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An approach to measure infill matric suction of irregular infilled rock joints under constant normal stiffness shearing

Libin Gong, Ana Heitor*, Buddhima Indraratna

School of Civil, Mining and Environmental Engineering, University of Wollongong, Wollongong, NSW, 2522, Australia

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ABSTRACT

Rock joints infilled with sediments can strongly influence the strength of rock mass. As infilled joints often exist under unsaturated condition, this study investigated the influence of matric suction of infill on the overall joint shear strength. A novel technique that allows direct measurement of matric suction of infill using high capacity tensiometers (HCTs) during direct shear of infilled joints under constant normal stiffness (CNS) is described. The CNS apparatus was modified to accommodate the HCT and the procedure is explained in detail. Joint specimens were simulated by gypsum plaster using three-dimensional (3D) printed surface moulds, and filled with kaolin and sand mixture prepared at different water contents. Shear behaviours of both planar infilled joints and rough joints having joint roughness coefficients (JRCs) of 8–10 and 18–20 with the ratios of infill thickness to asperity height (t/a) equal to 0.5 were investigated. Matric suction shows predominantly unimodal behaviour during shearing of both planar and rough joints, which is closely associated with the variation of unloading rate and volumetric changes of the infill material. As expected, two-peak behaviour was observed for the rough joints and both peaks increased with the increase of infill matric suction. The results suggest that the contribution of matric suction of infill on the joint peak normalised shear stress is relatively independent of the joint roughness.

1. Introduction

Rock joints, in particular those filled with compacted sediments, are the most common geological structures that can contribute to a drastic reduction in the stability of rock masses. The key factors affecting the joint shear behaviour include joint roughness, type and thickness of joint infill, stress history and water content of infill (Barton, 1978, 2013; Lama, 1978; Phien-wej et al., 1990; de Toledo and de Freitas, 1993; Papaliangas et al., 1993; Pellet et al., 2013). In some cases, infilled rock joints are located above the groundwater table, and thus matric suction of the infill material can play a significant role in the joint shear behaviour (Khosravi et al., 2013, 2016; Indraratna et al., 2014). Furthermore, below groundwater table, partially saturated conditions may also occur for infilled joints in drained strata adjacent to deep underground mine excavations (Tsang et al., 2005; Matray et al., 2007).

While the influences of water content and humidity conditions on the shear behaviour of infilled rock joints have been recognised in the past by introducing empirical parameters such as joint water reduction factor (J_w) in estimation of the joint shear strength (e.g. Barton et al., 1974), the role of unsaturation was conveniently ignored. More recently, Alonso et al. (2013) studied the influence of matric suction on the shear behaviour of rock joints without infill. Zhang (2017) examined the effective stress in clay rock theoretically and experimentally from unsaturated to saturated conditions. Indraratna et al. (2014) conducted a series of constant water content (CW) triaxial tests on infilled rock joints, considering the initial matric suction of infill for predicting the peak shear strength. Khosravi et al. (2016) further studied the shear behaviour of rock joints infilled with unsaturated silt, maintaining constant suction conditions using axis translation technique. Although this approach is well established for investigating unsaturated soil behaviour, it may not truly represent field conditions, where air pressure is atmospheric and water pressure is negative.

Furthermore, the influence of matric suction of the infill material on the joint shear behaviour has been only appreciated for in constant normal load (CNL) direct shear or traditional triaxial shear,

* Corresponding author.
E-mail address: aheitor@uow.edu.au (A. Heitor).

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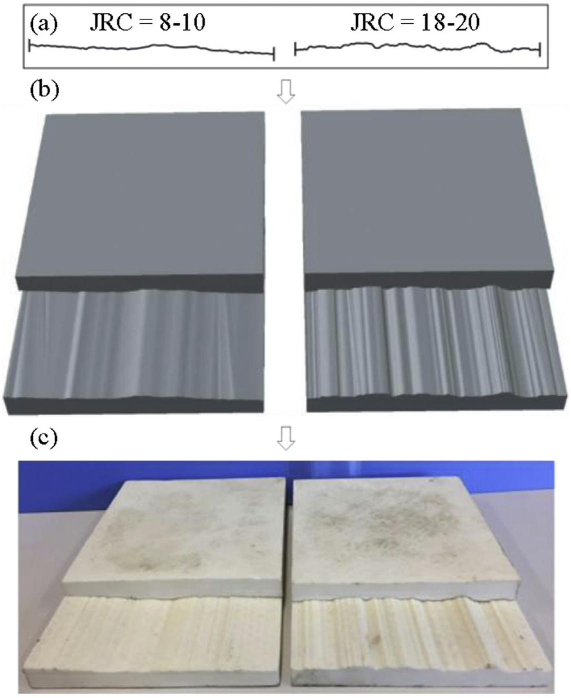

Fig. 1. 3D printing procedure for Barton's joint moulds: (a) Barton's standard joint profiles for JRC = 8–10 and 18–20, respectively (Barton and Choubey, 1977); (b) 3D CAD model used for the joint profiles; and (c) Printed joint moulds.

but in some cases, the in situ rock joints are more likely to experience constant normal stiffness (CNS) conditions (Indraratna et al., 1998). Moreover, the difference between CNS and CNL envelopes can be properly quantified only if the stress state variables can be measured, in which the role of pore water pressure and matric suction developed upon shearing was incorporated when significant volumetric strains occurred within the compacted infill. In addition, the effects of asperity attrition and over-compaction of infill within rough joints and their implications on the apparent shear strength have been highlighted by Indraratna et al. (2005, 2010a), but these models could not capture the role of suction. Therefore, Indraratna et al. (2014) proposed a constitutive model that could capture the effect of initial matric suction, but this model suffered from not being able to interpret the influence of suction variation with the shear displacement of a rough joint with compacted infill. During shearing, the average aperture between coupled joint surfaces varies, which leads to changes in the patterns of void ratio and degree of saturation within the infill layer, causing the fluctuation of the matric suction (Romero Morales, 1999; Rahardjo et al., 2004; Thu et al., 2006). This paper introduces an approach for directly measuring the matric suction of the infill material within the shearing joints using high-capacity tensiometers (HCTs) while maintaining the CNS load conditions. The purpose is to investigate the variation of matric suction of joint infill during shearing and its influence on the shear behaviour of irregular joints with compacted infill, so that the peak shear strength can be predicted more accurately.

2. Materials

2.1. Infill material

In this study, a mixture of fine sand (25%) and commercial kaolin (75%) was selected as the infill material. The index characterisation of the infill material reported in Indraratna et al. (2014) showed that the material has a liquid limit of 39% and plasticity index of 19. In addition, effective internal friction angle (ϕ') of 21° and cohesion (c') of 13.4 kPa were obtained in consolidated undrained (CU) triaxial tests. The required water content was added to the infill material and the samples were kept in constant humidity and temperature conditions for at least one week for moisture equilibration.

2.2. Simulated irregular rock joint specimens using three-dimensional (3D) printing

To accurately replicate the behaviour of rock joints in laboratory, typically artificial joint specimens are adopted rather than natural jointed specimens. The joint models ensure repeatability of the geometric profiles used for various tests. In this study, an innovative technique based on 3D printing was adopted for

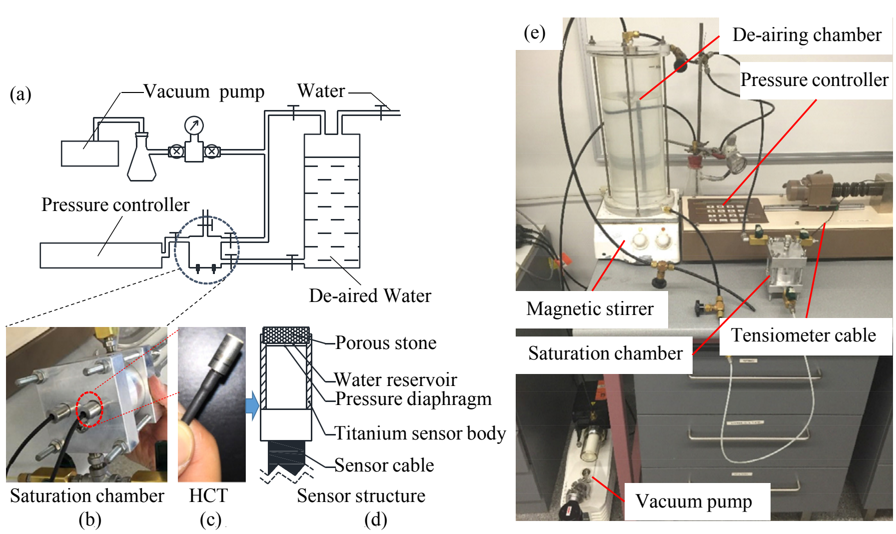

Fig. 2. Saturation system for the HCTs: (a) Schematic illustration of the saturation system; (b) Saturation chamber; (c, d) Detail of HCT-sensor; and (e) Photograph of the whole saturation system.

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