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# Applicability of Time Domain Reflectometry for Yuhuangge Landslide Monitoring

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**ABSTRACT: Yuhuangge (玉皇阁) landslide in Wushan (巫山), Chongqing (重庆), is one of the focal monitoring geological hazards in the Three Gorges Reservoir. Time domain reflectometry (TDR) and in-place inclinometers were arranged to monitor the deep deformation. Time domain reflectometry is based on transmitting an electromagnetic pulse into a coaxial cable grouted in rock or soil mass and watching for reflections of this transmission due to cable deformity induced by the ground deformation. Comparing the monitoring data of No. 5 Station, in the middle profile of the landslide, from June to December of 2008, the depth of slip surface determined by TDR is -33.58 m, which is consistent with the geological condition of the borehole nearby. The deformation curve trend of the TDR and inclinometer is similar, and it is uniform with the deformation caused by the Three Gorges Reservoir 175 m experimental impoundment. Further, TDR can monitor the tiny deformation accurately. Therefore, TDR is applicable to monitor the Yuhuangge landslide deep deformation and reflect the deformation characteristics well. It is significant to promote the application of TDR in landslide monitoring.**

**KEY WORDS: time domain reflectometry, Yuhuangge landslide, applicability, deformation monitoring, fluctuation of reservoir level.**

## INTRODUCTION

A landslide is a major geohazard that often requires a monitoring system, in which the localized shear deformation is most important. Inclinometer probes are widely used for such a purpose. Manually logged inclinometers can provide a deformation profile, which is piecewise linear with a typical gauge length of 50 cm. However, it is not practical to automate such inclinometer measurements. Since 1988, TDR technology was applied to rock deformation monitoring (Dowding et al., 1989, 1988); it has gotten the concern and attention of geotechnical engineers for its advantages, such as speed, accuracy, and remote control. It has also been used in geological disaster monitoring in the middle of 1990s (Heimovaara, 1994; O'Connor, 1991). In 2003, China

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Geological Survey established geological disaster monitoring and warning demonstration stations in Wushan County in the Three Gorges Reservoir. It used TDR, inclinometer, and many other instruments to carry out landslide and other geological disaster monitoring in the Three Gorges Reservoir. Yuhuangge landslide is one of TDR monitoring the demonstration sites. Studying the applicability of time domain reflectometry for Yuhuangge landslide monitoring is significant to promote the application of TDR.

### Principles of Time Domain Reflectometry

TDR was developed by electrical engineers as a method to locate discontinuities in coaxial transmission cables. The technique has been extended to measure the properties of materials in which conductors are embedded, such as soil water content and evaluation of material dielectric behavior (Hammy and Fejes, 1992; Hasenfus et al., 1988). It can be applied to monitor sliding within slopes (Su and Chen, 1998). When a coaxial cable is embedded in a drill hole, it works like a continuous sensor that can detect fracturing and relative movement at any location along its length. Figure 1 is the principle sketch map of TDR in landslide monitoring. Electrical pulses, in the form of electromagnetic waves, transmit to depths along the coaxial cable. The deformation of soil or rock mass will produce shear and tensile deformation of local coaxial cable, which would change the impedance characteristic of it. Electromagnetic waves will reflect and refract in these areas, which will be found in the reflected signals. The return time of reflected signal and the size of the reflection coefficient could determine the deformation location and size of the embedded coaxial cables (Zhang, 2007; Wu and Xu, 2002). Therefore, the location and deformation of the sliding surface were obtained.

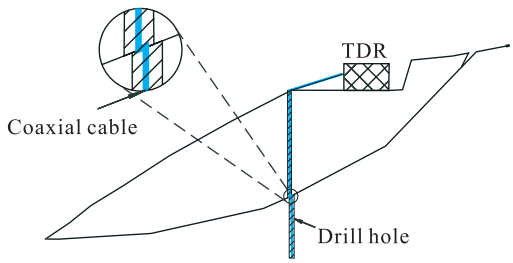


**Figure 1. Sketch map of TDR buried.**

## YUHUANGGE LANDSLIDE

### Basic Characteristics of Landslide

Yuhuangge landslide is located on the left bank of the Yangtze River, new Wushan County of Chongqing City. It is one of the most complicated geohazards of Wushan. The western boundary is near the Sidaogou. The eastern boundary is the lateral ditch of Toudaogou. The front is in the area of the Yuhuangge at the bank of the Yangtze River, the elevation is 130 to 160 m. The rear extends to the rear groove of Goujiaping, and the elevation is 500 to 520 m. The width is 780 m, and the length is 1 500 m. Total volume is about $9\times10^7$ $m^3$. The average terrain gradient of the slope is from 30° to 47°.

The front part of the landslide, Yuhuangge accumulation, below the Gaotang Village, is one of the important monitoring and warning landslides in the Three Gorges Reservoir, and it is also the emphasis of this article. The boundary is Erdaogou and Sandaogou. The rear edge is to Guangdong Road, and the front to the high overbank of the Yangtze River. The volume is about $125\times10^4$ $m^3$.

The Yuhuangge landslide is mainly composed of cracked rock, rubble and soil, and silty clay with pebble of the Triassic Badong Group ($T_2b^3$). The thickness of the front is 40–80 m. The thickness in the area of Xiping Vocational School is 100–198 m. The material and thickness in the rear vary widely. From top to bottom, it can be divided into two layers: rubble and soil and rubble or cracked rock. The bedrock is isabelline marlstone and argillaceous limestone of the Triassic ($T_2b^1$). The strength is weak.


**Figure 2. Monitoring system design.**

**Monitoring System Design**

Yuhuangge landslide has designed three monitoring sections, which are shown in Fig. 2. The middle, I–I′ geological profile is the principal section, and it is the axle wire. The tendency along the slope points to the Yangtze River. The trend is 163° (SEE). It is about 350 m. II–II′ is in the eastern part and III–III′ in the western part; monitoring profiles are GPS monitoring section.

Figure 3 shows the details of the monitoring system. It consists of five GPS for surface deformation monitoring, two in-place inclinometers and two TDR system to monitor the deep deformation, two pore-water pressure stratified monitoring spots, two soil moisture monitoring apparatuses, one vibration string, and one automatic pluviometer monitoring spot.

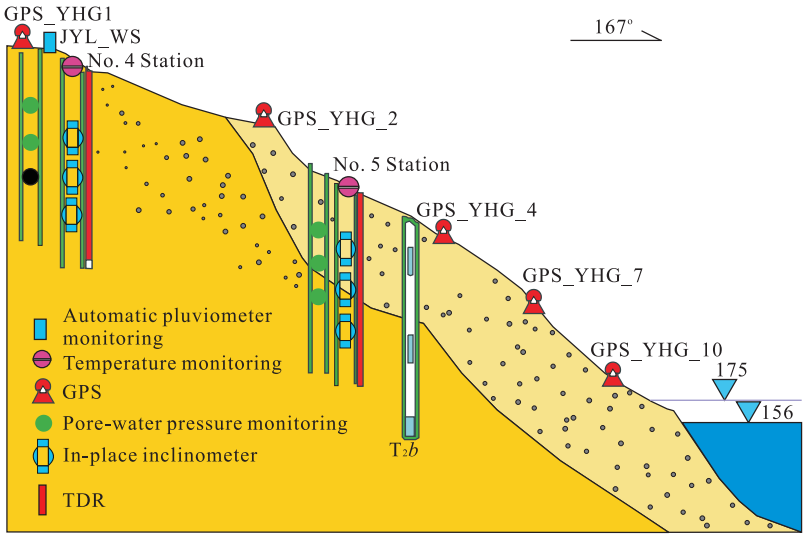


**Figure 3. Monitoring profile of Yuhuangge landslide.**

The TDR monitoring cycle of Yuhuangge is one day, and the processing data were announced timely, which truly realized the real-time monitoring process.

## APPLICABILITY OF TDR FOR LANDSLIDE MONITORING

To study the applicability of TDR for Yuhuangge landslide, the monitoring data of TDR and inclinometer were analyzed by choosing five monitoring stations from June to December 2008.

Figure 4 shows the monitoring data curves of five stations. Due to the upper curves (0 to -33 m) with small changes, the figure only mapped the TDR signal curves of the hole depth from -25.0 to -35.0 m to highlight the curves. Figure 5 is the geological columnar section of borehole nearby.

In Fig. 4, monitoring curves turn out apparent inflection in depth -33.58 to -33.76 m and the signal amplitude of lower part of monitoring change greater than the upper, which shows that the landslide deformation is larger in the depth. Therefore, the depth of the slip surface could be determined at about -33.58 m. According to the geological condition of the borehole nearby, it is silty clay with rubble breccia of soft-plastic state in depth of -32.4 to -34.2 m, which is the soft interlayer, and it is identified as the sliding zone in the field. That is a very good correspondence

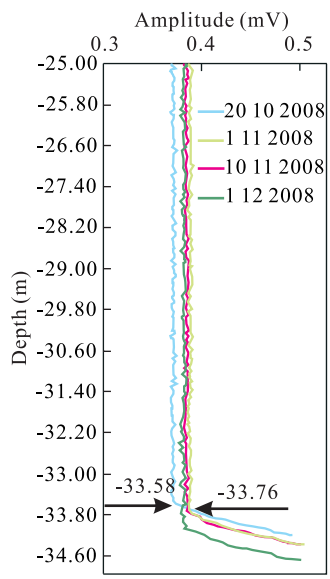


**Figure 4. TDR monitoring curves of No. 5 Station.**

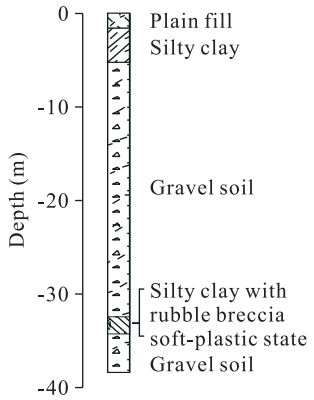


**Figure 5. Geological columnar section of borehole near No. 5 Station.**

with TDR monitoring curve. Therefore, it is suitable to use TDR for determining the location of the slip surface.

From 0 to -33.58 m, the monitoring curve trends in a vertical line, which notes that the coaxial cable in the borehole has almost no deformation. The curve shows an apparent 'burr' phenomenon, which is mainly due to the existence of 'noise', the interference signal, in the monitoring process. Therefore, monitoring information is required by the denoising processing in order to obtain the relationship between monitoring signal amplitude changes and deformation changes.

As the TDR is real-time monitoring technology, monitoring data are numerous, and there are 599 data per day and nearly 20 000 data per month.

However, for the deep landslide deformation monitoring, the most important consideration is the deformation at the sliding zone. Therefore, we only take the TDR monitoring data at the sliding zone each day to draw the signal curve. Figure 6 shows the TDR and in-place inclinometers near the slip zone monitoring curve of No. 5 Station from June to December 2008.

Some conclusions can be gained in Fig. 6 as follows.

(1) The deformation trend obtained by TDR and inclinometer from Yuhuangge landslide is consistent, which proved that TDR in the Yuhuangge landslide deformation monitoring is feasible. Li (2009) has obtained the statistical relationship between TDR signal

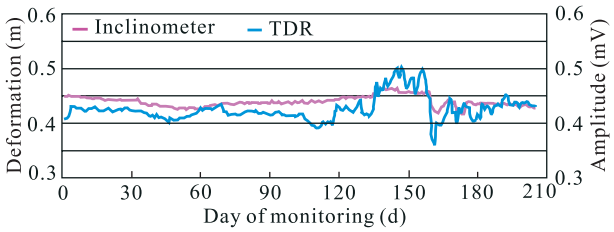


**Figure 6. Monitoring curves of the slip zone of No. 5 Station.**

amplitude and deformation of Xiakou landslide, Ya'an, Sichuan, through studying the correlation of TDR signal amplitude and inclinometer monitoring deformation values. It is of referential significance to study the applicability of TDR for the in-depth monitoring of Yuhuangge landslide.

(2) From October 15 to November 8 (i.e., 136–160 d), there is a clear band of increase in both of the two monitoring curves. This indicates that the relative deformation of the slip surface is large during this time. This is mainly due to the deformation increased by the impoundment. At the end of September 2008, the Three Gorges Reservoir began to have experimental impoundment to 175, and by November 6, 2008, the water level of the dam reached 172.5 m.

(3) There is an obvious fluctuation in the two monitoring curves from November 8 to 23 (from 160 to 175 d), but the general tendency was to descend, which proves that the relative deformation decreased on the sliding zone. On November 6, water storage was stopped in the Three Gorges Reservoir; as a result, the water level declined gradually and deformation of the landslide diminished gradually.

(4) The experimental water storing of the Three Gorges Reservoir to 175 m has a certain effect on Yuhuangge landslide, but the displacement is smaller and still in the normal range. For the Yuhuangge landslide, it is almost impossible to deform again, to a great extent, which has been controlled.

(5) The fluctuation of TDR curve is bigger than that of the inclinometer. On one hand, this shows the noise phenomenon of the signal; on the other hand, this proves that the TDR monitoring system is more accurate and viewing is more direct for capturing and monitoring the micro deformation of the landslide.

## CONCLUSIONS

According to the application of TDR for the Yuhuangge landslide monitoring and the comparison between TDR and inclinometer, some conclusions can be gained as follows.

(1) Based on the TDR monitoring data of Yuhuangge landslide from June to December in 2008, the depth of the sliding zone is about -33.58 m. It coincides with the geological condition of the borehole nearby. This proves that it is well suitable to use TDR for the sliding surface determination of Yuhuangge landslide.

(2) The deformation tendency of Yuhuangge landslide is the same, based on both TDR and inclinometer monitoring, which proves the feasibility of TDR in the landslide deformation monitoring.

(3) According to the TDR deformation monitoring of Yuhuangge landslide during the period of experimental water storing, from September to November in 2008 in the Three Gorges Reservoir, the TDR monitoring signals can reflect the deformation of the landslide. Compared with the inclinometer, the TDR is easier to monitor the micro deformation. The experimental water storing in the Three Gorges Reservoir has a certain effect on Yuhuangge landslide, but the amount of displacement is smaller in the normal range, which shows that the landslide is stable.

(4) The noise phenomenon exists in the TDR monitoring signal. The relationship between the monitoring signal amplitude and the landslide displacement changes can be obtained after the signal noise is eliminated.

## ACKNOWLEDGMENTS

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