COMPARISON OF TACHEOMETRY AND LASER SCANNING METHODS FOR MEASURING THE QUARRY IN JAKUBČOVICE NAD ODROU

POROVNÁNÍ TACHYMETRIE A LASEROVÉHO SKENOVÁNÍ PŘI ZAMĚŘENÍ ČÁSTI LOMU V JAKUBČOVICÍCH NAD ODROU

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Abstract

The presented this method is more efficient for surveying a site. Part of this is the calculation of the volumes of excavated muck using 3D models and their comparison.

The comparison of the measurements of part of the quarry in Jakubčovice nad Odrou using the tacheometry and laser scanning techniques was performed. The final assessment was in favour of the laser scanning method which provides capturing the entire object surface with a chosen level of detail compared to the tacheometry method, in which only characteristic points of the measured object, such as edges, are captured.

Abstrakt

Předložený článek se zabývá srovnáním klasické geodetické metody (tachymetrie) s metodou laserového skenování s cílem rozhodnout, která z uvedených metod je pro zaměření dané lokality efektivnější. Součástí je i výpočet objemů odtěžené rubaniny na příslušných 3D modelech a jejich srovnání.

Bylo provedeno porovnání mezi zaměřením části kamenolomu v Jakubčovicích nad Odrou tachymetricky a pomocí laserového skenování se závěrečným hodnocením ve prospěch skenování. Skenování poskytuje zachycení celého povrchu objektu se zvolenou mírou detailu oproti tachymetrii, při které jsou zachyceny pouze charakteristické body objektu, jako například hrany apod.

Key words: quarry, tacheometry, laser scanner, laser scanning, spatial polar method.

1 INTRODUCTION - BASIC DATA

1.1 Locality description

The village of Jakubčovice nad Odrou is located in the south-western part of the Oderské Vrchy Natural Park. There is a large quarry area at the north-west edge of the village. The total mining area of the quarry is approximately 130 hectares. (**Fig. 1**)

Fig. 1: Aerial photo showing the quarry in Jakubčovice nad Odrou

2 SURVEY PURPOSE

The measurement results can be used as a basis for calculating volumes of removed muck, material reserves, storage areas, etc. Another option is to use the measurement results to update mine surveying documentation (source [3]), in particular a quarry operation map.

3 SURVEY OBJECTIVES

The aim of this work was to survey a part of the quarry in Jakubčovice nad Odrou using the laser scanning method and the method of tacheometry and their comparison due to the assessment of the effectiveness of these methods.

4 SURVEY METHODOLOGY AND TACHEOMETRY PROCEDURE

4.1 Survey methodology

The tacheometry method is a basic method for the preparation of planimetric and altimetric map components.

The position of points of detailed survey is determined from a network of so-called tacheometric stations using polar coordinates (horizontal angle, length). The height of points of detailed survey is determined in a trigonometric way.

The stations are e.g. vertices of transit traverse. During surveying, mutual visibility between adjacent stations must be observed. In the case where it is impossible to measure hypsometrical points of detailed survey from a station, other stations are chosen that are most often determined by a radius bar. [2]

The method accuracy is given by both the precision of used total station, and other factors, for example the field control accuracy, accuracy of station determination, etc.

The calculation of points of detailed survey is carried out by a spatial polar method, which is defined by the relations:

$$\begin{aligned} X &= X_0 + s_d.\sin Z.\cos\sigma \\ Y &= Y_0 + s_d.\sin Z.\sin\sigma \\ Z &= Z_0 + s_d.\cos Z + v_p - v_c \end{aligned} \qquad (1)$$

where:

X_0, Y_0, Z_0 – station coordinates,

s_d – slope distance,

Z – zenith angle,

σ – bearing,

v_p – height of the device at the station,

v_p – target height.

To calculate the coordinates of points of detailed survey according to (1) the station coordinates and the bearing to the landmark must be known. The station coordinates may be determined by various methods, e.g. using a transit traverse, radius bar, backward intersection, GNSS technology (Global Navigation Satellite System). [4]

4.2 Survey procedure

The actual quarry survey was carried out in two stages; the first stage took place in early April, the second one at the end of July 2011. The survey was performed in stages due to the comparison of 3D models and the calculation of the volume of removed muck as well.

During the first stage of the survey it was impossible to perform measurements on top benches due to mining operations.

For the survey, the Leica TCR 1202 total station and the Leica system 1200 (GNSS) were used; the instrumentation parameters are listed in the sources [6], [7].

In both cases, the surveying of the given locality was preceded by the preparation phase, including the reconnaissance of the area in question, in order to check the visibility and locations of the points of field control. (see **Fig. 2**, **Fig. 3**)

To perform horizontal and vertical connection of the locality the points determined by the GNSS technology (fast static method) were used.

Fig. 2: Summary of points of mine minor horizontal control - Stage I

Fig. 3: Summary of points of mine minor horizontal control - Stage II

The survey itself starts at one of the stations. The measured data are recorded by the total station either into a memory card or internal memory. When measuring orientations, it is suitable to measure all quantities in both positions of the telescope. At the first stage, the survey was performed from 6 stations in total, at the second one from 11 stations. This is followed by the measuring of points of detailed planimetry and altimetry. The measurement is performed in one position of the telescope only. At the first stage, a total of 475 points of detailed survey was measured; at the second one it was 429 points of detailed survey in total. The accuracy of coordinates of the points of detailed survey meets the deviations given in [3].

4.3 Measured data processing

The calculation of the data measured by the GNSS technology was conducted using the evaluating LEICA Geo Office software, version 7.1.

The calculation of coordinates of the points of minor horizontal and vertical control was carried out in the Grom program, version 7.0. Corrections of measured lengths (due to refraction, cartographic distortion, elevation, Earth's curvature) were performed automatically by the software. Systematic errors resulting from temperature and pressure were corrected directly by the total station.

4.2 Survey results

Based on the measured and processed values, digital terrain models of both stages were created in the Atlas DMT program, version 4.7. The 3D model of the quarry - stage I - is shown in **Fig. 44** and **Fig. 5**, the 3D model of the quarry - stage II - is shown in **Fig. 6** and **Fig. 7**.

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Fig. 4: 3D model of the quarry - stage I (Atlas DMT software)

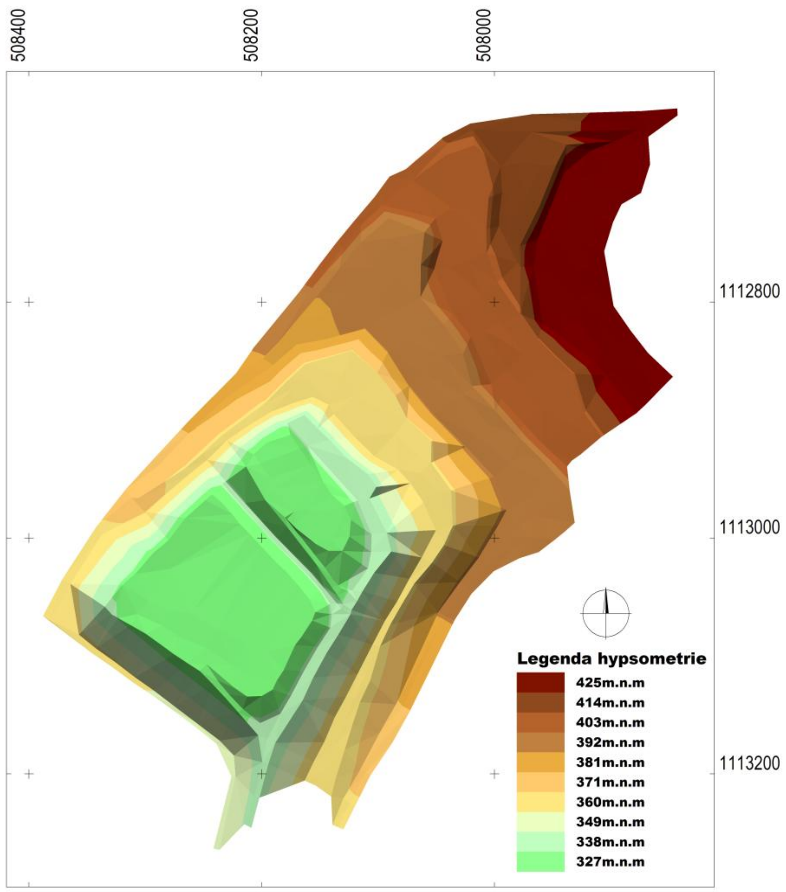

Fig. 5: Spatial model of the quarry illustrated using a hypsometric scale - stage I (Atlas DMT software)

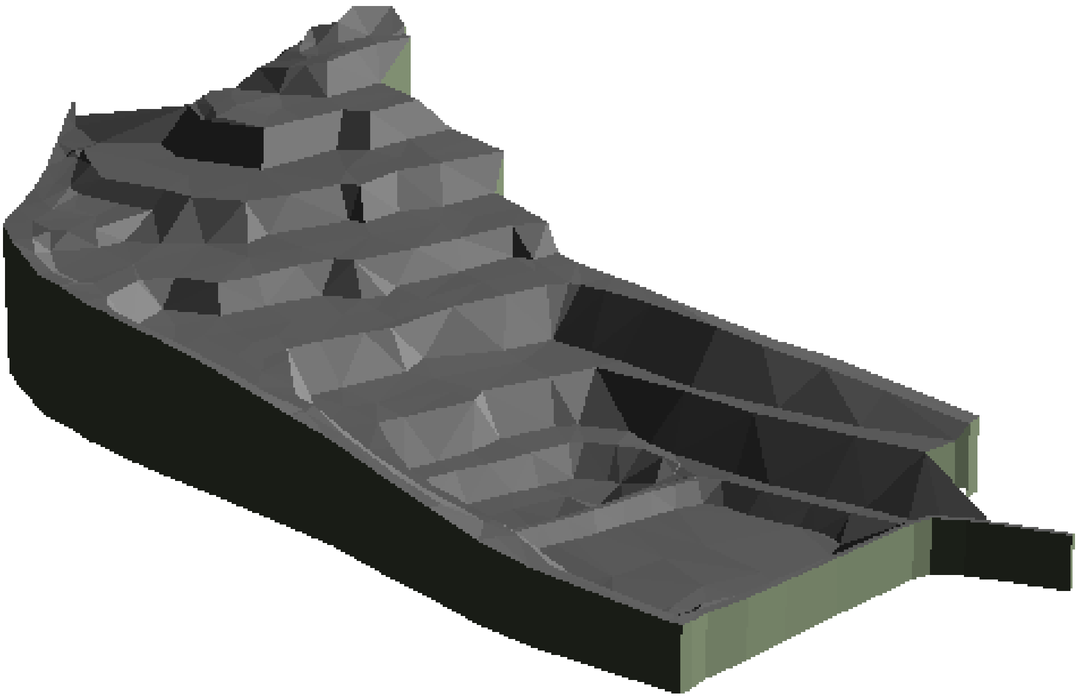

Fig. 6: 3D model of the quarry - stage II (Atlas DMT software)

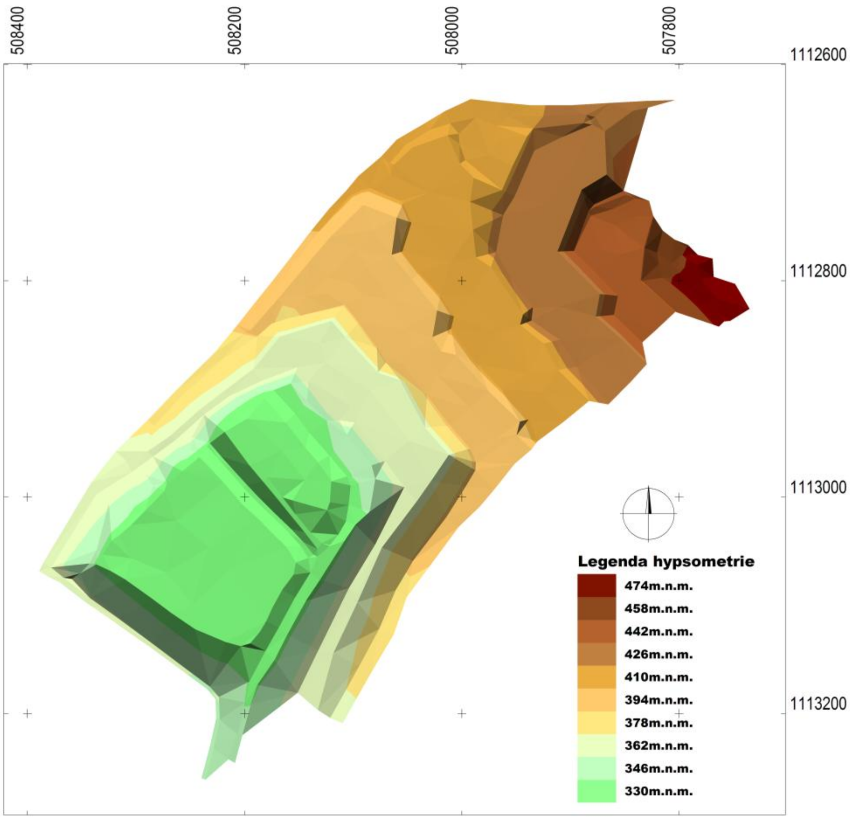

Fig. 7: Spatial model of the quarry illustrated using a hypsometric scale - stage II (Atlas DMT software)

5 SURVEY METHODOLOGY AND LASER SCANNING METHOD PROCEDURE

5.1 Survey methodology

The laser scanning survey method is used for the non-contact determination of spatial coordinates. The coordinates are mostly determined based on the principle of a spatial polar method, for which it is necessary to measure the slope distance between the point and the scanner as well as the horizontal angle and vertical angle to this point.

According to [1], the distances are measured using a laser rangefinder, which is able to measure up to several thousands of lengths per second. These rangefinders work usually on one of two basic principles:

- pulse - the principle of measuring the length of transit time which elapses between the sending and receiving of a signal,
- phase - the principle of measuring the phase difference between the sent and received signals.

There are several currently used methods for determining an angle. Here, only the most common ones are described:

- angles are obtained from the position of oscillating mirrors or a prism, which sweep the laser beam in one or two directions,
- angles are determined by turning the servomotors which provide the scanner movement.

The calculation of points of detailed survey is carried out according to the relations mentioned in chapter 4.1.

The laser scanning survey is a selective method, i.e. the points to be measured are not chosen exactly, as it is in case of tacheometric method using a total station, but a portion of sphere to be scanned and the scanning density are defined. The rest of measurements are performed automatically according to preset parameters, and all the work is managed by the utility software. This method receives a large number of measured points (often in the order of millions) no matter how important the points are.

All measured values are stored in the memory of a connected computer, ready for further processing. The resulting set of all measured points is called the cloud of points and is the basic output from the laser scanning method. Each point of the cloud contains the information about its spatial coordinates X, Y, Z, which are measured in a generally oriented coordinate system with the origin at the position of the scanner; optionally it is possible to store the information about the intensity of the reflected signal. If the survey is performed at a number of stations, it is possible to combine the individual scans into a single cloud, which can be transformed into any coordinate system (e.g. S-JTSK) using control points, naturally or artificially targeted, whose coordinates are known in both coordinate systems. [1]

5.2 Survey procedure

The quarry in Jakubčovice nad Odrou was surveyed using the scanning laser method in two stages, concurrently with the tacheometric survey. For the survey purposes, the terrestrial laser scanner Leica HDS3000 [8] was used. The first survey stage took place in April 2011 during which seven benches were measured (the rest could not be measured). The second survey stage was carried out in July 2011 during which nine benches were measured. In both stages, the benches were measured only to the level of a gravity incline, which is located approximately in the middle of the mining quarry area.

At the first stage, the measurements were performed from 20 stations, herewith that at each station measurements were carried out in a range of field of view of the lower scanning window [8] of the laser scanner. The scanning density was set to 50 mm × 50 mm at a distance of 10 m. At each station, except scanning a selected scene, the scanning of control points was performed as well. The control points were targeted by means of special HDS targets. The connection of stations was made at each bench using these control points. Each bench was then transformed into the S-JTSK datum. For this purpose, some of the control points (at least three at each bench) had to be measured also by a total station. The field control created for tacheometry purposes was used for this process. The total time of the first stage survey was about 20 hours.

At the second stage, the survey was conducted from 29 stations. The density and range of scanning was the same as in case of the first stage of measurements. The difference compared to the first stage consisted in the methodology of surveying control points. The connecting of clouds within a bench was refrained and all the clouds were immediately transformed into S-JTSK datum. This procedure was chosen to reduce the scanning time, because this survey method using a laser scanner measures substantially fewer control points. On the other hand, it is necessary to survey all control points using the total station.

5.3 Measured data processing

First a resulting cloud was created for each survey stage, which originated from the connection of sub-clouds from different stations into a common coordinate system. The transformation of individual clouds into a resulting coordinate system, which was in this case the S-JTSK datum, took place on the grounds of surveying control points, whose positions were determined both in the scanner coordinate system, and in the S-JTSK datum. The expected resulting absolute accuracy, taking into account all the factors, was estimated to be 3 cm.

It was necessary to clean the resulting clouds from the points, not desirable for creating a model. These were points not being a part of the quarry surface itself (handling equipment, solitary stones, ...). The refined clouds were subsequently exported to the DXF exchange format. This format was chosen as it is supported by almost all the processing software, and especially those software programmes that were used in the processing of this survey.

A digital model of the quarry surface was created on the basis of creating an irregular triangular grid. The triangular irregular network method was chosen as it accurately shows the contoured surface of the quarry, which cannot be automatically interlaced by any regular body. The triangular network was created in the Atlas DMT software for the purpose of this work. Before its calculating, the cloud of points was pre-processed, which included the dilution of points in the cloud (the distance between individual points to be 50 cm), in order to erase the difference in survey densities of individual parts of the quarry and to remove holes, resulting from non-surveying some covered parts of the quarry surface. Due to the reduction, the number of surveyed points decreased from the original total of 40 million to 2 million of points. This number of points was then used to create the resulting models. The pre-processing of the clouds of points was performed by the Geomagic Studio 12 software.

5.4 Survey results

Triangular irregular networks were created from the modified clouds of points in the Atlas DMT software, from which digital models of the quarry were subsequently created in both stages. The 3D model of the quarry elaborated from the cloud of the corresponding quarry survey at the stage I is shown in **Fig. 8** and **Fig. 9**, the 3D model of the quarry created from the cloud of the corresponding quarry survey at the stage II is shown in **Fig. 10** and **Fig. 11**.

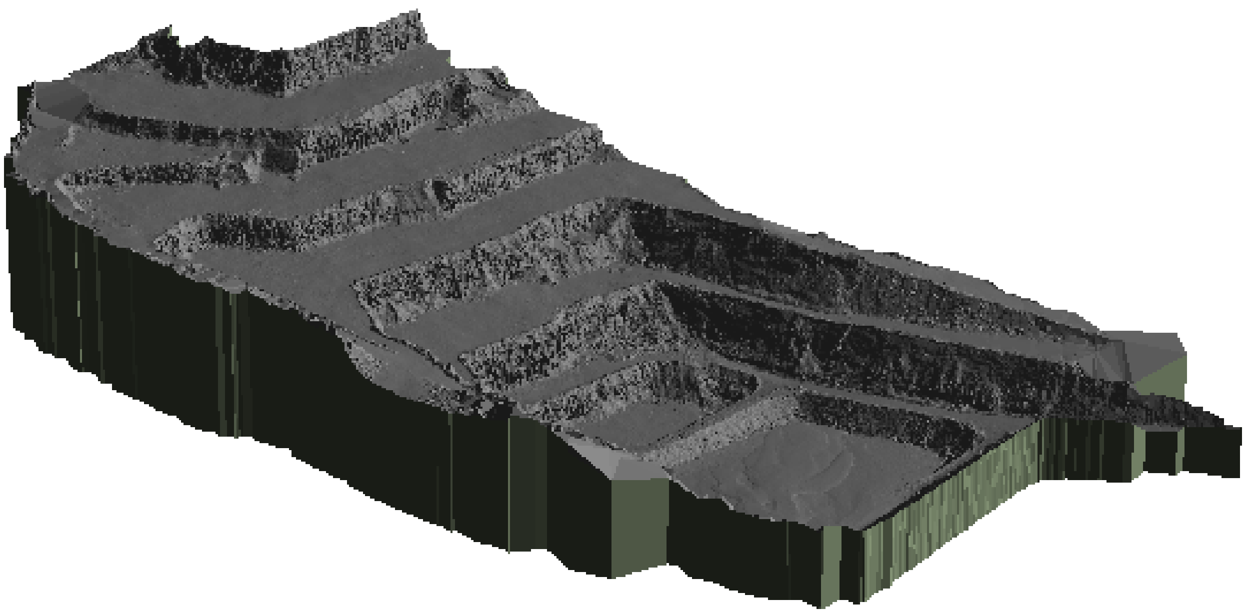

Fig. 8: 3D model of the quarry - stage I (Atlas DMT software)

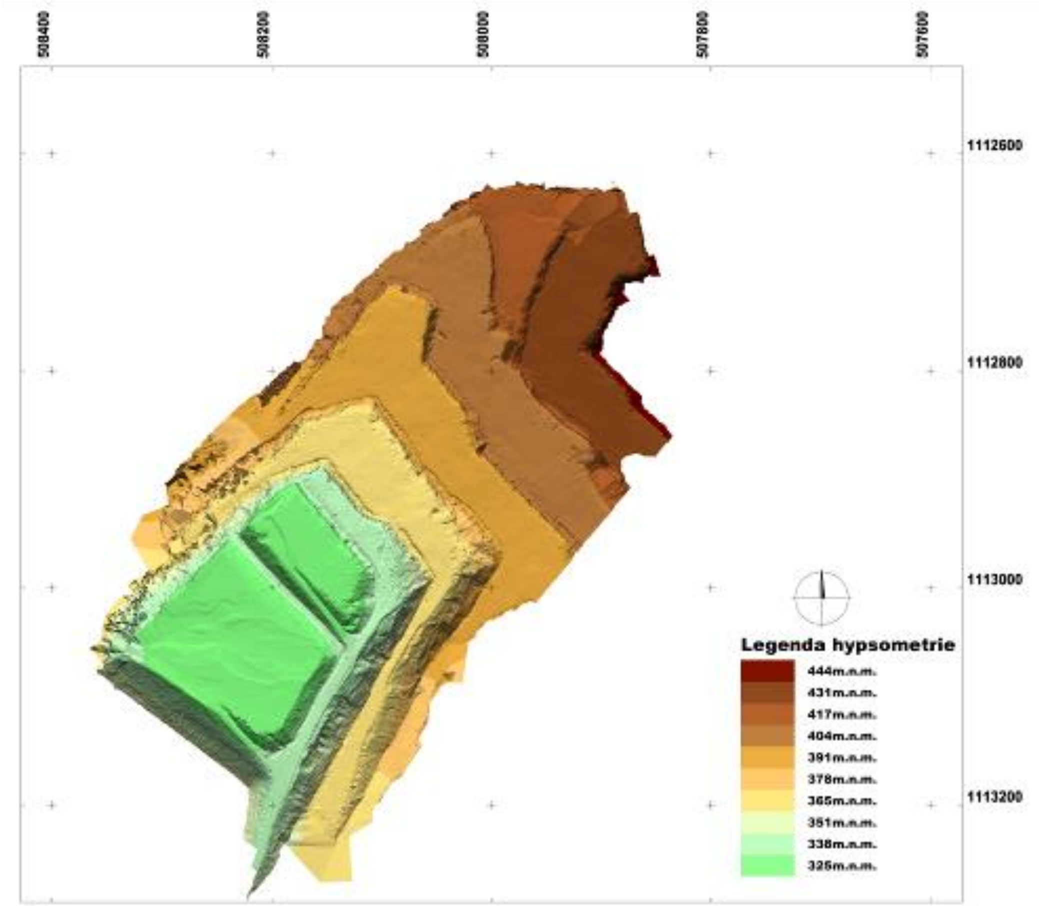

Fig. 9: Spatial model of the quarry illustrated using a hypsometric scale - stage I (Atlas DMT software)

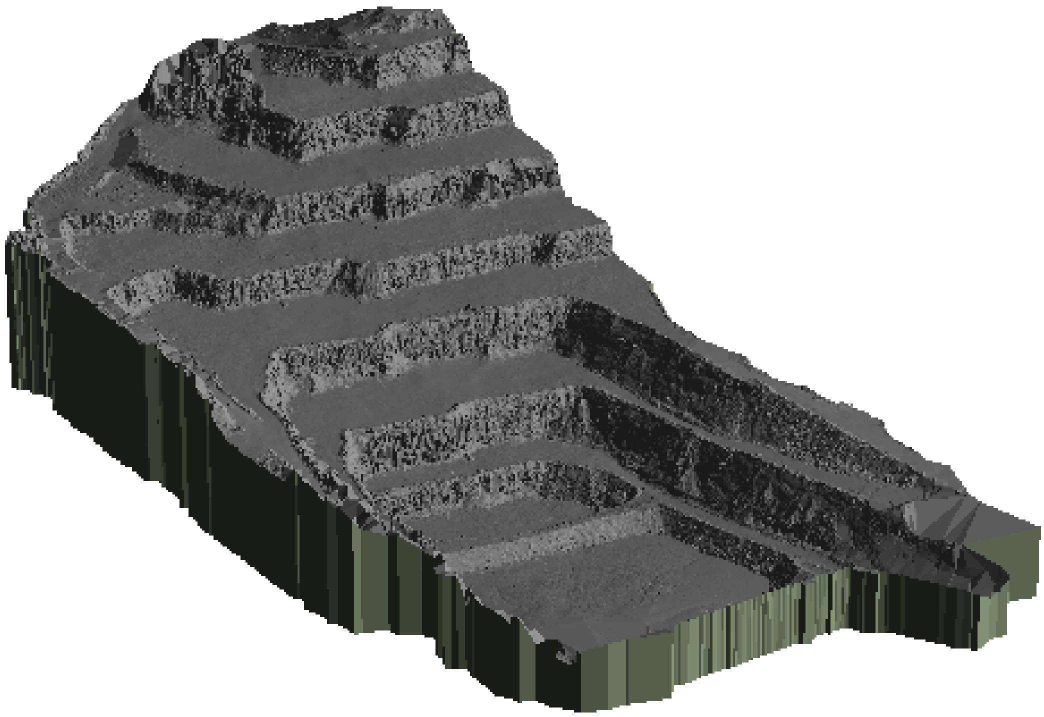

Fig. 10: 3D model of the quarry - stage II (Atlas DMT software)

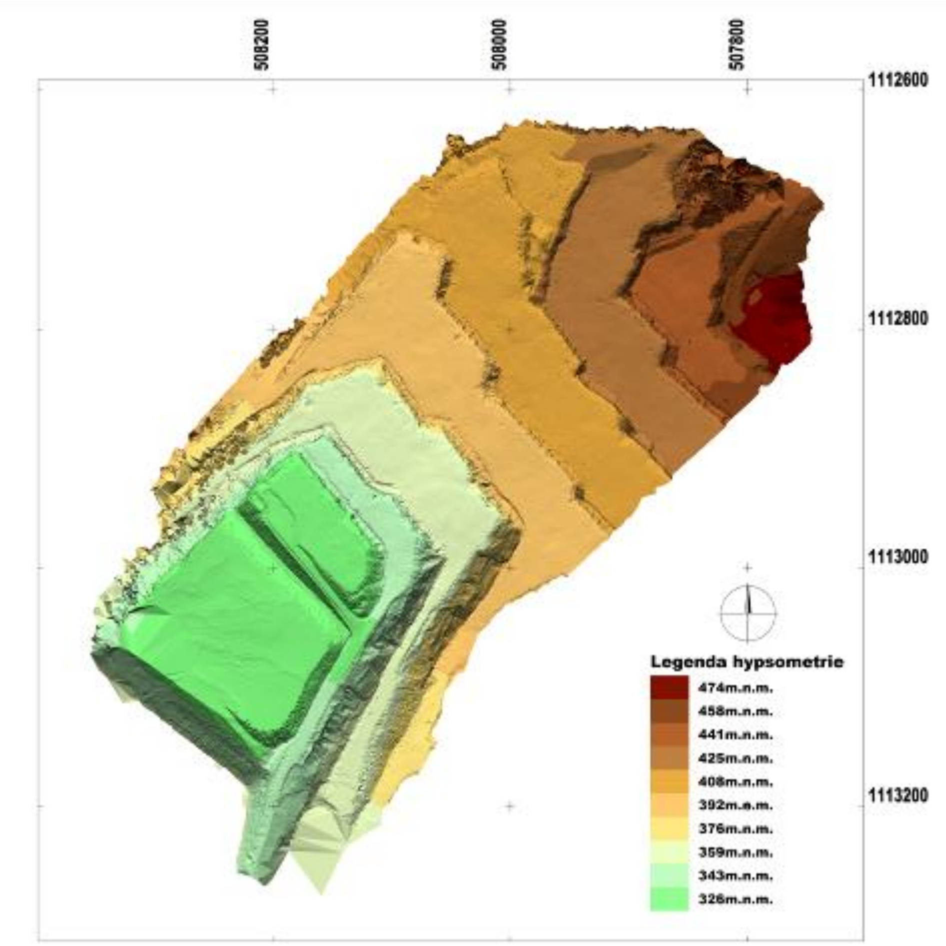

Fig. 11: Spatial model of the quarry illustrated using a hypsometric scale - stage II (Atlas DMT software)

6 3D MODELS COMPARISON AND VOLUMES CALCULATION

The models created from the classical geodetic survey (tacheometry) were compared to those that used the laser scanning method.

Fig. 12 shows the 3D model of the first stage - coloured in yellow, 3D model of the second stage - covered with the texture of an orthophoto map.

Fig. 13 shows the 3D models from the laser scanning method of both stages (visualization defined as in tacheometric models).

Based on this comparison, it can be said that the scanning method provides capturing the entire object surface with a chosen level of details compared to the tacheometric method which only captures characteristic points of an object, such as edges, etc.

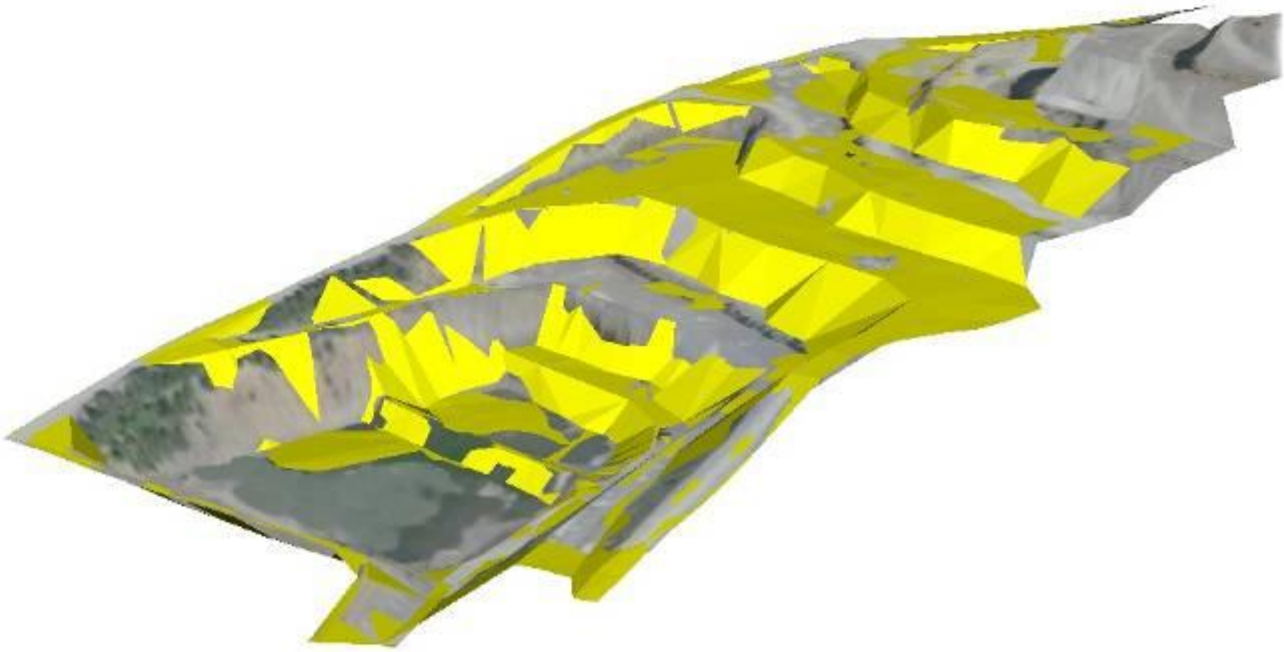

Fig. 12: Tacheometry survey - stage I, stage II (Atlas DMT software)

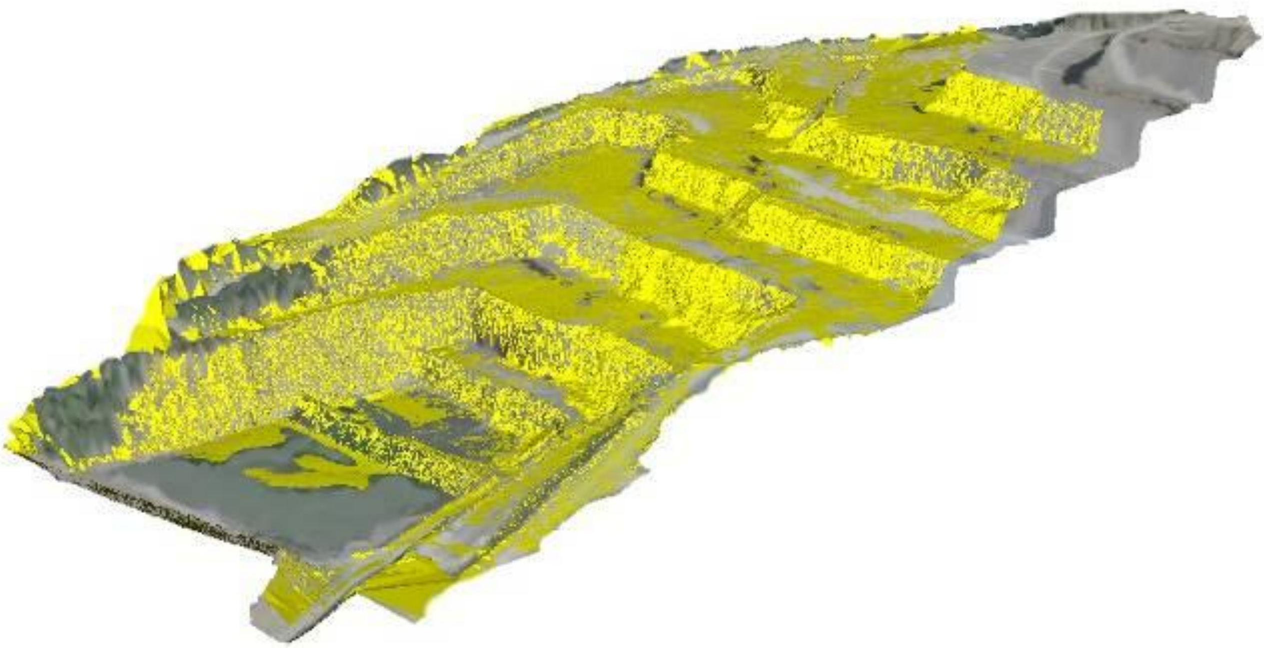

Fig. 13: Laser scanning survey - stage I, stage II (Atlas DMT software)

The comparison of models of both stages was performed by the Geomagic Studio 12 software as well. The comparison is illustrated in **Fig. 14**. The figure shows which parts were excavated (the grey strips along the edges of individual benches), and the parts where the rock was piled (the area of a tailings dump at the bottom of the quarry). It can be said that no significant changes occurred in the locations, where no colour predominates and where yellow and grey colours are irregularly blended. The randomness of colour blending can be attributed to accidental errors of measurements by the laser scanning method.

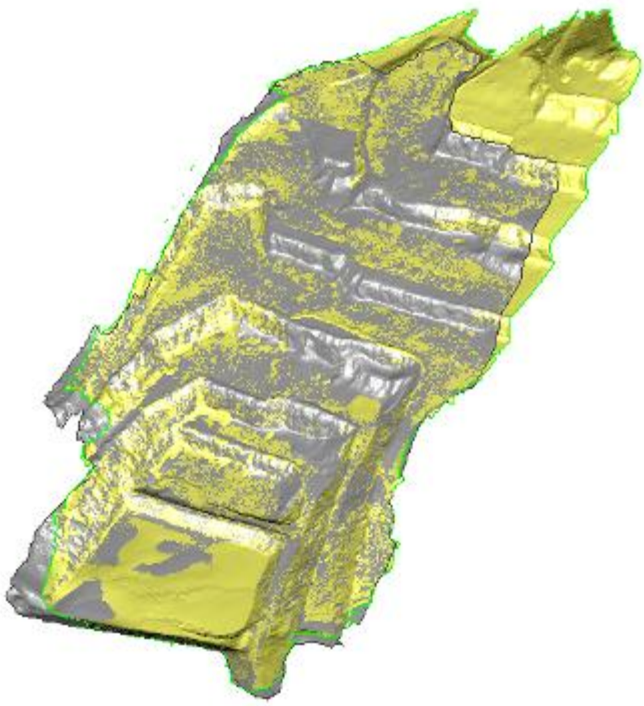

Fig. 14: Laser scanning survey - stage I, stage II (Geomagic Studio 12 software)

The calculation of volumes of excavated muck was carried out by the Atlas DMT software, version 4.7 too. Using the tool "Volume Calculation", the volume of the spatial formation, limited by both major and reference models of the terrain, was calculated. The calculation is performed in the plane determined by a common plan view of the main and reference models.

In the very calculation, the whole area is divided into auxiliary triangles. Over each auxiliary computational triangle the prism volume limited by heights of major and reference terrains at the vertices of the triangle is determined. The results are then values of positive and negative parts of the volume of the whole area. The partial volumes in the locations where the major terrain is higher than the reference one, are included in the positive part, while the volumes from the area where the reference terrain is above the major one, are added to the negative part. [5] (see **Fig. 15**, **Fig. 16**)

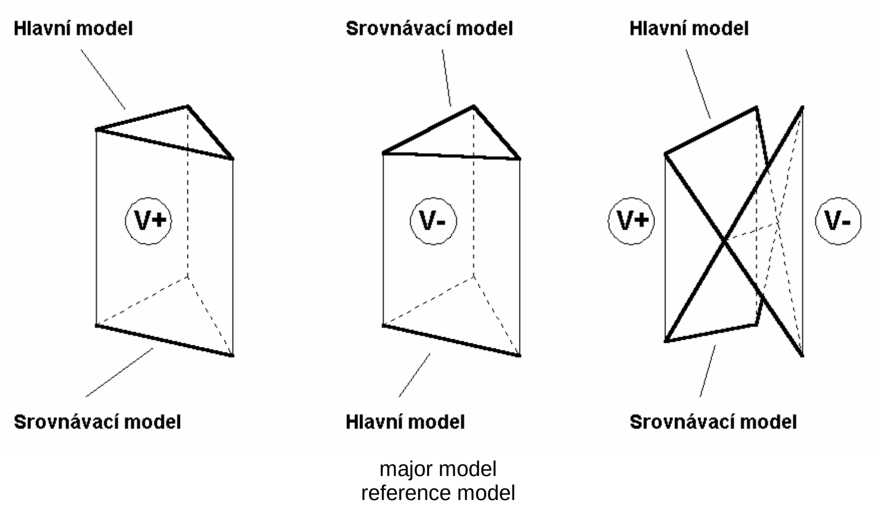

Fig. 15: Results of positive and negative parts of the volume of whole area

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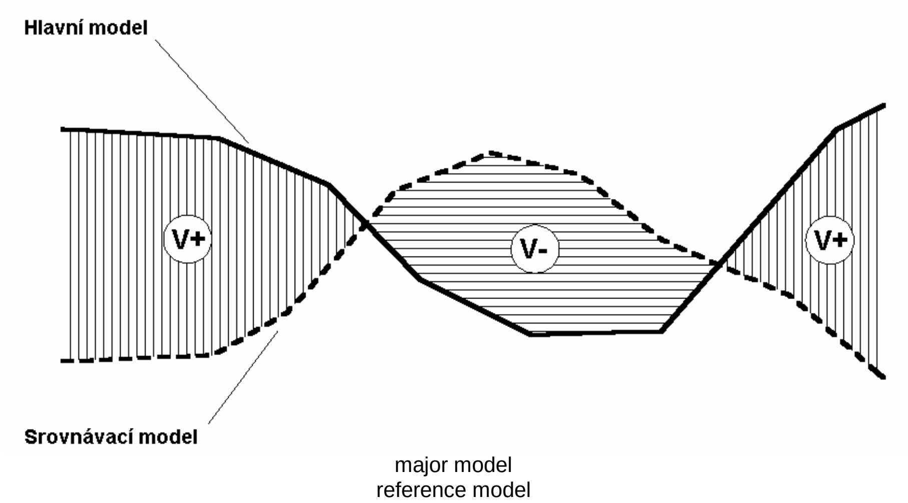

Fig. 16: Illustration of the values of positive and negative parts of the volume of whole area

Fig. 17 and **Fig. 19** show the positive volumes (volumes from the area where the major terrain is higher than the reference one) and the negative volumes (volumes from the area where the reference terrain is above the major one), the sum of the volume positive and negative parts and the sum of absolute values of both volume parts. The total surface area of the computing area is added too, along with its division into parts corresponding to a positive, negative and zero volume. The program-set total surface area of the major and reference terrains in the area of calculation is available too. [5]

When calculating the volumes resulting from the tacheometric survey, the stage I model was established as a major model, the model of the stage II was chosen as a reference one. The difference between these two models gives us the excavated volume for 3 months, or 88,879 m^3.

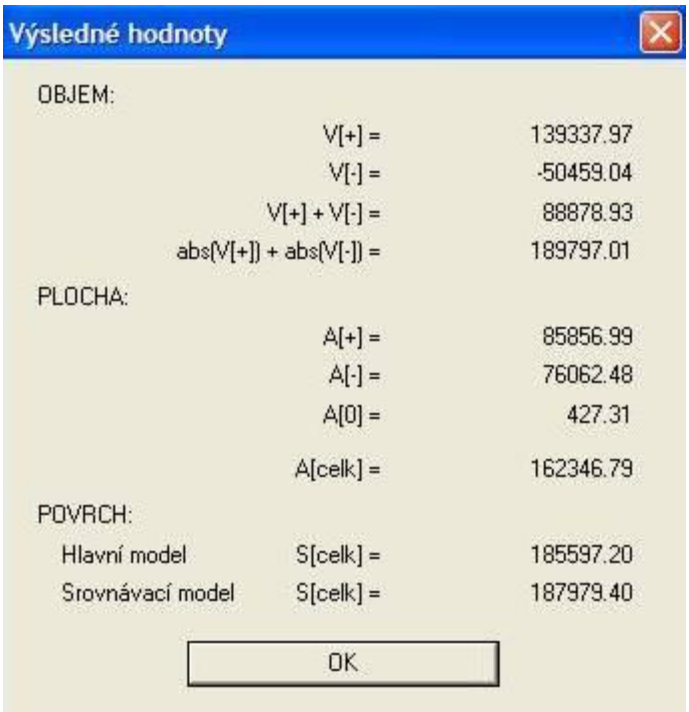

Fig. 17: Resulting volume (m^3) - stage I, stage II (tacheometry)

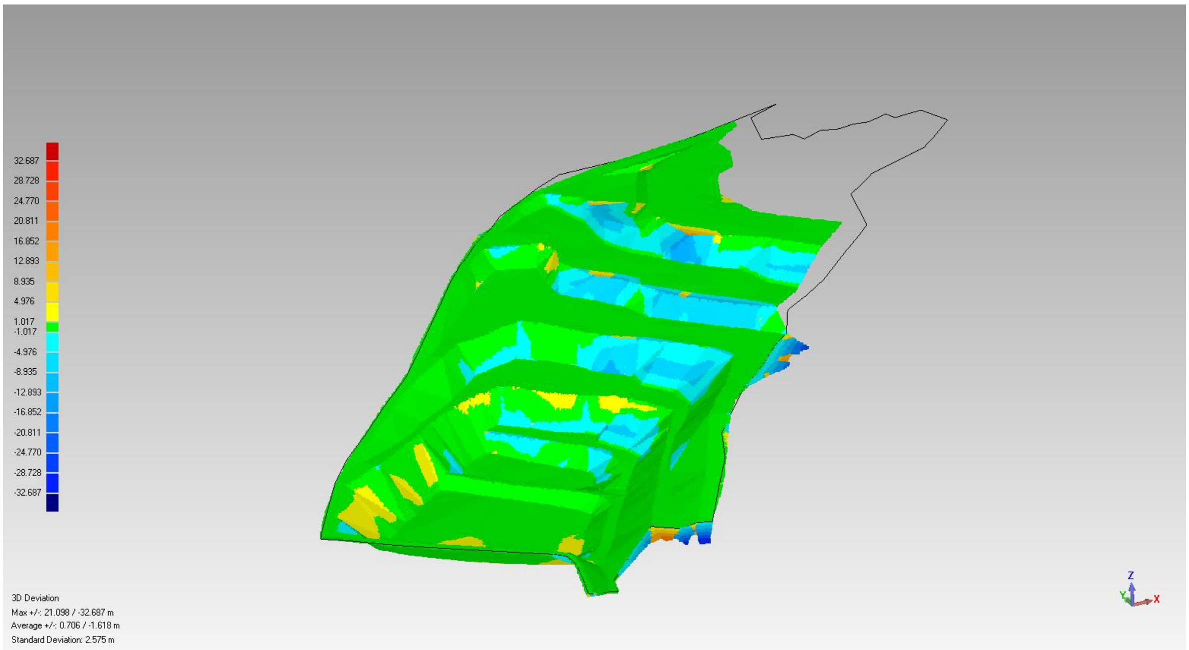

Fig. 18: Differential model - stage I, stage II (tacheometry)

The differential model in **Fig. 18** shows the differences, viewed in a hypsometric scale, between the first and the second stages surveyed by the method of tacheometry. In this figure, the excavated areas are clearly visible at first sight, and the values of changes in excavated rock can be estimated as well.

When calculating the volumes resulting from laser scanning survey, the stage I model was established as a major model and the model of the stage II was chosen as a reference one. The difference in these two models gives us the excavated volume for 3 months, or 75.648 m^3.

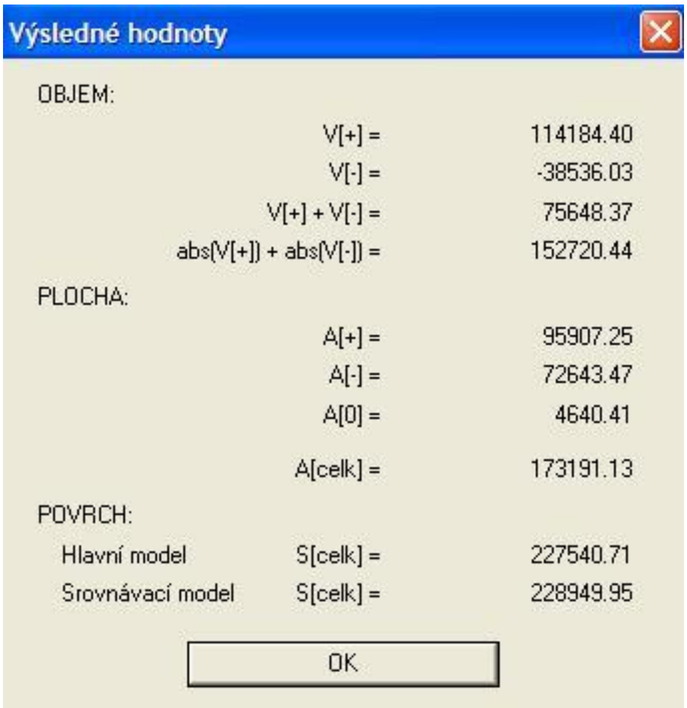

Fig. 19: Resulting volume (m^3) - stage I, stage II (laser scanning)

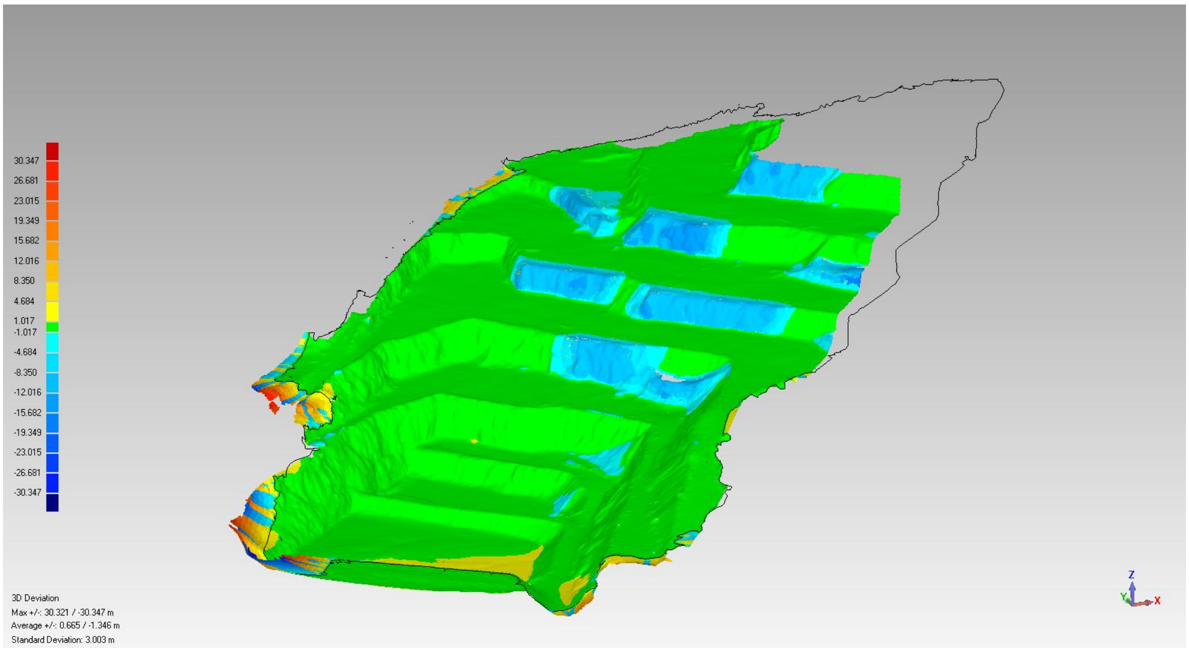

Fig. 20: Differential model - stage I, stage II (laser scanning)

Just as in the tacheometric method, in surveying by the laser scanning method a differential model between the first and second stages was developed. The model is illustrated in **Fig. 20.**

7 CONCLUSIONS

The paper describes the methodology of surveying the part of the quarry in the Jakubčovice nad Odrou by a tacheometric method and by a method of laser scanning. This survey has been performed to compare the two methods and to assess the usability of these methods in mine surveying.

Compared to the laser scanning method, providing capturing the entire object surface with a chosen level of detail, the tacheometric survey only captures characteristic points of an object such as edges, etc., which may contribute to a somewhat less accurate resulting model and also a less precise calculation of volumes of excavated rock.

The advantage of tacheometry, in which the data for planimetry and altimetry of maps is acquired in a rapid manner, is a significant reduction in surveying work in the field. However, it is possible partly to eliminate this disadvantage of laser scanning through the use of instruments with greater speed of scanning, or devices installed on mobile equipment (a car), whereby it is possible to significantly shorten the time of scanning at individual stations. The use of laser scanners with a larger scanning range could also contribute to the acceleration of the survey work.

The benefit of laser scanning is also easier surveying in poorly accessible places in a locality or in places where safety and health of operation is at risk, but mainly the greater complexity, density and thus the quality of survey.

The laser scanning method could be used in future to update mine surveying documentation, monitore mining operations, etc. It would thereby complete the currently used methods of aerial photogrammetry and tacheometry.

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RESUMÉ

Předložený článek se zabývá srovnáním klasické geodetické metody (tachymetrie) s metodou laserového skenování s cílem posouzení, která z uvedených metod je pro zaměření dané lokality efektivnější. Součástí je i výpočet objemů odtěžené rubaniny na příslušných 3D modelech a jejich srovnání.

Na základě tohoto srovnání lze říci, že efektivnější metodou pro zaměření dané lokality je laserové skenování, které poskytuje zachycení celého povrchu objektu se zvolenou mírou detailu oproti tachymetrii, při které jsou zachyceny pouze charakteristické body objektu, jako například hrany apod.

3D model vytvořený z laserového skenovaní vypovídá o skutečnosti mnohem lépe, než 3D model vytvořený z tachymetrického zaměření, avšak nedokáže generalizovat např. části suti.

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