10.1 Introduction

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. Groundwater, surface water, and precipitation runoff can be controlled to abate their deleterious effects on stability. Benches and berms are normally used to stop rocks before to fall prior and pose a significant hazard. Mechanical rock fall catchment systems or secondary supports may also be used to stabilize slopes in particular locations. However, even a carefully designed and constructed slope may fail because of unidentified geological structures, unexpected weather conditions, or seismic activities. For these reasons, regular examination and systematic monitoring of slopes are important for early detection of failure and associated hazard.

Slope never fails spontaneously. Prior to failure, slope provides indication in the form of measurable movement and/or the development of tension cracks. In contrast to this, landslide is a result of long-term movement of slopes creeping for hundreds of years resulting in accumulative movement of tens of meters. Such movement may be superimposed for a short period of more rapid movement resulting from major events like earthquakes. Undersuch conditions, 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 displacement can be characterized, in terms of depth of failure plane(s), direction, magnitude, and rate, using conventional slope monitoring, whereas, piezometers can be used for determination of water levels. Surveying of fixed surface movements deploying extensometers, inclinometers, and tiltmeters capture changes in direction and rate of slope movement depth and areal extent of the failure mass.

This chapter describes common methods of monitoring movement of slopes, and interpretation of the results. Here, it is considered that monitoring programs are most appropriate for active slopes such as open pit mines and quarries which have a limited operational life and where a carefully managed on-
going surveying program can be set up. The survey will enable to identify accelerating movement of
the slope and take measures to minimize the risk by moving operations away from the active slide.

10.2 Slope failure mechanism
Figure 1 shows a number of methods to analyse slope monitoring results that may help to identify the
mechanism of slope failure. This information can be useful in applying the appropriate method of
stability analysis and in the design of stabilization measures. The combined displacement and velocity
plot as shown in figure 1(a) depicts that the acceleration in the slope stopped after day 5. This change
in behavior is clearly evident on the velocity plot, whereas the velocity is constant after day 5. In
comparison, on the movement plot, the change in gradient is not so obvious. This slope movement
would be typical of regressive type instability. Figure 1(b) shows the magnitude and dips of movement
vectors for survey stations on the crest, mid-height and toe of the slide. The dip angles approximately
equal the dip of the underlying failure surface, indicating that a circular failure is taking place in which
the sliding surface is steep near the crest and near-horizontal at the base. This information also shows
the location of the toe of the slide, which may not be essentially coincide with the toe of the slope.
Figure 1(c) shows a movement vector for a typical toppling failure in which the stations located on the
overturning beds at the crest may move upwards by small amount, while there is little movement
below the crest. Figure 1(d) shows contours of slope velocity plotted along a plane of the pit show both
the extent of the slide, and the area(s) of most rapid movement.
10.3 Types of Slope Movement
There are different modes of deformation and failure that can exist within a steep slope. These failure mechanisms need to be understood in order to assist in a proper design of any monitoring scheme to be implemented for monitoring of a particular slope.

The prominent types of slope movement are as follows:

10.3.1 Initial response
When a slope is excavated or exposed, there is a period of initial response as a result of elastic rebound or relaxation of stress (Zavodni, 2000). This initial response is most common in open pit mines having rapid excavation rate. Martin (1993) reported that the amount of such initial response may vary from 150mm to 500 mm depending upon types of rock mass. The rates of movement during initial response period decreased with time and eventually indicate no movement.
10.3.2 Regressive and progressive movement

Following the period of initial response, slope failure can be indicated by development of tension cracks near the crest of the slope. 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. Eventually, an “operational slope failure” may develop which can be described as a condition, where the rate of displacement exceeds the rate at which the slide material can be safely mined (Call, 1982).

A clear distinction between regressive and progressive time–displacement curves (Figure 2) may be used as a practical means for differentiating plastic strain of the rock mass from operational failure of the slope. A regressive failure (curve A) is one that shows short-term decelerating displacement cycles if disturbing events external to the slope, such as blasting or water pressure, are removed. Conversely, a progressive failure (curve B) causes displacement at an increasing rate, unless stabilization measures are implemented (figure 2). Correct interpretation of the curves is valuable in understanding the slope failure mechanism and predicting the future performance of the slope.

Operations can be continued below slopes experiencing regressive movement, but it is necessary that the mining be conducted for short periods with frequent pullbacks, with care being taken to identify the transition to a progressive failure (Zavodni, 2000).
10.3.3 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. Other causes of such long-term movement are historical earthquakes that cause displacement, and climatic changes that result in periods of high precipitation and increased pore water pressure within the slope. In most of these cases, there is no evidence of recent movement because the rock surfaces are weathered and there is undisturbed soil and vegetation filling the cracks. It is possible that very slow creep developed, but no long-term monitoring program was available to confirm it. In such cases, presence of tension cracks does not necessarily indicate risk of imminent collapse. However, the hazard may be significant if there is evidence of recent movement such as disturbance to the soil and movement of blocks of rock, or there is a proposed change to the forces acting on the slope, due to excavation at the toe.
10.4 Sub-Surface Monitoring Methods

Sub-surface measurement is an useful component of a monitoring program to obtain a more complete picture of the slope behavior. The main purpose of these measurements is to locate the slide surface or sub surfaces, and monitor the rate of movement. In some cases, the holes are used for monitoring both movement and pore water pressures.

10.4.1 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. The advantages of the probe are the low cost and simplicity, but it provides little information on the rate of movement.

10.4.2 Time-domain reflectometry

Time-domain reflectometry (TDR) is another technique of locating a sliding surface, which can also monitor the rate of movement (Kane and Beck, 1996). 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. The reflection occurs because the change in distance alters the characteristic impedance of the cable. 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 (Figure 3 &4). 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.

The primary advantage of this technique is that the cable is inexpensive so it can be sacrificed in a rapidly moving slide mass. Also, the readings can be obtained in a few minutes from remote location either by extending the cable to a safe location off the slide, or by telemetry. The ability to make
remote readings can achieve significant savings compared to inclinometers because of the reduced travel time. The readout box directly shows the movement without the need to download and plot the results.

When combined with in-place tiltmeters and a datalogger, TDR can be used to determine the depth and direction of movement. Biaxial tiltmeters provide direction, while the TDR cable locates the depth at which movement is expected. The datalogger can be programmed to turn on the TDR cable tester and read the coaxial cable and the tiltmeters. A base station can be programmed to access the data through telemetry.

Figure 3: Working mechanism of TDR system
Figure 4: Computer aided data acquisition form TDR system.
10.4.3 Inclinometers

Slope inclinometers are geotechnical instruments used to measure horizontal displacements along various points on a borehole. For this reason, sometimes they are also called borehole inclinometers or simply inclinometers. 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 components of the inclinometer are a plastic casing with four longitudinal grooves cut in the inside wall, and a probe that is lowered down the casing on an electrical cable with graduated depth markings (Figures 5 & 6). The probe contains two mutually aligned accelerometers, to measure the tilt of the probe in mutually perpendicular directions. 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.
Figure 5: Various components of inclinometers

Figure 6: Inclinometer for measuring borehole deflection: (a) arrangement of grooved casing and inclinometer probe, (b) principle of calculating deflection from tilt measurement (Dunnicliff, 1993)
10.4.4 Extensometers

Borehole extensometers consist of tensioned rods anchored at different points in a borehole as indicated in Figure 7. A change in the distance between the anchor and the rod head provides the displacement information for the rock mass.

![Figure 7: Multi Point Borehole Extensometer](image)

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 (figure).

![Figure 8: Wire Extensometer](image)

A typical wire extensometers typically a measure baselines upto 80m in length with a precision of ±0.3mm per 30m of length (Gili et al., 2000). It offers high level of precision in the line of the measurement axis. The disadvantage, however, is that one dimensional displacement vector does not measure out-of-line displacements. The main sources of error in extensometers result from friction in the reference head and between the linkages, temperature induced sag, and the stress/strain...
characteristics between the linkages. All of these can have a significant impact on their use in a harsh mining environment. The extensometer must also be anchored outside the zone of deformation, which can be an issue if the deformation area is large.

10.5 Measurement of water level and pressure

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. It is more useful for simple water table situations. Other methods may be more desirable where monitoring is required on frequent basis. Under such cases, more sophisticated instruments like vibrating wire piezometers may be used.

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.
10.5.1 Standpipe Piezometer

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 (Figure 9). The filter tip is made of polyethylene or porous stone of 60 micron pores size. Riser pipe are installed downhole after the filter tip. A sand filter zone is terminated into place around the filter tip. The top of the filter zone is sealed with bentonite to isolate the porewater at the tip. The annular space between the riser pipe and the borehole is backfilled to the surface with a bentonite grout to prevent vertical migration of water. The riser pipe is terminated above ground level with a vented cap. Water levels in either the standpipe piezometer or the observation well are measured with a water level indicator.

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.
Figure 9: Schematic of a standpipe Piezometer.
10.5.2 Pneumatic Piezometer

A pneumatic piezometer operates by gas pressure. The piezometer is sealed in a borehole, embedded in fill, or suspended in a standpipe. Twin pneumatic tubes run from the piezometer to a terminal at the surface. Readings are obtained with a pneumatic indicator.

The piezometer contains a flexible diaphragm. Water pressure acts on one side of the diaphragm and gas pressure acts on the other. When a reading is required, a pneumatic indicator is connected to the terminal or directly to the tubing. Compressed nitrogen gas from the indicator flows down the input tube to increase gas pressure on the diaphragm. When gas pressure exceeds water pressure, the diaphragm is forced away from the vent tube, allowing excess gas to escape via the vent tube. When the return flow of gas is detected at the surface, the gas supply is shut off. Gas pressure in the piezometer decreases until water pressure forces the diaphragm to its original position, preventing further escape of gas through the vent tube. At this point, gas pressure equals water pressure, and the pneumatic indicator shows the reading on its pressure gauge. Figure 10 shows the working principle of pneumatic piezometer.

Various advantages of this piezometer include reliable operation, possibility of remote reading, no electrical component and indicator can be calibrated at any time. However, it suffers from a number of limitations such as accuracy depends on skill of operator, difficult and expensive to automate, requiring personal attention on site, reading time increases with length of tubing. There is also a chance that the pneumatic tubing can get blocked by condensation of dry nitrogen gas.
Figure 10: Working Principle of Pneumatic Piezometer
10.5.3 Vibrating Wire Piezometer

A vibrating wire piezometer is the most commonly deployed piezometer and is suitable for almost all applications. It consists of a vibrating wire pressure transducer and signal cable. It can be installed in a borehole, embedded in fill, or suspended in a standpipe. Readings are obtained with a portable readout or a data logger. It converts water pressure into a frequency signal via a diaphragm, a tensioned steel wire, and an electromagnetic coil. The piezometer is designed to cause a change in tension of the wire with change in pressure on the diaphragm. When excited by the electromagnetic coil, the wire vibrates at its natural frequency. The vibration of the wire in the proximity of the coil generates a frequency signal that is transmitted and recorded in the readout device or data logger. An increase in water pressure, reduces the tension in the wire by deforming the diaphragm inward thereby reducing the vibrating wire signal frequency. The readout device processes the signal, applies calibration factors, and displays a reading in the required engineering unit. One should read atmospheric pressure and the other downhole pressure. By subtracting the atmospheric from the downhole pressure, the true water level can be obtained. Key advantages of Vibrating Wire Piezometers include high resolution of 0.025% of full scale, high accuracy, rapid response and reliable signal transmission.
Figure 11: Schematic diagram Vibrating Wire Piezometer installed in a hole
10.6 Surface Monitoring Methods

In general, monitoring of the surface of a slide is likely to be less costly to set up and maintain than that of sub-surface measurements that require drilling holes to install the instruments. However, surface measurements can only be used where the surface movement accurately represents the overall movement of the slope. Other factors to consider in the selection of a monitoring system include the time available to set up the instruments, the rate of movement and the safe access to the site. These techniques include geodetic and terrestrial surveying, imaging techniques such as photogrammetry, and the use of satellite-based positioning techniques such as GPS. Other techniques include ground-based radar interferometry, satellite-based radar interferometry, microseismic emissions and laser scanning.

10.6.1 Crack Monitors

Measurement of width of the crack developed due tensile failure of the slope is a reliable and inexpensive means of monitoring slope movement. Figure 12 shows two methods of measuring crack widths. The simplest procedure is to install a pair of pins on either side of the crack and measure the distance between them with a steel tape (Figure 12). If there are two pins on either side of the crack, then the linear distance can also be measured to check the transverse displacement. The maximum practical distance between the pins is probably 2 m. Figure 13 shows a wire extensometer that can be used to measure the total movement across a series of cracks over a distance of as much as 20 m. The measurement station is located on stable ground beyond the cracks, and the cable extends to a pin located on the crest of the slope. The cable is tensioned using a proper weight, and movement is measured by the position of the steel block threaded on the cable.

Crack meters is also a very useful tool for early detection of deforming mass movements (Figure 13). It measures the displacement between two points on the surface that are exhibiting signs of separation. The distance between the pins is measured regularly to establish a time-series of the wall movements. Velocity and acceleration indicators can then be established for the time-series. The main disadvantage of this type of monitoring device is the risk involved with personnel making measurements on unstable ground. This issue is of concern for any technique that requires manual collection of the deformation data from the slope failure zone.
Figure 11: Method of monitoring tension wire in the cracks in slope
10.6.2 Surveying

On large slides where access to the slope is hazardous and there is a need to make frequent and precise measurements and rapidly analyse the results, surveying is the most suitable monitoring method. There are three components of a survey system.

1. One or several reference points on stable ground, which can be viewed from the instrument stations closer to the slide.
2. A number of instrument stations set up on reasonably stable ground at locations from which the slide is visible. If the co-ordinate positions of the movement stations are to be measured, then the instrument stations should be arranged such that they form an approximately equilateral triangle.
3. A series of stations set up just outside the slide area, located relative to the instrument stations. It is preferable that the measurement direction be in the likely direction of movement so that the distance readings approximate the actual slide movements.
10.6.3 Photographic Image Analysis

Digital camera and computer technologies provide tools to derive far more information from images than was possible just a few years ago. Small differences between pairs of images can be readily detected, changes can be quantified in pixel counts or area percentages, and images are time stamped for easy sequencing and animation. These capabilities can be used to enhance mine slope monitoring. McVey and others (17) used a 35-mm camera and carefully positioned reflectors to measure deformation over time in an underground mine. Processed film has been used to measure deflections to a resolution of 0.5 mm, but the use of reflectors adds substantial complexity to the installation process and limits analysis to sites with reflectors. Photographic change detection can be used in a time lapse mode to record such things as bench loading, fracture development, creep and mass movements, and fallen rock sources. A real-time slope monitoring system using low-cost video cameras can be used to generate rock fall warnings where workers could be at risk.

10.6.4 Total Station

Total station consists of a device to measure horizontal and vertical angles, along with capability to measure distance with help of Electromagnetic Distance Measurement (EDM) system. This allows the surveyor to measure 3D coordinates of points remotely, typically targeted by the placement of reflective prisms. It also permits recording of the data in a digital format to be later downloaded or
transmitted to a central processing site. The latest total station instruments are equipped with servo-
motors and automatic target recognition algorithms that reduce the need for personnel to physically
record the observations. Additionally, due to the introduction of reflectorless instruments, survey
prisms are no longer required at the slope surface. One advantage of using total stations to monitor
surface deformation is that the measurements can provide 3D position solutions of the point of interest.

10.6.5 Global Positioning System (GPS):

GPS is a radio navigation, timing and positioning system based on a constellation of 24 satellites in
orbit around the earth at altitudes of approximately 20000 km. These satellites emit continuous
electromagnetic waves coded on two frequencies (L1 = 1.2 GHz and L2 = 1.5 GHz). If the positions of
the satellites on their orbits are precisely known and if the antenna collects at least four satellites, the
receiver can solve by trilateration the three unknown factors (longitude, latitude, and height, or X, Y, Z
coordinates) defining its position.

For deformation monitoring, the GPS can be used in two different modes. The first method involves
high precision static methods such as Continuously Operating Reference Systems (CORS) that are
used to monitor regional scale deformations such as crustal dynamics, subsidence and geotechnical
movements. These continuous systems are normally combined to form permanent networks. The
second class of GPS technique is the use of episodic GPS data commonly used for monitoring on a
smaller scale (with baselines up to a few kilometres). The use of the episodic technique commonly
includes the monitoring of dams, open-pit mine walls and landslides. The primary technical
differences between the two GPS monitoring classes are the permanency of the GPS receiver locations
and the processing strategies employed to obtain deformation solutions.

GPS does not require direct line of sight between stations. The antennas, however, must have good sky
visibility, to receive the satellite signals without interference. It can work regardless of weather
conditions, and may be used with rain, mist or fog, strong sunshine, or at night. It can easily cover
larger areas than conventional surveying methods, with high precision.
10.6.6 Acoustic Emission Technique

The failure process of a rock slope is a transient phenomenon. Therefore, the rock slope undergoes fracture process irrespective to the duration of the deformation. During this process, low intensity elastic wave in the form of energy level are generated in the rock. The acoustic emission (AE) monitoring technique detects such waves generated due to initiation, formation and growth and coalescence of cracks. The characteristics of acoustic wave signal can be analysed to evaluate the location of the high energy zone. Further the intensity of the acoustic emission, dominant frequency and other associated wave characteristics can be used to access the propensity of an impending slope failure.

This techniques segregation of useful signal and filter of noise signal along with proper installation of Acoustic emission sensor for a meaningful use of the system. Detection of acoustic emission signal is very difficult in soil material and characteristics of waves propagating are different from that in the rock. Therefore, the system requires considerable knowledge of wave characteristic in different mediums for reliable analysis. It provides good results in hard rock mass.

Please provide better figure or event vs energy diagram. Hardy and hardy book

10.6.7 Laser image scanning system

3-D laser scanning has recently become popular in the mining industry because of its high precision and speed, which surpasses that of the traditional single-point measurement method. This technique captures the integrated, comprehensive, consecutive and associated panoramic coordinate data with high precision. It also describes factually the frame and configuration of the object. Therefore, the resulting estimates are closer to actual conditions. The rescale range analysis method and a 3-D laser image scanning system are used to obtain slope data. From this, the characteristic slope displacement may be analyzed.
A 3-D laser scanning system is capable to predict slope failure with better accuracy. However, the exact identification of a corresponding point in scan is a problem in this method.
10.6.7 Slope Stability Radar system

Slope stability is a critical safety and production issue for coal mines. A common technique to determine slope stability is to monitor the small precursory movements, which occur prior to collapse. It is a state-of-the-art development for monitoring slope movement in open pit mines. It offers unprecedented sub-millimetre precision and broad area coverage of wall movements through rain, dust and smoke. The real-time display of the movement of mine walls has allowed continuous management of the risk of slope instability at a mine operations level. There are two key roles where mines are now using the slope stability radar:

1. Safety Critical Monitoring: The radar is used during mining production as a primary monitoring tool of a designated unstable slope.
2. Campaign Monitoring: The radar is moved around the mine in a repeatable manner to compare movements at each site over an extended time, and determine problematic areas. Campaign monitoring in this manner is often used in metalliferous mines until determination of developing failure is observed.

The ‘slope stability radar’ has been developed to remotely scan a rock slope to continuously monitor the spatial deformation of the face. It is a technique for monitoring mine walls based on differential interferometry using radar waves. The system scans a region of the wall and compares the phase measurement in each region with the previous scan to determine the amount of movement of the slope. An advantage of radar over other slope monitoring techniques is that it provides full area coverage of a rock slope without the need for reflectors mounted on the rock face. The system offers sub-millimetre precision of wall movements without being adversely affected by rain, fog, dust, smoke, and haze. The system is housed in a self contained trailer that can be easily and quickly moved around the site. It can be placed in the excavation, or on top of a wall or on a bench to maximize slope coverage whilst not interfering with operations. The scan area is set using a digital camera image and can scan 320 degrees horizontally and 120 degrees vertically. The system provides immediate monitoring of slope movement without calibration and prior history. Scan times are typically every 1-10 minutes. Data is uploaded to the office via a dedicated radio link. Custom software enables the user to set movement thresholds to warn of unstable conditions. Data from the SSR is usually presented in two formats. Firstly, a colour ‘rainbow’ plot of the slope representing total movement quickly enables the user to determine the extent of the failure and the area where the greatest movement is occurring. Secondly, time/displacement graphs can be selected at any locations to evaluate displacement rates.
The SSR units have operated within highly variable geotechnical conditions including massive hard rock, intensely fractured, foliated ultramafics, weathered oxide pits, coal strata and waste dumps of variable characteristics. It permits users to enter parameters that define the conditions for alarm generation. Four alarms are often used at an operation

- Red Alarm – it is used as a critical alarm situation where an emergency situation is announced and the pit superintendent is notified to evacuate the area of concern as well as calling the geotechnical department.
- Orange Alarm – also called ‘geotech alarm’ where movements indicate a developing situation that the geotechnical department should be made aware of for providing guidance.
- Yellow Alarm – it is indicative of system failure in the radar which results in the pit superintendent being notified that the radar is unavailable and geotechnical department notified to assess the SSR.
- Green Alarm – it indicates a minor system failure where the SSR is shutdown and SSR viewer program restarted as per procedure.

The selection of alarm triggers is done on a custom basis by the mine geotechnical personnel as alarms can be set up on threshold displacement, time (using time and displacement to get a velocity trigger) and size of failure (figure 14). The SSR data is continuously dispatched to the control room and screened. When an alarm is triggered, on screen instructions with the alarm ensures that the appropriate target action response plan is undertaken.
The typical system consists of two main parts: the scanning antenna and radar electronics box connected via an umbilical cable (Figure 15). The scanning antenna consists of a 0.92m diameter parabolic dish mounted on a sturdy tripod and controlled by separate motors and gears for azimuth and elevation movement. The beamwidth of the antenna is approximately 2°.

The electronics box can position the parabolic dish to anywhere between –15° and 165° in elevation from the horizontal, and between –170° and 170° in azimuth. The 2D scan region is set manually for the application. The scan speed is approximately 25 minutes for 4000 pixels on the wall. The pixel size on the 2D image is determined by the range extent of a 1° angle increment. For a rock slope at 100 metres range, the pixel size is 2m x 2m approximately. Two-by-two pixels constitute one spatial resolution cell provided by the 2° beam divergence of the antenna.
One of the primary roles of the SSR is identifying unstable slopes. The broad area coverage and almost real time scanning means that large expanses of slope (e.g. 500,000 m²) can be scanned and results obtained in less that 10 minutes. After a relatively short time, areas of stable slope can be identified, as well as those areas that are showing greater deformation than expected (providing they show deformation greater than a millimetre). This increased deformation may represent areas of slope instability, possible leading to collapse.
**Synthetic aperture radar**

A technique for precise monitoring of movement over large areas is to use radar satellite remote sensing techniques. This technique is known as Interferometric Synthetic Aperture Radar (SAR) and involves capturing a radar image of the ground surface, which is then compared with images taken at a different time to obtain the relative ground movement. Significant features of this technique are that the image can cover an area as large as 2500 km² and relative movements can be measured in the range of 5–25 mm. The measurements are independent of the weather, cloud cover and daylight condition.

Every material on or off the earth’s surface reflects light in a characteristic pattern; the manner in which light of different wavelengths is reflected or absorbed from each material is known as its reflectance spectrum. By filtering reflected light to specific wavelengths (colors in the visible part of the spectrum), images can be created that enhance our ability to differentiate materials. Multispectral imaging makes use of a few broad wavelength bands in the electromagnetic spectrum, primarily visible and infrared. Hyperspectral imaging techniques makes use of this characteristics to obtain reflectance spectra for the region being imaged over a large number of discrete, contiguous spectral bands. A contributing factor in many highwall failures is the presence and distribution of mechanically incompetent, clayrich altered rock in pit walls. Most alteration minerals have characteristic absorption features that can be recognized with hyperspectral imaging and thus can be used to help identify these weakened, altered rocks. Synthetic aperture radar (SAR) use electronic techniques to create a very long virtual antenna by processing pulsed signal from a real antenna as it moves fast a target area. Because, the width of the radar beam is inversely proportional to the length of the transmitting antenna, this long virtual antenna allows high-resolution imagery. Interferometric synthetic aperture radar is a relatively low-cost system that can be deployed in light aircraft and operated at low altitudes. Displacement measurements can be used to track mass movement of failing slopes in surface mines and possibly to warn of imminent catastrophic collapse.