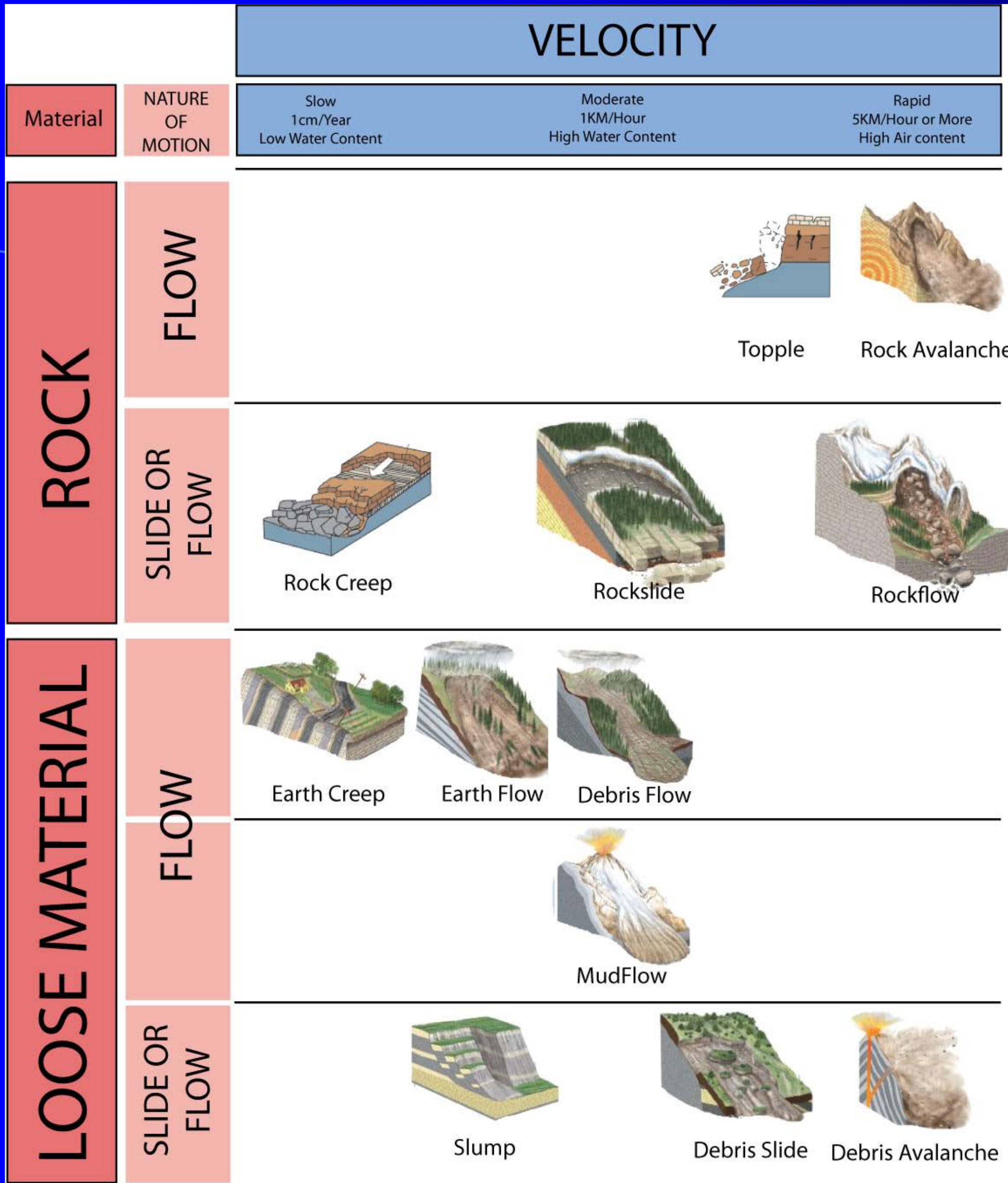
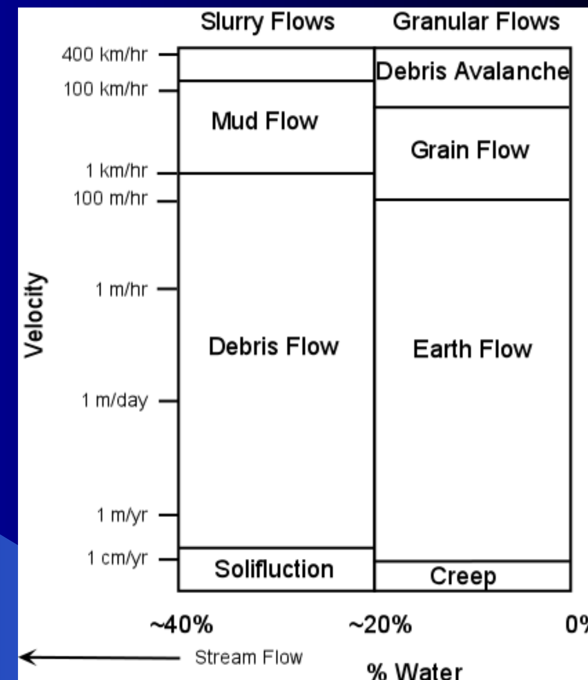
89.325 – Geology for Engineers
Mass Movement and Slope Stability


VELOCITY
Material
NATURE OF MOTION
Slow
1cm/Year
Low Water Content
Moderate
1KM/Hour
High Water Content
Rapid
5KM/Hour or More
High Air content
ROCK
FLOW
Topple
Rock Avalanche
SLIDE OR FLOW
Rock Creep
Rockslide
Rockflow
LOOSE MATERIAL
FLOW
Earth Creep
Earth Flow
Debris Flow
MudFlow
SLIDE OR FLOW
Slump
Debris Slide
Debris Avalanche


Slurry Flows
Granular Flows
400 km/hr
100 km/hr
1 km/hr
100 m/hr
1 m/hr
1 m/day
1 m/yr
1 cm/yr
Velocity
Mud Flow
Debris Flow
Solifluction
Debris Avalanche
Grain Flow
Earth Flow
Creep
~40%
~20%
0%
Stream Flow
% Water

Velocity class	Description	Velocity (mm/sec)	Typical velocity
7	Extremely rapid		
		5×10^{3}	5 m/sec
6	Very rapid		
		5×10^{1}	3 m/min
5	Rapid		
		5×10^{-1}	1.8 m/hr
4	Moderate		
		5×10^{-3}	13 m/month
3	Slow		
		5×10^{-5}	1.6 m/year
2	Very slow		
		5×10^{-7}	16 mm/year
1	Extremely slow		

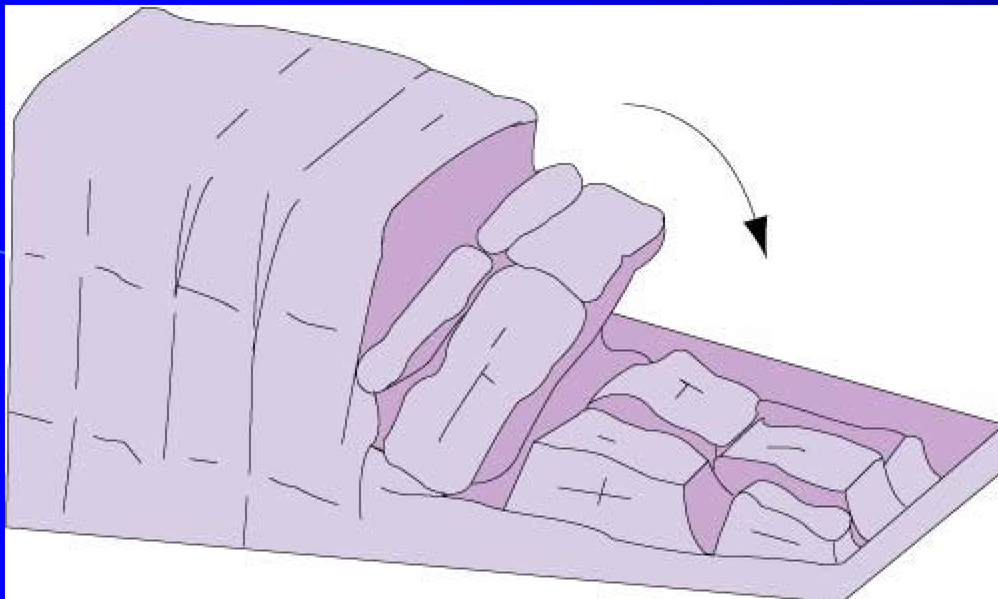
Table 13.2 Relative Level of Destructiveness for Slope Movements of Each Velocity Class

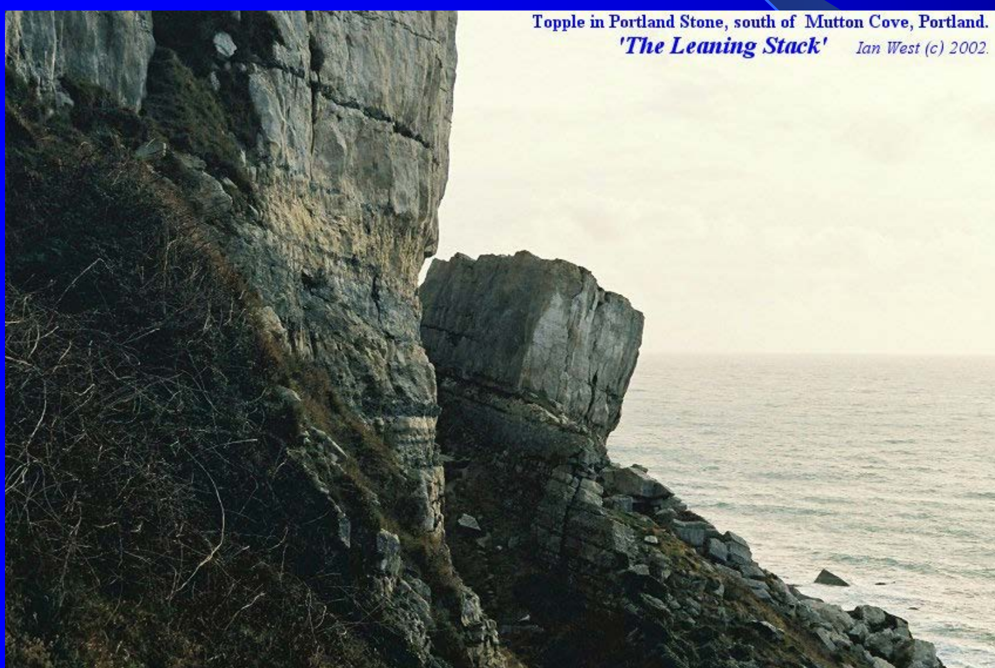
Landslide Velocity Class	Probable Destructive Significance
7	Catastrophe of major violence; buildings destroyed by impact of displaced material; many deaths; escape unlikely
6	Some lives lost; velocity too great to permit all persons to escape
5	Escape evacuation possible; structures, possessions, and equipment destroyed
4	Some temporary and insensitive structures can be temporarily maintained
3	Remedial construction can be undertaken during movement; insensitive structures can be maintained with frequent maintenance work if total movement is not large during a particular acceleration phase
2	Some permanent structures undamaged by movement
1	Imperceptible without instruments; construction possible with precautions

Source: D. M. Cruden and D. J. Varnes, 1996, Landslide types and processes, in *Landslides: Investigation and Mitigation*, A. K. Turner and R. L. Schuster, eds., TRB Special Report 247, Transportation Research Board, National Research Council, Washington, D.C.

Topple

Topple video





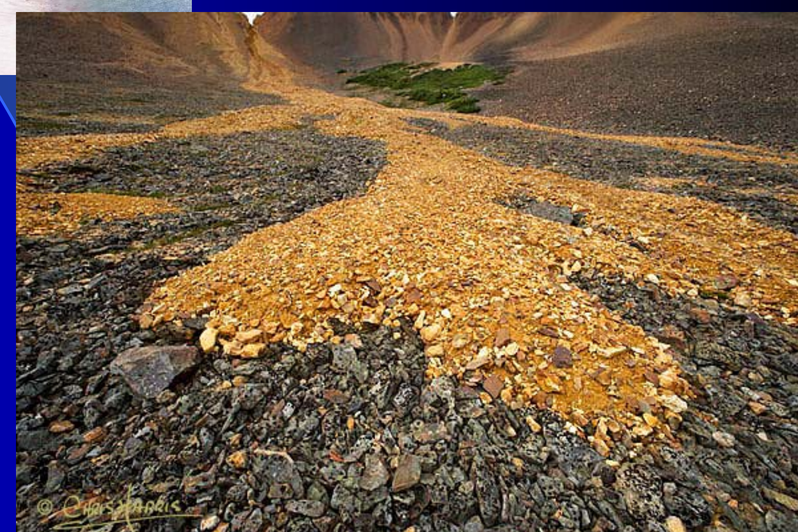
Rock Avalanche

Rock Avalanche video

Rock creep

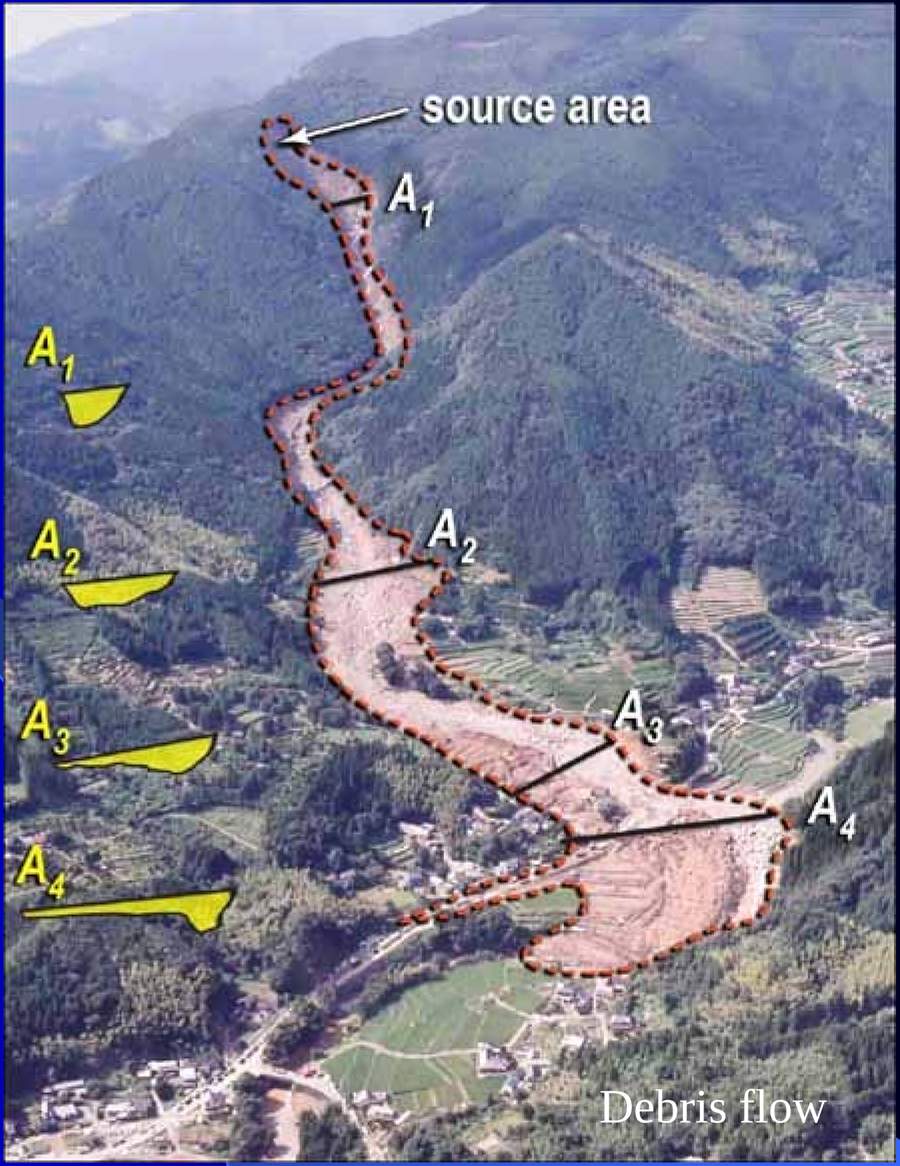
Rock slide

Rock flow

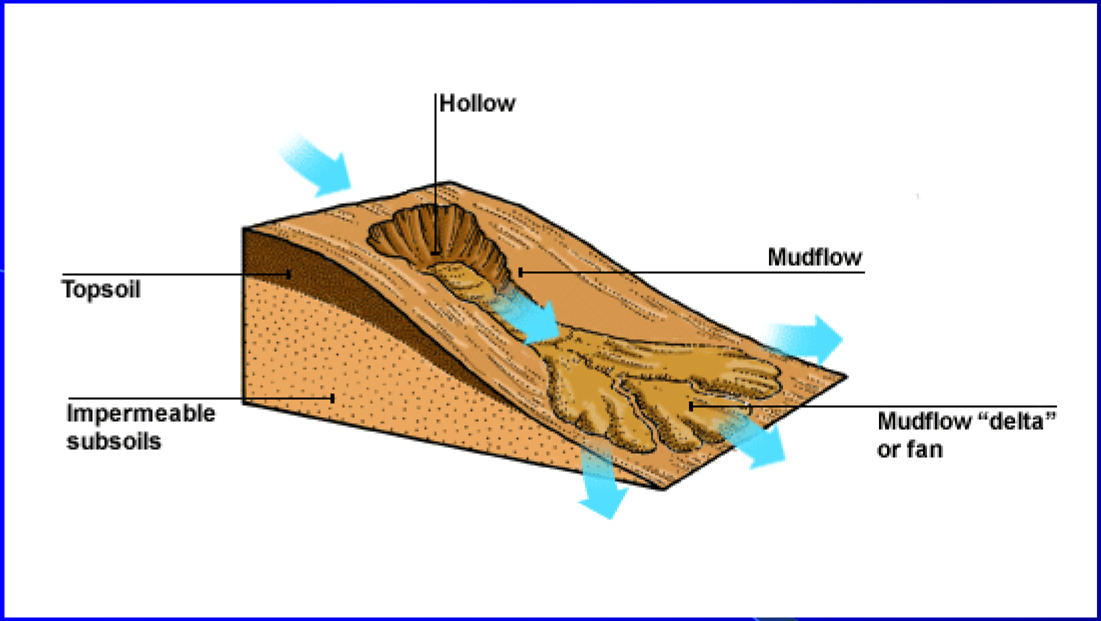



Creep

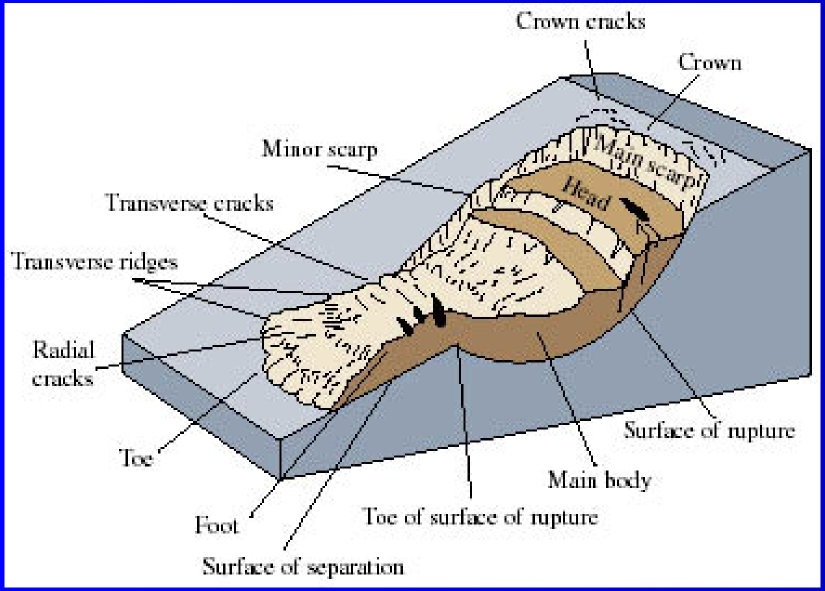

Earth flow

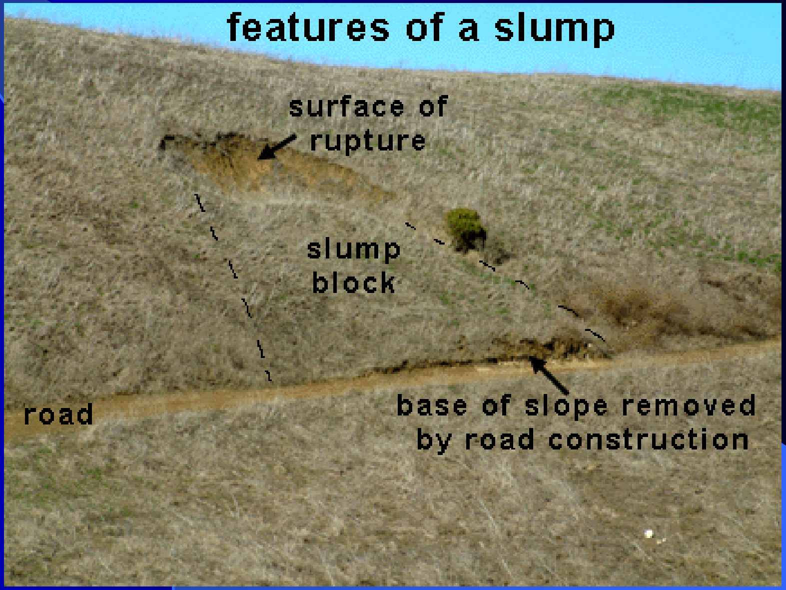

source area
A1
A2
A3
A4
Debris flow

Mudflow


Hollow
Mudflow
Topsoil
Impermeable subsoils
Mudflow "delta" or fan

Slump


Crown cracks
Crown
Minor scarp
Main scarp
Head
Transverse cracks
Transverse ridges
Radial cracks
Toe
Foot
Surface of separation
Toe of surface of rupture
Main body
Surface of rupture


features of a slump
surface of rupture
slump block
road
base of slope removed by road construction

Debris slide

Debris avalanche

Nicolet, Quebec lateral spread

Tropical Storm Irene and Mass Rt. 2

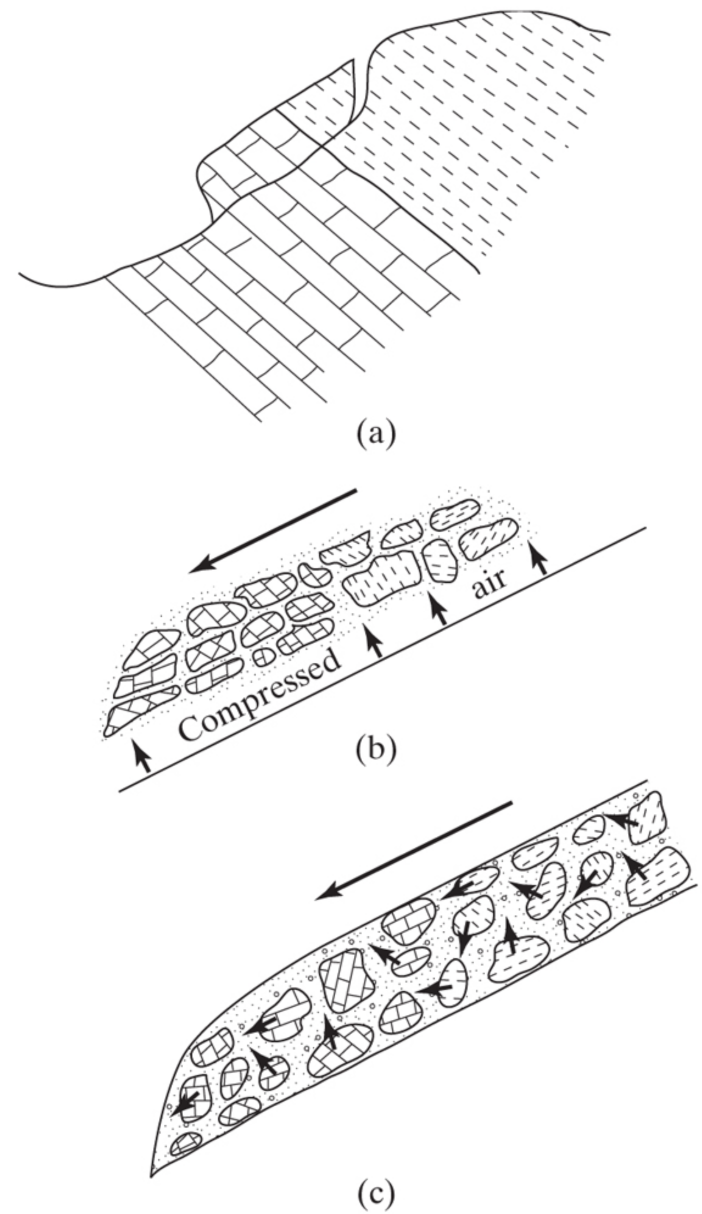
Hegben Lake Earthquake - Slide and Quake Lake

Flow mechanisms for rock avalanches

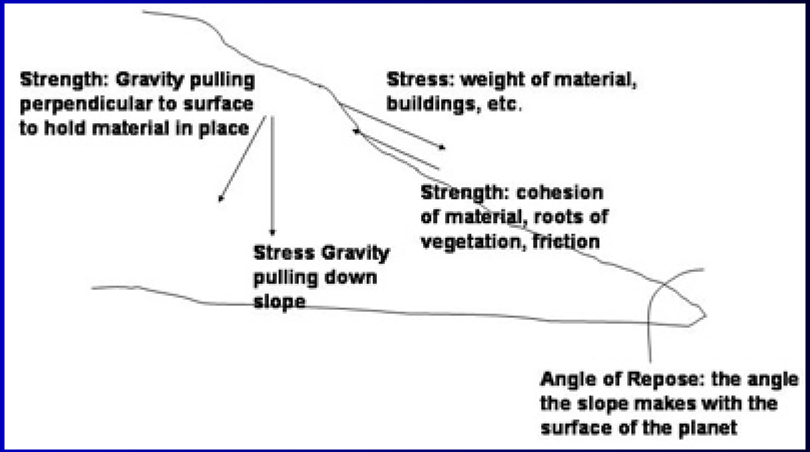
a. Block of rock launched into motion by earthquake or other triggering factor.

b. Debris slides on a layer of compressed air or

c. By grain flow, motion and stratigraphic order maintained by inertial collisions between trailing blocks and fragments ahead of them. Possible variant is acoustic fluidization where particles are in closer contact and are fluidized by acoustic (elastic) waves.



$$\text{Safety Factor (S.F.)} = \frac{\sum \text{resisting forces}}{\sum \text{driving forces}}$$



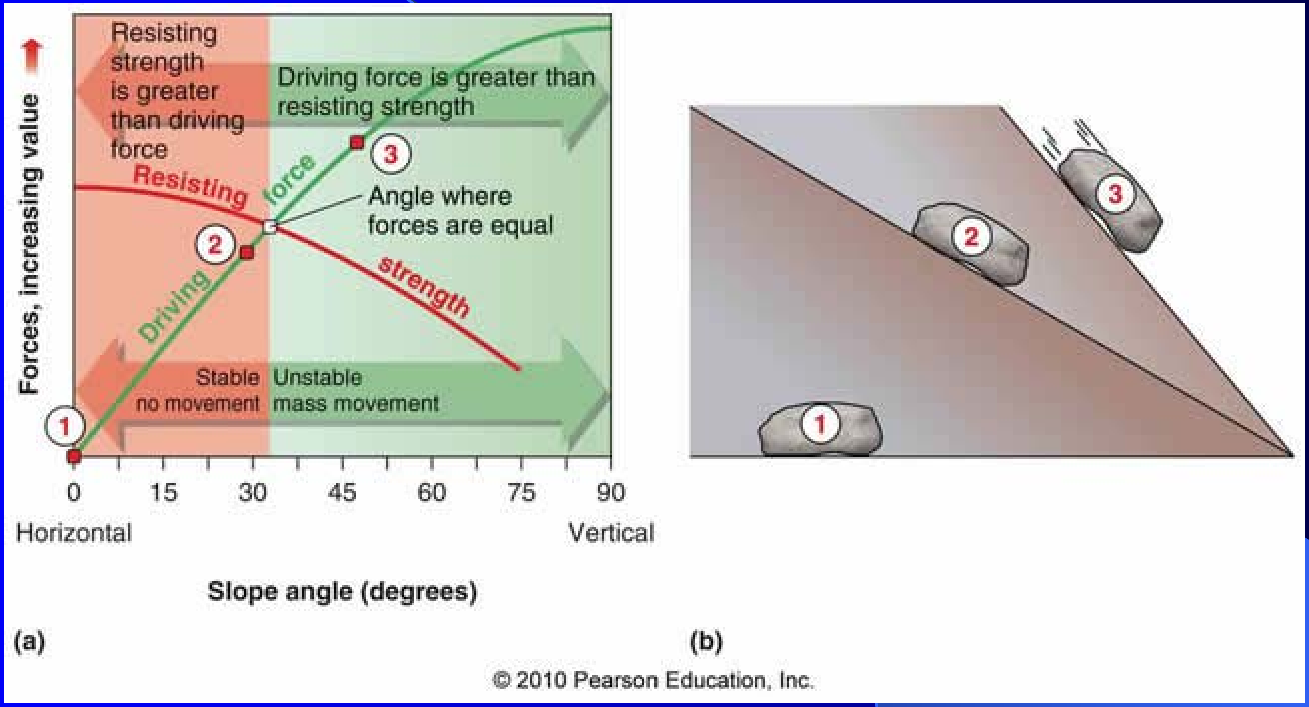


Table 13.3 Processes Causing Changes in the Safety Factor

Processes that cause increased shear stress

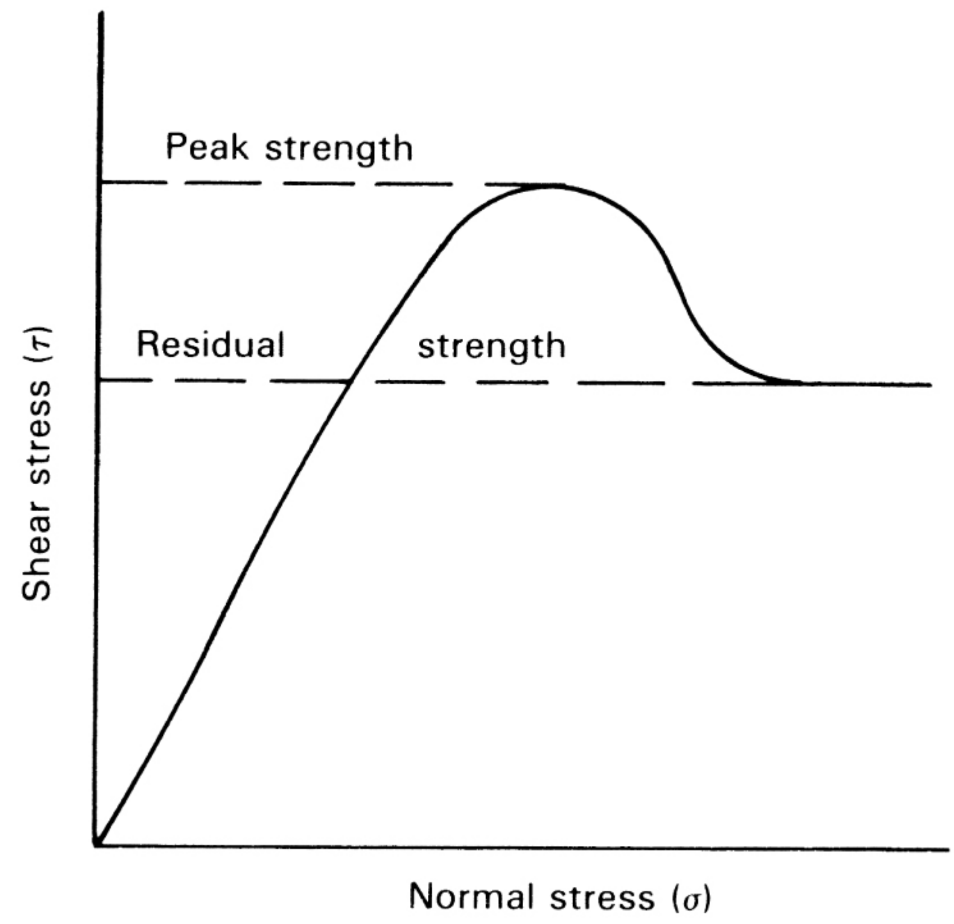
1. Removal of lateral support
   a. Erosion by rivers
   b. Previous slope movements such as slumps that create new slopes
   c. Human modifications of slopes such as cuts, pits, canals, open-pit mines
2. Addition of weight to the slope (surcharge)
   a. Accumulation of rain and snow
   b. Increase in vegetation
   c. Construction of fill
   d. Stockpiling of ore, tailings (mine wastes), and other wastes
   e. Weight of buildings and other structures
   f. Weight of water from leaking pipelines, sewers, canals, and reservoirs
3. Earthquakes
4. Regional tilting
5. Removal of underlying support
   a. Undercutting by rivers and waves
   b. Construction of underground mines and tunnels
   c. Swelling of clays

Processes that reduce shear strength

1. Physical and chemical weathering processes
   a. Softening of fissured clays
   b. Physical disintegration of granular rocks such as granite or sandstone by frost action or thermal expansion
   c. Swelling of clays accompanied by loss of cohesion
   d. Drying of clays resulting in cracks that allow rapid infiltration of water
   e. Dissolution of cement
2. Increases in fluid pressure within soil
3. Miscellaneous
   a. Weakening due to progressive creep
   b. Actions of tree roots and burrowing animals

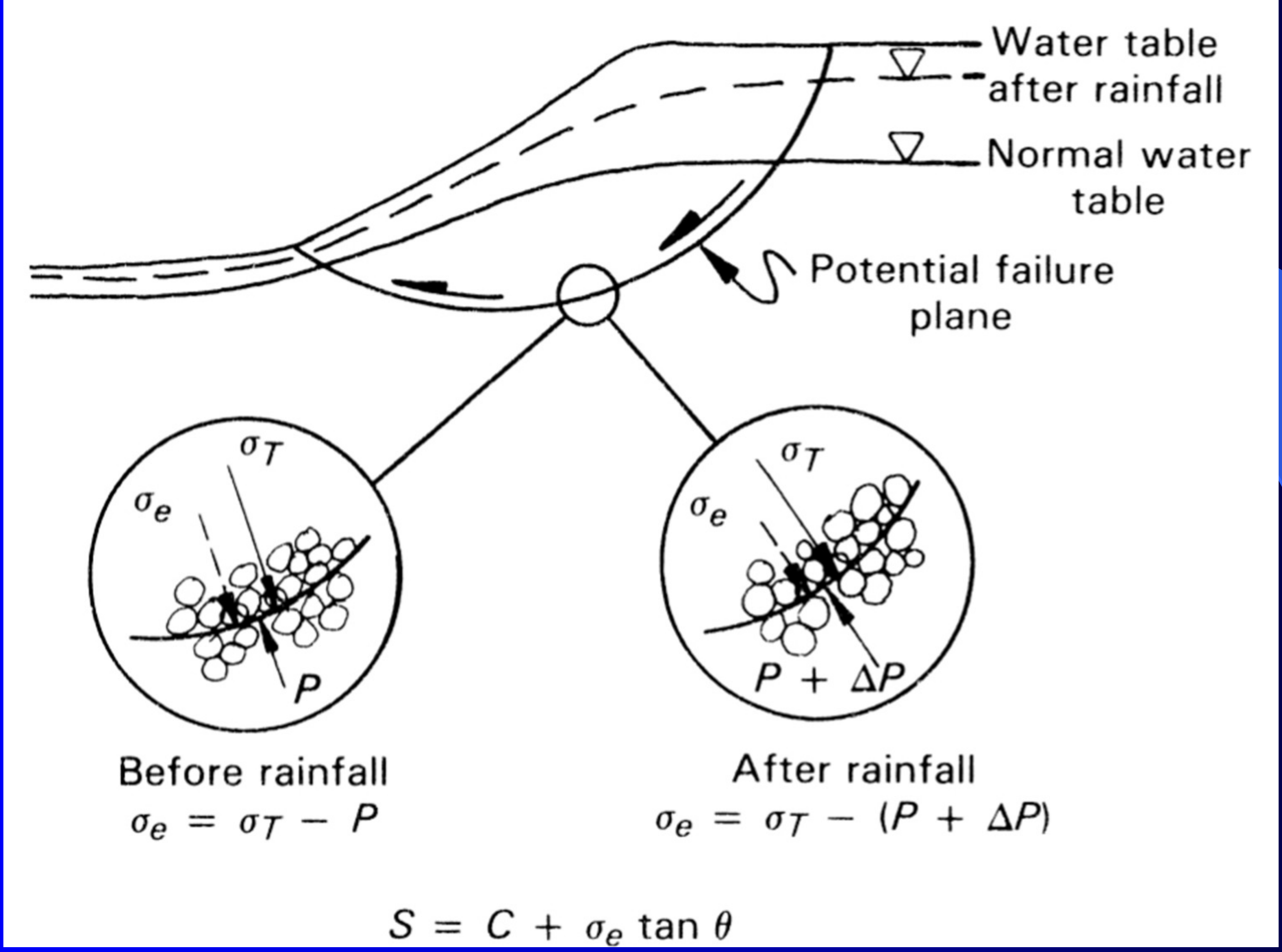
Overconsolidated clays

- Removal of overburden reduces pressure
- Expansion of clay leads to the development of fractures
- Peak strength of massive clay is greater than residual strength of fractured clay
- Laboratory tests done on small clay samples are not representative of the strength of the material

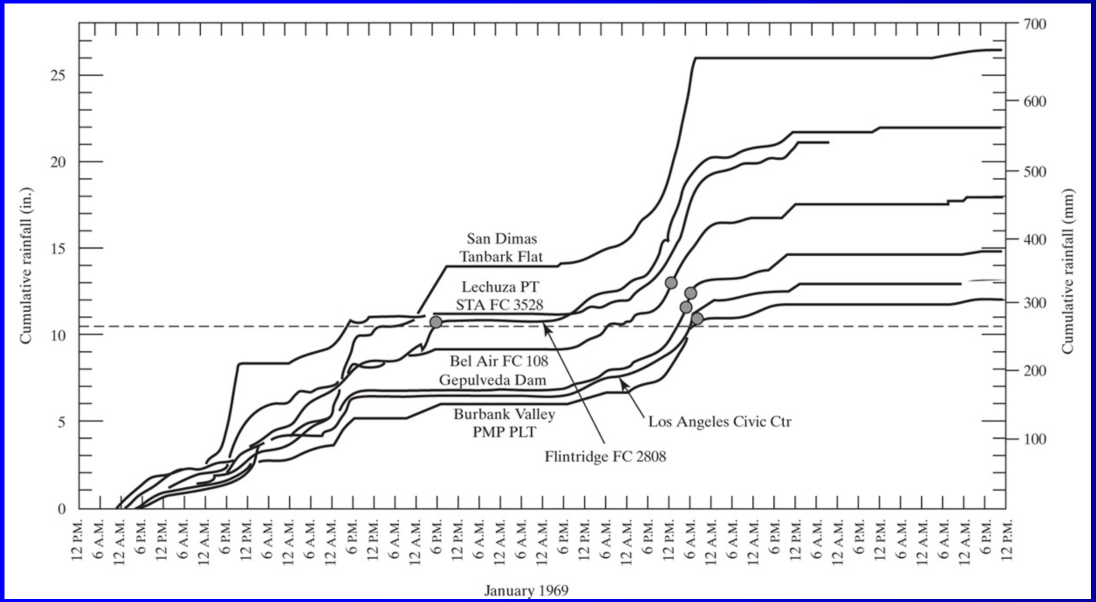


Influence of Water

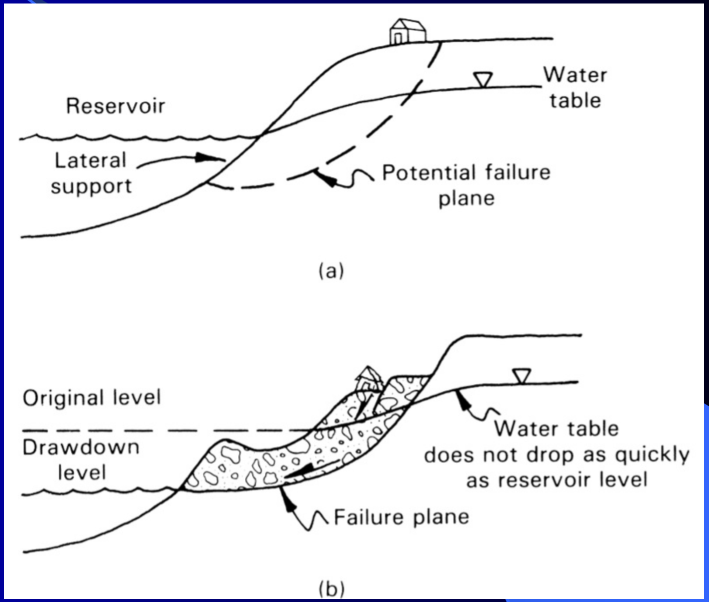
- Increase in fluid pressure (P) decreases effective stress (σ_e)
- Decrease in effective stress leads to a decrease in shear strength (S)



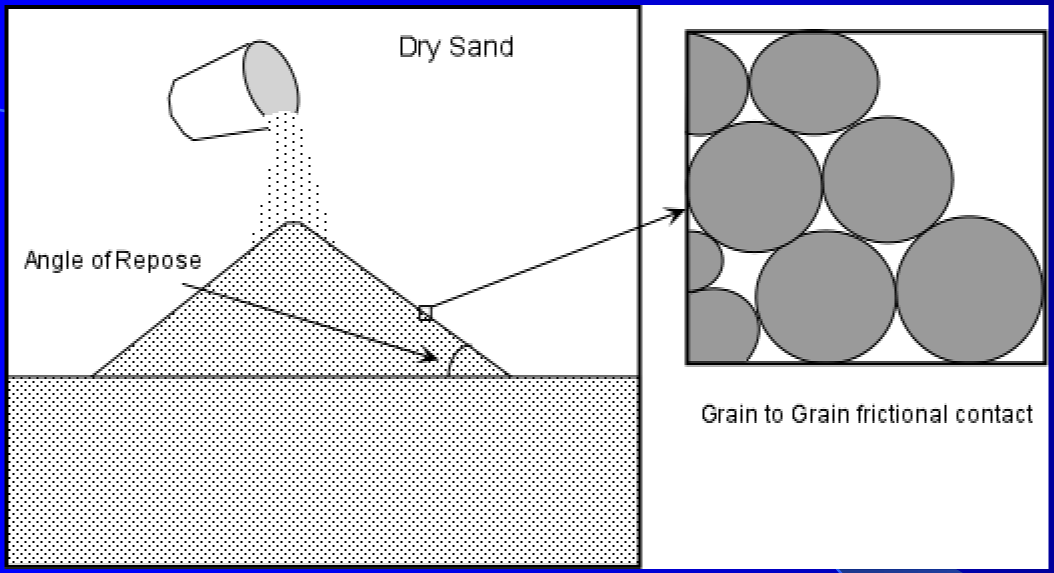
Relationship between periods of intense rainfall (shown by steepening of cumulative rainfall curves) and times of debris flows (represented by dots)

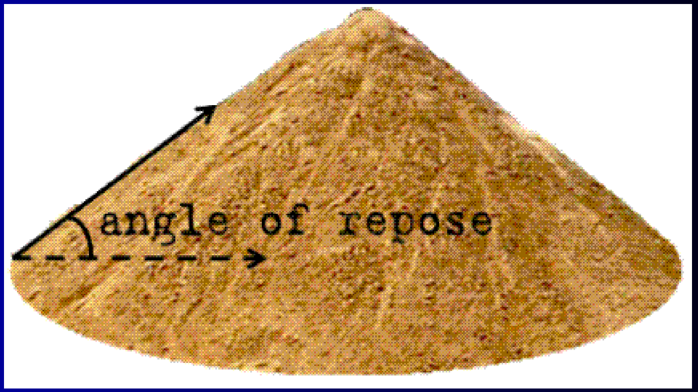


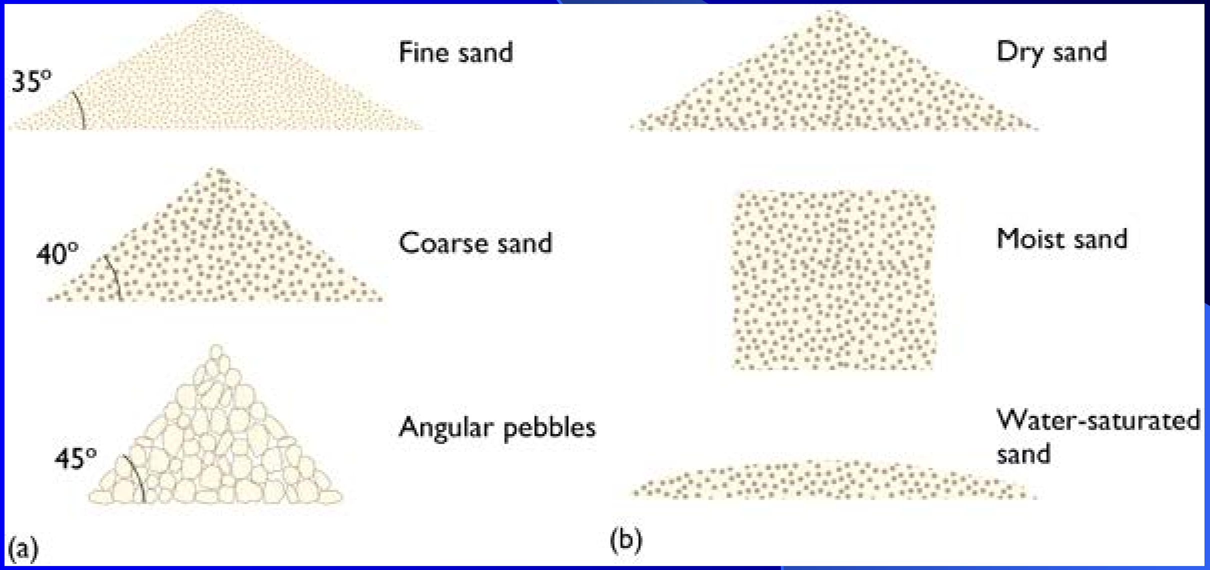
Reservoir bank failure due to rapid drawdown which removes lateral support with a concomitant decrease in effective stress due to delayed drop in water table.



Angle of repose - the maximum angle to the horizontal at which rocks, soil, etc, will remain without sliding.

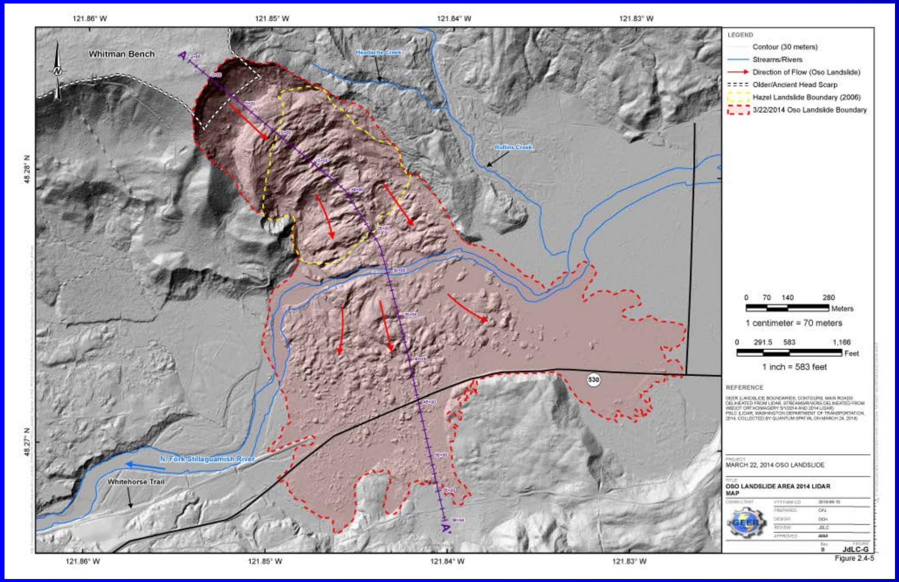




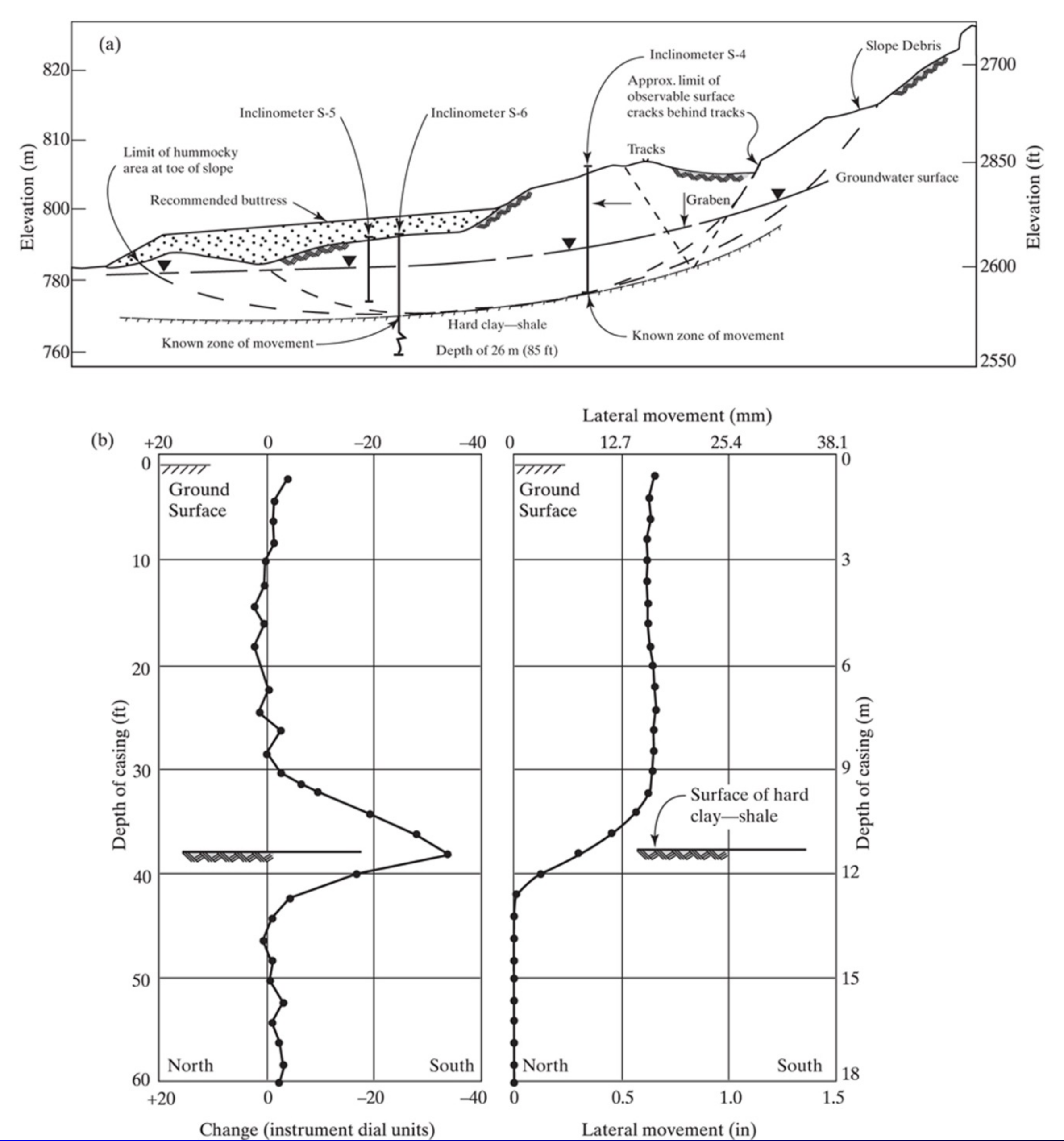


Recognition of Unstable Slopes

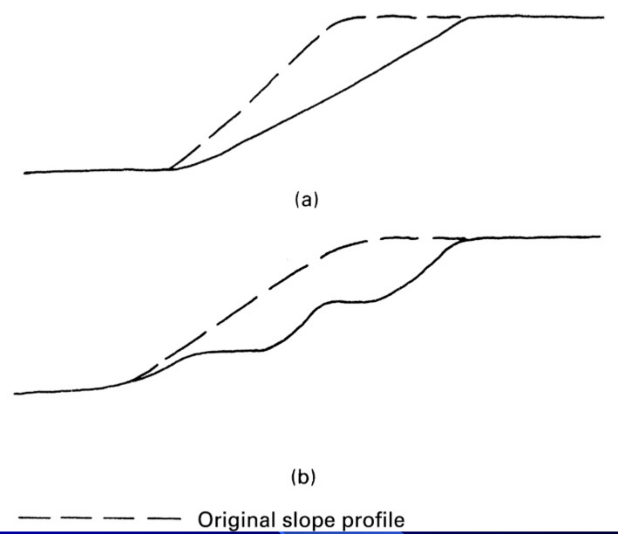
Recognition of Unstable Slopes
Bedrock and surficial geologic maps – reveal presence of materials susceptible to mass movement
Analysis of air photos and topographic maps – evidence of previous mass movement
Fracture and joint patterns
Locations of springs and seeps
Over-steepened slopes
Geophysical measurements – seismics, resistivity
Drill holes and core

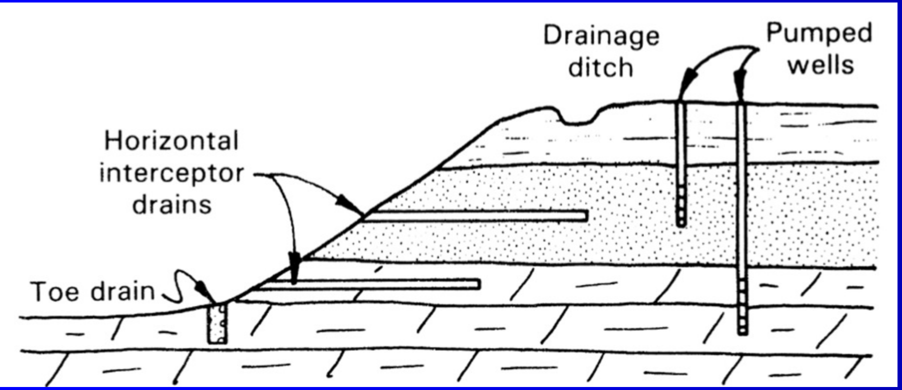


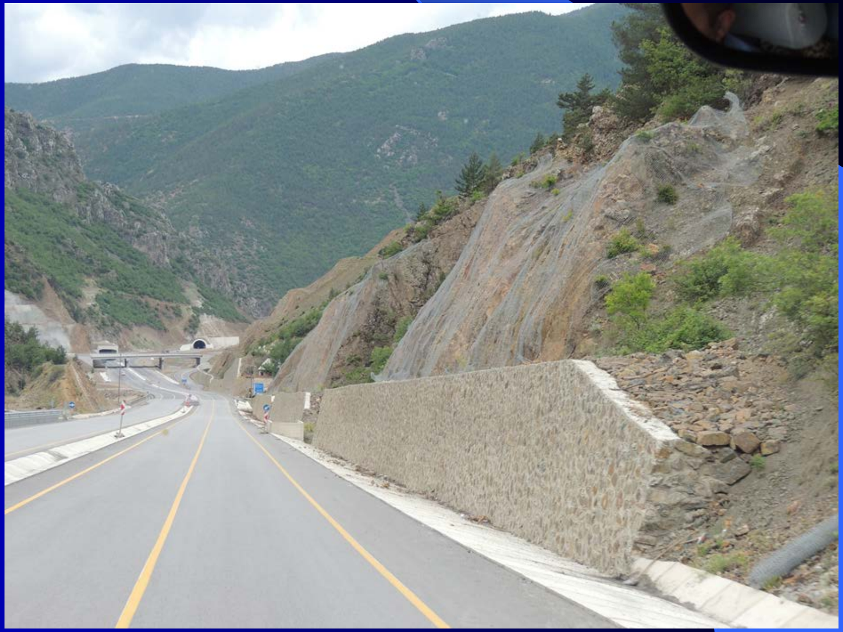
Monitoring downslope movement using inclinometers



Slope Stabilization
Reduce mass – flatten slope, excavate material, benching
Dewater slope
Retaining walls or fills at base of slope
Rock bolts







Retaining walls and benches - Turkey

Rock buttresses and rock bolts