Studying the tensile behaviour of compacted Hollin Hill clay

Yu-Jun Cui

Ecole des Ponts ParisTech

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1. Introduction

This report summarises the work conducted during my short term scientific stay in the University of Newcastle from 15th August to the 3rd September 2014. It includes a visit of the experimental embankment constructed in the past Bionicle project and a laboratory study on the tensile strength of compacted Hollin Hill clay used for embankment constructions. Note that this report focuses on the scientific contribution and other works conducted during my stay in Newcastle, such as the general discussions about the research perspectives in the field of climate impact on infrastructures, the future exchanges with the cost project etc., are presented in the host report. Note also that this work would not be possible without the precious help of Dr Paul Hughes and Dr Ross Stirling. They are greatly acknowledged.

2. Visit of the Bionicle experimental embankment

An experimental embankment was constructed during the Bionicle project (see Figure 1a). Different measurements have been done since then, including soil resistivity, moisture water content, suction, soil temperature, soil cracks' geometry, etc. It is worth noting that two weather stations were installed, one on the crest and another on the northern side of the embankment, allowing the comparison of the effect of micro-climate on the embankment behaviour. Note also that an interesting discussion was organised during my stay with people working in the field of geography to see the possibility of the embankment geometry (and more) monitoring using laser scanner.

Figure 1b shows one of the cracks identified in the southern slope of the embankment. Although the origin of the cracks are still in discussion, it is generally admitted that for given soil, when the internal extension stress mainly due to the suction gradient over depth is higher than the soil tensile strength, cracks occur. This explains why the topic of soil cracking has been attracting more and more interests.

(a) (b)

Figure 1. Bionicle experimental embankment. (a) An overall view with my friends Dr Hugues (middle) and Dr Stirling (right); (b) one of the identified cracks

3. Laboratory study on the tensile strength of compacted Hollin Hill clay

3.1. Soil physical and geotechnical properties

The study was not conducted on the soil used for the construction of the experimental embankment. The soil tested was the Hollin Hill clay for its availability in the laboratory. According to an internal report, the clay is mainly composed of clay (40%) and silt (52%). The Atterberg's limits are: liquid limit w_L = 53%, plastic limit w_p = 24%, plasticity index I_p = 29%. The standard Proctor compaction test gave an Optimum Moisture Content (OMC) of 15.4% and a maximum dry density of 1.71 Mg/m^3.

A standard Proctor compaction was carried out in order to check the values found in the report. Surprisingly, quite different values were found: OMC = 27% and a maximum dry density equal to 1.43 Mg/m^3. This suggests that the soil in the field is quite heteronymous and attention must be paid when applying the laboratory test results in the analysis at the field scale.

3.2. Samples' preparation

In order to investigate the sensitivity of tensile strength to changes in water content, it was decided to prepare samples by compaction at OMC conditions in three layers and then dried to reach different water content values. The samples were prepared in group of three, and 10 groups (A-J) were considered with a total of 30 samples (see Table 1). The three samples of group J are spare ones.

Table 1. Samples prepared for tensile stenting with the target and actual water content values

Specimen	**Target water content (%)**	**Actual water content (%)**
A1	3	7.0
A2	3	6.8
A3	3	6.7
B1	6	6.3
B2	6	7.8
B3	6	7.8
C1	9	10.7
C2	9	10.5
C3	9	10.9
D1	12	13.9
D2	12	13.4
D3	12	14.2
E1	15	16.1
E2	15	16.3
E3	15	15.9
F1	18	18.0
F2	18	16.5
F3	18	17.1
G1	21	
G2	21	
G3	21	

H1	24	
H2	24	
H3	24	
I1	27	26.9
I2	27	27.0
I3	27	26.7
J1		26.4
J2		
J3		25.4

The samples were dried in steps – exposed to temperature controlled air for a given time and then wrapped with plastic film for water content homogenization; this operation was repeated till the desired water contents (controlled by mass) were reached. It is important to note that the air exposure time should not be too long, especially when the samples are relatively wet, in the beginning of drying for instance. Otherwise, microcracks would occurs, compromising the tensile test results. A too long drying step would also lead to the loss of the desired water content values. This is the case for group G and H. Note also that a different mold was used for the preparation of samples E2, F1, G1, H1, H3, I3, J2. The dimensions of this mold is slightly different and thus the samples prepared with it are slightly more compacted, which leads to a higher tensile strength. In Table 1, the target and the actual water content values are presented.

3.3. Running the tests

The laboratory is equipped with a digital image correlation system that allows the analyse of strain distribution of a tested sample. This system was successfully used in the PhD work of Dr Stirling (2014). It was planned to use this system for analyzing the behaviour of Hollin Hill clay under traction. Figure 2 shows the preparation of the DIC system by Dr Stirling. This image test was not performed finally because of a technique problem that needs more time to be solved.

Figure 2. Preparation of the digital image correlation (DIC) system by Dr Stirling

As far as the tensile testing is concerned, a standard direct shear machine was used. The shear box was modified so that a soil sample is pulled with one part fixed (left part in Figure 2) and another part pushed away (right part in Figure 2). During the test, the tensile force was monitored using a loading cell and the horizontal displacement was monitored using a comparator. More details can be found in the PhD dissertation of Stirling (2014).

3.4. Test results

Typical test result is shown in Figure 3, with a very slight changes in the beginning, and then an abrupt changes till a peak that is followed by a sudden decrease. The peak stress value corresponds to the tensile strength of the soil specimen.

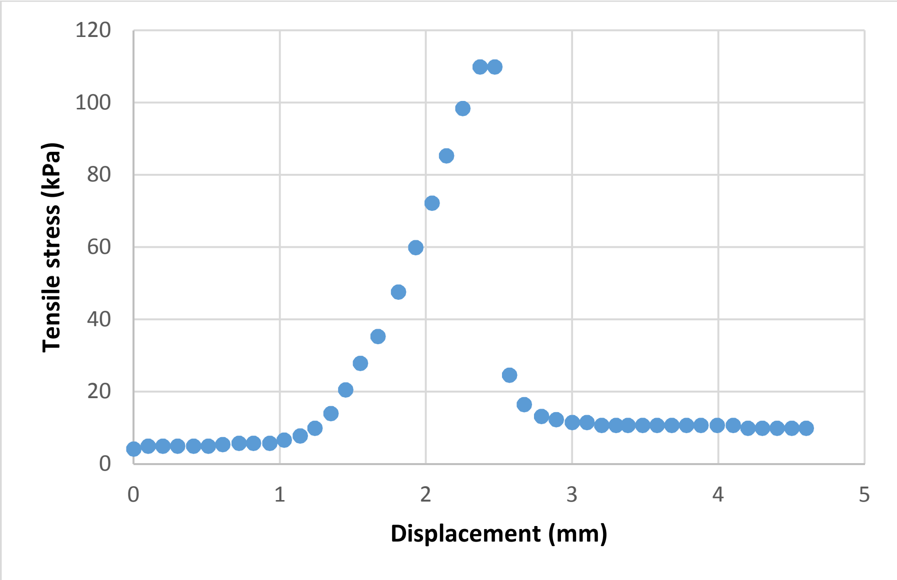

Figure 3. Tensile strength versus displacement for test on F3

Visual observation on the sample shows that in the case of one peak, the failure is often well positoned, in the middle of the specimen (see Figure 4).

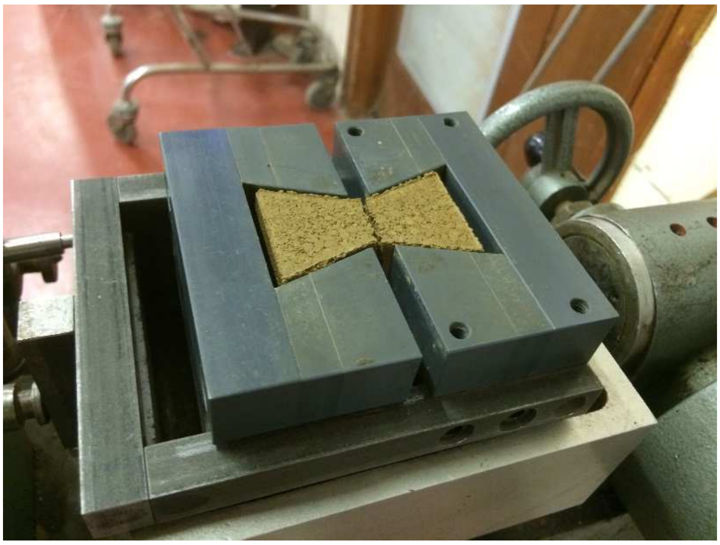

Figure 4. Failure postion in the middle when the stress-displacement has one peak

For some samples, two even three peaks can occur. Figure 5 shows the tensile stress-displacement curve of sample D2, with two peaks. Further inspection shows that in this case, the position of failure is not in the middle of specimen (see Figure 6). This is mainly due to the sample homogeneity in terms of density. Indeed, although the samples were compacted in three layers, the density of each layer was not rigorously controlled. The compaction using a small compactor can also lead to heterogeneity in the horizontal plan.

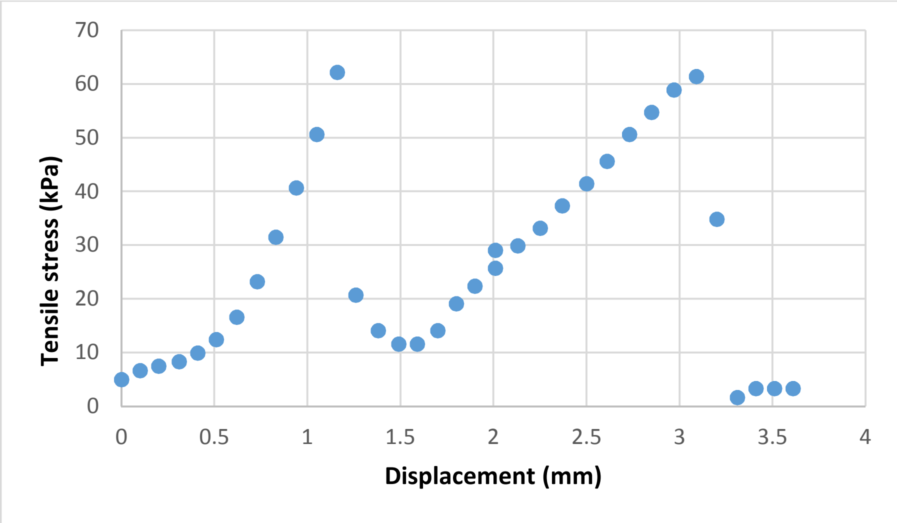

Figure 5. Tensile strength versus displacement for test on D2

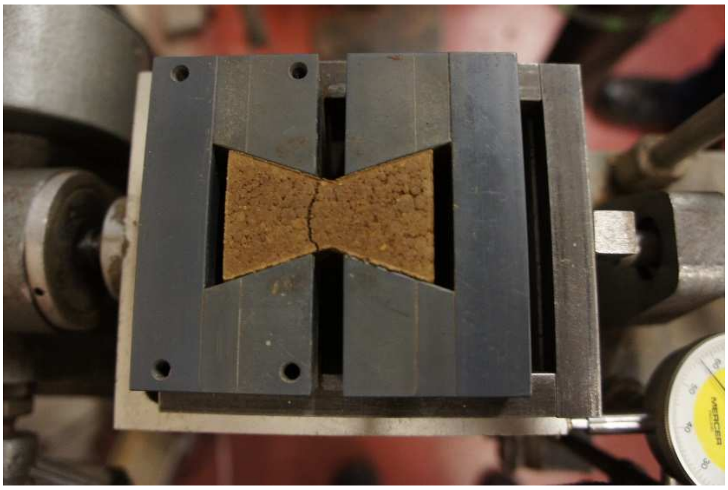

Figure 6. Failure postion in the middle when the stress-displacement has one peak

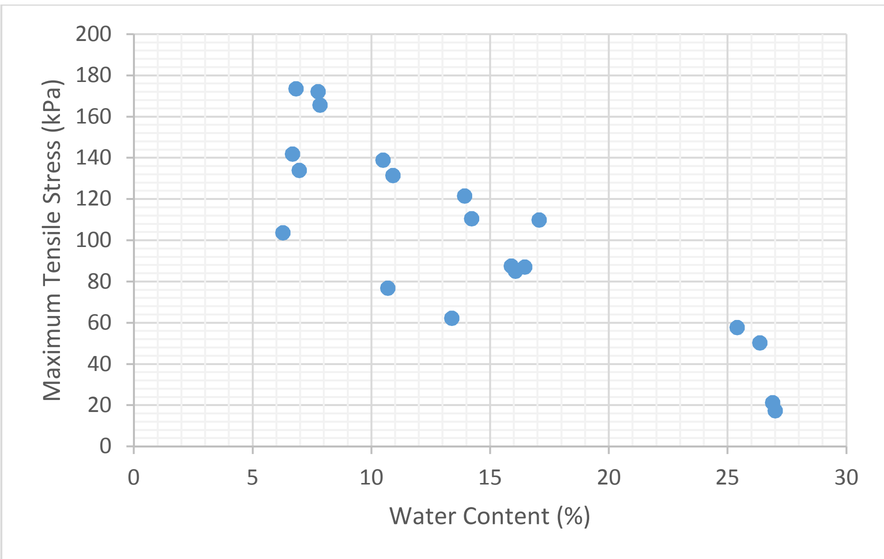

Figure 7. Maximum tensile stress versus water content

Figure 7 depicts the variations of the maximum tensile stress with water content. Despite the data scatter related to the samples' homogeneity, a clear increase of tensile stress with the decrease of water content can be identified, in agreement with results reported in the literature on other soils. This increase is commonly attributed to the effect of soil suction.

4. Concluding remarks

The visit of the experimental embankment confirmed the importance of investigating the soil cracking behaviour in the laboratory. For the laboratory testing, the Hollin Hill clay that was used for the constructions of embankment was studied using the experimental set-up developed in the PhD work of Stirling. With the help of Dr Hugues and Dr Stirling, the stadard proctor property of the soil was determined, 30 samples were prepared by compaction in three layers and then dried to reach different target water contents, more than 20 samples were subjected to tensile testing. The results allow the following conclusions to be drawn:

i) the soil in the Hollin Hill site is quite heterogeneous since the proctor value obtained is quite different from the value reported in the internal report;

ii) it is important to well control de drying time in order to avoid microcracks' occurrence and loss of the target water contents;

iii) it is important to ensure the sample's homogeneity in order to obtain good results characterized by a one-peak stress-displacement curve and a well positioned failure in the middle of the sample;

iv) the tensile strength is increased when decreasing the water content due to the increase of soil suction.

This study can be extended to the vegetation effect. With vegetation, the scenario becomes more complicated because two phenomena occur simultaneously. On the one hand, transpiration from vegetation increases the soil suction, enhancing the soil cracking; and on the other hand, the roots of plants/grass reinforces the soil against cracking. This investigation can be done based on an ongoing study at the site of the experimental embankment, with site lysimeters (see Figure 8).

Figure 8. Site lysimeters with water content measurements and grass roots monitoring, next to the Bionicle experimental embankment

5. Acknowledgements

The University of Newcastle is greatly acknowledged for the hospitality, and I’m also grateful to the European Commission for the financial support (Cost action TU 1202).

6. References

Stirling R. 2014. Multiphase Modelling of Desiccation Cracking in Compacted soils. PhD thesis of University of Newcastle, UK.