these potential events. Most mines are using radar to provide this final, "near real-time" warning of failures."

**SURFACE MONITORING**

Methods used on the surface fall into three main categories: visual survey and the use of extensometers; the use of total stations; and use of laser and/or radar systems. The most common approach by large mines is to use a combination, and this has been born out by research. Using data obtained from a large, metalliferous open-pit mine, Professor Bye at the SMI used a fault tree analysis to assess the impact of different geotechnical monitoring technologies on slope hazard management. Using the data he collected and applying fault tree analysis, it is possible to assess the success of different monitoring technologies.

For this particular example, the monitoring type success rates were as follows.

<table>
<thead>
<tr>
<th>Monitor success rates</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual monitoring only</td>
<td>32</td>
</tr>
<tr>
<td>Prism/crack metres only</td>
<td>45</td>
</tr>
<tr>
<td>Visual + prism/crack monitors</td>
<td>63</td>
</tr>
<tr>
<td>Visual + prism/crack + laser</td>
<td>86</td>
</tr>
<tr>
<td>Radar only</td>
<td>93</td>
</tr>
<tr>
<td>Visual + prism/crack + radar</td>
<td>97.5</td>
</tr>
<tr>
<td>Visual + prism/crack + laser + radar</td>
<td>99</td>
</tr>
</tbody>
</table>

These results would seem to suggest that radar is the most successful standalone technique for slope hazard monitoring for this example. But, it is important to note that these numbers are site-specific and relate to the technology, mining method, the systems used and local, geotechnical characteristics.

Graham Hunter, managing director of 3D Laser Mapping, says: "Most mines use multiple methods. The larger mines use laser, radar and total station. The smaller mines might choose laser and total station, or radar and total station. Most mines are also using ground monitoring where possible. So, most mines would have a total station and ground monitoring as standard, but the real question is should they use radar or laser... or both?"

Professor Bye told Mining Magazine: "Mining operations virtually always have variable geotechnical conditions and failure mechanisms. A multi-method monitoring approach is therefore essential to ensure a balanced slope risk strategy is in place. There are currently a number of operations that have adopted a comprehensive, multi-method approach and most large open-pits now employ a range of methods."

**EXTENSOMETERS**

A wire extensometer or crack monitor is essentially a metal rod inserted into the ground on the unstable side of a crack, with the monitor and pulley station located on a stable portion of the ground behind the last tension crack. The wire runs over the top of a pulley and is tensioned by a weight suspended from the other end. As the unstable portion of the ground moves away from the pulley stand, the weight will move and the displacements can be recorded either electronically and automatically transmitted back to the geotechnical office, or noted manually. Wire extensometers are mainly aimed at monitoring small movements in particular areas.

For subsurface, another type of extensometer can be used – a borehole variant. Changes in the distance between the anchor and the rod head provide the displacement information for the rock mass. Key manufacturers of extensometer products include Roktest, Geokon, Slope Indicator and RST Instruments.

**TOTAL STATIONS**

The nature and function of a total station is well described in a paper by one of the market leaders, Leica Geosystems: "Automatic prism-monitoring systems using motorised total stations have been used in mines since the early 1990s. Prisms are mounted on each of the points to be monitored, together with one or more stable reference points, with their observation controlled by a software application. The total station measures horizontal and vertical angles and slope distances to each prism, from which easting, northing and height values and, subsequently, displacements are computed.

"Usually, the total stations are installed at a permanent location and are levelled to align their main axis with the direction of local gravity. Attention is paid to select only very stable sites to ensure the co-ordinates computed from the station will remain in a consistent reference frame to simplify the detection of movement in the monitoring points."

"In mines, the total stations are usually placed at the top of the pit. At least one stable point is needed to orientate the total station, and account for rotations due to uneven heating and cooling of the monument and instrument. If the instrument cannot be located on a stable pillar then a free-station calculation using measurements to multiple stable control points can be used to account for movements of the total station."

Total stations are often referred to as robotic because once the station and prisms are installed in the mine no manual input is needed as the instrument movements are managed by software.

Neil Brown, senior product manager, GNSS Networks and Reference Stations, at Leica Geosystems told Mining Magazine: "In small-to-medium mines and quarries, a total station-based monitoring system, usually referred to in mining as a prism-monitoring system, is typically the primary method for monitoring. The reason is that it is a very cost-effective way of measuring 3D movements over the whole mine. Often, the prism system is supported by rain gauges and piezometers since water plays such an important role. When a problem is detected, local monitoring with extensometers is done."

As stated before, in large open-pit mines it is common to use multiple monitoring systems. The prism system is used to get an overview of the movement in the pit. Radar systems are used to monitor the areas that pose the most risk, such as where people are working or where movements have been detected or are expected. Mr Brown comments: "Prism and radar-monitoring systems are generally regarded as complimentary. One provides a wide area overview, the other a focused view on a small area. The huge difference in cost also plays a role – radar systems are much more costly than prism-monitoring systems."

Leica Geosystems is the leading provider of prism-monitoring systems, for both structural monitoring in general and mining applications specifically. Many mines use Leica total stations, such as the TPS1200+, with the associated software.
solution, GeoMoS, while others choose to use Leica total stations together with third-party software.

Two other players in total station systems are Topcon and Trimble. Topcon recently introduced the IS model – an enhancement of the world’s first imaging-system technology, which the company introduced in 2005 with its GPT-7000i total station. The Topcon GPT-9000Ai robotic total station provides unique precise reflectorless measurement up to 2,000m. Trimble offers the Geodimeter 3600 and 5600 total station ranges.

LASER SURVEY

A number of companies offer laser-survey solutions similar to those used in civil construction, but the products most actively marketed for mining are from 3D Laser Mapping, which is the major distributor of Riegl’s scanners such as the LMS-Z range in sub-Saharan Africa (and the UK and Ireland), and the i-Site offering from Australia’s Maptek, also a world leader in mining software. In addition, Leica (with the HDS4400 mine-scan systems), Trimble and Topcon also offer laser-survey solutions.

On the choice between laser and radar, Dr Hunter highlights three main areas of consideration. Firstly, there is the extent of monitoring area. The laser can either be used in a single location (mounted on a pillar in a cabin) for hourly monitoring or for monitoring many areas on a daily basis, with a pillar at each location. The radar cannot monitor multiple areas. In cost terms, he adds: “The laser system is typically one-third of the radar system after all costs are considered. The radar typically also requires a maintenance technician on-site for the majority of the time to maintain high reliability.”

Professor Bye told Mining Magazine: “There are now very cost-effective and smaller laser systems that can be used for both general mine-survey work and slope monitoring. I believe this represents the best approach for a small operation.”

Thirdly, the laser can measure to 6mm accuracy over a 1,000m range (or 20mm over 3,000m). The radar can measure to sub-millimetre accuracy.

Micro-seismic surveys help to provide a 3D understanding of rock movement.

however, the beam footprint is 10 times larger than the laser. Another point is that the laser can be used for other tasks around the mine, such as measuring volumes or stockpile stability, but they are susceptible to poor visibility conditions.

The 3D Laser Mapping client base for laser systems includes AngloGold Ashanti, De Beers, Kumba Iron Ore, Goldfields, Anglo Platinum, Newmont and Barrick. Kumba Iron Ore at the Sishen and Thabazimbi mines use the laser to measure many locations (once per day) for long-range monitoring and high-risk areas. Anglo Platinum at Mogalakwena Section uses the laser in a similar way to Sishen, but it has four lasers: one for each open pit in a fixed location, measuring continuously. Goldfields Ghana at the Damang mine and AngloGold Ashanti Tanzania at the Geita mine use their lasers in a fixed location measuring continuously.

Thomas Gaisecker, manager, international sales at Riegl Laser Measurement Systems told Mining Magazine: “Laser scanning gives (for the) first time the possibility to get not only information of movement from single-points, but also now from the whole area of the slope, which can be covered by millions of measurement points. This high density of points gives information about possible movements or instabilities over the whole slope.”

The velocity and direction vectors of movements can be measured by the use of fixed targets inside the slope. These targets can be either measured by traditional total-station surveying or by the use of the laser scanner. The latter can detect reflector-targets automatically because of the high reflectivity coming back from these targets.

Mr Gaisecker adds: "In comparison to traditional surveying, the investment for a single scanner is higher, but it delivers much more accuracy because of the density of measured points. The work done till now with traditional surveying can be realised much faster and more accurately with less people in the field. Another aspect is that the surveying can be done from a remote position, which is very important because of security reasons.”

RADAR SURVEY

Radar is the most recent solution to be introduced to the market, but it has rapidly gone from being very much the new kid on the block to being widely used and accepted by the majority of open-pit mines. Again, lower-cost monitoring methods such as prisms and extensometers are used for background monitoring of general wall areas, but, once instability has been detected, radar is often the best monitoring method. The radar systems consist of a dish that scans horizontally and vertically, usually mounted on a mobile trailer.

There are two main global players: Australia-based GroundProbe with the Slope Stability Radar (SSR); and Reutech Mining, based in South Africa with its Movement and Surveying Radar (MSR). There are currently over 80 GroundProbe SSR systems in use in 15 countries. Open-pit operators using multiple SSR systems include: Anglo American (24 units); Freeport McMoRan (15); Rio Tinto (seven); BHP Billiton (four); Codelco (three); Xstrata (three) and Barrick (three).

Some important Reutech MSR users include Batu Hijau (Indonesia); Teller (Australia); Sunrise Dam (Australia); Savage River (Australia), Navachab (Namibia), North Mara (Tanzania), Minera Los Pelambres (Chile), and all of Anglo Coal’s mines in South Africa.

David Noon, chief commercial officer and vice-president of marketing at GroundProbe, says of the SSR offering: “Slope Stability Radar provides real-time, sub-millimetre precision to provide early warning in critical wall areas, which would directly impact on productivity and safety. For example, open-pit mines seek to reduce production standby time following a blast, inclement weather or unexpected rockfall. Another example is gaining controlled access to areas that have been quarantined due to unacceptable slope risk. These mine operations are successfully employing Slope Stability Radars to provide effective risk management of wall control and enable production equipment to work sooner and safer.”

GroundProbe states that SSR systems have provided warnings to well over 200 rockfalls with sufficient warning for production to act.

In terms of radar versus laser, Cala van der Westhuizen, Reutech’s mining marketing manager, comments: “We do not regard laser as a competitor. Laser and radar complement each other in the total offering of slope stability monitoring. Lasers are used in a number of mines to provide early warning that movement is taking place and this is due to the ease of moving the relatively lightweight system from one position to the next. Once movement is detected by a laser, radar can be deployed to track the movement through 100% coverage in almost real time. The radar is most effective when used in these critical times, when visibility and accessibility cannot be guaranteed. The further advantage of radar is that it can measure movements smaller than 1mm – something that cannot be achieved by reflectorless lasers.”

Mr Noon echoes this: “Lasers are not used for production-critical monitoring. Lasers provide centimetre precision and are affected by dust, rain, fog, humidity and surface conditions. Lasers are useful for background monitoring, digital terrain mapping of the slope shape and volume estimating for survey purposes.”

In terms of radar development, Professor Bye says: “In addition to the bigger, long-range systems, radar companies are now working on smaller and lower-cost slope radars. These highly-mobile systems will be able to provide coverage of small, high-risk areas. The