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Shear behaviors of 'real' natural un-matching joints of granite with equivalent joint roughness coefficients

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ABSTRACT

Contact planes of a natural unfilled rock joint often portray dissimilar roughness characteristics particularly at shallow depth. Some researchers investigated shear strength behaviors of un-matching joints (i.e. joints with dissimilar surface morphologies) through laboratory experiments using mimicked discontinuities. This study aimed to explore shear behaviors of 'real' natural un-matching joints (with similar averaged joint roughness coefficients (JRCs)) in the Singhbhum Granite (India) based on laboratory investigations. Direct shear tests were performed on a total of 18 encapsulated jointed samples, split into three groups, under (a) three different low normal stresses (≤0.70 MPa) with increasing values; (b) three different high normal stresses (within a range of 0.98–1.99 MPa) with increasing values; and (c) one particular intermediate normal stress (≈ 0.99 MPa) for five times, where direction of shearing was kept same as the dip direction of the joints in situ. Shear behaviors of the investigated joints portray diverse patterns. Moreover, most of the obtained behavioral patterns look different from the typical shear stress-shear displacement graph in the literature that are based on direct shear test results in case of matching rock discontinuities. Influence of surface morphology on shear behavior, shear stress fluctuations with displacement, variation of JRC values with the increase in normal stresses and observations on peak friction angle were critically analyzed. Effect of cycles of shearing on shear strength was also examined. Plausible reasons behind the uniqueness of the results were explained.

1. Introduction

Behavior of a rock mass is controlled mostly by sliding on the discontinuities (e.g. joints, bedding planes, planes within a shear zone, faults etc.) at shallow depth where failure of intact rock materials is minimal because of low stresses (Singh and Rao, 2005; Hoek, 2007). This is a common issue in case of a rock slope slide where in situ failure in shear mode occurs under constant normal load (CNL) condition (Grasselli and Egger, 2003). Shear strength of rock joints depends on the factors like stiffness of surrounding rock mass, shear rate, joint roughness, scale effect, joint conditions, shear direction, degree of weathering and humidity conditions (Shrivastava and Rao, 2009; Pellet et al., 2013; Ozvan et al., 2014). A number of studies were carried out by several researchers in order to explore the influence of individual parameters on shear strength. Surface morphology has gained a significant attention in this regard (e.g. Barton, 1973; Barton and Choubey, 1977; Bandis, 1980; Bandis et al., 1983; Belem et al., 2000; Grasselli and Egger, 2003; Johansson, 2009; Asadollahi and Tonon, 2010; Hua et al., 2012; Usefzadeh et al., 2013; Bahaaddini et al., 2014 and 2016; Li et al., 2015 etc.). As evident from the existing literature, this particular issue has been explored through laboratory experiments mostly on mimicked joint surfaces made up of a different material (e.g. plaster of Paris or concrete-sand-cement or sand-cement) or on tensional rock discontinuities created by inducing indirect tension in the laboratory. A few studies have also focused on interlocked natural discontinuities with matching planes of contact (Wines and Lilly, 2003; Woo et al., 2010; Ozvan et al., 2014; Sanei et al., 2015; Hencher and Richards, 2015; Li et al., 2015). However, it is often observed that contact planes of a natural rock joint have dissimilar roughness characteristics. This is because of preferential weathering and subsequent erosion of the contact planes of natural rock joints due to movements of various fluids in situ. Sometimes, this can also be due to vibrations caused by nearby blasting, excavation or earthquake (Tang and Wong, 2016). As evident from previous studies, only a limited number of researchers have explored the shear strength issues of un-matching joints (i.e. joints with dissimilar surface morphologies) through laboratory experiments using replica joints (e.g. Belem et al., 1997; Zhao, 1997a and b; Tang and Wong, 2016; Tang et al., 2016). However, investigation of shear behaviors of 'real' natural rock joints with un-matching planes of contact or in other words, with dissimilar surface roughness characteristics/morphologies, frequently observed at shallow depth, does not seem to have gained much attention. Another important issue that also has not been explored includes assessment of shear behavior of natural un-matching joints with similar interface (or averaged) joint roughness coefficient (JRC). This study aims to shed light on both issues together

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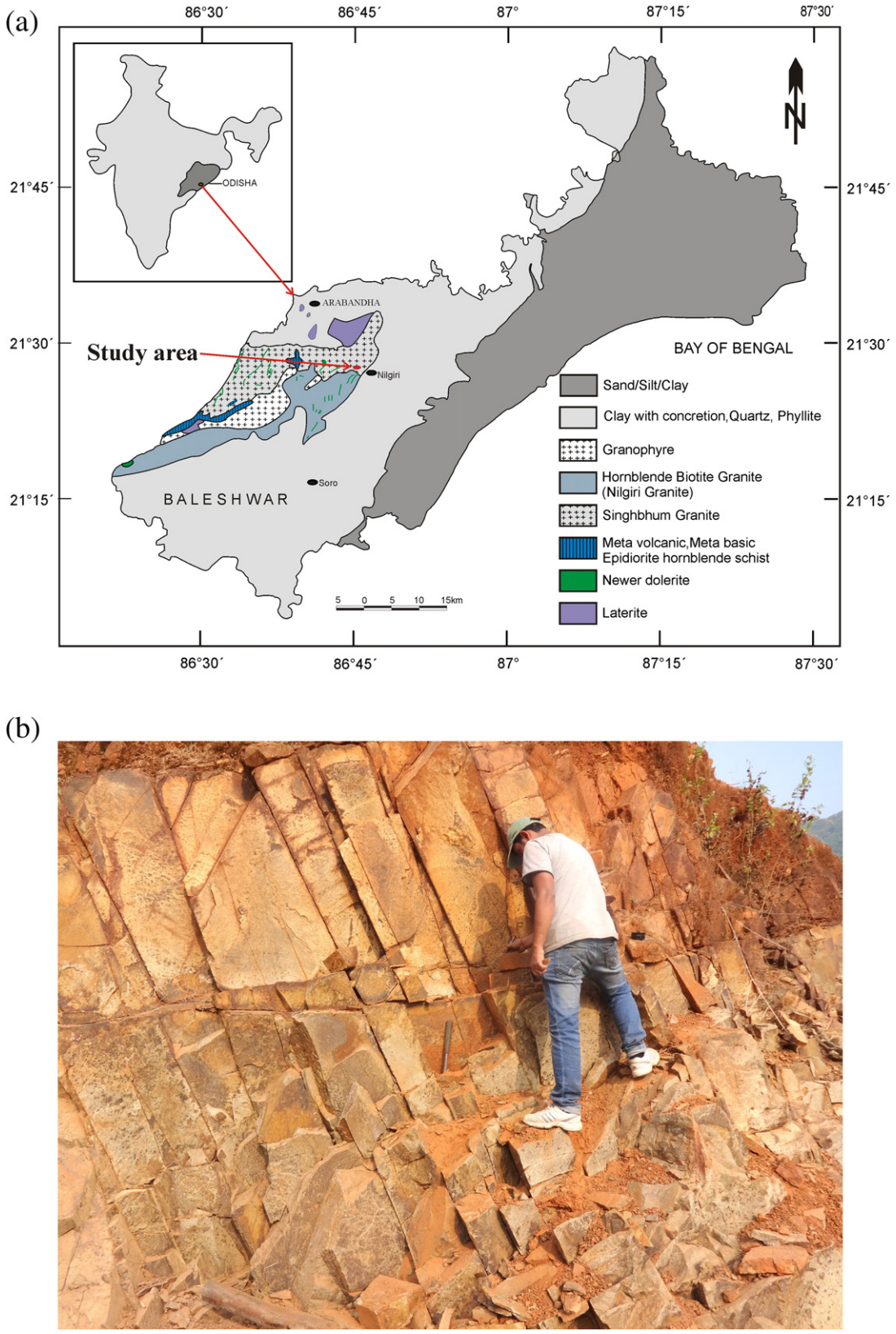

Fig. 1. (a) Geological map of Balasore district (in the state of Odisha, India) (modified after GSI, 2009) showing the sampled location. (b) An example of exposure where from jointed samples were collected.

based on the laboratory investigation of natural unfilled rock joints in the Singhbhum Granite (in the state of Odisha, India).

In many rock engineering problems, the maximum effective normal stress acting across joints considered critical for stability lies in the range of 0.1–2 MPa (Barton, 1976). On similar note, Hencher and Richards (2015) indicated that laboratory shear tests can be conducted on samples (dimension ≤100 mm × 100 mm) under a normal stress of up to 2 MPa which is the equivalent of about 70 m of rock and, therefore,