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Deformation Monitoring and Exploration on Shuping Landslide Induced by Impoundment of the Three Gorges Reservoir, China

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Synopsis

The Three Gorges Dam construction on the Yangtze River in China is the largest hydro-electricity project in the world. After the first impoundment in June 2003, many landslides occurred or reactivated. Shuping landslide is one of the most active landslides among them. In this paper, the deformation of the Shuping landslide monitored by GPS, extensometers, and crack measurements are summarized. Also, for the investigation of the groundwater situation, 1m-depth ground temperature measurement was conducted, and the groundwater veins were estimated. Based on the monitoring data and exploration results, a deformation model of the landslide caused by impoundment of reservoir was proposed.

Keywords: landslide, displacement monitoring, reservoir impoundment, groundwater

1. Introduction

The Three Gorges Dam construction on the Yangtze River in China is the largest hydro-electricity project in the world. The dam site is located at Sandouping village near Maoping town, the capital of Zigui County, Hubei

Fig. 1 Location map of the Shuping landslide and Qianjiangping landslide in Three-Gorge water reservoir area, Hubei Province, China

Province. The designed final dam height is 185 m, the final length 2309.5 m, and the designed final highest water level 175 m. When dam construction is finished, the Three-Gorge Reservoir will reach Chongqing City, about 660 km upstream from the dam. The first impoundment started from 95 m on June 1, 2003, and reached 135 m on June 15, 2003. As soon as the water level reached 135 m, many slopes began to deform and some landslides occurred (Wang et al. 2004). For example, in the early morning at 00:20 July 14, 2003, Qianjiangping landslide occurred in Shazhenxi town (Fig. 1) at the bank of Qinggan-he River, a tributary of the Yangtze River (Zhang et al. 2004). Direct economic losses caused by the landslide were about 7 million USD, and the asset value of Shazhenxi town was reduced by 40%. Twenty-two boats and ships were damaged and sunk in Qinggan-he River and the Yangtze River. Although a warning was announced by the local government based on precursory deformation of the slope two hours before the final failure, 13 people on the slope, and 11 fishermen on boats in the nearby river were killed.

Fig. 2 Shuping landslide consisting of two blocks at the main stream of the Three Gorges Water Reservoir

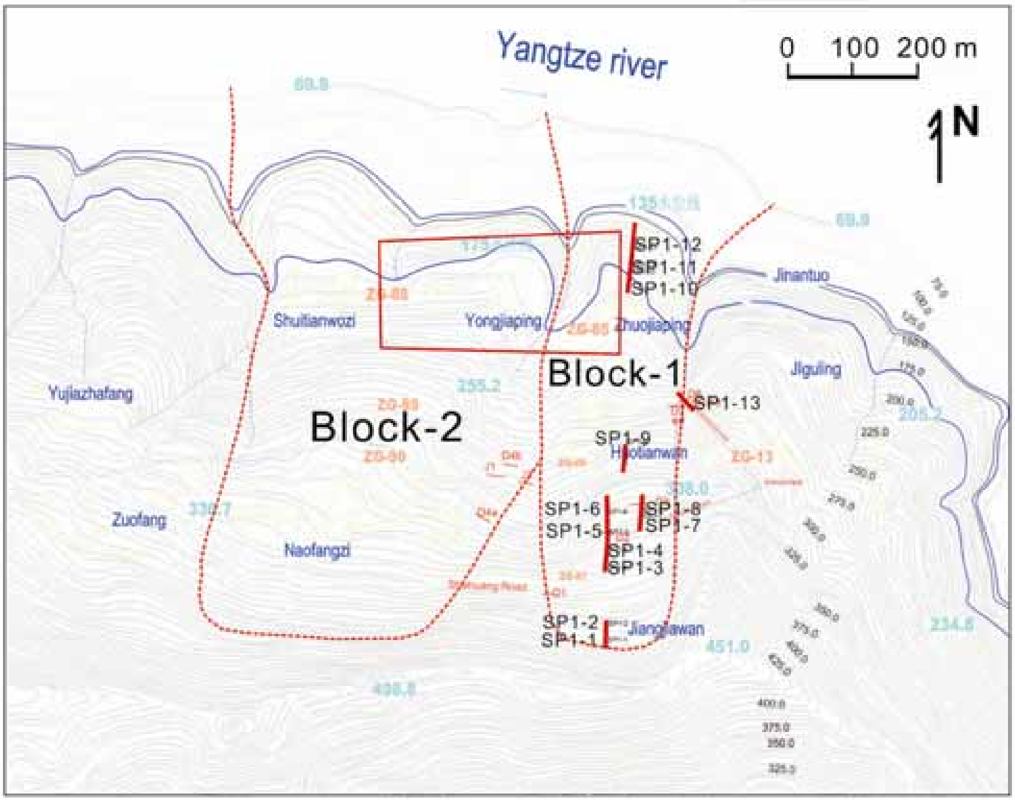

Fig.3 Plane of the Shuping landslide and locations of monitoring and measurement works

From the above example, it is very clear that monitoring of landslide deformation is very urgent in this important area, and time prediction of landslide occurrence based on the monitored data and field investigations are fatal issues for the safety of dam structure and human activity in the Three Gorges area. It is also a good field to monitor the landslide deformation caused by impoundment of reservoir, because the water level changing in the reservoir is in the largest scale around the world.

For these reasons and aiming to study the influence of impoundment on landslide deformation, we selected Shuping landslide, which is located at the main stream of the Yangtze River (Fig. 1) in Shazhenxi Town, just about 3.5 km from the Qianjiangping landslide, as our research and monitoring field. Figure 2 is an oblique photograph of the Shuping landslide, and Figure 3 is the plane of the landslide. The landslide ranged its elevation from 65 m to 500 m. Its width was about 650 m, the estimated thickness of the sliding mass was 40 m to 70 m according to the bore hole data, and the total volume was estimated as 2.0×10^{7} m^3. The toe part of the landslide was under the water level of the Yangtze River. The slope is gentle at the upper part and steep at the lower part with a slope angle of 22 degrees and 35 degrees respectively..

2. Features of the Shuping landslide

The Shuping landslide is an old landslide which consists of two blocks. This can be confirmed in the photograph (Fig. 2). After the first impoundment of the Three Gorges water reservoir ended on June 15, 2003, obvious deformation phenomenon appeared at the slope, and it became intense from February 8, 2004. Also, the two blocks shows different deformation rate at slope surface. The serious deformation situation made 580 inhabitants and 163 houses in danger directly, and all of the inhabitants were asked to live in the disaster prevention tents which were provided by the central government. Until May 2004, most inhabitants moved their houses out of the landslide area.

Figure 4 shows a crack at the right boundary of Block-1 outcropped at a local road. The right-hand side is the sliding mass consisting of red muddy debris of old landslide, and the left hand side is bedrock of sandy mudstone, muddy siltstone of Badong formation of Triassic period (T3b).

Figure 4 Deformation situation at the right boundary of Block-I outcropped at a roadside

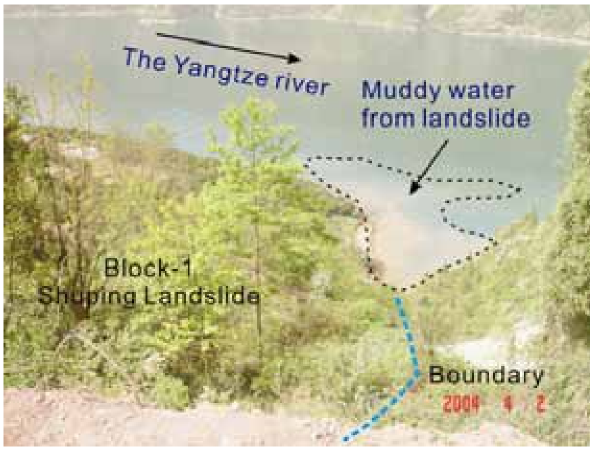

Figure 5 Muddy water seeped out of the toe part of the Shuping landslide (downstream side of Block-I)

Figure 5 shows muddy water coming from Block-1. It appears at the river even at continual sunny days showing no relationship with surface water erosion, but the underground water erosion from the inner part of the landslide.

3. Slope deformation characters of the Shuping landslide

Because the landslide area is a densely populated area and its intense deformation occurred just after the occurrence of the Qianjiangping landslide, the deformation situation was observed by the inhabitants and reported to the local government promptly. According to the urgent investigation report (Gan et al. 2004), the typical deformation behaviors were recorded as follows.

From the end of October to the beginning of November

2003: Cracks became obvious at the slope surface, especially at the upper part. These cracks were enlarged from January to February 2004.

On January 5 and February 8, 2004: The water at the toe part of the landslide became very muddy. From March, the muddy water appears almost everyday. Figure 5 shows the muddy water situation in April 2004. This phenomenon is a very dangerous sign for slope deformation, because it may mean that the newly sheared soil at the sliding surface was eroded by underground water gradually.

On January 25 and February 8, 2004: Sharp noises coming from underground were heard by the inhabitants at night for two times. The noise is possibly caused by shearing at the sliding zone.

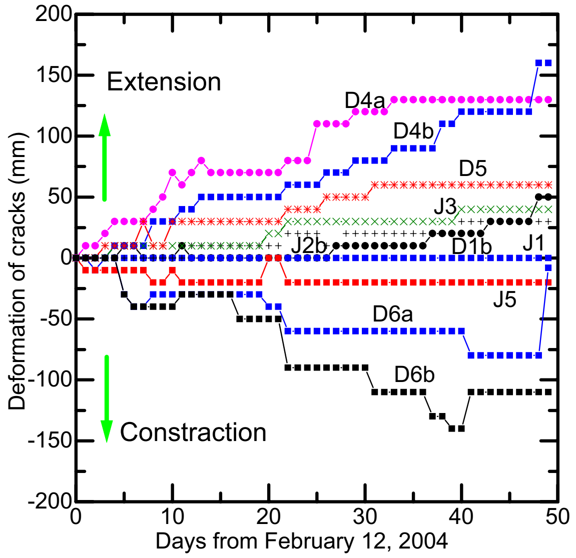

Figure 6 Measured results of crack deformation in Block-I

Because of the serious deformation situation, local government decided to monitor the cracks distributing in the slope from February 12, 2004. The inhabitants were asked to measure the width change of the cracks near their houses (see Fig. 3). For measurement, two small piles were set across a crack, and the distance between the two piles was measured three times one day. Figure 6 shows a part of the measured results of the cracks. However, because the inhabitants are moving out of this area, the measurement points are decreasing gradually.

Roughly, the measurement results of the crack deformation shows that the extension behavior occurred at the boundary and inside landslide, and contraction deformation occurred at the other parts in the landslide block. For the 50 days period from February 24, 2004, the maximum displacement including extension and contraction respectively reached about 140 mm, showing an active deformation.

4. GPS monitoring results

Two GPS monitoring lines were arranged at the central longitudinal section of the two blocks by China Geological Survey. Each monitoring line has three GPS monitoring points, i.e., ZG85, ZG86 and ZG87 from toe to upper part in Block-I, and ZG88, ZG89 and ZG90 from toe to upper part in Block-II (See Fig. 3). The monitoring started in July 2003, just one month after the first impoundment. The measurements were conducted one time each month by Rockfall and Landslide Research Institute of Hubei Province.

Figure 7 shows the monitored results of the GPS monitoring at the first six months after the impoundment. The displacement rate of Block-I increased rapidly after October 2003, and other two tendencies are also very clear. (1) The displacement at the lower part is larger than that at the upper part, this may be caused by water buoyant of the impoundment of the reservoir; (2) The displacement of Block-I is more active than Block-II, showing that the two blocks are independent from each other.

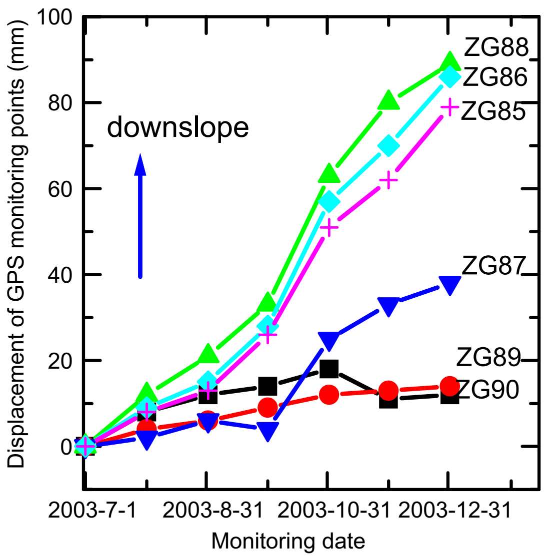

Figure 7 GPS monitored results along the central section lines of Block-I and Block-II

5. Installation of extensometer and the monitoring

results

Until April 2004, the displacement monitoring of the Shuping landslides included crack measures conducted three times each day, and the GPS monitoring conducted one time each month. However, because of the evacuation of the inhabitants, the crack monitoring was interrupted gradually. Located at the main stream of the Yangtze River, it is not enough for the Shuping landslide to be monitored only with GPS. Although GPS monitoring has high precision, the time interval of measurement is too large. Facing this situation, two extensometers donated by Kowa Co. LTD., a Japanese company were installed in the Block-I of the Shuping landslide in April 2004. The extensometer is Sakata-Denki style. The monitoring can continue for one week or one month automatically. A warning system is also connected with the extensometer. When the displacement rate exceeds 2mm/hour, a warning will be announced.

Figure 8 Extensometer installed in Shuping landslide
The deformation is recorded on the rolled paper (left) and also saved in a memory (right box)

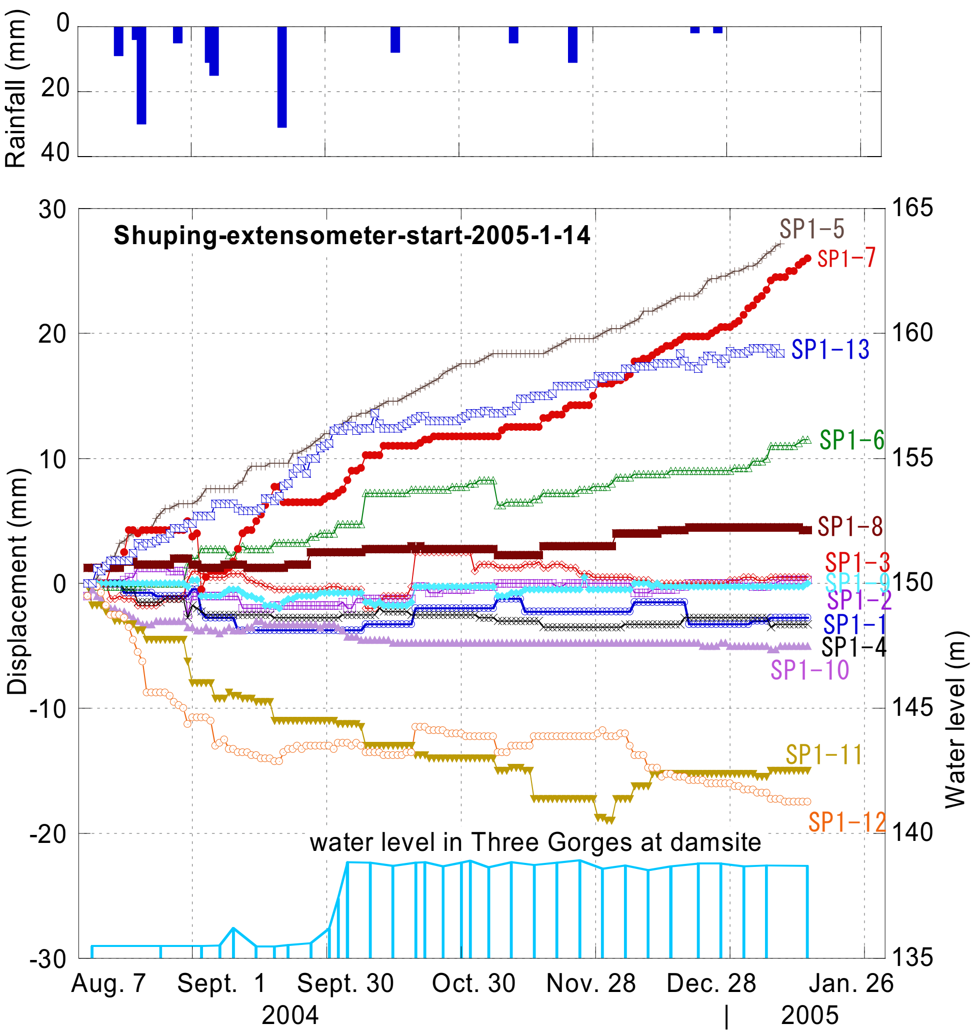

Figure 9 Monitored results of the extensometers (middle), the precipitation data in Yichang City (top) and water level in the Three Gorges Dam site (bottom)

The automatic monitoring with the extensometer was confirmed to be working well (Zhang et al. 2004). However, two extensometers are not enough for such a large landslide. In August 2004, another 11 extensometers were installed along the central line of the longitudinal section of Block-1, with emphasizing on the serious deformation parts. Also because of the limit of funds, the extensometers cannot form a continual longitudinal section line.

Figure 8 shows the extensometer installed in Shuping landslide. The positions of all of the thirteen extensometers were shown in Figure 3 as "SP1-x". Among them, SP1-1 and SP1-2 were set across the main scarp; from SP1-3 to SP1-6 were set below the Shahuang road which has a high traffic. SP1-7 and SP1-8 were set almost parallel with SP1-5 and SP1-6. SP1-9 was set at the low part. Then, SP1-10, SP1-11, and SP1-12were set near the Yangtze River at the toe part of the landslide. SP1-13 was set at the right boundary of Block-1 shown in Figure 4, because the crack extension is obvious.

Figure 9 is the monitoring results of all the thirteen extensometers, companying with the water level in the Three Gorges at dam site showing at the bottom, and the rainfall records of this area showing at the top.

The monitoring results show some tendencies of the landslide displacement. (1) The SP1-1 and SP1-2 at the main scarp did not record obvious displacement. One possible reason is that the setting positions of the two extensometers did not cross the main scarp. (2) The deformations at SP1-5, SP1-6, SP1-7 and SP1-8 are the most active ones. (3) The toe part of the landslide shows compression behavior. Comparing with the largest displacement at the lower part by GPS monitoring in the first six months after the first impoundment, it may estimate that the toe part moved down faster at the first period and became silent now; the upper part moved slowly at the first stage, and now followed the movement of the lower part and compressed the lower part. An exact examination will be conducted with the comparison of the recent GPS monitoring data along the central longitudinal section, which is not open in this period.

Another important tendency was recorded in the monitoring results. In mid-September, the water level of the Three Gorges was raised for about 3 m, corresponding to this water level raising, the displacement velocity of SP1-5, SP1-6 and SP1-7 increased obviously, reflecting the influence of the impoundment on the slope deformation.

6. 1m-depth ground temperature measurement for groundwater veins

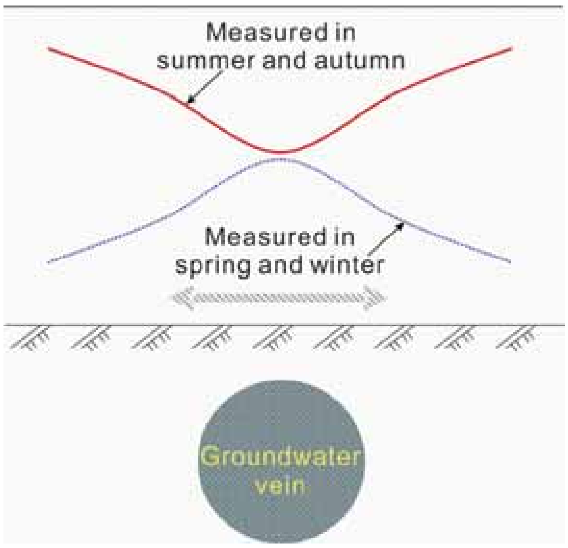

Figure 10 Principle of the 1m-depth ground temperature measurement

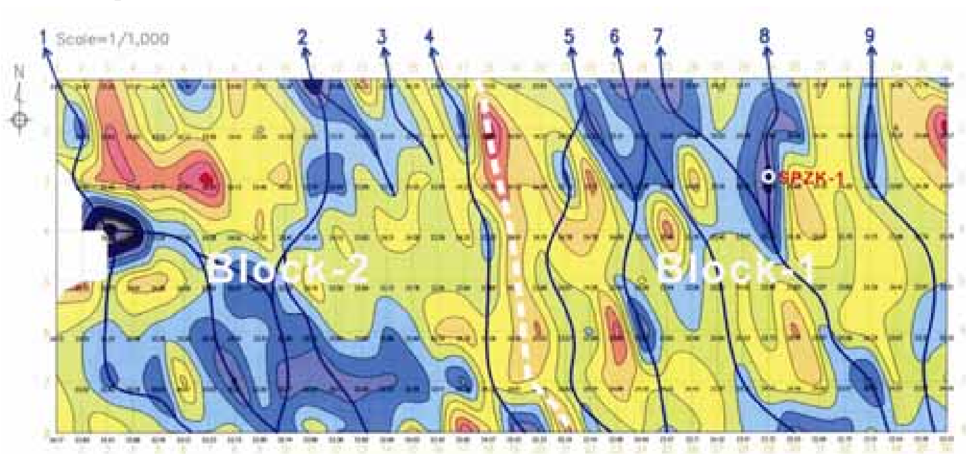

Fig. 11 Groundwater veins distribution estimated from 1m ground temperature measurement

Takeuchi (1972) developed a method for the investigation of groundwater veins through 1m-depth ground temperature measurement. This method is widely applied in the practice of groundwater exploration in landslide area, especially in Japan (Takeuchi 1996).

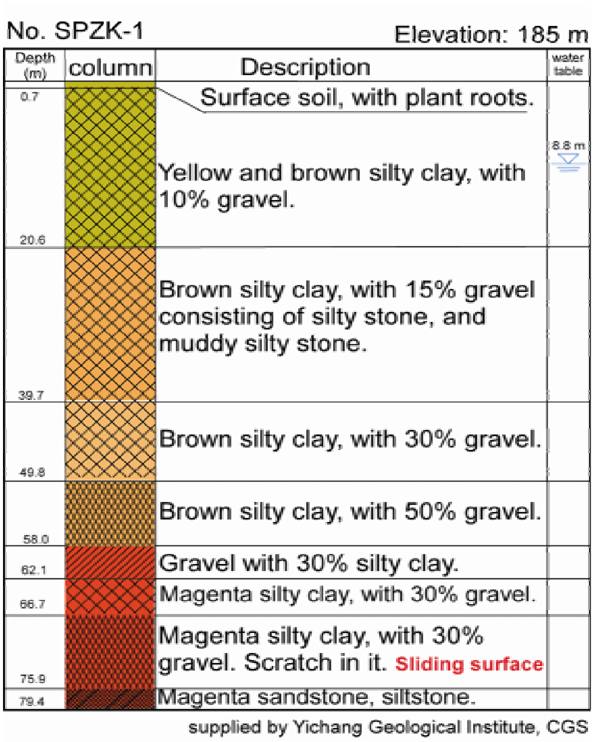

Figure 12 Column diagram of borehole SPZK-1 in Block-1 of Shuping landslide

Figure 10 shows the principle of the 1m ground temperature measurement for groundwater vein. Comparing with the ground without water, the ground with water always has a temperature similar with that of the groundwater. Generally, groundwater temperature does not change so much around a year. While, the temperature in the ground without water is controlled by the atmosphere temperature. It is higher than groundwater in summer and autumn, and lower in spring and winter. Through analyzing the temperature distribution in an area, the distribution situation of groundwater vein can be estimated.

To detect the groundwater veins in the lower part of the Shuping landslide, 1m-depth ground temperature measurement was conducted. The measured area was shown as a square in Figure 3. Figure 11 is the measured results. From the ground temperature distribution, two independent groundwater vein groups were estimated existing in Block-1 and Block-2. The exit of the groundwater vein in Block-1 is lower that that in Block-2. It is estimated that the groundwater veins No.8 and No.9 correspond to the muddy water seeped from Block-1.

To confirm the above estimation, and to explore the sliding surface, a borehole drilling was conducted at SPZK-1, as shown in Figure11. Figure 12 is the column diagram of this borehole. The groundwater table was found at 8.8 m deep, and the sliding zone formed at the depth between 66.7 and 75.9 m. The sliding zone consisted of silty clay with 30% gravel. Scratches caused by sliding are rich in the zone.

7. Summaries and conclusive remarks

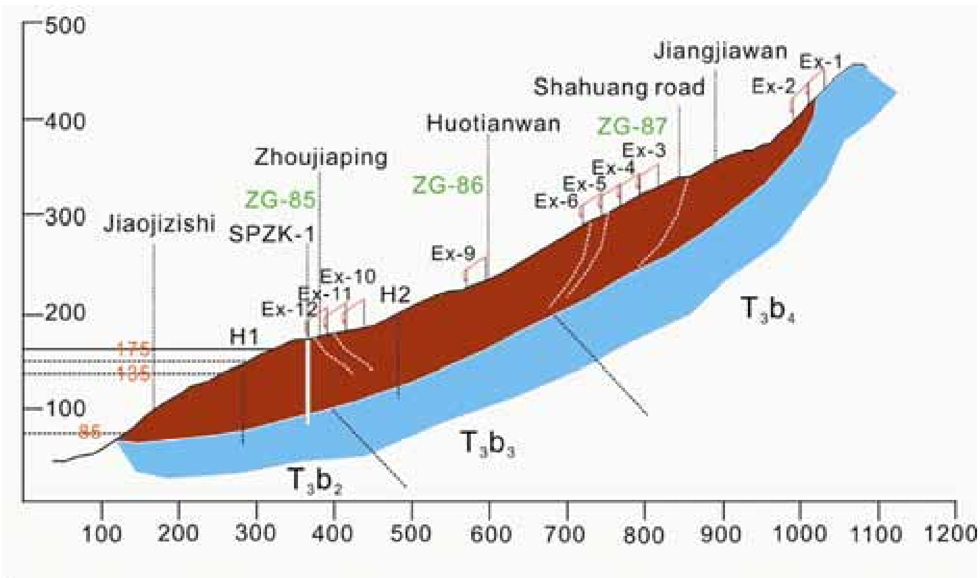

Figure 13 Longitudinal section of the Shuping landslide

Through the GPS monitoring, crack displacement measurements, extensometer monitoring along the longitudinal section of Block-1, the deformation style of the Block-1 of Shuping landslide can be sketched as Figure 13. Sooner after the impoundment of the water reservoir, the toe part displaced downward faster than the upper part. In the current stage, one and half years after the first impoundment, the slope deformation style changed. The displacement of the lower part almost terminated while the upper part displaced downward gradually, and compressed the toe part.

For the Shuping landslide, reactivating from an old landslide and with rich groundwater in it, the influencing factors on the slope deformation is complicated. From the half year monitoring with the extensometers, it is very clear that the slope displaced soon after the impoundment of the water reservoir. It is very important to keep the monitoring continued especially during the next stage of impoundment which will be conducted in June 2006 (Water level will be raised from 139 m to 156 m.). Also the influence of the rainfall on the slope displacement can be analyzed in the next half year when the water level is kept constant at the upcoming rainy season.

Acknowledgements

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中国三峡ダム貯水池地域における湛水による樹坪地すべりの変動観測及び調査について

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要旨

中国三峡地域では、ダム貯水による斜面変動が活発になっている。本研究では，貯水による斜面安定性への影響を解明するために，活発的に変動している樹坪地すべりにおいて，伸縮計を用いて斜面変動の連続観測を行なった。地下水存在状態を解明するために，1m深地温探査を行った。その結果、斜面内部の地下水の分布は斜面変位に直接関係していることは分かり、また、計13台の伸縮計の観測結果より，斜面変動の様子が概ね把握できた。

キーワード:　地すべり，変位観測，貯水池，地下水