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CONSIDERATIONS ON THE WAYS OF DETERMINING THE MOVEMENT OF THE EARTH'S SURFACE DUE TO THE PHENOMENON OF SUBSIDENCE

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Abstract

The paper aims to present some theoretical and practical aspects related to the movement over time of the land surfaces affected by the groundwater exploitation of multi-layered deposits in the area.
The methods and techniques described are intended to facilitate a rigorous observation of the evolution of risk and hazard phenomena, presenting a complex summary of the way of obtaining specialized information, as efficiently and precisely as required by the Romanian legislation regulations.
Given that the phenomenon of subsidence keeps on being of a broad interest through its implications on urban planning, environmental protection and on the surface buildings, the issues described in this paper lead to short, medium and long-term forecasts regarding the subsidence due to the exploitation of multi-layered deposits. These forecasts are very important in the sustainable development of the areas affected by underground mining.

Key words: *movement, surveying, subsidence.*

INTRODUCTION

In the context of the current worldwide energy crisis, recent years have led to intense concerns for the discovery of new chemical and energetic elements, for deposits' improvement, for a closely management of reserves and not least for the increase of multi-layered deposits production capacity.
In the case of underground mines, the phenomenon of subsidence results in filling the void created by extracting the ore and its spread to the earth's surface, with repercussions over tens of meters on the affected the area.
Underground exploitation of multi-layered deposits in Jiu Valley mining basin frequently leads to the surface's displacement and deformation, as well as to the deterioration of industrial and civil objectives placed at mines surfaces.
In order to solve the issue of protecting the industrial and civil objectives placed at mines surfaces, certain measures are needed for the surface's protection against sinking. It is also necessary to monitor the earth surface's movement and deformation, as well as the tension of the building elements on the surface.
For observations on how the earth's surface displaces and distorts, as well as for observations on the surface targets, surveys are most frequently used.
Often, observations are confined to carrying out middle geometrical levelling paths over a network of tracking marks, and to measuring the distances between them.
Following the topographical measurements carried out, we can determine the values of movement parameters horizontal sinking and movement), and the deformation parameters (inclination, curvature, horizontal deformation).

Solving the problem makes it possible to anticipate the effects of underground mining on the surface, and it also allows taking appropriate measures for the protection of surface industrial and civilian targets (Ortelecan, 1997).

MATERIALS AND METHODS

Topographic methods used in determining the ground surface movement

The topographic methods used for surface movement tracking were the first to reveal the influence that underground mining has on the ground surface.
The topo-geodetic methods used to determine the occurrence of the phenomenon of subsidence, are the most often used due to their peculiarities in providing the absolute and relative sizes of the deformations observed.
Parameters are determined through direct and indirect measures, which are grouped into the following methods: geodetic, topographic, photogrammetric, laser scanning and interferometery.
The geodetic methods for determining the parameters of the land surface's displacement and deformation are run according to rigorous instructions, mandatory to be followed, established and approved by resort ministries (Ortelecan, 1997).
According to the existing guidelines, geodetic methods are classified into regional measurements carried out for the entire surface of the mining basin, and local measurements conducted over each mining perimeter.
Regional measurements are carried out regularly, through high-precision levelling measurements, using certain fixed points outside the mining zones of influence.
Local measurements consist in determining the coordinates (x, y and z) of fixed point's networks or of tracking alignments which lead to the movement parameters. Surveys are run by conducting observations in the tracking marks placed above the topographic mines.
Observations in the tracking marks may be made by topographic methods using specialized instruments such as: classical precision theodolite, precision level, total station, GPS technology and the new mixed system of the total station with integrated GPS system.

Figure 1. Smart Station integrated system

The mixed system of the total station with integrated GPS (Smart Station) is actually a dual frequency (L1 and L2) RTK GPS. Each frequency has 12 channels in direct connection with the total station. This revolutionary system of the last decade has a special feature in that it provides an absolute and/or relative positioning of the GPS points, inclusively through the RTK kinematic differential process. Total stations' possibilities, in turn, are remarkable both in individual determinations (angles and distances) and in determining the coordinates.
The photogrammetric methods provide further data necessary to clarify certain phenomena that cannot be captured by surveying. These methods assure a unique fidelity in determining the shape of the sinking riverbed, but they offer very little precision in determining the specific movement parameters.

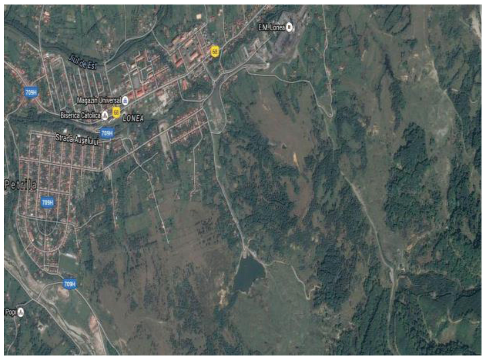

Figure 2. Ortophotomap – Lonea, Hunedoara County, Romania

The method of laser scanning is a method of geodetic technique through which a structure's geometry can be fully and automatically

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measured without the aid of a reflective environment, with high precision and high speed. The measurement results are highlighted by a lot of points, which in literature is called points cloud.

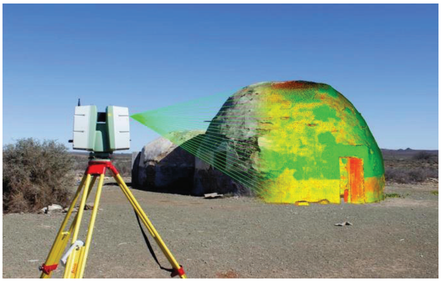

Figure 3. Terrestrial laser scanning system

The interferometry method is one of the most revolutionary methods used for satellite monitoring of earth movements and is made of a satellite equipped with a radar whose antenna is pointing toward the land area. Antenna’s tilt is called the nadir angle.
The use of interferometry aims to detect and to measure the surface movements on a small scale. This method involves the generation of two interferograms from three images: a reference interferogram and the second one to capture the changes that took place at the ground surface (Palamariu et al., 2015).

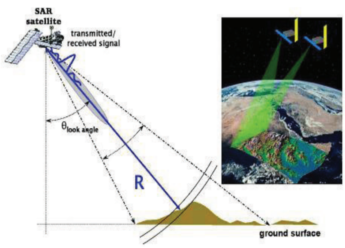

Figure 4. Data acquisition through DinSAR technology

Topographic determinations made within the tracking networks

The earth's surface movement is determined either by geodezic-topographic methods held in the influence area of exploitation works, either by analytic methods, applying methods known in the technical literature or coming from the interpretation of personal topographical measurements.
The surveying conducted for the tracking network can be grouped into: measurements for the support network, which takes the form of a micro-triangulation network or of a precise poligonometric network, placing thus the support network so that it frames the tracking station by stable and sufficient points; primary measurements consisting of framing the alignments' support parts within the triangulation network and of determining the parts' position before displacement on the surface; control measurements that are run near the working face, in the marginal area, in order to capture the moment when the surface movement occurs; current measurements, which are run periodically, at well-defined intervals depending on the three phases of the phenomenon of surface movement.
Systematic measurements for tracking the vertical and horizontal movements of the tracking marks are performed in the alignments of the tracking networks in order to determine the parameters of the surface movement.

Topographic methods for determining horizontal displacements

The methods used in determining the horizontal displacements of the tracking marks, following the land movement under the influence of groundwater exploitation, are the direct and the indirect methods.
Direct methods for determining the horizontal displacements of tracking marks consist of periodic measurements along the tracking alignments, at times established in accordance with the construction project.
Longitudinal horizontal displacements are determined after measuring the distances between points, while transversal movements are determined as the differences between points' deviations from the direction of the observation line.
When ground conditions do not allow direct measurements, indirect methods are used. Indirect measurements consist in defining the planimetric and the altimetric position of tracking marks, through methods such as: triangulation method, the method of

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intersections or traversing, through which horizontal or vertical displacements are determined, based on the observations made.

One of the most commonly used methods is the direct method of alignments. This method requires a team made of an operator and two assistants.

Thus, the following accessories will be used: tensioners 1, ribbon or tape 2, sheets 3, dynamo-meter 4, and milestones 5.

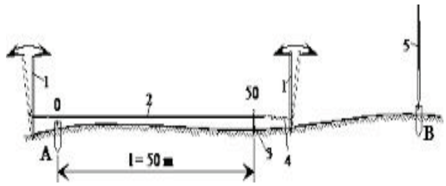

Figure 5. Direct measurement of lengths

Due to the fact that topographical plans trace only the distances in sight, all inclined distances measured directly on the ground, will be reduced to the horizon, depending on the alignment's slope angle (α) or the zenith angle (z).

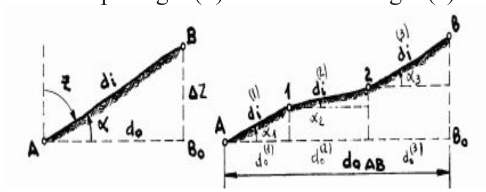

Figure 6. Reducing distances to the horizon

Another method for determining the horizontal displacements is the observation of parallaxes angles.

This method involves the creation of an alignment as close to the line joining the points of the elements under observation.

Thus, as points of the alignments support network, there is point S1 and point S2, which serve as fixed reference points for the equipment used. Metal bushings are embedded within the points under observation. During measurements, inside the bushings there will be installed stable trademarks or simple metal parts, to be targeted for determining the horizontal angles.

Determining the horizontal angles corresponding to a deviation of the observed points (1, 2...n) is preferable to be run with a highly accurate theodolite. The theodolite must be placed in point S1, from where φ_i angles are measured towards the alignment S1 -S2, and analogously, from station S2, ψ_i angles are measured against the same alignment. Thus, the angle measurements are being performed on both faces of the theodolite's telescope (Neamtu et al., 1988).

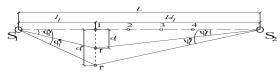

Figure 7. Alignment method - parallactic angle measurement

The distances between points S1 and S2 of the support network towards the observed points are determined by direct or optical measurement. The horizontal angle measurements of the observed points, made in the two positions of the theodolite's telescope, lead to a series of comments and an observation cycle may comprise between 3 and 5 series of observations. Each series implies the calculation of the φ_i, respectively ψ_i averages measured for each item under observation (Neamtu et al., 1988).

Topographic methods for determining vertical displacements

Topo-geodetic methods are in many cases the only methods suitable for determining the absolute deformations and displacements. In other cases they serve as means of controlling the sizes of deformations and displacements strains defined by other unconventional methods.

The principle of measuring the vertical displacements and strains is to repeatedly determine the quantities measured within the tracking marks.

As long as topo-geodetic measurements only allow an analysis based on the vertical displacements' character and sizes, they need to be linked to the observation and study of the underground system, to the rock mechanics, in order to discover the origin of these displacements and to indicate the possibilities of eliminating them.

The errors resulting from surveying the vertical displacements are of particular importance in the calculation of derived quantities such as inclination and curvature (Ortelecan, 1997).
Vertical displacements for scientific purposes are determined with high-precision level meters that provide a measurement error of $m0 = \pm 0.5$ mm/km.
The error of determining the values of tracking marks depends on the topographic tracking network, on the length of each line and the distance between mobile landmarks.
In order to determine the vertical displacements at least two instruments are needed: a precision topographic level and an invar rod. The topographic level is an optical instrument equipped with a telescope that can rotate only horizontally. Through the telescope we can read the height on the rod, located on the point for which we want to determine the altitude.

Figure 8. Topographic level and rod

Further, we shall present two of the methods mostly used to determine the vertical displacements: geometric leveling method and trigonometric leveling method.
In the first instance (middle geometric leveling), the station is built with the level in the middle of the alignment between points 1 and 3.
The difference in level between the two points, 1 and 3, will be equal to the difference between the value registered on the rod in point 1 and the value indicated on the rod in point 3.
Trigonometric leveling is based on the fact that, knowing the altitude of the station point and the land's inclination, one can determine the vertical movement and then the altitude of the point where the rod is placed.

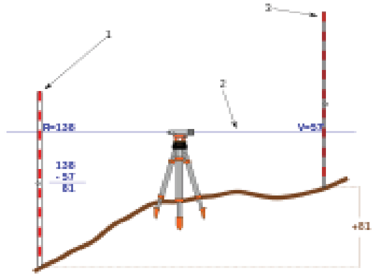

Figure 9. Middle geometric levelling
(https://ro.wikipedia.org/wiki/Nivelment)

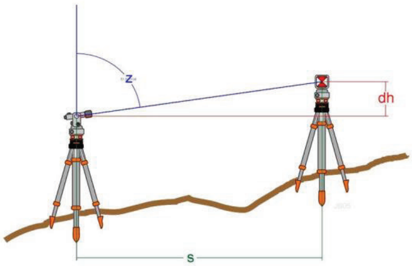

Figure 10. Trigonometric levelling
(https://ro.wikipedia.org/wiki/Nivelment)

Between the point where the precision theodolite is set and the point of reading, there is a right-angle. We know the angle's length S and the angle of fall α.
The difference in level between the two points is given by:
$dh = s * tg\ \alpha$, where $\alpha = 100g - z$

CONCLUSIONS

The topographic methods used to study the surface displacements and strains require a surveillance station consisting of transversal and directional alignments towards the deposit direction or of alignments networks.
Tracking networks fairly determine the surface movement, but require a large number of parts and a considerable amount of observations.
Direct topographic methods consist of measuring the absolute movements of the direct marks which ultimately reduce to the direct measurement of the distances between the measuring marks and to determining their heights through geometric leveling from the middle.

Since direct topographic methods provide high accuracy in determining the parameters of surface displacement and deformation, they are most often used in practice.

Indirect topographic methods consist in determining the marks' coordinates (x, y, z), which help defining the surface displacements and deformations by applying analytical relations.

Indirect methods have experienced a poor development due to the difficulties of placing the support network and due to the lack of the working parts' visibility.

The absolute and differential surface movements for specific given conditions are determined through topographic methods, without taking account of the rocks' physico-mechanical properties. Also, these methods do not clarify the movement of the whole package of rocks from the mining to the surface layer. However, topographic methods are still the most used methods for assessing the parameters of movement and deformation of transitional or final sinking river beds.

Topographic methods also give the possibility to verify the hypotheses and theories established on the partition functions and on the abstract models for specific geo-mining conditions.

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