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Influence of dry density on the Soil-Water Characteristic Curve of compacted granite residual soils of Taishan section, Guangdong, China

HOSSAIN MD. SAYEM[1*] & LING-WEI KONG[2]

Abstract

The Soil-Water Characteristic Curve (SWCC) is a conceptual and interpretative tool through which the internal mechanisms and the behaviour of unsaturated soils can be understood. On the other hand, one important factor that affects the SWCC is the density. The main objective of this research is to evaluate the influence of dry density on the SWCC for different densities compacted granite residual soils collected from Taishan section, Guangdong, China based on laboratory experiments. In this study, the compacted granite residual soil samples are prepared at four different dry densities using different compaction efforts and the matric suction is measured by 15 bar pressure plate extractors. The results show that with the increasing dry density, the water-holding capacity of the soils decrease because of the overall pore volume reduced and the soil particles are drawn closer together. It also found that the VAN GENUCHTEN (1980) model fitting parameter α, n and m are affected directly by the density and the relationship is linear. The air entry value increases with increasing density and uniform pore size distribution might be formed at higher density. Overall, the experimental results are capable of capturing hydraulic behavior of different densities compacted granite residual soils and might be used for practical purposes.

Keywords: Granite residual soil, dry density, matric suction, SWCC, pressure plate extractors.

Introduction

The soil water characteristic curve (SWCC) defines the relationship between the amount of water in the soil and soil matric suction (FREDLUND & XING 1994). The amount of water can be a gravimetric water content (w), volumetric water content (θ), or degree of saturation (S). The soil matric suction (u_a-u_w) is the difference between the air pressure and pore water pressure. The SWCC is a conceptual and interpretative tool through which the behavior of unsaturated soils can be understood. It reflects the internal mechanisms of unsaturated soils and widely used to predict hydraulic conductivity, soil water storage, compressibility and shear strength of unsaturated soils

Authors' Addresses: HOSSAIN MD. SAYEM[1*] & LING-WEI KONG[2], [1]Department of Geological Sciences, Jahangirnagar University, Dhaka 1342, Bangladesh, [2]State Key Laboratory of Geomechanics and Geotechnical Engineering, Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, Wuhan, Hubei 430071, China. *Email: sayem_geo@yahoo.com*

(FREDLUND & RAHARDJO 1993; HAO *et al*. 2015). The SWCC is not unique for a soil. Numerous researchers mentioned that the general shape of the SWCC is influenced by several factors such as initial moisture content, void ratio, density, grain size distribution, method of compaction, soil fabric and mineralogy, the process and history of drying or wetting paths as well as the stress state (TINJUM *et al*. 1997; ROMERO *et al*. 1999; VANAPALLI *et al*. 1999; NG & PANG 2000; MILLER *et al*. 2002; LU & LIKOS 2004; YANG *et al*. 2004; BIRLE *et al*. 2008; HESHMATI & MOTAHARI 2012; SAYEM & KONG 2016). It is important that, each of these factors makes change of pore structure which leads to the change of SWCC.

One specific factor that significantly affects the SWCC is the dry density of the soil. ASSOULINE (2006) stated that a change of soil density can lead to a significant change of the SWCC, and such a change in soil density is a common feature of natural or compacted soils. In recent times, the study of the effect of density on the hydro-mechanical behavior of unsaturated soils has attracted much attentions (NG & PANG 2000; GALLIPOLI *et al*. 2003; WHEELER *et al*. 2003; SUN *et al*. 2006; MILLER *et al*. 2008; NUTH & LALOUI 2008; GALLAGE & UCHIMURA 2010; SHENG & ZHOU 2011; ZHOU *et al*. 2012; BIRLE 2012; JIANG *et al*. 2017). It is found that the air-entry value of the SWCC increases with the dry density of the soils (YANG *et al*. 2004; MIAO *et al*. 2006; LI *et al*. 2009). LI *et al*. (2009) also found that the slope of the SWCC is more when the density of the sample is smaller. GALLAGE *et al*. (2013) mentioned that with increasing dry density, the average size of the pores in the soil matrix drops and consequently the saturated volumetric water content reduces. However, SUN *et al*. (2007) and BIRLE *et al*. (2008) reported that it is more difficult to identify the impact of initial density on the SWCC expressed in terms of water content. SREEDEEP & SINGH (2005) have stated that the dry density will not affect the soil suction until a certain critical value of dry density has been reached.

SWCC is commonly expressed using best fit equations with several fitting parameters. In literature, a number of mathematical models have been proposed by different researchers to describe the SWCCs. LEONG & RAHARDJO (1997) reviewed all those models and concluded that FREDLUND & XING (1994) and VAN GENUCHTEN (1980) proposed model are most popular and well accepted. However, at matric suction 1000000 kPa, the water content of soil is consider as zero for FREDLUND & XING (1994) proposed model which is not possible for all kind of soils. On the otherhand, VAN GENUTCHEN (1980) proposed model can predict the residual water content more perfectly. So in this research, the VAN GENUCHTEN (1980) model was chosen to obtain the best-fit the SWCCs.

The studied area, Taishan section is located at areas around Jiangmen city in the southwestern region of Pearl River Delta and Guangdong Province, China. Recently, the central government of China attaches great importance to the development of the Guangdong-Hong Kong- Macau Greater Bay Area. Though, Jiangmen city has higher

GDP per capita above the national average, are still considered as 'developing city' far behind Shenzhen and Guangzhou. Therefore, it is expected that huge constructions and development work will be done in near future in the study area.

The study soil is the granite residual soils which are the weathering product of their parent material. The engineering properties and behavior of residual soils vary widely from place to place even within depth depending upon the rock of origin and the local climate during their formation (FOOKES 1990; RAHARDJO *et al*. 2004). These soils are found in many parts of the world and are used extensively in construction, either to build upon, or as construction material of both geotechnical and geo-environmental structures such as embankments, pavements, earth fills and soil barriers. Many geo-engineering problems (such as landslides, subsidences, damage of road and railway tract, building collapse) are also associated with these soils for their partly saturated states (SAYEM *et al*. 2016). Therefore, geotechnical engineers are interested in understanding the hydro-mechanical characteristics of both natural and compacted residual soils for an appropriate assessment of its engineering behavior. The main objective of this study is to evaluate the effects of dry density on SWCC of compacted granite residual soils of Taishan section, Guangdong, China.

Materials and Methods

Basic properties of the soil

The study area is situated at Taishan section (step mileage DK158+732.57), Jiangmen city of Guangdong province which belongs to the southwest part of Pearl River Delta and near the western edge of the Shenzhen-Mao high-speed railway (Fig.

Fig. 1. Location map of the study area.

1). The studied soils are reddish brown in color and known as granite residual soil which are mainly composed of clay minerals and quartz with small amount of pyrite and gibbsite. Among the clay minerals, kaolinite content is around 95% and minor amount of illite also presents.

Table 1. Index properties of the studied granite residual soils.

Gs	Atterberg Limits (%)			Free swell (%)	Grain size distribution (%)			
	W_L	W_P	I_P		Gravel	Sand	Silt	Clay
2.75	57.1	30.7	26.4	12.6	18.1	26.1	24.8	31

The basic engineering properties and grain size distribution of the soil samples are examined in the laboratory that is shown in Table 1 and Fig. 2 respectively. The maximum dry density (ρ_{dmax}) and the optimum moisture content (OMC) of the collected disturbed soils measured by the Standard Proctor Test and are 1.71 g/cm^3 and 19.5% respectively (KONG *et al*. 2017). In this study, the compacted soil samples are prepared at four different dry densities using different compaction efforts which are named as 100% (ρ_d=1.71), 97% (ρ_d=1.66), 92% (ρ_d=1.57), 87% (ρ_d=1.49) at water content of 19.5% and is shown in Fig. 3.

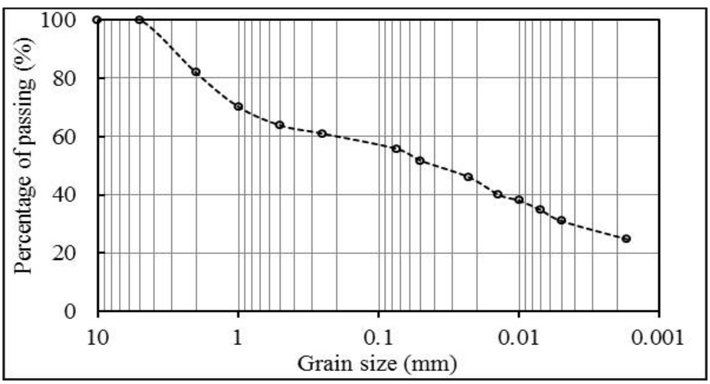

Fig 2. Grain size distribution curve of disturbed granite residual soil.

Experimental procedures

The SWCC up to 1,500 kPa suction was obtained experimentally on saturated samples of 4 different densities using a pressure plate apparatus (1500F1 type) produced by Soil moisture Equipment Corporation of USA (Fig. 4). This apparatus works in the principle of axis translation technique. The samples height and diameter are 20 and 61.8 mm, respectively. A 3-N load is applied on the sample to ensure good contact between the soil samples and the ceramic disk. The airtight chamber of the pressure plate is then pressurized to a desired suction. The high air entry membrane and the porous ceramic stone allow nothing but water to flow through. Experiments are performed based on the reference, ASTM D6836-02 (2002).

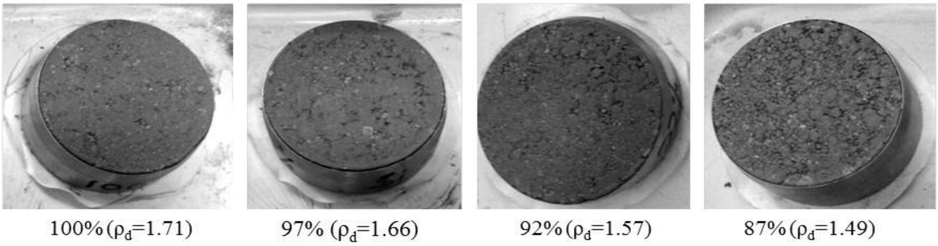

Fig. 3. Compacted granite residual soil samples with different dry densities.

Fig. 4. 15 bar Pressure Plate Extractor.

Total 8 compacted soil samples of 4 different densities (each of 2) are tested and average values are used to obtain the soil-water characteristic curves for this research. The entire SWCC and the corresponding fitting parameters are obtained by using the VAN GENUCHTEN (1980) model with the help of 1st Opt15PRO software developed independently by the 7D-Soft High Technology Inc., Beijing, China. It is an automatically running software package for the analysis of mathematical optimization problem easily and effectively. When an equation with undetermined coefficients is inputted to the program, the software will automatically perform iterative regression until a converged solution is obtained thereby determining the best coefficient values. The important feature is that it no longer needs the end-user to provide or guess the initial start-values for each parameter (LIN 2011; ZHANG *et al.* 2017; WANG *et al.* 2018). The mathematical formula is-

$$\theta = \theta_r + \frac{\theta_s - \theta_r}{\left[1 + (\alpha * \psi)^n\right]^m}$$

where θ is the volumetric water content; θ_r is the residual water content; θ_s is the saturated water content; ψ is the suction pressure (kPa), i.e., ($u_a - u_w$), where u_a is the pore-air pressure and u_w is the pore-water pressure; and α , n, and m are soil parameters.

Results and Discussions

The variations of water content with respect to matric suction of different densities compacted granite residual soil samples of Taishan section, Guangdong, China are shown in Fig. 5. The obtained soil-water characteristic curves in terms of volumetric water content and fitting parameters of SWCCs of those soil samples are shown in Fig. 6 and Table 2 respectively. By viewing the both figures as shown, the relationship between water content or volumetric water content and matric suction is non-linear and the initial dry density of soil samples has a significant effect on SWCC. Though the studied soils have similar mineralogical and fluid composition, the shape of the SWCC varied due to variations of dry density and the curves shift downwards with increasing dry density.

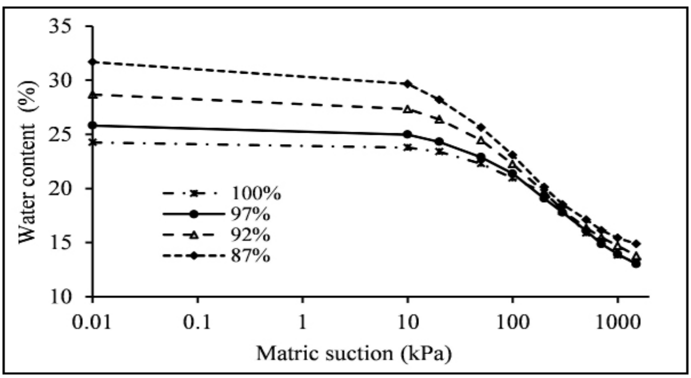

Fig. 5. Variations of water content with matric suction of different densities compacted soils.

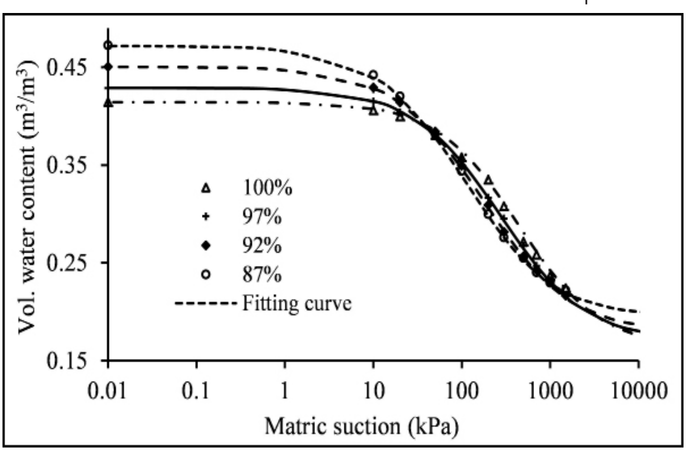

Fig 6. SWCC fitting curves with different densities compacted soils.

Table 2. SWCC parameters of different densities compacted soils.

Sample name	ρ_d (g/cm^3)	SWCC fitting parameters					
		θ_r	θ_s	α	n	m	R^2
100%	1.71	0.1635	0.4144	0.0023	0.8920	1.0558	0.9869
97%	1.66	0.1721	0.4290	0.0031	0.8630	1.1383	0.9958
92%	1.57	0.1810	0.4455	0.0044	0.8262	1.1997	0.9875
87%	1.49	0.1964	0.4720	0.0064	0.8116	1.2518	0.9768

The results show that the initial saturated and residual volumetric water content decreases with increasing dry density and the relationship is linear (Fig. 7). This might be due to that the soil particles are drawn closer together with increasing dry density and then resulted in a decreased void ratio and consequently the water-holding capacity of the soils. VANAPALLI *et al*. (1996) reported that the soil pore volume and permeability reduces with dry density. On the other hand, TINJUM *et al*. (1997) mentioned that the SWCCs of compacted clay soils depend on the compaction water content and compactive effort. If the soil is compacted at the same water content, the pore sizes reduce with a higher compactive effort. Therefore, with increasing dry density, the overall pore volume of the soil reduced, hence the value of θ_s and θ_r also decreased and the result is consistent with VANAPALLI *et al*. (1996) and TINJUM *et al*. (1997) observations.

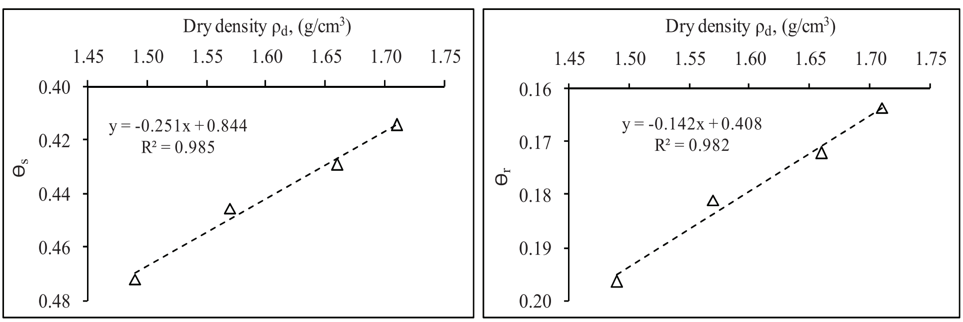

Fig. 7. Relationship between saturated and residual vol. water content with dry density.

It also seems that the VAN GENUCHTEN (1980) model fitting parameter α , n and m are affected directly by the density. The relationship between the VAN GENUCHTEN (1980) model parameters and the dry density of investigated soil can be explained by simple linear function. The value of α and m decreased with increasing dry density but the value of n increased with increasing dry density (Fig. 8). Therefore, the values of α and m exhibit opposite trends whereas the value of n shows positive trend with increasing dry density. The uniform pore size distribution could be formed for the granite residual soil samples compacted at the same initial water content with different densities. The value of α is inversely proportional to the air entry value (AEV) and the obtained results indicate that the AEV increases with dry density. It is likely

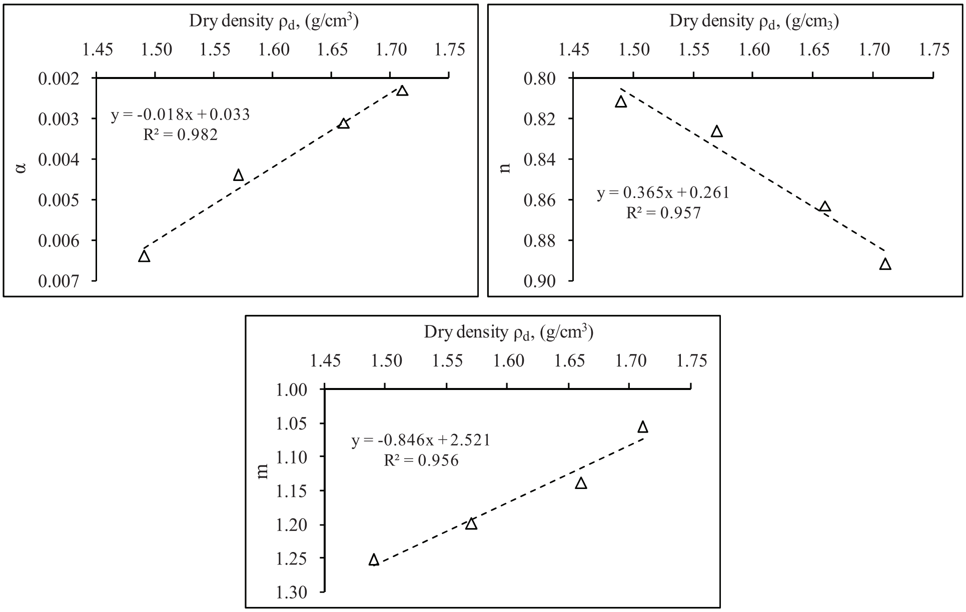

Fig. 8. Relationship between VAN GENUCHTEN (1980) fitting parameters (α , n, m) with dry density.

that the low dry density soil has wider ranges of pore sizes and its connectivity is very well. So, the excretion rate of water in low density soil sample is relatively fast during the process of inlet air and dehydration than that of high density soil. Therefore, with high dry density, the air entry value is higher than that of a low density soils.

Conclusion

This paper is aimed to investigate the influence of dry density on the Soil-Water Characteristic Curve (SWCC) using laboratory experiments for different densities compacted granite residual soils of Taishan section, Guangdong, China. From the test results, it is found that initial dry density of soil samples has a significant effect on SWCC. With increasing dry density, the curves shift to the left and the water retention capacity of the soil reduces i.e. the initial saturated and residual volumetric water content decreases. The VAN GENUCHTEN (1980) SWCC model fitting parameter α , n and m are also varied with dry density and the relationship is linear. The parameter α and m decreased with dry density, and the parameter n increases with increasing dry density. The air entry value (AEV) increases and uniform pore size distribution might be formed at higher density. Finally, the study demonstrated that the dry density is an important factor that influences the hydro-mechanical behavior of the studied soils.

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চীনের গুয়াংডং প্রদেশের তাইশান এলাকার সংগৃহীত কমপ্যাক্টেড গ্রানাইট অবশেষ মৃত্তিকার মৃত্তিকা-জল বৈশিষ্ট্যযুক্ত বক্র রেখার উপর শুষ্ক ঘনত্বের প্রভাব

হুসাইন মোঃ সায়েম ও লিং-ওয়েই কং

সারসংক্ষেপ

মৃত্তিকা-জল বৈশিষ্ট্যযুক্ত বক্ররেখা (এসডব্লিউসিসি) একটি ধারণা মূলক এবং ব্যাখ্যা মূলক মডেল বা মানদন্ড, যার মাধ্যমে মৃত্তিকার অভ্যন্তরীণ প্রক্রিয়াসমূহ এবং অসম্পৃক্ত আচরণ বোঝা যায়। তাছাড়া, মৃত্তিকার একটি গুরুত্বপূর্ণ উপাদান হল ঘনত্ব, যা উক্ত বক্ররেখাকে প্রভাবিত করে। এ গবেষণার মূল লক্ষ্য হলো, ল্যাবরেটরী পরীক্ষার উপরভিত্তি করে চীনের গুয়াংডং প্রদেশের তাইশান এলাকা থেকে সংগৃহীত বিভিন্ন ঘনত্বের কমপ্যাক্টেড গ্রানাইট অবশেষ মৃত্তিকার জন্য এসডব্লিউসিসির উপর শুষ্ক ঘনত্বের প্রভাব মূল্যায়ন করা। এই গবেষণায়, কমপ্যাক্টেড গ্রানাইট অবশেষ মৃত্তিকার নমুনাগুলি বিভিন্ন সংযোগের প্রচেষ্টা ব্যবহার করে চারটি ভিন্ন শুষ্ক ঘনত্বে প্রস্তুত করা হয়েছে এবং ১৫ বার প্রেসার প্লেট নিষ্কর্ষক দ্বারা উক্ত নমুনাগুলির ম্যাট্রিক সাকশন পরিমাপ করা হয়েছে। প্রাপ্ত ফলাফলসমূহে দেখা যায় যে, ক্রমবর্ধমান শুষ্ক ঘনত্বের সাথে সাথে সামগ্রিক ছিদ্রের পরিমাপ হ্রাস পায় ও মৃত্তিকার কণাগুলি একসাথে ঘনিষ্ঠ হয়, যার কারণে মৃত্তিকার পানি ধারণ ক্ষমতা হ্রাস পায়। এতে আরও প্রতীয়মান হয় যে, VAN GENUCHTEN (১৯৮০) মডেল ফিটিং পরামিতি, α, n এবং m ঘনত্ব দ্বারা সরাসরি প্রভাবিত হয় এবং এ পরামিতি সমূহের মধ্যে সরল রৈখিক সম্পর্ক বিদ্যমান। ক্রমবর্ধমান ঘনত্বের সাথে বায়ু প্রবেশের মান (Air Entry Value) বৃদ্ধি পায় এবং অধিক ঘনত্বে অভিন্ন ছিদ্র আকার বুনন গঠিত হয়। সামগ্রিক ভাবে বলা যায় যে, বিভিন্ন ঘনত্বের গ্রানাইট অবশেষ মৃত্তিকার উপর গবেষণামূলক ফলাফলগুলি জলীয় আচরণ ধারণে সক্ষম এবং বাস্তব জীবনে প্রয়োগ করা যেতে পারে।