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Steady and transient sliding under rate-and-state friction

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Abstract

The physics of dry friction is often modelled by assuming that static and kinetic frictional forces can be represented by a pair of coefficients usually referred to as μ_s and μ_k, respectively. In this paper we re-examine this discontinuous dichotomy and relate it quantitatively to the more general, and smooth, framework of rate-and-state friction. This is important because it enables us to link the ideas behind the widely used static and dynamic coefficients to the more complex concepts that lie behind the rate-and-state framework. Further, we introduce a generic framework for rate-and-state friction that unifies different approaches found in the literature.

We consider specific dynamical models for the motion of a rigid block sliding on an inclined surface. In the Coulomb model with constant dynamic friction coefficient, sliding at constant velocity is not possible. In the rate-and-state formalism steady sliding states exist, and analysing their existence and stability enables us to show that the static friction coefficient μ_s should be interpreted as the local maximum at very small slip rates of the steady state rate-and-state friction law.

Next, we revisit the often-cited experiments of Rabinowicz (*J. Appl. Phys.*, 22:1373–1379, 1951). Rabinowicz further developed the idea of static and kinetic friction by proposing that the friction coefficient maintains its higher and static value μ_s over a *persistence length* before dropping to the value μ_k. We show that there is a natural identification of the persistence length with the distance that the block slips as measured along the stable manifold of the saddle point equilibrium in the phase space of the rate-and-state dynamics. This enables us explicitly to define μ_s in terms of the rate-and-state variables and hence link Rabinowicz's ideas to rate-and-state friction laws.

This stable manifold naturally separates two basins of attraction in the phase space: initial conditions in the first one lead to the block eventually stopping, while in the second basin of attraction the sliding motion continues indefinitely. We show that a second definition of μ_s is possible, compatible with the first one, as the weighted average of the rate-and-state friction coefficient over the time the block is in motion.

Keywords: stiction loss; stick-slip; friction angle; bistability; non-monotonic friction; slope stability; landslide.

1 Introduction

It has long been recognised that the force required to initiate sliding between two solid interfaces in (dry) frictional contact is usually greater than the force needed to sustain sliding, see [37] for a brief historical summary. This behaviour of solid frictional contact led to the distinction between the static and dynamic coefficients of friction, denoted μ_s and μ_k respectively, and forms the basics of Coulomb's model of friction [8, 46, 37]. Although being a convenient simplified description of the physics of friction, considering these two coefficients as different constants allows a first account to be made of the motion of a rigid block sliding on an inclined surface or the classical stick-slip phenomenon which characterises the saw-tooth dynamics of spring–block systems [8] and is also pertinent to many

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