Research Review on Landslide Monitoring Technology at Home and Abroad

Feng zhen-yang, Liu dong-yan, Zhu zhen-wei
School of civil engineering Chongqing university, Chongqing, China, 400030

ABSTRACT

The landslide monitoring and early warning research situation in Civil and abroad were reviewed and summarized from the two aspects of monitoring method and technology in the paper. Firstly landslide monitoring index is briefly summed up, according to different landslide monitoring indicators, landslide monitoring methods are classified and summarized, and conventional and advanced monitoring methods are correlated by the application of each monitoring index, there is not great difference about the current method and technology of landslide monitoring, professional instrument has become the conventional equipment, only because of price factors it can not be popularized in China; lots of monitoring and early warning works are done in the recent years, and fruitful results are achieved. but according to the statistical data, the successful warning rate is low, proportion of professional warning in successful warning instance is too low and large amount of geological disasters are taken place outside existing early warning condition; because early warning scope is too large, it is difficult to achieve efficiency in the precaution of a single point. real time, continuity and effectiveness of landslide monitoring are still needed to solve and improve.

KEYWORDS: Landslide; monitoring and early warning; current status on research; monitoring method

INTRODUCTION

Monitoring and early warning, as one of the important measures of geological disaster risk mitigation, is being paid more and more attention. At the beginning of this century, landslide monitoring and early warning are developled in China. on April in 2003, "Agreementon of the joint meteorological early warning of geological disasters " is signed with Chinese Meteorological Bureau by the Ministry of land and resources;then this work also is developed by the provinces, city, county. until the end of October 2010, There are 30
provinces (autonomous regions, municipalities directly under the central government), 223 cities, 1035 counties to carry out the meteorological early warning of regional geological disasters. All kinds of single landslide monitorings have been developed, such as the Three Gorges Reservoir area (2001), Sichuan Ya’an (2001), Wushan county (2003) landslide monitoring and a professional geological disaster monitoring and early warning is spread to Yunnan, Shanxi, Fujian etc. Nowadays, geological disaster monitoring and early warning work in our country has been developed for 10 years, domestic research on this work has accumulated to certain experience; the research condition at home and abroad is summarized in the next text, it is necessary to make an analysis on the development trend in the future.

From the two aspects of landslide monitoring indicator system, monitoring method, a review about the research status of this field both at home and abroad and the development trend of the future are made, its aim is to summarize the current achievement to find the breakthrough and provide experience and reference to the actual work in the future. The landslide geological hazards is emphasized in the text.

LANDSLIDE MONITORING INDEX SYSTEM

With the developing and evolving process of landslide, certain related factors to landslide will change. the relationship between these factors and landslide is established by the scientific theory. these change factors are the so-called monitoring indicators, including geological macro track index, displacement monitoring index, inducing factors index, water dynamic monitoring indicators, Geophysical Monitoring Index and chemical field monitoring index, etc.
<table>
<thead>
<tr>
<th>Monitoring indicators</th>
<th>The main monitoring objects</th>
<th>The main monitoring method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Geological features of monitoring</td>
<td>The crack, inclined building</td>
<td>Stickers, buried nails, painting method, cable, buried pile method etc.</td>
</tr>
<tr>
<td></td>
<td>The absolute displacement</td>
<td>GPS automatic monitoring method, laser radar measurement, InSAR measurement technology</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total station measurement, digital close range photogrammetry, 3D laser scanner technology,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BOTDR distributed optical fiber sensing technology</td>
</tr>
<tr>
<td>2. Displacement monitoring</td>
<td>The ground relative displacement</td>
<td>Borehole inclinometer, hole displacement meter,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>OTDR optical fiber sensing technology</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Distributed optical fiber sensing technology</td>
</tr>
<tr>
<td></td>
<td>The displacement of deep underground</td>
<td>Monitoring, remote professional network</td>
</tr>
<tr>
<td></td>
<td></td>
<td>automatic rain gauge, temperature gauge with pore water pressure monitoring technology</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Distributed optical fiber sensing technology</td>
</tr>
<tr>
<td>3. Predisposing factors monitoring</td>
<td>Earthquake, meteorology, human activities</td>
<td>Distributed optical fiber sensing technology</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Monitoring, remote professional network</td>
</tr>
<tr>
<td></td>
<td></td>
<td>automatic rain gauge, temperature gauge with pore water pressure monitoring technology</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Distributed optical fiber sensing technology</td>
</tr>
<tr>
<td>4. Water dynamic monitoring</td>
<td>Surface water, groundwater</td>
<td>Water level meter, osmometer, pore water pressure gauge, TDR soil moisture meter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Distributed optical fiber sensing technology</td>
</tr>
<tr>
<td></td>
<td>Distributed optical fiber sensing technology</td>
<td>Water level meter, osmometer, pore water pressure gauge, TDR soil moisture meter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Distributed optical fiber sensing technology</td>
</tr>
<tr>
<td>5. Geophysical Monitoring</td>
<td>Stress, strain, acoustic emission</td>
<td>Bolts shall be vertical meter, cable stress, vibrating soil pressure meter, steel string type sensor, pipe strain gage, Distributed optical fiber sensing technology</td>
</tr>
<tr>
<td></td>
<td>Distributed optical fiber sensing technology</td>
<td>Bolts shall be vertical meter, cable stress, vibrating soil pressure meter, steel string type sensor, pipe strain gage, Distributed optical fiber sensing technology</td>
</tr>
<tr>
<td>6. Chemical field monitoring</td>
<td>Water temperature, water quality, the radioactive element</td>
<td>Radon and tracking method</td>
</tr>
<tr>
<td></td>
<td>Distributed optical fiber sensing technology</td>
<td>Radon and tracking method</td>
</tr>
</tbody>
</table>
THE CURRENT CONDITION OF LANDSLIDE MONITORING TECHNOLOGY AND METHOD

methods for monitoring landslide has been summarized\cite{4-9} by predecessor, application methods according to the different monitoring indicators are classified and summarized in the paper.

Geological macroscopic track monitoring

There are various signs in landslide development process, such as crack, tilt of houses and trees, spring dynamic etc. In the process of forming landslide ground crack phenomenon have different appearance, arc crack is found in the back; heave mound and expansion cracks are found in the front; research on rainfall inducing landslides reveal that front spring and groundwater dynamic observation can also indicate the state of landslide. construction period safety of Three Gorges shiplift and temporary shiplock high slope is monitored by Shi Zhaoqiong, Ge Wensheng through adopting\cite{10} the wire displacement meter and dislocation. error requirements of landslide and high slope in displacement measurement can be satisfied by this method, error requirements of dam surface joints and cracks in displacement measurement requirement can be meet also; landslide surface monitoring points’ trajectory curve is studied by Hu Xianming and Yan echuan\cite{11}, the dimension of landslide monitoring points trajectory curve is determined to reflect the deformation stage and the evolution trend of landslide.

3.2 Displacement monitoring.

(1) the ground absoute displacement monitoring.it is The conventional detection method, collapse point of sliding body in 3D coordinates at different instancesby geodesy method is measured to gain direction of displacement and displacement rate. theodolite, level instrument, infrared range finder, laser, total station and high precision GPS\cite{12} are used. In 2008, 16 heavy disaster County and 11308 earthquake landslide inventory map are completed rapidly by RunqiuHuang\cite{13} etc by using aerial remote sensing information of the Japanese ALOS satellite image data after the Wenchuan earthquake , Chinese Aerial Geophysical Survey and Remote Sensing Center, and the investigation data of geological disaster emergency departments of land ; the rapid completion of the, these landslide monitoring points have a certain scale and it still poses a potential threat to residents of the earthquake zone.survey datums have played an important roldirectly to the landslide hazard assessment, site selection and reconstruction . In 2010 Dai\cite{14} using aerial remote sensing data and spot, IRS-P6 and CBERS satellite image data in Wenchuan earthquake area in the range of 41750km2 interpretation to slide 56000 (landslide area of 811Km2). In 2011, 5 SAR datum are acquired by Wang Guijie, Xie Mo Wen\cite{15} using ALOS satellite PALSAR sensor, and
landslide activity on the area of the Jinsha River Wudongde Hydropower Station Reservoir area are identified and analyzed using D-InSAR technology by them. In 2011, Chongqing Chengkou landslide analysis of geological disasters are monitored by Ma ze-zhong [16] using unmanned aircraft at low altitude remote sensing technology; process and method of data acquisition and data processing technology by the unmanned aircraft in low altitude remote sensing technology in complex terrain and meteorological conditions are analyzed, and the application to disaster assessment and disaster loss evaluation of exploration has been made. Since 2006, monitoring is done by Chinese and Canadian geological survey, a joint monitoring is conducted in Jiaju village landslide of Sichuan with SAR and GPS; continuous monitoring of the horizontal displacement is provided by GPS, vertical displacement monitoring once a month is provided by SAR and good monitoring effect is achieved, it is proved through the practice to have good effect [17] on high and steep zone in Sichuan using the InSAR technique to determine the new landslide.

(2) The ground relative displacement monitoring. It is a monitoring method of collapse slope deformation about relative displacement between the sites. Monitoring with the closed, subsidence, uplift, fault of the key parts of the main crack are one of the important contents of displacement monitoring. The current conventional monitoring instrument include a vibrating string extensometer, resistor type displacement meter, crack meter, strain meter, convergence gauge and large displacement meter etc. In 2010, corresponding theoretical analysis and practical measurement about application of 3D laser scanning technology to landslide deformation is done by Xu [18], the preliminary satisfactory result has been obtained. Combining this technology with GPS, total station etc, it can achieve very good accuracy, especially in the rapid, deformation stage of landslide but large deformation will destroy all kinds of monitoring facilities. if the case landslide monitoring system can be established rapidly using 3D laser scanning measurement to meet the requirements of landslide prediction. In recent years, BOTDR distributed optical fiber sensing technology has also been applied to the monitoring of landslide; in 2008, a new distributed slope monitoring system based on BOTDR is designed by Shi bin [19], and its application in artificial fill slope monitoring of Ning Huai Expressway sections are done; because optical fiber sensing network is very sensitive to the soil, it can be achieved on the slope deformation monitoring and the spatial localization of deformation area, deformation monitoring results meet the requirements of landslide monitoring and early warning.

(3) Deep displacement monitoring. In the method drill through the sliding zone to stability area in the landslide deformation body is done, then special monitoring devices are put into this area to monitor. The main monitoring instruments include borehole inclinometer, hole displacement meter, composite fiber monitoring device, etc. In 2006, new model system for landslide monitoring is created by JOHN SINGER [20] with the combination of the coaxial cable and TDR technology, and the installation standards and testing methods are determined. In 2011, composite fiber based devices are developed based on ODTR technology by Zhu Zhengwei [21], and the effect of its application to the engineering of landslide monitoring is very good; at the same time, the initial high measuring precision, large measuring range of
motion are fullfilled, and the direction of movement of the external load can be judged. Common ground of these two kinds of monitoring methods in conjunction with inclinometer monitoring method requires that the device and the landslide deformation is common to gain synchronous displacement of landslide.

3.3 Predisposing factors monitoring

Trigger factors of landslide are generally rainfall, human activity and earthquake, etc.

(1) the earthquake monitoring. Earthquakes generally are monitored by professional network. When the geological disaster located in high seismic zone, nearby seismic station data should often be collected timely to evaluate the effect of earthquake on collapse landslide stability in the region. In 1986, monitoring of micro earthquake on coal mining area are done by Yang Chengxiang [22] with a Poland SYLOK microseismic monitoring system in Mentougou coal mine, the mine of multi-channel microseismic monitoring technology is studed for the first time in china. In 2010, the slope microseismic monitoring system is established by Xu Nuwen, Tang Chunan [23] etc, the potential failure of rock mass and the sliding surface of slope area can be identified; it can provide some reference to injection and reinforce of the slope, and also provides a new research idea for the stability analysis of high rock slope.

(2) the rainfall monitoring. Rainfall is an important factor in triggering landslides, so rainfall monitoring has become an important part of landslide monitoring and the basis of the regional landslide prediction [24]. In 2006, instability mechanism of landslide accumulation characteristics that resulted from rainfall is studied by Fu Helin [25]. In 2011, lifting and falling deformation of the slope in the cement plant and rainfall in the area are monitored by Liu Guangning [26] using automation remote monitoring system; through the data collection and analysis, and influence of reservoir water level fluctuation on landslide deformation is gasped.

(3) the human activity monitoring. Human activities such as mining, earth, burrowing slope cutting blasting quarrying, top loading, cut slope, soil irrigation often induce geological disasters, monitoring scope, intensity and speed of human activities should be monitored.

Groundwater monitoring

Groundwater is the major factor of the landslide stability, so it is very important to monitor the underground water table, pore water pressure, soil water content. Usual monitoring instruments include water level meter, osmometer, pore water pressure gauge, TDR soil moisture meter, etc. Nuclear magnetic resonance technology in recent years has been used in landslide monitoring, it has achieved remarkable results. In 2002, using nuclear magnetic resonance technology, initial coefficient of each layer of rock mass in landslide, for example the water content, porosity and permeability, etc are analysed by Hu Xin Li [27] using nuclear magnetic resonance technology. According to the change of moisture content,
character of the slope structure, groundwater distribution and each layer of sliding zone are determined. So the stability of landslide is determined.

**Physical field monitoring**

(1) Stress monitoring. In the deformation process of geological body, internal stress of geological body must be changed and adjusted, so monitoring of stress change is necessary. Common instruments include bolt stress meters, anchor stress meter, vibrating wire pressure gauge, etc.

(2) Strain monitoring. Strain in different depth embedded in the borehole, adits, shafts, monitoring of landslide, landslide body is monitored. The embedded corrosion concrete strain gauge is adopted, and it is a steel string type sensor, or pipe strain gage.

(3) Acoustic emission monitoring. The monitoring of acoustic signal is done. Such as the debris flow alarm, it is the infrasound signal that capture source of debris flow and realize the early warning, the infrasound signal use air as medium, its speed is about 344m per second, the signal attenuate and propagate through the minimal minimum gap. According to observation, it alarms in advance at least 10min, up to 0.5h above.

**Chemical field monitoring**

Chemical field monitoring is to techniques of monitor disaster chemical field change information, such as radioactive elements (radon gas measurement, mercury), geochemical methods and microtremor measurement. It is currently used in the monitoring of geological disasters such as landslide body containing radioactive elements (uranium, radium) and concentration of decay products (such as radon), chemical elements. In 1996, migration rule of radon (Rn) under the crustal stress is discovered by Jin Ze, and the problems of landslide forecasting is analyzed in-depth by using the law. When geological hazard body chemistry field changes, it often is associated with deformation of disaster body, it is advancing relatively to the displacement deformation.

**THE STUDY OF CURRENT SITUATION**

(1) It is not much different between technology, method, landslide monitoring at home and abroad at present, besides the coating method, the traditional embedded pile method, the conventional equipment for monitoring landslide includes borehole inclinometer, pore water pressure, automatic rainfall station, etc. Only because of price factors it can not widely be applied. Recently, some new technologies are quickly applied to the landslide monitoring field, such as InSAR, BOTDR, 3D laser scanning. Collection and transmission of monitoring data are also automated and remoted. The monitoring system and early warning system tends to the trend of Web-GIS development.
(2) landslide susceptible zoning and risk zoning on an area with critical value of rainfall are used, different alert level can be set, a number of rainfall monitoring station are set up in the region, rainfall monitoring plus rainfall forecast can be undertaked landslide early warning and forecast. the ideas and the method of regional rainfall landslide monitoring and early warning are followed. Whether it is foreign or domestic, great effect is gained for the method to warn to the public (especially when there is extreme climate conditions), but because the range of warning is too big, for the single point control, it is difficult to take the disaster measures.

PROBLEMS AND SOLUTIONS

A large number professional monitoring and early warning work are carried out in china for nearly 10 years, and fruitful results are achieved, but according to the history and present situation, the successful warning rate is low. The proportion of professional warning in successful warning instance is too low; in 2004, successful warning examples of 715 national geological hazards are analized. the success rate of residents’ self-judging accounts for 3.5% of the total, survey control in group accounts for 86.7%, professional critical rainfall forecast is only 9.8% of the total; on the other hand, the massive geological hazards (about 1/3) are placed outsides the existing warning point, namely failure warning rate is very high. The causes of the above results are mainly the following: first, warning object of monitoring and early warning model is a large scope, and the geological conditions in this range is different from slope degree, slope type, rock mass structure, groundwater, etc. all landslides in the range are warned to use a critical value, and it is not realistic. Secondly, because the warning is a regional scope, all the slope outside the warning area are excluded from the early warning target, but in fact the landslide is often taken place in low prone area, so some potential hazards will be missed. thirdly, now most monitoring system belongs to point monitoring method, many previously identified danger points in some extreme weather conditions do not landslide. Fourthly, on the contrary, many potential pitfalls can not be identified by investigators.

Whether Prediction is consistent with the actual landslide, this is the criteria of evaluation and prediction correctness. In view of this, the focus problem of the existing landslide monitoring and early warning effectiveness is mainly how to work in the region (usually several hundred to several thousand km² area) for landslide investigation and identification of hidden dangerous points, until hidden dangerous points are identified, work in the next step can do. It is the basis for all the work. omission of hidden points make the monitoring missing, much check of hidden points caused waste of a number of monitoring resources: but how can accurately identify the danger points and place it into the monitoring system, whether or not a professional monitoring can be prevented, this makes the monitoring and early warning free. Therefore, how to identify the risks in the vast area, not to leak check and over-check is the key to improve the success rate of monitoring and early warning. landslide development law is analyzed in the region, and the effective identifying technology
for the danger is found, it is not only an important way to solve this problem, but also the future development trend.

On the other side, the concept of risk management in geological disaster monitoring is introduced and it is also a valid solution. The census area of landslide is checked, in accordance with the degree of density of landslide importance of society and economy, different census scale accuracies are selected for different regions. Each single landslide that is investigated is evaluated the risk size and ranking, and size of danger is predicted. The danger degree of the single landslide is ranked to determine the superior indicator and position and make each landslide apply different monitoring schemes including professional monitoring, simple monitoring, or manual inspections, etc and different monitoring interval. Resources for monitoring are allocated reasonably, monitored and warned effectively.

REFERENCES


