Influence of initial water content on the water retention behaviour of a sandy clay soil

Influence de la teneur en eau initiale sur le comportement de rétention d'eau d'une argile sableuse

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ABSTRACT: In order to model the impact of climate changes on the infrastructure for the built environment, such as embankments and cuttings, an understanding of the water retention behaviour is required. To this end, a series of filter paper tests were carried out on remoulded samples of a sandy clay material of medium plasticity. The soil samples were prepared with different initial water contents and dynamically compacted. Filter paper tests were performed to determine the soil water retention curve (SWRC) from a saturated state. Other subsamples were wetted or dried to reach different water contents for testing. The obtained results were then compared with the SWRC. The drying tests showed typical behaviour of scanning curves, however the wetting curves showed untypical behaviour, where the curves appeared to overlap each other with no clear pattern. The observed behaviour from laboratory samples can be extrapolated to field conditions, where future climate change will have a major impact on the water retention behaviour on earth structures, which will have implications for the geo-mechanical behaviour.

RÉSUMÉ : L'impact du changement climatique sur les constructions géotechniques, comme les remblais/déblais, doit être appréhendé. Dans cette optique, une série d'essais par la méthode du papier filtre a été réalisée sur des échantillons reconstitués d'une argile sableuse à plasticité moyenne, afin d'analyser les conséquences sur la courbe de rétention d'eau du sol. Le matériau a été préparé avec des teneurs en eau initiales différentes afin d'obtenir des échantillons par compactage dynamique. Ces échantillons ont été utilisés soit directement pour effectuer la méthode du papier filtre, soit leur teneur en eau a été modifiée après compactage. Les résultats obtenus ont alors été comparés avec la courbe de rétention d'eau. Les tests en séchage montrent un comportement classique sur les courbes de transitions, alors que ceux en humidification montrent un comportement atypique puisque les courbes se croisent sans donner une tendance claire. A partir des résultats expérimentaux, une extrapolation peut être réalisée concernant le comportement des ouvrages géotechniques, où les changements climatiques futurs auront des répercussions sur le comportement hydromécanique du sol.

KEYWORDS: Filter paper, SWRC, Scanning curves

1 INTRODUCTION.

Earth structures (i.e. road embankments, railway embankments, earth dams and flood defences) can fail when pore water pressures increase significantly (and soil suction drops) following intense rainfall or flooding. With predicted changes in climate patterns, such failures are likely to become more frequent with significant economic implications. The 4th Assessment Report of IPCC (IPCC, 2007) states: "Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century". The increased global warming will affect climate patterns, with longer and drier summers followed by wetter winters with more intense storms predicted for UK and northern Europe. To model the impact of these changes in climate on earth structures requires an understanding of the water retention behaviour.

The water retention behaviour can be characterized by determining the soil water retention curve (SWRC) for a specific soil. A SWRC is defined from the relationship between water content and suction. The water content can be expressed either as gravimetric water content, w, volumetric water content, θ or even degree of saturation, S_r. A SWRC is typically S-shaped and is hysteretic (Figure 1), meaning that for a given water content, higher suctions can be obtained when following a drying path than following a wetting path. In some cases a soil may not follow a continuous path from a totally dried or totally wet state. It is very common to find soils in an intermediate state when the direction of water content change is reversed. These intermediate stages are known as scanning curves. In Figure 1 two kinds of scanning curves are presented as simple examples: an ascending scanning curve where the initial condition was reached while following a drying path and was subsequently wetted and a descending scanning curve where the intermediate stage starts on the wetting path of the SWRC and the material gradually dries until the drying path of the SWRC is reached. In reality any point between the primary wetting and drying paths can exist, but by following wetting or drying the curve will eventually converge with one of the primary paths of the SWRC.

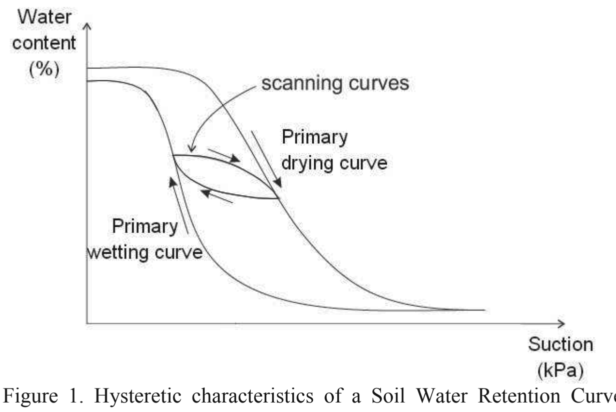


Figure 1. Hysteretic characteristics of a Soil Water Retention Curve (after Lourenço, 2008).

The SWRC is dependent on various physical, chemical, mineralogical and mechanical properties. One factor that influences the SWRC is the initial water content. Many studies have been put forward in recent years on the effect of the initial water content on SWRC, mainly considering SWRCs following drying paths. Vanapalli et al. (1999) observed the influence of compaction in soil samples at different levels (at optimum, wet and dry of optimum water contents). Where, the SWRC following a drying path was determined for samples dry of optimum, it was found to be steeper than the SWRC at optimum or wet of optimum. The attributed reason was that the samples tested dry of optimum have a highly aggregated macro structure, thus resembled the behaviour of coarser material. However, the micro structure governs the SWRC wet of optimum (as soils are unlikely to be aggregated in this condition). It has been observed that at high suctions all SWRCs seem to converge to a single curve. Studies have been conducted by Marinho and Chandler (1993), Ng and Pang (2000), Birle et al. (2008), among others, that have shown that the SWRCs are greatly influenced by the initial water content.

In this paper a series of suction measurements using filter paper tests is presented that were carried out on remoulded samples of a sandy clay soil. Soil samples were prepared with different initial water contents (10%, 13%, 15%, 20% and 22%) and dynamically compacted that were then used to perform the filter paper tests. Other samples were wetted or dried to reach the other water contents for testing. The results obtained were then compared with the soil water retention curve (SWRC) for this material drying from a saturated state.

2 MATERIALS AND METHODS

2.1 *Material properties*

The soil material used in this study was glacial till sourced from a stock pile in County Durham, UK. From the particle size distribution shown in Figure 2, the soil material is classified as well graded sandy clay. As for the index properties, the liquid and plastic limits were found to be 43.3% and 23.7% respectively, meaning a plasticity index of 19.6.

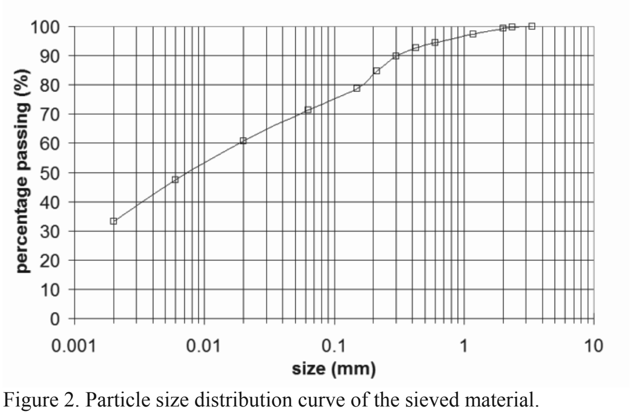


Figure 2. Particle size distribution curve of the sieved material.

Due to the variability in sample preparation, observed in preliminary tests, the soil material was sieved to a maximum particle size of 2.80mm to remove occasional gravel sized particles. The resulting compaction curve is shown in Figure 3, where the optimum water content was found to be 15.5% at a maximum dry density of 1.719Mg/m^3.

2.2 *Sample preparation*

Samples with size 100mm in diameter and 200mm in height were dynamically compacted after preparation at 5 different water contents: 10%, 13%, 15%, 20% and 22%. Subsequently, subsamples were trimmed down to discs with 55mm in diameter and 20mm in height.

For testing purposes, discs with similar water content were later dried or wetted to other water contents (e.g. subsamples at an initial water content of 15% were dried to 10% or 13% and wetted to 20% or 22%). The drying procedure used was air drying, while the wetting procedure was conducted inside an humidifying chamber. In both cases, after the subsamples had reached the target water content, they were sealed off for a period of at least 5 days for water content homogenization. Detailed information on these procedures can be found in Mendes (2011).

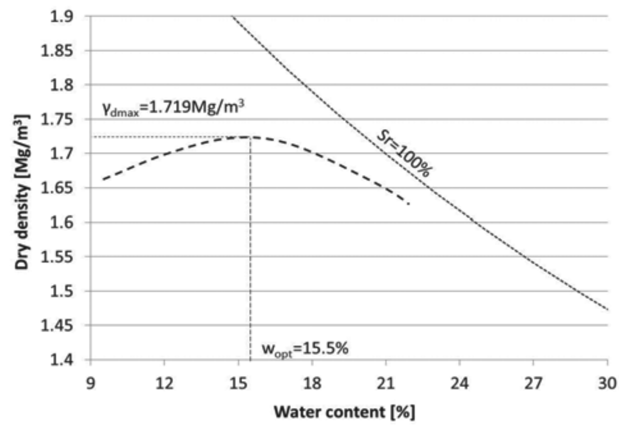


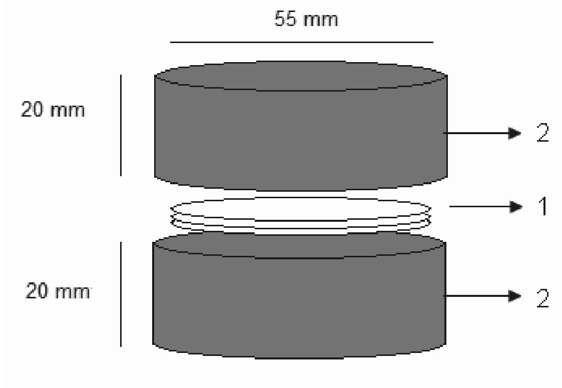
Figure 3. Compaction curve obtained for the sieved material.

2.3 *Filter paper technique*

The filter paper technique was used to determine the soil suction. This technique can measure soil suction either by vapour flow (non-contact filter paper – total suction) or by liquid flow (contact filter paper – matric suction). This measurement is achieved by letting the soil-filter paper system to reach equilibrium. When this equilibrium is reached the measurement of soil suction can be determined. The major advantages of the filter paper technique are the wide measuring range, from 0 up to 30MPa, and low cost. The major drawbacks, however, are the long term equalization period (5 to 14 days) and the quality of the measurement, which is dependent on the experience of the user and also on the calibration curve that relates the water content of the filter paper to suction.

The method for the filter paper technique used in this work was adapted from Bulut et al. (2001) for the measurement of soil matric suction. Three filter papers, in this case Whatman 42, were placed in intimate contact between two sample discs of similar water content, as shown in Figure 4. The outermost filter papers were used to prevent contamination from soil particles and the middle filter paper was used for the measurement. The whole setup, filter papers and disc samples, was sealed with electrical tape to prevent contact between the filter papers and air and placed inside a glass jar. The jar was later wrapped in plastic film, coated in paraffin wax and submerged in a water bath at 25^{o}C for an equalization period of 14 days. After the equalization period, both sample discs and filter paper were quickly removed from the glass jar in order to determine the filter papers' wet mass to a level of accuracy of 0.0001g. These were later oven dried for determination of the water content. The water content of the filter paper was then used to determine the corresponding suction, by means of a calibration curve, associated with the known water content of the sample discs.

Based on the work of Noguchi et al. (2011) it was found that the calibration curve that gave a best match for this particular soil was that obtained by van Genuchten (1980) in the form of equation (1).



Legend:
1 – contact filter paper;
2 – soil sample disc.

Figure 4. Schematic of the filter paper technique (adapted from Bulut et al., 2001).

$$\Psi = 0.051\left[\left(\frac{248}{w_f}\right)^{9.615} - 1\right]^{0.473} \qquad (1)$$

where Ψ = soil suction (kPa)
w_f= filter paper water content (%).

3 RESULTS AND DISCUSSION

The suction measurements obtained for the different water contents, along with the soil water retention curve (SWRC) following the primary drying path obtained by Noguchi et al. (2011), are presented in Figures 5 to 8. The primary drying SWRC obtained by Noguchi et al. (2011) was obtained from samples prepared initially at 25% of water content, close to a fully saturated state. As shown in Figures 6 or 8, the primary drying SWRC has the typical shape of a bimodal function.

3.1 *SWRCs following drying paths*

Figure 5 shows the best fit curves obtained for the SWRCs at different initial water contents following drying paths. It is clear from Figure 5 that the obtained curves are initially lower than the primary drying curve obtained by Noguchi et al. (2011) for a specimen prepared at 25% water content. However, later, at around 10-11% of water content, or 1500-2000 kPa of suction, it can be observed that the curves converge to the primary drying SWRC. This suggests that the SWRC of soils compacted at lower water contents follow drying paths that are very like the behaviour of scanning curves.

Figure 6 shows the matric suction SWRC following drying paths in terms of the degree of saturation. Due to changes in methodology, volumetric measurements were only obtained in tests for initial water contents of 20% and 22%. Comparing them with the primary drying curve obtained by Noguchi (2011) the two curves 20% and 22% initially fall under, but later converge with the primary curve.

These results show many of the features identified in the conceptual model for drying proposed by Toll (1995). As suggested by Vanapalli et al. (1999), there is a higher resistance to desaturation (flattening of the SWRC) with decreasing initial water content.

3.2 *SWRCs following wetting paths*

The behaviour of the SWRCs obtained following wetting paths, however, shown untypical behaviour. As is observed from Figure 7 the SWRCs that followed a wetting path moved

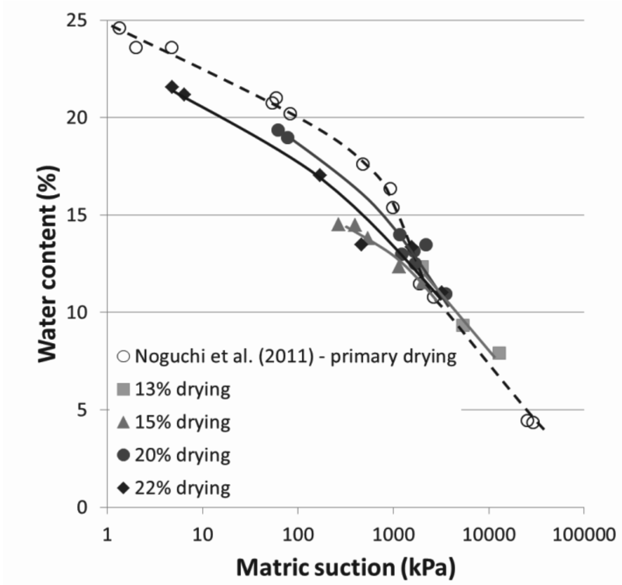


Figure 5. SWRCs following a drying path for all water contents.

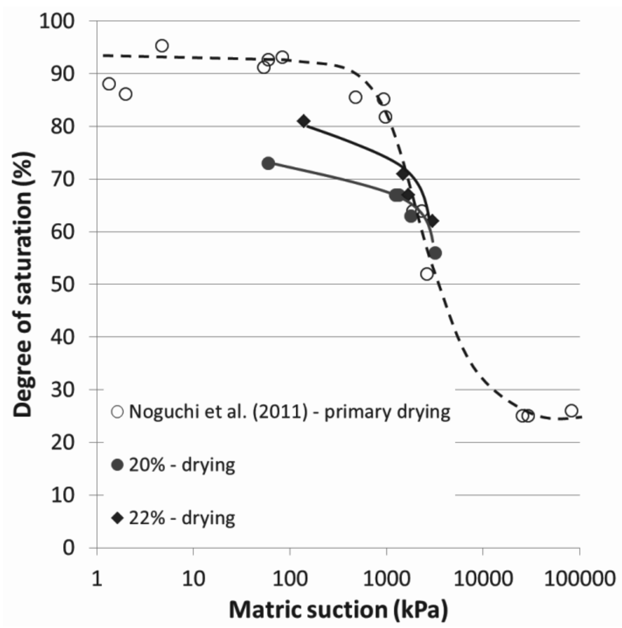


Figure 6. Suction-degree of saturation relationship for all SWRCs following drying paths.

towards the primary drying curve, rather than towards the primary wetting curve. Although the primary wetting curve was not determined, the impression is that the behaviour of the wetting SWRCs seems different to that expected. The SWRCs seem to cross the primary drying curve in an ascending form, where the SWRC obtained from 10% of water content was the first to cross at 300 kPa of suction followed by the SWRC for the water content of 13%, 15% and so on.

Similar results were observed in the matric suction – degree of saturation relationships for the SWRCs show in Figure 8. The lack of tests where volumetric measurements were obtained was not sufficient to fully understand the behaviour of the SWRCs that followed a wetting path. However, a general trend of the SWRCs was observed in Figure 8 where the SWRCs overlapped each other. However, it has to be remembered that samples compacted at lower water contents will have different soil fabrics. It seems this is more significant in affecting the wetting behaviour than the drying.

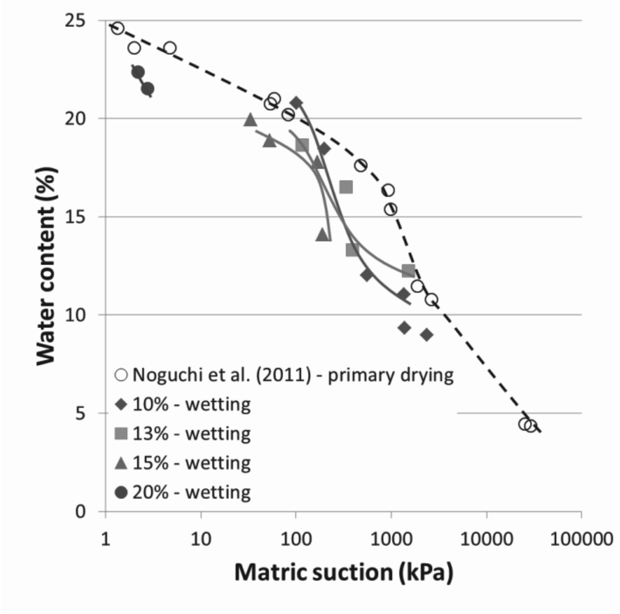


Figure 7. SWRCs following a wetting path for all water contents.

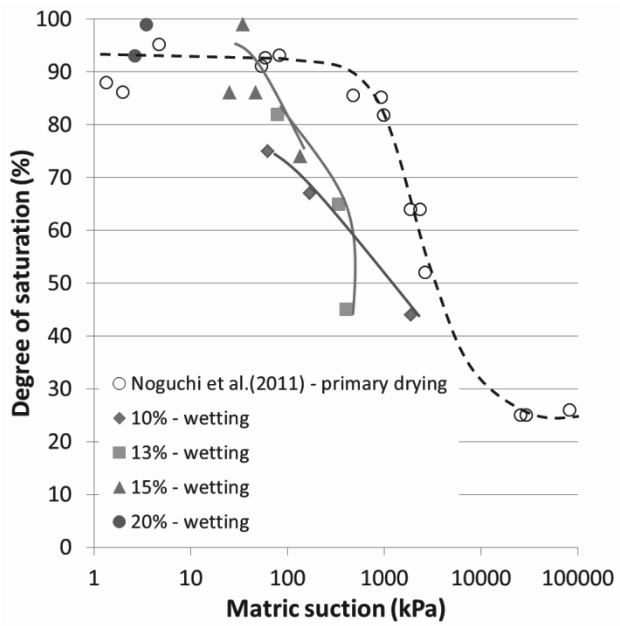


Figure 8. Suction-degree of saturation relationship for all SWRCs following wetting paths.

3.3 *Impact of climate change on the water retention behaviour in earth structures*

Climate change predictions suggest that the UK and parts of northern Europe will experience wetter winters with more intense rain storms and drier summers with longer drying periods (Toll et al., 2012).

In terms of water retention behaviour in earth structures, during extended dry periods suction is likely to reach higher values, possibly to values greater than currently observed. Moreover, there is also the possibility that higher values of suction may extend to greater depths than before. However, during winter months it is likely that suction will decrease rapidly due to more intense storms. As higher fluctuations in suction between seasons should be expected, this can lead to a decrease in serviceability of earth structures.

4 CONCLUSIONS

A study is presented of the influence of the initial water content on the water retention behaviour of a sandy clay soil. Using the filter paper technique, soil water retention curves (SWRCs) were obtained for samples with different initial water contents (10%, 13%, 15%, 20% and 22%). SWRCs following drying and wetting paths were obtained for the different initial water contents and compared with the primary drying curve for a sample prepared at a water content wet of optimum.

It was found that the drying curves tended to merge around 11% (equivalent to a suction of 1500-2000kPa) converging to the primary drying curve. However, the SWRCs that followed wetting paths showed atypical behaviour tending to intercept the primary drying curve at high water contents / low values of suction. This was also shown by the matric suction – degree of saturation relationship with the SWRCs intercepting the primary drying curve. This might lead to the view that the paths followed by the SWRCs were different to what might be expected. However, this behaviour can be explained by the difference in fabric of samples prepared dry of optimum water content.

5 ACKNOWLEDGEMENTS

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