

GEODETIC DETERMINING OF STOCKPILE VOLUME OF MINERAL EXCAVATED IN OPEN PIT MINE

GEODETICKÉ URČENIE OBJEMU VYŤAŽITELNÝCH ZÁSOB NERASTU V POVRCHOVOM LOME

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Abstract

In the contemporary geodetic practice it is practically a must to use modern geodetic apparatuses and a variety of the CAD (Computer Aided Design) software for processing and visualising spatial data. The present paper deals with geodetic surveying of Kečerovce open pit mine to determine, for the purpose of mine reopening and commencing with mining of andesite, the volume of non-extracted volumes of andesite. The open pit mine is situated on the foot of Slanské vrchy mountain range. Determining of the auxiliary survey control points and the quarry vicinity was performed by GNSS technology and RTK method. Detailed surveying of the open pit mine was performed through an electronic total station. By measurements attained spatial data were processed by pertinent proprietary software. Subsequently, the determined spatial coordinated were imported into the graphic-calculating softwares for further processing and visualisation. These graphical-calculating applications make possible not only 3D modelling and visualising of surfaces but also their analysing, especially then determining the volumetric data that represent various aspects necessary to assess as activities within the related branches so possible future development.

Abstrakt

V súčasnej geodetickej praxi je nevyhnutnosťou používať moderné geodetické prístroje a rôzne CAD (Computer Aided Design) softvéry pre proces spracovania a vizualizácie priestorových údajov. Tento príspevok sa zaoberá geodetickým zameraním povrchového lomu Kečerovce za účelom určenia objemu nevyťažených zásob andezitu pre znovu otvorenie lomu a začatie ťažby andezitu. Predmetný lom je situovaný na upätí Slanských vrchov. Určenie pomocných geodetických bodov a okolia lomu sa vykonalo technológiou GNSS RTK metódou. Podrobné zameranie lomu bolo realizované univerzálnou meracou stanicou. Priestorové údaje získané z meraní sa spracovali v príslušných firemných softvéroch. Následne získané priestorové súradnice boli importované do graficko-výpočtových softvérov pre ďalšie spracovanie a vizualizáciu. Tieto graficko-výpočtové softvéry ponúkajú okrem 3D modelovania povrchov a vizualizácie aj ich analýzu, najmä určenie objemových údajov reprezentujúcich rôzne aspekty pre posudzovanie činností v daných odvetviach s možným ďalším rozvojom.

Key words: calculation cubature, open pit, modelling, visualising, terrain surface

1 INTRODUCTION

In the geodetic practice, determining of the volume presents a highly frequent task. Geodetic measurements present the basis for volumes determining, and using them realised are precision surveying of the terrain shape. In question are determining of various volumes of stockpile, mineral deposit resources or recoverable reserves, potential volume of waste dump, possibly of non-extracted stockpiles remaining in

the extractable open pit mine area. According to [1] the quarry is both a workplace and plant for extracting minerals shallowly situated under the earth surface. Within the quarry, most frequently determined are being volumes for the purpose of determining volumes of already mined minerals or possibly for determining extractable volumes of minerals. For the reason, performed within the quarry are geodetic surveys so that, e.g. by a combination of GNSS and a terrestrial technology, precisely surveyed was the quarry terrain shape. These activities stand for field works. The office work is to process the attained data to a format suitable for further processing to determine the volume out of acquired data.

2 DETERMINING STOCKPILE VOLUMES OF SURFACE DEPOSITS

Calculation of the stockpile volume presents a purposeful and self-contained procedure of collecting, processing and assessing the data on geological position and quantity of industrial minerals in their natural or anthropogenic embedding, which allows coming to decisions on their further utilisation.

At determining volumes, a frequently applied step is to determine volume of certain areas, which is performed by multiple ways:

- by calculation equations for elementary formations,
- by planimetric means,
- using a grid,
- by integrating – by integral calculus.

Determining volumes and overburden rocks in open pit mines falls amongst important and integral parts of the mine surveying operations. Core of determining volumes of bodies that are delineated by irregular (topographic) areas dwells in that that irregular bodies are appropriately broken down to smaller geometrical bodies, volumes of which are determined by pertinent solid geometry equations. Even though calculations of volumes are approximate only, they prove to be sufficient for a raft of practical tasks. The calculation of volumes issue is extensively described in [2], which is performed by multiple ways:

- disassembling to regular geometric formations,
- by use of cross-sections,
- from surface/grid levelling results,
- from the form of contour lines,
- by use of digital triangular 3D model.

a. Determining volumes by use of cad systems

Software surface modelling and subsequent determining of the volume presents the most frequently used way of arriving to information on the stockpile (quantity) of a mineral (industrial mineral) in given locality (storages of the mineral, waste dump, etc.). Determining the stockpile volume of minerals in open pit mines is predominantly utilised to plan the quarry extraction and operation. Modelling a body surface is an integral part of almost all infrastructural projects, from designing slopes at line structures through modelling the landscape and the terrain up to planning of mining operations.

Best the issue can be resolved in software environments e.g. AutoCad, MicroStation etc., which contain effective tools for the body surface modelling. When designing models of bodies calculated is volume of the material. Yet, modelling of a measured real surface in a software environment presents just an intermediate step to determining the volume (see also [3]).

Used for determining the volume of irregular objects most frequently are three methods:

- use of defined surfaces – the method is based on defining two surfaces with subsequent assigning of points one of which performs the function of the real surface (measured surface – upper surface) and the other one performs the function of reference surface (vertical alignment – lower surface). Both the upper and bottom surface are determined by triangulation based on spatial data. The solid circumscribed by these surfaces is divided into n triangular prisms (Fig. 1) and volume of a prism is determined using the equation:

$$V_i = P \frac{\sum_{i=1}^3 H_i}{3} . \quad (1)$$

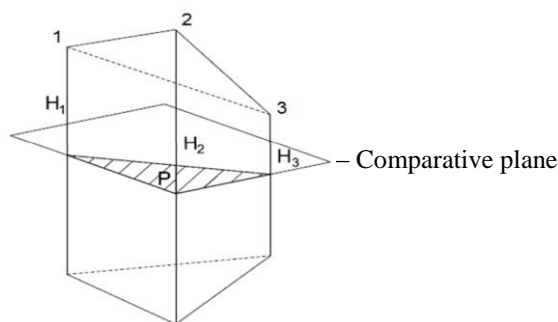


Fig. 1 Illustration of a triangular prism

- use of horizontal sections – contour lines – non-symmetrical object can be divided into layers applying a system of horizontal planes crossing the body. The surveyed terrain will be graphically represented by a map elevation-related features in which can be represented by contour lines. Equidistance of contour lines, i.e. thickness of a layer is to be determined at designing the plant see [4]. To more precisely determine volume of a layer, it is appropriate to use the Simpson's equation, specifically for volume of the layer between P_{570} and P_{571} (Fig. 2):

$$V_{570,571} = \frac{h}{6} \left(P_{570} + 4 \left(\frac{\sqrt{P_{570}} + \sqrt{P_{571}}}{2} \right)^2 + P_{571} \right). \quad (2)$$

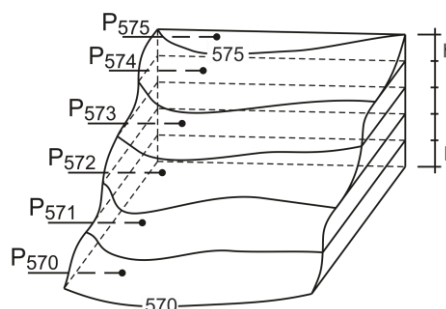


Fig. 2 Dividing the formation by horizontal sectioning

The overall formation volume is calculated by integrating partial volumes of individual layers $V_C = \sum V_i$.

- use of parallel vertical cross sections – this way of calculating is much more demanding than the one utilising surface defining. At this way of volume calculations is the volume determined on the basis of mathematical difference between the terrain surface and the developed surface of the corridor. To determine the volume of excavation or possibly embankments producing earthworks developed has to be surface of the corridor, terrain and traces of cross sections. Cross sections are as a rule selected as running parallel in intervals of 5, 10, 20, 50, possibly 100 m depending on segmentation of shape. Volume of the formation limited by two sections (Fig. 3) is determined analogically with the preceding case:

$$V_i = \frac{h}{6} \left(P_1 + 4 \left(\frac{\sqrt{P_1} + \sqrt{P_2}}{2} \right)^2 + P_2 \right). \quad (3)$$

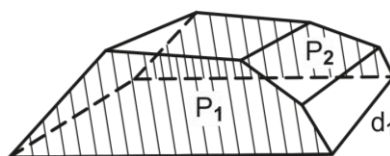


Fig. 3 Cross sections of the formation

b. Factors that influence precision of determining volumes

The overall precision of determining volumes of bodies is influenced by errors occurring during performing measurement and processing activities (errors in the terrain or landscape measurement, erroneously

set up graphical supporting materials, errors in planimetry, etc.), as well as approximations errors. The latter errors are the most materially influencing overall imprecision of the volume being determined. Hence, it follows that a body of real dimensions and shape is replaced by a geometrised shape that most closely reflects the real shape, which inevitably follows from the fact that used to determine a volume is mathematical expression.

According to [5], precision of determining volumes by software means is predominantly influenced by the below factors:

- the number of geometric survey control points on the ground plan contour and on surface of the pile by which is the extent and shape of the pile as of an irregular body determined,
- ignorance of the form of the pile subsoil, i.e. height form of the subsoil surface, which is during calculations approximated by a planar area,
- manner of the mathematical expression of the pile surface, segmentation and irregularities in the surface area of the pile,
- way of the pile geometrisation – its disassembling into a set of specific types of elementary geometrical bodies, as well as utilisation of certain relations for determining their volumes.

3 CREATION OF THE DIGITAL TERRAIN MODEL

Digital terrain model is being, in the field of geo-informatics, used approximately since 1950. It presents an integral part of digital processing in the geographic information systems (GIS) environment. Further, it provides the space for modelling, analysing and depicting with topography and the terrain relief phenomena [6].

The relief digital model (DMT), according to [6], describes surface of the Earth void of vegetation and human-built structures such as buildings, bridges, etc. DMT, according to [7], works exclusively with elevations (or heights above sea level) of points. Digital models include a series of cartography techniques by help of which expressed can be the form and shape of the terrain using the [8]:

- contoured model,
- colour hypsometry,
- terrain hachures
- slope
- 3D model.

According to [7], the terrain digital model (DMT) – is digital representation of the Earth's surface in the memory of a computer composed of data and an interpolating algorithm that allows deriving heights of the intermediate points.

By the surface types, DMT can be divided in:

- Polyedric model of the terrain – planes are represented by irregular triangles. The grid of triangles is made up using triangulation algorithms. Used at construing is the Constrained Delaunay Triangulation. The most significant presentation is TIN. TIN represents the vector-based description of the polyedric model at introducing typological relations among individual triangles.
- Raster model of the terrain – consists of regular planes with common edges = grid. According to [8], this can be developed by deterministic interpolation method IDW and a stochastic method, e.g. trend, kriging.
- Plate model of the terrain – according to [9] utilises dividing the surface into irregular plates of varying sizes, usually of triangular shapes. Made use of at partial planes is nonlinear interpolation that takes into account form of the area of the neighbouring plates.

DMT precision is, as detailed in [10] influenced by the below factors:

- density and arrangement of input points,
- data collection methods (spatial coordinates) – the geodetic methods used fall amongst the most exact ones. Measurements are performed by use of universal measuring stations, the GNSS technology, photogrammetry along with distance Earth surveying (DES),
- interpolation methods – are used to estimate values at places where measured data are unavailable (distribution and density of elevation points varies).

Modelling of DMT using various interpolation methods

Points of known values can be arranged both regularly and irregularly. The serious of methods that include calculations of unknown values occurring between these regularly or irregularly arranged points are called interpolation procedures – methods. Interpolation serves in the process of terrain modelling calculation of values in areas where the values were not measured. In question at interpolating contour lines usually is determining of height (of coordinate z) or calculation of position (coordinates x , y). *Interpolation* stems, according to [11], in that that an unknown function that characterises real form of the investigated plane is replaced, based on the given real values of selected points, by a function of simpler type. The function is labelled interpolating function and the points of discrete geodetic control are called the interpolation nodes. Based on the values of heights of the interpolation nodes the functions allow calculating, with a required precision, detailed form of height values among input points, and possibly form of partial derivations for determining morphometric quantities of the geo-relief. The most commonly used are methods based on weighted linear average of surrounding values. In general, these can be expressed, according to [12], [13] using the equation:

$$z^* = \Sigma(w_i \cdot z_i), \quad (4)$$

where: z^* is the value estimate,
 w_i is the weight (spaceless number from 0 to 1),
 z_i are known values.

Classification of interpolation methods

Existent are various points of view according to which can be interpolating methods divided (according to [14]):

- a) Deterministic methods
- b) Stochastic methods

Deterministic methods perform interpolation directly from the input point measured values. Non-utilised is the probability theory that calculated after each point will be identical final estimate.

Stochastic methods include a randomness element. The resulting spatial prediction is understood to be one of the many that could have been developed. The method is based on the statistic model that assumes spatial dependence among input points.

4 THE INVESTIGATED OPEN PIT MINE

The quarry is located in the Košice region, in cadastral territory of Kecerovský Lipovec laying on the western side of Slanské vrchy (Fig. 4 left). Andesite has been extracted from the discussed open pit mine since 60s of the past century, and though the quarry is at present not in use it is being prepared for commencement. Andesite is extrusive igneous rock of grey to dark grey colour and when it is effloresced it can attain yellowish, ochre or red shades. Andesites, according to [15], occur in the form of superficial deposits or small shallow intrusions. Andesite is most commonly intended for constructional purposes.

The geodetic surveying was performed for the purpose of determining the stockpile volume of andesite found in the quarry. Results of geodetic surveying will be used as a supporting fact for re-starting mining of the mineral, whereas the quarry remains up to the day inactive. Geodetic surveying preceded the open pit mine terrain reconnaissance (Fig. 4). Its purpose was to get acquainted with the terrain, to propose appropriate surveying methods and arrange temporarily stabilised surveying points. Combination of the GNSS a terrestrial technology (in more detail discussed in [15] [17]) was used to profile the andesite open pit mine. The very measurement was performed on March 6, 2012 in bright sunny weather conditions. Dual frequency GNSS tracker Leica GPS900CS (RTK method) was used to locate the points of measurement as well as detailed points in the grassy and bushy terrain outside of the quarry. Based on the reconnaissance results decided was on arrangement of five profiling points for terrestrial surveying. The principle of surveying in geodetic local nets is dealt with in, for example [16].

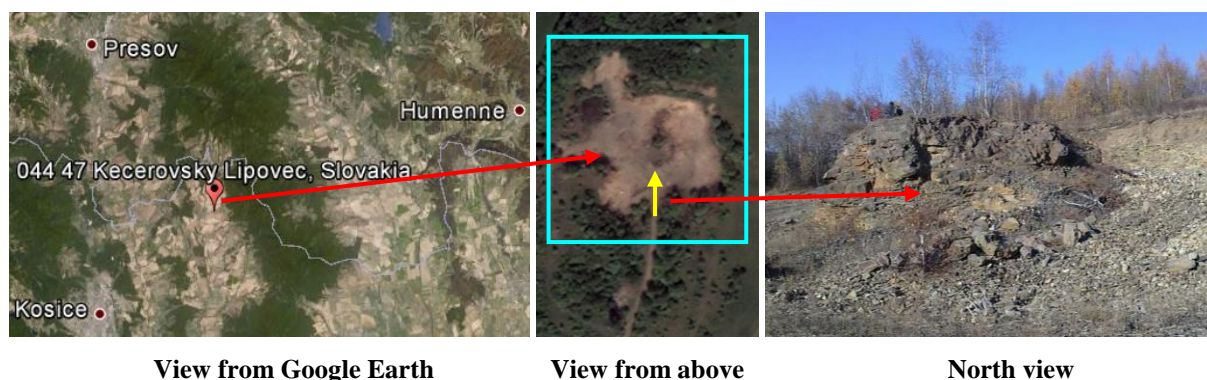


Fig. 4 Pictures of the quarry

Decided that used for detailed surveying of the open pit mine would be a selective method based on using universal imaging total station (UMS) Leica Viva TS 15. Position of the device – points 5001 to 5005 were determined by use of GNSS receiver Leica GPS900CS. Points of measurement were temporarily stabilised by crosses engraved in stationary rocks, whereas the subsoil did not allow using another way of stabilising (e.g. reinforcing bars).

Measurements of accessible planimetric and vertical elements of the open pit mine were performed by UMS on a surveying prism. Inaccessible detailed points, along with upper and lower edges of the open pit rock face, were determined via prism-free measuring mode that uses passive reflection of rays. Within the terrain, profiled were some 700 detailed planimetric and vertical points.

Measurement of the grassy and bushy terrain surrounding the open pit mine was performed by use of GNSS receiver and the RTK method, which resulted in localisation of approximately 150 points.

The measurement data were exported from the UMS in the form of index of coordinates XYZ in the *.txt format. Data obtained from the GNSS receiver were processed by software Leica Geo Office 7.0, and the output of the software presented also a list of coordinates XYZ in the *.txt format. The data were subsequently processed by CAD software AutoCAD CIVIL 3D 2008 (*.dwg) and by MicroStation V8 complemented by TerraModeler (*.dgn) superstructure/extension.

To secure higher quality visualisation of specific points these are in TIN, where elevation relations are depicted in colours (Fig. 5)

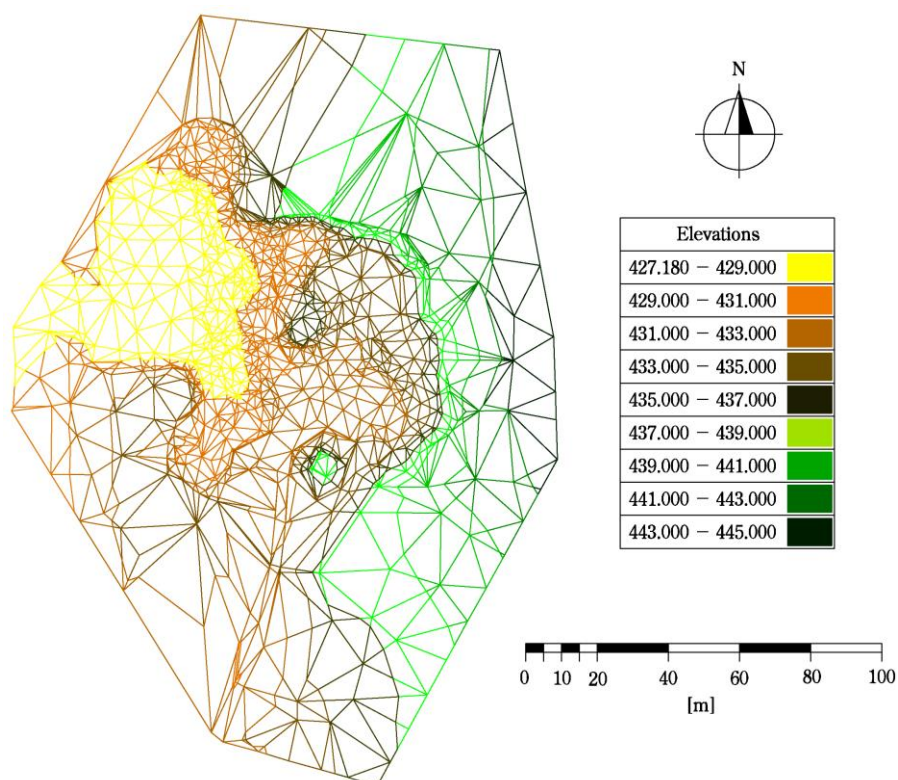


Fig. 5 Visualisation of detailed points through TIN

a. Precision of determining volumes

The process of creation of a 3D model and of determining its shape-wise properties (distance, area, volume) does not often presents the goal of task-solving; it rather presents a means to its resolving. The terrain model presents the basic element of all projects and is used at creating longitudinal profiles, models of the corridor, at calculating volumes or creating terrestrial objects.

The most recent CAD software provide continuous interconnection of all objects with the surface, and there is the guarantee that results will be at all times up-to-date, whilst at modelling of a terrain establishing of volumes is performed automatically (for more information kindly see [18]).

Precision of determining the 3D model volume depends also on consistent work performed during modelling of the surface. If a body surface is created unrealistically, realistically solved will not be the solution goal either (e.g. the volume being determined). 3D model of the discussed open pit mine was processed in three types of the terrain digital model.

DMT modelling is most often performed using the TIN model (Fig. 5). The grid of triangles is made up by use of triangulation algorithms (Delaunay triangulation). Entering the process of creation are break lines so that the quarry was represented in as much detail as possible. Polyedric TIN model approximates real terrain more appropriately than the raster model provided that the terrain points are also appropriately arranged. To develop real terrain, the measured points were located on singularities.

Contour model (Fig. 6) consists of contours with pertinent elevation (height) data. Contour lines break down to basic contour lines (with contour interval of 1 m), reinforced contours (with contour interval of 5 m) and supplementary contour lines (auxiliary – with interval of 0.5 m).

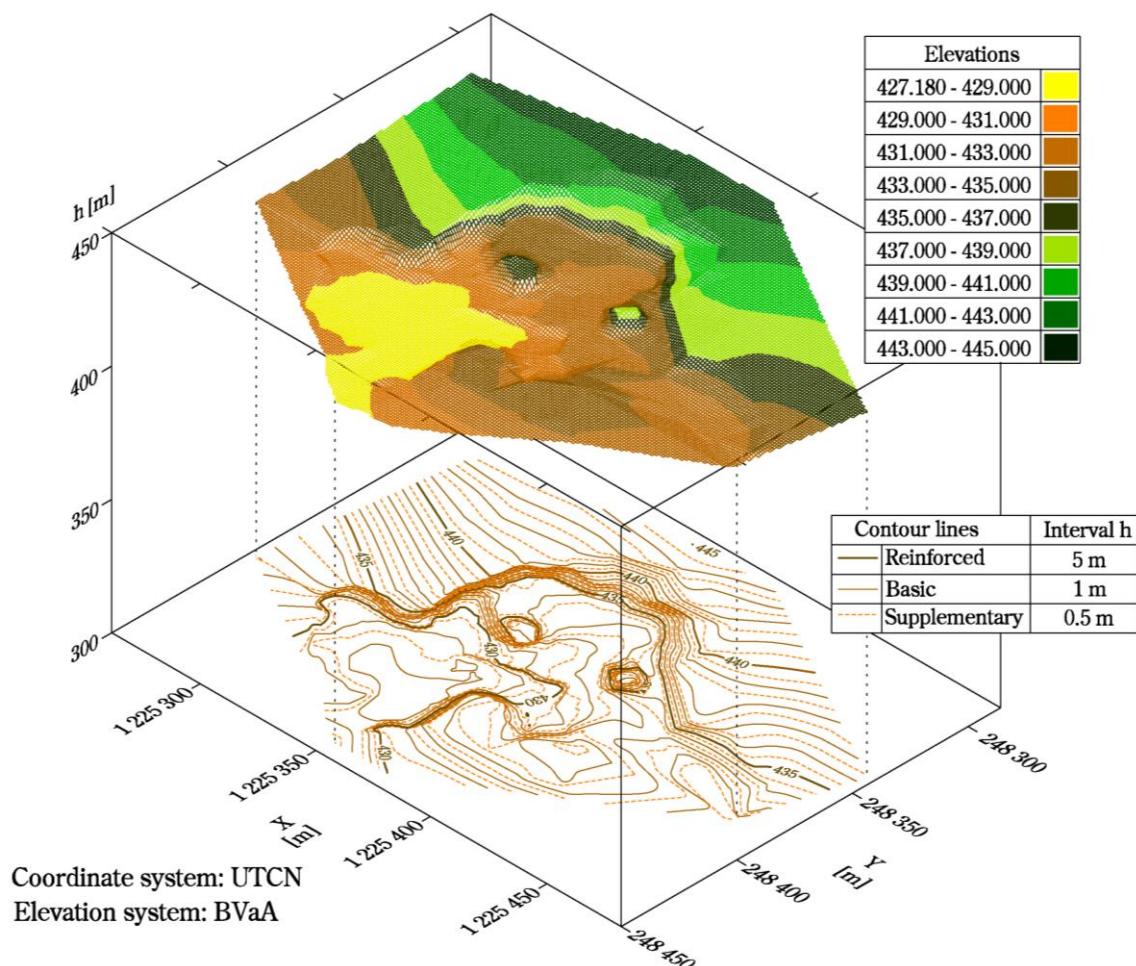


Fig. 6 DTM visualisation by the combination of GRID and the contour line model

GRID falls amongst regular raster structures. The GRID model is made up of regular grid of regular shapes, most frequently of squares (Fig. 6), when the surface is divided into cells. Each cell is bearer of the height above sea level relating to the centre of the square (GRID) or to that of the grid node. [10]

b. Determining the stockpile volume by software

The modelled open pit mine terrain was further processed to determine the stockpile volume of the mineral. All of the three ways of determining the volume differ in the quantity of stockpile determining procedure.

Calculation of the volume using two terrains is, compared with the other two suggested procedures, relatively fast. Currently modelled terrain had to be supplemented by another terrain that represented reference plane delimiting the reserves from the bottom. The software sets volume of the body delineated by the two surfaces. The lower terrain modelling was performed by using the open pit mine boundary points assigned to which was the selected elevation for reference plane on the level of 420 m above sea level (Fig. 7). The plane was selected for the need to establish the lowest exploiting level. Calculated based on comparison of two surfaces was the numeric value of the stockpile volume. Presented in Fig. 8 is an illustration of both surfaces in the GRID structure.

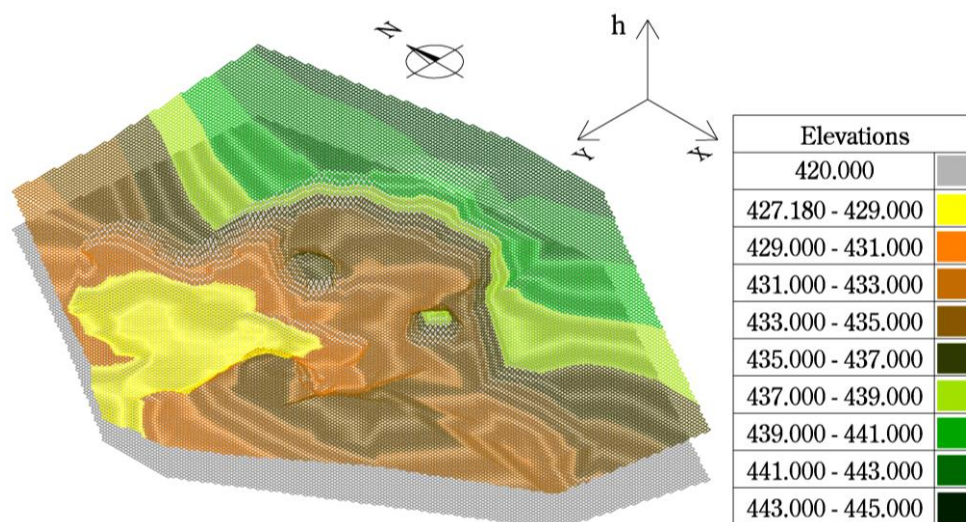


Fig. 7 Iso view of visualisation of two terrains using GRID

Calculating the volume by use of horizontal sections lied in generating the contour lines (Fig. 8) and in determining the volume of areas of surfaces circumscribed by selected contour lines having the interval of $h = 2m$. Partial volumes were determined independently for each horizontal layer, see Tab. 1 according to (2).

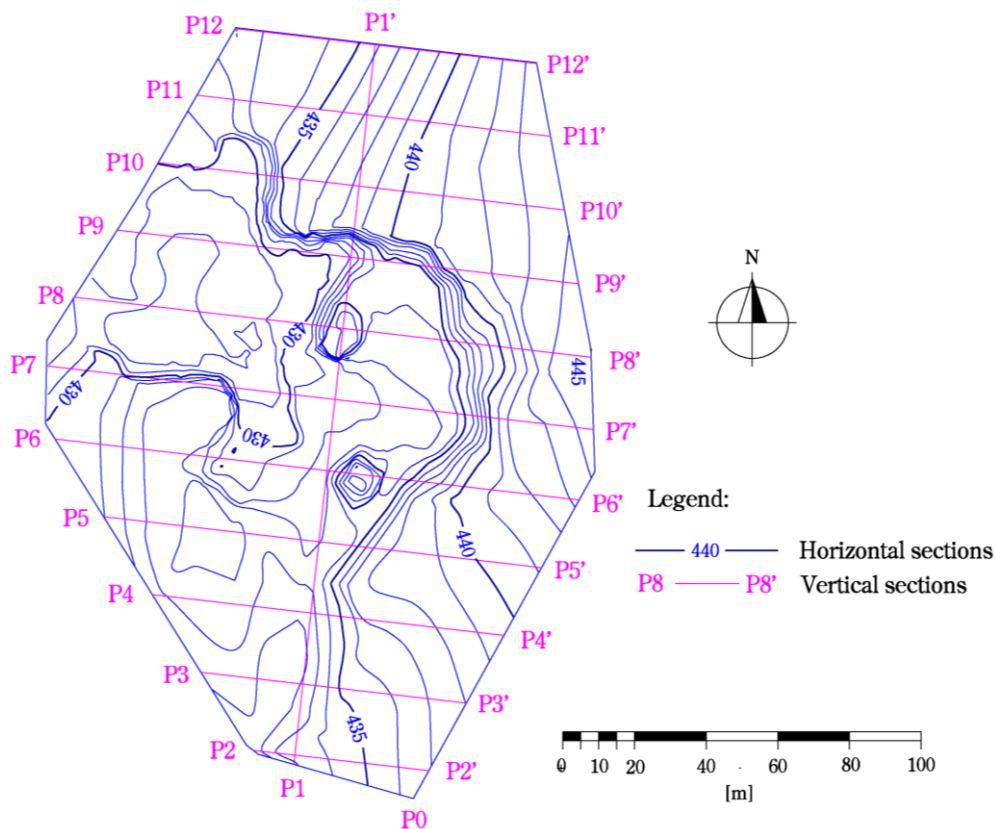


Fig. 8 Illustrations of vertical and horizontal sections

Calculating the volume by use of parallel vertical cross sections was performed employing 11 created cross sections. Further to the request of the principal and based on ratios of precision and size of the quarry, the section interval was selected to be per 20 m (Fig. 8, P0, P1-P12). Calculated, based on by software generated parallel vertical cross sections and on determining their planar areas, was the extractable mineral's volume calculated. Volumes of irregular spatial formations bounded by vertical sections were determined based on the relations known from stereometry (Tab. 2) according to (3).

Tab. 1 Calculation of the volume using horizontal sections

Elevation of the contour line	Contour delineated area	Volumes between contour lines	Total volume
[m]	[m ²]	[m ³]	[m ³]
420	23339.70		352942.2
422	23339.70	46659.4	
424	23339.70	46659.4	
426	23339.70	46659.4	
428	22477.20	45806.9	
430	19306.50	41783.7	
432	16918.26	36224.8	
434	12661.10	29579.4	
436	9177.10	21838.2	
438	6816.58	15993.7	
440	4729.60	11546.2	
442	2464.20	7193.8	
444	399.90	2864.1	
445	0.00	133.3	

Tab. 2 Calculation of the volume using cross sections

Section	Section area	Spacing of sections	Partial volume	Total volume
	[m ²]	[m]	[m ³]	[m ³]
P0	0.00			351757.1
P2-P2'	709.71	10.04	2375.2	
P3-P3'	1062.31	20.00	17720.2	
P4-P4'	1505.36	20.00	25676.7	
P5-P5'	1943.01	20.00	34483.7	
P6-P6'	2277.92	20.00	42209.3	
P7-P7'	2081.05	20.00	43589.7	
P8-P8'	1960.58	20.00	40416.3	
P9-P9'	1848.21	20.00	38087.9	
P10-P10'	1952.92	20.00	38011.3	
P11-P11'	1734.16	20.00	36870.8	
		20.00	31716.0	

c. Comparison of the volume calculations

The surface between individual cross sections does not have to present a linear area (planar structure) at all times. This uncertainty influences precision of the volume calculation. The volume calculated based on two surfaces and Microstation V8 and AutoCAD environments renders relevant results. Selected for the reference volume when comparing final volumes was the one determined within Microstation V8 environment. Volumes determined using two defined surfaces in the CAD software are, at such high quantities of non-extracted stockpiles, differing by minute per-cent value (0.03 %). The difference between volume determined using horizontal and vertical cross-sections demonstrates with both software products larger but statistically insignificant deviations falling within - 0,21 % and + 0,18 %. Imprecisions of these determined volumes are especially due to segmentation of the terrain, morphological shape of areas, size of interval of horizontal and vertical cross-sections, and hence due to generalisation of bordering areas between individual cross-sections (**Chyba! Chybný odkaz na záložku.**).

Tab. 3 Final evaluation and analysis of determining the stockpile volume

Software environment	Volume determined using	Volume	Difference	
			[m ³]	[%]
MicroStation V8 with Terramodeler extension	Two surfaces	352 217.8	-	-
	Vertical cross sections	351 757.1	+ 460.7	+ 0.13
	Horizontal sections	352 942.2	- 724.4	- 0.21
AutoCAD Civil 3D 2008 CZ	Two surfaces	352 311.5	- 93.7	- 0.03
	Vertical cross sections	351 586.3	+ 631.5	+ 0.18
	Horizontal sections	352 825.3	- 607.5	- 0.17

5 CONCLUSIONS

The geodetic surveying was performed to determine the volume of exploitable stockpiles of andesite in the mentioned quarry. The arrived at spatial information were used for further processing by CAD systems. The basic step of software processing was modelling of the terrain based on by measurements attained data that would be most closely reflect the terrain real shape. In total considered during processing were 6 ways of determining the stockpile volume within two selected CAD software suites (MicroStation V8, AutoCAD). By mutual comparing of six volumes it was determined that the results attained showed statistically insignificant differences in the interval of $\langle -0.21\%, +0.18\% \rangle$. Used for the modelling process were during field measurements attained spatial data in combination with modern terrestrial and GNSS technologies. The arrived at results are presented in both graphical and tabular forms. Upon processing the considered issue we have concluded that the relatively most precise method of determining the volume seems to be utilisation of the method of two surfaces. Utilisation of the method is not influenced by selection of the software to be used. Presently, in the geodesy practice is the processed issue significantly applicable. Ensuring attainment of maximum precision is contingent to quality of the geodetic gear used and to the experience of the surveyor not only at performing field work but at processing as well. The contribution of authors is in the field of the issue under consideration a comparison of presently used procedures at determining volumes of irregular formations.

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RESUMÉ

Článok je venovaný určovaniu objemov nepravidelných telies, konkrétne rieši určenie objemu ložiskových zásob andezitu v povrchovom lome. Modelovanie povrchov a následné určenie objemu je najpoužívanejší spôsob získania informácií o stave zásob resp. množstva nerastu príp. inej suroviny v predmetnej lokalite či v úložisku nerastu, na skládke a pod. Jedným z dôležitých krokov je modelovanie digitálneho modelu terénu, kde sa využívajú štruktúry TIN a GRID. Avšak modelovanie reálne meraného povrchu v softvérovom prostredí je iba medzikrokom k určovaniu objemov. Na určenie objemu nepravidelných telies sa využívajú najčastejšie tri spôsoby a to pomocou dvoch zadefinovaných povrchov, rovnobežných zvislých priečných rezov a horizontálnych rezov. Vykonala sa analýza výsledných objemov z jednotlivých softvérov a spôsobov určenia objemu ložiskových zásob. Rozdiel objemov určených pomocou dvoch nadefinovaných povrchov v dvoch rôznych CAD softvéroch je zanedbateľný. Pri porovnaní s ostatnými spôsobmi sa rozdiel v percentuálnom vyjadrení rozdielu objemu pohyboval v rozmedzí od -0,21 % po +0,18 %.