GPS AUTOMATIC MONITORING SYSTEM FOR OUTSIDE DEFORMATION OF GEHEYAN DAM ON THE QINGJIANG RIVER

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ABSTRACT In this paper, the background of developing GPS Automatic Monitoring System for outside deformation of Geheyuan Dam is described concisely. The framework, precision and features of the system are stated in detail. Finally, the prospective application of the system is introduced.

1 Introduction

Located at the upper reaches of the Qingjiang River, Hubei Province, China, Geheyuan Hydropower Station is an important amplitude modulation and frequency modulation power station of central China electricity net, and it is one of the three stave-exploited hydropower stations in China, with the total capacity of 1.2 million kilowatt and an output of 3.04 billion kilowatt-hour electricity annually. It is extremely significant that the establishment of the station ensures the safe and stable running of the electricity net in central China, eliminates the flood disaster in the middle and lower reaches of the Qingjiang River, avoids the meeting of Qingjiang flood peaks with Yangtze flood peak so as to relieve pressure of preventing and controlling flood of Jingjiang reaches and lower reaches of the Yangtze river, dredges the sea-route of the Qingjiang River so as to provide convenient transportation for the west mountainous area of Hubei Province and to promote resources exploitation and commodity currency, and develops tourism of Qingjiang Valley, etc..

Geheyuan Hydropower Station Dam is a gravity arch dam of three centers of circles and varying sections. The maximum height of the dam is 151 meters, the elevation of the dam crest is 206 meters, and the arc span of the dam crest is 653 meters. The part of the dam, with the elevation of below 150 meters is arch dam, and that with the elevation of above 150 meters is gravity dam. The dam lies in concavity valley of rather complicated topography.

The collection and management of data are mainly manual in the previous security monitoring system, which has the following disadvantages inevitably: 1) The collection of data is slow, the field workload is massive and takes long period of time, all of which make it always prone to leave out crucial signals. 2) The deformations data collected manually from monitoring sites are not synchronous. 3) The deformation monitoring is affected by the environment, which results in the lack of accurate information of deformation during key periods. Under such circumstances, Qingjiang River Water and Electricity Development Limited Company of Hubei Province in collaboration with Wuhan Technical University of Surveying and Mapping tried to develop a new system to replace the former deformation monitoring system.
monitoring system. The new GPS Automatic Deformation Monitoring System aims at implementing round-the-clock, consecutive, and synchronous three-dimensional real-time deformation monitoring, and carrying out the automation of data collection, transmission, processing, analysis, display, storage and warning.

Since September 1995, three stages including Feasibility Argumentation, Technique Design and System Construction have passed. In March 1998, GPS Automatic Monitoring System for Outside Deformation began running. On October 24, 1998, the Expert Committee, including academicians of Chinese Academy of Sciences Dou Guoren, Chen Junyong and Li Deren, organized by Geheyan Hydropower Station and the Science Committee of Hubei Province, evaluated and approved the research project.

2 The framework of GPS automatic monitoring system

GPS Automatic Monitoring System for Outside Deformation of Geheyan Dam consists of three sections: data collection, data transmission, data processing, analysis and management (see Fig. 1).

![Fig. 1 The framework of the system](image)

2.1 Section of data collection

Among all of the GPS receivers, as the datum marks GPS 1 and GPS 2 are placed on both sides of the dam, while GPS 3~GPS 7 are on the top of the dam as the deformation monitoring marks (see Fig. 2).

2.2 Section of data transmission

The framework of data transmission of GPS Automatic Monitoring System for Outside Deformation of Geheyan Dam is as follows (see Fig. 1).

Panel messages of receivers over all the monitoring sites are transmitted to the General Control Room by the industry control computer on the dam by RS-232 multiple serial interface and long-distance communication mode in real time. At the same time, by multi-way switch mode, industry control computer transfers data (observables, ephemeris data and so on) of all the receivers to the server according to the time interval set by the Control Center.

Datum marks are far away from the General Control Room. GPS 1 is 0.6 km away from the General Control Room, while GPS 2 is 1.2 km away, and they are on the opposite sides of the Qingjiang Riv-
er. Because of the limitation of terrain and physiog-
nomy, the paving of fibers or cables is difficult, so 
wireless communication mode is adopted for data 
transmission. Both datum marks adopt the newly-
developed DS amplified-frequency wireless commu-
nication technique so as to improve the capability of 
anti-disturbing.

To improve the performance of the wireless trans-
mission further, HUB in the General Control Room 
adopts high plus, all-direction antenna in order to 
receive data sent by the two datum marks, while on 
the dam oriental antennas are adopted.

When above techniques are applied, all devices of 
the monitoring system are connected integrally. 
The operators can monitor the working status of all 
the real-time monitoring datum marks and with 
GPS receivers on them from the General Control 
Room. Especially the operators can send corre-
responding messages to control all the receivers. 
Workstations and PCs in the General Control Room 
can process and analyze data timely according to the 
time interval set in advance.

2.3 Data processing, analysis and management

The key to the automatic running of the GPS Au-
tomatic Monitoring System for Outside Deforma-
tion of Geheyan Dam is the section of data process-
ing, analysis and management. This section consists 
of four modules: general control, data processing, 
data analysis and database management.

(1) Module of general control

The module of general control is the data ex-
change center of all modules in the system, and it is 
also the main user interface of the system. Its main 
functions are:

(a) To display panel messages of all GPS re-
ceivers on datum marks and monitoring stations, 
and send user’s commands to modify parameters 
(for example, sampling interval, elevation mask, 
time span, etc.).

(b) To send data to the module of processing for 
data processing and analysis, and get results.

(c) To load the database with observations, re-
results of data processing, results of data analysis 
which can be used by the module of database man-
agement.

(2) Module of data processing

The main functions of module of data processing 
are: automatic data processing; judging the reliabil-
ity of the outcome; controlling and processing the 
possible errors in the course of processing; reserving 
outcome and cleaning up data.

(3) Module of deformation analysis

The main functions of the module of deformation 
analysis are: automatic saving and automatic pro-
cessing the data of deformation, which mainly in-
cludes: coordinate transformation, precision analy-
sis, stability analysis of datum marks, deformation 
analysis of monitoring marks, display of the course
line of displacement, time domain analysis, frequency domain analysis.

(4) Module of database management

The data structure used in GPS Automatic Monitoring System for Outside Deformation of Geheyan Dam is relatively complex and the amount of data is enormous. For example, the observation data can reach an amount of 16MB within one day. These data need to be reserved for a long period of time, and they are needed for query at any time. Therefore, it is indispensable to introduce DBMS into our system. The main functions of the module of database management are: data security management, data updating, data querying, automatic data backup, printing report forms, restoration of database.

3 The precision of the system

We assess the system precision by means of the following two modes: the internal consistency and the external consistency.

The internal consistency adopts the precision reckoning formula of adjustment computation to assess the internal precision of the deformation observation given by the GPS automatic monitoring system. It indicates that the accuracy of the deformations data given by the monitoring system can satisfy the precision norms prescribed in technical design and project contract: the horizontal and vertical displacement precision of 6h solutions is superior to 1mm and that of 1h or 2h solutions is superior to 1.5mm.

| Station Name | $m_{x_6}$ | $m_{y_6}$ | $m_p = (m_{x_6}^2 + m_{y_6}^2)^{1/2}$ | $m_h$ |
|-------------|----------|----------|-----------------|-----|
| GPS 5       | 0.38     | 0.31     | 0.49            | 0.73 |
| GPS 6       | 0.38     | 0.31     | 0.49            | 0.74 |
| GPS 7       | 0.39     | 0.32     | 0.50            | 0.75 |

Table 2 The precision of 2h solution of the system/mm

| Station Name | $m_{x_2}$ | $m_{y_2}$ | $m_p = (m_{x_2}^2 + m_{y_2}^2)^{1/2}$ | $m_h$ |
|-------------|----------|----------|-----------------|-----|
| GPS 5       | 0.46     | 0.38     | 0.60            | 1.17 |
| GPS 6       | 0.46     | 0.38     | 0.60            | 1.17 |
| GPS 7       | 0.48     | 0.40     | 0.62            | 1.20 |

To assess the precision of the GPS automatic monitoring system more objectively, the tests to evaluate the external consistency have been conducted. The content of the tests includes:

1) Comparison with the displacement of the micrometer.

2) Comparison with the observations of the automatic plumb-line.

3) Comparison with the observations of the artificial plumb-line during the flood peak of 1998.

4) Comparison with the precise level results during the deluge of 1998.

We have carried out several simultaneous tests during the feasibility research, the technical design of the project, and the purchase of GPS receivers. Comparing with the displacement of the micrometer, the result indicates that the precision of GPS plane displacement is about 0.36 mm in x component and 0.37 mm in y component.

Table 3 The result of simultaneous tests/mm

| SN  | Readings of Micrometers | Displacements of Micrometers | Results of GPS | $\Delta x' = \Delta x - \Delta x' $ | $\Delta y' = \Delta y - \Delta y' $ |
|-----|-------------------------|-------------------------------|---------------|-----------------------------------|-----------------------------------|
| 1   | -22.00                  | 10.00                         | 377 992.8     | 11 060.7                          | -0.5 - 2.6                       |
| 2   | -22.00                  | 7.00                          | 377 992.3     | 11 058.1                          | -0.4 - 0.5                       |
| 3   | -22.00                  | 4.00                          | 377 992.4     | 11 054.2                          | -0.4 - 6.5                       |
| 4   | -22.00                  | 1.00                          | 377 993.1     | 11 051.7                          | 0.3 - 9.0                        |
| 5   | -22.00                  | 13.00                         | 377 992.8     | 11 063.1                          | 0.0 - 2.4                        |
| 6   | -19.00                  | 3.00                          | 377 995.9     | 11 063.6                          | 3.1 - 2.9                        |
| 7   | -16.00                  | 6.00                          | 377 998.7     | 11 064.2                          | 5.9 - 3.5                        |
| 8   | -13.00                  | 9.00                          | 378 001.1     | 11 063.6                          | 8.3 - 2.9                        |
| 9   | -10.00                  | 12.00                         | 377 995.3     | 11 063.4                          | 12.5 - 2.7                       |
| 10  | -30.00                  | 15.00                         | 377 994.7     | 11 066.0                          | -8.1 - 5.3                       |

Note: $n = 9$ $m_{x_6} = \pm 0.36$ mm $m_{y_6} = \pm 0.37$ mm
The radial displacement of the points which are provided by the automatic plumb-line is compared with that of the corresponding points surveyed by the GPS automatic monitoring system in the same period. The result shows that there is no remarkable difference between them. The radial precision of the GPS plane displacement is about 0.78 mm.

| Time | Displacements Provided by the Automatic Plumb-line/mm | Displacements Provided by GPS/mm | Difference /mm |
|------|------------------------------------------------------|--------------------------------|----------------|
| 6~11 | 1.55                                                 | 0.72                           | 0.83           |
| 6~13 | 1.68                                                 | 1.42                           | 0.26           |
| 6~15 | 4.29                                                 | 4.42                           | -0.13          |
| ...  | ...                                                  | ...                            | ...            |
| 7~14 | 1.20                                                 | 0.92                           | 0.28           |
| 7~16 | 0.97                                                 | 0.42                           | 0.55           |
| 7~17 | 1.41                                                 | -0.38                          | 1.79           |

Note: $m_{pr} = \pm 0.78$ mm

The radial displacement of the points which are given by the artificial plumb-line is compared with that of the corresponding points surveyed by the GPS automatic monitoring system in the same period. The result shows that they are consistent with each other fairly well. The radial precision of the GPS plane displacement is about 0.92 mm (We postulate that the observations of the artificial plumb-line are identical with the true value).

During the fourth flood peak of the Yangtze River in 1998, the Geheyan hydropower station organized surveyors to monitor the vertical displacements of the dam with precise geometric leveling method. The results accorded with the corresponding data measured by GPS automatic monitoring system. The precision of the vertical displacement observed by GPS is $\pm 1.02$ mm (We postulate that the observations of the artificial plumb-line are identical with the true value).

The outside precision tests demonstrate that the accuracy of the monitoring result of six hours attains to the accuracy of submillimeter level, and the accuracy of the result of one to two hours is better than 1.5 mm.

4 The characteristics and innovation of the system

1) In this system, GPS positioning technology, for the first time, has been applied to the dam deformation monitoring by establishing the high precise,
all-weather, laborless, real-time monitoring system, which opens up a new domain for the application of GPS technology.

2) GPS data of the key section of the monitoring system adopt the design of redundancy 43%. Backup and hot-backup technology are applied to the key data processing equipment, several kinds of anti-disturb technology and data examining technology are applied to communication net, which assure the high reliability and feasibility of the whole system.

3) The system adopts a series of updated precise GPS data processing technology which makes the monitoring precision of plane and vertical movements attain submillimeter level, and the responding time of the seven GPS receivers less than 10 minutes.

4) Automatic Data Processing Subsystem, Data Analysis Subsystem, Database Subsystem and Monitoring Subsystem, are included in this system. The system is the first GPS automatic monitoring one in China.

5) According to topography and environment of the dam area, the system synthetically adopts data transmitting methods such as wireless microwave and wired fiber to establish the LAN. Virtually, with FTP (File Transmission Protocol), the communication between clients and servers of different operating systems is realized. The application of multiple serial interface communication and multi-way switch and time multiplex technology ensures the real-time, automation and reliability of the system and provide abundant experience to the establishment and popularization of the GPS automatic monitoring network system.

6) The system develops and uses the special field protection equipment of GPS antenna, which is adiabatic, anti-sunburn and anti-anamorphic. The practice provides the assembly of the GPS field deformation monitoring antenna with new technological criteria and working norms in the future.

5 The effects of the system in the super flood of 1998

Geheyan Dam had experienced the trial of the high water level of 1997 and 1998 since the adoption of GPS automatic monitoring system in 1996. During that special period of time, the GPS automatic deformation monitoring system showed its predominant performance very well.

The year 1998 was not a common year. A super flood in the whole valley of the Yangtze River occurred in that year. Not only the posture of the Yangtze River but also that of the Qingjiang River were so austere that flood prevention was a major event concerning our country.

Especially when the fourth and the sixth flood peaks of 1998 emerged in the Yangtze River, Geheyan Dam sluice staggered them, and thus made the water level in the Qingjiang River rise quickly. At the emergent moment, when the water level was higher than that of normal sluice, the GPS Automatic Deformation Monitoring System provided the accurate deformation data of the dam in every 2 hours to the headquarters of flood prevention. According to these data, the decision-makers of the headquarters made their decisions and issued their orders to keep the water level at the possible ultimate height to maintain the water in the Qingjiang River, which had greatly relieved the pressure of preventing and controlling flood along the lower reaches of the Yangtze River and made prominent contribution to the avoidance of Jingjiang flood.

6 Conclusion

The application of GPS technology in dam deformation monitoring has many advantages, which include high speed, complete automation, all-weather ability, the ability to provide the displacement of three dimensions at the same time, etc. Because the precision can satisfy the demand of the norm. This system provides new technical means to right the purpose of the automatic monitoring of outside deformation of the dam.

The system can be widely applied in the safety monitoring of reservoir and dam, large-scale buildings, TV towers, large bridges, large nuclear power stations, coast, diastrophism, and environment, etc. The system not only has prominent social and economic benefit, but also has important application...
and popularization value.

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