RESEARCH ON DATA PROCESSING OF DEFORMATION MONITORING FOR SIDE SLOPE BY NEW DEVELOPED SPECIAL GPS SOFTWARE

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ABSTRACT:

The deformation monitoring network with GPS is often separated, and it appears short-baseline and high-drop between monitoring sites. In theory, the base stations must be set up in the stable place. But because of the limitation of the geological condition and working environment, the reference point shows unstable sometimes. This paper study the influence to the result of the precision of the starting point coordinates and the approach of the adjustment of baseline network with multi-GPS. The baseline network is constituted with simultaneous observation loop (SOL) and non-simultaneous observation loop (NOL). Considering the difference between datum network and monitoring network, the model of adjustment is different between them. Analyzed the data of SOL and NOL, and the data mixed of several SOLs, an approach suited to the case is supplied. Taking into consideration of the deformation monitoring network's independence, it is suited to adopt quasi-stable adjustment over datum network. The quasi-center is treated as the initial data through this kind of adjustment. The system errors and the influence to monitoring sites of reference stations' movement are eliminated. Under the constraint of such method, all data of monitoring sites are integrated to the quasi-center which is a virtual point. All jobs of adjustment are made in WGS. Aimed to get the final deformation information of the monitoring area, all monitoring sites' coordinates are transformed to the system of polar coordinates of station center of the quasi-center. It is studied how the influence of the initial data's precision worked all over the monitoring periods. Based on the theory above mentioned, the software is come true with the function of adjustment of baseline network and monitoring network and deformation monitoring. It is proved that the software is suited to the real situation of the colliery, after tested the program with the data of a colliery and compared with the commercial software package.

1. INTRODUCTION

The large-scale slope comes into being during opencast mining. Deformation monitoring on the side slope, accompanied by the process of mining, is full of danger. How to carry out side slope deformation monitoring safely and efficiently and process monitoring data in a rational manner so that results can truly reflect the actual situation has become the focus of current research. Levelling surveying and GPS technology are currently the main methods of side slope monitoring.

As a conventional surveying method, levelling has many advantages, such as high-precision, mature data processing methods, reliable results and so on. But, it is a time-consuming job in large surveying area with lots of monitoring sites. The side slope is monitored once a month, but it last for a longer observation time. Deformation of monitoring sites happens during the period of observation. It is not strict to use adjustment of indirect observation over the monitoring data of a month. Taking deformation of monitoring stations as parameters, the adjustment process will lead to lower accuracy of the final solution by introducing too many parameters. However, it is hard to realize real-time monitoring.

GPS has been applied to many aspects of the surveying, which has the advantages of high efficiency, short-observing time, full-time working and so on. In practical, it is usually worked with simultaneous observation loop (SOL) and non-simultaneous observation loop (NOL). In order to attain the most accuracy, SOL should be adopted in monitoring and adjustment. NOL can be used in common situations. There are too many packages of commercial software which require almost high level of GPS control points as the initial data. Someone suggested the adjustment joint with ground levelling data. These packages of software and algorithms have been used widely. But, because of the problem of accuracy of GPS elevation, the effect of data processing on elevation is not less than perfect. In independent control network with no high-precision control points, the baseline network and the laid completely out of difficult geological deformation of the impact of regional circumstances, the above-mentioned software and algorithms to deal with the actual results do not conform to the real situation.

This paper studied the application of side slope monitoring mode of GPS and the corresponding data processing algorithms. The specific content including: 1) the monitoring mode of GPS in short-baseline and high-drop slope conditions by opencast mining; 2) the adjustment of independent control network which is influenced by complex geological environment; 3) the adjustment of monitoring network under the influence of control network; 4) the analysis of monitoring stations' deformation.

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2. MODE OF DEFORMATION MONITORING AND ADJUSTMENT

Mode of Deformation Monitoring

In GPS technology, it can be broadly divided into absolute positioning and relative positioning. Among them, the current accuracy of absolute positioning still can not meet the needs of the precision measurement. Relative positioning is worked under the way of simultaneous observations with several GPS devices. The baseline algorithm can eliminate many errors and the final results have a very high accuracy. Control points should be selected in regional geological solid area surrounding the surveying area. In theory, it is required that control points should be planted in deep soil. However, taking into account the convenience of practical work, requirements often differ. For general applications, the use of the classical adjustment of the control network meets the requirements. In the case of complex geological conditions, the control network will certainly be affected. The factors which affect the deformation monitoring accuracy can not be ignored.

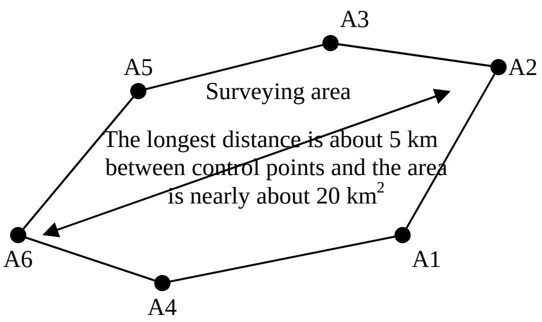

Figure. 1 Control network

There are 6 sets of GPS equipment available in the studying area. Considering the convenience of operation, 6 control points are selected and planted (as shown in Fig. 1). Control network and monitoring network are observed once a month. During the observation of control network, in order to increase the observation accuracy of as much as possible, it is required that simultaneous observation should be lasted 2 hours at least. According to the actual situation, 2+4 (as shown in Fig. 2) or 3+3 (as shown in Fig. 3) may be used in monitoring network monitoring. The time of observation of each monitoring station should be 30 minutes at least.

Quasi-Stable Adjustment

In the classical model of adjustment, it requires sufficient initial data. However, the classical method of adjustment, which is rank defect to the adjustment of independent control network, is no longer applicable here. After an analysis of the actual situation, quasi-stable adjustment is suitable.

Let u adjusted value of coordinate parameters be $\underset{u\times 1}{\hat{X}}$, observation vector $\underset{n\times 1}{L}$, the corresponding error equation is as follow:

$$A\hat{X} = L + V \tag{1}$$

The above equation has the same form with the adjustment of indirect observation. But, the only difference is the coefficient matrix A is of rank defect here.
According to the least squares method, with the condition $V^T PV = \min$, normal equation can be built from（1）

$$A^T PA\hat{X} = A^T PL \tag{2}$$

Lacking of initial data, the inverse matrix of coefficient matrix of normal equation $N = A^T PA$ is not existed. So（2）is improperly posed. The rank is the amount of coordinate datum. Let the amount of coordinate datum conditions be d, the form is as follow:

$$\underset{d\times u}{S^T}\,\underset{u\times 1}{\hat{X}} = 0 \tag{3}$$

In separated GPS control network, the baseline is vector of 3 dimensional, so $d = 3$.

Additional datum（3）is linear independently with normal equation（2）, which equivalent to:

$$\underset{u\times u}{N}\,\underset{u\times d}{S} = 0 \tag{4}$$

So, the problem is transformed to the parameter adjustment with constraint. Under the condition of $\psi = V^T PV + 2K^T (S^T \hat{X}) = \min$, the normal equation is as follow:

$$A^T PA\hat{X} + SK = A^T PL \tag{5}$$

Multiplied S^T left on both side of (5), taking into account of (4), $S^T SK = 0$ is got. Matrix $S^T S$ is orthogonal, so $K = 0$.
Multiplied S left on both side of (3), added together with (5) and taking into account of $K = 0$, the equation $\left(A^T PA + SS^T\right)\hat{X} = A^T PL$ is got.

The solution of $\left(A^T PA + SS^T\right)\hat{X} = A^T PL$ is:

$$\hat{X} = \left(A^T PA + SS^T\right)^{-1} A^T PL \tag{6}$$

In order to improve the accuracy of the final results, the weight matrix can not be set up to identity matrix simply. Covariance matrix of a single baseline which is a 3×3 matrix can be given by the commercial software directly. Each of baselines is linear independently. For baseline network, there is:

$$D = \begin{bmatrix} \underset{3\times 3}{D_1} & 0 & & 0 \\ 0 & \underset{3\times 3}{D_2} & & 0 \\ & & \ddots & \\ 0 & 0 & & \underset{3\times 3}{D_i} \end{bmatrix} \tag{7}$$

The sub-matrix of the diagonal is the covariance matrix of each baseline, and i is the index.

From (7),

$$P = \left(D/\sigma_0^2\right)^{-1} \tag{8}$$

Where, the value of σ_0^2 can be selected arbitrarily.

3. ADJUSTMENT AND ANALYSIS OF DEFORMATION MONITORING

There is a need to determine the expression of datum S before control network adjusting. With different application, the S has the different expression. Assume that all the control points are quasi stable here, so $\underset{1\times u}{S^T} = \begin{bmatrix}1 & 1 & \cdots & 1\end{bmatrix}$. For higher accuracy, hypothesis testing can be used to check whether a point stable or not.

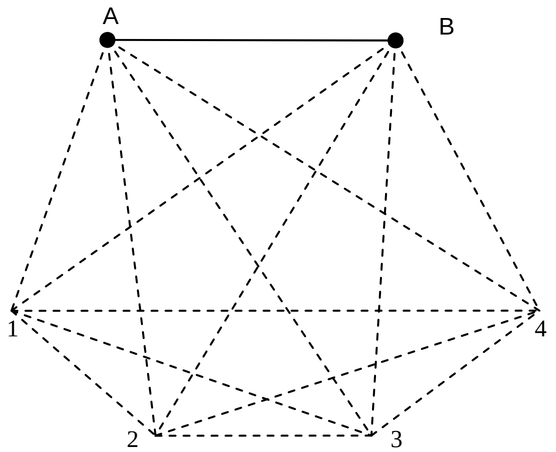

Figure. 2 2+4 SOL
A, B are control points; 1,2,3,4 are monitoring sites

Taking the control points which are participated in the observation currently as the quasi stable points, the expression of S is determined easily for monitoring network adjustment.

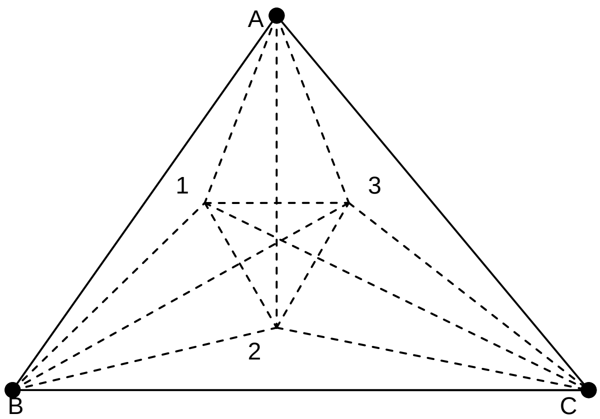

Figure. 3 3+3 SOL
A, B, C are control points; 1, 2, 3 are monitoring sites

The basic SOLs what are used in this paper are as shown in fig. 2 and fig. 3. The barycenter is not changed before and after the quasi-stable adjustment. So, there is:

$$\sum_{i=1}^{n} X_i = 0, \sum_{i=1}^{n} Y_i = 0, \sum_{i=1}^{n} Z_i = 0 \qquad (9)$$

In levelling, the results of adjustment can be used in deformation monitoring directly. But, coordinate transformation is necessary, because the baseline is the observation under the frame of WGS84. The origin of the system of polar coordinates of station center is a point of WGS84. The positive x-axis which point to north is along the direction of meridian. The positive z-axis which point to out is along the direction of the normal line of the origin. And the positive y-axis which point to the east is on the tangent plane.

As shown in（9）, results of the adjustment take the quasi-center as the origin. Different point has the different projection coordinates of the system of polar coordinates of station center under the frame of WGS84. The center of projection is required. After analyzing the effect of the accuracy of the center of projection to the deformation monitoring, the average of the coordinates of the control points which are observed in absolute positioning firstly is adopted. The projection equation is:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = H \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_D - \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_C \qquad (10)$$

Where, $\begin{bmatrix} X & Y & Z \end{bmatrix}_D^T$ is the geocentric coordinates of target points, and $\begin{bmatrix} X & Y & Z \end{bmatrix}_C^T$ is the geocentric coordinates of the center of projection.

And $H = \begin{bmatrix} -\sin B_C \cos L_C & -\sin B_C \sin L_C & \cos B_C \\ -\sin L_C & \cos L_C & 0 \\ \cos B_C \cos L_C & \cos B_C \sin L_C & \sin B_C \end{bmatrix}$,

B_C, L_C is the geodetic coordinates of the center of projection.

In deformation monitoring, $\begin{bmatrix} X & Y & Z \end{bmatrix}_D^T$ denotes current observation, and $\begin{bmatrix} X & Y & Z \end{bmatrix}_C^T$ denotes last observation. The results of processing are shown in the follow tables.

Table 1 Deformation of monitoring site jn6-2

Current Date	Reference Date	North	East	Elevation
200807	200805	-97.4	23.3	-26.9
200808	200807	-168.5	57.8	-51.7
200810	200808	-172.4	47.0	-65.1
200812	200810	-81.8	22.2	-10.2
200901	200812	-75.8	14.5	-38.7

Table 2 Deformation of monitoring site jn5-1

Current Date	Reference Date	North	East	Elevation
200807	200805	-105.4	42.9	-31.1
200808	200807	-161.9	89.7	-54.1
200810	200808	-227.5	119.7	-88.8
200812	200810	-83.9	39.6	-30.3
200901	200812	-63.3	33.2	-15.0
200902	200901	-31.6	14.1	-12.6
200903	200902	-34.4	15.4	-13.5
200904	200903	-5.1	7.7	-42.9

Table 3 Deformation of monitoring site jw346-2

Current Date	Reference Date	North	East	Elevation

200812	200810	4.1	306.6	-346.3
200901	200812	14.4	166.5	-181.2
200902	200901	7.1	97.7	-107.7
200903	200902	5.3	59.4	-157.8
200905	200903	10.7	124.5	-130.7

Note: On the above tables, the unit of north, east and elevation is mm. In the column of north, a positive value means a bias to north, and a negative value means a bias to south. In the column of east, a positive value means a bias to east, and a negative value means a bias to west. In the column of elevation, a positive value means up, and a negative value means descending.

The monitoring data of May 2009 and the software are shown in Figure. 4.

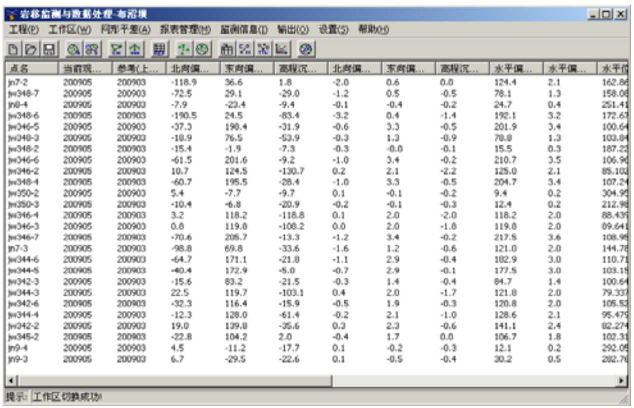

Figure. 4 The software

4. CONCLUSIONS

Main factor which influences the application in deformation monitoring of GPS is the accuracy of elevation. Studied for the deformation monitoring under independent control network in depth, quasi-stable adjustment is suited to the situation here. Firstly, the control network is processed with quasi-stable adjustment. And based the datum data adjusted, the indirect adjustment is used to process the monitoring network in SOL. At last, all data of deformation monitoring are transformed to the coordinate of the system of polar coordinates of station center of the quasi-center. Considering the offset of north and east, the results conform to the real situation perfectly. The algorithm above-mentioned is not only used in the situation, but it also can be used in the region with complex geological conditions. It also can be used to build NOL with 2 set of GPS equipment at least. Difference is only the lower accuracy compared with SOL. In the actual application, different mode could be adopted to meet the needs.

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