Monitoring of rock blocks movements

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The paper deals with determination rock blocks movements in the area of Bila voda stream sink in the Moravian Karst. Size and direction of movements have been determined in the frame of the projects 205/04/0047 and 205/07/1211 of the GACR (Grant Agency of the Czech Republic) since 2004. The technology of space resections and levelling has been used. Used software allowed adjustment various type of observations. One of them is the model coordinates of block points in the local coordinate systems. This approach allowed us to determine space coordinates of points in the case, when we have not sufficient number of observations. The largest displacements appeared in the years 2008-2009 on the blocks E and F.

Key words: *rock blocks movements, adjustment various type of observations*

Introduction

Determinations of rock blocks movements have took place in the area of stream sink of Bila voda brook in the Moravian karst since the year 2004. The rock blocks were arose by crash of rock wall in to Bila voda brook in the year 1965. The movements of block have arisen during higher flow rate, mainly during spring floods, and the blocks have been shifted to the stream sink. This fact can cause during floods great problems, because water does not flow away and water level increases and several hundred meters long lake arises. One of the goals of the project N. 205/07/1211 of the Grant agency of the Czech republic focused on Bila voda stream sink has been determination of the rock blocks displacements and their rotations**.** Measurements have been carried out usually two times per year – after spring thaw and in the autumn. Up to now we have processed 11 stages of measurements. The observed points on blocks were placed close to edges of blocks and were stabilized using copper snap-head rivet with little drill hole. The standpoints were chosen as free on relatively stable places ensuring safe observations and good intersection condition, similarly as photo station in close range photogrammetry. Seven main blocks have stabilized 3 and more points. Points are placed on positions with good visibility and equally on block to sure the best determination of displacements. For determination of space coordinates of points has been used the method of space resection. Between some standpoints have been measured distances and elevation of some points have been determined by levelling. As fixed point were chosen two points on solid rock near brook and five points in rock wall above sink. Sometimes becomes situation that is not possibility to observe all points or some points are measured only from one standpoint. It means that we have no coordinates of point in measured stage. Reasons of such situation can be damage of point or some obstacles. One possibility to overcome these troubles is interpolation of absenting data from previous and following positions. If the movement of block is not linear, such a solution is not precise. The second possibility is use attribute that mutual position of points on one block is invariable. Points on block have the same position in a local coordinate system (model system) of block. This solution was checked up in processing of the last two stages.

Solution

Principle of method is based on using of model, that represents set of points on one block in own coordinate system. Model coordinates input into adjustment as measured data. For creation of model we need 3 points at least. The program ORIENT developed in the Institute of Photogrammetry and remote sensing on TU Vienna was used for solution of our task [1]. There is used for photogrammetric task, but is possible to use for calculation with polar data. Program ORIENT handles with two group of data. The first group contains measurements and second one is group of unknown parameters. For each point determined by horizontal angle α, zenith angle ξ a slope distance s we can write 3 observation equations:

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$$\begin{bmatrix} v_\alpha \\ v_\zeta \\ s+v_S \end{bmatrix} = \begin{bmatrix} -1/s.\sin\zeta & 0 & 0 \\ 0 & 1/s & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \sin\alpha & -\cos\alpha & 0 \\ \cos\alpha\cos\zeta & \sin\alpha\cos\zeta & \sin\zeta \\ \cos\alpha\sin\zeta & \sin\alpha\sin\zeta & \cos\zeta \end{bmatrix} \mathbf{R}^{\mathbf{T}} \begin{bmatrix} X-X_0 \\ Y-Y_0 \\ Z-Z_0 \end{bmatrix}$$

In which v_α is residual of measured horizontal angle, v_ξ is residual of measured horizontal angle and $s+v_s$ is corrected distance.

Matrix **R** describes orientation of local Cartesian coordinates system (x, y, z) of instrument derived from polar coordinates α, ς, s and global geodetic coordinates system (X, Y, Z).

$$\mathbf{R} = \begin{bmatrix} \cos\varphi\cos\kappa & -\cos\varphi\sin\kappa & \sin\varphi \\ \cos\omega\sin\kappa + \sin\omega\sin\varphi\cos\kappa & \cos\omega\cos\kappa - \sin\omega\sin\varphi\sin\kappa & -\sin\omega\cos\varphi \\ \sin\omega\sin\kappa - \cos\omega\sin\varphi\cos\kappa & \sin\omega\cos\kappa - \cos\omega\sin\varphi\sin\kappa & \cos\omega\cos\varphi \end{bmatrix}$$

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} -1/s.\sin\zeta & 0 & 0 \\ 0 & 1/s & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \sin\alpha & -\cos\alpha & 0 \\ \cos\alpha\cos\zeta & \sin\alpha\cos\zeta & \sin\zeta \\ \cos\alpha\sin\zeta & \sin\alpha\sin\zeta & \cos\zeta \end{bmatrix}$$

Last part of observation equations describes shift of origin of local coordinate system. For two angles of rotations has to be valid following equation ω=φ=0, but vertical axe of total station is not in the same direction as plumb line. Quantities ω, φ are considered as observed:

$$\varphi = v_\varphi + \varphi_{obs} \qquad\qquad \omega = v_\omega + \omega_{obs}$$

The same approach is used for coordinate Z determined by levelling:

$$Z = v_Z + Z_{obs}$$

In case that the coordinates of fixed points are not considered rigorously fixed, we can add following observation equations

$$\begin{bmatrix} v_X \\ v_Y \\ v_Z \end{bmatrix} = \begin{bmatrix} X - X_{obs} \\ Y - Y_{obs} \\ Z - Z_{obs} \end{bmatrix}$$

Observation equations for model (block) coordinate are following:

$$\bar{x} + v_x = \frac{1}{m}(r_{11}(X-X_0) + r_{21}(Y-Y_0) + r_{31}(Z-Z_0))$$
$$\bar{y} + v_y = \frac{1}{m}(r_{12}(X-X_0) + r_{22}(Y-Y_0) + r_{32}(Z-Z_0))$$
$$\bar{z} + v_z = \frac{1}{m}(r_{13}(X-X_0) + r_{23}(Y-Y_0) + r_{33}(Z-Z_0)),$$

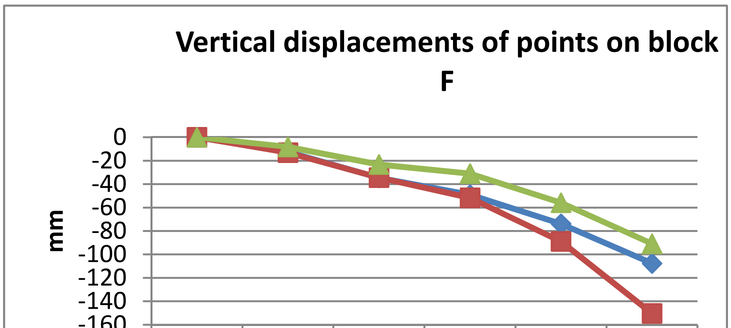
Where m is scale of model (usually m=1) and r are elements of rotation matrix of model. Standard deviations of observed data introduced in adjustment were following:

$$\sigma_{\alpha,\varsigma} = 4\,mgon, \sigma_{\varphi,\omega} = 5\,mgon, \sigma_s = 0.002\,m, \sigma_{ZLEV} = 0.001m, \sigma_{X,Y,Z} = 0.0005m, \sigma_{x,y,z} = 0.001m\,.$$

Average standard deviations of adjusted coordinates of points were following in the basic stage: $\sigma_X = 0.6\,mm,\ \sigma_Y = 0.7\,mm,\ \sigma_Z = 0.3\,mm.$ The measurements in basic stage carried out two groups of observers. Next stages were measured only one times and standard deviations were about 50 % larger. Outliers were eliminated using robust estimation. Proposed method have been proved on simulated example and then used for processing of two last stages. There were proved possibility to determine position of point observed only from one standpoint with connection of model coordinates. Accuracy of coordinates is influenced of course by low number of observations. Actual effect of method will be possible to evaluate after several stages, especially in case nonlinear development of displacements.

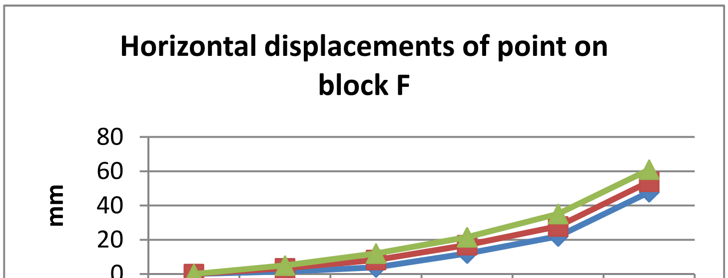
Evaluations

In the years 2004-2009 were measured 11 stages. The results have been gradually published [2]. Several hundred meters long lake arose during spring floods in the year 2005 and 2006. The results confirmed excepted values of displacements of blocks. Average annual vertical displacements of block were 11 mm. In the years 2008 and 2009 blocks E and F increased movements, although spring floods were smaller. The largest displacement was found out on block F, which is in the middle of stream of Bila voda brook – Fig. 1. Total vertical displacements of point N. 25 amounted to 150 mm. Horizontal displacements of block F are shown on Fig. 2. The largest horizontal displacements in period 2004-2009 have shown points N. 25 and N. 26 of block F. During all period 2004-2009 the blocks were moving to the sink see Fig. 3, sink place is marked by letter P. Rotations of blocks are variable the largest values of rotations we can find on block F which is located in main stream of brook (ω = 1,33 gon, φ = -0,67 gon, κ = -0,58 gon). The largest inclination of block F of value 1,33 gon lies in direction of main stream.



	2004	2005	2006	2007	2008	2009
24	0	-12,5	-34,6	-49,0	-73,9	-107,7
25	0	-13,1	-34,4	-51,7	-88,9	-150,4
26	0	-8,2	-23,2	-31,0	-55,9	-90,9

Fig. 1. Vertical displacements of rock block F in the years 2004-2009.



	2004	2005	2006	2007	2008	2009
24	0	1,4	3,9	12,0	22,0	47,8
25	0	3,4	8,2	16,9	27,8	53,9
26	0	5,0	12,0	21,5	35,1	61,0

Fig. 2. Horizontal displacements of rock block F in the years 2004-2009.

Laser scanning using precise scanner Imager 5006 was tested in the year 2008. The scanning did not come up expectation. On surface of blocks lie too little natural particles, that did not allow to achieve accuracy on level 1-2 mm. Only targeting of points can bring sufficient accuracy.

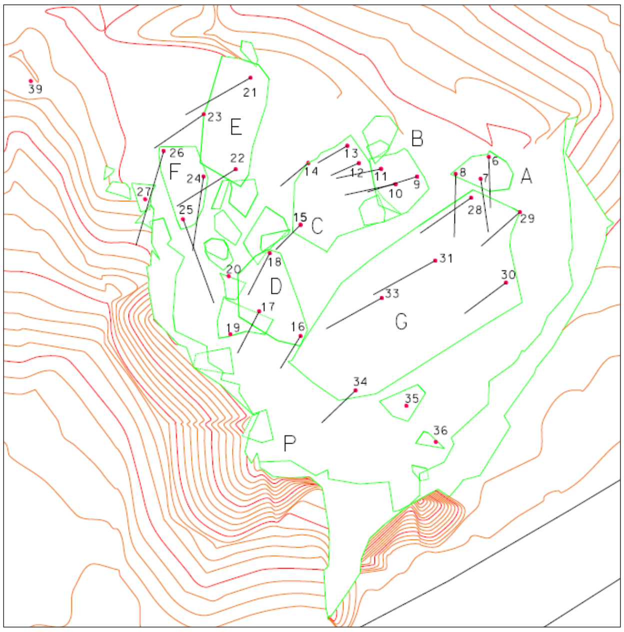


Fig. 3. Horizontal displacements of rock blocks in the years 2004-2009.

References

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