Study on 2G Technique and Method for Landslide Monitoring

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Key words: 2G technique and method; landslide monitoring; Georobot; polar coordinate method ; differential correction method

SUMMARY

The landslide monitoring has being paid to much academic attention by researchers in the world wide; and lots of monitoring technique has been advanced. Each monitoring technique has its own advantages, disadvantages and the application range. This paper puts forward a new way for landslide monitoring, viz. 2G technique and method (the combination and integration of GPS and Georobot), which has less been applied for landslide monitoring in China and other countries, and there are some applications of landslide monitoring with GPS or Georobot solely in these areas. The 2G technique and method has the advantages of GPS and Georobot, such as setting up datum point with GPS and monitoring deformation points with Georobot, and then the deformation monitoring network may be simplified or not be set up. This paper discusses and studies several key technologies, such as the theory of polar coordinate measurement and its precision analysis, the method of interpolated meteorological correction, the method of differential correction etc., used in the process of from the scheme design to the implementation of landslide monitoring with 2G technique and method. And the reliability and effectivity of the application of 2G technique and method for landslide monitoring is validated by testing and application. Finally, it points out that the discussion and study about 2G technique and method in this paper have important instructional significance and application perspective for the deformation monitoring of other projects.

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1 PROPOSITION OF THE QUESTION

Landslide monitoring is a overlapping and comprehensive science referring to the integrated approach of geology, geomatics, mechanics, mathematics, physics, hydrometeorology [2]. It provides reliable data and a scientific basis for gaining knowledge of and mastering the evolutionary process of landslides, catching the characteristic information of collapses and landslides in time and making a correct analysis, evaluation, prediction and control of landslides[1,2]. Thanks to the characteristics of landslide hazard, such as temporal-paroxysmic, spatial-randomicity, phyletic-variety, conditional-terribleness, sequential-ponderance, the technologies and methods of landslide monitoring must have the corresponding characteristics of rapidity, flexibility, veracity and integration etc.

What is meant by 2G technique and method? Corresponding to 3S, it's the combination and integration of GPS (Global Positioning System) and Georobot. It's the modern technique and method for landslide deformation monitoring. It has not been applied for landslide monitoring in China and other countries, and there are only a few applications of landslide monitoring with GPS or Georobot solely in these areas. For example, GPS technique has been used for the periodic monitoring in the representative landslide of Three Gorge area by the model of static positioning, GPS multi-antenna continuous-dynamic technique and method has been successfully applied for landslide monitoring of Manwan hydropower station. There are also respectable cases of landslide monitoring with Georobot. However, how to being according to the actual requirements for landslide monitoring, combining Georobot and GPS, studying systematically and deeply the 2G technique and method from the layout of landslide deformation monitoring network, landslide dynamic deformation monitoring to monitoring data processing, all of which are very important issues for landslide monitoring. Therefore, taken Jinpingzi landslide of Wudongde hydropower station and the representative landslide (viz. Yemaomian and Huanglashi) of Three Gorge area as research target, a series of resolutions, adapting to our national conditions, are given. Proved by experimentation and application, the resolutions are automatic highly, precise (up to millimeter-order), reliable, flexible, economical and easy taking, which have also instructional significance and application perspective for the deformation monitoring of other projects.

2 RESEARCH RESULTS

1）According to the inner reliability of observations and the theory of precision matching

between sides and angles, the software about the optimization design of control network is developed. As far as the landslide monitoring network concerned, it should be designed for the terrestrial network, GPS network or combination network (GPS and high precise distance measurements with EDM) on what conditions, which is given in this paper.
2) The software system of landslide deformation automatic monitoring and data processing with Georobot (called as Georobot_Net) is developed. Firstly, Georobot is used for automatic observation of landslide monitoring network, then the automatic correction of the observations is processed automatically with the help of the software Georobot_Net, if combined with the adjustment software of network, the elementary deformation analysis of monitoring network can be made. Supposing the monitoring network is designed for GPS network, additional terrestrial sides should be surveyed for checking, which are regarded as observations for combining adjustment. Detailed comparisons between the terrestrial network and GPS network are made in this paper.
3) The software system of landslide deformation automatic monitoring using Georobot (called as Geo_DAMOS) is developed. The polar coordinate measurement of automatic monitoring with Georobot, the method of differential correction and the method of interpolated meteorological correction are mainly studied. The strategies and methods about up to millimeter-level precision (viz.0-9 millimeter) of landslide dynamic monitoring using Georobot are put forward. Two types (continuous monitoring and periodic monitoring) of landslide monitoring with Georobot are discussed. For continuous monitoring, the surveying data and the results of deformation analysis can be transferred to central processing station by lineate or wireless communication, which can realize non-attended continuous monitoring and alert ant non-person working in the status of danger. Compared with GPS technique, using Georobot for deformation monitoring of landslide area, the advantages are more monitoring points and more rapid, the disadvantages are requiring inter-visibility among monitoring points, being more influenced by the outer conditions(such as being unable for observation in rain or fog) , the precision dropping down when distance increasing, etc..

3 THEORY OF LANDSLIDE MONITORING NETWORK LAYOUT

3.1 Layout of landslide monitoring network

Deformation monitoring network can be designed for the terrestrial network with terrestrial surveying technique, GPS network with spatial surveying technique and combination network with both GPS and terrestrial surveying technique. It can be taken for the base point network.
As far as landslide deformation monitoring network (viz. base network) as concerned, the monitoring points are situated in the landslide body and there are many headspace obstacles, thus it’s very difficult for the sole GPS monitoring network to have high precision results,

although baselines can be calculated by the way of postponing the GPS observation time. Therefore, the landslide deformation monitoring network should be designed for what type according to the characteristics of GPS technique, precision of receiver, the characteristics and precision of Georobot.

When the average side of landslide deformation monitoring base network is less than 1500 m, it's better to design for terrestrial network and be observed with Georobot. While for large landslide and having good headspace condition, and when the average side of network is over 1500 m, it's better to design for GPS network, or the combination network of GPS network as the main part and measuring terrestrial side as the auxiliary one.

As far as the landslide body deformation monitoring network (viz. pass point network) concerned, it may also be set up with Georobot and GPS technique. Base points and monitoring points may be observed simultaneously or dividually. Generally speaking, the pass point network has more measuring cycles, sometimes requires dynamic monitoring, in this case, it's best to be observed by Georobot.

3.2 Theory of precision matching between side and angle

Theory of precision matching between side and angle is that side measurement is relevant to lengthways error, while angle measurement is relevant to transverse one, both are nearly relevant to side. Assuming MSE of orientation denoted $m_r^{"}$, the fixed error and the proportional error denoted respectively a and b , side denoted S, then,

The transverse error m_q caused by MSE of orientation is:

$$m_q = \frac{m_r^{"}}{\rho^{"}} S \qquad (1)$$

The lengthways error m_L caused by MSE of side length is:

$$m_L = \sqrt{a^2 + (bs)^2} \qquad (2)$$

Whether precision between side and angle is matched or not with the ratio $K = m_q : m_L$ of transverse error to lengthways one. It's absolutely matched when $K = 1$. It's impossible for precision between side and angle absolutely matched because of the variational side lengths. We think that it's basically matched when k change the range from 0.5 to 2. The above studied is called of theory of precision matching between side and angle of terrestrial network.

If the intelligent Georobot TCA2003 (nominal angle accuracy of 0.5", nominal distance

accuracy of $1mm + 1ppm \cdot S$) from Leica company is applied for observation. According to different value of K, the corresponding side length is calculated, and listed in Tab.1. And the analyzed results are shown in Fig.1. As shown in Tab.1 and Fig.1, for Georobot TCA2003, precision between side and angle is basically matched when the side length is less than 1500 m and more than 200 m and the value of K is less than 2.0 and more than 0.5; both the transverse and lengthways error are smaller than 1.0 mm and have very high precision when the side length is less than 200 m; when he side length is more than 1500 m, the transverse error coming from angle measurement turns evidently larger, thus in this case , side is only required measuring and angle may not be measured.
Therefore, theory of precision matching between side and angle should be considered when monitoring network is designed. If the landslide deformation monitoring network is observed with Georobot TCA2003, it's required to consider not only the location of network point but also the side length among network points, it's best for the longest side length to be less than 1500m.

Tab 1.The analysis results of theory of precision matching between side and angle

Value of K	0.5	1	2
Distance(m)	210	450	1460

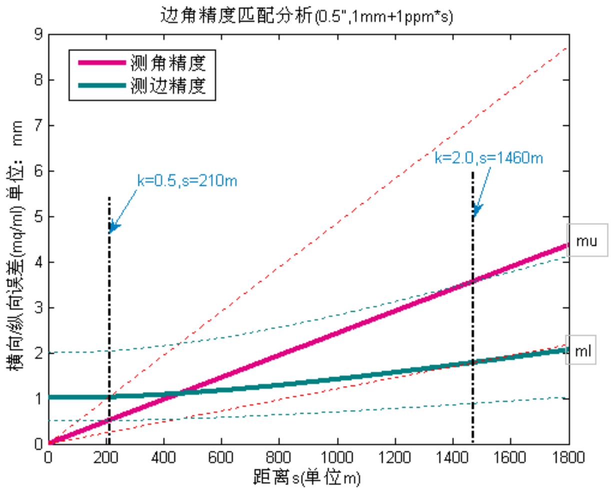

Fig 1. The analysis results of theory of matching between side and angle

4 GEOROBOT TECHNIQUE AND METHOD

4.1 Polar coordinate method and its precision analysis

The Georobot polar coordinate measurement system is composed of Georobot, cooperative target (viz. prism), computer and software. It's shown as Fig.2. Georobot is put on the base station, which is generally the point of monitoring network, is base point, regarded as the origin of polar coordinate. Base points (totally 3-4), usually being also the points of monitoring network, should be located in the steady places outside of the deformation area. They are built not only for direction, but also for the differential correction of distance and level difference. The target points are commonly set up in the deformation body equably. The prisms, sighting base station, should be deposited in both base points and target points. The computer may be placed in the base station. While the monitoring software, installed in the computer, controls Georobot by communication cable. Provided that it needs long non-attended monitoring, the special observation house must be built nearby the base station

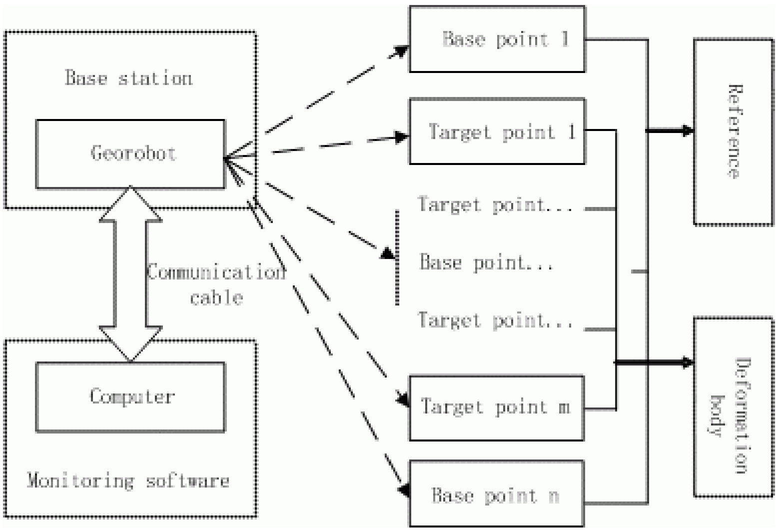

Fig.2 Frame of the Deformation Monitoring System Based on Georobot

As shown in Fig.3, regarding base station O as origin, the plumb line direction as Z axis, the direction of orientation as X axis, thus the left-hand rectangular coordinate O-XYZ is set up. Supposed the observations of monitoring point P are respectively horizontal angleβ,vertical angle α, inclined distance S, then the coordinates of point P in this reference are:

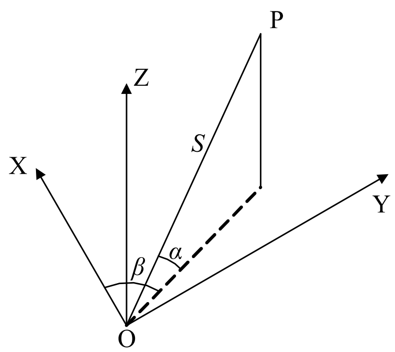

Fig.3 Sketch Map of Polar Coordinate Measurement System

$$\begin{cases} x = S\cos\alpha\cos\beta \\ y = S\cos\alpha\sin\beta \\ z = S\sin\alpha \end{cases} \quad (3)$$

The coordinates in the reference of base points can be calculated by coordinate transformation when two or more base points are observed with Georobot.

Making derivations of horizontal angle β, vertical angle α, inclined distance S in the formula(1), and letting the horizontal distance D as D=Scosα, then we can get:

$$\begin{cases} d_x = \frac{x}{S}d_S - \frac{y}{\rho''}d_\beta - \frac{xz}{D\rho''}d_\alpha \\ d_x = \frac{y}{S}d_S + \frac{x}{\rho''}d_\beta - \frac{yz}{D\rho''}d_\alpha \\ d_z = \frac{z}{S}d_S + \frac{D}{\rho''}d_\alpha \end{cases} \quad (4)$$

The mean square error (MSE) of three-dimensional coordinates is expressed by with matrix form：

$$\begin{pmatrix} m_x^2 \\ m_y^2 \\ m_z^2 \end{pmatrix} = \begin{pmatrix} (\frac{x}{S})^2 & (\frac{y}{\rho''})^2 & (\frac{xz}{D\rho''})^2 \\ (\frac{y}{S})^2 & (\frac{x}{\rho''})^2 & (\frac{yz}{D\rho''})^2 \\ (\frac{z}{S})^2 & 0 & (\frac{D}{\rho''})^2 \end{pmatrix} \begin{pmatrix} m_S^2 \\ m_\beta^2 \\ m_\alpha^2 \end{pmatrix} \quad (5)$$

Then, the MSE of point P is：

$$m_P = \pm\sqrt{m_x^2 + m_y^2 + m_z^2} = \pm\sqrt{m_S^2 + (\frac{D}{\rho''})^2 m_\beta^2 + (\frac{S}{\rho''})^2 m_\alpha^2} \quad (6)$$

The plane MSE point P is：

$$m_{P_{平}} = \pm\sqrt{m_x^2 + m_y^2} = \pm\sqrt{\frac{D^2}{S^2}m_S^2 + (\frac{D}{\rho''})^2 m_\beta^2 + (\frac{S^2 - D^2}{\rho''^2})m_\alpha^2} \quad (7)$$

The elevation MSE point P is：

$$m_{P_{高}} = \pm\sqrt{m_z^2} = \pm\sqrt{\sin_\alpha^2 m_S^2 + (\frac{D}{\rho''})^2 m_\alpha^2} \quad (8)$$

If the landslide deformation monitoring is done with the intelligent Georobot TCA2003 (nominal angle accuracy of 0.5”, nominal distance accuracy of $1mm + 1ppm \cdot S$) from Leica company, then the precision analysis results are shown in Tab.2.

Tab.2 Precision analysis results of Georobot polar coordinate measurement

Inclined distance(m)	the MSE of point P (mm)	the plane MSE point P (mm)	the elevation MSE point P (mm)			
			$\alpha = 0°$	$\alpha = 10°$	$\alpha = 20°$	$\alpha = 30°$
100	1.1	1.0	0.2	0.3	0.4	0.6
…	…	…	…	…	…	…
500	2.0	1.6	1.2	1.2	1.3	1.3
…	…	…	…	…	…	…
1000	3.6	2.7	2.4	2.4	2.5	2.5
…	…	…	…	…	…	…
1500	5.3	3.9	3.6	3.6	3.7	3.7
…	…	…	…	…	…	…
2000	7.0	5.1	4.8	4.9	4.9	5.0

From the precision analysis results of Tab.2, we can know that it can be up to millimeter-level precision within the distance of 2000m using the above-mentioned Georobot, and it can meet the precision requirements of most landslide monitoring. Considering the meteorological, topographic influence and others, the measuring distance is suitable for 1500m or less.

4.2 Differential correction method

Considering the base points and station points for direction are stable and unchangeable (their movements can be confirmed by the periodic monitoring of network or GPS), the observations of horizontal angle, vertical angle, inclined distance may be changing thanks to the influence from the meteorological change and the movement of zero direction of horizontal circle. Therefore, it proper dada processing method must be given for correcting the systematic error, due to outer factors. Differential correction is a method of using base point data for correcting the observations of monitoring points. It will be discussed as following.

4.2.1 Differential correction of horizontal angle

Differential correction of horizontal angle can weaken the influence of atmosphere refraction and the movement of zero direction of horizontal circle. The horizontal angles of the base points in measuring cycle j (j=1, 2,$\cdots$, m, m is the times of measuring) are taken for base azimuth. The horizontal angles of n (n is the count of base points, generally n =1or 2) base points are respectively denoted as $Hz_{ij}\,(i=1,2,\cdots,n)$ in this measuring cycle, and those are respectively denoted as $Hz_{ik}\,(i=1,2,\cdots,n)$ in the measuring cycle k at the same measurement station. Then the correction value δ of horizontal angles between measuring cycle k between measuring cycle j is as follows:

$$\delta = \frac{\sum_{i=1}^{n}(Hz_{ij} - Hz_{ik})}{n} \qquad (9)$$

Afterwards, the horizontal angle of each deformation point P in measuring cycle k (denoted as $Hz_P^{'}$) plus the correction value δ is the final horizontal angle (denoted as Hz_P) after the differential correction of horizontal angle.

$$Hz_P = Hz_P^{'} + \delta \qquad (10)$$

4.2.2 Differential correction of inclined distance

The meteorological correction is up to 10 ppm when the temperature has changed 10.0^{o} C. Therefore, the influence of distance measuring caused by the meteorological change can't be ignored. It's required that the thermometer and barometer should be placed on each measuring station and target point for getting meteorological data. But in most case, it's not economical. Considering the measuring station point and base points are steady, the change of inclined distances from measuring station point to base points among different measuring cycles can be regarded as the influence of outer conditional and meteorological change. The working of measuring meteorological data may not be done if the differential correction of the inclined distances from measuring station point to base points has been calculated based on this change of inclined distances.

The inclined distance from measuring station point to n base points is respectively denoted as d_{i1} (i=1,2,…,n)in the first measuring cycle, while those in measuring cycle k is denoted as d_{ik} (i=1,2,…,n). Then the proportional coefficient Δd of meteorological correction is calculated as follows.

$$\Delta d = \frac{\sum_{i=1}^{n}\frac{d_{i1} - d_{ik}}{d_{ik}}}{n} \qquad (11)$$

If the inclined distance of monitoring point P is $d_p^{'}$ in measuring cycle k, then the inclined distance d_p after differential correction is:

$$d_p = (1+\Delta d)d_p^{'} \qquad (12)$$

4.2.3 Differential correction of elevation difference

In the polar coordinate measurement, differential correction of elevation difference is made to decrease the influence of elevation difference caused by the effect of earth curvature and refraction. The elevation difference from measuring station point to n base points is respectively denoted as h_{i1} (i=1,2,…,n)in the first measuring cycle, while those in measuring cycle k is denoted as h_{ik} (i=1,2,…,n). Under the Condition of steady measuring station and base points, the correction value *c* of the effect of earth curvature and refraction is as follows.

$$\begin{cases} c_i = \dfrac{h_{i1} - h_{ik}}{(d_{ik} \cdot \cos\alpha_{i1})^2} \\ c = \dfrac{\sum_{i=1}^{n} c_i}{n} \end{cases} \qquad (13)$$

Thereinto: α_{i1} is the vertical angle of base point *i* in the first measuring cycle, d_{ik} is the inclined distance of base point *i* in the measuring cycle *k*. After calculating the correction value *c*, the differential correction formula of trigonometric elevation difference between monitoring point *P* and measuring station point is expressed:

$$h_{pk} = d_{pk} \cdot \sin\alpha_{pk} + c \cdot (d_{pk} \cdot \cos\alpha_{pk})^2 \qquad (14)$$

In above formula, α_{pk} and d_{pk} are respectively the vertical angle and inclined distance of monitoring point *P* in the measuring cycle *k*.

After differential correction of inclined distance and elevation difference, the inclined distance is denoted as d_p, the elevation difference is denoted as h_p, and then the calculation formula of horizontal distance D_p is:

$$D_p = \sqrt{d_P^2 + h_P^2} \qquad (15)$$

4.3 Method of interpolated meteorological correction

Firstly, several representative monitoring points and base points, such as located in the margin or center of measuring area, are selected, then the thermometer and barometer are placed on them and the meteorological information (such as temperature, air pressure) is written when measured. That is the method of interpolated meteorological correction. In inner data processing, the temperature and air pressure values of each monitoring point or base point are interpolated. Then, the following formula is used for meteorological correction.

$$\Delta D = 285.92 - (\frac{0.29065 \times P}{1 + \alpha \times t} - \frac{4.126 \times 10^{-4} \times h}{1 + \alpha \times t} \times 10^{x}) \qquad (16)$$

Thereinto: ΔD is the meteorological proportional coefficient (unit 10^{-6}); P is the value of air pressure (unit is mb); t is dry temperature (unit is ºC), h is relative humidity (unit is %, generally h=60); α is the coefficient of atmospheric expansion (α=1/273.16); $x = \frac{7.5 \times t}{237.3 + t} + 0.7857$.

If the measured inclined distance of monitoring point is D, then the final inclined distance D' after interpolated meteorological correction is:

$$D' = (1 + \Delta D)D \qquad (17)$$

5 LANDSLIDE MONITORING MODE

Landslide monitoring mode has two types: viz. mobile monitoring mode and fixed remote continuous monitoring mode. Following we discuss them in turn.

5.1 Mobile monitoring mode

The same as the general monitoring method, the operation steps of mobile monitoring are: firstly, fix Georobot onto the observation stand of the station and level it, at the same time, put the prisms onto the monitoring point, then, record the station name and doing station settings, after backsight the base point for orientation, according to pre-setting of observation order and number of observations, Georobot will automatically search, track, identify and collimate accurately targets, record observations, calculate all kinds of limit difference values, make the over-limit re-observation or need operation of manual interruption. If observation of all the monitoring points in the landslide deformation body have finished, then the outer measuring work have been over in this measuring cycle. If the next station needs measuring too, then move instruments to the next station and make the same measuring operation. The mobile monitoring mode can save time and manpower, improve the working efficiency and data precision greatly.

5.2 Fixed remote continuous monitoring mode

When the landslide deformation is small, mobile monitoring mode can meet the requirements. But when it's rapid, it's best to adopt the fixed remote continuous monitoring for those important and conditioned landslides. The problems of remote controlling and data communication should be resolved mainly. Remote controlling is controlling Georobot and computer automatically. Communication has lineate and wireless two modes. The fixed remote continuous monitoring system requires that the prisms and Georobot are placed in the measuring locale long. But it's difficult for ordinary landslide to be carried out in our country because the instruments need being cared and protected.

6 BENEFICIAL RESULT ANALYZING

In order to test and check the feasibility and validity of 2G technique and method for landslide monitoring, Jinpingzi landslide of Wudongde hydropower station in Yunnan, China, is selected for testing and practical application. This landslide monitoring network is composed of 15 monitoring points (named from TN01 to TN15), control area is $4.2km^2$, the maximal elevation difference among monitoring points is 830 m, the longest side is 1960 m and the average side is 940 m. Some comparisons and analysis are made between the general monitoring and Georobot monitoring of this landslide network, the results are shown in Tab. 3

Tab 3.The analysis results of comparison of landslide monitoring network

Observation method	general monitoring	Georobot monitoring,
Monitoring equipment & Software	4 T3 theodolites 4 EDM equipments	1 Georobt (Leica TCA 2003) 6-8 prisms Georobot_Net
Personnel collocation	4 technicians 5-8 workers	1-2 technicians 8-10 workers
Outer observation time	about 25 days	about 7-10 days
Inner processing time	5 days	2 days

The deformation monitoring network of this landslide body (district Ⅱ) has 19 points, they are 6 monitoring network points (TN08, TN09, TN12, TN13, TN14 and TN15) , 2 collimating line points and 11 pass points (from TP01 to TP11), among them, TN08, TN12, TN14 and TN14 are referred base points, TN09 and TN13 are the base points and measuring station points. Some comparisons and analysis are made between the general deformation monitoring and Georobot deformation monitoring of this landslide body, the results are shown in Tab. 4

Tab 4.The analysis results of comparison of landslide body deformation monitoring

Observation method	general monitoring	Georobot monitoring,
Monitoring equipment & Software	4 T3 theodolites 4 EDM equipments	1 Georobt (Leica TCA 2003) 6-8 prisms Geo_DAMOS
Personnel collocation	4 technicians 5-8 workers	1-2 technicians 8-10 workers
Outer observation time	about 8-10 days	about 2-3 hours
Inner processing time	3 days	half a day

According to the analysis results of comparison in Tab.3 and Tab.4, whether it's landslide monitoring network (viz. the base network) or whether it's the landslide body deformation monitoring network (viz. pass point network), compared with the general monitoring method, monitoring landslide with Georobot can not only save much manpower and resources, but also greatly shorten working time and improve the working efficiency. Especially for the pass point network, the deformation info of monitoring point can be obtained in time with Georobot.

7 CONCLUSIONS

Most landslides are situated in the steep mountains, difficult to pass through, the general monitoring method cost more time, manpower and money, and it's difficult to get the deformation information in time when landslide deformation is expedite. Therefore, 2G technique and method for landslide monitoring is put forward. This paper discusses and studies several key technologies, such as the theory of polar coordinate measurement and its precision analysis, the method of interpolated meteorological correction, the method of differential correction etc.. And the reliability and effectivity of the application of 2G technique and method for landslide monitoring is validated by testing and application. The discussion and study about 2G technique and method in this paper have important instructional significance and application perspective for the deformation monitoring of other projects.

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BIOGRAPHICAL NOTES

Zhenglu Zhang, professor, Ph.D supervisor. He is concentrated on the research and education in precision engineering geodesy, deformation monitoring analysis and forecast, measurement data processing and engineering geo-information system. He has made contribution in the areas of automatic measurement system, the application of measurement robot, GPS and special instrument with multi-sensors.

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