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Velocity-frequency-amplitude-dependent frictional resistance of planar joints under dynamic normal load (DNL) conditions

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ABSTRACT

The problem of how dynamic friction of faults influences the observed earthquakes remains largely unsolved. Our paper presents results of experiments aimed to understand the complex frictional behavior of faults under dynamic normal load (DNL) conditions under consideration of horizontal slip velocity, dynamic normal force amplitude and normal impact frequency using a dynamic shear box device. Data were obtained by continuous measurements of shear and normal forces as well as corresponding displacements. We identified a phase shift between peak normal force and peak shear force with peak shear force lagging. Consequently, the dynamic friction coefficient shows cyclic behavior and the minimum value of the dynamic friction coefficient increases with increasing of slip velocity which is in conflict to the traditional views under constant normal load (CNL) conditions. We found, that dynamic fault friction coefficient during earthquakes may increase or decrease depending on velocity-frequency (VF), velocity-amplitude (VA) and velocity-frequency-amplitude (VFA) parameter. These findings have significant implications for seismic hazard assessment and reliable forecasting of earthquakes.

1. Introduction

The problem of how dynamic friction of joints influences the observed earthquakes and blasting remains largely unsolved (Ide et al., 2007, 2016; Houston, 2015). Dang et al. (2016a, 2017a) investigated the direct shear behavior of a planar joint under dynamic normal load (DNL) conditions. A significant phase shift between peak normal stress and peak shear stress is reported and a new shear strength criterion is proposed. However, Dang et al. (2016a, 2017a) only investigated the dynamic friction behavior influencing of different static normal loads, dynamic normal impact frequencies and dynamic normal force amplitudes, slip velocity was not taken into consideration. Slip velocity dependent behavior of joints is very important for a lot of geotechnical applications (Liu et al., 2012, 2013; Tao et al., 2013; Liu and Dang, 2014; Cao et al., 2016; Dong et al., 2016; Li et al., 2016, 2017; Zhou et al., 2017). A lot of researchers have investigated the velocity-dependent behavior in the recent past (Barton and Choubey, 1977; Crawford and Curran, 1981; Gillette et al., 1983; Barla et al., 1990; Jafari et al., 2003; Hong and Marone, 2005; Atapour and Moosavi, 2014; Nguyen, 2013; Nguyen et al., 2014; Jiang et al., 2016; Wang et al., 2016; Dang, 2017).

Barton and Choubey (1977) investigated the velocity-dependent frictional resistance of saw-tooth joints made by shale. The slip velocities varied from 0.01 to 200 mm/min. Lab test results showed that friction coefficient increases with increasing slip velocity. Crawford and Curran (1981) performed direct shear tests at different slip velocities on different rock types (e.g., syenite, dolomite, sandstone and granite). The slip velocity varied from 0.05 to 200 mm/sec. They found that friction coefficient increases with increasing slip velocity for harder rocks; however friction coefficient decreases with increasing slip velocity for softer rocks. Gillette et al. (1983) and Jafari et al. (2003) conducted direct shear tests on artificial rock joints under constant normal load (CNL) conditions. They had similar results with Barton and Choubey (1977) indicating that shear strength increases with increasing shear velocity under the same normal load levels. Hong and Marone (2005) investigated the slip velocity-dependent frictional behavior of Westerly granite faults under dynamic normal stress conditions. Slip velocity varied from 3 to 1000 μm/s. They found that dynamic friction coefficient changes with changing of normal stress and changing of slip velocity. Atapour and Moosavi (2014) investigated the effects of shear velocity on the shearing behavior of plaster–plaster and concrete–concrete joints. The slip velocity varied from 0.3 to 30 mm/min.

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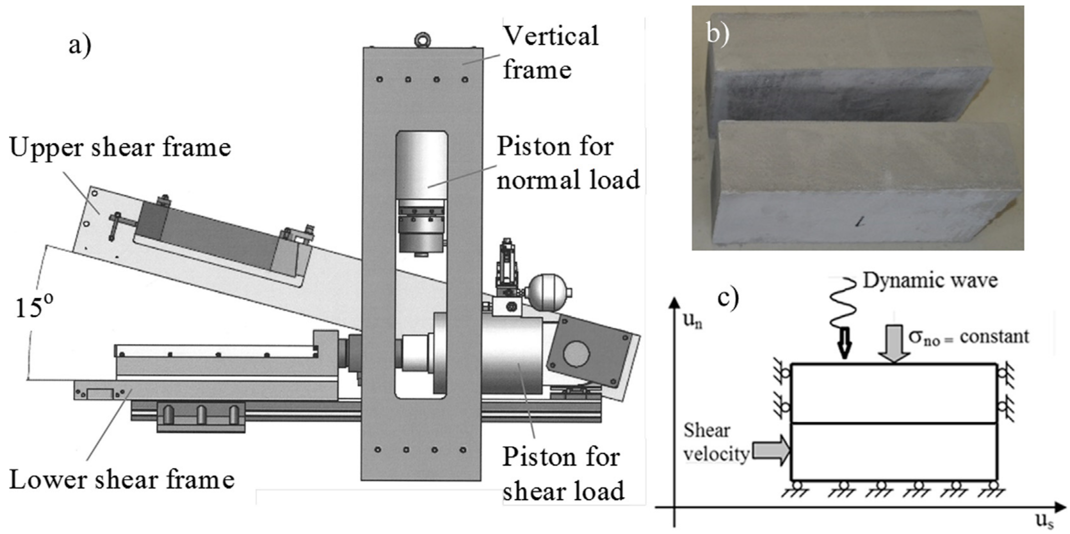

Fig. 1. Lab test set-up, (a) big direct shear box device GS-1000, (b) test specimen (size: 300 mm × 160 mm × 150 mm (length/width/height) and (c) test procedure.

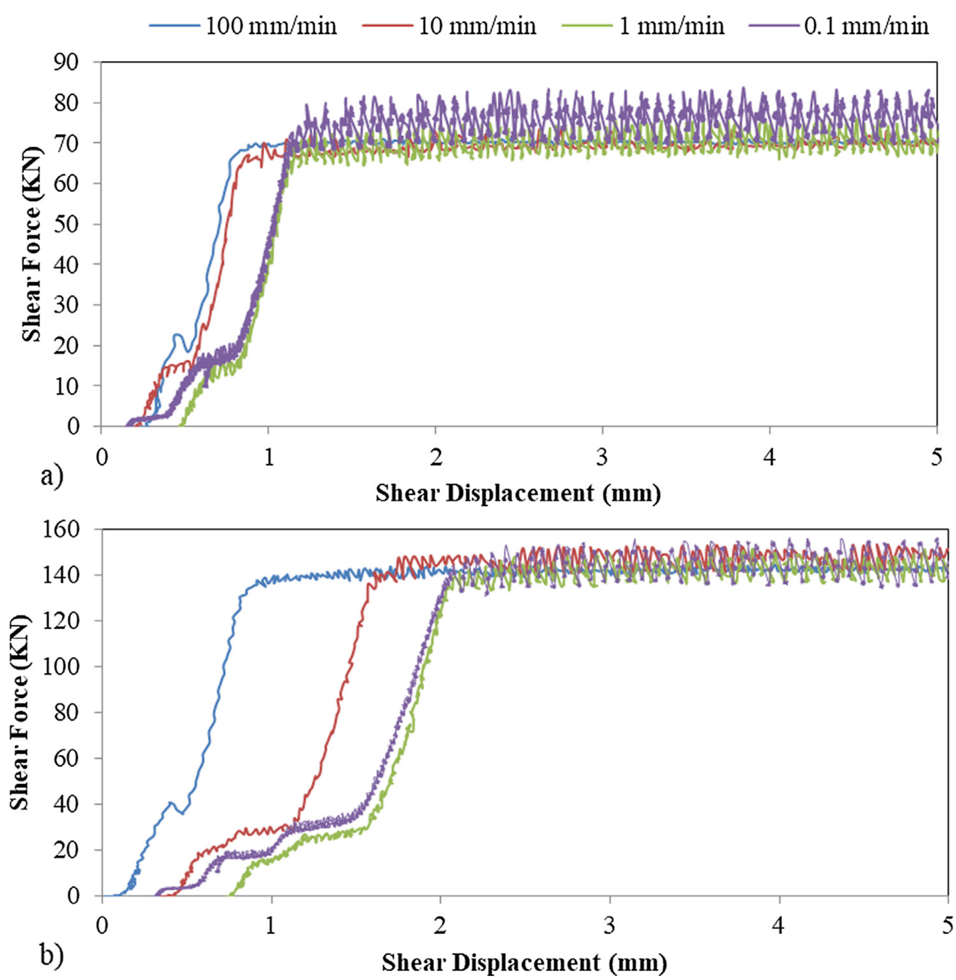

Fig. 2. Shear forces vs. shear displacement at different shear velocities, (a) normal force 90 kN and (b) normal force 180 kN.

The results show that shear strength increases with increasing of slip velocity for concrete-concrete specimen, while shear strength decreases with increasing of slip velocity for plaster–plaster specimen. Nguyen (2013) performed the direct shear tests on schistose rock under CNL conditions at shear velocities of 1 mm/min, 10 mm/min and 50 mm/min. Lab test results showed that peak shear stress increases with increasing shear velocity. Wang et al. (2016) performed direct shear tests under CNL conditions. Slip velocity and joint roughness coefficient were taken into consideration. Test results indicated that the peak shear strength is controlled by slip velocity and joint roughness.

Blasting and earthquakes change the normal and shear stresses on surrounding joints (Stein, 1999). Houston (2015) reported that episodic tremor and slip happens on a plate boundary interface in earthquakes. It means that, during slip, shaking vertical to the slip direction occurs