The water retention characteristics of road pavement material stabilised with hydrophobic additives

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ABSTRACT

The water retention characteristics of soils (also referred to as soil water characteristic curves, or SWCCs) have been studied by a number of investigators over quite a long period. Despite this, very little research has been performed investigating such characteristics of stabilised road pavement materials.

This paper is related to the effect of adding a dry powdered polymer to a water-sensitive geomaterial on the water retention characteristic curve of the mixture. Dry powdered polymers are a new type of binder with the specific property of increasing the water repellency of the geomaterial. It is reported that this property results in much less water being retained in the soil at lower pressures and an increased difficulty in wetting the soil. A sandy geologic deposit considered as a marginal material for pavement construction is stabilised with a commercial hydrophobic binder called H2Off. Water retention characteristics applicable to this material mixed with the recommended amount of the binder are presented. The results are discussed in the general theoretical context of unsaturated water flow.

1 INTRODUCTION

Moisture causes a vast range of problems in road pavements, especially those constructed with what are known as marginal (especially water-sensitive) soils. As more and more roads are constructed, these marginal materials will need to be used in road construction. These soils will therefore need to be modified somehow. One of the methods for modifying soil is to mix it with an additive in field so that they will feature satisfactory behaviour.

The additive under investigation in this paper is known as H_2Off, a hydrophobic dry powdered polymer (DPP) manufactured by Blue Circle Southern Cement. This additive has already been shown to slow the wetting of initially dry soil samples (McDowell 2005; Wightwick et al 2006). This paper investigates the effect of the DPP on the drying behaviour of a sandy soil, in particular the water retention curve.

2 THEORETICAL BACKGROUND

The behaviour of certain properties of soils when the soil is not completely saturated can be extremely difficult to determine. For this reason, many soil properties are estimated based upon the value of that property when the soil is completely saturated, and the water retention, or soil water characteristic, curve of the soil. As the name implies, this curve shows the amount of water that will be retained at a certain matric suction within the soil. It is generally observed that this curve will differ from the wetting curve of the same soil, a phenomenon known as hysteresis.

Many attempts have been made over the years to estimate the water retention curve from other, more easily measured, parameters, in particular the particle size distribution. The first of these was proposed by Arya and Paris (1981). Their procedure, of first estimating the pore size distribution, and from this, the water retention curve, has since been followed by many other researchers to estimate the Soil Water Characteristic Curve (SWCC) from the particle size distribution (e.g., Fredlund et al 2002).

One of the properties of soil that has been known to affect the water retention curve is the degree of hydrophobicity (or hydrophilicity), which is also known as water repellency (affinity). This effect has been noted by a number of researchers, including Bauters et al (1998) and Ustohal et al (1998).

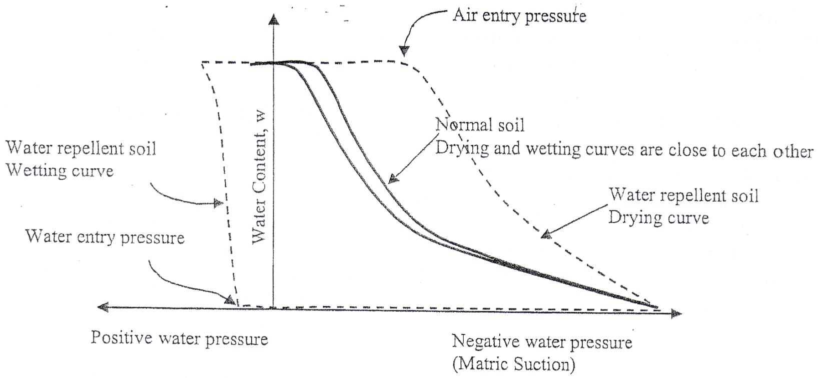


Figure 1: SWCC for water repellent and normal sandy soil (modified after Bauters et al (1998))

As can be seen from Figure 1, Bauters et al (1998) observed that the water retention curve is right-shifted with an increase in the hydrophobicity of the soil. In other words, less water is removed from a hydrophobic soil than a hydrophilic soil at the same matric suction.

In contrast, Ustohal et al (1998) found that less suction is needed to remove the same portion of water from a hydrophobic soil than from a hydrophobic one. Their results for a hydrophilic quartz sand, hydrophobic Teflon beads, and silanised sand, a material of mixed hydrophobicity are shown in Figure 2.

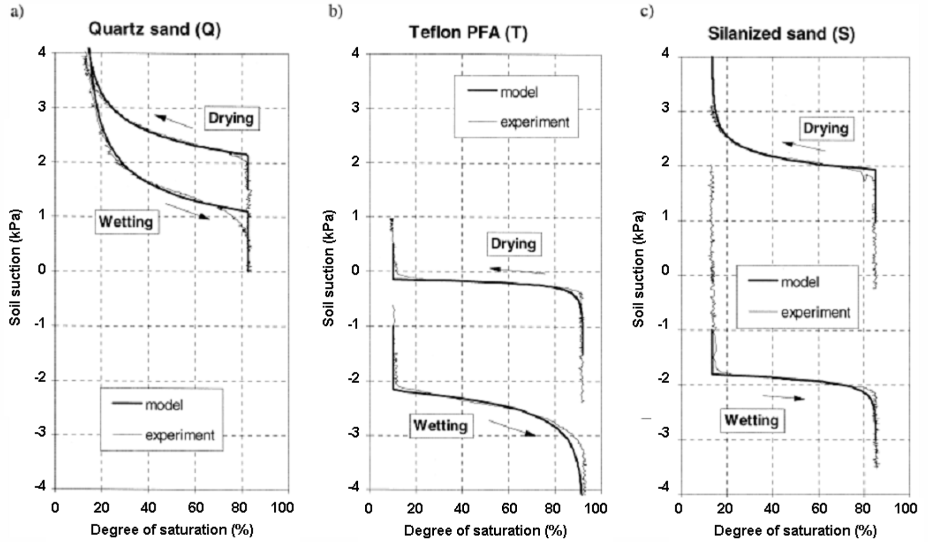


Figure 2: SWCCs for (a) quartz sand (hydrophilic), (b) Teflon grains (hydrophobic), and (c) silanised sand (mixed hydrophobicity) (modified after Ustohal et al (1998))

From Figure 2, it can be seen that the hydrophilic sand has both its wetting and drying curves in the positive suction (i.e., negative pressure) regime, whereas positive pressure is needed to wet the hydrophobic Teflon beads. The silanised sand (sand that has been treated with a polar agent to make it hydrophobic) has very similar (hydrophilic) drying behaviour to the quartz sand, yet displays hydrophobic behaviour when wetting. This behaviour is known as mixed hydrophobicity. The hysteresis between wetting and drying experienced by the silanised sand is much greater than that felt by the quartz sand or the Teflon beads.

A possible explanation for the discrepancy between the results found by Bauters et al (1998) and Ustohal et al (1998) can be found by considering the drying behaviour of soil. In order for soil to dry, the moisture within the soil must escape from the soil matrix. In most experiments, the water is drawn out of the bottom of the soil sample. It is possible that in Bauters et al's experiment, the hydrophobic sites within the soil blocked the flow of water, while such a phenomenon was not observed in Ustohal et al's experiment. Because of this, there may be some situations where the addition of hydrophobe can cause the soil to be more difficult to dry and others where it is easier to dry a soil with increasing hydrophobicity. It appears that this difference in behaviour is a function of the pore size distribution and the corresponding distribution of the hydrophobic sites.

3 MATERIALS AND METHODS

3.1 Source material

The soil under investigation comes from Wanganella Homestead, just north of Deniliquin in New South Wales and was supplied by RTA. The particle size distribution of this soil (hereafter known as "the sand"), is shown in Figure 3.

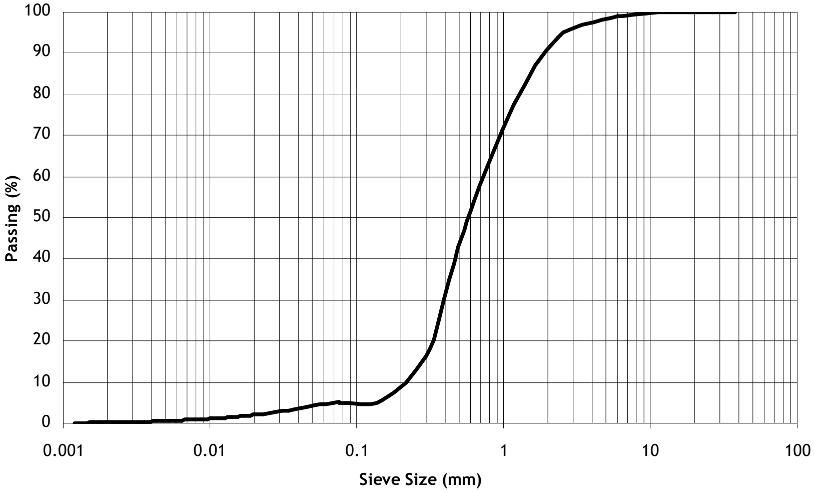


Figure 3: Particle size distribution of the sand

Table 1 shows some of the other properties of the sand. Based upon these properties and the particle size distribution seen above, the sand can be classified as a Poorly-Graded Sand using the USCS.

Table 1: Properties of the sand

Cone liquid limit	21%
Plastic limit	9%
Linear shrinkage	3%
Plasticity index	12%
Specific gravity	2.62
OMC	10.7%
MDD (kg/m^3)	1810
USCS Classification	SP
CBR (unsoaked)	25%
CBR (soaked)	25%

It has been observed (Wightwick et al. 2006) that adding H_2Off to the sand results in a decrease in the optimum moisture content (OMC) to 10.1% at a maximum dry density (MDD) of 1820kg/m^3. It should therefore be expected that the modified soil will have less suction at its OMC.

3.2 Dry powdered polymer

The hydrophobicity of the sand was increased by mixing with a Dry Powdered Polymer (DPP) manufactured by Blue Circle Southern Cement under the product name H_2Off. The DPP was designed to increase the water resistance of water-sensitive soils for use in road pavements (McDowell 2005). Table 2 lists a few properties of the DPP (Blue Circle Southern Cement 2005).

Table 2: Properties of the hydrophobic additive

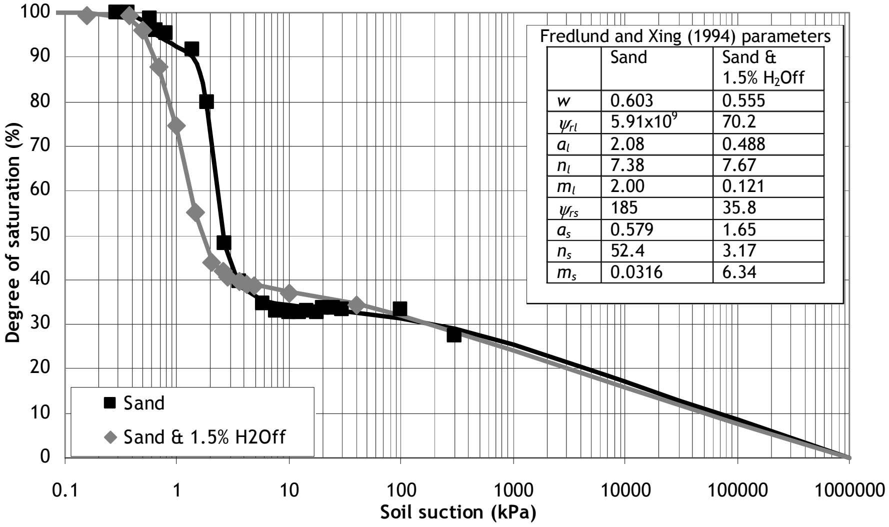
Appearance	Light tan to grey powder
Odour	Slight
Specific gravity	2.8 – 3.0

3.3 Water retention characteristic curve experimental setup

The soil water characteristic curves were determined for the original sand and for the sand mixed with 1.5% additive by weight. This is the recommended dose rate for suitable soils (McDowell 2005). The samples were tested in a Tempe cell, although with a slight modification to the standard experimental setup as found in, for example, Fredlund and Rahardjo (1993). Because small suctions were needed, it was decided that it was necessary to use the head difference between the top of the sample and the connector on the outlet flask to produce suction within the samples. Therefore, the flask was placed on a moveable platform at certain distances below the Tempe cell, thus emulating a hanging column apparatus.

4 RESULTS

The water retention curves for the natural sand and the sand containing 1.5% additive by dry weight are shown in Figure 4. The solid lines are the best-fit Fredlund and Xing (1994) approximations.



Fredlund and Xing (1994) parameters

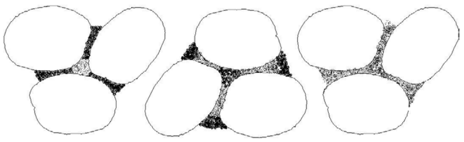
	Sand	Sand & 1.5% H_2Off
w	0.603	0.555
ψ_{rl}	5.91x10^9	70.2
a_l	2.08	0.488
n_l	7.38	7.67
m_l	2.00	0.121
ψ_{rs}	185	35.8
a_s	0.579	1.65
n_s	52.4	3.17
m_s	0.0316	6.34

Figure 4: Water retention curves of the natural sand and sand mixed with 1.5% additive

It can be seen from Figure 4 that the addition of the DPP to the sand results in less suction being needed to remove a set amount of water from the sand than is needed when the sand is in its natural state. This result agrees with the observations of Ustohal et al (1998).

5 DISCUSSION

It is important to consider the distribution of the additive in the soil. Given adequate mixing, it is generally assumed that the additive will be uniformly distributed throughout the soil matrix. This may not necessarily be the case. Since the particles of the additive are a lot smaller than the bulk of the soil, unless the additive has some sort of mechanism to bind itself to the surface of the soil grains, the additive may either be concentrated close to where the grains touch each other (choke points in the coarse-grained skeleton, as in Figure 5(a)) or in the largest pores (where the soil grains are furthest apart from their neighbours, see Figure 5(b)). For the purposes of this paper, it is assumed that the additive is uniformly dispersed throughout the sand, as in Figure 5(c).



(a) (b) (c)

Figure 5: Distribution of a fine material in the pores of a coarse-grained material: (a) and (b) nonuniform distribution; (c) uniform distribution (after Cote and Konrad 2003)

Using the assumption of uniform distribution of additive, Arya and Paris's model (1981) was used to predict the shape of the water retention curves for the sand when found in its natural state and when mixed with various amounts of the additive. It was assumed that the soil is perfectly hydrophilic (i.e. with a contact angle = 0°) and the additive perfectly hydrophobic (contact angle = 180°). The contact angle of the sand/additive mixture was then estimated to be 57° using the famous Cassie equation (1944). The predicted soil water characteristic curves and the experimentally obtained results are shown in Figure 6.

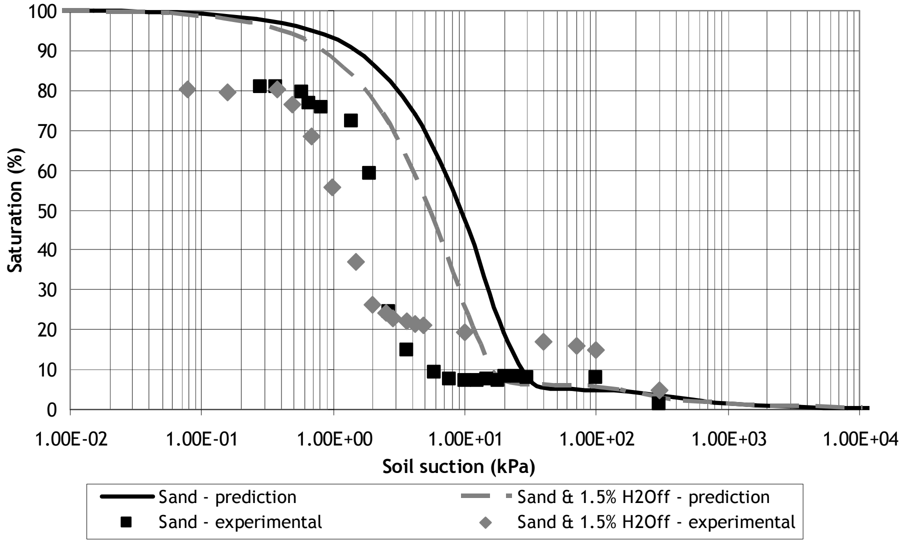


Figure 6: Predicted and experimental water retention curves for the sand in its natural state and containing 1.5% additive

Figure 6 shows a significant difference between the water retention curves predicted using the Arya and Paris model and those obtained from experiment. There are a number of reasons for this. It was observed the bimodal nature of the sand resulted in migration of the fine portion of the soil within the soil matrix. This resulted in washout of the fine fraction when the samples were initially saturated and clogging of the soil near the base of the specimen when water was being drawn out of the soil. It is also likely that the estimated contact angles of 0° for the sand and 180° for the additive were incorrect. It can also be observed that 100% saturation was not obtained in these tests. These issues will be a subject of future study.

CONCLUSIONS

The addition of the DPP to the sand results in the water retention curve of the soil being left-shifted. In other words, the addition of the hydrophobe makes the soil easier to dry. It would be interesting to see the effect of increasing the amount of DPP on the water retention curve. Would doubling the amount of DPP (to 3% dry weight soil) result in a doubling of the ease of drying?

In order to improve the predicted water retention curves, the contact angle of the soil, DPP, and the mixture need to be firmly established. Also, the uniformity of the distribution of the additive within the soil needs to be investigated. Once these things have been established, the water retention curves can then be used to predict the unsaturated behaviour of the soil.

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