An Investigation of Certain Dynamic Instabilities in Dry Sliding – Findings

The dry frictional sliding of two flat *layered* half-spaces with a constant coefficient of friction was investigated. Self-excited oscillations were shown to exist for a wide range of material combinations. The magnitude of these dynamic instabilities depends on the shear moduli ratios and on the mismatches in the shear wave speeds of the sliding materials. Their existence is due to destabilization of waves at the sliding interface. These dynamic instabilities can eventually give rise either to partial separation or to regions of stick-slip. The greater the mismatch in shear wave speeds of the sliding materials, the less likely is stick-slip as opposed to loss-of-contact. Furthermore for a given material pair, high contact pressure and slow sliding speeds make stick-slip more apt to occur. The normal and shearing stresses at the bonded interfaces were also determined. These dynamic stresses can be greater in magnitude than the nominally steady-state stresses. Furthermore the dynamic stresses fluctuate rapidly as they travel with the slip wave velocity of the materials, rather than at the much slower sliding speed. *Thus an important result is that these dynamic stresses can play a significant role in delamination of surface layers.*

The effect of *surface waviness* on steady sliding has been investigated. Results include the determination of the effect of sliding speed and of the coefficient of friction on the contact area, contact pressure distribution, and gap opening displacements. It has been found that the speed and the friction coefficient can alter the contact area. The steady-state problem is of importance in the design of seals. Also the steady-state analysis forms the foundation for the study of the effect of waviness on the dynamic instabilities encountered in sliding, which is being investigated. At this point, the basic formulation and procedure for the steady sliding problem have been completed and some numerical results are being obtained.

The sliding of two different elastic half-spaces was investigated under the condition that the sliding speed sufficiently far from the interface is uniform. It was found that *stick-and-slip waves* (*i.e.* a superposition of slip waves which forms a rectangular wave in the contact pressure and in the slip velocity) can propagate along the interface and allow for the interface sliding conditions to differ from the observed sliding conditions. The slip waves may be generated by the recently discovered instability mechanism of steady sliding. It was found that the apparent coefficient of friction can be less than the interface friction coefficient. Furthermore the apparent friction coefficient can decrease with sliding speed even though the interface friction coefficient is constant. Hence the measured coefficient of friction does not necessarily represent the behavior of the sliding interface. *Thus an important finding is that slip-wave destabilization provides a physical mechanism which is capable of predicting a decrease in the coefficient of friction as a function of sliding speed.* Finally the presence of slip waves may make it possible for two frictional bodies to slide without a resisting shear stress. It is emphasized that many other effects may influence the negative slope of the apparent-coefficient-of-friction vs. velocity curve. Nonetheless it has been shown that the presence of slip waves can at least partially explain this commonly encountered friction phenomenon.

Two elastic half-spaces of different material properties, which are pressed together by a uniform pressure and subjected to a constant shearing stress, has also been investigated. The shear stress is less than is required to produce global slipping according to Coulomb’s friction law. Nonetheless it has been found that a *separation wave pulse* can exist which causes the two
bodies to slide without slipping. *Thus an important result is that two bodies can slide, due to a separation pulse, with less friction than would be necessary for global slipping.* The separation zone has a vanishing slope at its leading edge and an infinite slope at its trailing edge. However the order of the singularity at the trailing edge is small enough so as not to produce an energy sink. This work deals only with the *propagation* of the pulse; the mechanism which generates the pulse has not yet been addressed. Results for the pulse wave speed, the sliding distance, and the maximum gap opening, are given for various material combinations and for a range of the remote shear-to-normal-stress ratio.

In a related study the possible existence of an intersonic *slip-pulse* has been investigated, *i.e.* a finite-width region, on the interface, of altered normal and shear stress which satisfies the Amontons-Coulomb law of friction. Such pulses are shown to exist for sufficient friction and for modest mismatches in material combinations. The pulse is weakly singular at the leading edge and bounded at the trailing edge. Furthermore it travels at speeds just below the lesser dilatational wave speed and in the opposite direction of sliding of the lower wave-speed material. In addition, a pair of equations are given which relate the interfacial normal and shear stress to the interfacial slip velocity. These relations are analogous to the classical subsonic results of Weertman, but are valid for an arbitrary speed range. *This work is important in the area of slip and rupture dynamics along dissimilar material interfaces.*

The influence of *body waves* on the steady sliding of two elastic half-spaces has been investigated. It was shown that steady sliding is compatible with the formation of a pair of body waves (a plane dilatational wave and a plane shear wave) in each body radiated away from the sliding interface. This phenomenon exists if the friction coefficient is greater than a certain minimum value and occurs with a speed-dependent or with a speed-independent friction law. Each wave propagates at a different angle such that the trace velocities along the interface are equal. The angles of wave propagation are determined by the elastic properties, the densities, and by the coefficient of friction. The amplitude of the waves are subject only to the restriction that the perturbations in interface contact pressure and tangential velocity satisfy the inequality constraints for unilateral sliding contact. The possible existence of a slip pulse, formed by a superposition of these waves, has been established. Such a pulse constitutes a propagating slip zone in which the frictional slip condition is satisfied. *The formation of such a slip zone, surrounded by regions of stick, allows for the apparent friction coefficient to be less than the interface friction coefficient.*

It has also been found that an *incident rectangular dilatational wave* can allow for relative sliding motion of two elastic bodies with a ratio of remote shear to normal stress which is significantly less than the coefficient of friction. This reduction in friction is due to periodic stick zones which propagate along the interface. Thus it is possible that dilatational waves can be generated and used in order to cause two surfaces to slide with very little (ideally zero) or even with negative friction. Furthermore by changing the angle of the incident waves, the direction of sliding can be made to reverse. *This finding could lead to a new type of ultrasonic propulsion in which there is less frictional heating than in conventional ultrasonic propulsion.*