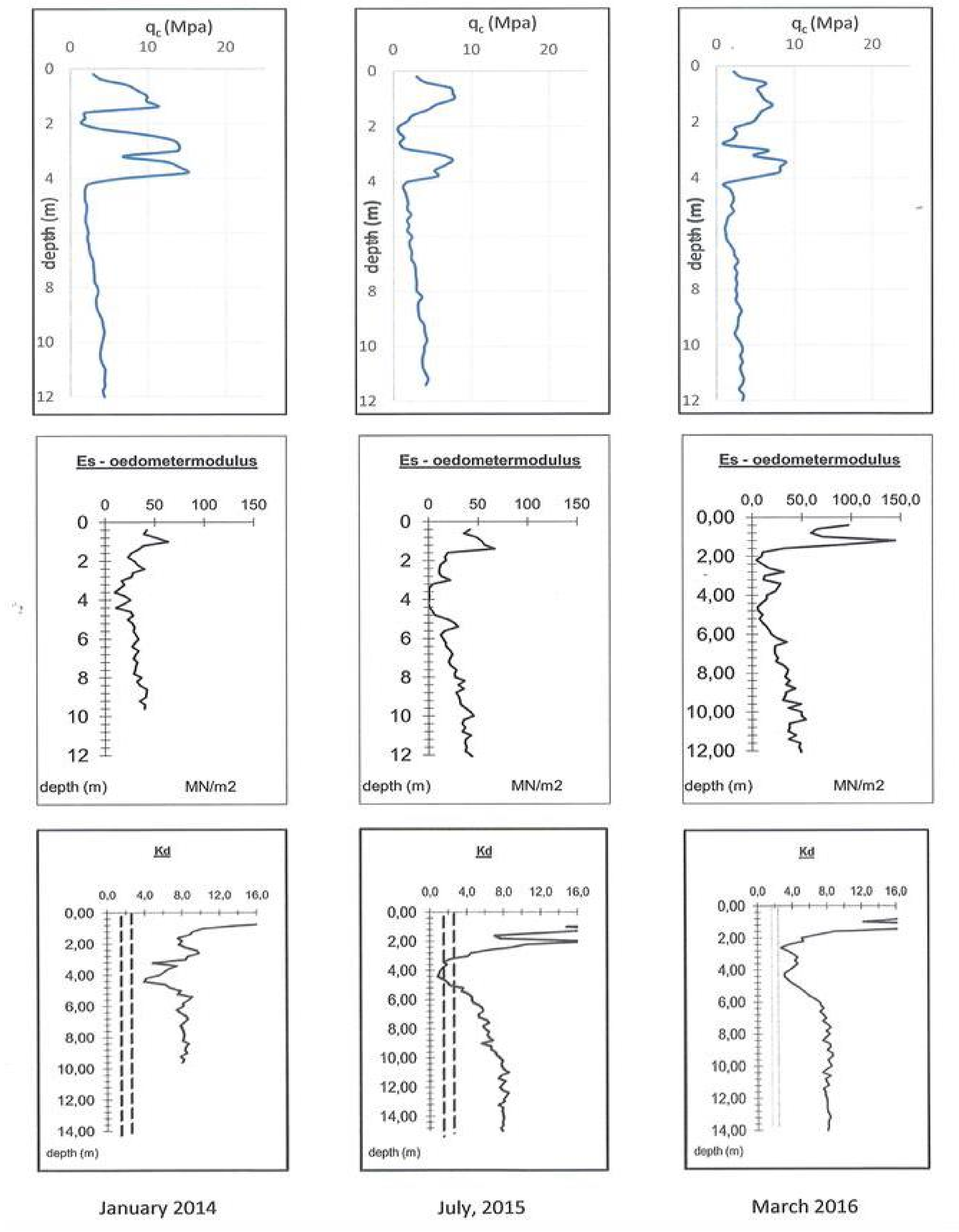

Figure 10. Results of CPT and DMT

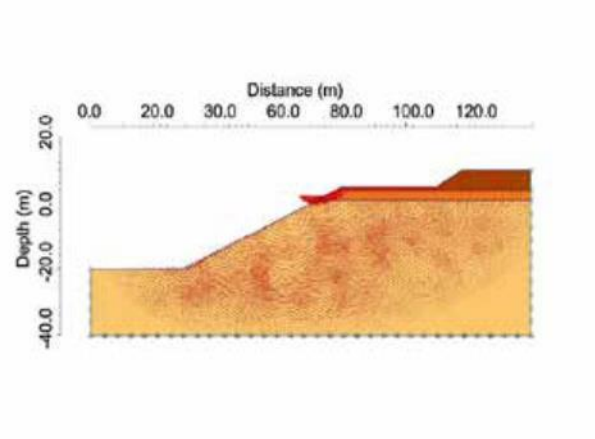

Figure 11 – PLA[illegible]IS-analysis

6 STABILITY ANALYSIS

In order to get a better understanding of the effects resulting in this instability and in order to design an appropriate remediation, additional investigation was done to determine the design soil characteristics (CPT-tests and laboratory tests (triaxial tests, oedometer tests)). This analytical and numerical analysis is not discussed in detail in this article. Out of the theoretical analysis it became clear that the effect of the groundwater pressures on the horizontal equilibrium was dominant.

The Fig. 11 presents the calculated critical horizontal disequilibrium due to the presence of the groundwater out of an equilibrium analysis the zone within the most critical global sliding surface. But in the upper part of this zone the equilibrium is broken in the upper layer (lower part of the quaternary deposit and top layer of the Boom clay (big red arrows)). In reality it could be seen that the sliding in the upper part of the Boom clay was more pronounced than in the analysis made with Plaxis.

The analysis resulted in a design where a deep drain has to be installed at a depth of 5 m., as shown in the Fig. 2. This drain was installed in November 2015. The red line in figure 2 is the position of the drain in plan view. After the installation of this drain, there was an immediate effect on the depth of the groundwater. The original depth of 1,5 m increased to a depth of about 4.5 m. The safety of the slope stability increased from 0,9 to 1.31.

7 CONCLUSIONS

In 2014 an important sliding occurred in the top layer of an excavation pit in the Boom Clay. Because previously small slidings occurred around the pit, an extensive monitoring program was started before this important sliding, based on the execution of DMT-tests and CPT-test.

This way the stability of the slope could be evaluated before, during and after sliding. Comparison between the DMT-test before and after the sliding shows clearly an important reduction of K_D (factor about 4) and E_D in the sliding zone (resulting in lower values of E_s). It is important to notice that the K_D-value also were reduced in the layer immediately below the sliding zone. The CPT-measurements showed a decreased strength (q_c reduced with a fac tor about 2) and stiffness in the soil, but the sliding zone could not be indicated that pronounced. After a period of about two years, the K_D-value in the sliding zone increased towards values corresponding with the state of normal consolidation. The CPT-d[illegible]

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