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REAL-TIME MONITORING AND EARLY WARNING OF LANDSLIDES AT RELOCATED WUSHAN TOWN, THE THREE GORGE RESERVOIR, CHINA

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Abstract

A total of 4200 landslides have been identified in the Three Gorges Reservoir area. It is planned that a total of 3200 landslides (i.e., 75% of the total number of landslides) will be monitored. Since 2003, the authors have carried out a geo-hazard real-time monitoring and early warning project at relocated Wushan town (Wushan new town) in the Three Gorges Reservoir area. Its purpose is to establish monitoring and early warning demonstration station. The station has three main functions: (1) Internet-based, (2) Comprehensive monitoring, and (3) Early warning. Based on the landslide monitoring experience at the Three Gorges Reservoir area, the early warning critical value at Wushan new town is established and presented in this paper. The critical situation is divided into four levels: I level early warning (indicated as blue), II level early warning (indicated as yellow), III level early warning (indicated as orange), and IV level early warning (indicated as red). Judging from the Yuhuangge landslide monitoring data in this area since 2004, the Wushan new town is at the blue early warning level. However, monitoring data of displacement at deep borehole showed that the displacement increased 5 mm in five months with an average velocity 1.0 mm/month. The velocity is 10 times higher than that at the early deformation stage. For this reason, the early warning level is changed from blue to yellow, which means an accelerated deformation period and emphasizes the need for denser monitoring. Recently, the displacement velocity decreased and became lower than 1.0 mm/month, so the warning level was returned to blue.

Keywords: *Landslide, Three Gorges Reservoir, real-time monitoring, early warning*

1 Introduction

There are 4200 landslides distributed in the Three Gorges Reservoir area of Central China. Among them, 3200 landslides, i.e., 75% of the total, will be monitored. The monitoring has become an important way of avoiding the casualties due to sudden failure of landslide. Since 1999, a monitoring and warning system was gradually established and improved. This system combined mass monitoring with professional technology and covered the whole reservoir area. It has the following three aspects:

1. The monitoring system is based on the comprehensive monitoring and used the field information obtaining technique (CMS-based) as the core. It is mainly constituted with technical monitoring system and local resident inspection and precaution system.
2. The information system is based on the network data analysis and has manage-

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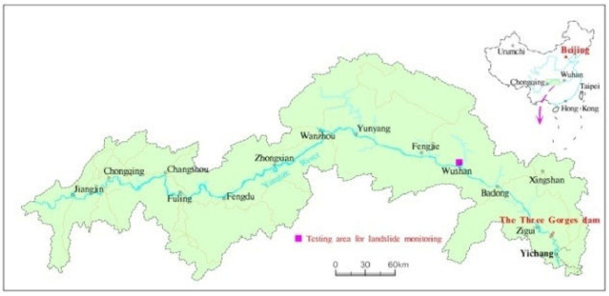

Figure 1: Location map of Wushan testing zone of landslide monitoring

ment function as the core (NET-based). It uses Internet/Intranet, GIS, GPS, Remote Sensing, distributed data processing technology and database technology. It is constituted with many subsystems, such as data acquisition, database management, data analyzing and processing, data exchange, information issue and emergency response.

3. The warning system is based on the GIS and has the disaster prevention and reduction function as the core (GIS-based). It includes 6 subsystems: regional early warning and analyzing system, professional geo-hazard forecasting and early warning system, forecasting system, expert assisting decision-making system, artificial intelligence simulation system and information issuing system.

Because there are dense populations in the reservoir area and geo-hazards may be triggered by a 30 m water level changing during reservoir operation, a real-time monitoring system must be developed. Since 2003, a demonstration station on real-time monitoring and early warning has been established at relocated Wushan town (Figure 1), one of the severest geologic:

1. Internet-based: the real deformation and fracture of the slopes could be known in real-time by visiting websites such as http://www.cgs.gov.cn/ or http://www.wss.org.cn/. The data can be automatically acquired, transmitted by remote wireless lane, and issued to network in real-time.
2. Comprehensive monitoring: a multiple-parameter-monitoring system that could show the slope surface and underground deformation simultaneously has been developed. The new time-domain-reflection (TDR) and piezometer are specially developed to monitor borehole displacement and groundwater seepage.
3. Early warning: a warning criterion under the state of reservoir operation has been set up and modified through lots of case-study.

2 Site conditions

Wushan town is the capital town of Wushan county. It is located at the entrance of the Wu Gorge, the second gorge of the Three Gorges. It is one of the relocated towns in the reservoir area. There are 20 large-scale landslides around the new town. The Yuhuangge landslide is the largest one, on which a large number of buildings and structures have already been relocated and reconstructed. The area of the landslide is one quarter of the whole town (Figure 2).

After the impoundment of the Three Gorges Reservoir, the toe of the landslide was submerged. As a result, the stability change is related with the safety of lives and property of the new town and it will bring enormous damage to the society. The Yuhuangge landslide is located on the bank of Yangtze River, west of the new town (Yin, 2004). Its toe elevation at the general sea level is 130-160 m. Its main scarp elevation is 500-520 m. Its width is 780 m and length is 1500 m. The total volume of the landslide mass is estimated to be 90,000,000 m^3 and its average ground surface gradient is 30°-47°. There are 3 terrances above 250 m elevation and 2 ancient sliding planes (Figure 3). The sliding exit of the lower mass is 130-160m elevation and the sliding exit of the upper mass is 200-230m elevation.

Figure 2: Overview of Yuhuangge landslide, Wushan County, Three Gorges

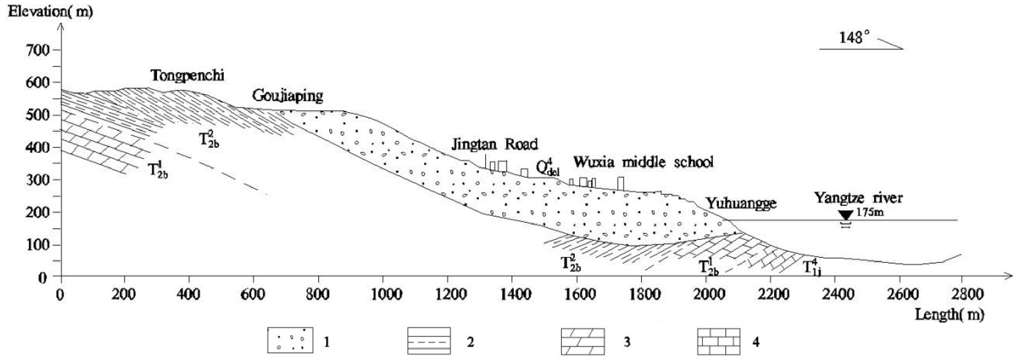

Figure 3: Profile map of Yuhuangge landslide, Wushan county 1. Quaternary landslide deposit; 2. T_2b^2 purple-red mudstone; 3. T_1b^1 argillaceous limestone; 4. T_1j^4 limestone

3 Real time based monitoring network

3.1 Definition and structure of real-time monitoring on landslides

Real-time monitoring (RTM) means that monitoring data is acquired remotely when it is collected; the acquisition process is automatic and requires no technicians on site. Compared with the traditional monitoring methods, RTM is continuous and traceable in the acquisition process. Data acquisition cycle is very short, usually within hours or even shorter. It is very important for early warning to continuously track the landslide displacement process. The management and computation of the quantity of data required hardware and software development.

Remote transmission of data monitoring is another significant feature of real-time monitoring. Normally, the monitoring control center is located at town area with convenient telecommunication, but landslide is usually far from town. The acquired data from landslide has to be “migrated” to the monitoring control center via the public communication network or other media and transferred to the result for purpose of target layer. The migrated processing is called as “remote transmission of monitored data”. Two types of transmission are applied. One is with the wire, such as installing communication cables or optical fiber; the other is without wire, such as using GSM/GPRS or CDMA networks, UHF radio or communication satellites.

Therefore, establishing real-time monitoring systems for landslide movement requires not only choosing reasonable monitoring methods and a design of effective monitoring networks, but also a powerful hardware and software support. These include automatic monitoring instruments, automatic data acquisition instruments, high-efficiency and fast data transmission methods, automatic processing and storing of monitoring data, and monitoring information releasing.

The real-time monitoring system in Wushan demonstration station integrates the following three parts: (a) field station which is located on the landslide, includes monitoring instruments, auxiliary facilities and data acquisition; (b) data transmission system between the landslide and the control center, and (c) data processing and releasing system in the control center (Wang, 2008). There are six field stations and one central station. The stations are connected by GPRS wireless media.

3.2 The Yuhuangge landslide monitoring network

Monitoring methods and instruments

The Yuhuangge landslide is a deep-seated colluvial landslide. Before the reservoir impoundment it was stable, and only a few buildings were on it. It also had some local cracks. The slope stability was decreased because of the rising water table of the reservoir and the irrational slope cutting. In order to determine the displacement at the creep stage, monitoring methods and instruments with high resolution, high reliability, high stability and high automation have been installed (Table 1). It uses (a) GPS with high-accuracy double frequency to monitor ground displacement, (b) time domain reflection technology (TDR) and immobile borehole and inclinometer to monitor deep displacement, (c) piezometer to monitor pore water pressure. It also has precipitation monitoring and reservoir water level monitoring. The instruments were verified suitable for the slope stability monitoring under monitoring reservoir fluctuation. They include groundwater flow, groundwater micro velocity, ground temperature and micro-velocity, fiber optic strain analysis.

Monitoring network layout

The monitoring network consists of the monitoring sites and monitored sections. These were established in order to determine where displacement occurred, its magnitude, rate and trigger factors. There are 3 longitudinal and 3 cross monitoring profiles in the landslide site (Figure 4).

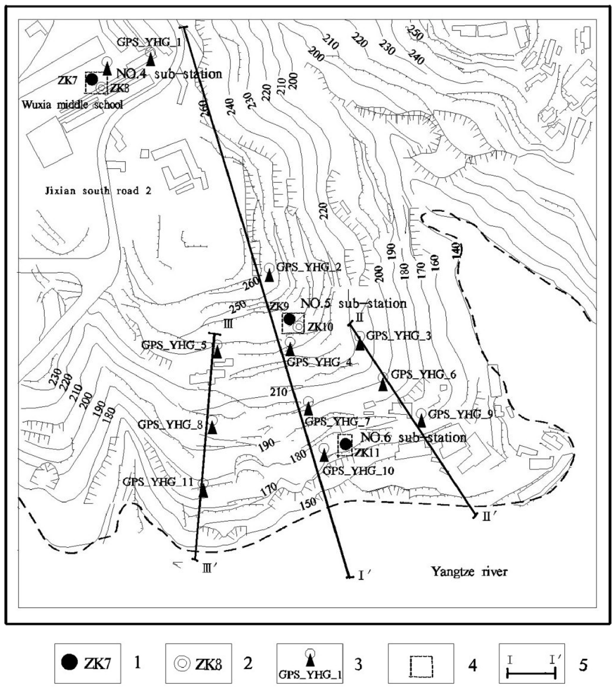

Figure 4: Layout map of Yuhuangge landslide monitoring system Yuhuangge 1.pore water pressure boreholes; 2. deep displacement boreholes; 3. ground displacement points; 4. sub station; 5. profile lines

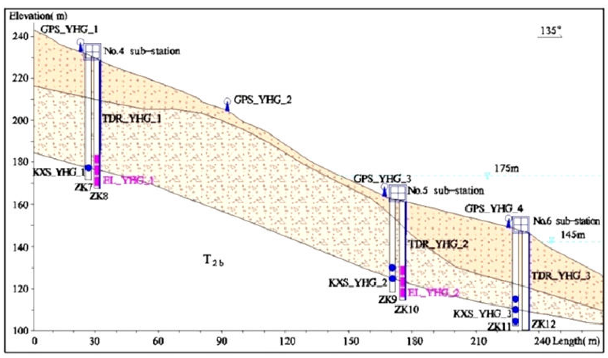

Figure 5: I-I′ section of monitoring system of Yuhuangge landslide

Table 1: List of monitoring methods in Wushan demonstration station

Contents		Methods	Instruments	Parameters	Purposes
Landslide 3D displacement	Ground displacement	GPS	Ashtech UZ CGRS	Ground horizontal and vertical displacement	Knowing the landslide 3D spatial location changing, judging the sliding boundary, sliding distance and direction
	Deep displacement	TDR	TDR monitoring system (designed by itself)	Deep deformation location and deformation amount	Mainly used for judging the amount and depth of landslide sliding surface
		Drilling inclinometer	Sinco-stably drilling inclinometer	Sliding surface horizontal displacement Ground temperature Temperature	Knowing the sliding distance, sliding direction and temperature changing on the landslide sliding surface, mixing environment temperature changing
Water development	Pore water pressure	Pore water pressure monitoring	Pore water pressure monitoring instrument (designed by itself)	Pore water pressure Ground temperature Moisture content (unsaturated) Water level (saturated)	Knowing the degree of saturation in different depth of landslide, water level, pore water pressure, temperature change and the relationship with landslide deformation
	Precipitation	Automatic Rain gauge	Dump type automatic rain gauge	Precipitation Precipitation intensity	Knowing the precipitation in the area, analyzing the relationship between precipitation and groundwater, analyzing the influence of precipitation to landslide deformation
	Reservoir water level	Collection		Yangtze River and Daning River water level	Analyzing landslide deformation dynamic in the condition of reservoir water level drastic and cycle change, analyzing the influence of reservoir water level change to landslide stability
	Landslide ground water flow	Automatic flow meter	Ultrasonic open channel automatic flow meter	Landslide groundwater flow	Analyzing the relationship between groundwater dynamic and landslide deformation
Strain	Landslide bridge strain	BOTDR	BOTDR	Strain along the direction of fiber-optic distribution	Demonstration application, exploring the feasibility and prospect of BOTDR technology using for landslide deformation monitoring

I-I′ monitoring section is the main control section. It is set in the medial axis part of the landslide (Figure 5). It is normal to Yangtze River along the slope. The slope length is 350 m. This section is used to analyze deformation, groundwater and ground temperature at elevations along the landslide as well as to determine landslide trajectory, failure mechanism and stability.

Monitoring central station

The monitoring central station is the kernel of monitoring data processing, analyzing and issuing. The main functions are as follows (Figure 6):

- issuing data acquisition control commands to field stations and receiving data from each field station;
- converting the monitoring data and writing the outcome data into database;
- issuing monitoring data, graph and outcome information on the website to the internet users;
- issuing control commands to field stations and receiving monitoring data from each field station;
- checking, converting and calculating various types of monitoring data automatically and writing the outcomes into underlying database;
- storing various kinds of monitoring data and issuing the data to the homepage;
- providing related information and monitoring data to Internet users and managers.

3.3 Data acquisition and transmission

The data acquisition and transmission system is used for downloading various kinds of monitoring data from each field station and transforming the data to the central station server automatically (Figure 7). The main functions are as follows:

- Data acquisition host computer (Industrial Control Computer) can distribute the instructions to each instrument control computer when it receives data acquisition control commands from center station, order the instruments to collect monitoring data according to the control parameters (acquisition time, acquisition cycle) and store the data to assigned location.
- Data files are named after a certain rule. These contain key information such as station number, monitoring data (instrument) type, acquisition date and time, for identification and processing by the server.
- Transmission and backup of the data files to the server within a designated time or as fast as possible.
- The ability to backup in case of an operation failure.

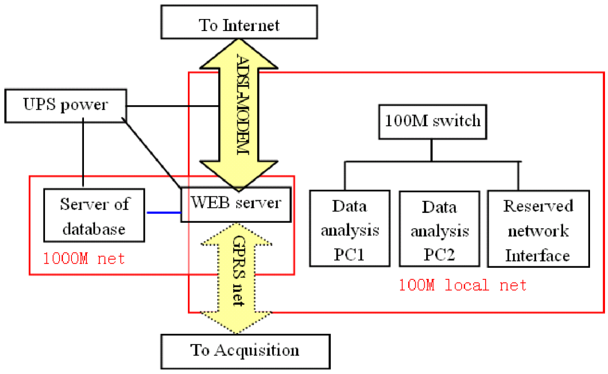

Figure 6: Schematic diagram of hardware devices connection in central station

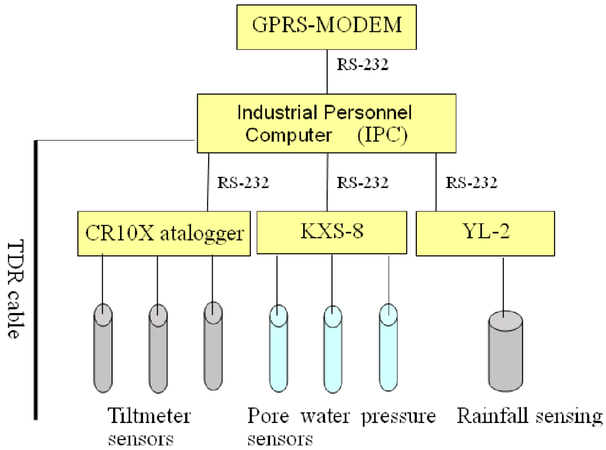

Figure 7: Schematic diagram of data acquisition and transmission hardware connection

4 Information analysis and releasing

4.1 Function and composition

- Managing of various kinds of foundation information and multivariate monitoring data using the database;
- Providing information on the geological environment and information related to work deployment and reporting to Internet users by network;
- Providing the real-time monitoring data (setup password to entrance) and graphical representations of data to Internet users;
- Providing downloading functions for Internet users (setting permission) for raw data, constructing progress reports including photos;
- Providing remote management function to the network managers (setting strict permission) for information uploading, adding, deleting and modifying;

The information reporting system is composed of two parts. These are the demonstration geohazard integrated information system which is based on GIS technology and the homepage. The two parts exchange data by using B/S structure.

4.2 Integrated information system in the system demonstration station for geohazard

The integrated information system in the demonstration station for ge-hazard was developed based on ArcGIS, a powerful tool of geographic information system. It is used for managing demonstration station data that include spatial, data properties, drilling and monitoring data and providing technical support for construction of 3D model, monitoring information comprehensive analyzing and releasing.

4.3 Homepage of real time monitoring real-time

The homepage releases information to users. In order to provide an interactive environment for information release, access modes, management and maintenance, the homepage is divided into four parallel components: a navigation area, a releasing area, a manager's area and a download area (Figure 8).

The navigation area provides necessary guiding information for the remote users, including public information, photos, and related linkage to other professional network. Also, news about the monitoring station and the real time warning issues are included. The manager's area is designed for system managers particularly to remotely manage information such as text, pictures, data and compile information such as adding, modifying, deleting, uploading and downloading. Only system managers can operate it.

The download area allows permitted users to download files related to the monitoring demonstration station, such as monitoring reports, photos, and common software. The reporting area is the core content of the homepage. It provides a query function to search survey results including real time monitoring data real-time and graphical representations of the data.

Real-time monitoring presents graphical presentation of data from all kinds of monitoring methods. For the purpose of convenient access, an inheritable structure of website is designed as follows: landslide—section—benchmark point—time interval—data & graph. At the homepage, a monitored landslide is firstly chosen on the county image/map; secondly, a monitored section is chosen on the monitored landslide; thirdly, benchmark point of monitoring site can be chosen in the section, a time interval over which monitoring was carried out is specified. Graphical display of the section is the presentation of data from all kinds of monitoring displayed with graphical links for easier access (Figure 9). Users can inspect the deformation and displacement for the specified monitoring period and can easily download these graphical files to their personal computers.

Figure 8: Homepage of information issue of the Wushan Demonstration Station

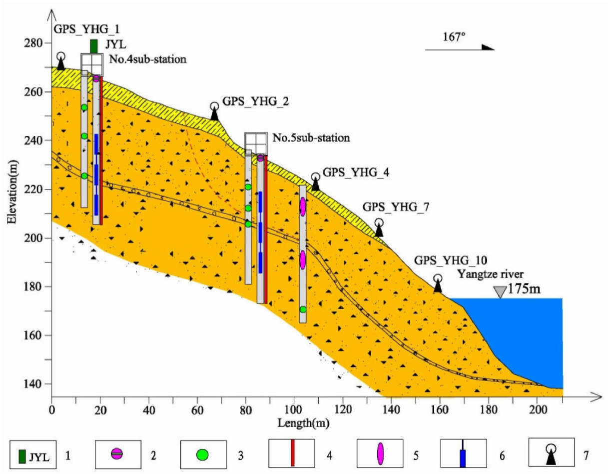

Figure 9: Section of Real-time monitoring location (by what you see is what you get): 1. rainfall; 2. ground temperature; 3. pore water pressure; 4. TDR; 5. water content; 6. deep displacement; 7. GPS

5 Landslide hazard early warning

The real-time monitoring network has been monitored landslide is firstly chosen on the county image/map; next, a monitored section is chosen on established since the May of 2004. Herewith, the results of landslide monitoring and early warning system are discussed.

5.1 Early warning criteria analysis

The criteria of landslide early warning are established based on monitoring data at the Wushan new town and lots of cases of other landslides in the Three Gorges over the years. A four-grade early warning criteria of landslide are defined as follow (Table 2).

I-level early warning (Blue): Safe state, only general inspection and regular monitoring are needed. The information is issued to the group of experts.

II-level early warning (Yellow): Abnormal phenomena are obvious. Temporal and spatial density of monitoring points must be added and monitoring methods must be extended. The information is issued to the group of experts.

III-level early warning (Orange): The monitoring graph of abnormal phenomena are steep, ground cracks occurred obviously and sliding occurred locally. Continuous comprehensive monitoring and general inspection should be conducted 24-hour per day. The emergency evacuation and fast emergency engineering work is necessary. A consultation and discussion should be carried out among experts and government decision-makers.

IV-level early warning (Red): The monitoring graph of abnormal phenomena are sharp, ground cracks widely appeared that shows large scale landsliding. A 24-hour comprehensive monitoring and general inspection, engineering stabilizing, and restricting reservoir water level fluctuation should be conducted if necessary. The risk mitigation and evacuation will be announced and conducted by the government.

5.2 Early warning from ground displacement monitoring

According to the GPS receivers distributed on the Yuhuangge landslide and the leveling result for early warning (Table 3), the average horizontal displacement of the landslide was 0.02-0.28 mm/month on the slope surface, with a direction nearly to the South that is basically consistent with the slope direction, and the vertical displacement rate was 1.28-2.21 mm/month.

Longitudinal section analysis: at the YHG4, YHG7 and YHG10 monitoring benchmarks of section I, horizontal displacement rate is 0.02-0.28 mm/month and vertical displacement rate is 1.64-2.21 mm/month; at the YHG3, YHG6 and YHG9 monitoring benchmarks of section, the horizontal displacement rate is 0.05 mm/month and vertical displacement rate is 1.49-1.73 mm/month; at the YHG5, YHG8 and YHG11 monitoring benchmarks of section III, the horizontal displacement rate is 0.03-0.16 mm/month and vertical displacement rate is 1.32-1.74 mm/month. The results show that the landslide is creeping without significant deformation abnormality.

Cross section analyzing: in the upper part of

Table 2: Recommended early warning critical value of Yuhuangge and neighbor landslides

Early warning level	Color	Monitoring value				Measures
		Ground displacement (mm/month)	Deep displacement (mm/month)	Pore water pressure (kPa/month)	Ground strain (με/month)	
□ level	Blue	<10.0	<1.0	<10.0	50.0	MacroscoPhoto inspection, ordinary monitoring
□ level	Yellow	10.0～30.0	1.0～15.0	10.0～50.0	50.0～100.0	Increasing monitoring density and monitoring methods
□ level	Orange	30.0～300.0	15.0～150.0	50.0～100.0	100.0～150.0	Comprehensive consultation, emergency evacuation, engineering emergency strengthening
□ level	Red	>300.0	>150.0	>100.0	>150.0	Engineering multiple strengthening, controlling reservoir water level changing

the landslide, the monitored displacement rate is 0.03-0.28 mm/month, the vertical displacement rate is 1.28-2.21 mm/month and the numbers of these sites are from YHG2 to YHG5. In the middle part, the monitored displacement rate is 0.09-0.52 mm/month, the vertical displacement rate is 1.69-1.94 mm/month and the numbers of these sites are from YHG6 to YHG8. In the lower part, the monitored displacement rate is 0.02-0.13 mm/month, the vertical displacement rate is 1.32-1.73 mm/month and the numbers of these sites are from YHG9 to YHG11. The result shows that the deformation is nearly on the same level though the data in the middle part is a bit larger than that in the other two parts. The landslide is generally creeping without significant difference of local deformation.

5.3 Early warning from deep displacement monitoring

A Time Domain Reflection (TDR) instrument which can monitor the landslide in real-time was set in the borehole of the Yuhuangge landslide. TDR is a coaxial cable that extends the complete length of a vertical borehole that penetrates a landslide through the sliding surface. A signal is pulsed through the cable. Micro-deformation of the cable due to movement within the landslide mass is detected from changes in the signal. The TDR system's hardware is consisted of four parts: a monitoring signal generator, reflected wave reception equipment including a data acquisition module, a data processing and control computer, and power supply. Virtual oscillograph and monitoring software was written for the system. Deep displacement monitoring between May 2004 and September 2005 detected a cumulative displacement of 1.60 mm, averaging 0.1 mm/month with direction non-repeatability. It showed that the displacement was not significant and the slope was stable. However, during the period from September 2005 to February 2006, the displacement rate increased rapidly to 5 mm and the displacement rate became to about 1.0 mm/month. It is 10 times bigger than the earlier deformation rate. The moving direction was definitively Southeast (the same as slope direction). The slope was stabilized in the mid-February 2006 (Figure 10). The deformation may be the result of internal adjustments within the landslide. Overall, landslide stability did not change: it remained in the creep

Table 3: Statistical table of Yuhuangge landslide ground displacement monitoring result

No.	First monitoring date	Cumulative horizontal displacement (mm)	Horizontal displacement velocity (mm/Month)	Cumulative vertical displacement (mm)	Vertical displacement velocity (mm/Month)	Horizontal displacement direction (°)
YHG1	2004-05-23	3.4817	0.11	-50.6258	-1.61	
YHG2	2004-05-23	1.9761	0.06	-40.1807	-1.28	
YHG3	2004-05-23	1.5056	0.05	-46.5795	-1.49	180
YHG4	2004-05-23	8.7513	0.28	-69.1635	-2.21	180
YHG5	2004-05-23	0.8469	0.03	-52.6019	-1.68	180
YHG6	2004-05-23	16.3734	0.52	-60.9768	-1.94	180
YHG7	2004-05-23	2.823	0.09	-53.0724	-1.69	180
YHG8	2004-05-23	5.0814	0.16	-54.6721	-1.74	180
YHG9	2004-05-23	1.5056	0.05	-54.2957	-1.73	180
YHG10	2004-05-23	0.7528	0.02	-51.3786	-1.64	180
YHG11	2004-05-23	4.1404	0.13	-41.4981	-1.32	180～250

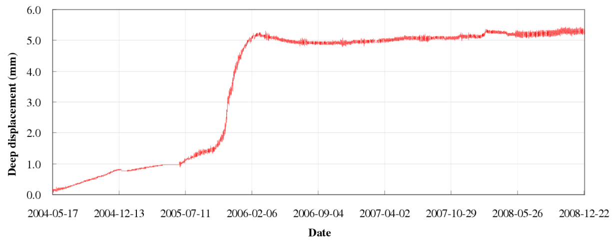

Figure 10: Sliding zone deformation with time curve graph of monitoring drilling hole, EL_YHG_2

sliding deformation stage. Because the deformation level did not change, its early warning status remained at the same level.

5.4 Early warning from pore water pressure monitoring

The Yuhuangge landslide is located in the shore of the Three Gorges Reservoir and its stability is obviously influenced by the reservoir water level. Therefore, pore water pressure monitoring is very important for this landslide. Since 2008, osmotic pressure measuring instrument was set in the landslide. The gauge capacity is 700 kPa, the resolution is 0.025% (0.175 kPa), and the precision is 0.1% (0.7kPa). The data acquisition interval time can be set between 1 minute and 30 days that can show groundwater abnormal in landslide.

The water level of the Three Gorges reservoir reached 175 m on October 2008. Monitoring data (Table 4, Figure 11a, Figure 11b) showed the ground water level was 170.50 m on 25 October 2008 at that point. It reached the highest level of 170.64 m on 23 November 2008 and subsequently fell to the lowest level of 170.36 m on 20 December 2008. Landslide pore water pressure correspondingly changed from 71.49 kPa on 25 October to 72.77 kPa on 23 November and then 70.11 kPa on 20 December 2008. This variation demonstrated that the landslide structure was somewhat loose and there was a good hydraulic connection between ground water and surface water. When the water level declines from 175 m to 145 m, high seepage pressure was formed whereas pore water pressure increased when reservoir water level rises. It will be impossible for slope failure problem here because

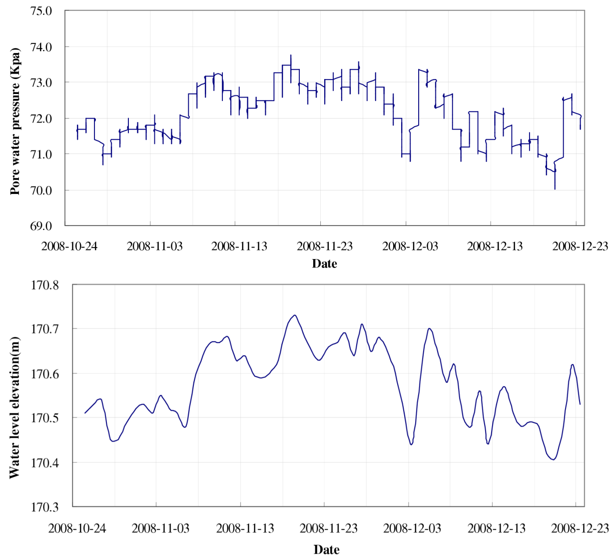

Figure 11: (a) Duration curve of pore water pressure, S5, Yuhuangge. (b) Duration curve of water level elevation, S5, Yuhuangge

lots of protective works have already been conducted and the reservoir water level situation has been considered for the stability standards of the landslide and the other bank slope of the reservoir.

5.5 Early warning from ground strain monitoring

Brillouin optic time-domain reflectometer (BOTDR), is a state-of-the-art fiber-optic sensing technologies. It is set up in net arrays for real-time monitoring in order to gain a detailed understanding of the deformation of a monitored landslide. It has a high monitoring accuracy because of Brillouin back scattering optical sensitivity and strain monitoring with an accurate magnitude of 10-5 (non-unit). Comparing with traditional monitoring technology, its characteristics are as follows: distributed measurement, monitoring crossing long distances, high accuracy and durability. Compared with conventional optic-fiber, the obvious advantages of the BOTDR are no special machining for the fiber in which transmission and sensing is integrated and no special protection needed, such as grating test technology.

Table 4: Duration curve of pore water pressure with reservoir water level, S5, Yuhuangge

Monitoring time	Monitoring frequency (Hz)	Monitoring temperature (^oC)	Pore water pressure (KPa)	Water level elevation (m)	Note
2008-10-25 14:00	2825.4	19.54	71.49	170.50	
2008-10-31 14:00	2825.2	19.54	71.69	170.52	
2008-11-07 14:00	2824.7	19.54	72.18	170.57	
2008-11-15 14:00	2824.6	19.54	72.28	170.58	
2008-11-23 14:00	2824.1	19.53	72.77	170.64	Highest
2008-11-30 14:00	2824.5	19.53	72.38	170.59	
2008-12-06 14:00	2824.4	19.55	72.48	170.60	
2008-12-13 14:00	2825.0	19.54	71.88	170.54	
2008-12-20 14:00	2826.8	19.53	70.11	170.36	Lowest
2008-12-23 14:00	2825.2	19.54	71.69	170.52	

BOTDR technology is adopted in the Wushan new town landslide monitoring. The longitude stress distributed curve graph was shown in Figure 12, for the Dengjiawuchang landslide. Two stress peaks occurred at the points of 358.5 m and 541.5 m along the fiber-optic (mirror image symmetry center was at 450 m point) and the stress gradually increased with time. It was indicated that strain focus was there with the strain was over 500 (l/l non-unit), i.e., if the length of fiber-optic cable(l) is 1.0 m, the increment of the length(l) is 0.0005 m, and the strain increasing was 125 /month.

The distributed curve of B2 fiber-optic is shown in Figure 13 also for the Dengjiawuchang landslide. It is shown with the graph that the fiber-optic distributed strain is centered with 450 m point mirror image symmetry and gradually increased at the point of 433.0 m that indicates the strain focus was exist and that the strain was over 800 with increase of 200/month.

The monitoring data on Canlian landslide nearby the Yuhuangge landslide showed the data from August 2004 to September 2005. Monitoring sites W1 had an abnormal high strain at the point of 290 m and 460 m of the optic fiber length. The two abnormal points are symmetrical with centered point at 425 m (terminal point of the monitoring line layout) that reflected the deformation occurred at the same place since the optic fiber was laid with double lines. The length corresponds to the slope deformation point of 90.5 m from the start point. Strain reached 1500 and increased at a rate of 115.4/month (Figure 14). The largest strain value recorded was 1060 between the period of 26 August 2004 and 9 March 2005. The strain increment rate was 176.7/month. This was verified by the development of a tensional crack (Figure 15). From 26 September 2006 to 23 November 2006, its strain increment reached 503 and strain rate reached 251.5 /Month. The tension crack was opening continously.

5.6 Early warning decision from comprehensive monitoring

The landslide monitoring data for the Yuhuangge landslide in the Wushan new town since 2004 assign it to early warning status of blue level. The surface horizontal displacement rate is 0.02 to 0.28 mm/month, vertical displacement is 1.28-2.21 mm/month and the pore water pressure fluctuation is 0.5 kPa/month.

The sliding surface was also monitored. Displacement along the surfac increased 5 mm in five months with an average velocity of 1.0 mm/month. The rate is 10 times greater than that was recorded during an earlier period. Consequently, blue status was changed to yel-

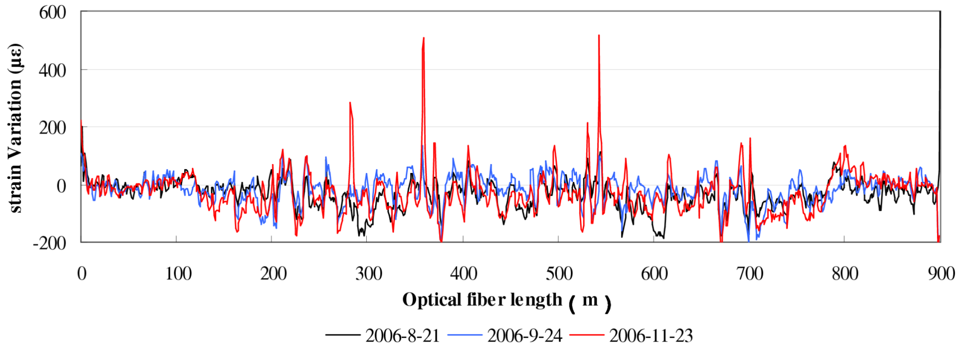

Figure 12: Lattice strain increasing value distributed curve of B1, Dengjiawuchang landslide

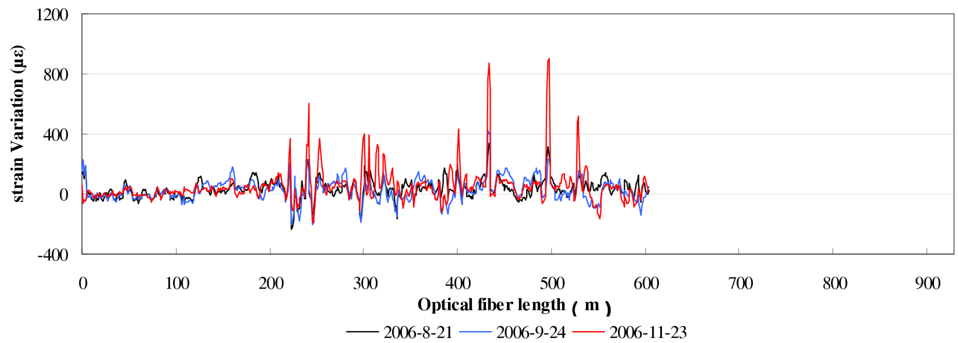

Figure 13: Lattice strain increasing value distributed curve of B2, Dengjiawuchang landslide

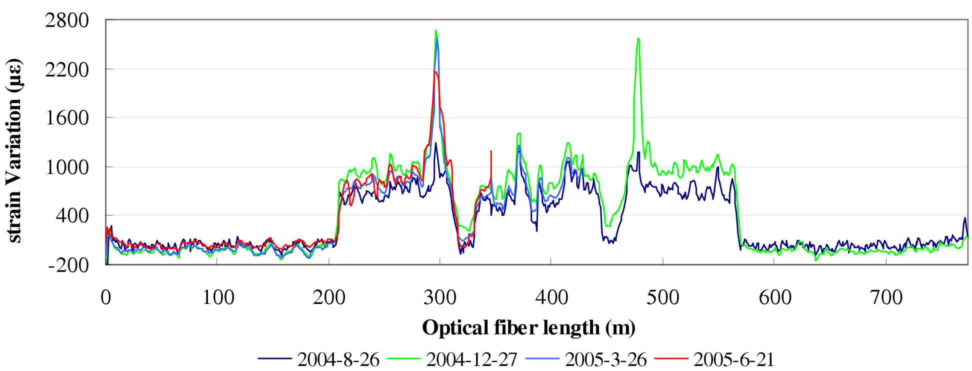

Figure 14: Monitoring site fiber-optic strain increasing value distribution graph of incomplete landslide W1

Figure 15: The ladder is cracking that is monitoried and positioned by BOTDR

low status because the interval of accelerated deformation indicated a need for a denser monitoring. Subsequently, the basal displacement slowed a rate less than 1.0 mm/month, and it was downgraded to blue status again. BOTDR monitoring on the Dengjiawuchang landslide adjacent to the Yuhuange landslide, the average strain was increasing 176.7/month and the largest reached 251.5/month. Thus, it was assigned a level of red status (>150.0). The surface survey showed that the concrete ladders were damaged by the tension crack on the landslide in the area of most active deformation. Emergency engineering was needed to deal with the destruction. In general, the Yuhuangge landslide is at the blue early warning status.

6 Conclusions

This paper introduces the demonstration station system implemented for geo-hazard real-time monitoring and early warning in Wushan new town in the Three Gorges Reservoir area. The system has three main functions: the automatic data acquisition, remote wireless transmission and internet-based real-time releasing system.

The early warning criteria of the landslides underlying Wushan new town includes four levels: blue, yellow, orange and red. The monitoring results of ground hydrological deformation and pore water pressure for the Yuhuangge landslide indicated a blue early warning status. The monitoring results of deep displacement increased the status to yellow and subsequently returned to blue early warning status. The monitoring on the Yuhuangge landslide and the Canlian landslides by BOTDR assigned the landslides to red early warning status. The field inspection found that the concrete ladders on the landslide were damaged by tension crack and engineering emergency reinforcement was needed.

At present, the Yuhuangge landslide is in the blue early warning status with the exception of local displacement anomalies. It is concluded that the monitoring techniques used in this demonstration project can be further applied to the monitoring of the other 3200 landslides in the entire Three Gorges Reservoir region.

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