SURVEYING AND MAPPING OF OPEN PIT MINES

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ABSTRACT

Surveys of open pit mines combine characteristics of engineering and topographic surveys. The surveyor provides guidance for miners to develop mining operations according to the earlier-established mine plan, then surveys the progress of mining and develops maps and models representing its current state. The maps and models are used for calculating the volumes and tonnages mined and for reconciling mining progress with the mine plan. Surveying of open pits usually involves the following activities:

a. establishment of a mine survey control network;
b. detailed topographic surveying of open pit and waste dumps;
c. data processing to calculate mined volumes and tonnages;
d. stability control surveys of open-pit and waste dump slopes;
e. support surveys for earthmoving-machine control systems.

Keywords: open pit, mining operation, underground mining, EDM

INTRODUCTION

A mine surveyor measures geometrical element like angles and distances, to determine the relative positions of survey control points named benchmarks, together with terrain and underground features in order to presents this information graphically on a map.

An open pit mine (figure 1) is commonly used when excavating a near surface deposit. The ore is excavated by using horizontal benches to get deeper into the ground.

Figure 1: Open pit mine

The Cartesian coordinate system is commonly used to define the positions of measured objects by means of x and y axes on the horizontal plane pointing east and north, respectively, and the z axis pointing in the zenith direction. This representation's system claim specific requirements on angular and distance measurements, whitch can be used for the calculation of position of one topographical point. Angles must be measured in horizontal or vertical planes. Distances must be measured along horizontal or vertical lines. If a distance is measured along a slope, the angle between the slope line and the horizontal plane must also be determined. For good years, accurate measurement of angles and distances owned a significant technical challenge. Over the last 10 years, developments especially in precision mechanics, optics, and electronics have led to the production of surveying instruments that are capable of highly accurate angular and distance measurements.

In the present, some standard instruments can measure angles with an accuracy of better than 1 arc second and distances with a precision of ± (1 mm + 2 ppm). Instruments for measuring angles are called theodolites. Instruments for measuring distance include tapes, subtense bars, and electronic distance measurement devices, shortly EDM. The previous strict division between these types of instrument is now blurring, and these instruments are merging into one universal instrument, the so-called “totally station.”

The past 30 years have also seen the development of new surveying instruments capable of determining position without reliance on traditional geometrical structures linked to benchmarks on the earth’s surface. This new technique uses the Global Navigation Satellite System or GNSS, as a framework of reference points, and space triangulation as a means to determine the location of surveying benchmarks and ground features. Moreover, because this technique uses electromagnetic signals as a carrier, distances between a Global Positioning System GPS receiver and satellites can be determined only in open areas on and above the earth’s surface. Surveys of tunnels and underground mines must still be performed by means of classical surveying techniques. Detail surveying has also undergone significant technological change.

Nowdays, developments in laser scanners have led to instruments capable of providing reliable and instant three-dimensional 3 D models of terrain and objects. Scanners also have relevance in underground mine surveying where they can be used remotely to determine the extent and volume of mined cavities without compromising surveyor safety.

MATERIAL AND METHODS

A mine survey control network for an open pit mine site represent a accurate, spatial infrastructure for relative referencing of natural and constructed topographical features, mining roads, benches, buildings and other structures. It enables surveyors to:

-perform cyclic surveys for the control and reporting of mining progress;

-establish and control the elevation and slope of working benches and haul roads;

-establish the volumes of mined ore and waste;

-control and manage the mine dewatering system.

In many cases the primary control network for a mine, (figure 2) is based on triangulation and or trilateration. It is necessary like control point positions to be:

-visible from the main working areas of the mine site;

-visible from multiple other control points;

-clear of mining activities and other disturbances.

Control point positions are usually determined from angle and distance measurements that can be supported by GPS observation.

The horizontal precision of a primary control network should be 1:20,000 or better. Control benchmarks are usually stabilized permanently by means of concrete filled steel pillars set on concrete foundations.

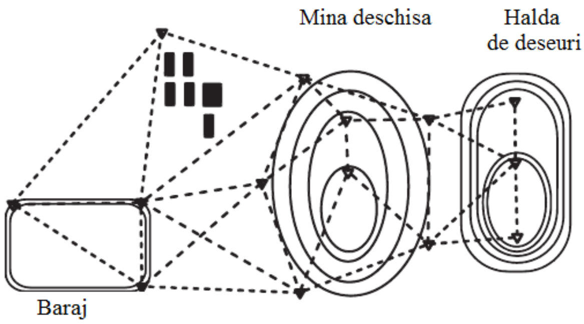

Figure 2: Mine-survey control network

A primary control network can be densified with secondary and tertiary control networks by means of any succession of *microtriangulation, intersection and resection, traversing, and profile lines*. Lower-class control points can be used as stations for detailed topographical and setting-out surveys. The positional precision of such points should be no worse than about ± 0.2 m. For such precision, closed traverses should be ≤2.5 km and open traverses should be ≤1 km.

A detailed topographical survey at an open pit mine focuses on the locations of bench-slope crests and toes, berms, road edges and gradients, ditches and water dams, waste dumps, power lines, buildings, and other permanent and temporary structures and it includes the collar positions of exploratory and blasting drill holes and information on existing cavities created by previous mining activities. The following survey methods are available: totally station survey, aerial and terrestrial photogrammetry survey, GNSS survey, and laser scan survey.

RESULTS AND DISCUSSIONS

A totally station survey involves determining the directions and distances to measured points and then simultaneously calculating the horizontal and vertical positions of the points by means of the so called from land surveying and geodesy: radiating method. Radiating survey is especially useful in open pit mines, where benches, slopes, and roads can differ in elevation. Survey data are collected, stored in instrument memory, downloaded to a personal computer in the survey office, and converted by application software into a map of the surveyed area. Today's totally stations do not require reflectors and can measure distances to almost any object up to several hundred meters away. Some totally stations can be combined with GNSS receivers (such as the Leica Smart Station, or Trimble Station etc.) for rapid station positioning, which is useful when a station cannot be set directly over a control point but should be done only in exceptional environments when a rapid survey is required. Final results must be checked later or linked back to the mine survey control network. Figure 3 shows a typical total station survey of a mining road and benches in an open pit mine.

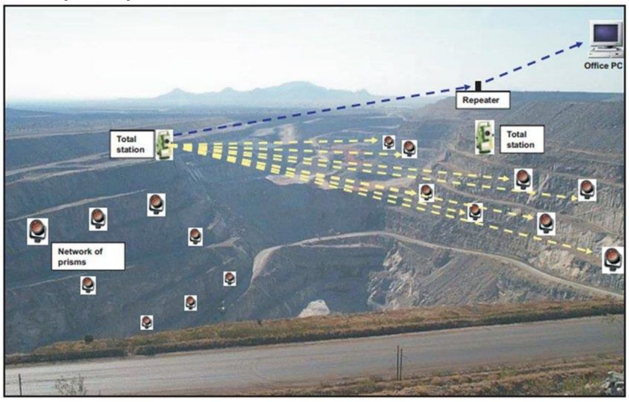

Figure 3: Totally station survey of an open pit mine

Mapping with the help of aerial photogrammetry is useful for large surface operations, especially those with large differences in elevation, areas that are difficult to access, or areas with large amounts of traffic. The method provides numerous advantages, including

-real time registration of details that can be revised at a future date;

-remote and safe collection of data;

-relatively rapid surveying of large areas.

Major disadvantages are that final results are not immediately available, but rather require weeks of data processing and that significant advance preparation is required to mark and survey control points, so the method is not economically feasible for smaller mining operations. The positional precision of details obtained by this method is in the range ± 0.1 – 0.2 m.

Mapping with the help of terrestrial photogrammetry is useful for high scarps and slopes with rock structures and slope deformations. The method involves taking images from control points of known position with special dedicated metric cameras. From images of an object taken from different locations, a 3-D model can be developed for use in map creation. Some systems use images produced by high-quality commercial digital cameras equipped with nonmetric lenses.

Current GNSS receivers using GPS real time kinematic shortly RTK technology deliver relatively high positional precision better than ±0.1 m, comparable to that delivered by total stations. GNSS is now the survey method of choice for open pit mines and is used not only for inventory surveys but also for conducting setting out surveys, positioning blasthole collars, and locating mining equipment Survey data are collected, stored in instrument memory, downloaded to a computer in the survey office, and converted by application software into 3-D models and maps of the surveyed area. With wireless data communication systems, maps can be produced in real time.

Since 2000 year, laser scanners and associated processing software have developed into fast, reliable, and accurate long-range surveying devices. Because they do not require the use of reflectors or staff at a mining face, they have made the entire range of surveying operations significantly safer. Scans are performed from a stationary position, and collected data are transmitted directly to the surveying office. Alternatively, some scanners can be mounted with GNSS receivers on the roofs of four-wheel-drive vehicles.

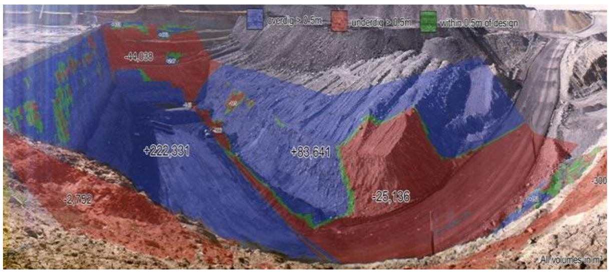

Figure 4: Laser scans of an open-pit mine

Survey data are collected, stored in instrument memory, and downloaded to a computer in the survey office where specialized surveying software manipulates the data, performs calculations, and creates 3 D digital models and maps. Mining regulations often require that maps be created to specific standards with respect to, typically, a scale or map coordinate system. In recent years, constantly updated 3-D digital models have replaced classical mine maps. Among the many surveying software packages available today, most popular are the so-called general mine design packages for creating geological models, mine designs, and plans.

The next softwares are popular:
-Gemcom Surpac from Gemcom Software International;
-Datamine Studio 3 from Datamine Corporate Limited;
-Vulcan from Maptek;
-Carlson Survey from Carlson Software.

Three dimensional digital models of mining operations enable relatively easy calculation on a personal computer of the volumes of waste and ore that have been mined. Most of such models use triangulated irregular networks to represent the original topography and working levels of a mine.

Rock volume between mine levels is calculated by taking the difference between solids, with the base at an arbitrary level (0 m etc.) and the top at the mine level represented by the triangulated irregular networks (Figure 5). Volume can also be calculated from a block model by summing the volumes of individual cells representing these deposits.

Modern open pit mining operations increase in efficiency as the ore to waste ratio increases, usually leading to maximization of pit-wall slopes. However, steeper slopes pose greater risk to personnel and mining equipment due to increased potential of slope failure. To uphold the required safety standards and reduce risk to an acceptable level, many open-pit mines must develop a holistic slope-monitoring program. Such programs should distinguish the following three slope-monitoring stages:
(1) overall monitoring of all pit walls and adjoining areas;
(2) focused monitoring of potential instability areas;
(3) detailed monitoring of areas with earlier-detected instability or failure.

Figure 5: Triangulated irregular networks used for volume calculations

Monitoring techniques should also take into account the expected mode of slope failure. There are four major modes of failure in open pits:
1. Circular failure with large rock movements along vertical planes at the top of failure and horizontal movement in the toe zone
2. Planar failure with rock-mass movement along an existing geologic discontinuity, such as a bedding plane, parallel to the slope face
3. Wedge failure when two sets of flat failure surface planes intersect and dip out of the wall; moderate vertical and horizontal movements are expected
4. Toppling failure when vertical or near-vertical structures dip toward the pit wall; large horizontal rock-mass movement is expected at the top of failure.

The relative locations of control stations and targets used in a slope-monitoring network should be selected so as to be maximally sensitive to expected rock movement.

Specialized geotechnical and surveying methods were used for slope-stability monitoring.

However, recent developments in satellite and terrestrial remote-sensing technologies have significantly impacted the methods currently used. Monitoring on a large scale can be done using interferometric radar technologies. If the primary concern is vertical movement or subsidence of areas adjacent to slope crests or bench areas of large open-pit slopes, satellite-based interferometric synthetic aperture radar or InSAR can be used to detect these movements. InSAR images can easily cover large areas of the whole open-pit mining operation. Ground-based radar systems, also using interferometric technologies, recently became the tools of choice for continuous monitoring of wall faces. The most successful and popular systems are Slope Stability Radar by Ground Probe from Australia and Movement and Surveying Radar by Reutech Mining from South Africa. These systems can provide continuous measurements of rock movement across the entire face of a slope wall with submillimeter accuracy. Real-time processing of collected data enables confident tracking of slope movement and management of risk while optimizing safety and productivity.

Monitoring on a smaller scale or of distinct targets can be done using classical surveying techniques. Control stations must be established at stable locations from which targets placed on pit walls are observed. Station stability must be ensured and controlled. Stations should be erected as concrete pillars set into bedrock or into a stable foundation.

Stations should be linked by means of a control network with other stations located far from the mining area and considered to be stable. Repetitive surveys, once or twice a year, must be performed to check the stability of the control network. For continuous monitoring of wall targets, automatic high-precision total stations can be used. Such robotic total stations are programmed to automatically measure directions and angles to targets and transmit data to a control computer in the survey office. Data are processed in real time and information regarding target movement is reported out. If movement is greater than the earlier-defined critical value, an alarm is triggered, enabling timely withdrawal of mining personnel and equipment. Automated slope monitoring systems are offered by major producers of surveying equipment as well as by independent developers. The most advanced and popular systems are the Leica Automatic Deformation Monitoring System by Leica Geosystems and slope monitoring software from Soft Rock Solutions from Australia. Support Surveys for Equipment and Machine Control Timely and precise positioning, as well as monitoring of mining equipment is increasingly important to capable mine control. The next activities are influenced by equipment positioning:

-drilling, where accuracy is critical to efficient blasting operations

-dragline positioning, where accurate and efficient movement of overburden material is critical for strip mining;

-elevation control, where continuous assessment of ground movement must be performed and adjusted in real time;

-grade control, where 3 D mapping of mineral deposits and control of ore digging and loading are required;

- track assignment, where mining haul trucks must be directed to the right place at the right time and each load of ore or waste, depending on its quality and characteristics, must be dispatched to its proper destination.

Accurate equipment positioning can be achieved by means of GNSS receivers using RTK technology. However, the vertical accuracy of a standard RTK GPS system is two to three times less than its horizontal accuracy, with vertical standard errors of ±0.01–0.02 m. Such accuracy is sufficient for most mine sites other than finish-graded roads that require tolerances of just a few millimeters. Such greater tolerances can be achieved by combining a rotating laser with a GNSS system. Accurate positioning of a dozer blade can be obtained in the horizontal position by using an RTK system and in the vertical direction by using a laser collimation plane. Lasers with a 10-m vertical swath increase this range even farther, allowing multiple machines, working at distances up to 300 m, linear, and 10 m, vertical, from the basestation, to receive grade corrections. Such systems provide the tightest machine controls technically available.

The leading machine control systems have been developed as collaborations between manufacturers of mining equipment and providers of GPS receivers. A computer-aided earthmoving system CAES combines GPS or U.S.A. Global Positioning System and GLONASS, Russia’s Global Navigation Satellite System positioning with an onboard display for the machine operator and wireless IP, Internet Protocol communications between the machine and the office. Graphical and textual cut or fill information provided to the operator eliminates the need for most survey staking. CAES can be used for haul road and bench construction and maintenance, production dozing, leach pad construction and maintenance, reclamation, ore grade control, material identification, and coal load out terminals. It is designed to be used on scrapers, loaders, dozers, shovels, motor graders, hydraulic excavators, and track-type tractors. Data on the status of each machine are sent wirelessly to the control office for monitoring by mining supervisors (Figure 6).

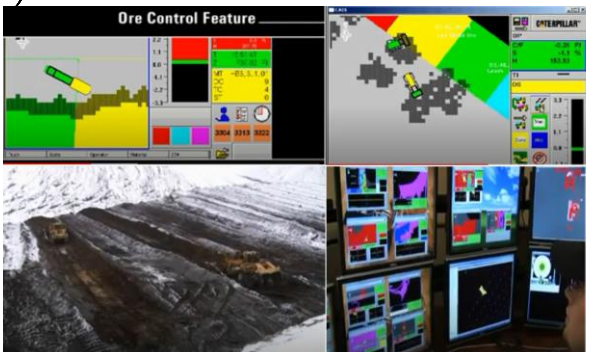

Figure 6: Computer-aided earthmoving system data on equipment position

CONCLUSIONS

In present at the Globe level we are in a period of technological development of measuring devices used in open pit mines. The technology is growing exponentially and it is necessary for mine engineers to acquire so quickly all the information useful to their job, in order to apply these technologies with minimal costs, in the shortest time. The topographic measurement and mapping technologies used in open pit mines can finally be classified into:

1. Technologies for determining distances and angles: with theodolites, total stations, smart electronic stations;
2. Technologies for determining level differences with instruments as: classic levels, electronic levels, etc;
3. Satellite technologies for determining planimetric and altimetric coordinates, more precisely instruments such as GNSS receivers;
4. 3D laser scanning technologies;
5. Photogrammetric technologies and UAVs.

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