Ecological Engineering 103 (2017) 207–216

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Experimental study on unsaturated hydraulic properties of vegetated soil

L. Song[a], J.H. Li[a,*], T. Zhou[a], D.G. Fredlund[b]

[a] Department of Civil and Environmental Engineering, Shenzhen Graduate School, Harbin Institute of Technology, Shenzhen University Town, Xili, Shenzhen 518055, China
[b] Golder Associates Ltd, 1721-8th Street East, Saskaton, Canada

ARTICLE INFO

Article history:
Received 20 July 2016
Received in revised form 3 March 2017
Accepted 1 April 2017
Available online 12 April 2017

Keywords:
Vegetated soil
Unsaturated hydraulic conductivity
Infiltration
Vetiver grass
Bermuda grass

ABSTRACT

Vegetation is often planted on the top of a cover in landfill for ecological restoration and rehabilitation. The vegetation roots, however, may result in preferential flow channels into the underlying waste, and hence increasing leachate generation. The hydraulic properties of the vegetated soil are important factors in assessing the performance of a cover. This study investigates the hydraulic properties of soils with two types of grass (Bermuda grass and Vetiver grass) under unsaturated conditions. The vegetated soils were subjected to seven-month drying-wetting cycles in field. Then the soil samples were retrieved from the site and used to conduct the infiltration tests in laboratory. To minimize disturbance on the soil samples, the sampling and infiltration tests were conducted in the same container. Experimental results showed that the hydraulic conductivity of the soil with Bermuda grass was smaller than that of the bare soil. However, the hydraulic conductivity of the soil with Vetiver grass was significantly larger than that of the bare soil. The results also indicate that the unsaturated hydraulic conductivity of a vegetated soil decreases with depth due to the roots. To reduce rainfall infiltration into the landfill, Bermuda grass with a fibrous root appears to be superior to Vetiver grass with a tap root for the cover.

1. Introduction

Clay barrier layers play an important role in reducing the leachate caused by rainfall infiltration into the disposed waste materials of landfill covers (Albright et al., 2006; Dwyer, 2003; Melchior, 1997; Montgomery and Parsons, 1989). Vegetation is often planted on the top of covers to minimize surface erosion (Waugh et al., 1994). The hydraulic properties of the clay barrier can be affected by the vegetation roots in the soil because of change in soil pore structure (Buczko et al., 2007; Scanlan and Hinz, 2010; Schwarz et al., 2010; Zhu and Zhang, 2015). Mitchell et al. (1995) and Rietkerk (1998) found that the infiltration rate in vegetated soil was higher than that in bare soil due to the preferential flow caused by the roots. On the contrary, Huat et al. (2006) and Ng et al. (2014) found that the infiltration rate in vegetated soil was lower than that in bare soil due to clogging of soil pores caused by the roots (Murphy et al., 1993; Scanlan and Hinz, 2010). There remains debate about the influence of vegetation on the hydraulic properties of soils.

The hydraulic properties of vegetated soils with different types of grass have been studied in the field (Dunkerley, 2002; Greene, 2002; Wilcox et al., 2003; Leung et al., 2015). These field studies focused on the saturated hydraulic properties of the vegetated soil. Under more realistic conditions the soil is usually unsaturated, which leads to significant difference in the hydraulic properties from that under saturated conditions (Fredlund and Rahardjo, 1993). Some laboratory studies have been conducted to measure the unsaturated hydraulic properties of the vegetated soil (Ng et al., 2014; Scanlan and Hinz, 2010; Li et al., 2016). The plants were usually grown in a container under well-controlled boundary conditions. The soil sample containers were often not large enough to allow the full development of the vegetated roots. Cracks that developed in the field were limited by the container and the well-controlled boundary conditions. In order to reflect the typical features in the vegetated soil, the in-situ samples experiencing drying-wetting cycles under natural weather condition, with fully developed roots and cracks, are required. However, there are challenges to obtain in-situ vegetated soil samples without disturbance.

The density of the plant roots varies with depth, which leads to a variation in hydraulic properties with depth. Ng et al. (2013) investigated the root induced suction distribution at different depths in a vegetated soil. It was found that a vertical suction zone was

* Corresponding author.
E-mail address: jinhui.li@hit.edu.cn (J.H. Li).

http://dx.doi.org/10.1016/j.ecoleng.2017.04.013
0925-8574/

identified to be up to four times the root depth. Such changes in root density and suction along depths will significantly affect the hydraulic conductivity. It is important to investigate the influence of roots at various depths on the unsaturated hydraulic properties of a vegetated soil.

This paper investigated the unsaturated hydraulic properties of soil with two types of grass. The vegetated soil samples which subjected to a relatively long period of drying-wetting cycles in the field were retrieved from the site and used in subsequent infiltration tests in the laboratory. In order to minimize disturbance, the sampling and the infiltration test were conducted using the same container. An experimental apparatus with soil volumetric water content and matric suction measuring systems were developed. The unsaturated hydraulic conductivity values of vegetated soils at various depths were quantified using the monitored data of volumetric water content and matric suction in the experiments.

2. Materials and methods

2.1. Material properties

The soil (30% sand, 56% silt, 14% clay) used in this study was a residual soil from an excavation site in Hebei Province, China. The plastic limit and liquid limit of the soil were 16% and 35%, respectively. The saturated hydraulic conductivity k_s of the soil at 80% relative compaction was measured according to the ASTM Standard D5084 (ASTM, D5084-10, 2010). The physical properties of the soil were summarized in Table 1.

In this study, two grass species (Bermuda grass and Vetiver grass) were selected to investigate the unsaturated hydraulic properties of the vegetated soil. The two species are commonly used for ecological restoration and rehabilitation in many areas of the world (Hu et al., 2010; Khan, 2003; Kripal et al., 2013). Bermuda grass is a perennial herbaceous plant with fibrous root system. The diameters of Bermuda grass roots are around 0.1–0.3 mm. The roots mainly grow within the top 40 cm below the soil surface. Vetiver grass is a perennial herbaceous plant with tap root system. The diameters of the Vetiver grass roots range from 0.1 to 2.4 mm and the roots can grow to 2–3 m below the soil surface.

In order to obtain the vegetated soil samples in the field, a test plot was prepared in Shenzhen, China. First, the soil was compacted uniformly using 80% relative compaction. Then the test plot was divided into three regions which are a Vetiver-growing region, a Bermuda-growing region, and a bare soil region (see Fig. 1). The bare soil region was used for the purpose of comparison. The three regions were exposed to the same weather from June to December 2014. The soils experienced many drying-wetting cycles and cracks were fully developed in these regions.

2.2. Experimental setup

A new apparatus was designed to investigate the unsaturated hydraulic properties of the vegetated soils in the laboratory. The experimental setup consisted of a rainfall simulation system, a soil container, a water collection system, and a measuring and data logger system (see Fig. 2).

The rainfall simulation system consisted of a rainfall simulator (80 mm in height and 265 × 265 mm in area) connecting to a Mariotte bottle. At the top of the rainfall simulator, a tube was connected to the Mariotte bottle aimed to supply water continuously to the rainfall simulator at a stable pressure. There were two valves between the Mariotte bottle and the rainfall simulator which were used to control the rainfall intensity. At the bottom of the simulator, there was a porous plate, simulating rainfall dropping from the rainfall simulator (Li et al., 2016). The simulator was connected with the sample container by two bolts.

The soil container was an acrylic box without cover (height of 200 mm, length of 240 mm, and width of 240 mm). The soil container has two main functions: (1) retrieving the vegetated soil samples in field site; and (2) conducting infiltration test on the vegetated soil samples in laboratory. Three holes (10 mm in diameter) were fabricated in each side wall of the container to install the sensors.

The water collecting system collected the drainage from the bottom of the soil column and the runoff from the soil surface separately. The amount of drainage and runoff were measured by water containers on electronic balances. The range of the balances was 0 ~ 3000 g, and the accuracy was 0.1 g. A slope of 5% was designed at the bottom of water collecting system aimed to facilitate water flow and prevent channel clogging. In order to prevent leakage between the sample container and water collecting system, a 15 mm height band was designed to ensure there was a tight connection. Vaseline was also applied along the side of the band.

The measuring and data logger system consisted of six volumetric water content sensors (EC-5) and six tensiometers (2100F tensiometers). The six volumetric water content sensors were installed through the holes on the two side walls of the sample container (see Fig. 2). The volumetric water content sensors E1, E2 and E3 were installed at the depths of 40 mm, 90 mm and 140 mm as shown in Fig. 2. The sensors E4, E5 and E6 were installed symmetrically on the opposite wall of the container. The six tensiometers T1 to T6 were installed on the other two walls at the same depths with that of the water content sensors (see Fig. 2). The measured suction of the tensiometers is limited to 100 kPa, and the accuracy of the tensiometer is ±0.25 kPa. The measurement range of the volumetric water content sensors is 0% – 100% and its accuracy is ±1% – 2% of the range. All of the sensors were connected to a data logger and a computer. The experimental data could be automatically recorded by the system.

2.3. Test program and procedures

Retrieving vegetated soil sample was an important step in the tests. However the existing method (ASTM, D7015-04, 2004) available for excavating undisturbed soil samples in field cannot be applied directly to the vegetated soil samples due to the presence of vegetation roots. In this study, an improved apparatus was designed to sampling the vegetated soil sample and conduct the following infiltration test in the same container. This method was capable to minimize the disturbance on the soil sample.

The sample region (250 × 250 mm^2) on the field site was marked and was 10 mm larger in width and length than the soil container (240 × 240 mm^2) (see Fig. 3a). The carved out region between the sample region boundary and the sample container were trimmed by hand using sharp knife. The sharp knife could readily cut through the roots reducing the disturbing to the vegetated soil samples. A hand-carved block soil sample was in the center of the sample region which was slightly larger than the sample container (see Fig. 3b). Vaseline was applied on the inner-wall of the sample container to avoid preferential flow along the wall in the subsequent infiltration experiments. In order to minimize disturbance, it is better to carve the block and push the soil container step by step to excavate the soil sample (see Fig. 3c). Finally the soil container and the sample were removed from the site (see Fig. 3d).

Four different soil samples were prepared to conduct infiltration experiments in the laboratory. The first soil sample was excavated from the Vetiver grass region in the field after seven-months of drying-wetting cycles (referred to as Vetiver soil in the following sections). The second soil sample was excavated from the Bermuda grass region with the same drying-wetting cycles as the Vetiver