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The effect of compaction conditions on the soil water retention behaviour of a compacted glacial till

Effet des conditions de compactage sur le comportement de rétention d'eau d'un till compacté

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ABSTRACT: An instrumented embankment has been established at Nafferton farm in North East England to investigate the response of an embankment to changing climatic conditions. The embankment was constructed using Durham Lower Glacial Till as the fill material. Soil water retention curves for the embankment soil have been measured in the laboratory using novel high suction tensiometer based equipment that can continuously measure water content, suction and volume change. A suite of soil water retention curves have been measured with a range of techniques, using filter paper, chilled-mirror hygrometer and including the new Durham SWRC apparatus. Good agreement can be seen from the different methods, defining a consistent "primary drying curve". The paper presents results for specimens compacted wet of optimum water content (gravimetric water content near 25%) and at the water content used for field compaction (gravimetric water content of 20%). Specimens compacted near saturation define a clear primary drying curve. Specimens compacted at the field water content show a flatter response, joining the primary drying curve as suction increases.

RÉSUMÉ: Une digue instrumentée a été établie à la ferme de Nafferton, dans le nord-est de l'Angleterre, pour étudier la réponse d'un remblai à des conditions climatiques changeantes. Le remblai a été construit en utilisant du till glacier inférieur de Durham comme matériau de remblai. Les courbes de rétention d'eau du sol de remblai ont été mesurées en laboratoire à l'aide d'un nouvel équipement à tensiomètre à forte aspiration, capable de mesurer en continu la teneur en eau, l'aspiration et les variations de volume. Une série de courbes de rétention d'eau du sol ont été mesurées à l'aide de diverses techniques, à l'aide de papier filtre, d'hygromètre à miroir refroidi et du nouvel appareil Durham SWRC. Les différentes méthodes permettent d'obtenir un bon accord, en définissant une «courbe de séchage primaire» cohérente. Le document présente les résultats obtenus avec des échantillons compactés humides de teneur en eau optimale (teneur en eau gravimétrique proche de 25%) et de la teneur en eau utilisée pour le compactage au champ (teneur en eau gravimétrique de 20%). Les échantillons compactés près de la saturation définissent une courbe de séchage primaire claire. Les échantillons compactés à la teneur en eau du champ montrent une réponse plus plate, rejoignant la courbe de séchage primaire à mesure que la succion augmente.

Keywords: Water retention; unsaturated soil; suction; embankment; glacial till

1 INTRODUCTION

The water retention behaviour of soils is an essential aspect of understanding the unsaturated behaviour of soil materials (Fredlund, 2002). It represents the relationship between suction and water content (which can be gravimetric or volumetric) or may be represented in terms of degree of saturation.

A typical water retention curve (in terms of volumetric water content) is shown in Figure 1. If the soil starts from a saturated state (at the saturated water content, θ_s) and is then subject to drying, it will follow the *Primary Drying Curve* (Figure 1). On wetting back from an oven dried state, the soil will follow the *Primary Wetting Curve*. There can be considerable hysteresis between these drying and wetting curves. The primary drying and wetting curves define an envelope of possible states within which the soil can exist. If the direction of drying or wetting is reversed, then intermediate paths called “scanning” curves will be followed.

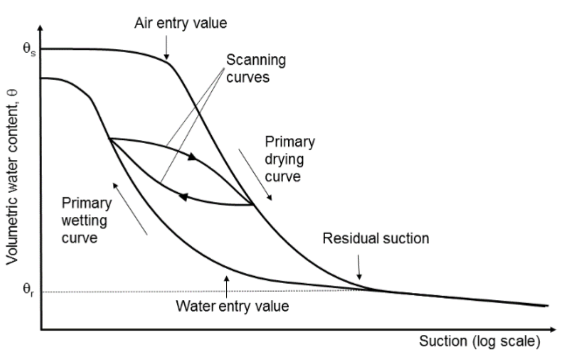

Figure 1. Typical Soil Water Retention Curve (after Toll, 2012)

This paper reports results for the water retention behaviour of a compacted glacial till obtained using a relatively new method of measurement for soil water retention curves, using high capacity tensiometers.

The results reported were obtained to support an investigation of the impacts of climate on long linear assests, such as embankments for transportation infrastructure. The project ACHILLES (Assessment, costing and enhancement of long-life, long linear assets: https://research.ncl.ac.uk/achilles/) has been established as a collaboration between six UK academic partners (Universities of Newcastle, Durham, Loughborough, Southampton, Bath and Leeds), the British Geological Survey and 11 asset owners and industrial partners to investigate the impacts of weather and climate on long linear assets.

The soil used in this study was a glacial till (Durham Lower Glacial Till) obtained from fill material used in the construction of an experimental embankment (called the BIONICS embankment) constructed at Nafferton Farm in North East England (Hughes et al., 2009). The fill material is a common fill material in North East England and hence representative of earthwork construction in the north of the UK.

2 MATERIAL TESTED

The glacial till material is a sandy clay soil. It was prepared by sieving through either a 2.0mm or a 2.8mm sieve to remove the larger particles to reduce the variation in properties. The sieved material comprised 30% sand, 35% silt and 35% clay. The Liquid Limit was 43.3% and the Plastic Limit was 23.7%, resulting in a Plasticity Index of 19.6 (Mendes, 2011). The particle density was 2.66 Mg/m^3.

Specimens for testing were prepared by compaction into a 100mm diameter mould using the equivalent compactive effort of the standard Proctor test (BS light compaction, BS1377, 1990). Smaller specimens having a diameter of 75mm and a thickness of 20mm were trimmed from the 100mm diameter compacted samples for testing in the water retention equipment. Samples were compacted at around a water content of 20%. This is representative of the water content used in the field during the compaction of the embankment (Hughes et al., 2009). In fact, water contents for testing for water retention varied between 14.6% and 22.0%. The dry densities and degrees of saturation of the 7 samples tested are reported in Table 1.

Table 1. Initial conditions for samples

Sample	**Water content (%)**	**Dry density (Mg/m^3)**	**Degree of saturation (%)**
1	14.6	1.758	76.5
2	19.4	1.725	97.7
3	18.1	1.719	88.7
4	22.0	1.655	97.5
5	21.1	1.685	99.2
6	21.0	1.627	90.1
7	20.9	1.616	87.1

The results for these 7 samples will be compared with a suite of tests reported by Toll et al. (2015) that were used to define the primary drying line for samples compacted wet of optimum at a water content of around 25%. These specimens were all prepared to be close to saturation (degree of saturation, Sr>95%).

3 THE DURHAM SWRC EQUIPMENT

Measurements of the soil water retention curves (SWRC) were carried out using the Durham water retention equipment. The experimental apparatus allows continuous measurements of water content, suction and volume change (Toll et al., 2015). The apparatus is made up of a lightweight frame (Figure 2) placed on an electronic balance to determine the change in sample weight and hence water content (as used by Lourenço et al., 2007; 2011).

Figure 3 shows a sample installed in the Durham SWRC apparatus. The sample is surrounded by a cowl that can be opened/closed to control the rate of drying of the sample.

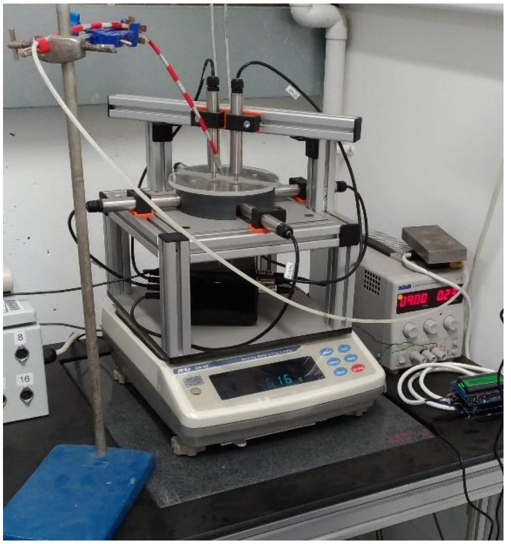

Figure 2. The Durham water retention equipment

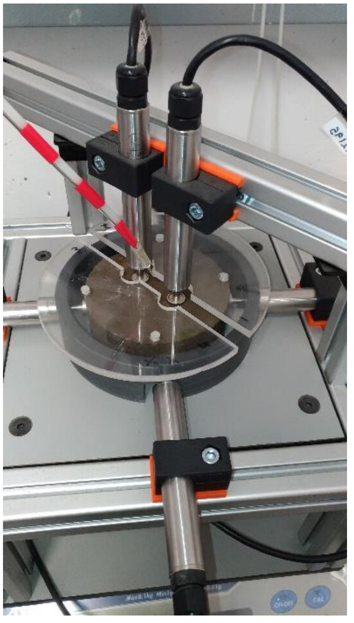

Figure 3. A sample installed in the Durham water retention equipment

For volume change measurements, four displacement transducers were installed through the four outside beams of the frame to measure radial displacement of the specimen and two more displacement transducers were fitted through the upper beam to measure axial displacement (change in height) (Figure 3).

Volume change of the specimen could then be calculated from the radial and axial deformations.

A high suction tensiometer developed at Durham University (Lourenço et al., 2006; Toll et al., 2013) was used to measure suction. These devices have been used for direct measurement of suction as large as 2000kPa. The tensiometer was fitted through a hole in the support plate, with a tight fitting rubber O-ring to secure it in place. The transducers were connected to a wireless datalogger (to eliminate the effect of cable stiffness on the measurement of mass as observed by Lourenço, 2008) and linked to a real-time data acquisition system (Toll, 1999).

Using the tensiometer technique, suction can be measured in samples either dried continuously while exposed to the atmosphere (continuous procedure) or by drying in stages (stage procedure). In the stage procedure, the specimen is sealed and allowed to equalise internally after each period of drying. Both approaches are quicker than traditional methods for obtaining SWRCs, taking around 2 days to establish a drying curve as opposed to weeks that can be necessary for pressure plate tests.

4 TEST RESULTS

Figure 4 shows a selection of results reported by Toll et al. (2015) for samples compacted at a water content of around 25% (>95% degree of saturation). Results are reported for the Durham SWRC apparatus, using both continuous and stage drying. These are compared with results from filter paper measurements (Noguchi et al., 2012) and using a chilled mirror hygrometer (WP4C device) reported by Stirling & Hen-Jones (2015). Good agreement is seen between the different types of measurement, defining a clear primary drying curve for the soil.

The results for the 7 samples reported here are shown in Figure 5. It can be seen that the samples compacted around 20% show a consistent pattern

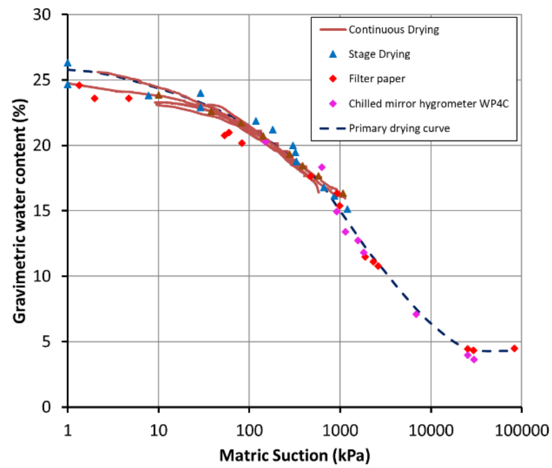

Figure 4. Primary drying from a gravimetric water content around 25%

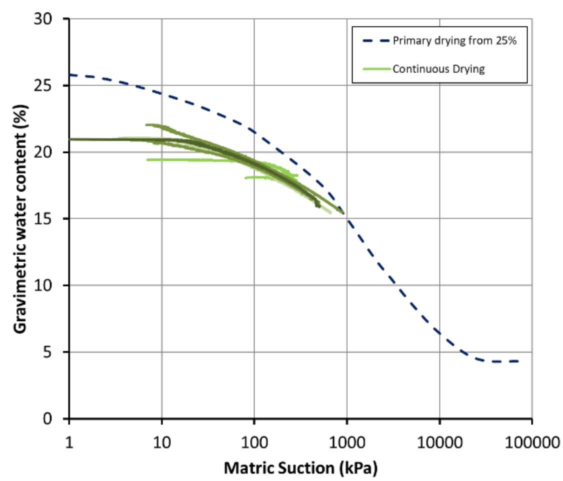

Figure 5. Continuous drying from gravimetric water contents around 20%

with a flatter response (less water content change) compared to the specimens starting from around 25% water content. The two samples at the lowest water contents (Sample 1 at 14.6% and Sample 3 at 18%) move across to join the paths followed by the wetter specimens as suctions increase. All of the curves move toward the primary drying curve as suction increases.

This demonstrates the importance of testing materials at the appropriate starting water content to establish an appropriate water retention curve that is representative of the initial conditions. It is interesting to observe that the results seem to be less sensitive to variations in the initial density.

5 CONCLUSIONS

A suite of soil water retention curves have been measured with a range of techniques, using filter paper, chilled-mirror hygrometer and including the new Durham SWRC apparatus. Good agreement can be seen from the different methods, defining a consistent "primary drying curve". The paper presents results for specimens compacted wet of optimum water content (gravimetric water content near 25%) and at the water content used for compaction in the field (gravimetric water content near 20%). Specimens compacted at around 25% define a clear primary drying curve. Specimens compacted near the field water content of around 20% show a flatter response, joining the primary drying curve as suction increases.

6 ACKNOWLEDGEMENTS

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