TECHNISCHE UNIVERSITÄT BERGAKADEMIE FREIBERG
Die Ressourcenuniversität. Seit 1765.

Lehrstuhl für Gebirgs- und Felsmechanik/Felsbau

Institute of Geotechnics
Chair of Rock Mechanics

Tel. +49 3731 39-2519
Fax +49 3731 39-3638
www.ifgt.tu-freiberg.de

Seismic fault slip affected by pore pressure and cyclic normal stress

Kang Tao, PhD candidate
Prof. Dr.-Ing. habil. Heinz Konietzky
Prof. Dr. Wen-gang Dang

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Introduction

Slip characteristics of tectonic faults are highly correlated with earthquake risks. However, the stress conditions in-situ are not static, because tides and seismic waves produce dynamic stress disturbances. The effect of geo-fluids also needs to be considered. The fault slip evolution considering both, stress perturbation and fluid pressure is poorly investigated in the laboratory.

Methods

We performed direct shear tests on saw-cut granite joints using a shear box device with external syringe pump. The lower part of the specimen was driven by constant load point velocity, and static/cyclic normal loads were applied to the upper part. LVDTs recorded horizontal and vertical movements: fault slip and vertical dilatancy, respectively. The impact of two factors are studied in the experiment: pore fluid pressure and applied normal stress oscillation amplitude.

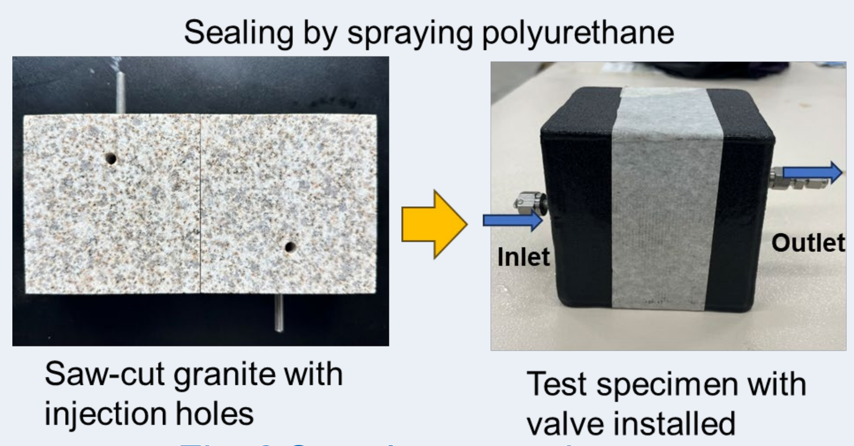

Fig. 2 Sample preparation

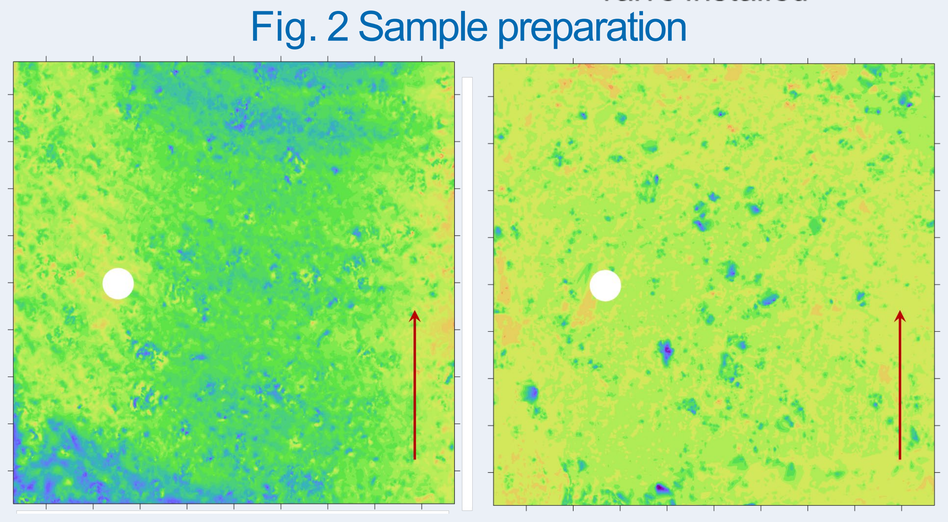

Fig. 3 Surface morphology before and after shear test

A total of 24 trials of direct shear tests were performed on one sealed joint sample. Three pore fluid pressure values (0, 500 kPa, 650 kPa) were selected. Subjected to each pore pressure level, the sample was sheared first under constant normal stress of 2 MPa, 3 MPa and 4MPa, respectively. Then, the sample was sheared under cyclic normal stress with variation amplitude of 20%, 40%, 60% and 80%, respectively, while the mean normal stress was kept as 4 MPa.

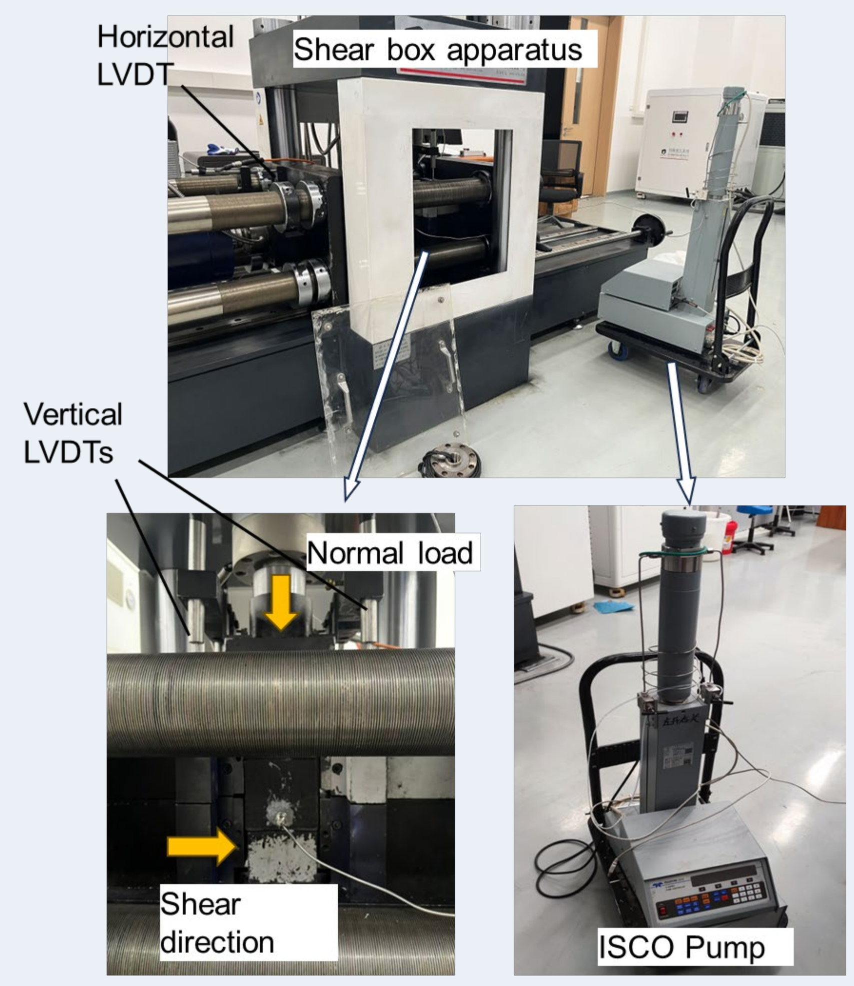

Fig. 1 Test apparatus and loading mode

Results and discussion

The fault shear stress is slightly improved under small normal stress cyclic amplitude. Compared with the shear strength under 4 MPa constant normal stress, the shear strength is mostly reduced. This weakening effect is more obvious under larger normal cyclic amplitude.

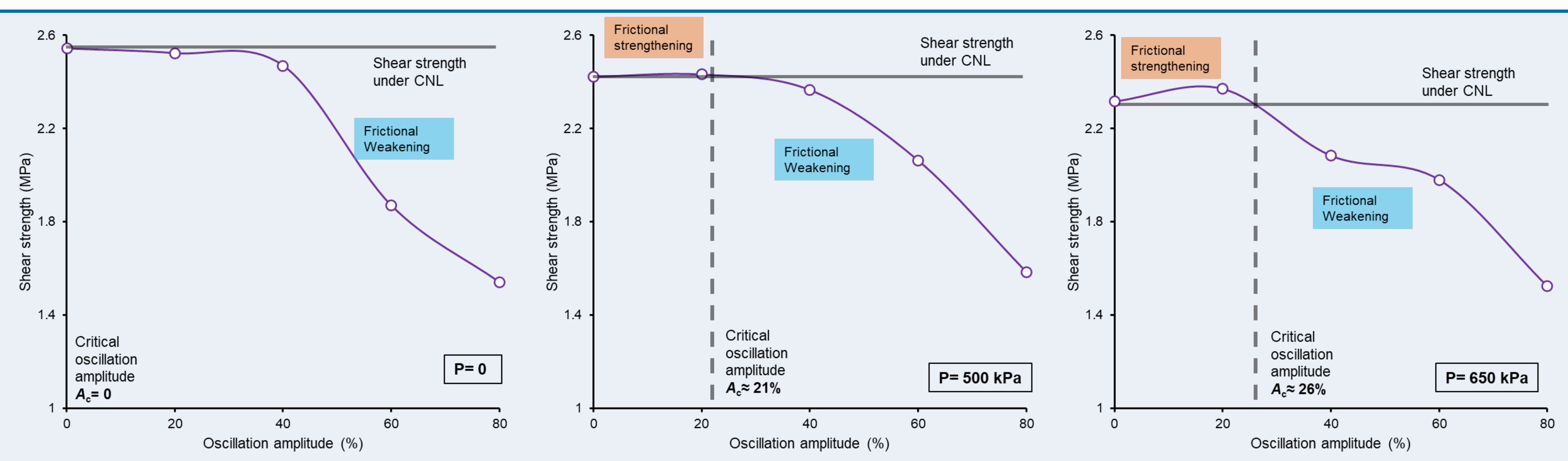

Fig. 4 Shear strengthening/weakening with different pore pressure affected by cyclic normal stress

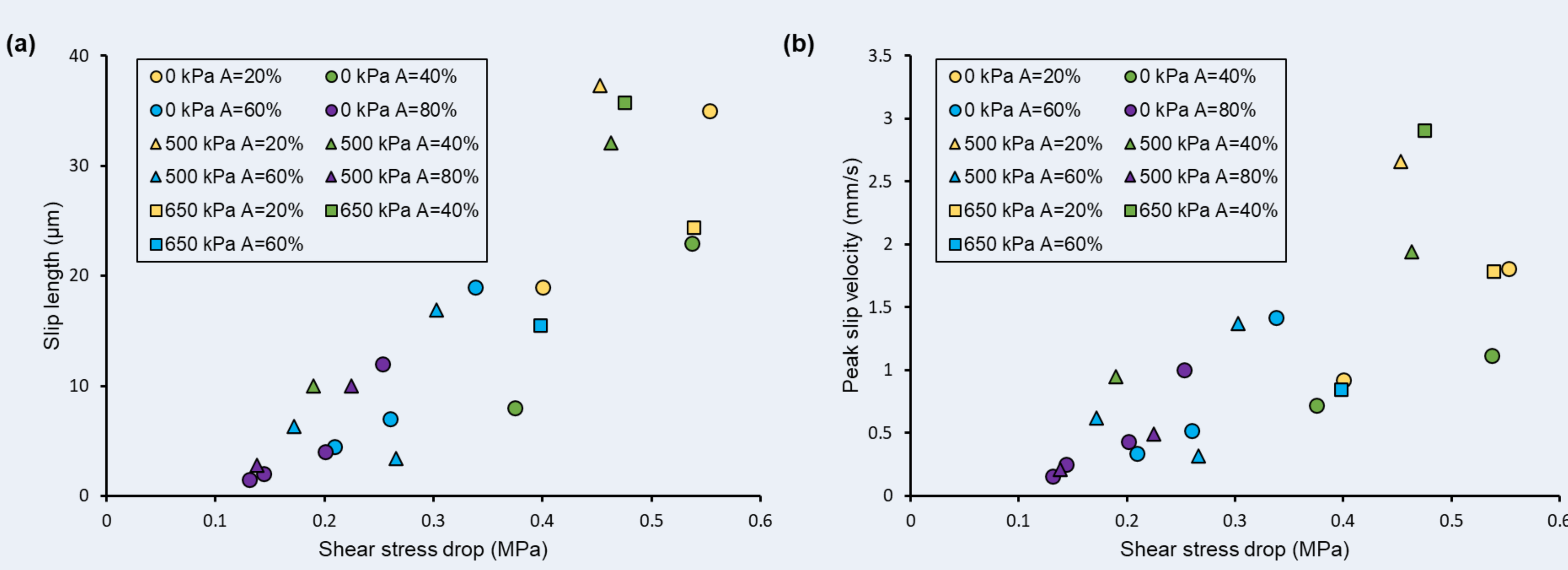

Fig. 5 Characteristics of slip events

The laboratory fault exhibits stick-slip behavior under both constant normal stress and cyclic normal stress. The shear stress drop of is positively correlated with the slip distance and peak slip velocity. It is found that the larger the normal stress amplitude, the milder the slip intensity. Static pore pressure has an inhibitory effect on the fault slips. The sample consistently shows stable sliding when pore pressure is 650 kPa and the amplitude is 80%.

Main findings

Static pore fluid pressure reduces effective normal stress and shear stiffness of the sheared fault. Under constant normal stress, the reduction in fault shear stiffness caused by fluids synchronously competes with the reduction in critical stiffness (K_c) as the effective normal stress decreases. The stick-slip events are most intensive under low fluid pressure and high normal stress. Under oscillating normal stress, as the normal stress oscillation amplitude increases, the overall fault shear strength weakens continuously. Frictional strengthening and aseismic slips always occur in the normal stress loading stage. Normal stress unloading leads to multi-step stick-slip behavior of the sheared fault. The normal deformation is controlled by both normal loading/unloading and asperity overriding. Increasing pore pressure and superimposed normal stress magnitudes lead to more dramatic shear stress changes, but the degree of seismic slip is reduced.

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