Acta Montanistica Slovaca Ročník **17** (2012), číslo **3**, 189-194

Geodetic survey of tuff wine cellars in Veľká Tŕňa

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Veľká and Malá Tŕňa are the centre of tokaj wine region in Slovakia. They have a long tradition of exquisite tokaj wine-making. There are cellar entrances in tuff hills near both villages in which people store wine in regular temperatures. Each cellar entrance divides into further corridors which end with a cellar. The outcome of the geodetic survey is the creation of documentation used for urban planning in the area, as well as an overview of further growth possibilities of wine cellars.

Keywords*: tokaj wine cellars, three-dimensional survey*

Introduction

Tokaj wine region lies in Lower Zemplín in the southeast part of Slovakia. It follows up a wine region of which large part originates in Hungary. This area is the smallest as well as the most attractive wine region of Slovakia. It consists of the southern slopes of Zemplín hills planted with grapevine for two millennia [1]. Municipalities of Bara, Čerhov, Černochov, Malá Tŕňa, Slovenské Nové Mesto, Veľká Tŕňa a Viničky belong here. It is one of the few areas in the world which grows grapes for the production of natural sweet wines.

Tokaj wine cellars

Quality wine cellars which are abundant here are a necessary part of viticulture. Slovak tokaj hills are of volcanic origin and therefore are suitable for growing common grapevine, but also for digging out the tuff cellars without support system. The basis of these cellars is created by paleozoic rock which subsided after intensive tectonic movements in the late tertiary. Their residue created a solid floe suitable for digging cellars as well as growing tokaj vine variety in the area of Veľká and Malá Tŕňa and Cejkov [3]. The area also contains smaller clusters of cellars, however the largest ones occur in tuff hills of Tŕňa [2].

Volcanic bedrock suitable for digging underground space was used by our ancestors who built the original wine cellars as a refuge against tartar invasion in the 15th and 16th century. The cellars had small entrances followed by narrow corridors in order to disguise as well as to defend against unwanted access into underground [7]. In some of the original historical tokaj wine cellars, which are now historically protected, were half meter holes of almost round shape dug in the floor surface, underneath which was even wider pit for storage of vine or other supplies [6]. It was only in the 17th century when the first tokaj cellars were founded for the wine production and maturation. They have been used ever since [2].

Fig. 1. Wine cellar entrance.

Fig. 2. Historical tuff cellar.

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Typical tokaj cellars dug out into tuff mass are 16 meters underground. They are accessed by relatively long, low and narrow corridors. This secures long-term constant temperatures of 10 – 12 °C (except for the differences in summer and winter temperatures of cca 1,5 °C) as well as air humidity of 85-95 %. Cellars contain rare, noble blackish gray mold which creates extraordinary environment for faster wine aging and its bouquet. Mold is in symbiosis with tokaj wine, it assimilates wine fumes by exploiting alcohol, aldehyds, aromatics and other organic substances such as substrates. By means of presence of vapor in cellar, it colonizes all surfaces – walls, barrels and bottles [7].

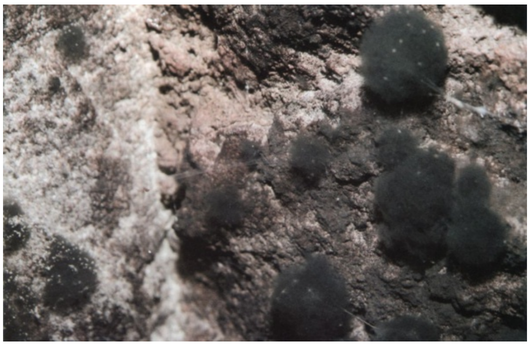

Fig. 3. Tokaj mold (Cladosporium cellare) on the cellar wall.

There are 33 cellar entrances in Veľká Tŕňa. Cellar entrances as well as the area around them are entered in the Database of Immovable Cultural monuments and Sites of the Slovak Republic [5]. Each cellar entrance is unique. Every entrance is divided into further corridors ending with a cellar. One cellar entry can be divided into 10 or more corridors.

Geodetic survey of cellars

Modern technologies allow extremely fast and highly precise survey of surface conditions as well as objects of centimetre dimensions [11]. The choice of technology used in geodetic survey depends on current conditions and required precision class [12].

Network of points created on the surface before the survey was located in front of the cellar entrances. Spatial position of these points was determined by means of GNSS technology.

Currently there are more ways of measurement by means of global navigation satellite system available. RTK (Real time kinematic) method is one of the relative kinematic measurements [14]. By use of this method, coordinates of control points were determined in coordinate system S-JTSK and elevation system Bpv, with accuracy ±10 mm in position and ±20 mm in elevation (indicated by the manufacturer of used device for the particular method [9]). Location of underground surveying points was determined by open traverses connected to the surface network. Surveying points were located according to the needs and particular situation depending on limitations and the quantity of breaks. Points were fixed by iron nails at the bottom of corridors. Surveying the points required particular attention since we had no control over the end points of traverses. Surveying points of traverses and of detailed points was performed simultaneously on the way into the cellar by spatial polar method using universal surveying devices Nikon DTM-332 and Leica TCR 305. Detailed points surveyed from fixed or free survey stations were selected on a typical break points (where corridors change their shape, slope, direction, size etc.) in order to capture the shape of cellars to its best. Working in the cellars required constant illumination similar to measuring in mining conditions despite installed electric lighting.

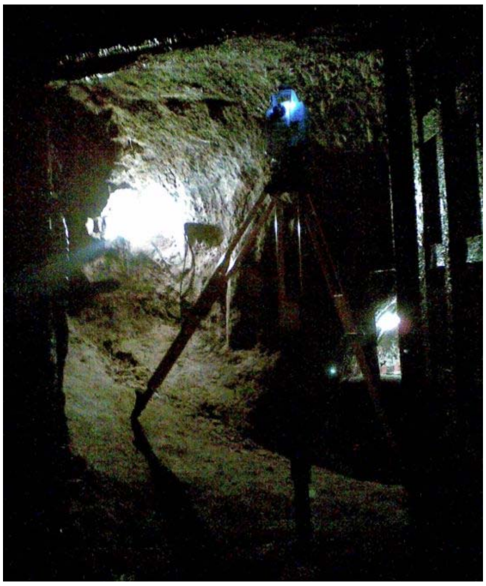

Fig. 4. Nikon DTM-332.

Except for the underground survey we also focus on surface measurement above cellars. Measurements can be performed as terrestrial, satellite or combined ones in accordance with the situation and equipment for measurements [15].

However, attention should be focused also on the examination of vertical shifts of topographic surface, since such measurements are standard when examining the impact of undermined areas on surface and its objects [16].

Processing of acquired data into the list of coordinates was followed by graphic representation in Microstation V8. From particular detailed points and on the basis of assigned codes and survey drafts were created schematic three-dimensional models of surveyed area (fig. 5).

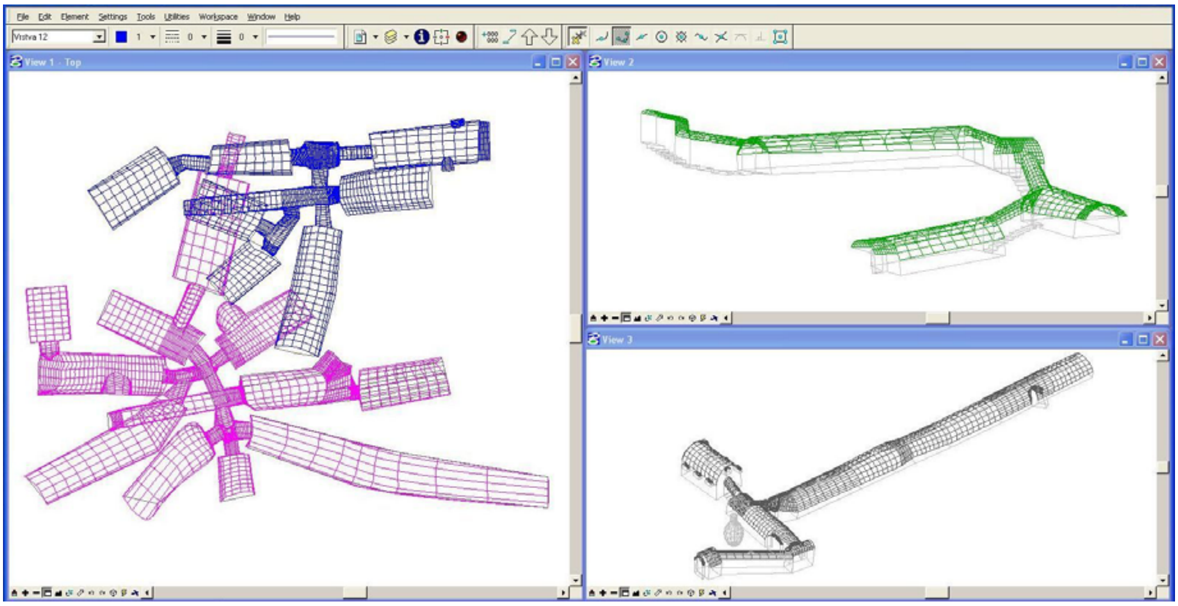

Fig. 5. Graphic representation of three-dimensional cellar model.

Analysis of survey precision

The results of the survey are influenced by various factors such as used survey equipment, psychological state of a surveyor or a disruptive impact of the environment. All these factors may cause basic errors which can be algebraically summed into final survey error [13]. The method of deriving the median spatial error of the last point of traverse is as follows:

Let unilaterally annexed and based traverse (fig.6) connect to point A (x_A, y_A) with focus on point B (x_B, y_B).

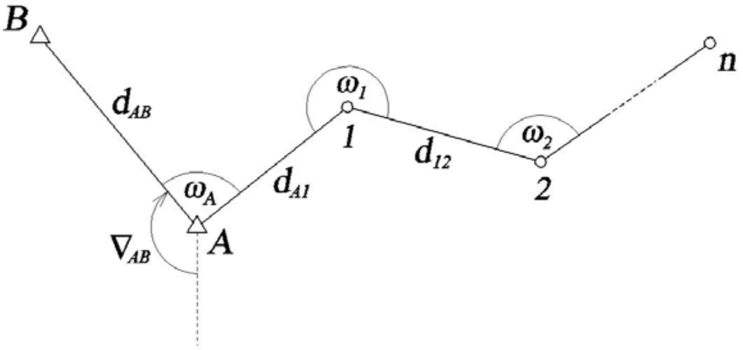

Fig. 6. Unilaterally annexed and based traverse.

To calculate the connecting bearing ∇_{AB} the following equation holds:

$$tg\nabla_{AB} = \frac{y_B - y_A}{x_B - x_A} \tag{1}$$

or

$$tg\nabla_{AB} = (y_B - y_A).(x_B - x_A)^{-1}.$$

Standard deviation $\sigma^2_{\nabla_{AB}}$ of connecting bearing ∇_{AB} is calculated using partial derivates of *f* of equation (2).

$$\nabla_{AB} = arctg\left[(y_B - y_A).(x_B - x_A)^{-1}\right] = f(x_A, y_A, x_B, y_B) \tag{2}$$

For calculating standard deviation $\sigma^2_{\nabla_{AB}}$ holds equation:

$$\sigma^2_{\nabla_{AB}} = \left(\frac{\partial f}{\partial x_A}\right)^2 \sigma^2_{x_A} + \left(\frac{\partial f}{\partial y_A}\right)^2 \sigma^2_{y_A} + \left(\frac{\partial f}{\partial x_B}\right)^2 \sigma^2_{x_B} + \left(\frac{\partial f}{\partial y_B}\right)^2 \sigma^2_{y_B}, \tag{3}$$

where $\sigma^2_{x_A}, \sigma^2_{y_A}, \sigma^2_{x_B}, \sigma^2_{y_B}$ are standard deviations of determining coordinates of points A (x_A, y_A) and B (x_B, y_B). Assuming that $\sigma^2_{x_A} = \sigma^2_{y_A} = \sigma^2_{x_B} = \sigma^2_{y_B} = \sigma^2_{x,y}$ and $\Delta x^2_{AB} + \Delta y^2_{AB} = d^2_{AB}$, then for the standard deviation $\sigma^2_{\nabla_{AB}}$ of the connecting bearing ∇_{AB} holds:

$$\sigma^2_{\nabla_{AB}} = \sigma^2_{x,y} \frac{2\rho^2}{d^2_{AB}}, \tag{4}$$

where ρ is radian (conversion constant).

For the calculation of arbitrary bearing ∇_{ij} in move holds:

$$\nabla_{ij} = \nabla_{AB} + \omega_A + \sum_{i=1}^{n} \omega_i - i.200^g. \tag{5}$$

By means of partial derivates of equation (5), the standard deviation of bearing ∇_{ij} is calculated by:

$$\sigma^2_{\nabla_{ij}} = \sigma^2_{\nabla_{AB}} + \sigma^2_{\omega_A} + \sum_{i=1}^{n} \sigma^2_{\omega_i}, \tag{6}$$

where $\sigma^2_{\omega_A}$ a $\sigma^2_{\omega_i}$ are standard deviations of measured horizontal angles.

For the calculation of coordinate differences Δx_{ij} and Δy_{ij} between two points i (x_i, y_i) and j (x_j, y_j) (fig. 7), in general hold following equations:

$$\Delta x_{ij} = d_{ij}.\cos\nabla_{ij}, \tag{7}$$

$$\Delta y_{ij} = d_{ij}.\sin\nabla_{ij}, \tag{8}$$

where d_{ij} is horizontal length between points i and j.

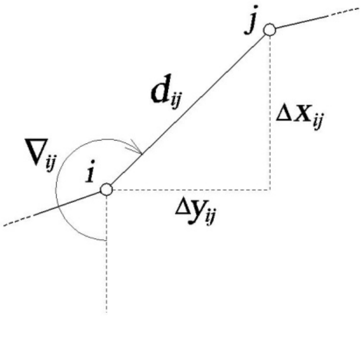

Fig .7. Coordinate differences between the two points.

By means of partial derivates of equations (7) and (8) then the standard deviations of coordinate differences Δx_{ij} and Δy_{ij} are:

$$\sigma^2_{\Delta x_{ij}} = \sigma^2_{d_{ij}}.\cos^2 \nabla_{ij} + d^2_{ij}.\sin^2 \nabla_{ij}.\frac{\sigma^2_{\nabla_{ij}}}{\rho^2}, \tag{9}$$

$$\sigma^2_{\Delta y_{ij}} = \sigma^2_{d_{ij}}.\sin^2 \nabla_{ij} + d^2_{ij}.\cos^2 \nabla_{ij}.\frac{\sigma^2_{\nabla_{ij}}}{\rho^2}. \tag{10}$$

Resulting standard deviations $\sigma^2_{x_n}$ and $\sigma^2_{y_n}$ of determination coordinates of the final point of traverse n (x_n, y_n) are then calculated as the sum of standard deviations of coordinates determination of initial point A (x_A, y_A) and standard deviations of coordinate differences in particular points of traverse.

$$\sigma^2_{x_n} = \sigma^2_{x_A} + \sigma^2_{\Delta x_{A1}} + \sigma^2_{\Delta x_{12}} + \sigma^2_{\Delta x_{23}} + \ldots + \sigma^2_{\Delta x_{n-1,n}} \tag{11}$$

$$\sigma^2_{y_n} = \sigma^2_{y_A} + \sigma^2_{\Delta y_{A1}} + \sigma^2_{\Delta y_{12}} + \sigma^2_{\Delta y_{23}} + \ldots + \sigma^2_{\Delta y_{n-1,n}} \tag{12}$$

Elevation differences ΔV_{ij} of particular points of traverse were measures trigonometrically (fig. 8) and calculated according to equation:

$$\Delta V_{ij} = d_{ij}.\cot g\ z_{ij}. \tag{13}$$

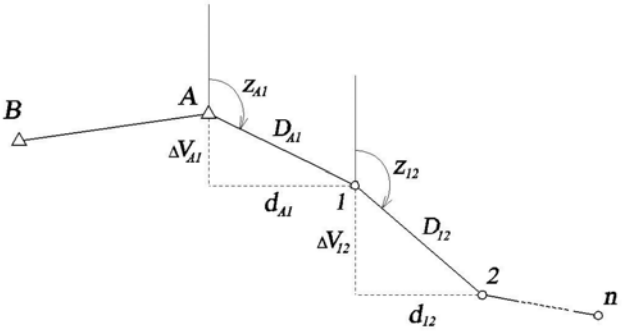

Fig. 8. Elevation differences between particular points.

Standard deviation of partial elevation difference $\sigma^2_{\Delta V_{ij}}$ is after partial derivations of relation (13) calculated by:

$$\sigma^2_{\Delta V_{ij}} = \sigma^2_{d_{ij}}.\cot g^2 z_{ij} + \frac{d^2_{ij}.\sigma^2_{z_{ij}}}{\left(1 + z^2_{ij}\right)^2 \rho^2}, \tag{14}$$

when $\sigma^2_{z_{ij}}$ is standard deviation of measured zenith angles.

Final standard deviation $\sigma^2_{V_n}$ of determination of elevation of final point of traverse is calculated as a sum of standard deviation $\sigma^2_{V_A}$ of initial point A and standard deviations of particular elevation differences $\sigma^2_{\Delta V_{ij}}$ between points of traverse.

$$\sigma^2_{V_n} = \sigma^2_{V_A} + \sigma^2_{\Delta V_{A1}} + \sigma^2_{\Delta V_{12}} + \sigma^2_{\Delta V_{23}} + \ldots + \sigma^2_{\Delta V_{n-1,n}} \tag{15}$$

Median spatial error σ^2_n of final point of traverse is calculated by the sum of equations (11), (12) a (15).

$$\sigma_n^2 = \sigma_{x_n}^2 + \sigma_{y_n}^2 + \sigma_{V_n}^2 \qquad (16)$$

Current state

Almost every family in Veľká Tŕňa owns a vineyard. Private vineyards are usually inherited and if they are fewer than the number of descendants, they are dug deeper and shared so everybody has a chance to store their vine products [4]. This is one of the reasons why the network of cellars is constantly growing by either estimation or in the direction of a more quality tuff. However, digging the new cellar corridors or underground area with a capacity above 250 m^3 is considered to be a mining method which is subject to legislation act [8].

Current state of cellar register in Veľká Tŕňa is reflected in cadastral map in areas of the ground surface penetration, that is in the area of cellar entrance including the owner's right to it in a file of descriptive information (SPI) of the cadastre (KN).

Conclusion

The aim of the survey was the creation of documentation not only for the purpose of positioning the cellar corridors but also for determination of the elevation conditions since many cellars intersect. The result of the survey should be a three-dimensional model of the particular cellar condition as well as planimetric and altimetric plan of surface area above.

The main significance of geodetic survey is to obtain information about the conditions of particular cellars which would prevent digging through, breaking down or consecutive distorting of private ownership which occurs here frequently. The last but not the least is the safety and stability of underground area.

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