A Case History on the Development of a Geotechnical Monitoring System at the Nanisivik Mine, Baffin Island

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Abstract

The Nanisivik lead-zinc mine of CanZinco Ltd., located in Canada's High Arctic, was brought into production in 1974. The room-and-pillar mining method was chosen for the extraction of the relatively flat-lying Mississippian-type orebodies. Post pillars were left during the primary mining. By the late 1980s, with much of the primary mining having been completed, plans were made for the recovery of the pillar ore by retreating from one extremity of the mined area to another. From that time, and with much of the funding provided through the Canada/Northwest Territories Mineral Development Agreement, the company, then known as Nanisivik Mines Limited, engaged the Mining Research Laboratories of CANMET (now a part of the Mining and Mineral Sciences Laboratories (MMSL) of Natural Resources Canada) to assist with the geotechnical studies required. During the next decade, NRCan staff determined the in-situ stresses at the site, and the properties of the geotechnical materials. This was followed with numerical modeling of possible extraction sequences and the design and installation of a monitoring system. In this paper, the authors focus on the latter, which evolved into a remote mine-wide ground stability monitoring system. This, in turn, has evolved into a system monitored over the ethernet, which can be used to monitor conditions at far-distant locations from the instruments. Further, the on-site monitors have also evolved to take advantage of both metallic and fibre-optic time domain reflectometry methods.

Introduction

The Nanisivik orebody, on the south side of Strathcona Sound, at 73E North and 84.6E W, was exploited through one of the northernmost mines in the world. Reportedly discovered by Arthur English, a member of Captain Joseph Bernier's Second Canadian Expedition to the High Arctic, it was named after the Inuktitut word for "the place where one finds things" (www.arctictravel.com/chapters/nanisvikpage.html).

The deposit is an excellent example of one at a remote location, which became economically viable through the development of transportation infrastructure - in this case, the building of ships such as the *MV Arctic*, in which the incorporation of icebreaker technology has permitted commercial navigation for a limited period each year.

After the mapping of the property by the Geological Survey of Canada, in 1954, it was explored by Texasgulf Inc., in 1957. Mineral Resources International purchased the property, in 1972, and formed Nanisivik Mines Limited. MRI subsequently became a subsidiary of AEC West Limited, which had been formerly known as the Conwest Exploration Company Limited. Breakwater Resources Limited became the next owner when it purchased Nanisivik Mines Limited, in 1996. Finally, CanZinco Ltd., a Breakwater subsidiary, purchased the mine in 1997. The operation was closed in the later summer - early fall of 2002. After disposing of scrap materials by storing these in the underground mine, the portals were sealed.

The Orebody

The Nanisivik sulfide deposits are hosted in carbonate rocks within a Proterozoic sedimentary sequence. The Main Zone is a flat-lying lens that extends for a distance of about 3000 m between outcrops on either end of a low hill. The lens is up to 20m in thickness, varies from 100m to 150m in width, and is overlain by up to 130m of hanging wall rock. It is oriented East-West, although it is sinuous in plan (Figure 1). An interesting feature of this deposit is the constant elevation of the hanging wall contact over its entire length.

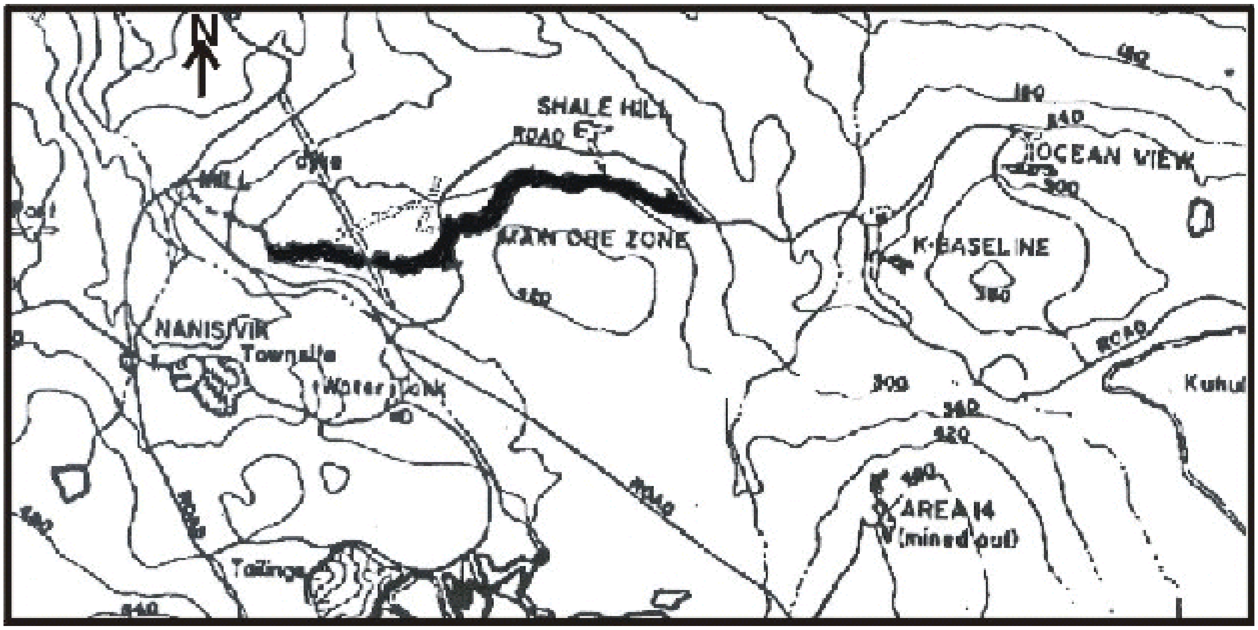


Figure 1: The location of the Main Ore Zone at Nanisviik

The carbonate host rock is composed of dolostone with bedding that dips 10 – 15 degrees to the North. Ground stability in the mine is enhanced by a permafrost regime that extends to a depth of about 600 m. The mean annual temperature at the mine site is from -10EC to -12EC.

At Nanisivik, the ore occurs as sphalerite and galena in a pyrite matrix. The lenses are within the Society Cliffs Formation, of dolomites. While most of these are near-horizontal, some near-vertical vein-like structures were found.

The Mining Method

During its operation, the mine produced from about 2200 to 2400 tonnes of ore per day, with 60% coming from the Main Zone and 40% from satellite zones. Due to the size and shape of the Main Zone deposit, the initial extraction was by room-and-pillar mining. The centres of the pillars, each about 8 m by 8 m, were on a 25 m by 25 m pattern. The initial extraction ratio was about 75%, with the remaining 25% being committed to pillars. By the conclusion of primary mining from the rooms, the 350 post pillars in the Main Zone mine contained about 800 000 tonnes of ore (Vongpaisal et al., 1991,1992). The successful extraction of these pillars would have a significant impact through prolonging the life and contributing to employment in the Northwest Territories. The conceptual plan was that the pillars would be recovered from the Main Zone by following a two-stage retreat proceeding from South to North and from East to West (Figure 2). This was largely concluded by the time of the closing of the mine.

The Geotechnical Studies

During the first stages of the work, commencing in 1988-1989, several boreholes (about 24 in all) were drilled for Monitors (GMMs), or CANMET strain monitors, or data loggers. Many of these were inspected using a borehole colour television camera. Concurrently, all of the core was logged and the rock types and geological discontinuities recorded. Additionally, in-situ dilatometer tests were used to determine the in-situ elastic moduli of the rocks, while the CSIR "doorstopper" technique was used to determine the in-situ stresses in the rock mass. The stress determinations, with limited success at first, were tried by our colleagues for the first time in frozen ground (Herget & Arjang, 1989; Arjang & Herget, 1989). The physical properties of the rocks from the mine site were also determined in the MMSL laboratories at Bells Corners, in the western area of Ottawa.

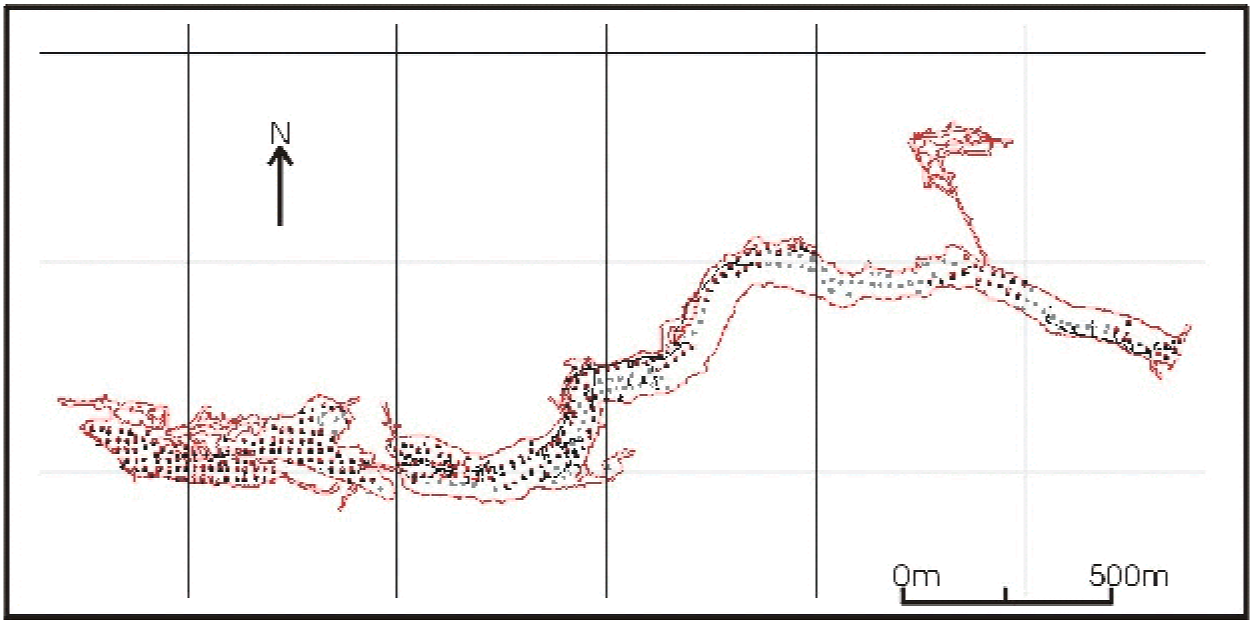


Figure 2: The Main Zone and the arrangement of post pillars at Nanisivik the installation of either Ground Movement

It is particularly relevant to this paper that Ground Movement Monitors were installed at the very beginning of the study. From the outset it was realized that the response of the rock mass to mining and the transfer of loads to the pillars as mining proceeded would be of paramount concern as regards the success of the pillar extraction strategy.

At the same time, as all of the above was taking place, finite element numerical modeling methods were used to assess the reactions of the ground to mining and the stabilities of the roof, the post pillars, and the sill pillar between the Main Zone and the zones beneath (Vongpaisal et al., 1990). From these studies it was concluded that the failure of the surrounding ground should not be a significant factor during the removal of the post pillars and that the complete removal of the pillars should be feasible.

During 1991, in order to verify the findings from the model analyses, the mine operator decided to proceed with the test mining of five pillars at the extreme eastern end of the Main Zone. Primary mining in the area had been completed and it was felt that the removal of test pillars would not interfere with the mine's production. The pillars selected could also be drilled and blasted using the equipment available at the mine site. Finally, it was believed that the area of the test pillar recovery also presented the most potential for experiencing ground control problems. Thus, a successful conclusion would bring added confidence to following the pillar recovery strategy.

All of the test pillars were mined successfully. As a result of the trial, the mine operator decided to proceed with the full-scale program of recovering the post-pillars.

The Evolution of Mine Monitoring at Nanisivik

During the first part of MMSL's involvement with the Nanisivik mine, a number of monitoring instruments (single-point ground movement monitors, multi-point extensometers, and vibrating-wire strain monitors) were installed in bore holes at key locations. In the first instance, these were connected to data loggers, which had been purchased from Richard Branker Research and customized by the firm to meet the requirements of MMSL's Mining Laboratory. Powered by batteries, it was believed that daily readings could be obtained for several months before it would be necessary to replace the batteries. As would be expected, the cold conditions affected the lives of the batteries, and, thus, while performance was not compromised, frequent checks of the functioning of the data loggers were required. The key point is that it was necessary for personnel to visit the sites of the installations in order to obtain readings.

Pillar recovery at Nanisivik progressed with very good success from 39 block at the east end of the Main Zone, moving westwards all the way to 20 block. However, in early February 1994 a large ground fall in 20-09 stope stopped the program abruptly. At this point, a shallow dipping structure (shale parting) was encountered in the hanging wall, and a large wedge failure occurred when the supporting pillars were removed. It was determined that a contributing factor to the ground fall was the presence of a 2-3m thick layer of sulfides that was left on the back during the first pass of room and pillar mining in the late 1970's and early 1980's. These remnant sulfides acted as dead weight on the dolostone hanging wall and placed greater tensile force across the weak bedding feature. Furthermore, the structure had never been properly mapped because the sulfide skin camouflaged the daylighting structure in the underlying dolostone.

It was recognized that once pillar mining resumed, a better ground monitoring system was required: one that could detect separation across weak bedding planes within the dolostone or separation of remnant sulfides from the hanging wall contact, and was capable of alerting mine staff of an impending ground failure. The desired system would have the ability to measure movement continuously, and would collect and transmit the information to a centralized monitoring and control station in the mine office; thereby eliminating the need for manual data collection in potentially hazardous areas of the mine. Another key specification was to have all the readings saved in a database for historical graphing purposes, and to set up alarm conditions that would trigger in the event that relative movement exceeded pre-set limits over various time spans. Such a system would be capable of monitoring slow creeping movement as well as faster, accelerating failure mechanisms.

During the mid-1990s the company had also installed an El-Equip leaky feeder communications system in the mine, thereby making possible direct linkages between personnel in the mines offices (and elsewhere) with personnel in the underground mine.

By 1998. it was decided that continuous and instantaneous monitoring of geotechnical instrumentation would be required in order to assess the response of the surrounding rock mass to the extraction of the post pillars. In the knowledge that the staff of the Mining Laboratory had been developing the technology for wireless communications between instruments and data loggers, the company requested CANMET's involvement in the design and installation of a mine-wide on-line geotechnical monitoring system through which data from the instruments could be transmitted to the offices. A channel of the El-Equip leaky feeder system was assigned for this purpose.

Since all of the in-situ monitoring equipment that had been installed by CANMET previously was no longer available, an entirely new series on instrument installations was required. During the first part of CANMET's work, the objective was to verify the possible effects of the extraction sequence proposed. During this, the second part, the objective was to develop a system, which could be used to monitor the conditions in the back after the post pillars, had been removed.

The System Developed by the Mining Laboratory

Since the objective was to provide a warning of any possible instability of the rock mass during the removal of the post pillars, the computer and monitor for the geotechnical monitoring system were installed in the Shift Bosses' office - close to the installation of the El-Equip Multi-com cabinet (Judge, 1998). The surface "Master" (a Multi-Rac Master, a 5903 radio modem) was installed in this cabinet, with the "transmit" and "receive" connections being made using RG58/U coaxial cables connected with BNC connectors. Since the transmit line was connected directly to the leaky feeder distribution panel, a series attenuator was used to prevent saturation.

Underground in the Main Zone, four stations were established to serve as "Slaves" to the "Master". Each consisted of an El-Equip 5903 radio modem, a 5202 controller, a 5501 analog input module, a power supply, and DIN rail connections packaged in a NEMA 4 enclosure.

The principle of the operation of the system was based on the Modbus protocol, through which the "Master" periodically polls the "Slaves" for information. This is accomplished through the computer sending out serial commands through the serial communications port (COM1). When transmitted from the Master radio at a pre-defined frequency the modulated RF signal is then injected into the leaky feeder network. The first part of each command consists of a unique address. In the system used, there could be as many 255 individual addresses each representing a slave. The addresses to be recognized are selected through a "DIP-switch" setting on the "Slave's" controller.

The instruments used in the system were Baytech ETT-204 Electronic Telltales. Each incorporated a 100 Kohm linear potentiometer with a 100-mm stroke length. These Ground Movement Monitors (GMMs) were installed at a number of locations that were selected in the back of the Main Zone (Figure 3). Each of these was tethered to a slave in the immediate area. In general, distances between instruments and slaves were restricted to 300 metres or less in order to minimize noise.

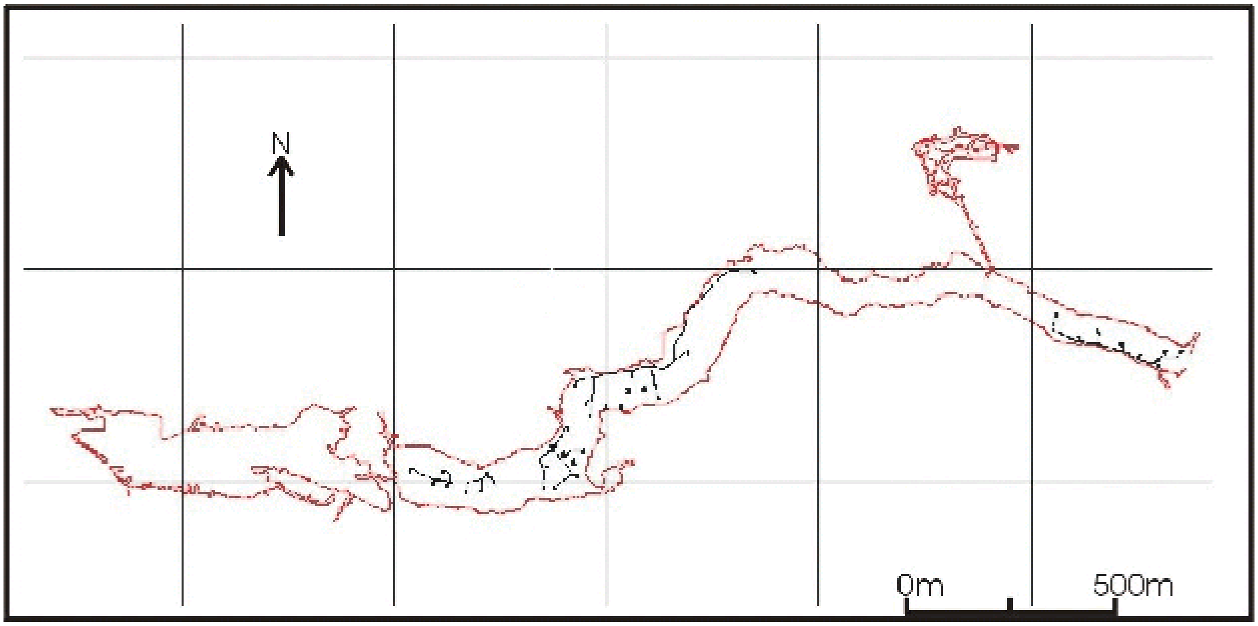
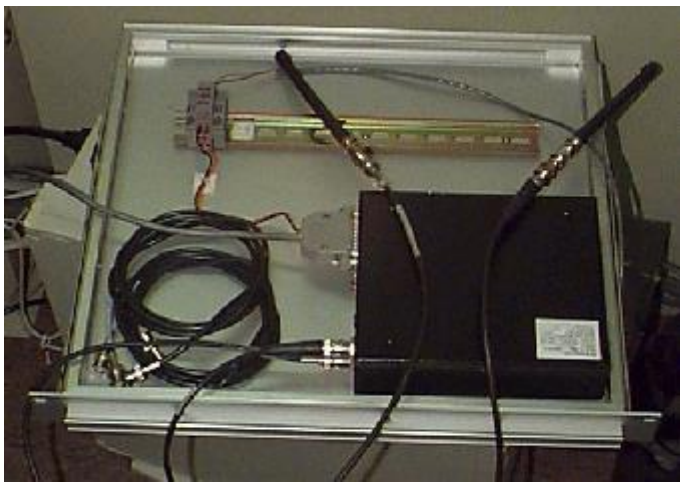
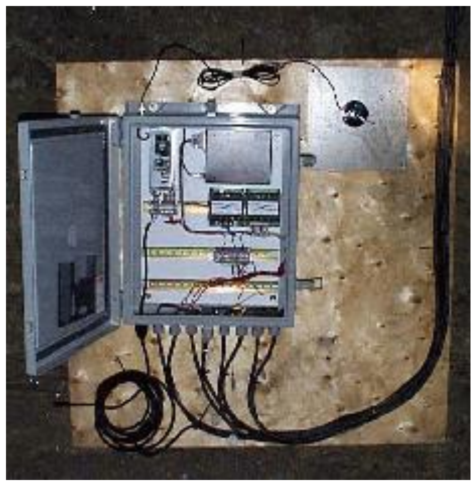


Figure 3: Initial locations of monitoring instruments in the Nanisivik mine, 1998

At each slave, the incoming RF signals are first de-modulated by the radio modem. When the controller recognizes these, as commands to the instruments connected to the slave, the signals requested are returned after having been modulated, via the modem, to a different frequency. In effect, each channel represents a pair of frequencies. Photographs of the master and a slave are shown in Figures 4 and 5, respectively.





Figures 4 and 5: The "Master" and a "Slave" station at Nanisivik

At the Shifters' office the dedicated computer and monitor were used to provide a constant display of the data being provided through the Ground Movement Monitors (Figure 6). The system was designed on the basis that up to 32 instruments would be used, with up to 8 analog units, or GMMs, per slave. Referring to Figure 6, an example for illustrative purposes only (with simulated data), it will be noted that the array displays the slaves on the ordinate and the GMMs on the abscissa.

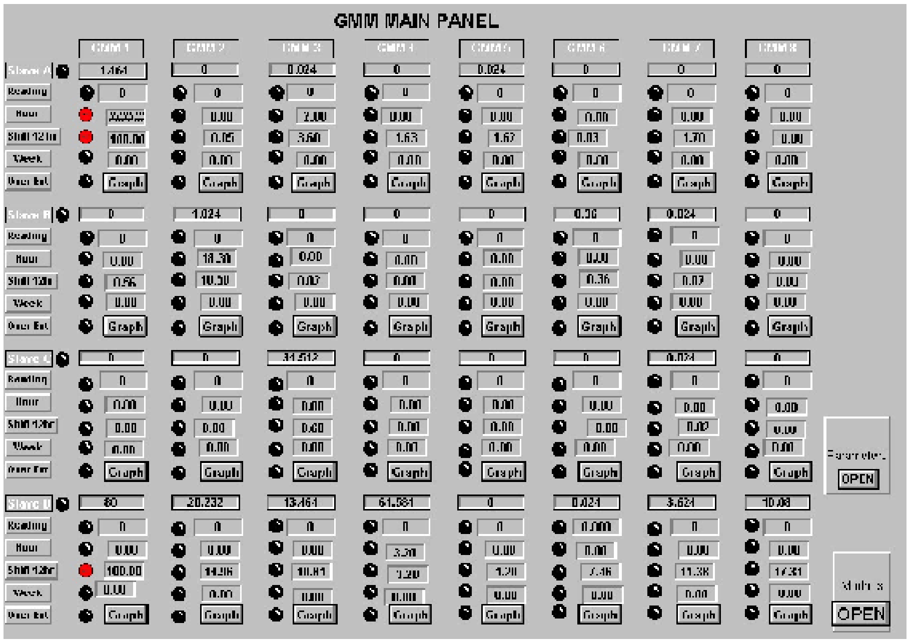


Figure 6: The monitor display as seen in the Shifters' office at Nanisivik

Also on the ordinate, a sub-ordinate grouping of fours readings is used to indicate: (1) the change between the current and the previous reading, (Reading); (2) the difference between the maximum and minimum displacements, in millimetres, at the instrument within the previous hour, (Hour); (3) the same for the previous 12-hour period, (Shift); and, (4) the same for the previous week, (Week). In addition, for each instrument, and above the four values mentioned, an uppermost reading indicated the total cumulative displacement since installation. Beneath each cluster of readings for an instrument a person with designated access to the system could press a button indicated by "Graph" in order to obtain a historical trend of the instrument reading.

Alongside of each reading location a virtual LED display would change from black to red in the event that a previously set alarm limit had been exceeded. Further, alarms would also be indicated if the mechanical limit of a GMM was being approached (Over Ext).

Finally, two buttons on the lower right part of the display could be used either to change the pre-set alarm limits, zero readings, and calibration factors (the "Parameters" button), or to trouble-shoot the network (the "Modbus" button).

In the system described, the instruments were polled for data every 5 seconds. On every occasion the entire screen display would be updated. At regular intervals, all of the data was stored to a disk.

Operating Procedures and System Maintenance

The default mode for the GMM monitoring software was the Main Panel, which showed the status of all the GMM's at a glance. In the event of an alarm condition, the monitoring computer would emit a warning sound, and a pop-up dialog box would appear on the screen. The dialog box specified the alarm condition triggered, and prompted the user to acknowledge the alarm. Acknowledgement was accomplished by logging in with the user's unique password, which was the only way to remove the dialog box and turn off the alarm sound.

The next step was to check the History Plot. The History Plot panel had user adjustable time scale and time span. If the plot showed that a pulse or spike had caused the alarm condition, it was a false alarm and it was noted as such in a GMM log book. No further action was required by the user, and technical services staff would reset the alarm. It was important to reset false alarms quickly so that the GMM alarm would be reactivated, and operations personnel would not lose faith in the system. In the first year after installation, false alarms would occur about 5-10 times per month for the whole system (31 GMM's).

If the plot showed a positive net displacement, the supervisor would conduct an investigation of the area. If the triggered GMM showed no evidence of being damaged, the assumption was made that ground movement had occurred in the area and all necessary measures would be taken to ensure that personnel and equipment do not enter the area. In this event, the investigating supervisor was also instructed to notify technical services staff immediately for a full investigation. All findings of the investigation would be noted in the GMM logbook.

On several occasions in 1998-99, real ground movement was detected by the system. In most cases, the movement was registered during shift change immediately following a pillar blast. The mechanism of ground movement in all of these cases was separation of remnant sulfides from the hanging wall contact within a non man-entry pillar mining stope. The ability to monitor the ground movement over time allowed mine staff to assess when a stope had stabilized, and was safe to commence remote mining activities with minimal risk to the operators and equipment.

Installation and maintenance of the hardware underground was the responsibility of the mine electrical department. The electrical department was brought on board right from the design phase of the project, and was fully committed to the system. They received training from MMSL staff on the specific technical aspects of the system during the site visit in March of 1998.

Subsequent Developments

Following the work at Nanisivik the opportunity arose to take advantage of improved communication and instrumentation technologies in the design and installation of another geotechnical monitoring system at NRCan's Mine-Laboratoire, near Val d'Or, Québec. In this application, which is described in a separate paper, the authors took advantage of modern LAN (Local Area Network) and internet technologies in order to remotely monitor what was occurring in the mine at a location about 500 kilometres from the mine site - in this case at the Bells Corners laboratory, in the suburbs of Ottawa. Additionally, time domain reflectometry (TDR) techniques were used to monitor the possible development of shearing zones in the back at a strategically important location. This necessitated the development of more sophisticated software so that a proper interface could be established between the TDR and communications technologies.

Other Developments

During the past twenty years there have been revolutionary developments in instrumentation, communications systems, and computing. Where, once, readings would be obtained at the location of an instrument by a ground control specialist using hand-held instruments (such as multi-meters), it is now possible to have on-line continuous monitoring systems which permit the same specialist to have instantaneous access to data, at any location, and all the time. At one major Canadian mine a system has been developed through which the occurrence of a significant event triggers an alarm signal which, in turn, being connected through cellular telephone technology, causes a message to be sent to the specialist's pager instantaneously to any location on earth. Immediately, the person is able to connect to the internet to download the data, which has been placed on the web-site. CANMET MMSL now can monitor what is taking place, in real time, at locations far distant from the observer. A ground control specialist can now access data at his or her desk from any number of locations around the world.

Likewise, micro-miniaturization has made it possible for one to develop equipment, which is "tiny" by previous standards. Borehole television cameras that are no larger in diameter than a fountain pen, and smaller, are available. Physicians can now examine the innermost parts of the human body without invasive surgery, and, further, to perform microsurgery.

The key point is that mine operators can now have any type of system that they want. At the Mining Laboratory of Natural Resources Canada a system has been developed through which engineers, situated at Bells Corners, can monitor the ground movements that are taking place at MMSL's Experimental Mine, near Val d'Or, Québec, about 500 km away. We have also developed monitoring instruments, through time domain reflectometry methods, which make multi-strand sloughmeters obsolete. We are presently working with a major Canadian company to develop a state-of-the-art ground monitoring system for an entire mine.

Conclusions

The installation of an on-line remote geotechical monitoring system was an essential component in the plan to recover the post pillars at CanZinco's Nanisivik mine, on Baffin Island, in the Canadian High Arctic. From an economic perspective, a significant part of the company's ore reserves had been committed to the supporting pillars. The successful extraction of these added to the life of the operation but also, and, through this, to the maintenance of employment in a remote Canadian community. CANMET was proud to be associated with this project and with the benefits that flowed to the company and to its employees.

Acknowledgements

Throughout the work at Nanisivik, the members of the mine's staff were exceptionally helpful and involved in the installation of the system and in continuing to develop it until the mine closed in late 2002. The authors would like to express their thanks to the Electrical Department, in particular Nat Levy, Bob Crosby and Ray Dupras.

Biography

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John Udd received his Bachelors, Masters, and Doctorate degrees, in Mining Engineering, from McGill University, in Montreal. After teaching at McGill for several years, and progressing to Director of the Mining Program, he joined Falconbridge, in Sudbury, as Senior Ground Control Engineer. Appointed the Director of the Mining Research Laboratories of the Government of Canada, in 1984, he presently occupies the position of Principal Scientist. Dr. Udd has written extensively on various topics in rock mechanics, mining education, and mining history. He is a Fellow of both the Canadian Academy of Engineering and the Canadian Institute of Mining, Metallurgy and Petroleum.

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Ken Judge received his Bachelors in Geology from Carleton University and his Electronics Engineering Technology Diploma from Algonquin College in Ottawa. Ken is a Senior Technologist with the Ground Control Program in Ottawa, Ontario as part of the Mining and Minerals Sector for Natural Resources Canada. Ken specializes in mining related instrumentation with emphasis on remote monitoring. Most recently, Ken has been developing techniques for remotely acquiring and quantifying Time Domain Reflectometry signals.

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