Influence of Soil Suction on Trench Stability

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Summary. A research project on the stability of temporary trenches in unsaturated soil is carried out in Belgium. The main objective of the project is to evaluate the seasonal variations of suction in the soil and to quantify the consequences of these suction variations on trench stability. Within the framework of the research, a full scale instrumented test trench with vertical sides has been excavated in June 2004 at the site of BBRI, characterized by quaternary loam (Limelette, Belgium), to compare calculations with full-scale observations. As expected first failures occurred during the winter, when suction in the soil was minimal. This paper presents the details of this experiment.

Key words: temporary, trench, slope stability, suction, full-scale experiment

1 Introduction

Common methods applied in Belgium for designing trenches and evaluating slope stability do not take into account the effects of suction when present in silty and sandy unsaturated soils. The suction is one of the reasons that steeply inclined slopes remain stable, while this stability can not be proven by common design rules. Because of the large occurrence of unsaturated loam and sand soils (possibly after water lowering) during excavations, a research project on the stability of temporary trenches in unsaturated soil is carried out in Belgium, with the financial support of the federal ministry of Economical Affairs. The main objective of the project is to assess the influence of precipitations on trench stability. In a first approach, it is assumed that the influence of precipitations on slope stability can be related to the variations of the suction in the soil. In order to evaluate this approach, theoretical predictions – based on "easily applicable" measurement systems, soil characterization procedures and calculation methods that can be promoted in the practice – were compared with full-scale observations obtained from the trench test experiments that are presented in this paper.

2 Geotechnical Context

2.1 Selection of a Site

Because of the large occurrence of unsaturated loam in Belgium, the site of BBRI at Limelette where the subsoil exists out of overlying quaternary loam ($I_p = 10\%$) was selected to carry out the test trench experiments. An extensive geotechnical investigation of the test site is described in Van Alboom and Whenham (2003).

2.2 Preliminary Investigation

In order to evaluate the soil layering in the test area, eight Electrical Cone Penetration Tests (CPT-E) were performed on the selected site. Further a boring with undisturbed sampling was executed to define through laboratory tests the physical and mechanical properties of the soil (Figs 1 and 2).

Gravimetric soil water content profiles were determined in order to characterise the soil layering in terms of water content susceptibility, and a first series of suction measuring devices were placed with the aim to assess the range of suctions developed at different depths as well as the evolution of this suction with the seasons (Fig. 3).

2.3 Additional Soil Characterization Tests

Additional laboratory tests were performed on undisturbed samples in order to allow further interpretation of the experiment. Besides, unsaturated

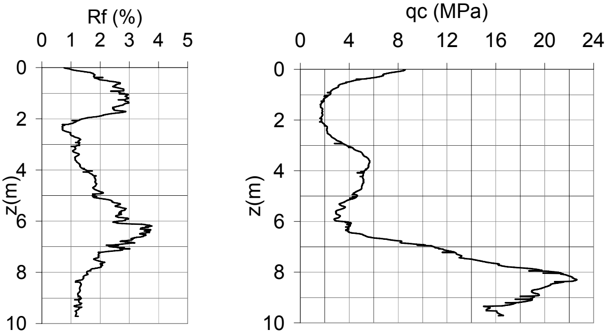

Fig. 1. Average values of the CPT-E results for the test site at Limelette

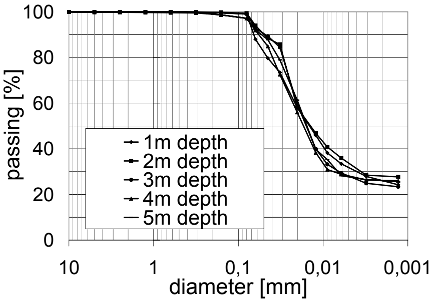

Fig. 2. Grain size distribution curve

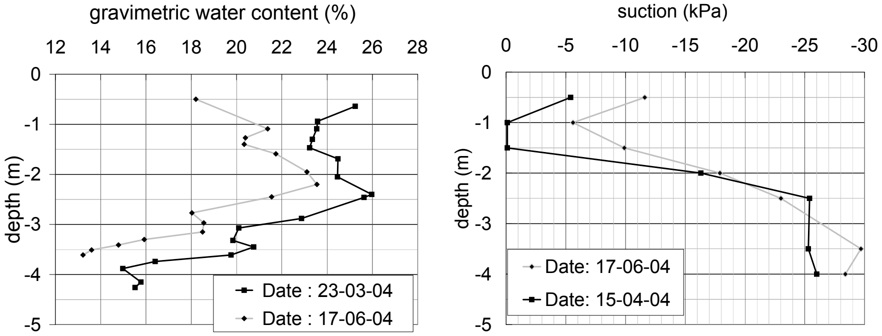

Fig. 3. Gravimetric water content and suction profiles at Limelette (preliminary investigation results)

specimens were tested using a modified triaxial apparatus. Tests were carried out under constant water (CW) conditions, where the specimen was drained with respect to the pore air pressure and undrained with respect to the pore water pressure during shear. Typical derived values of friction angle and cohesion from CU- and CW-triaxial tests are given in Table 1. Soil water retention curves were determined in the laboratory on undisturbed soil samples using the axis translation technique. Results are shown in Fig. 4.

Table 1. Typical results of CU and CW triaxial tests (sampling depth = 1.5 m)

Type of triaxial test	Applied suction s [kPa]	Effective cohesion c' [kPa]	Effective friction angle φ' [°]
CU-test	0	0	32.2
CW-test	20	19.2	35.7
CW-test	50	18.1	35.8

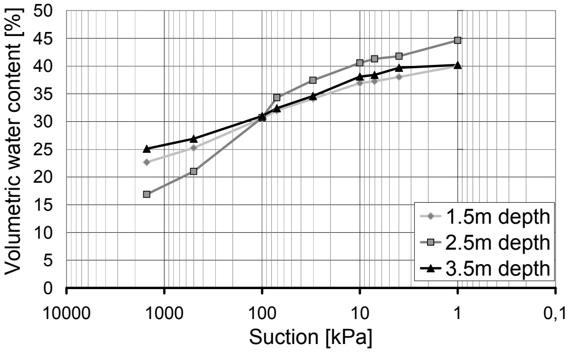

Fig. 4. Soil water retention curves determined on undisturbed soil samples – axis translation technique

3 Test Trench Experiment

3.1 Objective of the Experiment

The objective of the experiment was to observe the influence of the seasonal variations of suction in the soil on the stability of a full scale instrumented trench, and to compare this influence in terms of soil movements and failures with very simple calculation methods proposed in the literature (Fredlund and Rahardjo 1993, Vanapalli and Fredlund 2000). This experiment took place between June 2003 and June 2004.

3.2 Definition of the Geometry of the Test Trench

The geometry of the test trench was established based on the preliminary soil investigation data, taking into account the goal that was to observe the influence of suction degradation on slope stability. A length of 20 m was found to be sufficient in order to avoid 3D effects. Besides, it was calculated that a vertical 3 meters depth trench side would only be stable taking into account the cohesion increase attributable to the suction levels measured in the summer, while suction levels measured in the winter would not be sufficient. It was therefore decided to excavate a test-trench of 20 m length, with vertical 3 m depths sides.

3.3 Instrumentation

Based on the test-trench layout and in order to follow the suction and degree of saturation in the soil, an extensive instrumentation was specified (Fig. 5). Before the excavation was executed, reference tensiometers were placed all around the excavation area, at depths varying from 0.5 m to 3.5 m. Further

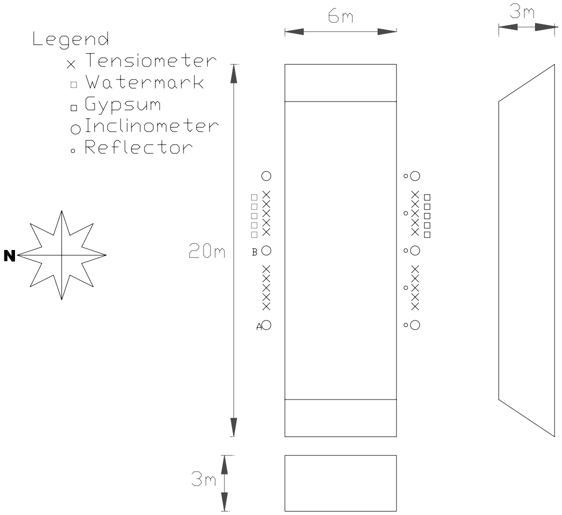

Fig. 5. Test-Trench layout and instrumentation

instrumentation consisted in watermark sensors for suction measurements and gypsum blocs for soil water content evaluation. Besides inclinometer casings and reflectors were installed in order to monitor soil movements.

3.4 Observations

The test trench was excavated in June 2004. Weekly averaged rain measurements obtained for the site as well as averaged suction results are presented in Fig. 6. For shallow measurements, the influence of precipitations on the suction results can clearly be observed. However, below 1.5 m depth, the response to rains in terms of suction variations is significantly "smoothed". From Figure 6, it can also be observed that while it rained much more in the summer, and in particular during the months of July and August, suctions were still measured even in the upper layers due to the evaporation being much more important than in the winter (from December to March).

Settlement and horizontal movements of the trench sides were monitored from June 2004 (before excavation of the test trench) using reflectors and inclinometers. Results of these measurements are shown in Fig. 7. Few displacements were measured, and the degradation of the trench side was observed to be limited to very superficial erosion until first failures occurred.

First failures of the test-trench occurred in January 2005 after heavy rains. These first failures – registered by webcams focussed on the trench sides – were shown to be localized and to occur very suddenly. Further failures occurred during the following days. This first experiment also illustrated the effects of erosion on the inclined sides (see Fig. 8).

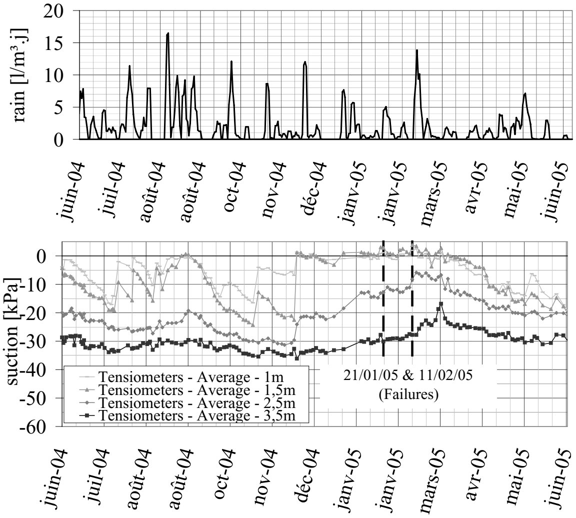

Fig. 6. Rain measurements and Averaged suction measurements

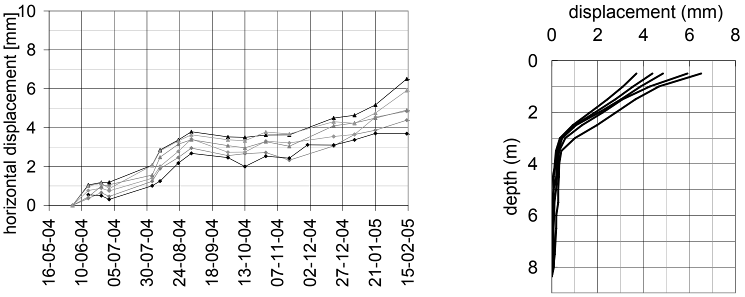

Fig. 7. Inclinometer results (horizontal movements measured at a distance of 1 m from the vertical trench sides): (**a**) movements measured at 0.5 m depth, (**b**) displacement profiles measured after the first trench failures

4 Conclusions

This contribution has given a general overview of an experiment carried out at the site of BBRI, within the framework of a national research project on the influence of precipitations on trench stability. This experiment involved the excavation and monitoring of a full scale instrumented test-trench. As expected, it was observed that the test trench remained stable during the first seven months, while first failures occurred in the winter when suction measurements were minimal.

Fig. 8. Upper left: June 2004 – after excavation of the test trench; Upper right: first localised failures (January 2005); Lower left: eroded inclined sides; Lower right: generalized failures (February 2005)

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