Particle Collisions

A necessary prerequisite for the understanding of interstitial fluid effects on granular material flows is the introduction of interstitial fluid effects into particle/particle interaction models such as that described in section (Npb). But the fluid mechanics of two particles colliding in a viscous fluid is itself a complicated one because of the coupling between the intervening lubrication layer of fluid and the deformation of the solid particles (Brenner 1961, Davis *et al.* 1986, Barnocky and Davis 1988). Joseph *et al.*(2001) have recently accumulated extensive data on the coefficient of restitution for spheres (diameter, D, and mass, m_p) moving through various liquids and gases to collide with a solid wall. As demonstrated in figure 1, this data shows that the coefficient of restitution for collision normal to the wall is primarily a function of the Stokes number, St, defined as $St = 2m_pV/3\pi\mu D^2$ where μ is the viscosity of the suspending fluid and V is the velocity of the particle before it begins to be slowed down by interaction with the wall. The data shows a strong correlation with St and agreement with the theoretical calculations of Davis *et al.* (1986). It demonstrates that the effect of the interstitial fluid causes a decrease in the coefficient of restitution with decreasing Stokes number and that there is a critical Stokes number of about 8 below which particles do not rebound but come to rest against the wall. It is also evident in figure 1 that some of the data, particularly at low St shows significant scatter. Joseph *et al.* were able to show that the magnitude of the scatter depended on the relation between the size of the typical asperities on the surface of the particles and the estimated minimum thickness of the film of liquid separating the particle and the wall. When the former exceeded the latter, large scatter was understandably observed. Joseph (2003) also accumulated data for oblique collisions that appear to manifest essentially the same dependence of the coefficient of restitution on the Stokes number (based on the normal approach velocity, V) as the normal collisions. He also observed characteristics of the tangential interaction that are similar to those elucidated by Maw *et al.*(1976, 1981) for dry collisions.

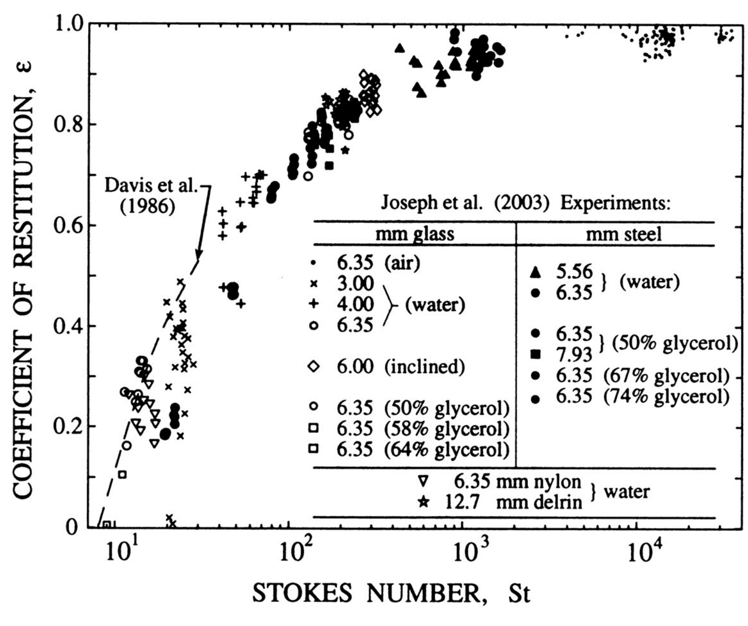

Figure 1: Coefficients of restitution for single particles colliding normally with a thick Zerodur wall. The particles are spheres of various diameters and materials suspended in air, water and water/glycerol mixtures. The experimental data of Joseph *et al.* (2001) is plotted versus the Stokes number, St. Also shown are the theoretical predictions of Davis *et al.* (1986).

Parenthetically, we note that the above descriptions of particle-particle and particle-wall interactions with interstitial fluid effects were restricted to large Stokes numbers and would allow the adaptation of kinetic theory results and simulations to those circumstances in which the interstitial fluid effects are small. However, at lower Stokes and Reynolds number, the interstitial fluid effects are no longer small and the particle interactions extend over greater distances. Even, though the particles no longer touch in this regime, their interactions create a more complex multiphase flow, the flow of a concentrated suspension that is challenging to analyze (Sangani *et al.* 1996). Computer simulations have been effectively used to model this rheology (see, for example, Brady 2001) and it is interesting to note that the concept of granular temperature also has value in this regime.