Study on feasibility of CORS application in surface movement deformation monitoring in mining areas

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Abstract

CORS has been widely established in China and abroad, and can be used in geodetic measuring, coordinate system retaining and surveying and mapping of city. However, some issues (stability of base stations, influence of survey precision on horizontal and vertical extension, et al) are still unsolved in Surface Movement Deformation Monitoring in Mining Areas. Based on the CORS, a method and flow for data processing and stability analysis of deformation monitoring network was proposed. Using rank defect free network adjustment, a robust estimation with minimum of first order norm of displacement component was offered to determine displacement of relative stability. The strategy can resolve the confirmation of robust iterative weights and the effects of different reference models. Displacement significance was tested with the normality method. Finally, according to this method , datum of GPS deformation monitoring in Mining Areas in Datong were calculated and preliminarily proved that this method was feasible and effective, providing a new monitoring methodologies terrain monitoring in mining areas.

Keywords: CORS (Continuous Operation Reference System), deformation monitoring, rank defect network adjustment, robust estimation, hypothesis test

1 Introduction

Coal is the major energy source for China. As the main province of coal resources reserve and production, Shanxi province owns a long history on it. Such a large-scale mining, for one hand, can bring huge economic benefits and create great wealth for the country. However, on the other hand, large-scale underground mining will cause ground deformation and ground settlement, which will affect people’s life in mining areas, and produce a serious threat to the safety of people's lives and property. So effective surface movement deformation monitoring is particularly necessary [1].

In a long time, the traditional methods and techniques for mining surface movement monitoring remained unchanged. The traditional methods, such as triangulation measurement and levelling, are still widely used. The weaknesses are also obvious. For example, 1) needs more time and costs; 2) greatly restricted by topography, climate and other external factors; 3) data delay. It is not the real-time response to the information, less efficient [2].

The emergence of GPS solves the defects of traditional measuring method. It is less affected by visibility; topography, climate and other external constraints, and its precision completely meet the requirements. However, there are still some problems with GPS observations: 1) for static GPS observation, there must be at least two known control points within the scope of survey area. Without known monitoring area, GPS survey is obviously unable to meet the requirements of deformation monitoring; 2) if the baseline length of static GPS observations is too long; the precision will be greatly reduced. For a certain working face, surface monitoring of GPS can meet the requirement, but to a wider regional monitoring, the GPS measurement becomes stretched [3, 8].

Continuously Operating Reference Service (CORS) can be defined as one or several fixed, continuously operating GPS reference station, using modern computer data communication network of LANWAN technology and the internet. CORS can automatically provide different types of GPS observations (such as carrier phase and pseudo-range), corrections, and the state Information of GPS and other relevant Service Projects of GPS to users with different needs and different levels in real time [4].

CORS, which is a revolutionary change of GPS technology, is the orientation of the development of GPS in the future. It not only has the advantages of GPS static measurement, but also perfectly resolved the lack of GPS [5]. First of all, it does not need the scene of known points, fixed reference stations which are more than dozens of kilometres or even hundreds of kilometres far away. This has greatly relieved constraints when designing and make arrangements of observation points. It can better reflect the ground deformation situation. Secondly, the length of baseline is not need to be considered as long as observation points are taken within CORS covered region at any time. In general, CORS reference stations are more than dozens of kilometres or even hundreds of kilometres, which can fully cover the

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whole range of mining areas [6]. So, no matter where the monitoring of both working face of surface monitoring and a wider regional monitoring can be taken under CORS. Currently in China, CORS has been applied in domestic construction, urban planning, land surveying and mapping, and many other fields. And it has already achieved fruitful results. However, CORS application in the field of mining surface movement monitoring is still a blank. Therefore, CORS application in this field has a high research value and practical significance [7]. Based on the Project "Research on surface strata movement law of Tashan mine 8,103 and 8,104 working face surface of Datong Mine area", CORS application in the field of mining surface movement monitoring is studied. There are 4 base stations constructed by 115 Exploration Institute of Shanxi Coal Geology, which formed a CORS System. The distance between the 4 CORS base stations is 40 ~ 100 km, entirely covering the Tashan mine. Studied results indicate that the monitoring accuracy of CORS is completely meeting the monitoring requirements and bringing practical guiding significance for the future of mining surface movement monitoring [9].

2 Establish monitoring network

Due to mining working face covered by the fourth loess. The terrain is so complicated, and topography are characterized in huangtuliang, plateau and hilly. Based on Tashan mine, when the arrangement of surface movement observation station, we should arrange observation line according to the terrain and landform flexible. Trend line of observation arrange in line with the central line of the ground surface over the 8104 working face. Tendency direction of observation line along the tendency direction of 8103, 8104 working face was layout as a broken line on the plain ground. The details of the arrangement are as follows:

There are two observations line in this program. One of them is a trend line expressed as Z. The length of Z trend observation line is 2,175m, separation distance of the observation point is 25m, the distance between observation point and control point is 50 m respectively and the number of observation station is totally 89, including 3 control points. The tendency line Q represents the observation line: The length of Q observation is 1,356m, separation distance of the observation point is 25m, the distance between observation point and control point is 50m respectively and the number of observation station is totally 59, including 6 control points. The length of the trend observation lines and the tendency observation line is totally 5,041m and a total of 143 points. The distance between observation point and control point is 50m respectively and there are a total of 9 control points [15].

Observation point layout schematic diagram is shown in Figure 1.

3 Analytical methods and processes based on Datong CROS land subsidence monitoring network

For high precision GPS monitoring network, in order to obtain better results of the analysis, in addition to the reasonable and correct calculation strategy of the baseline, the choice of benchmark is critical. These benchmarks include the position reference, the scale reference, orientation and time evolution and so on [9]. Stability deformation analysis should be based on a unified, appropriate benchmarks to correctly distinguish between variables and system errors. Therefore, the observation data of GPS monitoring network can be treated scientifically, the study and evaluation method of analysing the stability of data, which is not only the need of theoretical research, but also the practical application.

Tashan surface mine subsidence network stability analysis methods and procedures are as follows: 1) with high precision processing software, choose the right baseline processing strategy to solve the baseline; 2) take the centre of gravity of the monitoring points as a benchmark for rank-defect free net adjustment, get the coordinates of the monitoring points every period and the factor matrix; 3) according to the displacement of two phase calculations and the factor matrix, the displacements of a norm as the minimum robust estimation method to determine the relative stability of the displacement, to obtain the optimum stability of the monitoring array and displacement; 4) construct statistics, then conduct significance test to monitoring displacement, determine the possible instability point; 5) according to each phase of testing the stability of the datum, the use of quasi-stable adjustment calculate the amount of displacement [16, 17].

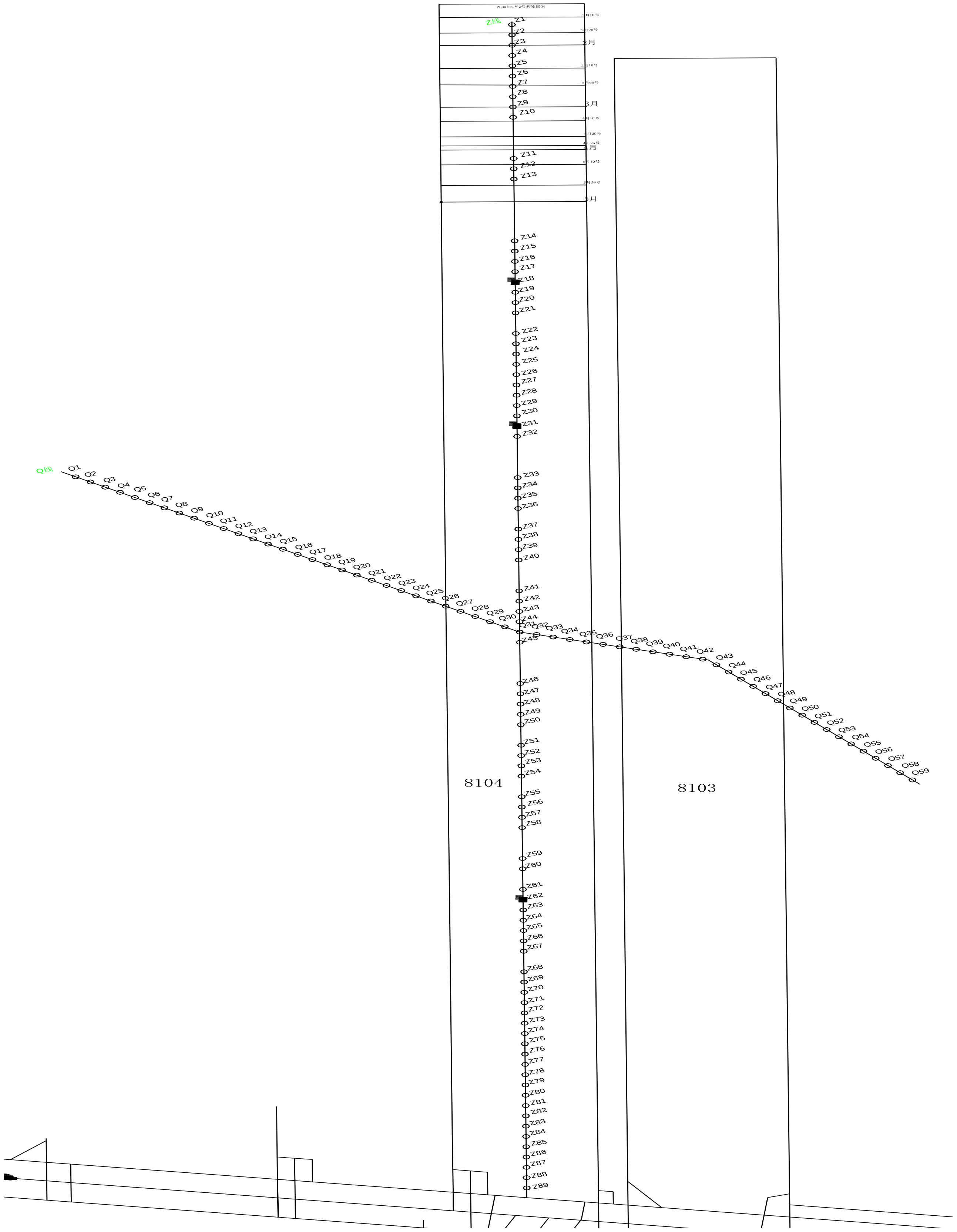

FIGURE 1 Observation station layout

4 Model construction and Baseline processing

GAMIT software which is developed by the Massachusetts Institute of Technology and IGS precise ephemeris are used in baseline solution. In baseline processing should consider the earth tide, tidal and polar motion correction; Satellite high Angle is 15°; Combine dual-frequency ionospheres LC as the basic observation; Use Saastamoinen model and parameter estimation to decrease troposphere error, and estimate a gradient troposphere per hour, deal with the daily time relaxation solution as the basic results every day. Baseline accuracy showed that daily coordinates solver accuracy in the north-south direction is 1~3mm, 2~4mm in the east-west direction; elevation accuracy is 8~10mm [10-12].

When processing baseline, double differential observations model is used. Get information of the baseline vector and the variance-covariance matrix with the method of the global combined net. If there are two observation station T1 and T2, the synchronous satellites SJ and SK where SJ is the reference satellite, then the double differential observation function can be expressed as:

$$\nabla\Delta\Phi^k(t) = -\frac{1}{\lambda}\left[\nabla l_2^k(t) \quad \nabla m_2^k(t) \quad \nabla n_2^k(t)\right]\begin{bmatrix}\delta X_2\\ \delta Y_2\\ \delta Z_2\end{bmatrix} - \nabla\Delta N^k + \frac{1}{\lambda}\left[\rho_{20}^k(t) - \rho_1^k(t) - \rho_{20}^j(t) + \rho_1^j(t)\right], \tag{1}$$

where $\nabla\Delta N^k$ can be written as:

$$\nabla\Delta N^k = \Delta N^k - \Delta N^J . \tag{2}$$

And the vector $\left[\nabla l_2^k(t) \quad \nabla m_2^k(t) \quad \nabla n_2^k(t)\right]$ can be expressed as:

$$\begin{bmatrix}\nabla l_2^k(t)\\ \nabla m_2^k(t)\\ \nabla n_2^k(t)\end{bmatrix} = \begin{bmatrix}l_2^k(t) - l_2^j(t)\\ m_2^k(t) - m_2^k(t)\\ n_2^k(t) - n_2^j(t)\end{bmatrix}. \tag{3}$$

If $\nabla\Delta l^k(t)$ can be expressed as:

$$\nabla\Delta l^k(t) = \nabla\Delta\varphi^k(t) - \frac{1}{\lambda}\left[\rho_{20}^k(t) - \rho_1^k(t) - \rho_{20}^j(t) + \rho_1^j(t)\right]. \tag{4}$$

Then the error equation can be express as:

$$v^k(t) = \frac{1}{\lambda}\left[\nabla l_2^k(t) \quad \nabla m_2^k(t) \quad \nabla n_2^k(t)\right]\begin{bmatrix}\delta X_2\\ \delta Y_2\\ \delta Z_2\end{bmatrix} + \nabla\Delta N^k - \nabla\Delta l^k(t)10 . \tag{5}$$

If the number of the synchronous satellite is n^J, the number of the epoch is n_t. Then write out $(n^J - 1)\times n_t$ error equations. The relative error equation can be expressed as:

$$V = \begin{pmatrix}A & B\end{pmatrix}\begin{bmatrix}\delta X_2\\ \nabla\Delta N\end{bmatrix} + L . \tag{6}$$

Therefore, the corresponding normal equation and the solution can be written as:

$$N\cdot\Delta Y + U = 0 , \tag{7}$$

$$\Delta Y = -N^{-1}U , \tag{8}$$

where ΔY, N and U can be expressed as:

$$\Delta Y = \begin{pmatrix}\delta X_2 & \nabla\Delta N\end{pmatrix}^T , \tag{9}$$

$$N = \begin{pmatrix}A & B\end{pmatrix}^T P \begin{pmatrix}A & B\end{pmatrix}, \tag{10}$$

$$U = \begin{pmatrix}A & B\end{pmatrix}^T PL , \tag{11}$$

where P is the weight matrix of the double differential observation.

Finally when the number of the satellite of the two observation stations is n^J, and the number of the epoch is n_t, the corresponding weight matrix can be written as:

$$P_{\nabla\Delta\phi}(T) = \frac{1}{2\sigma^2}\frac{1}{n^J}\begin{bmatrix}n^J-1 & -1 & \cdots & -1\\ -1 & n^J-1 & \cdots & -1\\ \vdots & \vdots & \ddots & \vdots\\ -1 & -1 & \cdots & n^J-1\end{bmatrix}. \tag{12}$$

5 Instance study

According to the aforementioned method and steps, carry out rank defect free network adjustment on the two monitoring networks. After six iterations, to get the most reasonable displacement of monitoring point and its stability weight matrix [13, 14]. In the N, E and U direction, stable iteration weight matrix is a 27 × 27 order diagonal matrix, its final iteration results are as follows:

ω = diag(0.5010 0.6024 0.0655 0.3818 0.074 7
0.0477 0.4587 1.0000 0.2693 0.7692
0.9231 0.4975 0.134 2 0.4219 0.0478
0.3425 0.2710 0.1720 0.2688 0.9929
0.1958 0.4651 0.5558 0.1575 0.2747
1.0000 0.746 3)27×27

Considering the needs of CORS monitoring data analysis, four points Z78, Z79, Z80, Z81 which are good for the levelling surveying were surveyed under third order levelling while CORS monitoring conducted over the same stage. After error distribution, the maximum levelling closure error W3 of the 6 stage is 5.7mm, the minimum W1 is 3.5mm. Both of them were less than the tolerance requirements of the closure error of third order levelling $\pm 4\sqrt{n}$ = 13.9mm. It is shown that the results of levelling measurement are qualified and it can be used to compare the observation data of CORS.

Comparison curve diagrams of each stage are shown in Figures 2-5.

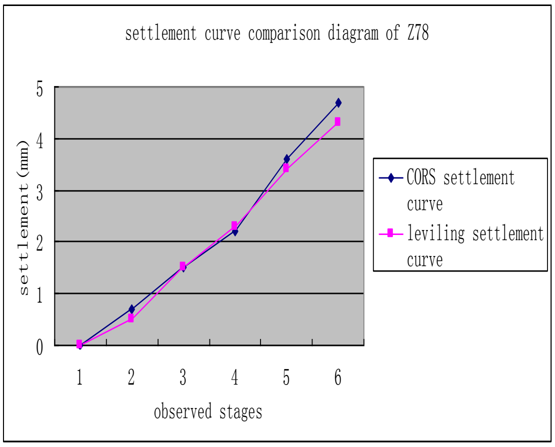

FIGURE 2 Settlement curve comparison diagram of Z78

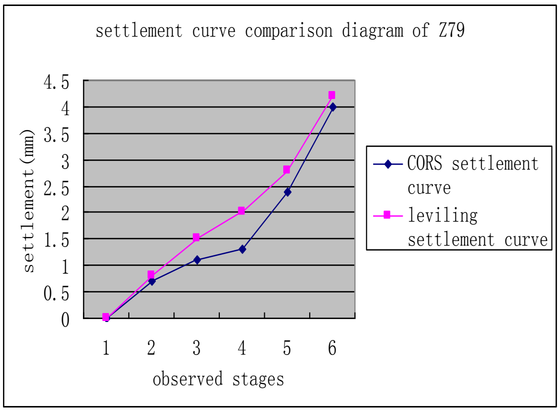

FIGURE 3 Settlement curve comparison diagram of Z79

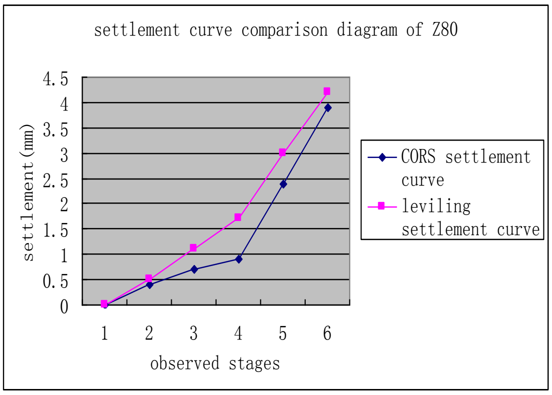

FIGURE 4 Settlement curve comparison diagram of Z80

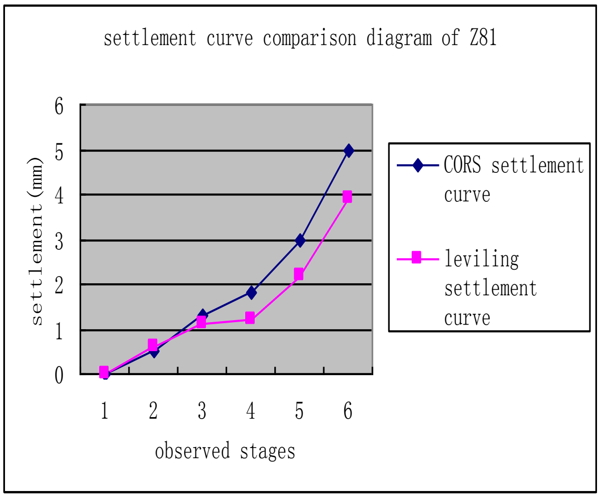

FIGURE 5 Settlement curve comparison diagram of Z81

Comparison of settlement curves between static GPS measurement under CORS and third order levelling surveying showed that the maximum difference between them is 1.3mm, the minimum is 0mm. From the curves, it can be seen that the two settlement curve agree with each other generally.

TABLE 1 Height Difference table of some observed points both by CORS and levelling

	Height Difference of stage 1/m		
point	**CORS**	**levelling**	**CORS- levelling**
Z78	6.8069	6.81	-0.0031
Z79	3.7111	3.7105	0.0006
Z80	1.0352	1.041	-0.0058
Z81	-1.1805	-1.1915	0.011
	Height Difference of stage 2 /m		
point	**CORS**	**levelling**	**CORS-Levelling**
Z78	6.8069	6.811	-0.0041
Z79	3.7113	3.7105	0.0006
Z80	1.0351	1.039	-0.0039
Z81	-1.1807	-1.19	0.0093
	Height Difference of stage 3/m		
point	**CORS**	**levelling**	**CORS- levelling**
Z78	6.8069	6.8135	-0.0066
Z79	3.7114	3.712	-0.0006
Z80	1.0346	1.042	-0.0074
Z81	-1.1807	-1.192	0.0113
	Height Difference of stage 4/m		
point	**CORS**	**levelling**	**CORS- levelling**
Z78	6.8071	6.8125	-0.0054
Z79	3.7114	3.7115	-0.0001
Z80	1.0343	1.04	-0.0057
Z81	-1.1809	-1.191	0.0101
	Height Difference of stage 5/m		
point	**CORS**	**levelling**	**CORS- levelling**
Z78	6.807	6.8115	-0.0045
Z79	3.7111	3.711	0.0001
Z80	1.0345	1.0425	-0.008
Z81	-1.1811	-1.1915	0.0104
	Height Difference of stage 6/m		
point	**CORS**	**levelling**	**CORS- levelling**
Z78	6.8073	6.812	-0.0047
Z79	3.7112	3.7115	-0.0003
Z80	1.034	1.0415	-0.0075
Z81	-1.1802	-1.1905	0.0103

The above tables are the differences of the height of the observation station using CORS measurement method compared with the levelling surveying at the same time. It is not difficult to see from the table that the maximum height error of the two methods is -11.3mm, the minimum is 0.1mm. And height error of the most of the points in all 6 observation stages is within ±10mm, height errors of some points in several stages are less than 1mm.

Height error diagram between CORS and levelling is shown in Figure 6 below.

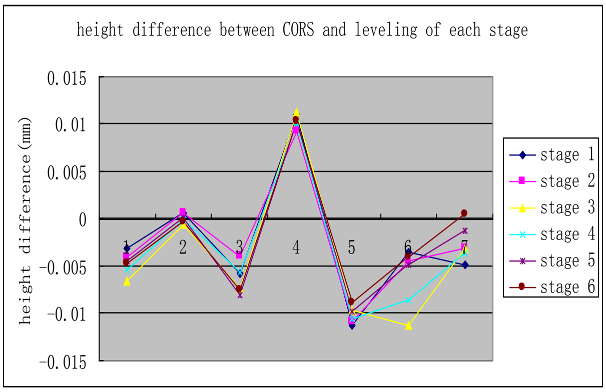

FIGURE 6 Height difference between CORS and levelling of each stage

From the above comparison and analysis, it can be seen that the height observation by CORS and by levelling surveying method is more or less the same, and the trends of changes are also corresponding. Therefore, it can be thought that statistic GPS height observation under CORS can substitute the levelling method. In addition, through the internal fitting accuracy, it can be seen that the accuracy of X, Y is better than H. So it is believed that the accuracy of CORS observations in X, Y, H direction can meet the requirements of ground deformation completely. Finally, we can conclude that CORS can fully meet the accuracy requirements, and because of its advantages of the high accuracy and there is no need to know the known control points, CORS monitoring can replace conventional methods of measuring ground deformation monitoring [18].

6 Conclusions

As mining subsidence problem has increasingly become a popular concern, the ground movement and deformation monitoring has been attracted more and more attention. Strata and surface movement caused by mining process is very complicated, it is caused from geological conditions, hydrology, mining field, topographical conditions and other factors. Therefore, the most effective, reliable and directive method is field observation for conducting mining surface movement deformation monitoring.

The emergence of CORS is a combined product of computer, data communication, Internet technology, and it is the trend of the development of GPS in the future. CORS has been applied in domestic construction, urban planning, land surveying and mapping, and many other fields, and it has already achieved fruitful results. Meanwhile, advantages of high precision and long baseline make CORS for mining deformation monitoring.

Through actual data, it can be proved that the precision of CORS observation can fully meet the requirements of the mining surface movement deformation monitoring. It is a fast and efficient method for ground movement and deformation monitoring of mining area.

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