Slope failure mechanism

Slope movement is most common in open pit mines. Several mines continue to operate safely with moving slopes with the help of monitoring to enable timely warning against deteriorating stability conditions.

Slopes are designed with a factor of safety to control the risk of injury and equipment damage due to likely danger of slope failures and rock falls. Geological structures, rock mass properties, and hydrologic conditions are important elements for design of safe and efficient slope structures.

Slope never fails spontaneously. Prior to failure, slope provides indication in the form of measurable movement and/or the development of tension cracks.

Monitoring of slope stability and landslides involve selection of certain parameters and observing their behaviour with respect to time. The two most important parameters are displacement and groundwater levels.
Slope failure mechanism

analysis of slope monitoring results (a) Regressive movement, (b) Movement vectors showing circular failure mechanism, (c) Movement vectors showing toppling failure mechanism and (d) Slope velocity contours showing extent of slope movement (Wyllie and Munn, 1979).
**Initial response:** the amount of such initial response may vary from 150mm to 500 mm depending upon types of rock. The rate of movement during initial response period decreased with time and eventually showed no movement.

**Regressive and progressive movement:** The development of such cracks is evidence that the movement of the slope has exceeded the elastic limit of the rock mass. However, it is possible that mining can safely continue under these conditions with the implementation of a monitoring system.

**Long-term creep:** Long-term creep may occur where there is no defined failure surface, such as a toppling failure or where the change in slope geometry is very slow, for example, due to stress relief following glacial retreat or erosion at the toe by a river.
Types of slope movement: (a) typical repressive and progressive displacement curves; (b) structural geological conditions corresponding to types of slope movement (Broadbent and Zavodni, 1982).
Sub-surface monitoring methods

- Borehole probes
- Time-domain reflectometry
- Inclinometers
- Extensometers
- Measurement of water level and pressure
Borehole probes

One of the simplest sub-surface monitoring methods is the borehole probe comprising a length of reinforcing steel about 2m long that is lowered down the drill hole on a length of rope. If the hole intersects a moving slide plane, the hole will be displaced at this level and it will no longer be possible to pull the bar pass this point. Similarly, a probe can be lowered down the hole, and in this way both the top and bottom of the slide plane can be located.
Slope failure mechanism

This method involves grouting into a borehole, a co-axial cable comprising inner and outer metallic conductors separated by an insulating material. When a voltage pulse waveform is sent down the cable, it is reflected at a point where there is a change in the distance between the conductors.

Movement of a sliding plane that causes a crimp or kink in the cable is sufficient to change the impedance, enabling the instrument to detect the location of the movement.

TDR has proven an economical way to locate shear planes in active slides of both soil and rock masses. Using innovative cable placement, multiple shear planes can be detected. Even tension cracks can be detected from horizontal cable placement.
Time–domain reflectometry

Working mechanism of TDR system
computer aided data acquisition form TDR system.
Inclinometers

Slope inclinometers are geotechnical instruments used to measure horizontal displacements along various points on a borehole.

These are ideally suited to long-term, precise monitoring of the position of a borehole over its entire length. By making a series of readings over time, it is also possible to monitor the rate of movement.

The probe is also equipped with a pair of wheels that run in the grooves in the casing and maintain the rotational stability of the probe. It is required to extend the borehole below the depth of movement so that readings made from the end of the hole are referenced to a stable base. The depth at which shear movement is detected by the slope inclinometer is the depth of the failure surface. The portion of the casing that has not sheared, represents the area above and below the failure surface, if there is one failure plane impacting the casing.
Inclinometers

Inclinometer grooves, A+A- is the primary direction, B+B- is the secondary direction

various compounds of inclinometers
Inclinometer for measuring borehole deflection: (a) arrangement of grooved casing and inclinometer probe, (b) principle of calculating deflection from tilt measurement (Dunnicliff, 1993)
Borehole extensometers consist of tensioned rods anchored at different points in a borehole. A change in the distance between the anchor and the rod head provides the displacement information for the rock mass.

Extensometers measure the axial displacement between a number of reference points along same measurement axis. The wire extensometer is widely used and may be installed on the slope surface, or within a borehole.

The extensometer must also be anchored outside the zone of deformation, which can be an issue if the deformation area is large.
Extensometers

Multi Point Borehole Extensometer
Wire Extensometer
The usual method of monitoring water table in a slope is to drill and case a borehole. The water surface is located by dropping a measuring tape down the boring.

Piezometers can be used to measure pore pressure of the groundwater within a geological structure. Differential pore pressure measurements allow the changing structural and rainfall conditions to be mapped. Common types of borehole piezometers are the vibrating wire, pneumatic and standpipe piezometers.

The type of piezometer to be used depends on the level of permeability of the surrounding rock mass. Vibrating wire piezometers should be protected from electrical transients and must also compensate for local barometric pressure when used in wells that are open to the atmosphere.
These piezometers are used to monitor piezometric water levels using observational well. A standpipe piezometer consists of a filter tip joined to a riser pipe.

A water level indicator consists of a probe, a graduated cable or tape, and a cable reel with built-in electronics. The probe is lowered down the standpipe until it makes contact with water. Contact is signaled by a light and buzzer built into the cable reel. The water level reading is taken from the cable or tape. Typical applications of standpipe piezometer include monitoring of pore-water pressure to determine the stability of slopes and embankments and assessment of ground improvement techniques such as vertical drains, sand drains, and dynamic compaction.
schematic of a standpipe Piezometer
Pneumatic Piezometer

Working principle of Pneumatic Piezometer:

- **Inactive:** Transducer Pressure < Water Pressure
- **Activated:** Transducer Pressure > Water Pressure
- **Ready to Read:** Transducer Pressure = Water Pressure
Schematic diagram Vibrating Wire Piezometer installed in a hole
Surface Monitoring Methods

- Crack Monitors
- Surveying
- Photographic Image Analysis
- Total Station
- Global positioning system (GPS)
- Acoustic emission technique
- Laser image scanning system
- Slope Stability Radar system
- Synthetic aperture radar
Crack Monitors

method of monitoring tension wire in the cracks in slope
Pin crack meter measuring crack displacement
Survey system to remotely measure slope movement
Slope Stability Radar system

Visual of Alarm Trigger and Failure Surface
pictorial view of slope stability radar system
A SSR deployed in a surface mining site