Environmental Geology  
Chapter 10 SLOPE PROCESSES, LANDSLIDES, and SUBSIDENCE

- **Landslides** – General term used to describe all mass wasting events
- **Mass wasting** is the downhill movement of rocks, soil +/- water, under the direct influence of gravity. Mass wasting is the step that generally follows weathering to erode a landscape.
- Landslide and other ground failures posting substantial damage and loss of life
- In U.S., average 25 deaths; damage more than $1 billion
- Landslide and subsidence: naturally occurred and affected by human activities

- **Forces at Work**
  - The controlling force of mass wasting is gravity.
  - **Addition of water;** oversteepening (beyond the angle of repose) of slopes, seismic shaking (earthquakes), addition of weight to a slope, and removal of vegetation can increase the likelihood of and even trigger mass wasting

- **Slope Processes-Angle of Repose:** The angle of repose is the steepest angle that a pile of sediments or soil can maintain without collapsing. This is generally between 25 and 40 degrees. The larger and more angular the particles, the higher the angle of repose will be. Loose, dry sand (as in dunes, etc.) typically has an angle of repose of 33 to 34 degrees.

- **Slope Processes-Slopes:** The most common landforms: Dynamic evolving feature, depending upon topography, rock types, climate, vegetation, water and geologic time

- **Types of Landslides-Slope gradient, type of slope materials, amount of water present, rate of movement are factors.** The rate of movement may be imperceptible **creep** to thundering **avalanches.** **Types includes** creep, sliding, slumping, falling, flowage or flow, and complex movement (sliding and flowage). There are many different processes lumped under the term “mass wasting”. These processes are categorized and described on the basis of (1) the **type of material** involved (debris, mud, earth, or rock); (2) the **type of motion** (fall, slide, flow); and (3) the **rate of movement** (rapid or slow).

- **Slow Mass Wasting** - The slowest forms of mass wasting include creep, the gradual downhill movement of soil and fractured rock layers; and **solifluction,** a type of soil flow that is common in areas with **permafrost** (permanently frozen ground) under a thin soil layer that thaws (but remains saturated) in the warmer months.

- **Rapid (Fast) Mass Wasting** - Slumps, Rockslides, Debris flows, Earth flows
• **Avalanches** - The fastest versions of these processes are termed rock and debris avalanches
• **Slump**, *(the downward sliding of a mass of rock or soil moving as a unit along a curved surface)*
• **Rockslides** *(blocks of bedrock breaking loose and sliding downslope)*
• **Earth flow** *(an unconfined flow of saturated, clay-rich soil that often occurs in humid areas after heavy rains or snowmelt)*
• **Debris flow** *(rapid flow of soil and rocks mixed with water)*
• **Avalanches** - The fastest versions of these processes are termed rock and debris avalanches
• **Complex Slides** – Can start out as one type and change to another as the slide progresses *(e.g. La Conchita, CA – 1995 and 2005)*

• **Slope Stability**
  • Safety Factor
    SF = Resisting Forces/Driving Forces
    If SF > 1, Then safe or stable slope
    If SF < 1, Then unsafe or unstable slope *(MOST DANGEROUS)*

• **Driving and resisting forces determined by the interrelationships of the following variables:**
  - Type of Earth materials
  - Slope angle and topography
  - Climate
  - Vegetation and water
  - Time

  **Resisting Forces** *(e.g. Shear Strength) / Driving Forces* *(e.g. weight of rock)*

• **FACTORS THAT INCREASE CHANCES OF MASS WASTING**
  • Steep slopes
  • Excessive groundwater pumping
  • Adding weight *(e.g. building a house or using a bulldozer)*
  • Adding water – irrigation or rainfall
  • High relief
  • Lack of vegetation *(natural or removed by humans)*
  • Planes of weakness **parallel to slopes**

• **Human Land Use and Landslide- Factors that can increase landslide potential due to human land use:**
  • Urbanization, irrigation
  • Timber harvesting in weak, relatively unstable areas
  • Artificial fillings of loose materials
  • Modification of landscape
  • Dam construction
• **Vaiont Dam – Worlds Worst Dam Disaster - ~ 2600 deaths**
  - On October 9, 1963 in Italy – Landslide displaced water – overtopped the dam – flooding downstream
  - Landslide at 30 m/s or 60 mph
  - Generating waves of water up to 300 ft high
  - [http://seis.natsci.csulb.edu/bperry/Mass%20Wasting/Slides.htm](http://seis.natsci.csulb.edu/bperry/Mass%20Wasting/Slides.htm)
  - Multiple factors
    - Weak carbonate rocks and clayey layer
    - Geologic fractures, sinkholes
    - Steep slope surface and creep due to the increased water pressure of the reservoir

• **Preventing landslides**
  - Drainage control: Reducing infiltration and surface runoff
  - Slope grading: Reducing the overall slope
  - Slope supports: Retaining walls or deep supporting piles
  - Avoid landslide hazards: Warning of and correcting landslides

• **Warning of Impending Landslides**
  - Monitoring changes
    - Human surveillance – visual inspections
    - Instrumental survey: Tilt meter and geophones
    - Shallow wells – signal when slopes contain too much water
  - Landslide warning system
    - Info for public awareness and education
    - Enough time for public evacuation
    - Stop or reroute traffic flow
    - Emergency services

• **Snow Avalanche**
  - Mountainous region
  - Rapid downslope movement of snow and ice
  - Thousands of avalanches in the western U.S.
  - More deadly if large-slab avalanches
  - Preventive measures:
    - Well-designed explosives
    - Engineering structures to retain, divert, or retard avalanches

• **Lahars** - The eruptions of snow- and ice-capped volcanoes commonly trigger large mass wasting events involving the rapid downslope movement of water-saturated mud and rock flows termed **lahars**. These are often significantly larger hazards than the lava and ash erupted by the volcanoes because they can travel so rapidly and for such large distances (tens of kilometers or more).
• **Subsidence**
  - Subsurface ground failure
  - Occurred naturally or induced by human activities
  - Slow settling or rapid collapse
  - Causes: Withdrawal of fluids or removal of solid materials

• **Withdrawal of Subsurface Fluids**
  - In exploration and extraction processes
    - Petroleum and natural gas
    - Groundwater - sinkholes
    - Geothermal water and steam
  - **Louisiana – 1980** - Oil rig drilled through salt dome into a mine. A shallow lake drained – No lives lost. 10 barges, oil rig and a tugboat lost

• **Karst Topography** - In wet climates, limestone will get highly dissolved by groundwater, and **caves** and **karst** topography (from sinkholes that form by collapse into empty caves). The danger of sinkholes is greatly increased when man drops the water table and empties out these cave systems, removing the buoyancy force that helped hold up the cave roofs. Florida is an area where this geologic hazard is significant today.
  - Sinkholes
    - Dissolution of carbonate rocks, limestone, and dolomite
    - Affecting most of the conterminous states
    - Natural or artificial fluctuations in water table increasing the problem
    - Triggering other problems: Sinkholes as waste dumping sites

• **Removal of Solid Materials - Salt and coal mining**
  - Salt dissolution and pumping
  - Active coal mines and abandoned coal mines
  - Ground failure due to depleted subsurface pressure
  - More than 8000 km² of land subsidence due to underground coal mining

• **Ground Subsidence and Earth Fissures** - As groundwater is withdrawn, the spaces between grains collapse. Excessive pumping of groundwater can lead to **ground subsidence**, or a dropping of the land surface, which can produce earth cracks (**fissures**) and destroy buildings and roads. Arizona has experienced this in the past due to excessive pumping for irrigation of crops like cotton in the Phoenix and Casa Grande areas. In the San Joaquin Valley of California, there has been 26 feet of subsidence.

• **Perception of the Landslide Hazard**
  - Landslide hazard maps not preventing development
• Common perception: “It could happen on other hillsides, but never on this one.”
• Infrequency and unpredictability of large slides reducing awareness of the hazards
• Often people taking the chances

• What Can You Do?
  • Professional geologic evaluation for a property on a slope
  • Avoid building at the mouth of a canyon, regardless of its size
  • Consult local agencies for historic records
  • Watch signs of little slides—Often precursor for larger ones
  • Look for signs of structure cracks or damages prior to purchase
  • Be wary of pool leaking, tilt of trees and utility poles
  • Look for linear cracks, subsurface water movement
  • Put observations into perspective, one aspect may not tell the whole story