Landslide hazard monitoring in China with an example from the Baota landslide, three gorges area

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Abstract: The purposes of landslide monitoring are applied to analysis, forecasting and control of landslide. The indicators in landslide monitoring include the geological indicators, ground displacement indicators, indicators of displacement in borehole, ground water indicators (pore pressure, ground water table, ground water chemistry), induced factor indicators (weather, human activity), geophysical indicators and geochemical indicators. The techniques in landslide monitoring include extensometer of ground fissures, inclinometer in borehole, global position system, remote sensing and integrated real time monitoring system. A case study of Baota landslide in the enclosed landscape of the three gorges projects of Yangtze river is detailed in this paper.

Résumé: L'objet du contrôle de glissement est de connaître et de maîtriser l'évolution du corp de pente, et de de saisir à temps les renseignements sur les caractéristiques du désastre de glissement rocheux et de terrain afin de fournir une documentation fiable et une base scientifique pour l'analyse et l'évaluation bien fondée, les prévisions et l'ingénierie de traitement etc de glissement. En Chine, l'indice du contrôle de glissement comprend le phénomène géologique de la surface de terre, le déplacement du terrain, le déplacement en profondeur, les facteurs concernés (les facteurs météorologiques, le tremblement de terre et l'eau de surface etc.), la pression et les caractéristiques chimiques de l'eau souterraine, le champs physique géographique de glissement et les activités humaines etc. En ce qui concernant les méthodes du contrôle de glissement, il y a celles d'observation simplifiée sur le phénomène géologique de la surface, du contrôle par appareils de surface, de mesure à distance GPS et de mesure par sensation à distance, de système prévisionnel en tremps réel etc. La thèse présente aussi l'étude de cas du système du contrôle de glissement de la tour dorée, et les données de contrôle servent à orienter l'exécution des travaux de traitement de glissement.

Keywords: landslides, monitoring

INTRODUCTION

The purposes of landslide monitoring are to follow and master the evolution of landslide mass, timely capture the information on features of landslide hazard, and provide the reliable data and scientific reference for correct analysis and evaluation, prediction, forecast and control of landsliding. Meanwhile, the monitoring results are also used as the measurement for checking landslide analysis and evaluation and effect of landslide prevention and control project. Therefore, monitoring is not only an important part of the investigation, research and control of landslide, but also an effective means to obtain information for prediction and forecast of landslide hazard.

LANDSLIDE MONITORING INDEXES AND METHODS

Indexes of landslide monitoring

Indexes of landslide monitoring include ground surface and geological phenomena, landslide displacement, ground water dynamic, geophysical field, surface water, meteorological factor, human engineering activities and other monitoring indexes.

Ground surface and geological phenomena

These include each type of signs during the development of landslide, such as ground fissure observation, leaning of houses and trees, spring water development, etc. During the formation of landslide, there were different manifestations for ground fissure phenomena, such as an arch rip occurring behind the landslide, swelling hill and fissure occurring in front of the landslide; it is found out in the research of rainfall-induced landslide that the state of landslide can be predicated through observation of spring water in front of the landslide mass and dynamic of ground water.

When the landslide is in a stable condition, the hydraulic pressure of ground water and the turbidity of water usually remain in a normal state. When the hydraulic pressure of ground water in the landslide is raised, the landslide begins to creep and deform, ground water and spring water become turbid and the landslide mass undergoes subsurface erosion, due to increased hydraulic gradient; When the landslide deformation develops to a certain extent, the leading edge is extruded, the current of ground water is blocked, and then the spring water disappears. Moreover, the ground water level at the trailing edge is elevated to form great hydraulic gradient, thus inducing occurrence of landslide. The above-mentioned features of spring changes during the development of landslide were recorded in a landslide occurring in Nanjiang County, Sichuan, China and many landslides occurring overseas (Wang, S., Du, Y. & Ding, E. 1996; Brand, E.W., Premchitt, J. & Philipson, H.B., 1984; Du, Y., Wang, S.& Ding, E., 1996; Enokida, M., Ichikawa, H.& Ouya,K.,1994; Iverson, R.M. & Major, J.J. 1987).

Landslide displacement

Three-dimensional displacement and moving direction of the landslide surface. Monitoring of deep lying displacement by borehole can directly reflect the feature of multilayer deformation of landslide mass and location of landslide zone. It is an essential part of landslide monitoring.

Ground water pressure and hydro-chemical features

These include ground hydraulic pressure, temperature, quality, spring water flow, water contents of soil mass, water content of fissures, etc. Most landslides are in close relation with the effect of ground water. The data from monitoring of hydraulic pressure of ground water, water content of soil mass, water contents of fissures is the necessary parameter for analyzing landslide deformation and stability. Furthermore, the parameters including ground water temperature and water quality are mainly used for finding out the source of ground water feed, so as to take the drainage measure.

Earthquake sound

Monitoring of the earthquake sound is to measure the intensity and signal features of sound wave released during deformation and damage of dangerous rock mass.

Ground stress

It is mainly used for monitoring the stress changes in different parts of the landslide mass and changes of ground surface stress, and distinguishing the tensile area from the stress area. These physical quantities cannot directly reflect the deformation amount, but can reflect the deformation intensity and facilitate analysis on development of deformation along with the other monitoring data.

Ground surface water

Monitoring of surface water includes dynamic changes of water level of the river, channel and trench, water quantity and sand contents, which are related to the landslide mass, as well as consumption amount and time of water used for irrigation.

Meteorological factor

Meteorological factors mainly include the rainfall, snowfall, snowmelt, air temperature and evaporation to be monitored; based on the statistics of landslide in our country, rainfall-induced landslide accounted for more than 65% of the total, moreover, the relation between rainfall and landslide has gained much attention in the foreign and domestic research on landslide. Data from monitoring of rainfall sometimes becomes the direct index to early warning.

Human activities

These include human engineering construction, production and living activities. The engineering construction activities include cutting into the mountain to reclaim farmland, build construction buildings, road cutting, construction of hydraulic and hydroelectric project, caving, slope cutting, loading, explosion and vibration for mining and excavation of slope; human production activities include reservoirs or channel leakage, water level changes, farmland irrigation, stacking of waste from industrial and agricultural production; human living activities include random discharge of domestic waste water, leakage of sewage pipelines, stacking of domestic waste, etc.

Landslide monitoring indexes of different types

The monitoring techniques and methods differ with the focus of monitoring on different types of landslides. With regards to precipitation-induced soil-type landslide, dynamic change of ground water, surface water and precipitation should be monitored; as for the precipitation-induced rock-type landslide, additional indexes including the water filling condition and height in the fissure should be monitored; as for the landslide induced by erosion and open cut, the major monitoring indexes include condition of erosion and excavation at the leading edge, width, height and angle obliquity and change of the cut slope angle, development of fissure on the slope top and filling of water. As for landslides induced by cave digging, the monitoring indexes include inclination, earthquake sound and ground pressure under the well. As for soil-type landslide, earthquake sound and ground stress can be excluded from monitoring. In addition, the focus of monitoring is also different due to the different factors inducing landslides. For example, as for the soil-type landslide, the main inducing factor is rainfall for the landslide in the southern laterite area, therefore, the focus of monitoring is on the amount of rainfall and continuity of rainfall; however, in the northwest loess area, a large proportion of landslides are caused by frost thawing, therefore, the focus of monitoring is change of water state in the soil caused by temperature change.

Landslide monitoring methods

Landslide monitoring systems usually include simple observation for ground surface and geological phenomena, ground instrument monitoring, remote sensing and remote monitoring, comprehensive real time monitoring and forecast, and other methods.

Simple observation on ground surface and geological phenomena

It is possible for us to follow various signs during the development of landslide through site observation, such as ground fissure observation, leaning of houses and trees, spring water development, etc.

Ground instrument monitoring

The ground instruments monitor the deformation of landslide at the ground surface and deep beneath the earth, development of ground water and geophysical indexes (such as earthquake sound, etc.)

At present, the said two methods are universally adopted for landslide monitoring and early warning in foreign countries (such as the Mill Creek landslide in the USA), and prove effective. These methods are also adopted for monitoring of great landslides (such as Xintan Landside, Baota Landslide, etc.) in the Three Gorges Reservoir Area.

GPS monitoring

The GPS method is adopted to monitor surface deformation of landslide. At present, this method is being applied for monitoring over 130 landslides in the Three Gorges Reservoir Area and Ya'an Gateway landslide. Based on the specific features of landslides, the monitoring points and network should be properly arranged.

Remote sensing & monitoring

Through the comparison of satellite images after occurrence of landslide, the effective monitoring was made on the process of development of flood hazard due to blockage of rivers by landslide dam caused by Tibet Yigong Landslide in 2000 and Sichuan Xuanhan Landslide in 2004.

Real time monitoring and early warning system

An automatic monitoring technique is adopted to conduct automatic collection of on-site data, to collect real time data, which is then remotely transmitted through telecommunications (satellites, cables, GPRS). Moreover, relevant model and GIS (geographic information system) techniques are applied to conduct data analysis and treatment and timely predict landslide. The system has already been established at Ya'an Gateway Landslide, Sichuan.

A CASE STUDY ON BAOTA LANDSLIDE MONITORING

Geological feature of Baota Landslide

Baota Landslide is an ancient landslide. The Jipazi Landslide occurring in 1984 was a part of it and was mainly induced by rainstorm (Jin, Peijie & Cao, Yueli. 1994). East part of the ancient landslide began to revive and deform since 1994. The deformation at the middle and upper part of the landslide mass was caused by rainfall and infiltration of surface water and induced by the effect of ground water. The deformation in front of the landslide was greatly influenced by the fluctuation of water level of the Yangtze River (Zhang et al. 1985). Two boundaries at the east and south side of the landslide mass are Dahegou River and Yangtze River, respectively, at the west side is the Jipazi Landslide. The gradient at the upper position of the landslide is big (Figure 1). The landslide bed consists of soft and hard mixed sand and rock interlayer. The upper part of the obliquity of rock layers is steep and the lower part is low. The back of the landslide mass is the loose accumulation horizon, in the lower part of the landslide mass, there are three-layer rock structures, and in the middle, there is a developed interlayer dip offset zone (Figure 2).

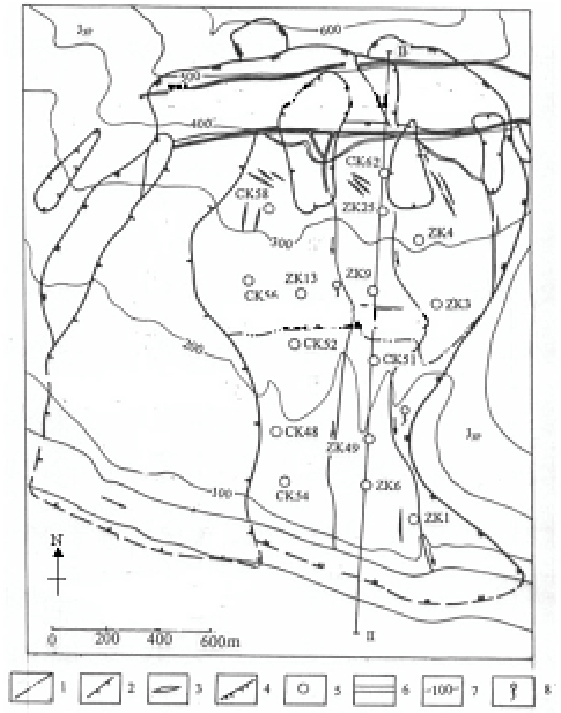

Figure 1. The geological plan of Baota landslide

1-Boundaries for the upper and lower part of the landslide mass; 2-landslide boundaries; 3-fissures; 4-boundaries for the ancient landslide; 5- borehole; 6-drain; 7-contour line; 8-spring

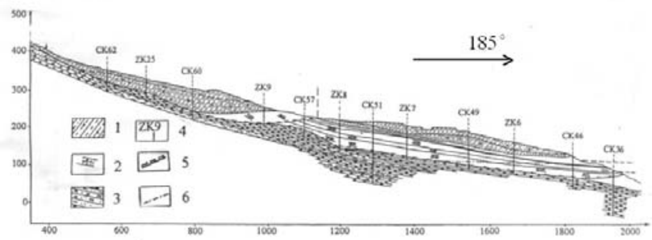

Figure 2. The geological section of Baota landslide
1-Clay mixed with detritus; 2-Cataclastic rock bodies; 3-Sand and mud rock of Penglaizhen cluster (J_{3P}); 4-No. of borehole
5-landslide zone; 6-Ground water level

Monitoring systems of Baota Landslide include: observation on ground surface, geological phenomena and ground water and ground displacement.

Observation on ground surface and geological phenomena

During the deformation of the landslide, there are observable traces left on the ground surface, such as the typical signs of deformation including the tension fissure at the trailing edge of the landslide, and swelling fissures which are caused by extrusion at the leading edge. In the rainy season of 1994, due to the damage of intercepting ditch by flooding at the trailing edge of Baota Landslide, the surface water poured into the landslide mass. This coupled with the leakage of water from a surface fish pond, caused the landslide to deform. A tension fissure was formed at the trailing edge of the Baota Landslide, in the middle of the Baota Landslide. Also at the leading edge of the upper landslide mass, a swelling fissure was formed due to extrusion.

Observation on ground water

The interrelationship between all types of water bodies in the landslide mass was found out through the monitoring of ground water levels (Figure 3), ground water temperature (Figure 4), and analysing the hydro-chemical and isotopes of ground water. In other words, the upper part of Baota Landslide is mainly affected by rainfall infiltration and artificial surface water infiltration, and the leading edge of the landslide mass was mainly affected by the Yangtze River during the flood period (Figure 5).

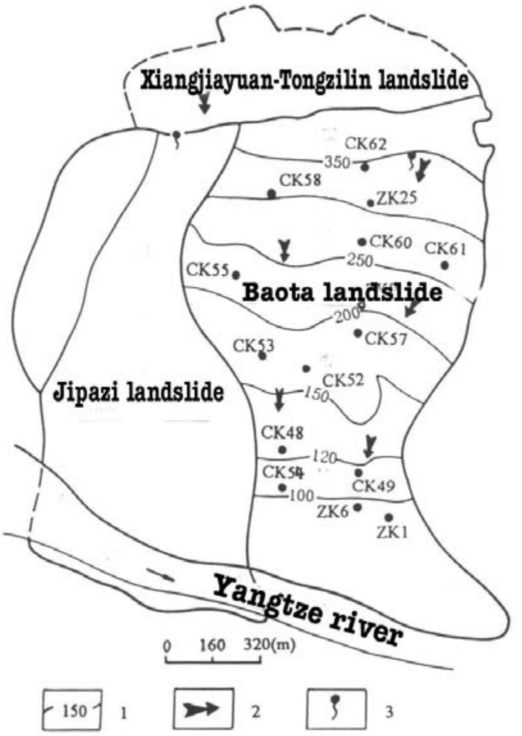

Figure 3. Contour map of ground water level of Baota landslide
1- Contour of ground water level 2- ground water flow directions; 3-Spring

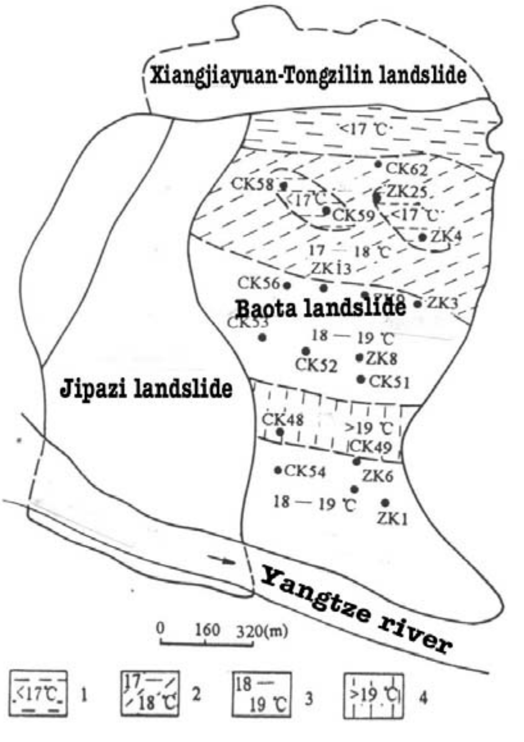

Figure 4. Isoline map of ground water temperature of Baota landslide

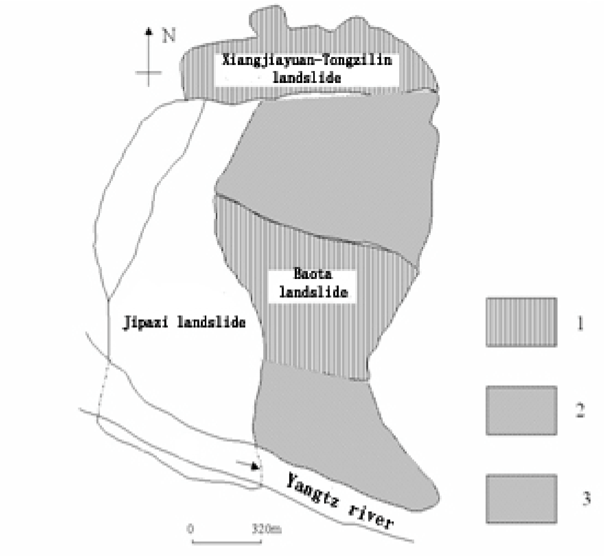

Figure 5. Zoning of ground water circulation condition of Baota landslide
1-Runoff areas; 2- -ground water recharge areas by Precipitation surface water; 3-Influence of the Yangtze River

Observation on ground displacement

The volume and movement of sliding layers of the landslide was found out through ground displacement monitoring. Compared with the inducing factor, the relation between the landslide displacement, precipitation and ground water level change can be analyzed. Based on the data from reconnaissance and data on monitoring of deep lying displacement, the revival and deformation developing at the back of the landslide mass mainly creep along the contact surfaces between the loose powder clay mixed with a debris accumulation horizon and the bedrock. The contact surface is just the sliding surface at the back of Baota ancient landslide. In the middle and lower part of the landslide mass, the interlayer dip offset zone universally exists between the ancient sliding surface and the sill like cataclasite, providing conditions for revival and deformation of the landslide mass. The landslide deformation features multi-layer sliding, and the deep lying monitoring of No. ZK6 hole also proves the rule (Figure 6).

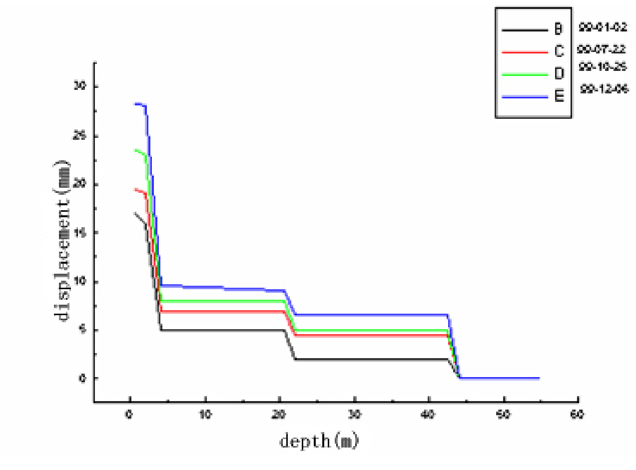

Figure 6. Observing curve on field measured deep lying displacement in borehole ZK6 of Baota landslide

CONCLUSION AND DISCUSSION

The purposes of landslide monitoring are to follow and master the evolution of landslide mass, timely capture the information on features of landslide hazard, and provide the reliable data and scientific reference for correct analysis and evaluation, prediction, forecast and control landsliding. In China, landslide monitoring indexes tend to be multi-disciplined, including monitoring of ground surface and geological phenomena, monitoring of ground displacement, monitoring of deep lying displacement, monitoring of inducing factors, monitoring of water pressure as well as geophysical and geochemical field monitoring. The three-dimensional and automatic monitoring techniques are the trends of development of monitoring methods, including simple observation of ground surface and geological phenomena, monitoring of ground instruments, GPS monitoring and remote sensing and monitoring, real time monitoring and forecast system. The monitoring data on Baota Landslide shows that the recent revival and deformation of the landslide is caused by rainfall, infiltration of pond water in the landslide mass and joint effect of the Yangtze River on the leading edge. The lower part of the landslide mass features multi-layer activities. The monitoring data will guide the implementation of the landslide prevention and control project.

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