Chapter 11
Monitoring on Shuping Landslide in the Three Gorges Dam Reservoir, China

Fawu Wang, Yeming Zhang, Zhitao Huo, and Xuanming Peng

Abstract The Shuping landslide was reactivated by the initial impoundment of the Three Gorges Dam Reservoir, China, in June 2003. For the purposes of landslide disaster mitigation in the reservoir area and identification of landslide movement and deformation caused by reservoir level changes, a monitoring system mainly consisting of drum-style extensometers was installed in the eastern part of the Shuping landslide. Systematical monitoring was started in August 2004 with installation of 13 extensometers above the waterline after the initial impoundment. In August 2006, 11 more drum-style extensometers were installed above the high waterline (175 m), and 5 flexible extensometers were installed along a longitudinal section in the elongation to low waterline. In August 2007, three more drum-style extensometers were installed to make the whole monitoring line connected. In this chapter, the monitoring results from August 2004 to May 2008 are presented, and the deforming of the Shuping landslide caused by both reservoir level changes and rainfall is examined.

Keywords Landslide · Monitoring · Displacement · Reservoir level change · Rainfall

Introduction

The Three Gorges Dam in China is the largest hydropower project in the world. The dam site is located near Maoping town, Zigui County, Hubei Province (Fig. 11.1). The main body of the dam, which is 181 m high and 2,310 m long, was finished by the end of 2006, and the reservoir level will reach a maximum of 175 m in 2009, allowing for full electric power capacity.

When the dam was partially completed, water impoundment was started in the reservoir to produce power and control flooding downstream. The first

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F. Wang (✉)
Research Centre on Landslides, Disaster Prevention Research Institute, Kyoto University
Gokasho, Uji, Kyoto 611-0011, Japan
e-mail: wangfw@landslide.dpri.kyoto-u.ac.jp

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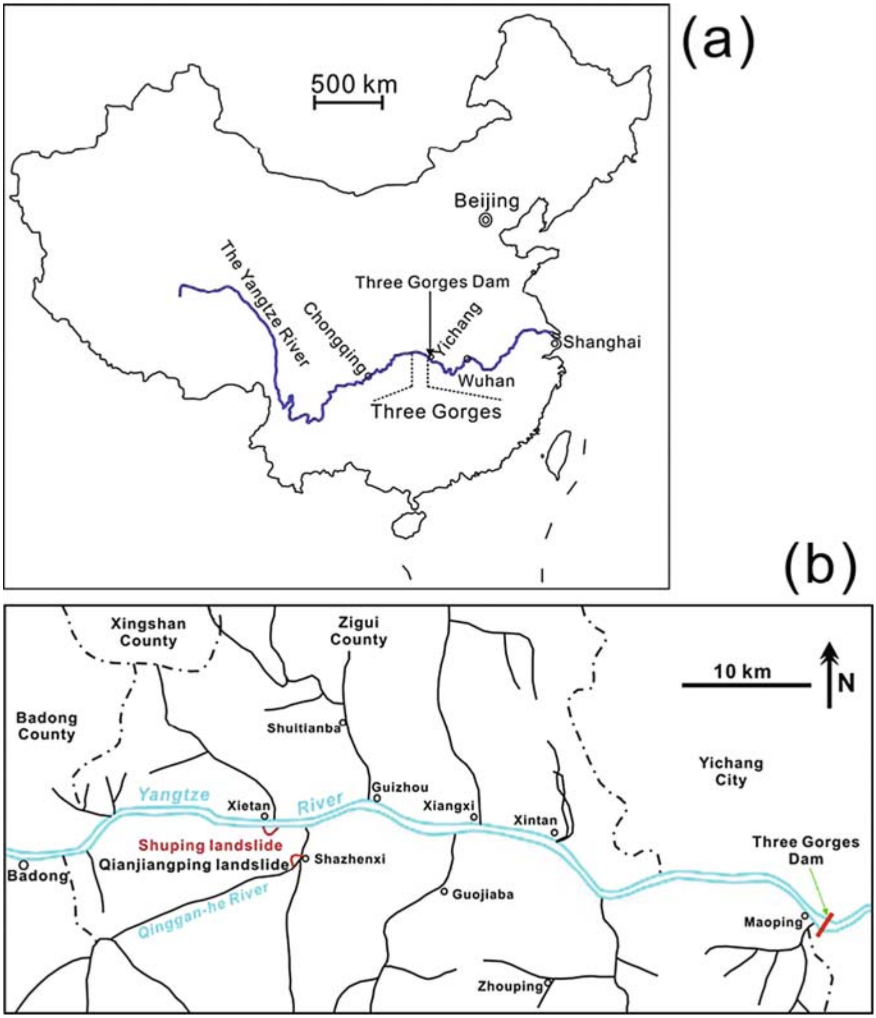

Fig. 11.1 Location map of the Three Gorges Dam and the Shuping landslide in China

impoundment was achieved on June 1, 2003. In 15 days, the reservoir level was increased from 95 to 135 m. Coincident with the impoundment, landslides occurred along the edge of the reservoir. Some of the landslides moved for long distances. In addition, some ancient landslides were reactivated and are currently causing ground deformation. One landslide in the Qianjiangping area of Shazhenxi town (Fig. 11.1b) moved rapidly and killed 24 people. Eleven people were killed directly by the sliding mass, and another 13 people were killed by landslide-induced seiches in the Qinggan-he River, a tributary of the Yangtze River (Wang et al. 2004, 2007). In the Shuping area, which is along the south bank of the Yangtze River, just 3 km from the Qianjiangping landslide, a large ancient landslide was reactivated during the first impoundment and caused ground deformation as the reservoir level changed (Wang et al. 2008).

In this chapter, we discuss the movement and deformation of the Shuping landslide, based mostly on the results of extensometer measurements since 2004.

Description of the Shuping Landslide

The Shuping landslide is located on the right bank of the Yangtze River, about 3 km northwest of Shazhenxi town, Zigui County, Hubei Province. The landslide is about 60 km upstream of the Three Gorges Dam site (Fig. 11.1b). Preconstruction landslide investigations for the purpose of the Three Gorges Dam identified the Shuping landslide as an ancient slide (Chen et al. 1997). The landslide area is underlain by sandy mudstone and muddy sandstone of the Triassic Badong formation (T_2b). In the Three Gorges area, many landslides occurred in this unit (Wen et al. 2004). Figure 11.2 is a photograph of the Shuping landslide, taken from the opposite bank of the Yangtze River. The landslide extends into the Yangtze River and a valley divides the landslide into two blocks designated as eastern Block-1 and western Block-2.

Figure 11.3 is the plan of the Shuping landslide, which lies between elevation 65 and 400 m with a width of about 650 m. Boreholes indicate that the landslide is between 40 and 70 m thick, and the landslide volume is about 20 million m^3. The average slope of the landslide ranges from 22° in the upper part to 35° in the lower part.

According to the local inhabitants, cracks appeared in the roads and houses on the slope as soon as the first impoundment was finished on June 15, 2003. Figure 11.4 shows a crack at the right boundary of Block-1 in an outcrop on a local road. Red, clay-rich landslide debris on the right side of the photograph is displaced against gray sandy mudstone and muddy siltstone of Triassic Badong formation (T_2b).

Fig. 11.2 A photograph of the Shuping landslide facing the main stream of the Yangtze River (taken from the opposite bank, facing south)

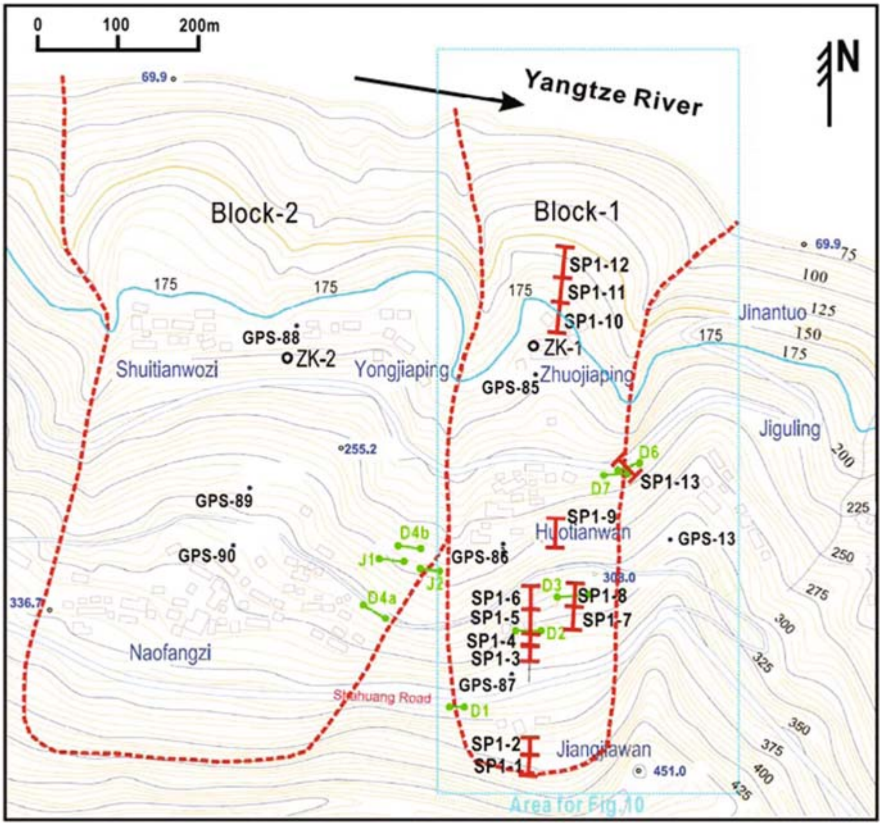

Fig. 11.3 Plan of the Shuping landslide (the locations of the extensometers shown in this map are those installed in 2004)

The reservoir level was kept nearly constant at 135 m for a long period after the first impoundment. Muddy water was observed coming out of the toe of Block-1 on January 5, 2004, and again on February 8, 2004. Since March 2004, the water near the toe has remained muddy. Figure 11.5 shows the muddy water at the toe in April 2004. The muddy water may be due to groundwater flow along the active slide surface. On the nights of January 25, 2004, and February 8, 2004, local inhabitants reported loud noises from the deep within the slope.

Figure 11.6 shows the cracks along the Shahuang Road in the upper part of the slide in July 2007. The road was paved in April 2007. The cracks reached about 10 cm in width in 3 months.

To monitor the movement of the Shuping landslide, the Chinese Ministry of Land and Resource installed six Global Positioning System (GPS) stations along the longitudinal axis of Block-1 and Block-2 (GPS-85 to GPS-90 in Fig. 11.3) and surveyed monthly. Figure 11.7 shows the first 6 months of movement data after the installation. In Block-1, more displacement occurred at the toe (GPS-85) and in the middle

Fig. 11.4 Crack at the right boundary of Block-1 outcropped at a local roadside

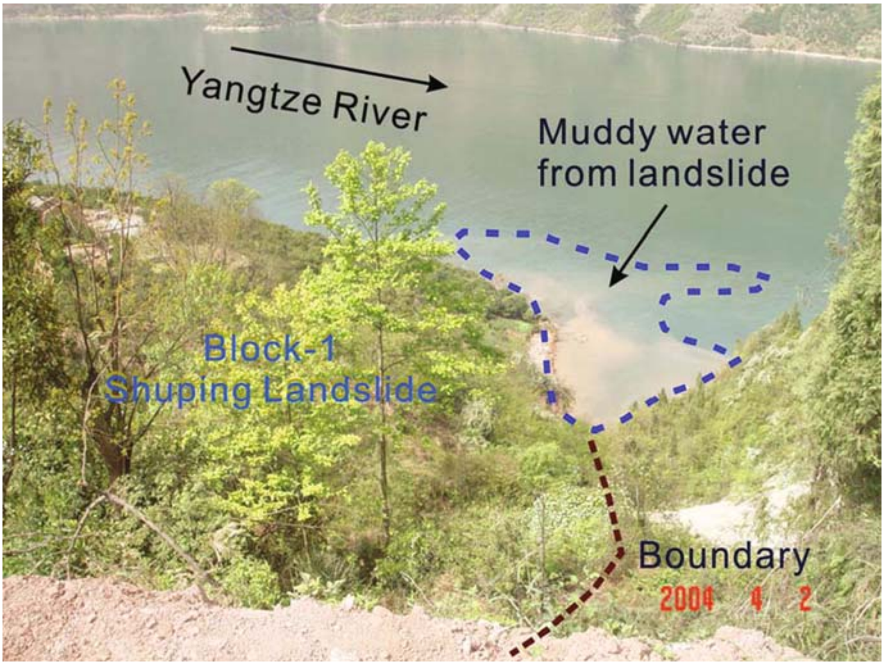

Fig. 11.5 The phenomenon of muddy water coming from Block-1 of the landslide (photo taken on April 2, 2004)

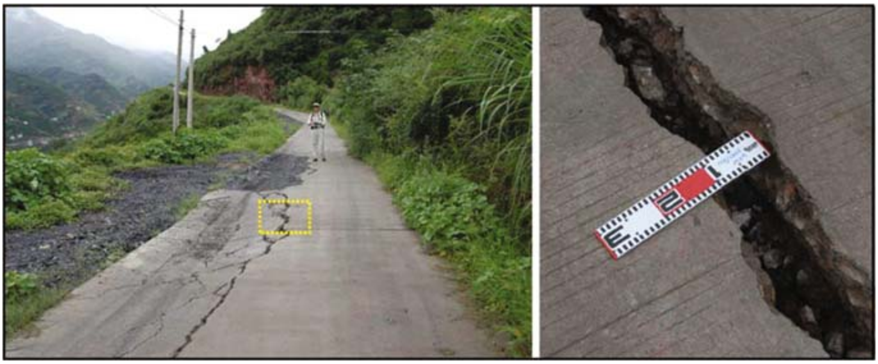

Fig. 11.6 Failure situation of the Shuping landslide at the Shahuang Road (photos taken on July 13, 2007)

of the slide (GPS-86) than in the upper part (GPS-87). In Block-2, more displacement occurred in the toe (GPS-88) than in the upslope parts of the slide (GPS-89 and GPS-90).

In China, local inhabitants are trained to recognize landslide deformation and report it to local officials. The local government may then have appropriate experts conduct detailed investigations. In the Shuping area, the inhabitants were requested to measure cracks three times per day. Figure 11.8 shows the crack monitoring

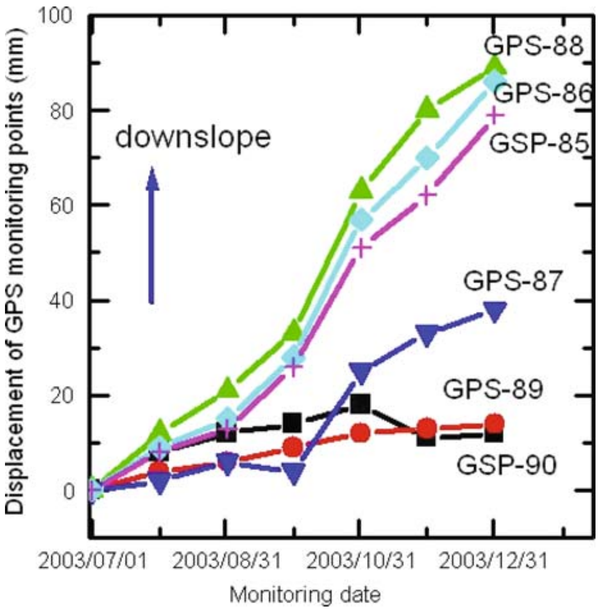

Fig. 11.7 GPS monitoring results on the Shuping landslide by Chinese Ministry of Land and Resource (measured by Geo-Hazard Mitigation Research Institute, China Three Gorges University)

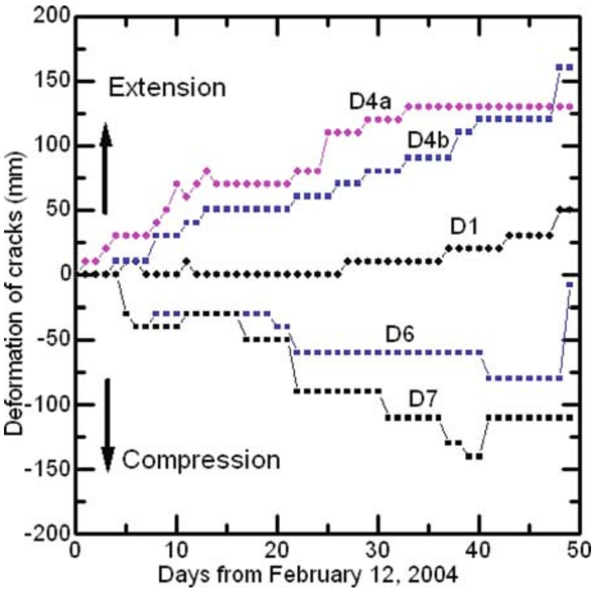

Fig. 11.8 Crack monitoring results on the Shuping landslide by the local residents (Zhang et al. 2004)

results for 50 days in early 2004. A maximum of 150 mm of both stretching and shortening occurred during the monitoring period (Zhang et al. 2004).

Based on the data, evacuation instructions were issued to the 163 families, a total of 580 people, to move out of the slide area. By May 2004, the relocation of the inhabitants of the Shuping landslide to other stable areas was finished.

Landslide Geometry

Estimation of the landslide geometry is critical to risk analysis. To determine the depth of the sliding surface (surface of rupture), a borehole was drilled in the lower part of Block-1 at ZK-1 (see Fig. 11.3 for the location) in December 2004. In the borehole, the groundwater table was about 8.8 m deep, and the surface of the rupture zone, which consisted of silty clay with gravel, was at a depth between 66.7 and 75.9 m. Slickensides were numerous in the zone (Wang et al. 2005).

Extensometers Monitoring Results

Part 1: August 2004–July 2006

In April 2004, we installed the first two drum-style extensometers in the Shuping landslide across two ground cracks, one at the east boundary crossing the crack shown in Fig. 11.4 and the other in the centerline of Block-1. Zhang et al. (2004) summarized the results of the initial movement monitoring.

In August 2004, 11 additional extensometers were installed nearly along the centerline of Block-1 (the locations are shown in Fig. 11.3). Extensometers SP1-1 and SP1-2 were installed near the main scarp of the landslide. Extensometers SP1-3 through SP1-9 were installed between the Shahuang Road and a local agriculture road (Fig. 11.3). One of these, SP1-5, crossed a continuous crack. Extensometers SP1-10 through SP1-12 were installed near the toe and the Yangtze River. Extensometers SP1-13 was located along the east boundary of Block-1. In addition, warning alarms were connected to extensometers SP1-5 and SP1-13. The alarms were set to a trigger when the displacement rate exceeds 2 mm/h. The maximum measurable displacement of each extensometer is 500 mm. To measure both stretching and shortening, the target of the extensometer was adjusted to the middle of the drum. The extensometer and standing pile were connected by a super invar line that was protected by a vinyl pipe. The measurements were recorded on both paper and a flash memory card. Data collection was conducted once a month, and at each time, the target was adjusted in order to ensure successful monitoring during the following month.

Figure 11.9 shows the monitoring results from the extensometers for the 2 years between August 2004 and July 2006. Rainfall near the landslide and the water level in the Three Gorges Reservoir (measured upstream of the dam by the China Yangtze River Three Gorges Project Development Company) are also shown. No stretching was detected across the main scarp of the landslide (SP1-1 and

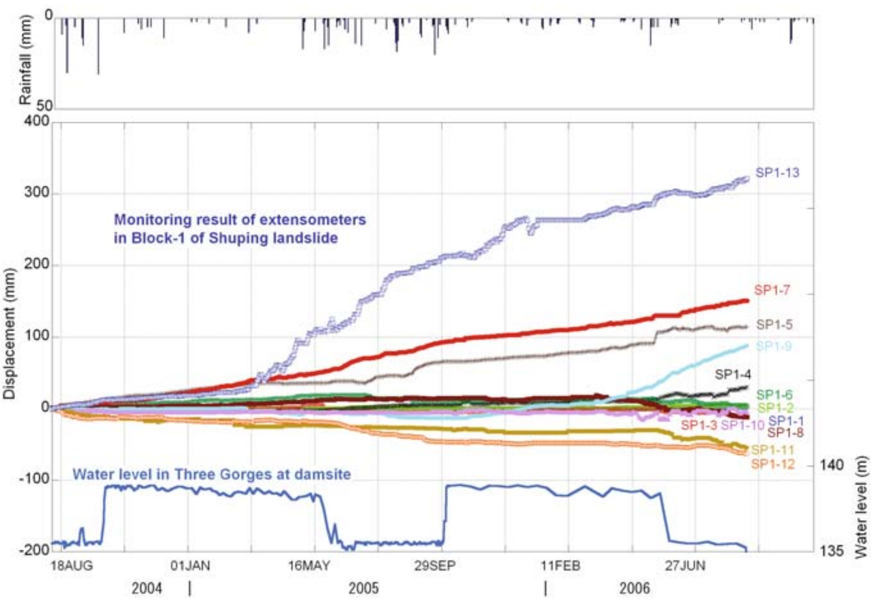

Fig. 11.9 Monitoring results with the drum extensometers for the period from August 2004 to August 2006 in Block-1 of the Shuping landslide. Rainfall for the period and the water level in the Three Gorges Reservoir are also shown

SP1-2), but stretching occurred in the middle of the slide (SP1-5, SP1-7, SP1-9, and SP1-13), and shortening occurred near the toe (SP1-11 and SP1-12). The monitored results correspond to observed ground deformation, including ground cracks, at least qualitatively. Deformation (and landslide movement) occurred synchronously with water-level fluctuations in the reservoir. Notably, the landslide was active when the reservoir level decreases. Locally, such as at SP1-5, the rate of movement increased during the period of rainfall (in the wet season). Thus, movement of the Shuping landslide appears to occur in response to both reservoir level changes and rainfall.

Part 2: August 2006–July 2007

In July and August 2006, an additional 11 extensometers were added to the monitoring system. As a result, a total of 22 extensometers were located in a nearly continuous line along the centerline of Block-1 above 220 m in elevation. In addition, two extensometers were located along the east boundary of the slide. However, our inability to place extensometers across the Shahuang Road and the local agriculture road resulted in two gaps in the monitoring line (Fig. 11.10). In the area near the high waterline, five flexible extensometers consisting of stiff carbon fiber rods connected to an extensometer transducer were installed to monitor the displacement (Fig. 11.11).

Figure 11.12 shows the monitoring results of the drum extensometers installed along the centerline and the east boundary of Block-1, changes in the reservoir level, and the daily rainfall at Xietan town (see Fig. 11.1b for location) measured by Zigui County Meteorological Observatory, Hubei Provincial Meteorological Bureau. Xietan is a small town on the opposite bank across from the Shuping landslide. Because the rainfall gauge is only about 1 km from the Shuping landslide, the data provide a reasonable estimate of the rainfall at the slide.

In Fig. 11.12a, the monitoring results from areas with the greatest deformation (stretching or shortening) are shown. The most stretching (about 240 mm) occurred at three extensometers, i.e., extensometer SP1-N-5 in the upper part of the slide and the two extensometers (SP1-N-23 and SP1-N-24) along the east boundary. At extensometer SP1-N-7 in the upper part of the slide a period of stretching was followed by a period of shortening. About 85 and 60 mm of shortening occurred at extensometers SP1-N-15 and SP1-N-11, respectively.

The remainder of the extensometers recorded smaller deformations (Fig. 11.12b, c, and d). In general, shortening deformation was more common than stretching in the upper half of the landslide. Continuous stretching was recorded at only three extensometers (SP1-N-4, SP1-N-12, and SP1-N-19) (Fig. 11.12b, c, and d), whereas shortening was recorded at most of the other extensometers.

Most of the movement occurred during a period when the water level in the Three Gorges Reservoir is lowered to prevent flooding in the wet (monsoon) season in the region. We speculate that the movement occurred as a result of the increased precipitation during the wet season, but the effect of the declining reservoir level on landslide stability requires additional consideration. Our monitoring results suggest

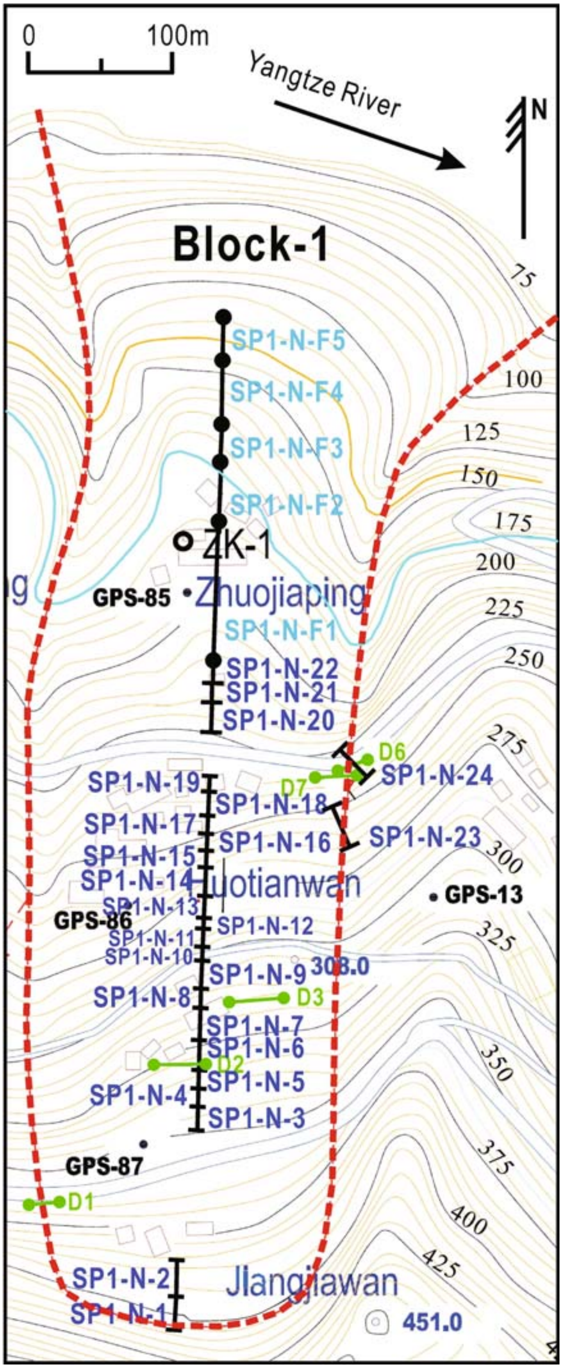

Fig. 11.10 Location of the extensometers installed in August 2006 in Block-1 of the Shuping landslide (the area of this figure is shown in Fig. 11.3)

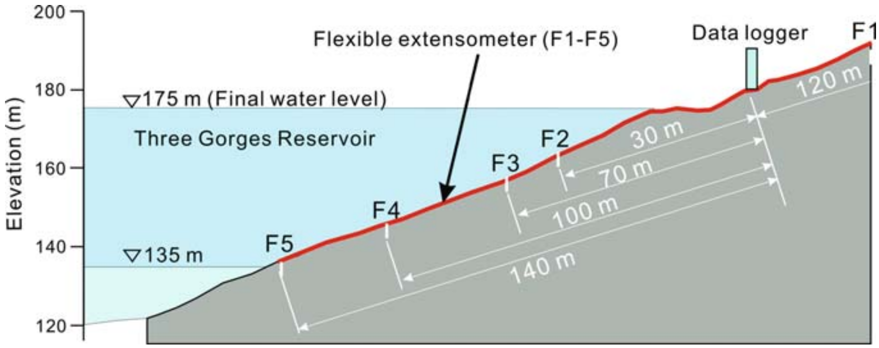

Fig. 11.11 Schematic showing the installation concept of flexible extensometers in the area affected by the changing water level at the toe part of the Shuping landslide, Block-1

that landslide stability is not increased during the period of lower reservoir levels, which has significant implications for landslide disaster mitigation.

Figure 11.13 shows that some of the deformation in the lowermost part of the landslide below the high waterlines coincides with the impoundment in October 2006. Additional deformation occurred during a period of gradually declining reservoir level, which began in February 2007 during the wet season.

Part 3: August 2007–May 2007

In August 2007, with three additional extensometers, a continuous monitoring system passing Shahuang Road and the local road was completed. During this work, maintenance and adjustment of the drum-style extensometers were conducted. The positions of some extensometers were changed to cross obvious cracks and make the monitoring system better. Figure 11.14 shows the modified extensometer line. As a result, a total of 24 extensometers were located in the line along the centerline of Block-1 above 220 m in elevation. In addition, two extensometers (M-25 and M-26) were located along the east boundary of the slide. The five flexible extensometers were kept in the area near the high waterline.

Figure 11.15 shows the monitoring result from August 2007 to May 2008. It is shown that the displacement of the Shuping landslide became active (1) when water level increased rapidly from 145 to 156 m in October 2007; (2) during the rainfall period around April. Also, the whole tendency is that the displacement gradually accumulated when the water level decreased from 156 to 148 m.

Longitudinal Deformation Model

Based on the monitoring results and field observations, we developed longitudinal deformation models of the Shuping landslide. Figure 11.16 shows the slope

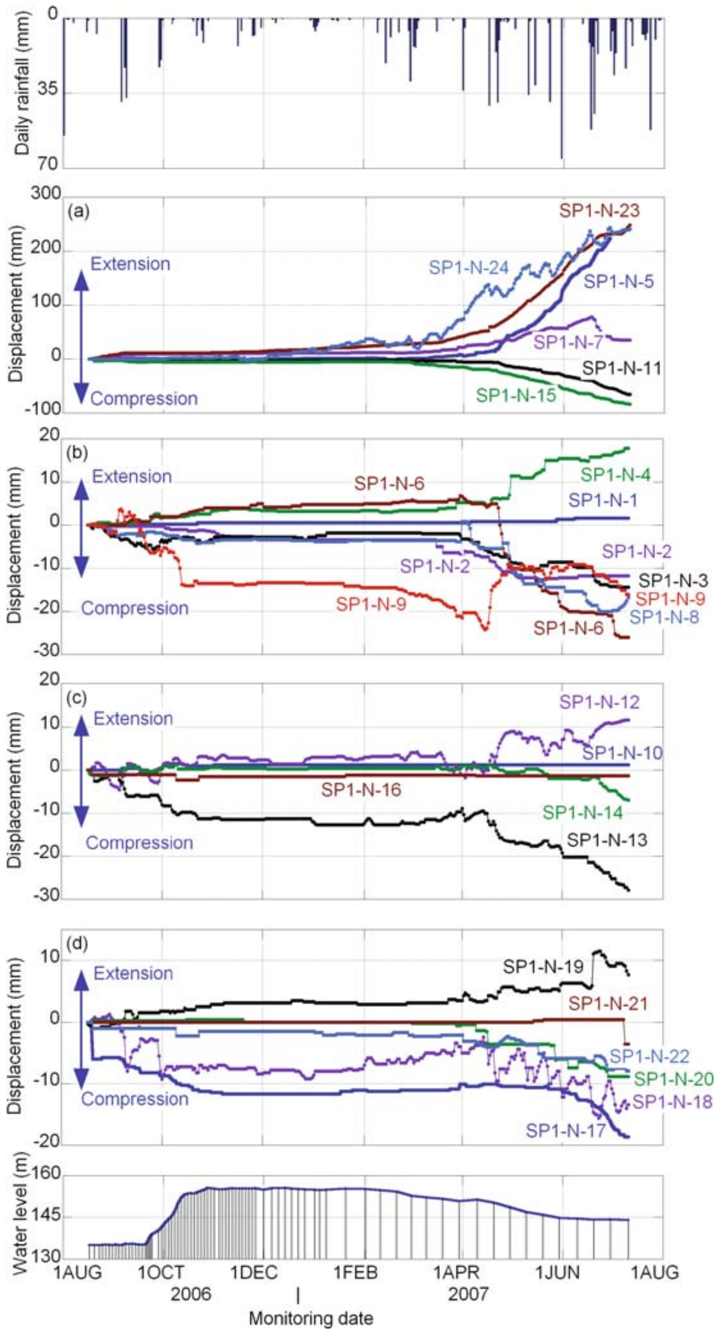

Fig. 11.12 The monitoring results of the drum-style extensometers in Block-1 of the Shuping landslide in the period from August 2006 to July 2007, the changing water level in the Three Gorges Dam Reservoir, and local rainfall data

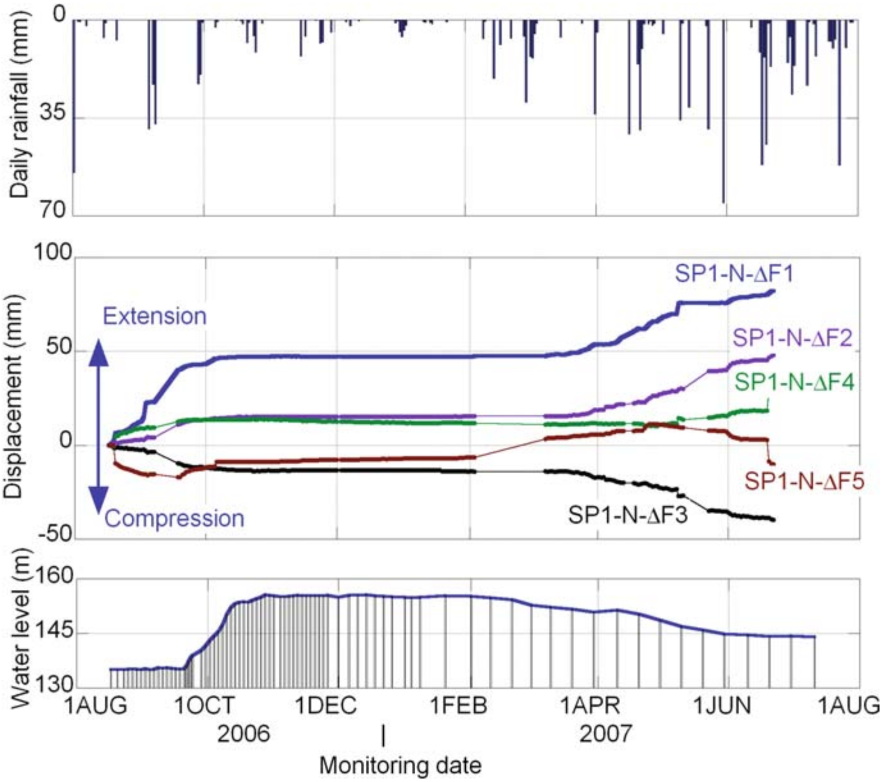

Fig. 11.13 The monitoring results of the flexible extensometers at the toe part of Block-1 of the Shuping landslide in the period from August 2006 to July 2007 and the comparison with the water level changing in the Three Gorges Dam Reservoir

deformation based on the first 2 years of monitoring from August 2004 to July 2006. Because of gaps in the instrumentation, the deformation model is not continuous or complete. Stretching occurred in the upper part of the slide near Shahuang Road, and shortening occurred in the lower slide near ZK-1. Figure 11.9 shows more stretching occurred near the Shahuang Road than shortening that occurred near the toe. However, the initial GPS monitoring indicated that the greatest displacements initially occurred in the lower part of the slide (Figs. 11.3 and 11.7). Thus, during the initial impoundment, the lower part of the slide moved most.

Figure 11.17 shows our longitudinal deformation model of Block-1 based on the monitoring results from August 2006 to July 2007. The *solid line* under the slope surface represents the displacement in that period. Lines tilted toward the river indicate stretching and those tilted upslope indicate shortening. The estimated landslide geometry is shown using *dotted lines*. An inclinometer in borehole ZK-1 indicates that the depth of the surface of rupture is about 45 m.

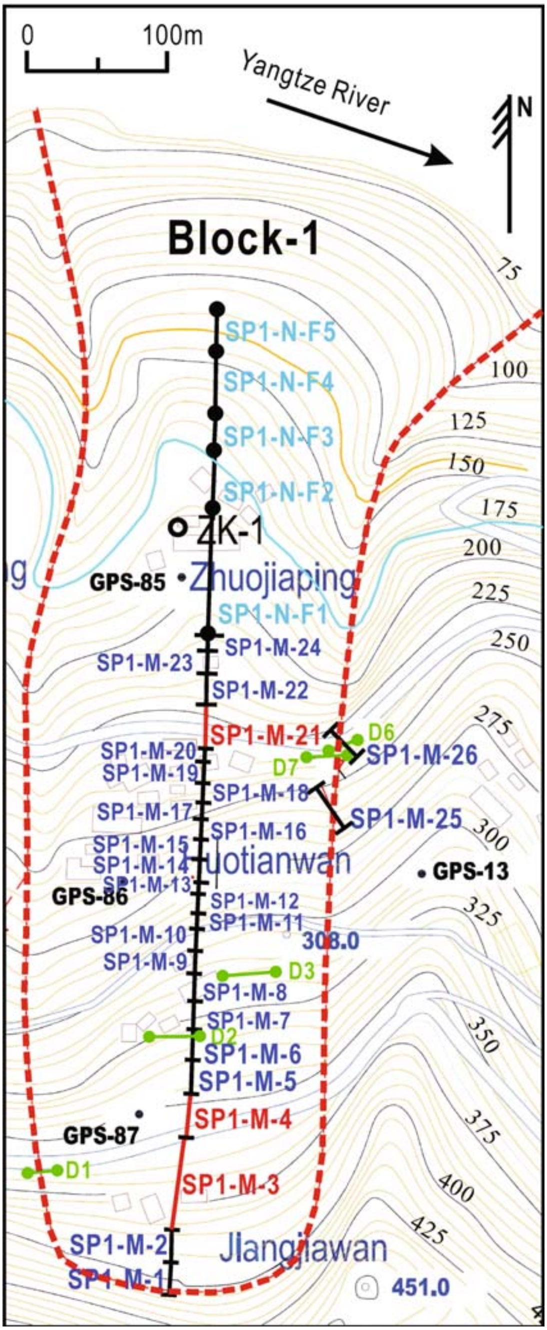

Fig. 11.14 The continuous extensometer monitoring line completed in August 2007

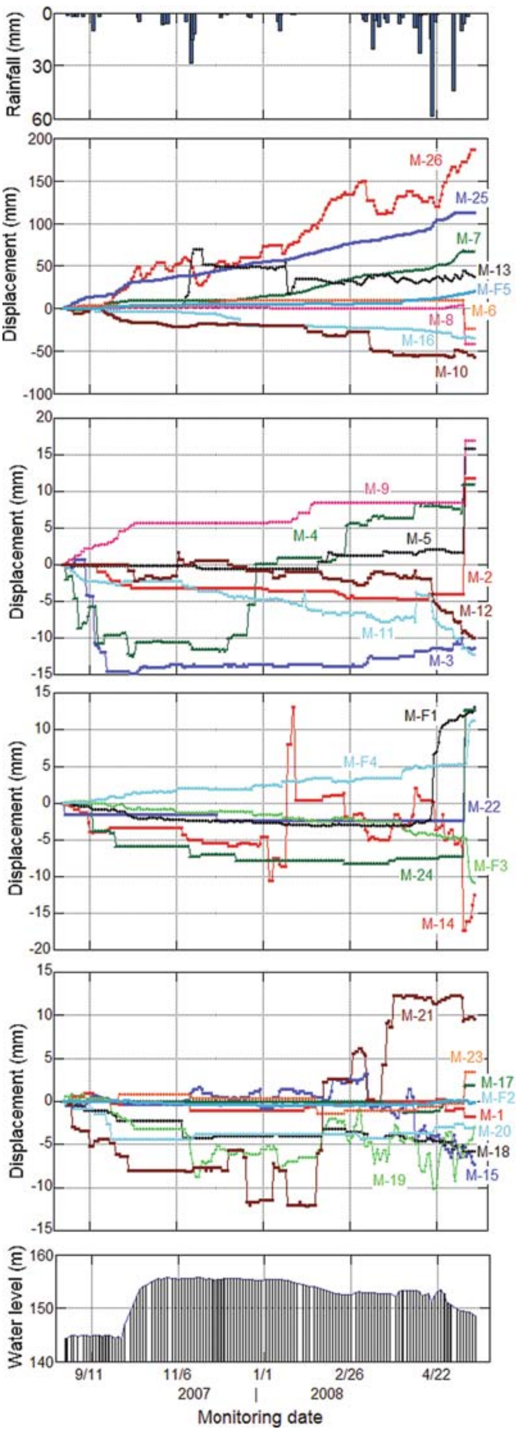

Fig. 11.15 Monitoring results with the continuous monitoring line from August 2007 to May 2008

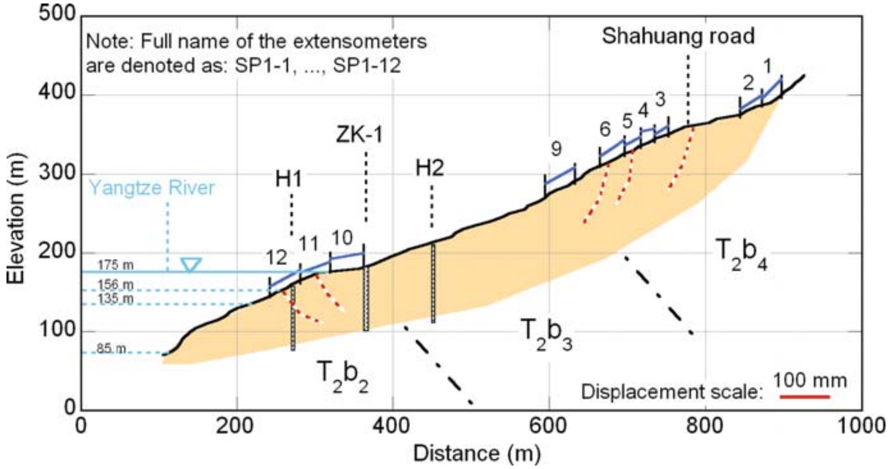

Fig. 11.16 Estimated deforming style of Block-1 of the Shuping landslide based on the monitoring results from August 2004 to July 2006 and the surveying results on the cracks distributing in the slope surface

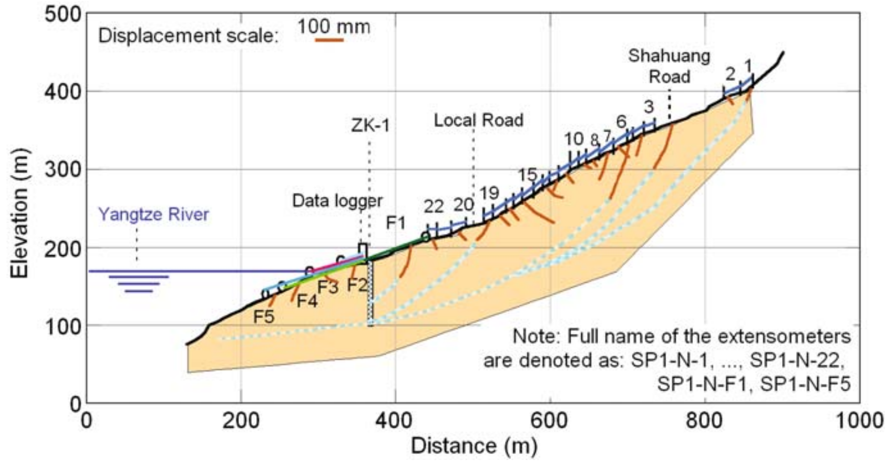

Fig. 11.17 Estimated deforming style of Block-1 of the Shuping landslide based on extensometer monitoring from August 2006 to July 2007

Conclusions

Based on extensometer measurements over a 3-year period, we conclude the following:

(1) Movement of the Shuping landslide corresponds to water level changes in the Three Gorges Reservoir. Interestingly, movement also occurs during periods of declining reservoir level.

(2) Comparison of displacement and deformation data over a 4-year period suggests increasingly complex deformation of Block-1 of the Shuping landslide. Areas of intermixed shortening and stretching occur currently on the slide.
(3) Movement of the landslide occurred during the wet season when reservoir level is lowered for flooding control. Thus, movement monitoring of this landslide is critical even during periods of low reservoir level.

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