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GPS in the tailings dam deformation monitoring

Wei Li[a,*], Chang Wang[b] a*

[a]University of Science and Technology Liaoning Resource and Civil Engineering Academy, Anshan, Liaoning ,114051,China

[b]University of Science and Technology Liaoning Resource and Civil Engineering Academy, Anshan, Liaoning , 114051,China

Abstract

Following the introduction of tailing dam deformation monitoring technology, this article describes its specific implementation measures and precision requirements. Deformation monitoring technology methods, the advantages of GPS technology in tailing dam deformation monitoring, GPS technology is not only more effective than other methods in tailing dam deformation monitoring, but also its cost is lower. Finally, it analyses the feasibility and advantages of using GPS technology in the dam deformation monitoring by engineering practice.

Keywords: Tailings dam, Deformation Monitoring, GPS Technology, Photogrammetry Method, 3D laser technique

1. Introduction

In recent years, with China's economy developing rapidly, the national economy increases progressively by about 10% per year. With the impetus of the high-speed economic development, the industry of primary raw materials such as steel, nonferrous metals and cement expands rapidly. Meanwhile, with the rapid development of mining industry on exploiting metal and non-metal, security problems on production and environmental of the tailings dam are becoming protruding. Especially, in the downstream of the tailings dam are populated areas, cities and towns, and large factories and enterprises. Therefore, the security problem of the tailings dam needs more attention. According to characteristics and distribution status of China's tailings dam, the problem on how to improve

* Corresponding author. Email: wangchang324@163.com

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management security level is an important problem faced by the whole society. The practice and promotion of monitor system carried out step by step on metal and non-metal mine can largely improve our cognitive level, security supervision and daily management level of disaster mechanism. What's more, it can also increase the disaster warning prediction power of enterprises、society and government of the tailings dam disaster, as well as establish synthetical judgment on more convenient security procedure management and dam-break of risk control. For magnitude quantity and wide spatial distribution in China, there are widely market prospect and important application value on the study of safety monitoring system of the tailings dam on metal and non-metal mine.

2. A brief introduction of deformation monitoring technology

2.1 Static deformation monitoring methods

2.1.1Photoelectric monitoring technology.

Photoelectric monitoring technology is a method that determines deformation by measuring the angle,side length and change of elevation with conventional measuring instrument (theodolite,range finder,level,total station),which is the primary method of monitoring deformation now. The common ground monitoring methods contain forward intersection of two direction (three direction), bilateral distance intersection method, polar coordinates method, collimating line, small angle, geometric leveling and precise trigonometric leveling method, etc. Angle intersection method and distance intersection method can monitor two-dimensional(X,Y direction) displacement of deformable body; collimating line method, small angle method and ranging method can observe level unidirectional displacement of deformable body; geometric leveling method and precise trigonometric leveling method can observe vertical displacement of deformable body.

2.1.2 Mechanical deformation measurement.

(1) Mechanical quasi-linear

To some deformation monitoring objects, because of its unique structure, special testing equipment can play an important role in forms of monitoring deformation, such as the measurement of Mechanical alignment, used in the main deformation of the dam, can determine relative change of dam according to the point on a quasi-linear, which can be horizontal or vertical. Because of the small corridor airflow influence of the dam, material of quasi-linear can be wire or nylon that is refractive-proof.

(2) Static leveling

Working principle of static leveling is using liquid to achieve the balance of the liquid surface of each vessel by passing connected devices. It measures vertical distances respectively from datum point to liquid level and observation point to liquid level, of which the difference is the height difference of those two points.

Static leveling is suitable for dam corridor or the basement of one building where geometric leveling is different to measure.

2.1.3 High precision GPS deformation measurement

GPS precision positioning technology, compared with classical measurement, not only can meet precision requirement(within±1mm) of dam deformation monitoring ,but also help to realize automation of monitoring work. For instance, in order to monitor the dam deformation, technician select a GPS

CORS and a number of monitoring points in deformation area far from appropriate position of dam,. In the base station and monitor station , technician install GPS receiver respectively which carry out continuous automatic observation. By using proper data transmission technology, monitoring data is real-time transferred to data processing center to carrying out treatment ,analysis and prediction of observation data

The precision of the horizontal displacement and vertical displacement, obtained by using precision broadcast ephemeris and 6～8 hours dual-frequency GPS observations, is better than 1.0 mm. Applied in building monitoring, GPS technology can not only be free from limitation under the intervisibility and climate conditions, which carry out all-weather monitoring in heavy fog and snowstorm conditions ,but also can collect transmite and manage data, analysis deformation and automatically forecast. So it can reach the purpose of remote online network real-time monitoring. Besides, GPS can still carry out dynamic deformation monitoring and export the result of real-time positioning according to10～20Hz frequency.

Baseline vectors, produced by GPS relative positioning, can obtain high precision geodetic altitude by survey adjustment. As the vital observation here is the relative settlement during vertical displacement monitoring. We could, without conversion, directly use geodetic altitude system, which will not only simplify calculating work, but also ensure precision of observation results.

2.2 Dynamic deformation monitoring methods

2.1.1 Photogrammetry methods

Measuring engineering structure deformation by Photogrammetry methods is to play a camera or video camera on some selected stable positions around deformable body and photograph. Then, displacement can be obtained by comparing the two-dimensional coordinates or three-dimensional coordinates at different time of monitoring point .

2.2.2 3D laser technique

(1)3D laser scanning

3D laser technique is a high technology invited in the mid twentieth century, which also is a new breakthrough in surveying and mapping technology after GPS position system. Besides, getting large-area-high resolution three-dimensional coordinates data from the surface of the object by high speed laser scanning measurement method, it can quickly collect a lot of space point information and provide a new technical means for establishing the object three-dimensional dynamic model .

(2) 3D optical scanning

3D optical scanning system projects grates fringe to object surface and gets fringe and color image with digital camera. After advanced, unique three-dimensional image processing and high speed, sophisticated treatment on fringe image, it can calculate every pixel corresponding points space coordinate(X,Y,Z) and color data(R,G,B)，and eventually generate three-dimensional color digital image.

2.2.2 Real-time dynamic GPS methods

With the improvement of GPS hardware and software, GPS dynamic monitoring system has been applied to various engineering structure, especially in bridge detection. The bridge GPS dynamic monitoring system generally includes GPS receiver and relevant fitting, such as fiber data transmission network, data sensing collection and classification, computer data control, etc. The main features of the system is omnidirectional displaying real-time bridge structure. When vehicle passing bridge, monitoring system can get progressive main span vertical tilt, deck deflection, bridge side position and overhead migration. In the traditional way, it can only get relative displacement or local displacement from the point measurement accelerator data. However, straightly surveying three-dimensional of bridge structure comes true by GPS.

3. Selection of deformation monitoring methods

At Present, methods commonly used in deformation, monitoring include geodetic method, special measurement means(containing various alignment measurement, inclinometer measurement, liquid static leveling system and strain gauge measurement), phtotgrammetry methods (containing close range photography and terrestrial stereo photogrammetry), GPS measurement, TCA surveying robot, 3D scanning, etc. All kinds of monitoring methods have different precision and adaptability. Table 1 enumerates some common monitoring methods, instrumentation and precision situation, and conduct analysis and comparison.

Table1 Common monitoring methods,instrument comparison

methods	instruments	precision	application evaluation
general geodesy method	total station level, Theodolite, rangefinder	Meet the requirements of different accuracy	Great flexibility, suitable for different structural building，the effect of terrain view and climatic conditions is the disadvantage, it is difficult to achieve automatic monitoring.
special measurement means	mechanical displacement meter	Dial indicator precision 0.01mm，dial gauge precision 0.01mm	High precision, the process of the measurement is simple. continuous monitoring and automatic observation is easy to realize, it can provide local observation information, but flexibility is inferior to routine measurement.
	displacement sensor	Can be achieved 0.01mm	
	goniometer	Accuracy is related to distant，highest to 1mm	Can measure deflection of building, tilt of high building, foundation settlement
	alignment measurement	General accuracy 10^{-5}～10^{-6}	It can measure the horizontal displacement of building, high precision. it is easy to automate, but flexibility is inferior to routine measurement.
Photogrammetry methods	photographic theodolite	Accuracy can be achieved mm level	observation precision is low, and it sometimes can not meet the requirement. Each monitoring point is asynchrony, it is related to the shape and size of precision building, it is limited to natural disasters and geographical condition
	digital camera		

TCA surveying robot	1mm+1×10^{-6}	It can measure settlement, displacement and tilt of building, it is easy to automation. but monitoring point is not asynchrony, and it is affected by climate, it can not monitor the whole day, the equipment cost is higher.
3D scanning	1～5mm	High precision, measurement process is quick, comprehensive, it need not place large of monitoring point, dynamic and automated monitoring is easy to realize; it gets the information of internal structure of the hidden points which is difficult is disadvantage, equipment cost is higher
GPS static(1—2 hour)	Flat Accuracy 1mm, Vertical Accuracy 1.5mm	It can monitor the whole day, simple operation, high automation, high precision，location speed is slow which is disadvantage
GPS—RTK way	Flat Accuracy can be achieved 10+1×10^{-6}mm, vertical Accuracy can be achieved 20+1×10^{-6}mm	It can monitoring the whole day, simple operation, high automation, location speed is quick, plane precision is high, vertical precision is low which is disadvantage.

At present, GPS has been widely applied to the production of mine surveying for its low price, and its precision totally meet the requirement of deformation monitoring. Therefore, more and more departments use it to carry out tailing dam deformation monitoring.

4. Application example in terms of GPS tailing dam deformation monitoring

A concentrator tailing dam is an earth dam which was built in 1985. Its bottom elevation length of dam is 58.5 1.5Km. Till November 18, 2007, 34 times routine measurements of dam displacement had been made, GPS deformation monitoring started in 2008.

4.1GPS deformation monitoring network design

(1) point diagram of observation point and datum point

6

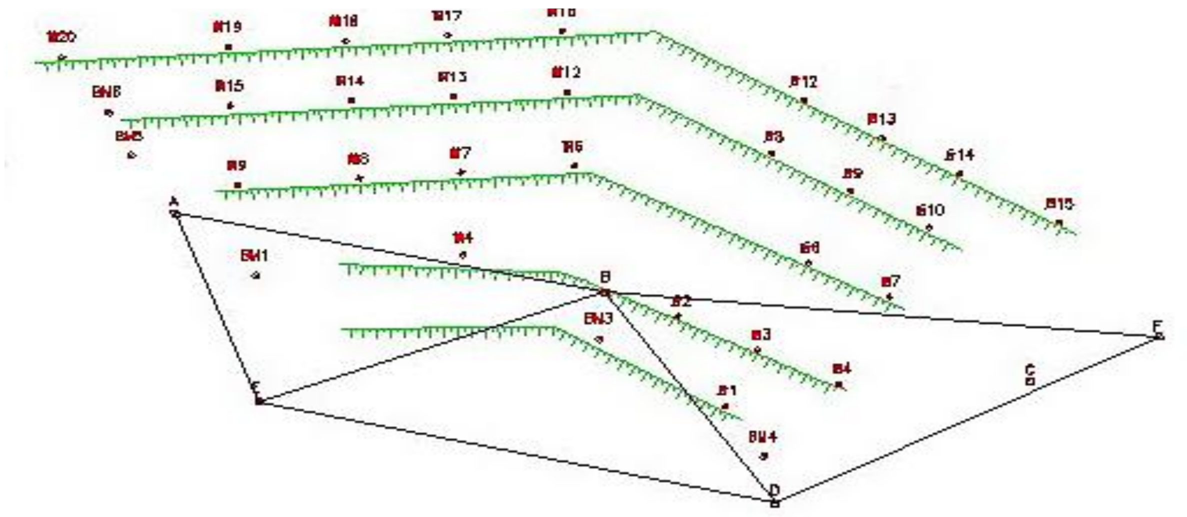

Fig. 1 Point diagram of observation point and datum point

(2) Network thumbnail of GPS deformation monitoring

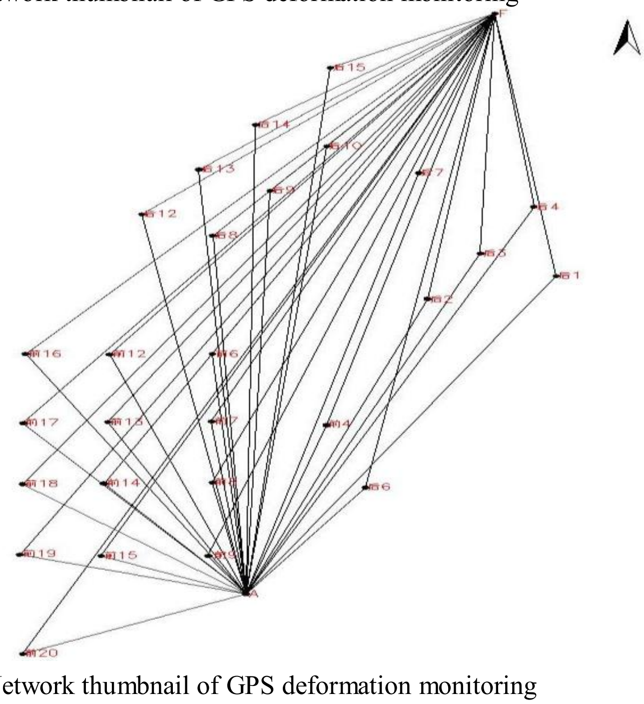

Fig.2 Network thumbnail of GPS deformation monitoring

4.2 Deformation monitoring scheme design

(1) Selection of equipment.

According to the requirement of the project, selection of equipment are double frequency binary static GPS receiver GB500 and PG-A1GPS zero phase antenna of Topcon company, precision is 3mm＋0.5ppm. Because straight-line distance of the whole dam is less than 2km, baseline precision can ensure overall accuracy in less than 4mm, which meet the overall requirement 5mm. Meanwhile, because of the largest height difference of the dam monitoring area achieves 60m, the effect on number of satellites in some individual points is very large. In order to ensure enough satellites which carry out static observation and point well-distributed, must use binary system which use American GPS system and Russia GLONASS system, the overall number is 18 more satellites than single star system.

(2) Selection of reference points.

Selection and Construction of reference points ensure the whole deformation monitoring system perfectly in the future. Therefore, perfection of that selection and construction of reference point must be ensured. We select A and F that have short distance to monitoring point as reference point in deformation monitoring network and they must guarantee foundation contact rock and long-term stability.

(3) Selection of monitoring points.

Selection of monitoring points need requirement as follows. Try to ensure that monitoring points can receive enough satellites. the choice of the main points must be arrange for GPS antenna and prism.

Reference select point notes:

1) Observing pier uses the centering equipment by force so that the precision of leveling can not affect observation results.

2) Make sure to use GPS zero phase antenna, can use chock-ring antenna in individual severe occlusion locals.

3) Try to ensure there is no influence above 10 degrees elevation angle over the observation point.

4) There is not strong electromagnetic interference around observation points.

A continuous observation time of an observation period should be more than 1～2 hours, and in all observation periods the number of satellites(elevation angle is greater than 15 degrees) which can be observed is less than 5

For data from short baseline collection, we can apply the broadcast-ephemeris to them and handle them by pinnacle software

(4) Observation process

① Determination initial baseline observation

Initial observation of six reference points takes a sampling rate of 5 seconds, observation time is two hours, calculate by pinnacle software, the standard data of initial calculation ensure that baseline, synchronizer ring and induction loop pass.

② Initial data observation

GPS observes all the monitoring points, calculate Initial data. A continuous observation time of an observation period should be more than 1～2 hours, and in all observation periods the number of satellites(height angle is greater than 15 degrees)which can be observed is less than 5.

③Compare each next observation with its pre-observation result, and determine the changed situation of tailings dam. Save and analyze each observation, and can analyze by the software of data analysis.

(5) Measurement method.

Six sets of GPS conduct static observation, six sets of GPS receiver have made enforcement convert unit, observation points set up enforcement convert unit, greatly reduces human error.

Fig.3 Enforcement convert unit

Each monitoring process is the same, the specific operation process is:

GPS01 was placed in a point, GPS02 was placed in F point. Stationary, GPS03, GPS04, GPS05 and GPS06 installed in the monitoring point, fix GPS03, GPS04, GPS05, GPS06 on all monitoring points and then orderly measure the statistic data in the form of closed loop synchronization in 1h along with GPS01, GPS02 receiver, according to GPS01, GPS02 point three-dimensional coordinates (X_{01}, Y_{01}, H_{01}) and (X_{02}, Y_{02}, H_{02}) ,and can calculate the three-dimensional coordinates (Xi, Yi, Hi) of monitoring point.

(5) Data processing.

According to GPS01, GPS02 point three dimensional coordinates (X_{01}, Y_{01}, H_{01}) and (X_{02}, Y_{02}, H_{02}), and calculate the three dimensional coordinates (X_i, Y_i, H_i) of monitoring point.

Assuming there are two three dimensional coordinates (X_i, Y_i, H_i) and (X'_i, Y'_i, H'_i) at the same monitoring point, the three dimensional deformation of monitoring point is:

$$\Delta X = X'_i - X_i$$
$$\Delta Y = Y'_i - Y_i \quad (1)$$
$$\Delta H = H'_i - H_i$$

In addition, because of the tailings dam deformation monitoring are high precision engineering measurement, we use simultaneous observation method for improving high precision observation results.

4.3 Statistics and analysis of various stages observation result (the April 2008 observation result as an example)

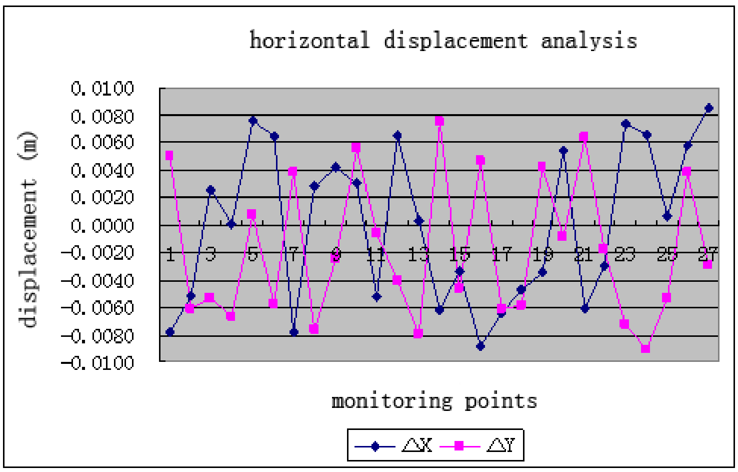

Fig.4 Level displacement analysis map

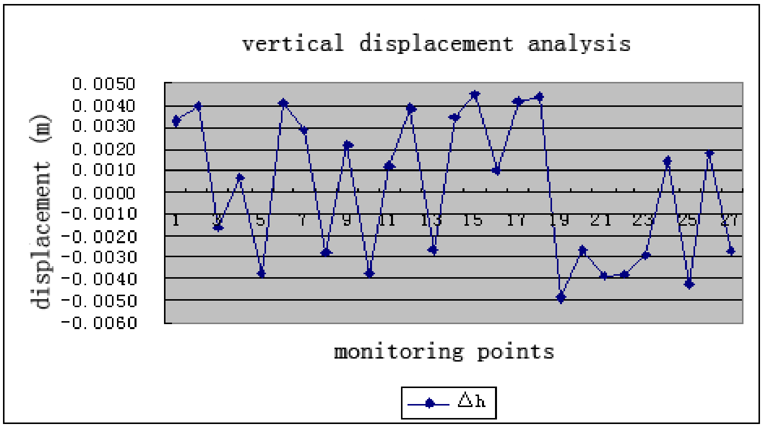

Fig.5 Vertical displacement analysis map

Statistical analysis: the largest horizontal displacement is *0.0091*m, and the largest vertical displacement is *0.0048*m, and they meet the limited error requirement.

5.Conclusions

CPS observe 27 monitoring points many times on the tailing dam, and use Pinnacle software to calculate observation data. Then, Count and analyze those observing data calculated by Pinnacle software. From statistical analysis of several observation, the largest horizontal displacement is 9.6mm, the largest vertical displacement is 4.9mm, the displacement of monitoring points meet the limited error requirement. Therefore, the following conclusions can be obtained

(1) Displacement of monitoring points was far lower than limited error, the change of monitoring sites is uniform;

(2) Operation of the tailing dam is stable, do not send out warning signal;

Practice proves that precision of tailing dam displacement monitoring with GPS is very high, compared with traditional measurement methods, GPS has several advantages as follows:

① No intervisibility between stations, when GPS observing , the wide upper sky above station is needed, and can receive satellites. Do not require intervisibility between station. Thus, the choice of occupied station become more flexible, and can completely set up point position according to work needs.

② High positioning accuracy, application practice show that GPS observation data have better both horizontal (relative to reference point, following the same)and vertical precision than 1.5mm by broadcast ephemeris in 1-2 hours, vertical precision was better than1.5mm.

③ Short observation time. With the continuous improvement of GPS system, data processing software are up to date, the time of observation is greatly shorten. Therefore, establishing control networks with GPS technology can greatly improve efficiency.

④Provide three-dimensional coordinates, GPS measurement can not only accurately determine plane position of measurement station, but also determine geodetic of measurement station in the same time.

⑤ Operation the whole day. The number of GPS satellites is large, and the distribution is uniform. It can observe at any time in 24 hours, and not be affected by the bad weather.

⑥ High automation degree. With the improvement of GPS devices, automation degree of GPS measurement is becoming higher and higher. Monitoring work can achieve fully automated, and establish monitoring system which needs no person to guard. It greatly reduces the manual burden, and improves production efficiency.

⑦ Low cost. Experiments show that the fee of tailing dam displacement monitoring by GPS is just 1/3-1/6 of the conventional method, which is advanced to its wide use

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