

Millimetre accuracy

Paul Moore looks at slope stability monitoring, focussing on methods being deployed to monitor tailings storage facilities in the wake of the Brumadinho TSF failure but also the latest in open pit wall surveying with radar and laser



On a global scale, tailings dam breaches are increasing in frequency, causing significant damage to the environment and even loss of life. This has led to a massive industry inward focus, with all the mining majors carrying out reviews of how their tailings facilities are managed and monitored, while the ICMM publication of the Global Tailings Standard, which has been developed through an independent review co-convened by the United Nations Environment Programme, Principles for Responsible Investment and ICMM, is a vital step towards improving the safety and security of tailings facilities, and rebuilding public trust in the sector.

To mitigate these catastrophic events in the future, numerous technologies and approaches are being developed and deployed. Tetra Tech, a leader in developing solutions to support the operational safety of geotechnical and natural structures, says it has developed microseismic technology that can monitor the structural stability of tailings dams and identify parameters that may cause a failure.

Tetra Tech's microseismic technology uses ambient seismic noise to detect internal changes in a tailings dam, observing velocity changes in the whole structure. This indirect technique measures the rigidity variation of the dam, and by continuously monitoring the change in wave velocity of the structure, identifies sources that may cause a failure. This method also identifies any anomalous behaviour, creating real-time data for Tetra Tech's geotechnical engineers to make decisions with confidence.

Tetra Tech says has recently implemented the microseismic technology to monitor tailings

dams in Brazil, commissioning more than 20 tailings dams and installing more than 180 geophones connected to 50 seismic stations. These systems are processing data collected continuously to support the safety of miners and dams in varying locations and ground conditions. The systems provide an extensive flow of data to identify early warnings about the integrity of tailings dams and allow its geotechnical engineers to remotely monitor each dam's structural stability and mitigate breaches.

Inmarsat brings new IoT options

Inmarsat, the world leader in global, mobile satellite communications, recently announced the launch of Tailings Insight, a new Internet of Things (IoT) solution for monitoring mining tailings storage facilities (TSFs). The solution

GroundProbe's aim is to tailor a monitoring solution to the customer's specific needs rather than providing a blanket system

builds on and upgrades its Tailings Dam Monitoring Solution and is available in two new propositions: Tailings Insight – Cloud and Tailings Insight – Plus. The flexible propositions are designed to respond to the differing needs of miners, and reflect Inmarsat's commitment to building more transparent, safer management of TSFs globally.

Inmarsat launched its Tailings Dam Monitoring Solution in March 2019 after several years of development with industry partners. As a fully managed service, the solution worked by collecting data from a range of industry-established sensors via Long Range Wide Area



Tetra Tech's microseismic technology uses ambient seismic noise to detect internal changes in a tailings dam, observing velocity changes in the whole structure

Network (LoRaWAN) edge connectivity, before transferring that data across Inmarsat's L-band network to a dashboard. This ensured that mining companies were able to see the status of key metrics in one place and in real-time, facilitating more responsive decision-making and safer mining operations. In order to create its new solution Inmarsat has further developed aspects of the original solution to build a new application and a powerful new interoperable platform that increases the solution's versatility.

The Tailings Insight – Cloud is a Software-as-a-Service (SaaS) application was developed in response to the industry need for a way of compiling tailings data from a multitude of sources. "The application easily integrates with existing on-site sensors and connectivity networks to enable real-time monitoring, as well as supporting historical data input for comparative analysis. With a fully customisable interface, multiple sensor map views, custom alarm monitoring, data logging, journaling functionality, sensor health reporting and easy data export, the updated application provides the most comprehensive set of features of any tailings application. Formerly only available as part of the fully managed solution, the application is now available in its own right, allowing personnel across mining companies and external bodies, such as regulators, auditors and insurers, complete visibility of TSF conditions on a site and global-level in one place."

Tailings Insight Plus – is a fully managed solution that incorporates Tailings Insight – Cloud, as well as featuring sensor integration, edge connectivity, satellite connectivity, and ongoing service monitoring and management. With Inmarsat controlling the entire, end-to-end process, it can offer service level agreements (SLAs) ensuring the continuous gathering of data, which best supports real-time monitoring. "The proposition can be installed at any mine globally and is ideal for TSFs without reliable connectivity, TSFs that require special attention due to their risk status and for mining companies looking to demonstrate their commitment to safe tailings management."

Commenting on the update, Joe Carr, Director of Mining Innovation at Inmarsat, said: "The response to Inmarsat's Tailings Dam Monitoring Solution in the last year has been very positive. It is clear that the industry wants to develop safer tailings practices, though in the process we have learnt this is not about a one size fits all approach. Miners have explained that there are a myriad of different approaches to tailings monitoring taking place every day. Many miners lack the reliable site-level connectivity required to enable real-time monitoring and management, though on some sites, some companies have this. The common need that we found amongst all of our customers

and the miners we have spoken to was a platform to help bring all of their data together."

He adds: "This is why we have created two propositions. With Tailings Insight – Cloud, we are removing the challenge of combining data from multiple sources and giving companies global visibility across their global TSF portfolios in one place, which supports faster, more informed decision-making and better governance. We take this a step further with our Tailings Insight – Plus proposition, the gold standard in tailings governance."

Carr concluded: "Both of these propositions will be key in helping mining organisations future-proof themselves and respond to the upcoming changes to tailings regulation globally. They can be used in conjunction with each other at different sites across a global portfolio and upgrading from Tailings Insight – Cloud to Tailings Insight – Plus is easy. We will continue to listen to the mining industry and work towards supporting a safer, sustainable and accessible future for the sector."

SRK rolls out automated VWP solution

Renewed global concern about the risks of tailings dam failure is accelerating a revolution in the use of automated sensors to generate big, real-time data to better monitor and manage these facilities, according to **SRK Consulting**.

"The need for knowing more about tailings dam conditions – and in real time – has become a major focus within the mining sector, demanding a step change in the way we collect, process and interpret data," Lyzandra Boshoff, Principal Engineering Geologist at SRK Consulting, said. "As part of these efforts, SRK has been rolling out initiatives using automated vibrating wire piezometers (VWPs) on tailings facilities."

Boshoff highlighted the particular significance of seepage and the associated pore pressure regime within a tailings facility as a vital aspect of the integrity and stability of the structure. This has conventionally been tracked by manual standpipe piezometers whose performance, while accurate, depends on the quality of installation and aftercare, she said. And, of course, manual data collection is subject to human error.

"This means expending considerable effort for relatively little data, which may often not exactly reflect the current situation by the time the information reaches the engineer for

analysis," she said. "Even the automated sensors using vibrating wire technology tended to rely on manual data collection from the logging devices connected to the sensors."

This is now changing as many telemetry hardware developers have improved their wireless capability and cloud technology to upload and store data, allowing data to be immediately accessed by engineers and management.

"This has changed the landscape of data flow and interpretation, as well as the potential size of the datasets that can be generated," she said. "SRK has been at the forefront of rolling out automated VWP networks, using logging systems that can send data wirelessly to cloud-based databases and can then be visualised and analysed in real time."

Among the technological innovations the company is developing is a customised database and visualisation platform specifically for VWP data. This includes built-in, automated validation and interpretive tools to automate some of the routine engineering interpretive work. It builds upon available software technologies to create a solution that is customised to the field of tailings dam management, while also presenting opportunities for applying the principles in a range of disciplines.

The datasets generated by VWP networks can be significantly large, depending on the frequency at which data is collected. Conditions on site would determine the detail required for tracking where potentially adverse circumstances may develop, the company said.

"These VWP networks are also useful when needing to confirm whether the mitigation measures in place are having the desired effect," Boshoff said.

Applying these technologies, SRK says it has been able to review the impact of construction process and other site activities and incidents on pore pressure responses, and analyse the impact of depositional patterns on the seepage flow regime within a facility.



SRK has been rolling out initiatives using automated vibrating wire piezometers (VWPs) on tailings facilities

SLOPE STABILITY MONITORING

“For the first time, we can see and correlate in real time what we have always predicted using models and assumptions,” Boshoff said. “Harnessing the power of big data, we can now test our assumptions and substantially raise the confidence of our observations. With the exponential growth in the application of technology in this field, more data is being generated and is available to be harnessed and interpreted.”

The sheer quantity of data generated means that engineers must innovate, finding new and more efficient ways to validate, evaluate and interpret the large incoming datasets.

Boshoff notes, however, that harnessing the full power of big datasets demands the appropriate database structures and validation processes to be in place – which is where SRK is investing considerable effort.

“To support this need, we have recently put in place a data services department at SRK, pulling together some of our brightest minds and data analysts,” she said. “This is helping champion our initiatives to harness these growing datasets into sound engineering information – so they can contribute to making informed engineering decisions.”

GroundProbe brings it all together

David Noon, COO at Orica-owned **GroundProbe**, says improving global tailings dam monitoring practices continues to be a key pillar of its vision of maximum safety for the mining industry. “In the last two years especially, a large number of mine sites have begun actively adopting best-practice monitoring solutions for tailings dams as a necessity, often incorporating GroundProbe systems. Globally, sites are beginning to accept that it is just as important to the overall safety of the mine that they monitor non-operational areas as well as areas of high production. In the last 24 months, GroundProbe has deployed custom monitoring solutions to tailings dams across Brazil, Peru, Canada, Mexico, Australia and multiple African countries. Each tailings dam is unique and so is the consequence of failure should the dam collapse. In most instances, several sensors are deployed to effectively manage the potential risk posed by a tailings dam collapse.”

If the solution incorporates multiple systems or sensors, Noon says it is integral that users have some way to bring all the data from the sensors together for analysis and identification of trends. “This is why over the past year we have committed our product development capabilities towards developing our world-class data aggregation software, MonitorIQ. MonitorIQ is a single-dashboard aggregation that gathers data from all on-site mine sensors to provide a complete overview of a slope or tailings dam. Unlike other data aggregation software in the market, our patented geotechnical analysis software, SSR-Viewer, is completely built-in. With all sensor data consolidated and complete access to all SSR-Viewer safety-critical features,



GroundProbe conducts 24/7 remote monitoring of its systems from one or more of its remote monitoring centres located in Balikpapan, Indonesia; Santiago, Chile; and Belo Horizonte, Brazil

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effective decision-making can be achieved, integral for tailings dams monitoring.” Looking towards the future, GroundProbe expects to see further automation and incorporation of AI and machine learning to produce smarter, more intuitive slope monitoring systems, capable of running more independently and managing data better.

GroundProbe also says it continues develop new products and refine its existing hardware across both its radar and LiDAR technologies. “In January this year we released the SSR-Agilis (3D-Real Aperture Radar); a standalone monitoring system designed to protect personnel and valuable equipment in active working areas of a mine site. The system is vehicle mounted, capable of being driven to any area of concern and deployed in minutes for real-time targeted monitoring. The SSR-Agilis is safety-critical by design, equipped with a range of local, remote and personal alerts. Alerts are dispatched via multiple channels, including: Personal Alert (PAL) devices; a flashing lightbar; audible siren with 1,500 m range; and the visualisation of triggered events in SSR-Viewer and MonitorIQ. These alerts allow for the fast and effective evacuation of a mine site in the event of an imminent collapse.” Noon adds that the GMS LiDAR technology, which is often used to monitor tailings dams or vegetated slopes, has undergone significant software developments, “ensuring its best-in class status.” Greater 3D visualisation functionality, enhanced algorithm optimisation and improved charting and analysis functionality have all enabled more in-depth data analysis.

The company doesn't believe that you can approach geotechnical monitoring with a one-size-fits-all solution as every mine site is different. GroundProbe estimates that around 90% of strip coal mines utilise 3D-radars, like its SSR-XT and SSR-Agilis, to conduct slope stability monitoring. 3D-radars scan in a targeted area using a real aperture radar - monitoring each unique pixel in azimuth, elevation and range - making it ideal for the steep topology of a strip coal mine. 3D-radars are also less susceptible to interference from machinery operating close to the slope, crucial in safety-critical situations. Alternatively, 2D-radars, like the SSR-FX and SSR-SARx systems, are commonly utilised at tailings dams. “Due to the more flattened face of a dam, and typically being a lower traffic area of a site, a fast-scanning 2D-radar is a suitable solution for broad area coverage of most tailings dams. LiDAR is also a common tailings dam solution for long term monitoring, with their ability to effectively measure prisms installed on slopes. GroundProbe's aim is to tailor a monitoring solution to the customer's specific needs rather than providing a blanket system that is only generally suitable for the desired purpose. Often

the most effective solution is a complete, well-rounded approach to ensure the highest level of safety. This tailored solution includes hardware, software, after sales support, and support from our Geotechnical Support Services unit.”

Finally, during the COVID-19 pandemic and associated lockdowns, several mining companies looked to GroundProbe to assist in providing safety-critical support during periods of restrictions on site, with the demand for its Geotechnical Support Services (GSS) dramatically increasing. Dedicated 24-hour remote monitoring of systems (GSS-Remote) and advanced report generation (GSS-Reporting) both saw high-demand over the past few months as on-site personnel were forced to work remotely. “Any number of GroundProbe products across any global site can be monitored and reported on through our Geotechnical Support Services unit. Typically, we conduct 24/7 remote monitoring of systems from one or more of our remote monitoring centres located in Balikpapan, Indonesia; Santiago, Chile and Belo Horizonte, Brazil. The combination of these remote monitoring centres provides seamless support in English, Bahasa, Spanish and Portuguese languages. By allowing on-site Geotechnical Engineers to outsource the monitoring of their systems to our remote monitoring centres, all geotechnical hazards and trends are closely monitored 24 hours a day, 7 days a week, ensuring no movement goes undetected.”

Reutech's esprit for innovation

Reutech Mining has released its fourth generation Movement and Surveying Radar, MSR^{IV} Esprit. This system makes use of Multiple-Input Multiple-Output (MIMO) technology, which it says is a first for the pit slope monitoring industry. This technology has illustrated a significant development for the industry through revolutionised scan speed, scatterer location detection and target resolution utilising a multiple array configuration.

The company told *IM*: “MIMO technology is an innovative method which employs the concept of applying multiple transmit and receive antennas in order to resolve the position of a scatterer or target. The antennas simultaneously convey a diverse spread of predefined waveforms (transmit and receive combinations) within a selection of frequencies, therefore resulting in a calibrated position based on many, opposed to a single frequency signal. Fading, clutter and self-



The Reutech Mining MSR^{IV} Esprit, which it says is the fastest scanning and most sophisticated slope monitoring radar in the industry

interference factors experienced by all radar arrangements have enhanced immunity with the application of MIMO principles due to the improved signal-to-noise ratio and other interference rejection techniques.”

With the application of the MIMO philosophy, the scan speed is significantly enhanced to less than two seconds for a fixed scan area comprising 90° in azimuth and 60° in elevation. The operating range is between 50 and 4 000 m for the staring array. The speed of the scan allows for greater proportions of the pit slope to be scanned at more regular intervals, therefore, emergent movement is identified much faster. With this exponential improvement, cumulative displacement of up to 2.7 m/h can be detected and tracked based on the physics of the selected operational parameters.

“Changes in atmospheric refractivity present slope monitoring radars with their most difficult challenge. Large changes in atmospheric refractivity as well as the presence of micro climates at some open pit operations can cause phase ambiguity, phase wrap or other significant errors in measurements.

The speed of the scan designated to the MSR^{IV} Esprit reduces the atmospheric disturbance measured between each scan. Therefore, the effect of atmospheric changes are tracked more accurately and can be removed much more efficiently, resulting in the true movement of the pit slope being displayed and plotted. The chances of atmospheric events (either widespread or discrete) having an effect on the pit slope data is minimised by the MSR^{IV} Esprit atmospheric compensation algorithms.”

The synthetic map and trend plot update time is regulated on a predetermined basis for the pit slope movement detection and alarming. It is important to note that the update times are selected on a scale of minutes opposed to the scan speed of the system. None of the accuracy is compromised, it is accumulated and displayed in a format that is compatible with real update times

for data interpretation.

“The system is georeferenced for full 3D identification of alarming points. Adaptable alarm settings may be applied for relative range (cumulative displacement), average velocity and velocity delta (acceleration or deceleration) for both negative and positive movement from the sensor. In addition, amplitude and coherence data as well as information pertaining to the refractive index can be utilised in order to interpret pit slope movement classes, patterns and transitions. This system will enable much tighter or finer alarms to be applied with a reduced possibility of false alarms. This functionality enhances operational avenues for the user in collaboration with pit slope management campaigns. In line with the Standard and Modular series of MSRs, MSR^{IV} Esprit data can be viewed on the MSR Connect platform. The full capabilities of the MSR^{IV} Esprit are being realised each and every time this system is deployed, no matter the condition of the pit slope or the atmosphere.”

Hexagon Mining & IDS GeoRadar connect slope stability monitoring with mine ops

As pit walls become steeper and open-pit mines look at pushbacks, slope monitoring technology is ever more important. So too is the need to alert personnel in real time of potential dangers.

Slope failure and rock falls are among the main



causes of casualties in mines. Mining companies invest a lot of money every year in monitoring equipment to keep that risk under control. In particular, the most dangerous areas in the pit are where the extraction is in progress due to the instability induced by blasting activities and the material removal, which can continuously affect the ground stability.

Closing an operation because of an incident can cost millions per day. A higher safety level ensures greater productivity. Integration announced in June between **Hexagon's** Mining division and its slope

Integration between IDS GeoRadar and the Hexagon Mining HxGN MineProtect portfolio means that mines can now receive real-time equipment visualisation with timely alerts about hazardous areas for people and machinery

monitoring arm, **IDS GeoRadar** now connects systems for safety and radar-based slope stability hazards. Via real-time equipment visualisation, integration ensures timely alerts about hazardous areas for people and machinery.

“The additional layer of information created by this integration means better risk evaluation and



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RIEGL ready for a remotely operated future

Thomas Gaisecker, RIEGL Manager Mining Business Divisions, says the company is ready to play its part in the fully remotely operated digital mine. Its main hardware lines (RIEGL VZ-i Series and RIEGL VZ-4000/6000 Terrestrial Laser Scanners) can be easily integrated in any network infrastructure by using LAN, Wi-Fi, and LTE-interfaces. This enables fully remote operation of its scanners. Furthermore, the RIEGL VZ-i Series scanners allow installation of customised apps for automatic data-acquisition and processing to derive automatic real-time results without any user interaction.

Three mining relevant apps have just been released, enabling RIEGL customers to make just in time system-relevant critical decisions, based on the results of these apps. The apps are named SlopeAngle App, DesignCompare App, and Monitoring App.

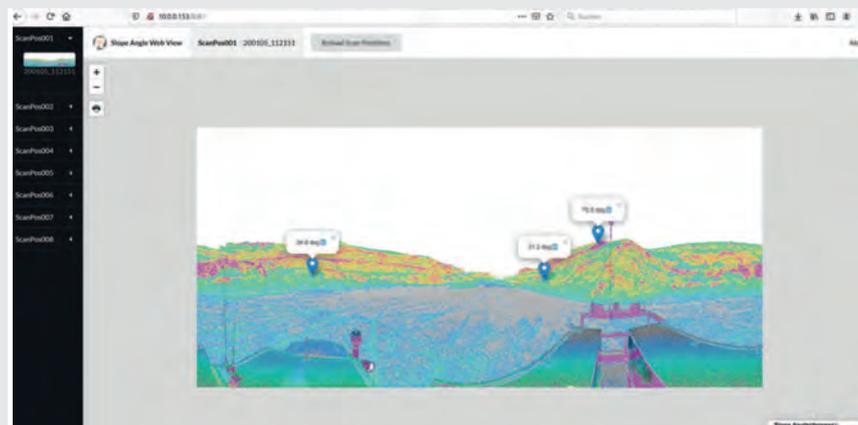
Gaisecker states: "To optimise the real-time information flow, a mine-network is essential. Operators of mining machines get the results from the apps running on the RIEGL scanner in real-time and can optimise their work." User specific schedules for scan data acquisition can be defined within all these apps. The SlopeAngle App delivers the calculated slope-angle from the scan-data. Critical slope-angles can be highlighted to support the operator of loaders to keep the slope-angles of stockpiles and dump-areas within the defined limits. The operators derive the information from the scanner on a web-browser on any device, which is connected to the mine network. No software installation or processing of the data is necessary. Everything is processed automatically within the app on the scanner.

The DesignCompare App calculates over-cut and under-cut to a given design-model. "Operators of heavy equipment like digging machines can optimise their work. This can save a lot of money. Under-cut is a waste of money, while over-cut is a safety relevant issue."

Finally, the Monitoring App was developed to calculate change-detection to a given reference-scan. This allows detecting movements of highwalls long before a human observer can see anything. Interpreting the trends of movements over a time-series of scans allows estimation of possible wall-failures. This gives enough lead-time to evacuate people and remove machinery from the endangered areas.

"Integrating the RIEGL hardware into the mine-network and making use of the brand-new developed apps is the real next step towards the full digital mine. RIEGL hardware and firmware architecture is also open for developers. Using python scripting and C++ programming every software programmer can develop apps for the RIEGL VZ-i series scanners."

Lastly the company has introduced the new GeoTec Plugin for its postprocessing software products RiSCAN PRO/RiMINING. "This plugin enables geotechnical analysis of scan data by providing the necessary statistical tools within an easy to use graphical interface. Besides the calculation of dip-direction and dip-angle of rockfaces it allows analysing of discontinuities by creating pole-plots and colourising the scan-data by clusters of similar orientation. This gives specialists a better understanding of stability, joints, and faults of the analysed rockfaces."



Screenshot from RIEGL SlopeAngle App web-browser. Critical slope-angles over 70° are highlighted; markers can be set interactively to monitor these points over a time-series of scans

is one more way to ensure everyone gets home safely," said Nick Hare, President of Hexagon's Mining division. "It's also a great example of our autonomous connected ecosystems strategy – connecting previously siloed processes in one platform that will save lives."

The single platform is part of the newly released HxGN MineProtect Collision Avoidance System (CAS) 4.6. It means mines can now receive real-time equipment visualisation with timely alerts about hazardous areas for people and machinery. Workers and equipment are protected

from injury-threatening events by being forewarned of no-go-zones.

No-go zones are identified in IDS GeoRadar's IBIS Guardian software, which creates geofenced zones and hazard maps and is correlated with radar alarms. Guardian's integration with CAS 4.6 and complementary HxGN MineProtect solutions, Personal Alert and Tracking Radar, ensures that alarms are automatically triggered when a no-go zone is approached.

Vehicle drivers immediately know which zone they should avoid because the zone is closed automatically. Mine management also benefits. In the past, a geo tech would need to call the supervisor and the supervisor would visit the specific field and close the road. This could take from 30 minutes to a couple of hours.

"Guardian can now improve risk management being integrated with the HxGN MineProtect portfolio," said IDS GeoRadar President, Alberto Bicci. "Vehicles and machinery are visualized in real time on the 3D radar displacement map and consequently traffic management, based on slope hazards, can be further optimised through real-time monitoring data from our complementary solutions, Hydra-X, IBIS-FM and IBIS-ArcSAR."

Mapek laser tech ups safety at Letšeng

Mapek says its laser scanner technology is ideal for volumetric survey, geological and geotechnical data analysis, and tactical and strategic slope deformation monitoring. Letšeng Diamond Mine is an open pit mine in the north of the Kingdom of Lesotho. At 3,100 m above sea level, it is one of the highest altitude diamond mines in the world, and is famous for the production of large, top quality diamonds. Two kimberlite pipes bearing low-grade ore are currently being mined as consecutive pushbacks via conventional mining methods.

Safety is very important to the operation, and Letšeng is keen to embrace technical innovation to ensure timely and accurate detection of unstable slopes.

A Mapek XR3 laser scanner is used to acquire point cloud data for geotechnical analysis, volumetric calculations and rockfall assessment. Compared with traditional methods, laser scanning provides direct, detailed 3D geometric mapping, quick and accurate measurements and significantly faster data processing, as well as cost reductions, says Mapek. Letšeng Geotechnical Manager, Nkopane Lefu commented that the system was very user friendly and that Mapek staff provided responsive support.

The 3D technology can deliver the detailed and dense data required for geotechnical analysis, creating a high resolution point cloud over large areas in several minutes. Laser scanning has improved the mapping database because now all

areas including inaccessible and unsafe areas can be covered. Discontinuity properties including orientation, spacing, surface roughness and persistence can be determined remotely and accurately over long distances.

The scans are imported into Maptek PointStudio software for analysis. Scans can all be georeferenced at the same time, and after filtering of trucks, vegetation, snow or dust, a complex 3D surface is created for geotechnical mapping.

Various methods for extracting discontinuity data are used, including automated techniques that examine orientation trends and a semi-automated method that depends on user structural interpretations of specific features. Manual point cloud analysis gives the geotechnical engineer the same control as in the field, with the benefit of unrestricted data coverage.

On the other hand, the automated method is quick, uses more detailed data and reduces the potential bias of the geotechnical engineer. Every visible joint plane is assessed and characterised.

The orientations of the geological defects are then plotted on the stereonet to analyse and determine discontinuity orientations and major joint sets. The data can also be exported as a csv file into rock mass analysis software.

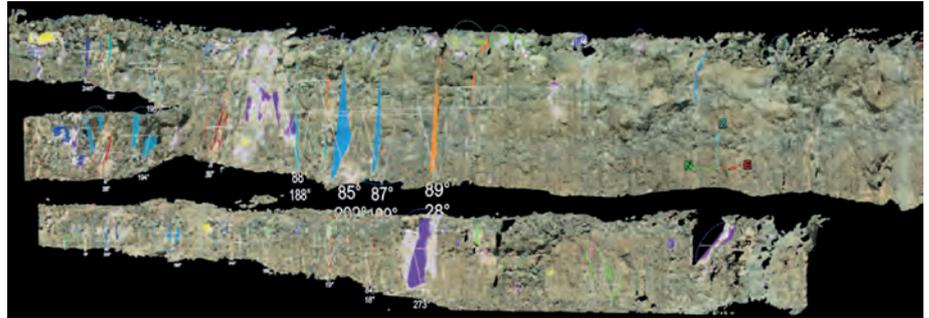
PointStudio geotechnical tools allow for accurate measurement of surface roughness. The selected surface is divided into grids depending on user preference. The results are then used to determine the joint roughness coefficient (JRC).

Data from one Letšeng pit was used for kinematic analysis to determine possible modes of failure, by analysing the relationship between the major joint sets/planes of individual joints, the slope and the basic friction angle. The results indicated that possible localised failures are restricted to bench scale and inter-ramp failure is not likely. The data can be used in limit equilibrium and numerical modelling packages for detailed slope stability analysis.

Mapping of blast blocks is vital for blast design to minimise highwall damage and to achieve controlled and desired fragmentation. At Letšeng, highwall control is of high priority because of the recently implemented steep slope. Every trim block is mapped and geological information is analysed for geological defects and rock mass strength. PointStudio can extrapolate joints throughout the trim blocks to predict blast integrity.

Open pit mining best practice calls for timely detection of potential rock slope instabilities and effective management of identified instabilities, making both strategic and tactical slope monitoring an integral part of any mine program.

Letšeng deploys prisms for long-term deformation monitoring, radar in critical areas for tactical monitoring, and the XR3 laser scanner for hazard identification, strategic and tactical



monitoring.

The scanner is used for both periodic and continuous slope monitoring. Scans must be taken from a fixed point for periodic monitoring, so beacons are constructed strategically around the pits. Scans are imported into Maptek Sentry office software for data processing and analysis.

Continuous monitoring is conducted using Sentry field software hosted in the Sentry DMS system in a deployable trailer. The DMS comprises a Maptek XR3 laser scanner, built-in tripod, solar panels, weather station, standby generator and Wi-Fi antenna mast for communications. Scans are downloaded automatically into the built-in computer for processing.

Output data includes displacement, velocity, moisture intensity and inverse velocity time graphs. The behaviour of each graph can be related to environmental factors such as rainfall, wind direction and intensity. Trigger alarms can be set and notifications sent through local mine networks.

Benches are the fundamental building blocks of the pit slope and their geometry and behaviour often controls the inter-ramp and hence the slope design. Letšeng has implemented rigorous quality control and quality assurance on the highwalls to ensure that the required catchment is achieved.

The 3D point cloud data is used to compare the actual slope to design, which quantifies the frozen toes as well as crest damage. Crest compliance is calculated by comparing actual and design crestline, while toes are determined by comparing the actual bench face with design. Intensive rock barring is

A Maptek XR3 laser scanner is used at the Letšeng Diamond Mine to acquire point cloud data for geotechnical analysis, volumetric calculations and rockfall assessment

performed on the crest above where it has been compromised beyond an allowable 10 m. Overall slope compliance is assessed in PointStudio where cross sections of the actual slope are overlain on the designed slope.

Maptek states: "Since acquiring the Maptek XR3 laser scanner geotechnical engineers at Letšeng can collect significantly larger datasets more safely. The smart PointStudio geotechnical tools are used to characterise geological defects and determine possible failure modes. Sentry technology is applied in slope deformation monitoring as well as mining compliance measurements. Management can now make more informed safety-related decisions based on slope behaviour."



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Safe, deep mining

Paul Moore looks at key developments including the use of pumpable resin with bolts & SDAs for rock reinforcement

There has been a big move in the ground support industry in recent years to offer pumpable resin systems for underground rock bolting, delivered via dedicated mechanised bolting rigs. Orica-owned **Minova** told *IM* that it is introducing its UniPass Bolting Technology – described as an innovative ground support system for one and two step rock bolting, which combines Minova hollow bolts and self-drilling anchors with its patented bulk injectable resin, CarboThix. By combining these two products, Minova says it has created “a unique rock bolting solution that has been engineered to suit even the most demanding requirements of hard rock underground mining and tunnelling environments.” The use of pumpable resin and hollow bolts is quickly gaining traction in underground operations due to the ease of use, clean operating environment, improved safety, and the ability to provide instant ground support, enabling the miner to move faster.

Mines are extracting ores deeper than ever before, resulting in higher rock stresses, potential increase of convergence, dynamic events, and rock bursts. There is an increased demand on ground support applications, the products used and the safety of operators. Existing rock reinforcement solutions can be prone to limited ductility, installation difficulties, especially in broken ground and limitations on the efficiency and productivity of installation processes. Minova’s Peter Assinder, Global Head of Sales, Marketing and Technology comments: “Mining companies are looking to decrease such risks and increase productivity by speeding up the bolting cycle and introducing mechanisation and further automation options. OEMs and their contractors are also looking to enhance the quality of materials used in mines to deliver installation consistency.”

For the last eight years, Minova says it has been developing a solution which it says provides answers to the requirements for increased automation, greater mine mechanisation, improved productivity and moving miners away from the working face. “Working with a major OEM of mechanised bolting equipment, Minova further developed their industry leading pumpable resin CarboThix and self-drilling hollow bolts to enable single pass installation of ground support, which Minova has termed UniPass.”

The OEM company that Minova worked with to develop the UniPass system is Epiroc, with the system designed to work with its Boltec M and Boltec E models. Last year Peter Bray, Global Product Manager, at Epiroc, had this to say: “An important factor to achieve a workable rock reinforcement solution is to have a system where the bolt design, bonding agent and bolting rig all work together to provide a robust and reliable bolt installation. To this end, Epiroc has worked hand in hand with a leading bolt and chemical supplier to create a bolting system that addressed the issues faced with long-term bolting in poor ground conditions.” The result of this work is an integrated pumpable two-component resin system that can be used with a Self-Drilling Anchor style bolt in tougher ground conditions or, alternately, with a one-step or two-step hollow bolt in both hard and moderate rock.

A major part of any new development process involves extensive laboratory and mine site testing. Minova was the material supplier for the ground control work package of the EU funded Horizon 2020 Sustainable Intelligent Mining Systems (SIMS), a 3-year program from 2017 to 2020, to demonstrate new technologies for the mining industry. Minova’s hollow bolt and pumpable resin technology was extensively and

Minova’s UniPass Bolting Technology is described as an innovative ground support system for one and two step rock bolting, which combines Minova hollow bolts and self-drilling anchors with its patented bulk injectable resin, CarboThix

successfully tested on Epiroc Boltec machines at LKAB’s Malmberget mine in northern Sweden as part of the SIMS work.

Assinder comments: “The results surpassed the benchmarks set by the work program in terms of number of bolts installed per shift. The work undertaken during SIMS further allowed Minova to develop and fine tune the bolts and resins and installation accuracy and consistency, including optimum mixer units for the resin across a range of operating environments and approved greases to flush the bolting system after each bolt installation.”

The company adds that it is important to note that supporting materials and processes are almost as important as the bolt and grout materials, to ensure consistent quality of installation. “Minova’s static mixers and greases ensure that the two-component resin is mixed and installed correctly for every bolt installation. Additionally, an extensive testing program, including on mine environmental monitoring and laboratory testing provided extra confidence concerning the structural and environmental stability of the resin.”

A series of dynamic drop tests undertaken in Europe and Canada further proved the performance of the hollow bolts in dynamic environments for a number of bolt and resin configurations, thus providing confidence to the mine customers that Minova’s new technology is appropriate for their operations. Minova’s portfolio comprises Static, Yielding and Dynamic Hollow Bolts and three main CarboThix resins (Standard, Fast and Rapid) to provide an all-in-one bolting system that has been engineered to suit the most demanding requirements of underground mining and tunnelling environments.

The products offered are designed to improve installation times and to address hole collapses when used in fractured ground. It is a flexible system that features a load-bearing hollow bolt that is encapsulated by a resin grout body. All bolts are available with or without welded sacrificial drill bits to allow for both one step and two step bolting processes. The welded on drill bit has been specifically designed and manufactured to allow a reduced borehole annulus, lower resin consumption, improved load transfer, shortened drilling time and guaranteed performance (no bits breaking or spinning-off during installation) whilst providing additional anchorage capacity.

Minova manufactures a wide range of grout solutions for rock bolting applications. UniPass bolting technology introduces CarboThix, its