Peer-reviewed Conference Contribution

Data-driven discovery of injection-induced inter-slip creep on rock fractures

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Injection-induced inter-slip creep on rock fractures reveals how fracture friction recovers from the last slip event and weakens again before the next slip event. Forecasting the occurrence of slip behaviors, either inter-slip creep or dynamic slip, relies heavily on understanding the evolution of friction controls during the inter-slip creep, particularly those significantly modified from the previous slip events. Here we collected the experimental data from a series of fluid injection experiments and built a dual-stage attention-based recurrent neural network (DA-RNN) model to uncover the contributions of controlling factors to the occurrence of slip behaviors.

We conducted two sets of fluid injection experiments on sawcut fractures in Bukit Timah granite using Material Testing System experimental system with Vindum dual syringe pump [1]. We applied a normal stress of 11 MPa on the fracture and a shear stress equal to 80% of the shear strength to simulate a critically stressed fracture. We injected distilled water into the fracture at a constant pressurization rate of 0.05 MPa/s to induce a fracture slip. We also calculated the fluid pressure gradient over the fracture, which is defined as the difference between the injection and monitoring pressures divided by the fracture length. The fracture in the two sets under the same stress and injection conditions exhibits similar slip behaviors before and after the first dynamic slip event, in terms of a dynamic slip followed by an inter-slip creep (Figures 1a and 1b). However, the inter-slip creep continues during the first set, while multiple dynamic slip events appear in the second set.

To better understand the difference of slip behaviors in the two sets, we used the experimental data to train the DA-RNN model, which involves the attention mechanism to predict the slip behaviors based on the most relevant input parameters [2]. The attention distribution of the DA-RNN model reveals an attention increase to normal stress and an attention decrease to shear stress after the first dynamic slip event (Figures 1c and 1d). The minimal attention to shear stress is comparable to the maximum attention to normal stress, indicating that both the stresses control the subsequent slip behaviors. However, the attention to shear stress in the second set dramatically increases and far exceeds that to normal stress. The shear stress thus becomes the dominant control of slip behaviors, promoting the propagation of rupture front and the occurrence of dynamic slip [3]. The attention increase to normal stress during the subsequent inter-slip creep signifies the recovery of asperity contacts, restrengthening the fracture friction and leading to the multiple dynamic slip events. This study demonstrates the data-driven discovery using the DA-RNN model to better understand the evolution of experimental controls and the prediction of slip behaviors during fluid injection.

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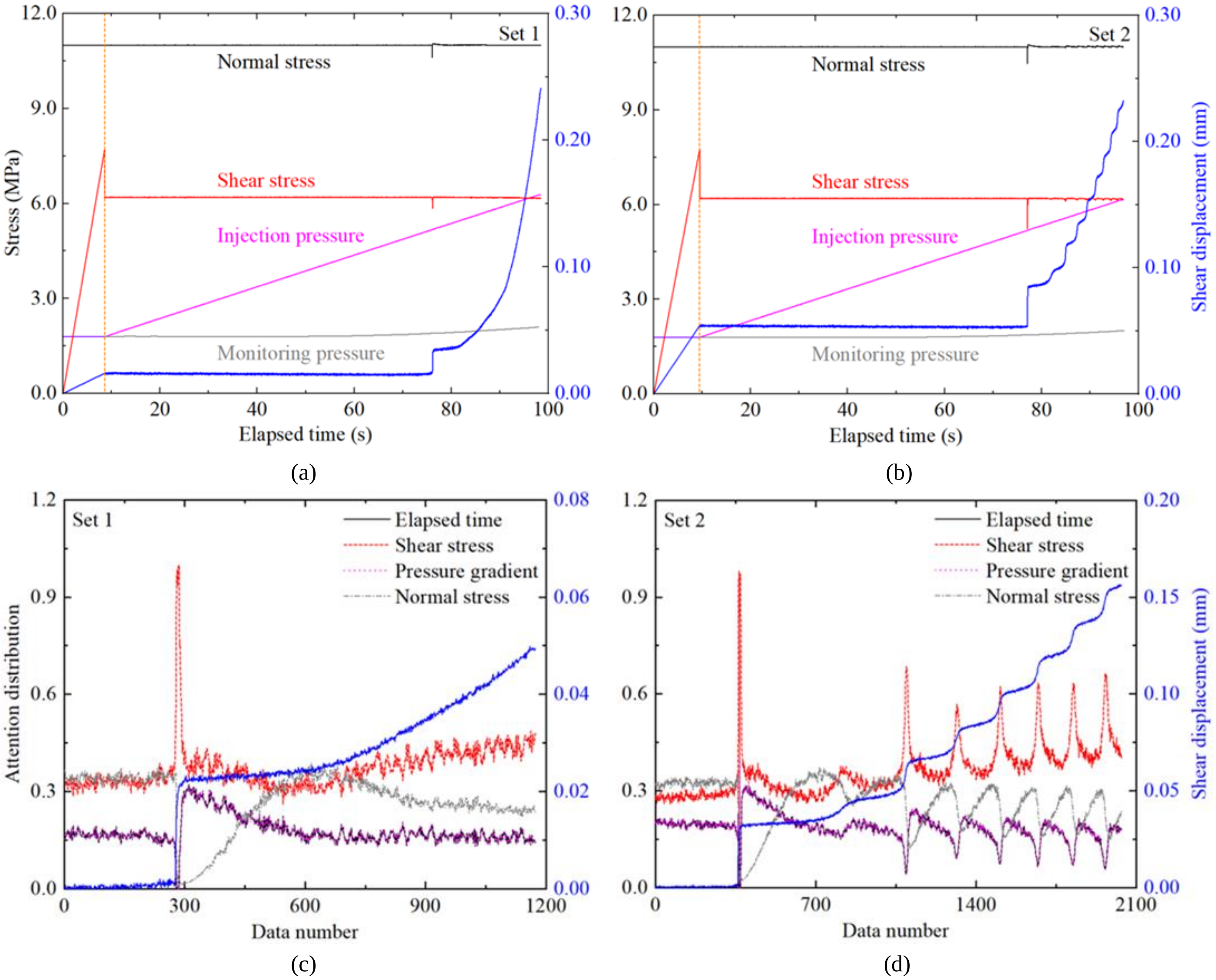

Figure 1: (a, b) Experimental results of sawcut fracture and (c, d) attention distributions of experimental controls.

Contributor statement

Zhou Fang: Methodology, Formal analysis, Investigation, Writing – original draft. Wei Wu: Conceptualization, Funding acquisition, Supervision, Writing – review & editing.

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