There are many types of slope failure. 
Slope failure, also referred to as mass wasting, is the downslope movement of rock debris and soil in response to gravitational stresses. Three major types of mass wasting are classified by the type of downslope movement: falls, slides, and flows. 

In addition, another type of ground failure: subsidence, is important to human existence. 

Material is constantly moving downslope in response to gravity. Movement can be very slow, barely perceptible over many years. 

Or, movement can be devastatingly rapid, apparent within minutes. Whether or not slope movement occurs depends on slope steepness and slope stability. 

Some slopes are gently rounded, while others are extremely steep. Profiles of naturally-eroded slopes are primarily dependent on climate and rock type.
Common Slope Elements

Slopes common in semiarid regions or on rocks resistant to weathering and erosion.

Convex-concave slopes common in semihumid regions or in areas with relatively soft rocks.

MASS WASTING PROCESSES

Flowage, or flow = downslope movement of unconsolidated material. Particles move around and mix with the mass.

Sliding = downslope movement of a coherent block of earth material.

Falling = free fall of earth material, as from a cliff, the free face of a slope.

Subsidence = sinking of a mass of earth material below the surrounding ground level; can occur on slopes or on flat ground.

Common type of landslide consisting of an upper slump motion and a lower flow.

Upper slump

Lower flow
Read Table 6.1 in Keller (2000)

<table>
<thead>
<tr>
<th>Type of Movement</th>
<th>Material Involved</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ROCK</td>
</tr>
<tr>
<td></td>
<td>SOIL</td>
</tr>
<tr>
<td>Falls</td>
<td>rockfall</td>
</tr>
<tr>
<td></td>
<td>soilfall</td>
</tr>
<tr>
<td>Slides</td>
<td></td>
</tr>
<tr>
<td>Rotational</td>
<td>rock slump block</td>
</tr>
<tr>
<td>Translational</td>
<td>rock slide</td>
</tr>
<tr>
<td></td>
<td>slump block</td>
</tr>
<tr>
<td></td>
<td>debris slide</td>
</tr>
<tr>
<td>Flows</td>
<td>Slow</td>
</tr>
<tr>
<td></td>
<td>rock creep</td>
</tr>
<tr>
<td></td>
<td>soil creep</td>
</tr>
<tr>
<td></td>
<td>earthflow</td>
</tr>
<tr>
<td></td>
<td>mudflow</td>
</tr>
<tr>
<td></td>
<td>debris flow</td>
</tr>
<tr>
<td></td>
<td>debris avalanche</td>
</tr>
<tr>
<td>Complex</td>
<td>combinations of slides and flows</td>
</tr>
</tbody>
</table>

When is a slope not stable?

Slope stability is based on the interplay between two types of forces: driving forces and resisting forces. Driving forces promote downslope movement of material. Resisting forces deter movement. When driving forces overcome resisting forces, the slope is unstable and results in mass wasting. The main driving force in most land movements is gravity. The main resisting force is the material's shear strength.

Gravity: Does gravity act alone? NO!! Slope angle, climate, slope material, and water contribute to the effect of gravity. Mass movement occurs much more frequently on steep slopes than on shallow slopes.

Water plays a key role in producing slope failure. In the form of rivers and wave action, water erodes the base of slopes, removing support, which increases driving forces. Water can also increase the driving force by loading, i.e., adding to the total mass that is subjected to the force of gravity. The weight (load) on the slope increases when water fills previously empty pore spaces and fractures. An increase in water contributes to driving forces that result in slope failure.
Resisting forces act oppositely of driving forces. The resistance to downslope movement is dependent on the shear strength of the slope material. And shear strength is a function of cohesion (ability of particles to attract and hold each other together) and internal friction (friction between grains within a material).

Chemical Weathering (interaction of water with surface rock and soil) slowly weakens slope material (primarily rock), reducing its shear strength, therefore reducing resisting forces.

IMPORTANT: The shear strength of the slope material is decreased by increasing the pore water pressure (pressure that develops in pore spaces due to the increased amount of water).

Safety Factor (SF) = \[
\frac{\text{Resisting Forces}}{\text{Driving Forces}} \]

If SF > 1 then SAFE
If SF < 1 then UNSAFE

NOTE: A safety factor of ~1.25 or somewhat higher is acceptable for slope stability. A safety factor of ~10 is often used in building design to accommodate slight variances in materials and construction practices.
Calculate the safety factor using $D$ to obtain driving force and $N$ to obtain resisting force. This is a simplified example, so the clay layer is assumed to have constant internal friction, i.e., the shear strength is the same everywhere, when wet.

$$D = W \sin A = \text{driving force}$$

- the downslope component of gravity.

$$N = W \cos A = \text{the normal component of W}$$

- contributes to the shear strength along the slip plane
- contributes to the resisting force.

The safety factor involving a clay layer may be calculated by the unit thickness method using the following equation:

$$SF = \frac{SLT}{W \sin A}$$

**EXAMPLE**

- $S = \text{shear strength of the clay layer} = 9 \times 10^4 \text{ N/m}^2$
- $L = \text{length of the slip plane} = 50 \text{ m}$
- $T = \text{unit thickness (assume 1)} = 1 \text{ m}$
- $W = \text{area (500 m}^2\times \text{ thickness (1 m)} \times \text{unit weight} (1.6 \times 10^4 \text{ N/m}^2) = 8 \times 10^4 \text{ N}$
- $A = 30^\circ$, $\sin A = 0.5$

$$SF = 1.125 \text{ (conditionally stable)}$$

Can you think of examples where this can be applied?
Ground material affects the pattern of slope failure:
Type # 1 → Homogeneous material leads to rotational failure.

![Homogeneous material leads to rotational failure](image1)

Ground material affects the pattern of slope failure:
Type # 2 → Material with planes of weakness leads to translational failure.

![Material with planes of weakness leads to translational failure](image2)

Ground material affects the pattern of slope failure:
Type # 3 → Rock and colluvium slope leads to soil slip failure.

**NOTE**: There are actually only two types of failure patterns, rotational and translational. Shallow soil slip is also a type of translational movement.

![Rock and colluvium slope leads to soil slip failure](image3)
**FLOWS**

Flows are the downslope movement of unconsolidated material in which the material behaves like a viscous fluid. Flows can be very slow or can be exceedingly fast.

**Creep**

a type of flow

Example: trees on a slope where the base of each tree bows outward in the downslope direction

What other examples can you see in daily life?

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**EFFECT OF WATER**

Perched water table decreases slope stability by causing temporary increase in pore water pressure which reduces shear strength in the earth material.

Colluvial soil; relatively permeable.

Bedrock; low permeability.

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**Influence of TIME on the development of a landslide:** progressive creep (left) and progressive wetting (right).
**SUBSIDENCE**

Depression is the result of subsidence. By definition, subsidence is the very slow to rapid sinking or settling of the land surface.

Subsidence can be the result of natural causes. Some type of carbonate rock underlies topography containing numerous natural depressions, known as sinkholes. The topography is known as karst topography. Limestone and dolomite, both carbonate rocks, are soluble and susceptible to chemical weathering. Chemical weathering produces void spaces (very very small to cavernously large). Sinkholes result when enough “support” has been removed from the carbonate layer. The surface then collapses into the void space, producing a sinkhole.

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**Retaining Wall**

Used to help stabilize a roadcut

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**Landslide near Dam**

Figure from Keller (2000)
Landslide on Road

A 1994 landslide near McClure Pass, Colorado. This area of the Rocky Mountains has chronic problems where roads cross landslide areas. Consequently, repairing the road is a never-ending problem. This photo was taken by Terry Taylor, Colorado State Patrol. USGS, Geohazards.

Landslide on Hillside Development

1996 landslide, Chehalis, WA. A failed residential development on a hillside. Photograph by K. L. Schuster, USGS.

Avalanche

Figures from Keller (2000)
Sinkhole in Karst Topography

Sinkhole at Winter Park, Florida. This sinkhole occurred in 1981. It is a common feature in karst topography. Photograph by A. S. Navar, USGS. Geohazard.