Effect of Density in the Water Retention Curve of a Compacted Silt-Bentonite Mixture

Emad Jahangir, Hossein Nowamooz, and Farimah Masrouri

Abstract. In unsaturated swelling-shrinking soils, like clay soils, water content change results in significant volume change and drying is associated with high water content gradients.This work presents initially the soil water retention curve (SWRC) of a bentonite-silt mixture compacted at three different initial dry densities (1.27, 1.35 and 1.55 $Mg.m^{-3}$). The SWRCs were fitted by the van Genuchten (1980) and Brooks and Corey (1964) type functions. The estimated parameters were used to model the SWRC of the intermediate samples.

Keywords: SWRC, swelling soils, initial density, bimodal soil fabric.

1 Introduction

The soil water retention curve (SWRC) is one of the important hydraulic functions for modeling flow transport in porous media. It contains important information regarding the amount of water contained in the pores at a given soil suction and the pore size distribution corresponding to the stress state in the soil (Fredlund et al., 2002). Unsaturated soil parameters such as shear strength, volume change, diffusivity, and adsorption are related to the SWCR (Fredlund & Rahardjo, 1993). Various empirical equations have been suggested to describe the SWRC. Among these equations, the relationships proposed by Brooks & Corey (1964), van Genuchten (1980) and Fredlund & Xing (1994) have been used in geotechnical engineering. Due to

Emad Jahangir
Nancy Université
e-mail: Emad.Jahangir@ensg.inpl-nancy.fr

Hossein Nowamooz
INSA de Strasbourg
e-mail: Hossein.Nowamooz@insa-strasbourg.fr

Fariamh Masrouri
Nancy Université
e-mail: Farimah.Masrouri@ensg.inpl-nancy.fr

difficulties and labor costs when measuring SWRC, it has become necessary to develop methods to describe the function utilizing available data.

This work presents initially the SWRC of a bentonite-silt mixture compacted at three different initial dry densities (1.27, 1.35 and 1.55 $Mg.m^{-3}$). A three-parameter van Genuchten (1980) type function as well as a two-parameter bimodal Brooks and Corey (1964) were fitted to the obtain SWRC for loose and dense samples. The SWRC of the intermediate density samples were then estimated based on these models.

2 Experimental Program

The study was conducted on an artificially prepared mixture of 40% silt and 60% bentonite. The mineralogical composition of the compacted material was determined by X-Ray Diffraction (XRD). The silt contained 60% quartz, 20% montmorillonite, 11% feldspar, and the remaining part was made up of kaolinite and mica. The bentonite was composed of more than 90% of calcium montmorillonite. The main geotechnical properties of the materials and of the mixture are shown in Table 1. The size of the particles used to prepare the samples was less than 400 µm, and these particles were obtained via sieving. The initial dry densities (ρ_{di}) of the compacted soil were about 1.27, 1.35 and 1.55 Mg/m^3, respectively, under three vertical pressures of 1000, 1500 and 3000 kPa and an initial water content (w_i) of 15% in the dry side of optimum. In this paper, these samples are respectively called loose (L), Intermediate (I) and dense (D). The initial matric suction, measured by the contact filter paper method (ASTM 1995), was between 20 and 25 MPa for all compacted samples.

The variation of degree of saturation for all compacted samples was studied during a wide suction cycle ranging between 0 and 289.7 MPa using the osmotic method for suctions below 8.5 MPa (Delage et al. 1998, Cuisinier & Masrouri 2005) and the vapor equilibrium technique for suctions higher than 8.5 MPa (Lide, 2002). A wide range of suction comprised between 0 and 287.9 MPa was applied to the samples producing a wetting path between 20 and 0 MPa and a drying path between 20 and 287.9 MPa. At the end of this phase all the samples dried in the oven were saturated at the same time. Subsequently, a range of suction between 0 and 289.7 MPa was imposed to all saturated samples.

3 Modeling Results

Figures 1 and 2 present the SWRC of loosely and densely compacted samples (1.27 and 1.55 Mg/m^3). The SWRC results were fitted by Brook and Corey and van Gunechten functions generally used in unsaturated geotechnical engineering. The Brooks and Corey equation for the SWRC is written as follows:

$$\begin{cases} Sr = (\frac{\psi_b}{\psi})^{-\lambda} & \psi \geq \psi_b \\ Sr = 100 & \psi \leq \psi_b \end{cases} \tag{1}$$

in which Sr is the degree of saturation; ψ is the suction; λ is a fitting parameter, which represents the slope of the curve in a logarithmic space and ψ_b is the bubbling pressure (or air entry pressure). The relation of van Genuchten is written as follows:

$$S(\psi) = \left[\frac{1}{1+(\alpha\psi^n)} \right]^m \tag{2}$$

ψ is the suction, α, m et n are constant model parameters (Table 1). It can be noted that almost the same air entry value can be obtained in the SWRC (estimated by both models) for loose and dense states on the wetting and drying paths.

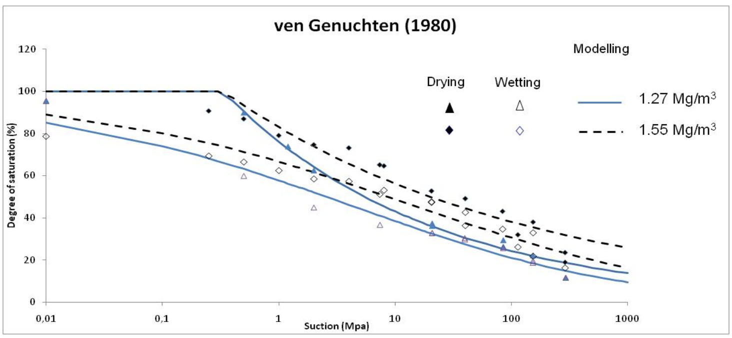

Fig. 1. SWRC for loosely and densely compacted samples estimated by van Gunechten (1980) equation.

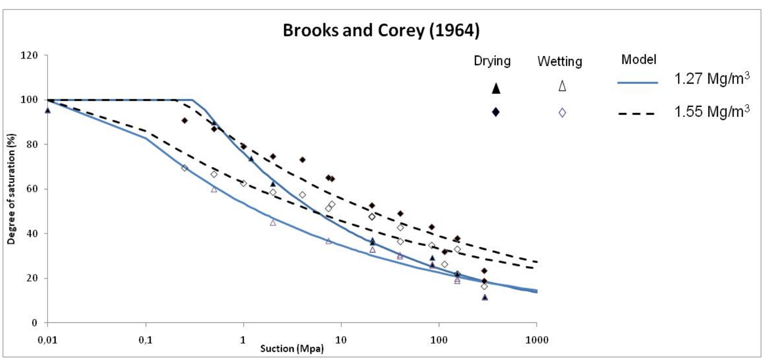

Fig. 2. SWRC for loosely and densely compacted samples estimated by Brooks and Corey equation.

Table 1 summarizes all the parameters of the van Genuchten model. It seems that the parameter n is affected directly by the density. This parameter increases with the increase of density for both wetting and drying paths. The parameter m is affected inversely by the density, so it decreases with the increase of the density. The parameter α remains almost constant in the loose and dense states and consequently the same air-entry value can be obtained from the different curves.

Table 1. Estimated parameters of van Gunechten equation.

van Genuchten model		α (1/MPa)	n	m
Loose state	Wetting path	3	24.19	0.01
	Drying path	0.03	0.29	1.79
Dense state	Wetting path	3	41.10	0.004
	Drying path	0.021	0.295	1.469

Table 2 presents all the parameters of the Brooks and Corey model. The parameter λ decreases with the increase of density for wetting and drying paths. The air entry value (s_e) decreases slightly from loose to dense states for both hydraulic paths.

Table 2. Estimated parameters of Brooks and Corey equation.

Brook and Corey model		λ	s_e (MPa)
Loose state	Wetting path	0.333	0.248
	Drying path	0.037	0.189
Dense state	Wetting path	0.232	0.155
	Drying path	0.034	0.137

Using the fitted parameters of these models at two different initial states, the SWRC of the intermediate sample (1.35 Mg/m^3) during several suction cycles was predicted. To estimate the parameters for the intermediate samples, a linear regression was performed between the loose and dense soils parameters.

The following points can be noted:

- In the van Genuchten model, the parameters n and especially m are affected by the soil initial state.
- In the Brooks and Corey model, the initial dry density increase influences more the parameter λ.
- The whole results showed a good capacity of the models to predict the hydric behaviour of the intermediate samples.

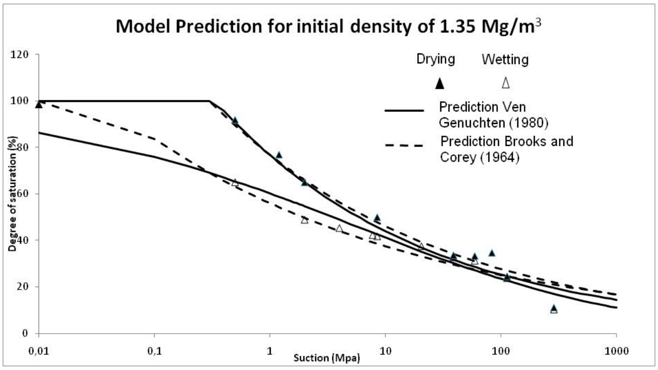

Fig. 3. Model prediction for the intermediate compacted samples based on Brooks and Corey and van Gunechten equations.

4 Conclusion

This work presents initially the SWRC of a bentonite-silt mixture compacted at three different initial dry densities (1.27, 1.35 and 1.55 $Mg.m^{-3}$). A van Genuchten and Brooks and Corey type functions were used to obtain SWRC at the dense and loose initial states. The proposed equations were then used to model the SWRC of the intermediate samples. It can be pointed out that the air entry value is less affected parameter in the both van Genuchten and Brooks and Corey model comparing to the fitted parameters (m, n and λ).

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