Time-Dependent Friction and the Mechanics of Stick-Slip

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Abstract — Time-dependent increase of static friction is characteristic of rock friction under a variety of experimental circumstances. Data presented here show an analogous velocity-dependent effect. A theory of friction is proposed that establishes a common basis for static and sliding friction. Creep at points of contact causes increases in friction that are proportional to the logarithm of the time that the population of points of contact exist. For static friction that time is the time of stationary contact. For sliding friction the time of contact is determined by the critical displacement required to change the population of contacts and the slip velocity. An analysis of a one-dimensional spring and slider system shows that experimental observations establishing the transition from stable sliding to stick-slip to be a function of normal stress, stiffness and surface finish are a consequence of time-dependent friction.

Key words: Stick-slip; Friction.

Introduction

At the most general level laboratory observations of rock friction give reasonably consistent results. To a first approximation rocks like metals and most other materials obey two fundamental empirical laws. First, the frictional force is linearly proportional to the force acting perpendicular to the slip surface. Second, the frictional force is independent of the area of the sliding surface. Together these observations provide the conventional relationship between shear stress, \( \tau \), and normal stress, \( \sigma \), acting on the surface at the time of slip:

\[
\tau = \mu \sigma
\]  

(1)

where \( \mu \), the coefficient of friction, is assumed to be constant. Additionally, for rocks and most other materials \( \mu \) is generally insensitive to composition and hardness and has values between 0.5 and 1.0. On these points most experimentalists would agree.

However, more detailed observations reveal a variety of interesting phenomena and relationships that show \( \mu \) is not constant. Frequently, a given set of observations may prove to be elusive, defies intuitive explanation and is often found to apparently contradict some other set of experimental observations. This situation implies, of course, that unrecognized variables are affecting the results. Much of the recent published work on rock friction has dealt with the variables that may affect the

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details of frictional response. With the recent increased interest in the mechanics of
earthquake faulting as they bear on earthquake prediction, several questions related
to the cause of unstable fault slip (stick-slip) are of particular interest. Some topics
of interest that are discussed here include: the relationship between stick-slip and
stable sliding; the relationship between static and sliding friction; and the role of
preseismic slip to the stick-slip instability. It is the thesis of this paper that at least
partial solution to the above problems is found in fairly subtle interactions between
time-, velocity- and displacement-dependence of $\mu$ and the combined elastic charac-
teristics of the test machine and sample system.

**Time-dependency**

Time-dependency of static friction of rocks was first noted by DIETERICH (1970,
1972). In those experiments slip on surfaces of granite, graywacke, quartzite and
sandstone showed an increase of the coefficient of friction, $\mu$, with the logarithm of
the time of stationary contact (Fig. 1). For these experiments $\tau$ and $\sigma$ were held
constant for intervals as long as $10^5$ seconds. At the end of the interval, the shear

![Figure 1](image-url)

Time-dependence of the coefficient of static friction of quartz sandstone (from DIETERICH, 1972).