

Grain Flows

- Definitions
- Modes of flow

Grain flow

- Momentum exchange between particles is primarily a result of direct particle to particle contact
- Frictional regime - momentum exchange is dominated by rubbing of particles
- Collisional regime - momentum exchange is dominated by well-defined collision of particles

More Definitions

- Fluidization: the buoyant effect of an interstitial fluid passing upward at some threshold fluidizing velocity
- Saltation: the skipping or jumping of particles along the top or at the front of a channelized flow mainly through the effect of collisions with other particles or with the ground

Turbulent Suspension

- Particles are transported within fluid phase
- Buoyant effects dominated by turbulent eddies in the fluid
- No collisions with other particles or the ground
- Size of suspended particles in the cloud depends on the velocity of the flow.

More Definitions

- Laminar flow:
 - flow lines are parallel and flow is regular
- Turbulent flow:
 - flow lines are convoluted and the flow is chaotic

Turbulent Boundary Layer

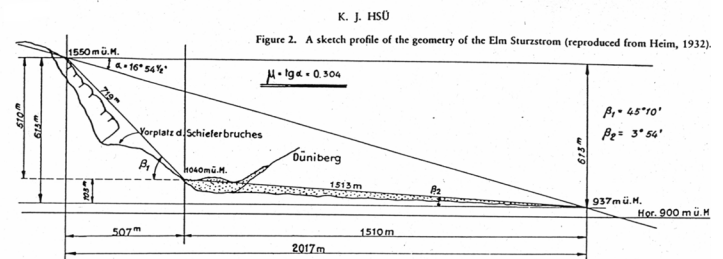
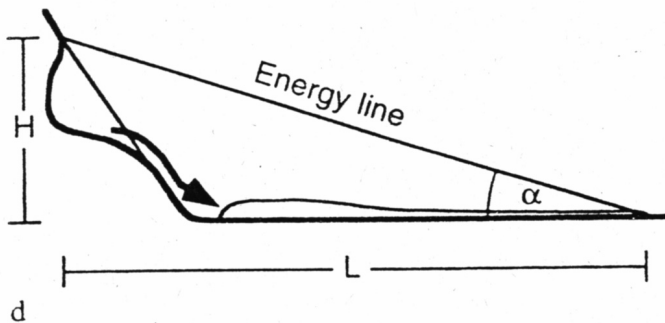
- Zone at the top of a dense flow
- Transition from saltation of grains to turbulent suspension in a cloud
- Controlled by the fluctuation of large eddies
- Extremely complex and impossible to model exactly.

General Modes of Grain Flow

- Shear-rate independent friction
 - Mohr-Coulomb yield criteria
- Shear-rate dependent friction
 - stress varies linearly with shear rate
 - stress varies as square of shear rate (Bagnold)

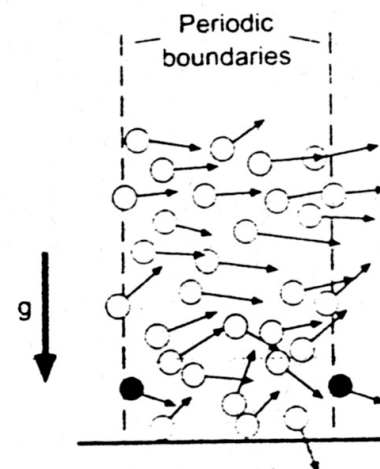
Mobility

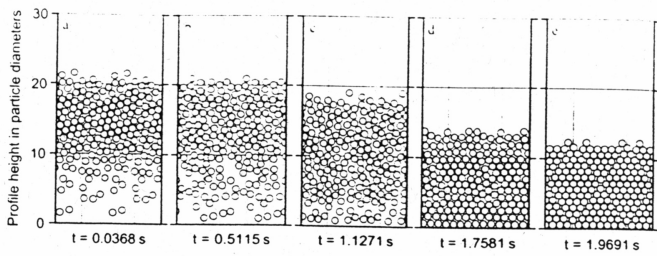
- Fluidization
 - An escaping internal fluid (gas) increases the mobility of the flow
- Acoustic fluidization
 - Energy from acoustic waves provides the mobility



Kinetic Theory of Collisions

- Elastic models
 - Conservation of kinetic energy of collisions
- Anelastic models
 - Conversion of kinetic energy to heat





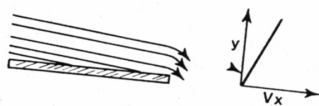
Categories (Ishida et al. 1980)

- Non-fluidized flows
 - Immature sliding flows
 - Sliding flows
 - Splashing flows
- Fluidized flows
 - Bubbling flows
 - Gliding flows

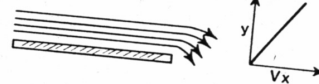
Velocity Profiles

Non-fluidized Flows

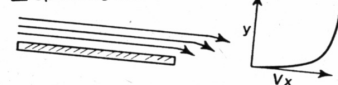
I Immature sliding flow



II Sliding flow



III Splashing flow



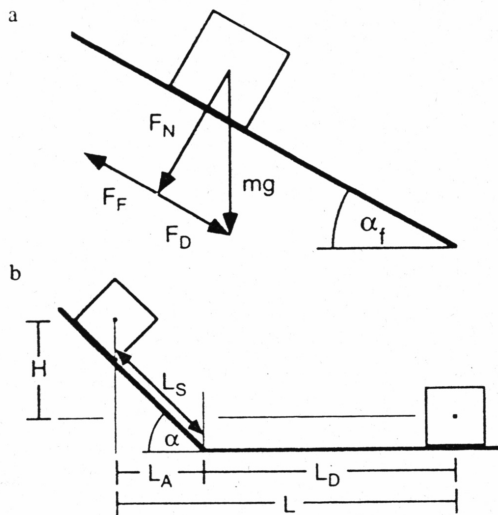
Fluidized Flows

IV Bubbling flow

V Gliding flow

Immature Sliding Flows

- Slope is nearly the angle of repose
- Wedge of non-moving material at base of flow
- Particle interactions dominated by friction
- Steep straight or convex velocity profile
- Distinct free surface at top of flow
- Stops at obstacles



Sliding Flows

- Higher angle slope than immature sliding
- All material in flow is moving
- Steep straight velocity profile
- Distinct free surface at top of flow with some jumping particles
- Stops at obstacles

Splashing Flows

- Concave velocity profile
- Chaotic particle motion
- Kinetic theory of motion applies
- Higher shear rate at base than at the top
- Vigorous saltation
- Top of flow is poorly defined
- Atmospheric drag at top of flow
- Deflected by obstacles

Other Flow Types

- Bubbling flows
 - Deflected by obstacles
 - Curved velocity profile
- Gliding flows
 - Deflected by obstacles
 - Curved velocity profile

Snow Avalanche Analog

- Mellor
- Rigid body slide

$$a_0 = g(\sin \alpha - \mu \cos \alpha)$$
- Motion resistance (τ)

$$\tau = a_0 + a_1 v + a_2 v^2$$
 - a_0 is a basal friction coefficient
 - a_1 is a viscous shear parameter
 - a_2 is for turbulent shear at the base and top of flow

Rapid Granular Flow

- Models of Denlinger (1987), Ishikawa et al. (1991), Straub (1996)
- Resistance stresses controlled by short-lived intergranular collisions
- Constitutive equation

$$\tau = \alpha \sigma d^2 (dv/dy)^2$$

