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Experimental Study of Soil Water Characteristic Curve for a Clayey Soil Reinforced with Model Geocell for Freezing-Thawing Cycles

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Abstract. The category of geosynthetics includes geocells as a common subclass. As a low-cost, easily-installed solution to soil stabilisation problems, geocells are gaining popularity in the field of geotechnical engineering. Assessing and measuring the matric potential of geocell reinforced soil subjected to alternating freezing-thawing cycles depends on understanding the water retention behaviour of the soil. The water retention properties of geocell reinforced soil are influenced by alternate freezing-thawing cycles. For the objective of this study, the thawing soil freezing characteristic curve (SFCC) of a clayey soil with variable numbers of model geocells was determined (0, 1, and 2 number). With the progression of freezing-thawing cycles, which dramatically changed the retention behaviour of reinforcing soil, the matric potential was measured using the filter paper method methodology. The thawing SFCC for reinforced soil with model geocell was assessed using the van Genuchten model. For the studied soil with varied numbers of model geocells, the VG model was evaluated for five consecutive freezing-thawing cycles, demonstrating its efficacy in determining the retention behaviour of geocell reinforced soils. The experimental findings showed that the matric potential in SFCC has considerably enhanced due to the presence of model geocell.

1 Introduction

Geocells are three-dimensional honeycomb polymeric cells that stabilizes soil. According to a literature study by Yuu et al. (2008), geocell reinforcement theories and design approaches are significantly behind field implementations, notably for roadways [6]. The 1970s introduced the concept of cellular lateral confinement. The US Army Corps of Engineers devised this approach to increase bearing capability of poorly-graded sand [14]. Paper saturated in phenolic water-resistant glue was used to make the first geocells. Later, metallic geocells, notably aluminium ones, were considered for strength but proved impracticable due to handling difficulty and high cost. Geocells are formed by joining geogrid sheets with bodkin bars (Carter and Dixon 1995). HDPE is the most common polymer used to manufacture geocells by welding extruded strips to form honeycombs. Geocells vary in material, aspect ratio, height, and thickness. Early research on geocells for weak subgrade base reinforcement focused on reinforcement mechanisms, geocell characteristics and shape, and infill material.

1.1 Soil freezing characteristic curve and soil water characteristic curve

The relationship between unfrozen water content, freezing soil temperature, and water potential is described by the soil freezing characteristic curve (SFCC), which is analogous to the soil water characteristic curve (SWCC) or water retention curve (WRC) for unsaturated soils [3, 8, 13]. Bittelli et al. (2003) were able to test water retention characteristics in the lab quickly because of similarities between the SFCC and SWCC [8]. These curves were limited to thawing operations because supercooling occurrences are common during freezing in laboratory conditions (analogous to wetting processes). Theoretically, it has long been known that the properties of soil and water can influence freezing characteristics [12-13]. Additionally, enough experimental data has demonstrated that the two characteristic curves do in fact closely match one another [3, 8, 9]. Accurate measurements of SWCC remain a challenge, despite even after advances in unsaturated soil mechanics is noted [12]. As a consequence, physics-based or semi-empirical approaches have been added to SWCC calculation methods. These techniques were created to

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aid the relationship between SWCC and other intrinsic soil properties. Maulem (1976) proposed theoretical models based on the idea of a "bundle of capillary cylinder" [16]. Various equations have been proposed to represent SWCC. Commonly used models include the Brooks and Corey, van Genuchten, and Fredlund and Xing equations.
The van Genuchten (1980) [10] model is

$$\theta_w = \theta_r + \frac{(\theta_S - \theta_r)}{\left[1+\left(\frac{\psi}{a}\right)^b\right]^c}$$

where the optimized parameters are θ_r, α, n, and m. Each of these parameters is described by Leong and Rahardjo (1997) [2]. The parameter α is the pivot point of the curve, and its value is directly related to the value of the air entry suction. As α increases, the air entry suction also increases. The parameter n controls the slope of the SWCC about the pivot point, which occurs at a normalized volumetric water content. As n increases, the sloping portion of the curve between ψ_a and the knee (the point of inflection at the lower portion of the curve as it approaches a horizontal position) of the SWCC becomes steeper. The parameter m rotates the sloping portion of the curve. As m increases, the range of the curve between ψ_a and the knee of the SWCC decreases. The stability of the curve-fitting process is improved by equating the parameter m to $1 - n^{-1}$ [11].

1.2 Filter paper method

The only way to calculate total and matric suction is to use filter paper. In this method, the moisture between the contact and/or non-contact filter paper and the soil specimen are brought to the equilibrium condition in a constant temperature environment. Due to direct interaction between the filter paper and the soil, the water in the liquid phase and solutes can freely exchange. The water content of the filter paper is determined after the equilibrium has been established. The soil suction is then measured using the appropriate filter paper calibration curve. Then the determined SWCC appeared to have the requisite water content, as well as a general suction that is very similar to the target suction.
The objective of this research is to understand the water retention behaviour of a clayey soil reinforced with geocell in an unsaturated condition using filter paper method technique for freezing-thawing (FT) cycles. Here, the geocell is sandwiched in between the soil layers and the sand was filled within geocell. Thus, a specimen contains 1 layer of geocell filled with fine sand sandwiched in between 2 layers of unsaturated soil. The suction parameters of all soil specimens after run of successive FT cycles were determined from filter paper water content using calibration equations as per ASTM D5298 [1].

2 Materials and method

2.1 Tested soil

The experimental soil classified as CH soil which is expansive soil was collected from the Jahangirpura area of Surat city, Gujarat, India. The soil had a specific gravity of 2.75. The measured consistency limits of soil according to IS: 2770 (Part III), 1980 are w_L = 63.8%, w_P = 22.5% [5]. The compaction characteristics using standard Proctor test were calculated as 1.59 gm/cc (maximum dry density, MDD) and 16.57% (optimum moisture content, OMC) respectively, as per IS 2720 (Part VII), 1980 [6]. According to the Unified soil classification, the soil is graded as clay with high plasticity (CH) based on its physical properties (UCSC).

2.2 Model geocell

The investigation and attempts are made to demonstrate the potential use of plastic as soil reinforcement for clayey soil in unsaturated condition. In the study, the reinforcement to the soil within the sort of geocell has been innovated, that is created from plastic straws and foam sheet. The purpose of using plastic straw as geocell is because of the constrained in experiment. It is difficult to use the actual geocell (real size) in the experiments performed. Hence small version of geocell using plastic straw was fabricated giving it a base of foam sheet to support the smaller size of geocell.

2.3 Filter paper

For the experimental study, Whatman No. 42 filter paper was used to assess SWCC.

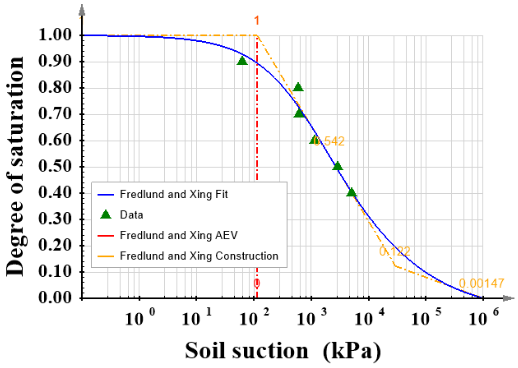
2.4 Sample preparation

For this study, samples were moulded with three different combinations and they have been named relative to the inclusion of geocell layer e.g.,
Sample with 0 number of geocell – GC0
Sample with 1 number of geocell – GC1
Sample with 2 numbers of geocell – GC2
For all soil specimens, a consolidation mould with a 60 mm diameter and 20 mm height was employed. The moulded specimen was then passed through required number of FT cycle at a chilled factor of -24 °C using a chest freezer. A contact filter paper was placed between two soil specimens that had been moulded to a certain degree of saturation subjected to required number of FT cycles (0, 1, 3, and 5). The prepared sample with contact filter
paper was placed in an airtight container and wrapped in duct tape to stop moisture loss. The entire test sample collection was then transferred to a dark space with a constant temperature of 20 °C and no more than 3 °C temperature variations. To allow for an equilibrium period, the water content of the soil specimen in the container was brought into contact with filter paper for a minimum of 7 days. Figure 2 shows the compaction curves for the tested soil.

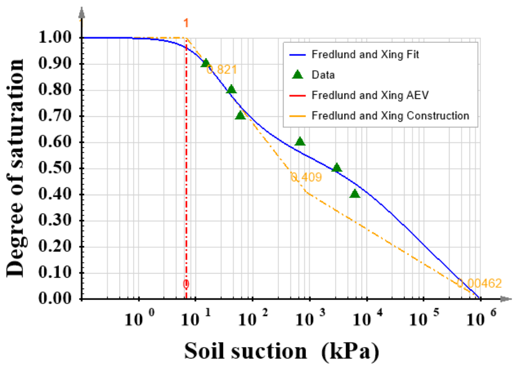
3 Test result and discussion

The calculated contact filter paper water contents were viewed using two calibration curves suggested in the literature ASTM D 5298 [1] using the filter paper method for matric suction calculation to check the effect of geocell reinforcement on soil water characteristic curves.

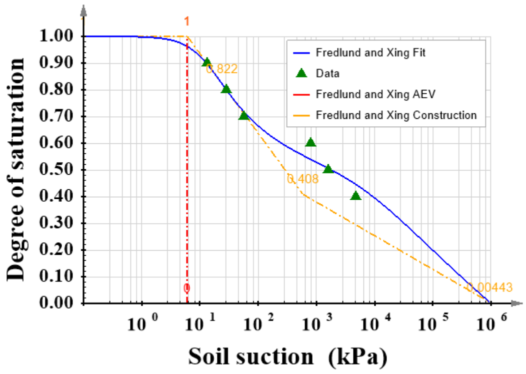
The results showed that the matric suction values based on ASTM D5298 [1] calibration equations are reasonably well located on the SFCCs while using the FPM technique to measure or track suction of the soil specimens with 0, 1, and 2 layers of geocell. Figure 1 to Figure 3 shows the soil freezing characteristic curve of soil sample GC0, GC1, and GC2 assessed using the van Genuchten model. It is seen that the inclusion of geocell affects the calibrated suction values of soil specimen for different degree of saturation; matric suction values increased with increase in number of geocell layer.



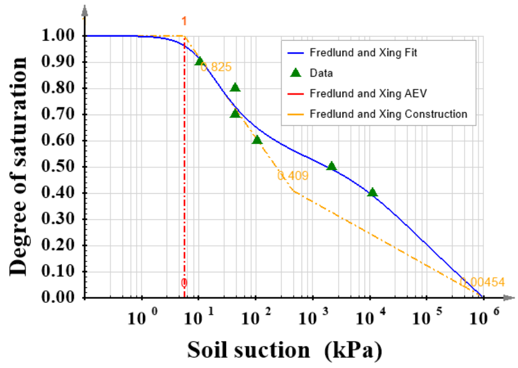
0 FT cycle



1 FT cycle

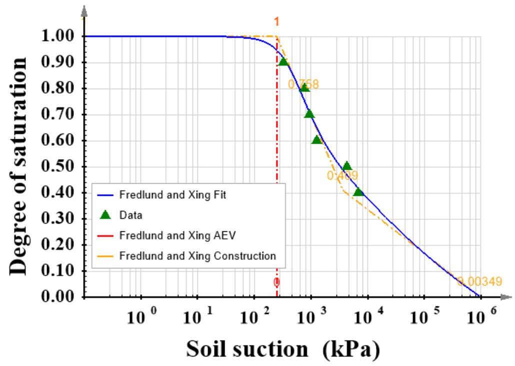


3 FT cycle

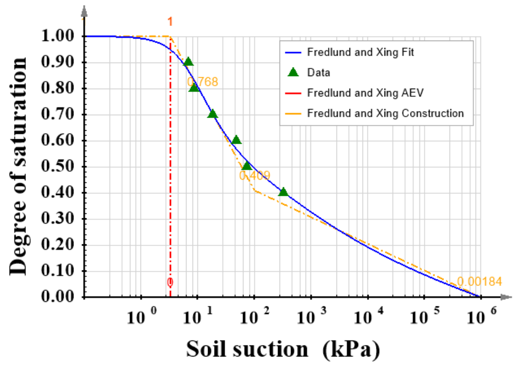


5 FT cycle

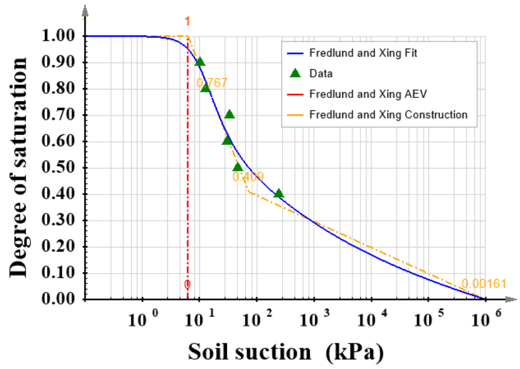
Fig. 1. Soil freezing characteristic curve of soil sample - GC0



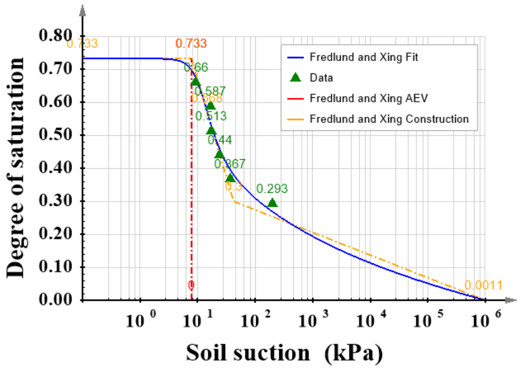
0 FT cycle



1 FT cycle

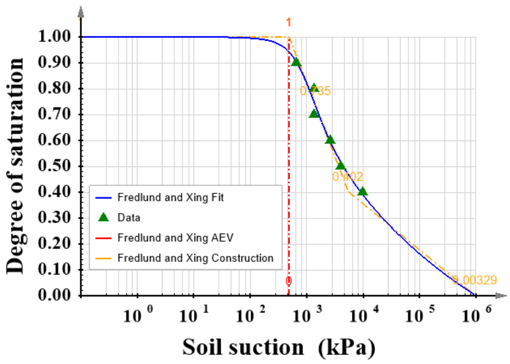


3 FT cycle

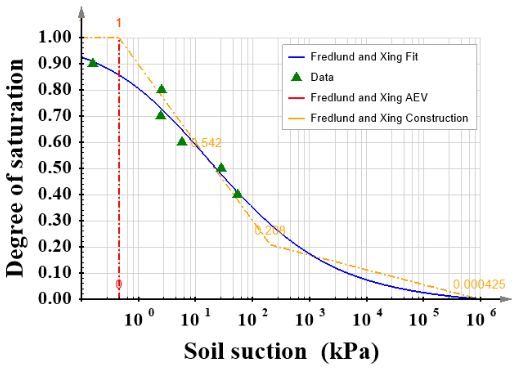


5 FT cycle

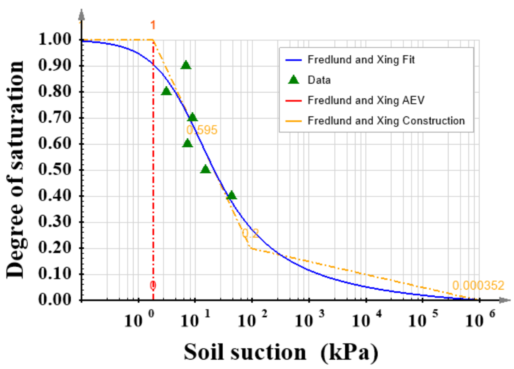
Fig. 2. Soil freezing characteristic curve of soil sample – GC1



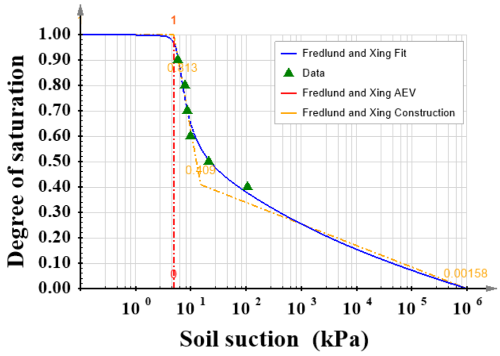
0 FT cycle



1 FT cycle



3 FT cycle



5 FT cycle

Fig. 3. Soil freezing characteristic curve of soil sample – GC2

Figure 4 shows the freezing-thawing behaviour of tested soil at Proctor density. The freezing-thawing cycle plays definite role on suction parameter of a frozen unsaturated soil. It has been seen that for fully compacted soil, matric suction values reduced for 1 FT cycle, increased for 3 FT cycles, and again reduced for 5 FT cycles. The major change of suction parameters was observed between 1 to 3 numbers of FT cycles for each compaction level. This is due to the phase transition of water voids present into the soil specimen to ice.

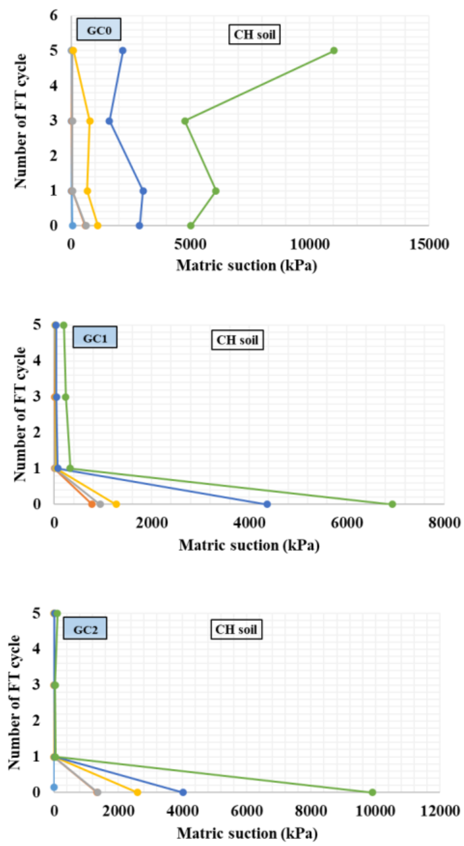


Fig. 4. Effect of number of freezeing thawing cycle on suction parameter

4 Conclusions

Based on the measured matric suction values of a clayey soil, the relationships between matric suction and compaction water content were developed for tested soil. The approach presented in this paper provides a promising way of interpreting the complicated soil suction behavior by taking into account simultaneously the changes in the degree of saturation of soil and number of freezing-thawing cycles (FT cycles).

On the basis of laboratory tests utilising the filter paper method, the impact of geocell as reinforcement on the suction parameters of an unsaturated soil was examined. The usage of geocell as a reinforcement layer in between soil layers has increased suction characteristics, according to analysis of the soil water characteristic curve. The soil water characteristic curve in the clayey soil, including the matric suction, under unsaturated condition, was significantly impacted by the inclusion of geocell.

References

1. ASTM D5298-10, *Standard test method for measurement of soil potential (suction) using filter paper,* (2010)
2. E. C. Leong, H. Rahardjo, *Permeability functions for unsaturated soils,* J. Geotech. Geoenviron. Eng., **123 (12)**, 1118–1126, (1997)
3. E. J. A. Spaans, J. M. Baker, *The soil freezing characteristic: Its measurement and similarity to the soil moisture characteristic*, Soil Sci. Soc. Am. J., **60 (1)**, 13 – 19 (1996)
4. IS 2720, *Methods of test for soils*, **Part III,** (1980)
5. IS 2720, *Methods of test for soils, Determination of water content – dry density relation using light compaction*, **Part VII**, (1980)
6. J. Yuu, X. J. Yuu, A. Rosen, R. L. Parsons, D. Leshchinsky, *Technical review of geocell-reinforced base courses over weak subgrade*, In: Proceedings of the First Pan American Geosynthetics Conference & Exhibition, 2-5 March, Cancún, Mexico, 1022-1030 (2008)
7. K. Watanabe, M. Flury, *Capillary bundle model of hydraulic conductivity for frozen soil,* Water Resour. Res., **44 (12)**, W12402 (2008)
8. M. Bittelli, M. Flury, G. S. Campbell, *A thermodielectric analyzer to measure the freezing and moisture characteristic of porous media,* Water Resour. Res., **39 (2)**, 1041 (2003)
9. M. T. van Genuchten, *A closed-form equation for predicting the hydraulic conductivity of unsaturated soils*, Soil Sci. Soc. Am. J., **44**, 892 – 898, (1980)
10. M. T. van Genuchten, F. Leij, S. Yates, *The RETC code quantifying the hydraulic functions of unsaturated soils*, Rep. No. **EPA/600/2-91/065**, U.S. EPA, Office of Research and Development, Washington, D.C. (1991)
11. R. A. Gardner, *A method of measuring the capillary tension of soil moisture over a wide moisture range,* Soil Sci., 277 – 284 (1937)
12. R. D. Miller, *Freezing phenomena in soils,* Applications of soil physics, D. Hillel, ed., Academic Press, New York, 254 – 299 (1980)
13. R. W. R. Koopmans, R. D. Miller, *Soil freezing and soil water characteristic curves,* Soil Sci. Soc. Am. J., **30**, 680 – 685 (1966)
14. S. L. Webster, *Investigation of beach sand trafficability enhancement using sand-grid confinement and membrane reinforcement concepts,* Report **GL-79-20 (1)**, U. S. Army Engineer Waterways Experiment Station, Vicksburg, (1979)
15. Y. Mualem, *A new model for predicting the hydraulic conductivity of unsaturated porous media,* Water Resour. Res., **12**, 513 – 522, (1976)