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STOCK VOLUMES DETERMINING AS THE BASIS FOR THE PLAN OF OPENING, PREPARATION AND EXTRACTION PROCESSING IN OPEN STONE-PIT QUARRIES

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Abstract

Geodetic surveying and volume calculation of mineral deposits, that consequently serve as the basis for the „Plan of opening, preparation and extraction“ processing is the common work of mine surveyors. This paper presents methodic procedures and solutions of this task at andesite deposit at Ruskov quarry in Slovak Republic near city Košice. The spatial data collection was done by GNSS technologies in combination with modern terrestrial laser scanning method using Leica Scanstation C10. Volume calculations were solved by TIN surface model calculation, and also by classic procedures using vertical cuts and contour lines, that were mutually compared. The paper solves also the problem of the number of points necessary for valid volume determination. Therefore, the comparison was done based on results gained during stock volume determination specifically for the extraction wall enlarging the mining area where the number of points was gradually reduced.

Keywords: stone quarry, volume of extraction, TIN, GNSS, TLS.

1. Introduction

The main aim of the work is the geodetic surveying and volume calculation of the andesite deposit Ruskov that subsequently has to serve as the basis for processing of “The plan of opening, preparation and extraction”. Together with the application for the license the organization submits the plan of opening, preparation and extraction and compulsory documentation. Plans of opening, preparation and extraction are processed for the complete reserved deposit or for its specific integrated part; in the case of new or reconstructed mines or quarries, these plans may be processed gradually according to individual periods of works at the opening, preparation or extraction. Measurements were done in the coordinate system S-JTSK and height system Bpv which are compulsory coordinates systems in SR. Their definitions and parameters are listed in the edict of the Office for geodesy, cartography and cadastre No. 300/2009 as amended which administers the law of the National Council of the Slovak Republic No. 215/1995 Z.z. on geodesy and cartography. Methods that are at present used for documentation of natural formations and anthropogenic objects are mainly and are published in several works:

- *Spatial polar method with the use of total station or TLS,*
- *Geometric leveling,*
- *GNSS methods,*
- *Photogrametric methods and earth remote sensing*

The methods mentioned above differ as to their principles, accuracy, cost of instruments and software equipment, and also as to the speed of specific object measurement. Geodetic measurements and methods are published with regards to the progress of geodetic technology in several sectors of economy and research in papers focusing on civil engineering [1], mining [2][3][4][5][10], architecture, industry [7][8][9], archeology [6], etc. The result of the process of terrain measurements is the set of coordinates and height points necessary for subsequent analyses and evaluation of documented events or objects. Further data processing depends on the goal of their further utilization. An example we may mention are different basic and thematic maps often put in the form of planimetry and altimetry plans usually projected to cartographic plane. Regarding the nature of measured data, that usually are spatial, their processing in the form of spatial 3D models represented by a point cloud, TIN net or mesh is more appropriate. On the basis of such models it is afterwards possible to derive several representative parameters, such as spatial distances, volumes, determination of changes in the shape or dimensions of objects, create sections, etc.

2. Basic Principles of Methods Used for Measurement

Spatial polar method

Basic principle for determination of coordinates of measured points using the spatial polar method is based on the measurement of horizontal and vertical angles, and slope or horizontal distances from the station to the measured point.

Rectangular coordinates and height of the measured point will be calculated from relations:

$$y_1 = y_A + S_1.\sin\sigma_{A,1},$$

$$x_1 = x_A + S_1.\cos\sigma_{A,1},$$

$$z_1 = z_A + v_p + S_1.tg\beta_1 - v_c,$$

where: y_1, x_1, z_1 are the coordinates of the determined point, y_A, x_A, z_A coordinates of the station, S_1 horizontal distance of the determined point from the station , $\sigma_{A,1}$ bearing to the determined point, v_p, v_c height of instrument and prism height, β vertical angle (Fig.1).

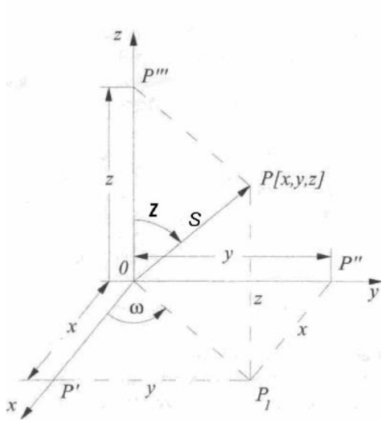

Fig. 1: Spatial polar method - scheme

Accuracy of positional coordinates is expressed as mean positional error m_P, accuracy of trigonometric height determination is expressed by mean error m_h according to relations:

$$m_P^2 = m^2{}_{pA} + \sin^2 z.m_S^2 + s^2.\cos^2 z.\left(\frac{m_z}{\rho}\right)^2 + s^2.\sin^2 z.\left(\frac{m_\omega}{\rho}\right)^2,$$

where: m_{pA} mean positional error of instrument station, s slope distance, z zenith angle, m_ω mean error of the measured direction, m_z mean error of the measured zenith angle, m_s mean error of measured distance.

$$m_h^2 = m^2{}_{hA} + \cos^2 z.m_S^2 + s^2.\sin^2 z.\left(\frac{m_z}{\rho}\right)^2,$$

where: m_{hA} mean error of instrument station height, s slope distance, z zenith angle, m_z mean error of the measured zenith angle, m_s mean error of measured distance.

Spatial polar method for determination of point coordinates is utilized by total stations (TS) and terrestrial laser scanners (TLS).

GNSS method in conditions of the Slovak republic

GNSS (Global Navigation Satellite Systems) are systems built for determination of the position and time on the Earth. The position of the measured point is situated at the intersection of the spherical surfaces with the radius given by distances between the satellite and the measured point. Basic alternatives of spatial position determination using GNSS may be absolute and relative, the later one because of its higher accuracy of coordinates determination (in mm) is in geodetic application utilized almost exclusively. There are multiple methods for position determination by GNSS. The mostly used are: static method and real time kinematics method (RTK). To provide a relative determination of the position by GNSS, two simultaneously measuring GNSS apparatuses are needed. One is located during the whole measurement at the point with known geocentric coordinates, and is called referential. Using the second one, called rover, the surveyor gradually moves along the point which is to be determined. Between both stations during measurement, there is a continual radio link or GPRS connection (Fig.2).

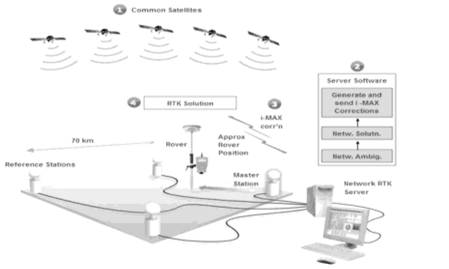

Fig.2. Principle of RTK method for GNSS [11]

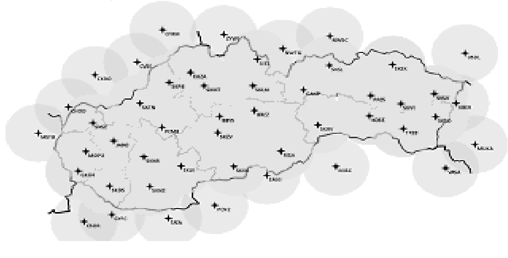

Fig.3. Configuration of referential stations SKPOS on 01/27/2014 [12]

Direct flow line of the two instruments creates the baseline. The length of the measured baseline influences the accuracy of measurement, meaning that the shorter the baseline, the more accurate is the measurement. As referential station, the GNSS apparatus itself should be situated on the most suitable point of the State spatial net, which is a part of the geodetic base of the Slovak republic. However, more suitable is the use of the permanent transmission of corrections – e.g. the Slovak spatial observing service (SKPOS), introduced by the Office of geodesy, cartography and cadastre of Slovak Republic. SKPOS is created by points of the class A of the State spatial net (Fig.3) that are permanently stabilized at objects governed by the Office of geodesy, cartography and cadastre SR.

The quality of GNSS measurement is influenced by several factors: multipath, influence of satellite configuration, influences of the environment in which the signal is transmitted from the satellite to receiver, mainly ionosphere and troposphere influence, satellite and receiver time synchronization, accuracy of determination of satellite path parameters, values of offsets and variations in phase centers of antennas and antennas calibration.

3. Digital terrain model (DTM) – basic principles

The model represents the topographic area of the relief in digital form without vegetations, buildings etc., and defines the earth surface. It enables to automate volume calculations, calculations of areas covered by the earth body etc. The terrain area cannot be defined directly mathematically and therefore by missing irrelevant details and surface roughness, a generalized topographic area arises which can be represented by a contour model, TIN model or GRID model.

Contour line model

Contour line models belong to basic demonstration of terrain elevations and serve mainly for the creation of advanced digital terrain models. However, the expression of terrain course is non-continual, because individual contours represent only elevations given by basic spacing of contours. Line description of the terrain is given by the net of main terrain lines expressing vertical profiles.

TIN model

TIN model (Triangulated Irregular Network) belongs to vector topologic structures representing the terrain. It represents a very suitable and efficient tool to express the terrain because it shows a set of irregular triangles connecting measured points of the terrain into a unified field. TIN model depicts the terrain more appropriately at minimal requirements for calculation procedures, and can represent any terrain including holes, overhangs and vertical surfaces. Shortcomings of the TIN model appear during the representation of flat terrains, when even small change in the height of one of the points leads to considerable changes in the course of contours and quantity of volumes. This shortcoming can be diminished by including critical points and edges.

GRID model

It belongs to models representing the terrain topology by regular raster structure which dissects the terrain into matrices of cells. Among mostly encountered cell shapes we find squares, because of its simple calculation algorithms, but also equilateral triangles, rectangles, hexagons, or other n-angles can be used. The accuracy and validity of the terrain representation depends on the raster structure density (size of the cells). In the majority of cases, the altitude can be found in every cell and applies to the whole cell. GRID models enable a large scale of spatial analyses, such as spatial match, adjacency, scattering and so on. Granted for their simplicity and intelligibility they belong to the most utilized terrain models. It is suitable for modeling of any relatively flat surface without abrupt height changes.

Comparison of TIN and GRID models

The main advantage of raster models is low requirements for processing of a big amount of data, because planimetric coordinates of GRID points are being calculated later, and are not directly stored in the memory during the calculation process. GRID models are used when the terrain is regular and mostly horizontal. Values of heights or depths of the GRID do not represent real measurements. When the density of measurements is lower than the density of the GRID raster, points receive interpolated height values, and on the contrary when the density of measurements is higher than the size of GRID raster, omission of some values occurs what leads to an unwanted smoothing of the model. Additionally, the GRID is not adaptive, and it is not possible to create fields with higher point density, what in TIN model can be achieved by including the higher number of measured points and smaller triangles.

4. Surveying Works and Data Processing

The station of the instrument Leica Scanstation C10 was positioned regularly at supporting measuring points stabilized temporarily by metal pipes. Coordinates of these points were given by the GNSS method RTK using SKPOS corrections. Terrestrial laser scanning was done because of relatively regular shape of walls with basic point density maximally 50cm at the measured object. Quarry areas which were invisible from any position of the scanner because of vegetation obstacles and highest levels of the quarry were additionally measured by GNSS.

Measured data were pre-processed by Leica Cyclone 8.3 and Trimble Realworks 6.5 softwares. Preprocessing included data filtration for removing points representing vegetation in the quarry as well as further objects, as mining devices and buildings. Spatial resampling has created a point cloud processed into the structured text form with equal distances between points on the measured object.

Tab. 1: Structure of coordinate list of measured points in the text form

Y [m]	X [m]	Z [m]	I	R	G	B
248308,11	1246573,81	445,890	72	125	112	56

Regarding the above mentioned basic characteristics of DTM for further modeling of the quarry, the TIN model was chosen. Processing was realized on the software platform Trimble Realworks 6.5. The ensuing model was further edited eliminating mistakenly generated triangles. A survey disclosed the tailings with thickness of 1 m over the deposit in upper parts of the quarry, and 2 m at lower levels. To determine the tailings volume it was necessary to adjust the source model by editing heights of detailed points for specific levels of the quarry. Further, two models of the deposit were processed – one with the tailings and the second without. Volume of the deposit part was determined considering the enlargement of the extraction area. The surveying procedure was similar as above. Terrestrial laser scanning was the main measuring method. The volume was determined from already created TIN models of the quarry wall. Using spatial sampling, models of the quarry wall with 50%, 10% and 1% of points from original point number were created. The volume value gained at TIN model with 100% of measured points served as the baseline for comparison.

Tab. 2: Point files and numbers of points

Point cloud number	Approximate number of points
Point cloud 1 - 100% of points	70000
Point cloud 2 - 50% of points	35000
Point cloud 3 - 10% of points	7000
Point cloud 4 - 1% of points	700

Volume calculations from cuts

From created TIN models, five mutually parallel cuts oriented upright to the chosen main axis of the quarry in constant distances 75 m were done (Fig.4). Profiles were created for the area with the specified mining border. Profiles show the terrain course with the tailings, and the deposit without it (Fig.5).

Areas of individual profiles were determined graphically. Profile areas were counted twice; first for content area with the tailings, then without. Tailings area was determined as the difference between them. The volume defined by two adjoining cuts was calculated according to the relation $V_{1,2} = \frac{P_1 + P_2}{2} \cdot d_{1,2}$, where $d_{1,2}$ is the distance between cuts, P_1 a P_2 is the content area of individual cuts. The whole volume is the sum of partial volumes.

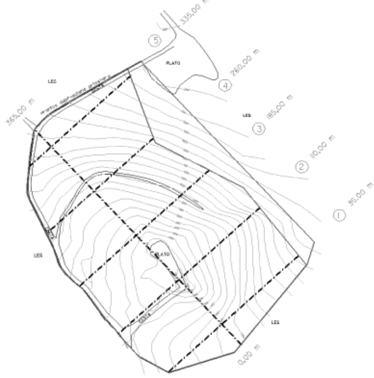

Fig.4. Contour plan and the situation of cuts

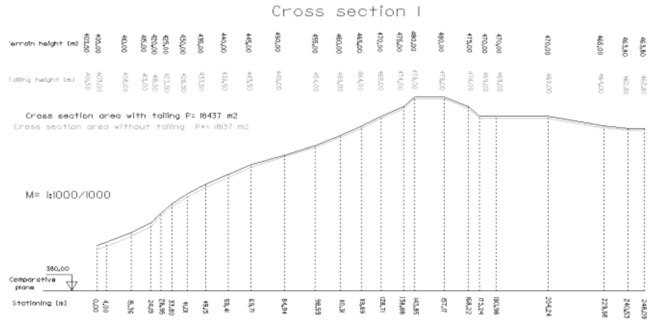

Fig. 5. Vertical cut of the deposit

Volume calculation from contour lines

Contour lines (Fig.4) were generated from text point datasets that had created the base for TIN models creation in heights from 380m to 480 m with an interval of 5m. Areas defined by contours were determined graphically for fields with the specified border of mining. Procedure of volume calculation was analogical to the method of calculation from cuts.

Volume calculation from TIN model

Model creation and volume calculation was done using the Trimble Realworks 6.5 software. Upper surfaces created the terrain models with and without tailings. The defining bottom terrain was created by points generated for the whole quarry area with height value 380m. Results of calculation of the stock volume using TIN models are considered among mentioned methods as the most probable, with high validity and we consider them to be referential.

5. Results

Comparisons of results of stock volume calculations for the whole deposit by chosen methods are quantified in tables 3. and 4.

Tab. 3. Final volumes of Ruskov quarry with specified border of extracting space

Volume calculation from cuts [m^3]	Volume calculation from contour lines [m^3]	Volume calculation from TIN model [m^3]
3 901 976	4 193 712	4 177 649

Tab. 4. Differences in quarry volumes calculated by individual methods with specified border of extracting space

Volume calculation	Difference [m^3]	Difference [%]
TIN - cuts	275 673	-6,60
TIN –contour lines	16 063	+0,38

Table 5 shows volume calculations for individual point sets according to table 2. They are expressed as absolute difference in m^3 and in percentages. Strictness of the created TIN model depends on the number of points in individual datasets, which further influences the determination of stock volumes.

Tab5: Volume values calculated by Trimble RealWorks software for individual point clouds

Number of points	TLS 100% of points	TLS 50% of points	TLS 10% of points	TLS 1% of points
Volume [m^3]	16520	16558	16580	16385
Difference [m^3]	-	+38	+60	-135
Difference [%]	-	+0,23	+0,36	-0,82

6. Conclusion and Discussion

The aim was to survey and determine the stock volume of the deposit in the surface quarry, as the basis for the preparation of the "The plan of opening, preparation and extraction". The paper describes the process of the measurement work in terrain and the processing of the data gained about the quarry. The final result is the calculation of the volume of the deposit. Volume calculation was done by classic methods using cuts and contour lines, and the volume calculation from TIN models.

As the referential value for stock volume, the value gained from the TIN model was used. Comparing results in table 3 and 4 we conclude that the method of volume calculation from cuts has the highest differences to referential method (amounting to 6,60%). Comparison of stock volume calculation using contours to referential calculation shows the difference +0,38%. Both classical methods are considerably time demanding during data processing. They may be recommended as a check to reveal major processing errors. Their application in current practice may be in volume determination at existing graphic backgrounds such as planimetry and altimetry plans, basic mining maps or existing geologic cuts of the deposit. In the course of determination of possible perspective enlargement of extracting area we dealt with the issue of the number of points necessary for its valid determination. Number of points in individual sets is in table2. Point number was changing only on the extracting wall, other surfaces such as the upper plateau and bottom terrain remained identical in all point sets (comparison in table 5). Regarding relatively regular and direct course of the wall differences appeared to 0,82%, which represents the volume difference in the range of a generally acceptable value. In condition of such extracting walls one can therefore use also a total station with manual targeting to precise points.

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