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Helical filter paper technique for uniform distribution of injected moisture in unsaturated triaxial specimens

Muhammad Irfan[a,b,*], Taro Uchimura[b]

[a]Department of Civil Engineering, University of Engineering & Technology Lahore, G.T. Road, Lahore 54890, Pakistan
[b]Department of Civil Engineering, The University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo, 113-8656, Japan

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Abstract

The field stress path experienced by a soil element during rain-induced slope failures is reproduced by injecting water in an initially unsaturated specimen under constant total stress conditions. The accumulation of injected moisture near the base of triaxial specimens causes non-uniformity in the specimen leading to progressive failure. A new idea of using a helix shaped filter paper wrapped around the specimen's periphery to uniformly distribute the injected water is presented. Water injection experiments were conducted and the behavior of specimens with and without the presence of filter paper was compared under constant shear stress. The use of helical filter paper ensured more uniform distribution of injected moisture, and reduced the discrepancy of moisture along specimen's height by around 50%. Improvement in moisture uniformity of the specimen also reduced the possibilities of progressive failure during water injection experiments. The helical filter paper technique was found to hold a strong potential for the reproduction of rain-induced landslide conditions in laboratory triaxial experiments.

Keywords: Triaxial tests; Unsaturated soil; Landslide; Water injection tests; Moisture distribution

1. Introduction

The realistic reproduction of field stress path plus the prevailing mechanism of rain-induced landslides in laboratory element tests requires water to be injected into unsaturated soil specimens. Brand (1981) postulated that the decrease in soil matric suction due to rainwater infiltration causes a reduction in the effective normal stress acting on the potential failure plane. This lowers the available shear strength which may trigger slope failure. It then follows that initially unsaturated specimens, maintained under constant total stress conditions (at field stress levels), can be infiltrated with water in order to replicate the field stress path as well as actual landslide mechanism. Han (1997) and Melinda et al. (2004) attempted to reproduce the failure mechanism of rainfall-induced landslides and the corresponding field stress path by using direct shear apparatus. For the experiments conducted in direct shear apparatus, the failure plane is always pre-defined and the measurement of volumetric strain of unsaturated specimens is quite difficult. Getie (2012) and Ghani (2014) performed similar experiments in a simple shear apparatus (Specimen *diameter*=60 mm, *height*=20 mm). For the experiments performed in simple shear apparatus, the rotation of principle axes make the analysis complicated. Additionally Ghani et al. (2013) showed that slippage of the simple shear plates at the

*Corresponding author at: Department of Civil Engineering, University of Engineering & Technology Lahore, G.T. Road, Lahore 54890, Pakistan.
E-mail address: mirfan1@msn.com (M. Irfan).
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top and bottom of the specimen makes it very difficult to obtain consistent results during water injection experiments. In all such experiments, water is typically injected into the soil specimens through a saturated ceramic disk with high air entry value fitted at the ends of shear box. Injected during simple shear/direct shear tests, the water can be distributed relatively evenly in soil specimens due to their small height to diameter ratio. However, the works of Ghani (2014) and Getie (2012) show that the distribution of water is not perfectly uniform along the height of specimen. Another option for reproducing rainfall-induced slope failures in the laboratory is to conduct water injection experiments in a triaxial apparatus. Modern computer controlled triaxial machines can maintain constant total stresses on the specimens with relative ease. The direction of principle stresses remains vertical (for σ_1) and horizontal (for σ_3) throughout the course of water injection, so the analysis of results compared to simple shear tests is simple. Citing these advantages Brenner et al. (1985), Atkinson and Farrar (1985), Eigenbrod et al. (1992), Farooq et al. (2004) and Chen et al. (2004), etc. performed slope failure studies using unsaturated triaxial specimens. However, the discussions of the present study and those described by Farooq (2002) show that the distribution of injected moisture along the longitudinal axis of the specimen remains largely non-uniform. Water injected in a triaxial specimen is typically injected through a saturated ceramic disk installed at the base pedestal. The injected water thus wets the bottom of specimen first, before rising to the top through capillary suction. At any given time, there is unequal distribution of water along the longitudinal axis of specimen. This makes the sample non-uniform, leading to progressive failure initiating from the bottom. For more uniform distribution of water in a triaxial specimen, a technique using a ceramic disk and a helix shaped filter paper wrapped around the specimen has been suggested in this paper.

Filter paper side drains are often used in triaxial experiments on saturated specimens to decrease the consolidation time and to speed up the rate of pore water pressure equalization in specimens (Bishop and Henkel, 1962; Oswell et al., 1991). However, their use in unsaturated specimens has not been reported in literature. The present study is focused on the use of helical filter paper side drains in unsaturated specimens. Its effects on the deformation response, and the distribution of injected moisture in the unsaturated specimens are elucidated in this paper.

2. Materials and methodology

Test material used in this study comprised of Edosaki sand; brown colored natural sand procured from a trench pit in Tsukuba, Japan. Edosaki sand used in this study had around 9% fines, and a specific gravity (Gs) of 2.639; minimum (e_{min}) and maximum (e_{max}) void ratios were found out to be 0.647 and 1.160, respectively (all tests conducted according to *Japanese Geotechnical Society* (*JGS*) standards). Particle size distribution of Edosaki sand is shown in Fig. 1.

All the experiments were performed in a stress-controlled triaxial testing apparatus. A schematic illustration of the triaxial apparatus used in this study is shown in Fig. 2. Base pedestal of the setup

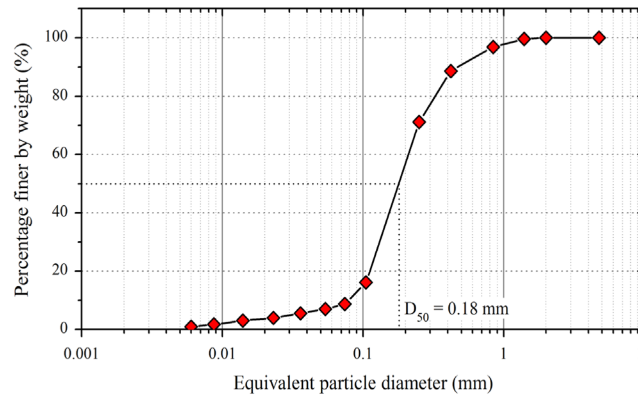

Fig. 1. Particle size distribution of Edosaki sand.

was modified to house a ceramic disk. Ceramic disk having an air-entry value of 100 kPa was selected. Ceramic disks with higher air-entry values have smaller pores which would make water infiltration more difficult. Meanwhile, the shape of ceramic disk was donut-like in order to accommodate a piezoelectric sensor at its center. The piezoelectric sensor was installed as part of a separate study which is not covered in this paper. Further details of experimental setup are discussed in Irfan and Uchimura (2015). Before the start of each experiment, the ceramic disk (along with base pedestal) was saturated by submerging it in de-aired water tank and subjecting to absolute vacuum (i.e., −101.3 kPa) for 24 h. Saturated ceramic disk was connected to a water burette placed outside the triaxial cell. Water from the burette could thus flow through the ceramic disk into the soil specimens.

Cylindrical triaxial specimens (*height* = 150 mm, *diameter* = 75 mm) were prepared by wet tamping Edosaki sand in 10 equal layers directly on top of saturated ceramic disk. All the specimens were prepared at an initial moisture content corresponding to 30% saturation ratio. Just before specimen preparation, the connection between ceramic disk and water burette was closed and the surface of ceramic disk was wiped with a dry cloth. Specimens were initially kept at 25 kPa isotropic stress level. Axial stress was then gradually increased to achieve the desired principle stress ratio ($K = \sigma_1/\sigma_3$) which represented the field consolidation. After 1 h of consolidation, connection between ceramic disk and water burette was opened and water started to permeate through the ceramic disk into the soil specimen. The rate of infiltration was controlled by regulating the infiltration pressure applied on top of water burette. Two local deformation transducers (*LDT*) (Goto et al., 1991; Hoque et al., 1997), 112 mm in length, were directly attached to the specimen by means of pseudo-hinges to record axial deformations. *LDTs* could measure strains up to 3–4% only, thus a backup measurement of axial strain was conducted by means of an externally mounted *LVDT*. For observing radial deformations of unsaturated specimens, three clip gauges viz., *CG-1*, *CG-2* and *CG-3* were attached near specimen's top, middle and bottom, respectively. A summary of the initial test conditions of various test specimens used in this study is presented in Table 1.