SURVEYING AND MAPPING OF UNDERGROUND MINES

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ABSTRACT

A mine surveyor provides services from early design and project implementation throughout a mine’s life to closure. Surveyors deal in spatially referenced information and measure angles and distances to document the positions of mining features and boundaries, and present the information in the form of mine maps.In an underground mine, surveys are typically performed in dark, confined and often wet spaces, and special equipment and methods have had to be developed to comply with underground safety regulations. Deep mine surveys must be performed in 3 D and underground and surface surveys must be correlated. Underground surveys are performed at different levels of precision.

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

INTRODUCTION

Underground mining is used if the ore deposit is shaped in a way that isn’t beneficial for open pit mining or if surface mining has gone deep enough that underground mining is the next logical step to keep production rates high and costs low. A schematic of an underground mine can be seen in Figure 1.

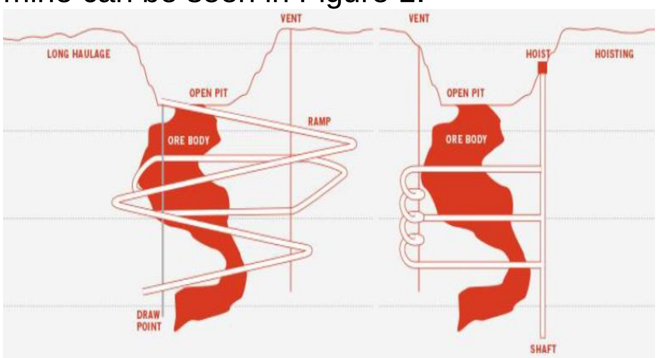


Figure 1: Schematic of an underground mine

In an underground mine, surveys are typically performed in dark, confined and wet spaces, and special equipment and methods have had to be developed to comply with underground safety regulations. Mining drifts (drives) and tunnels tend to be long and narrow, requiring the use of traverses as the main survey control. Control points are generally located in the back (roof) rather than in the floor, where they are less subject to heavy traffic and less vulnerable to damage. Adverse conditions to which instruments are exposed include dripping water, high-velocity ventilation air, high temperature, dust, strong electromagnetic fields, and mine gases, and therefore only safety-certified equipment can be used. Areas that are unsafe to access may require the use of specialized equipment that can be remotely controlled.

MATERIAL AND METHODS

Deep-mine surveys must be performed in 3-D, and underground and surface surveys must be correlated.

The location of mine workings must be accurately controlled, especially in relation to mining lease boundaries and other important surface features such as highways, railroads, power lines, gas lines, wells, and historical buildings. Adjacent mine workings must be surveyed and presented in the same coordinate system to eliminate unintended breakthrough that could lead to disastrous gas or water inrushes. Maps of all surrounding mines and other relevant areas must be reviewed and fitted to the master map of the mining operation before the start of any mining project—a job made difficult because, all too often, adjacent mines, highways departments, railroad companies, gas companies, surface landowners, or mineral owners use different coordinate systems.

Surveys are performed at three levels of precision:

-creation and survey of a primary control network for the mining area and permanent workings;

-survey of mine headings and development areas;

-survey of short traverses necessary to map active mining areas;

A primary control network is generally tied to the second or third order of the Romanian National Geodetic Survey network and must adhere to the same precision specifications. In many cases the configuration and geometrical characteristics of the mine entrances require use of traverses as an underground control network. Traverses usually have many short (40–50 m) traverse legs and direction is difficult to maintain. It is advisable to perform surveys using quality theodolites or Totally Stationthat are maintained and checked regularly. When an underground control network extends over a large area and traverses are long with many legs, the use of gyro-theodolites may significantly improve their directional precision. An example of a control network with ties to the geodetic network is shown in Figure 2.

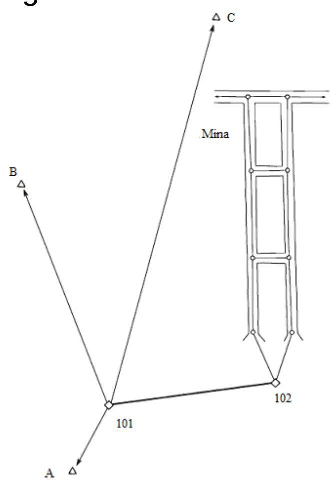


Figure 2: Control network for an underground mine

The second and third levels of survey are generally performed by resident mine surveyors using typical surveying equipment such as totally stations, standard theodolites, EDMs and levels.

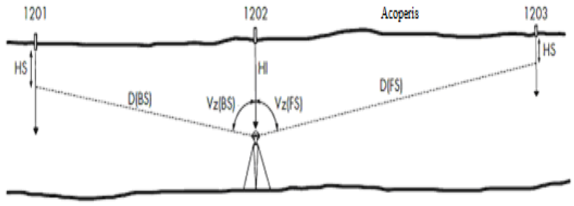
Equipment used for surveying in underground traverses is not too different from that used on the surface: electronic total stations, the primary angle and distance measuring instruments, enable automatic reading and storage of directions and distances. Distances are measured electronically with the help of EDM devices that are coaxially mounted in a telescope. For use underground, instruments should be protected from dust and moisture. For use in gassy mines, instruments must be certified for use in such environments; that is, they must be explosion-proof. Most theodolites and Totally Stationtoday have been properly sealed at the factory and can be used in such environments. If, for safety reasons, EDM devices cannot be used, a steel tape can be used for distance measurements. Underground survey stations are usually stabilized in the backs of underground drives by the following means to protect them from damage. Survey stations should be identified with brass, aluminum, or plastic tags. Identification numbers on the tags can be either:

-sequential, assigned to stations as they are created, regardless of location;

-position coded to identify station location (level, drive, or station number).

Modern theodolites and Totally Station are equipped with optical or laser plummets for fast, easy centering over or under the control point. If laser plummets are not allowed, standard plumb bobs can be used.

Most underground leveling is performed while traversing, due in part to time constraints, generally by means of the trigonometric leveling technique. Vertical angles can be measured with high precision, and thus trigonometric leveling provides similarly accurate results. During traversing and leveling, it is important that instrument height and target or signal height also be measured accurately. Measurements collected at an underground traverse station are shown in Figure 3.



D(BS)=slope distance to backsight
HI=instrument height
D(FS)=slope distance to foresight
Vz(BS)=zenith angle to backsight
Vz(FS)=zenith angle to foresight
Hs=target height

Figure 3: Classical traversing

Traversing with Totally Station in the Walls. Although the back provides a secure location for control points, it presents a number of disadvantages for mine surveying, the most obvious of which is the difficulty of installation and access. Locating control points in backs in a modern high volume underground mine usually requires lifting apparatus to heights of >5 m. In contrast, locating control points in walls makes installation and access easier, faster, and safer.

Because a theodolite cannot be set under a control point, wall-station traversing requires use of a surveying technique other than that used for classical traversing. Rather, the resection technique (free stationing), with all available distances and horizontal angles measured, is used to determine instrument position. Wall mounted points are observed from a temporary instrument station located in the drive. Wall station traversing has become popular in underground mining operations and it is important that surveying professionals have an in depth understanding of the methodology, precision, and limitations of the technique. The instrument and target are shown in Figure 4.

Figure 4: Wall station traversing: configuration of instrument

Totally station instruments must be coaxial; that is, distances and angles must be measured along the same line of sight and software must be able to determine instrument position from resection observations by means of the least-squares best-fit calculation method. Analyses of wall-station traverse precision suggest that, for optimal directional precision, a configuration must have acute-triangle geometry.

Temporary instrument stations located normal or near normal to wall stations decrease the precision of bearing transfer. If acute triangle geometry is not always possible, the surveyor should take additional observations to the previous and next instrument station to add rigidity to the survey structure and use forced centering when observing consecutive instrument stations, ensuring that the initial triangle geometry is acute.

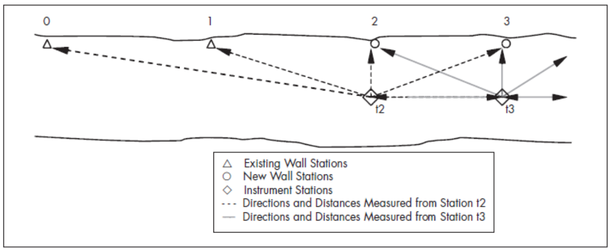


Figure 5: Wall-station traversing: additional observations between instrument statio

Recent experiences suggest that wall-station traversing significantly increases the safety of surveying operations in modern underground mines with large drives. However, it requires the use of modern coaxial theodolite and zero-constant reflectors. Distance measurements must be accurate to ± (1 mm + 2 ppm) and angular measurements must be accurate to ± 5″.

Position and Direction Transfer, from surface to underground. Determination of an underground baseline with coordinates and orientation (azimuth) to a surface coordinate system involves position and direction transfer. Special care must be taken with direction transfer, because errors significantly impact the correct positioning of underground control points.

The standard position error (σ_P) is linked to the initial orientation error (σ_{Az}) by the following relationship:

$$\sigma_P = (\sigma_{Az} / \rho'') \cdot L$$

where: ρ''=206265";L = direct distance between baseline and a traverse point;

How position error grows as a function of initial orientation error and distance from the baseline is shown in Table 1.

The total position error for a traverse point includes components linked not just to orientation but also to measured angles and measured distances.

The means of underground access determines the method for positional and directional transfer. The following methods are available:

-traversing directly from surface to underground through a mine adit and decline;

-shaft plumbing using two or more plumb lines in one vertical shaft;

-shaft plumbing using a single plumb line with gyro orientation of the initial azimuth underground;

-shaft plumbing using a single plumb line in two or more separate shafts or rises, followed by so-called fitted traverse linking of these wires

The traversing method involves creating a traverse that starts at permanent monuments on the surface and passes through an access tunnel or adit to the underground workings.

After initial traditional traversing, the procedure is as follows:

-establish a position on a spad in the roof of the underground drive and measure subsequent traverse legs with the instrument set under the surveying stations.

-when extending a control network, use double-angle traverses. Measure both left and right (clockwise and counterclockwise) angles at each station and check for – closure; double-center the instrument—that is, re-center it before each measurement.

-for improved traverse precision, force-center the instrument and targets to eliminate centering errors between instrument and targets.

-level the theodolite accurately, especially in the steep sections of a decline, for accurate direction transfer.

Tabel 1

Position error induced by orientation error σ_P

Distance from baseline L [km]	Initial Orientation Error (σ_{Az}) [m]		
	±15"	±15"	±30"
0.5	0.036	0.048	0.073
1.0	0.073	0.097	0.145
2.0	0.145	0.194	0.291
3.0	0.216	0.291	0.436
4.0	0.291	0.388	0.582

The shaft-plumbing methods assume that the plumb lines are truly vertical. This assumption is particularly critical when the distance between plumb lines is relatively short (<5 m), as when both lines are located in one shaft. Two plumb lines with random deflections e_1 and e_2, separated by distance *b*, result in a direction error (σ_{Az}) of:

$$\sigma_{Az} = \frac{\rho''}{b} \cdot \sqrt{\frac{e_1^2 + e_2^2}{2}}$$

For example, plumb lines with random deflections e_1 = e_2 =±1 mm, separated by distance *b* = 4 m, result in a direction error of ± 52″.

A typical single-shaft plumbing setup is shown in Figure 6.

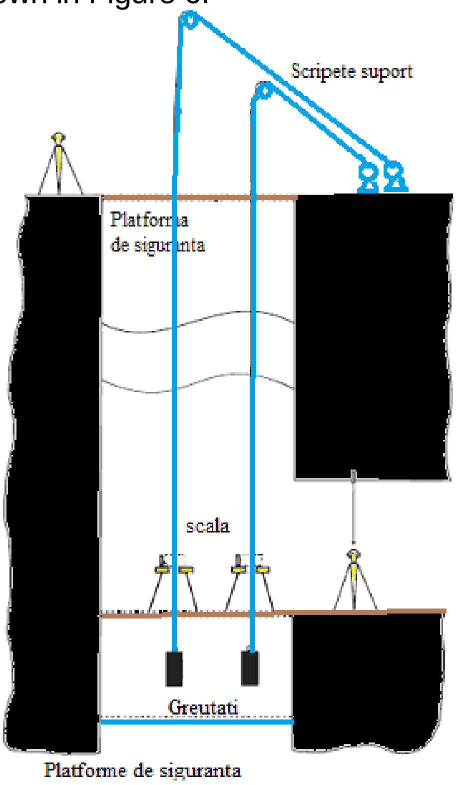


Figure 6: Single shaft plumbing setup

When plumb lines are located in different shafts, the baseline is at least several hundred meters and the resulting errors have significantly less impact on direction transfer.

The procedure is as follows: Lower the wire initially with a small weight attached, fix it in position at the upper end, ensure that it hangs freely without touching any shaft fixtures, and attach a heavy bob to the wire. As a general guideline, the weight of the bob in kilograms should be one-third to one-half the shaft depth in meters.

To dampen oscillation, immerse the bob in water or oil and eliminate disturbances such as strong air currents from the ventilation system or falling water. Note, however, that oscillation of freely hanging bobs cannot be completely eliminated. Determine the vertical position of the plumb line by taking readings at the extreme left and right of oscillation on a scale placed behind the wire. Take readings from two stations located on two perpendicular lines.

Determine the mean position of the line from these readings by fixing (clamping) each plumb line to its mean position using a special apparatus called a Smith plate. Because a theodolite cannot be set under a plumb line, for direct measurement of orientation angles, the theodolite should be positioned next to the shaft and one of the following special geometrical solutions should be used to determine the orientation of the plane passing through the plumb lines.

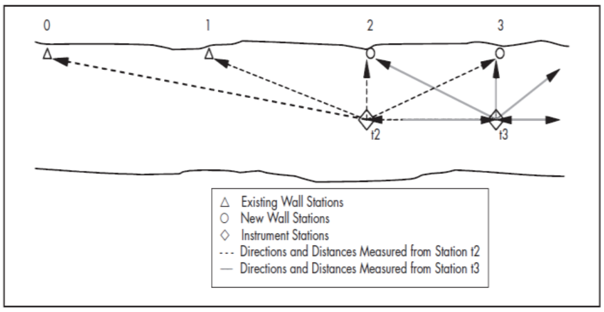


Figure 7: Wall-station traversing: additional observations between instrument stations

a. **Coplaning or aligning.** The instrument is set exactly on the line passing through both plumb lines.

b. **Weisbach triangle.** A triangle is used to link both plumb lines and the instrument station. The instrument is positioned close to one of the plumb lines in such a way that the angle at the instrument station is acute (<10') and measured with utmost precision.

c. **Hause quadrilateral.** When the instrument cannot be set at or close to the line passing through both plumb lines, a quadrilateral can be used to link both plumb lines and two instrument stations.

For optimal orientation **precision,** standard shaft plumbing should be performed in two shafts that are far apart from one another. The procedure is as follows: Conduct a simple surface traverse survey to give the location of each wire in the official map grid system. Then conduct an underground traverse survey to connect the two plumb lines. Initially calculate coordinates of this traverse in a local, arbitrary coordinate system. Then, because the map grid coordinates of the traverse endpoints (plumb lines) are known from surface surveys, recalculate the coordinates of all other points to the surface coordinate system by means of coordinate transformation.

Transfer elevations underground by means of long shaft tapes.

- Calculate corrections to the tape length due to temperature, stretch, and pull, and adjust the measured length accordingly.
- Measure vertical distances with the help of an EDM device.

The details of underground drives, drifts, and tunnels are derived from control stations established in mining structures. In most cases, detail surveys are conducted concurrently with control surveys. Traditionally, the method of chains and offsets was used to perform detail surveys. The procedure is as follows: Stretch a reference tape between traverse stations. Measure offsets to the right and left walls at regular intervals (2–3 m) with a short tape.

Measure vertical distances to the roof and floor with surveying staffs or poles; Note the details, distances, and offsets of existing features. It is sufficient to approximate the perpendicularity of offsets, due to their shortness and the measurement precision (±0.05 m). Higher precision (±0.01–0.02 m) is required in drives or tunnels with permanent roof and wall supports. Prepare a sketch of the survey in approximate scale.

In cases such as when rebuilding a tunnel or drive, prepare a detailed cross-sectional survey. For a reference line, it is traditional to use a plumb line attached to a spad installed in the roof. Measure offsets at different elevations between the plumb line and the walls.

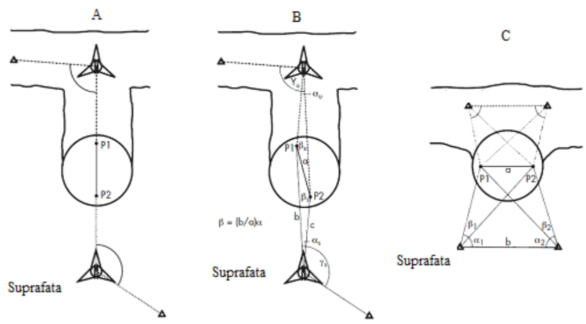


Figure 8: Geometrical solutions for direct measurement of orientation angles A. Coplaning; B - Weisbach triangle; C - house quadrilateral

RESULTS AND DISCUSSIONS

Today, **totally station with reflector less EDM devices** are used almost exclusively to perform **detail surveys.** The procedure is as follows: Survey a few lines running at different elevations and representing the outline of the structure of interest. Download the collected data from instrument memory to a computer in the survey office for processing, plotting, and, in most cases, creation of a 3-D model of the structure. The newest surveying technologies use laser scanning devices for fast, continuous collection of detailed and accurate transverse profiles when the device is moved.

Mines extracting massive deposits are surveyed almost exclusively in 3 D. Totally Station are used to survey access and development drives; laser based monitoring systems are used to survey cavities and stopes in the latter case, with the instrument inserted into the stope by means of a boom. The motorized surveying head scans the opening with the help of a laser rangefinder. A total station can determine the position of a device by tying it with positions of existing control stations. Special inspection and surveying devices are also available to survey inaccessible vertical shafts and ore passes. Collected data are converted to 3-D models with the help of specialized computer software. These models are linked with other models of development and access drives to provide a 3 D model of the whole mine. Such models enable creation of plans and cross sections in any scale or projection.

Relatively thin **tabular deposits are** traditionally surveyed in two dimensions, with the projection plane parallel to the deposit. Such surveys should be performed in coal mines or mines from which metalliferous reef type deposits are extracted, using chain readings and orthogonal offsets to provide detail.

The procedure is as follows: For a reference line, use a steel dip tape stretched between strike gullies or drifts. Use orthogonal offsets and triangulation to relate the position of the dip tape to spads installed in the gullies. Use a short tape and a surveying stick to measure offsets between the tape and the stope face. Also measure the width (height) of the face. If the deposit is on an inclined plane (reef), reduce the distances measured along the dip to true horizontal distances. In the survey office, create a horizontal map and use a planimeter to determine the areas between face positions and the volumes extracted.

CONCLUSIONS

Recent developments enable 3-D surveying of thin tabular deposits by means of electronic Totally Stationcombined with data collection and display hardware and software. The results of an underground survey can be viewed in real time on a personal computer.

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