Application of TDR cables for landslide monitoring

Miau-Bin Su[1] Chien-Hsin Liao[2]

[1] professor, Civil engineering Department, National Chung-Hsing University, Taichung, Taiwan, R. O. C.; PH 886-4-2286-1031; email: mbsu@dragon.nchu.edu.tw
[2] PhD student, Civil engineering Department, National Chung-Hsing University, Taichung, Taiwan, R. O. C.; PH 886-4-2284-0437 ext.234

Abstract

A landslide site in central Taiwan was studied using TDR technology. It is a part of the Li-Shan landslide remediation project conducted for the last 15 years. Total affected area for this landslide was estimated larger than 2 kilometers square and has a major central cross-island road passing through it.

Coaxial cables have been used as a portion of the monitoring system for Li-Shan landslide. The result showed that the sliding surfaces detected using TDR cables were compared fairly well with boring-log report. Sliding occurred right at the interface of the highly weathered slate and intact rock mass. Observation and GPS surveying on ground surface showed good consistent with subsurface monitoring result in regard to sling zoning and slide occurring duration.

Key Words TDR, landslide, monitoring system

Forward

Landslide area in Li-Shan village is located at the intersection between the east-west cross-island highway route 8 and route 7A heading to I-Lan in central Taiwan(as shown in Fig.1). In April 1990, an intense and spectacular landslide hazard occurred in this area following a prolonged torrential rain. The catastrophe lead to destroy the pavement foundation on route 7A, disrupted the transportation facilities, and triggered the nearby buildings such as Li-Shan Grand Hotel to crack and settle severely. After the disaster, the provincial government adapted a series of emergency remediation measures to mitigate the spread extent of the landslide. Subsequently, a contingent project for remediating the landslide was officially approved after an intensive investigation between 1991 and 1993[1]. The approved project, "Investigation and Renovation Planning for Landslides in Li-Shan Area" were executed between 1995 to 2002. The performance evaluation on the Renovation work for Li-Shan landslides were conducted at the end of 2002 to evaluate its achievement and to judge about future needs for protecting this area.

Geology and Topograph

Topographically, Li-Shan is located at the west wing of Central Ridge, with elevation between 1800 to 2100m(m.s.l). Most slopes are dipping to the northwest with slope angle between 15o~30o down to the Teh-Chi Water Reservoir. Geologically, Li-Shan is located at colluvial deposits originally from the Miocene Lu-Shan slate formation. Due to the high erosion rate, the slate formation in this area is highly weathered and jointed.

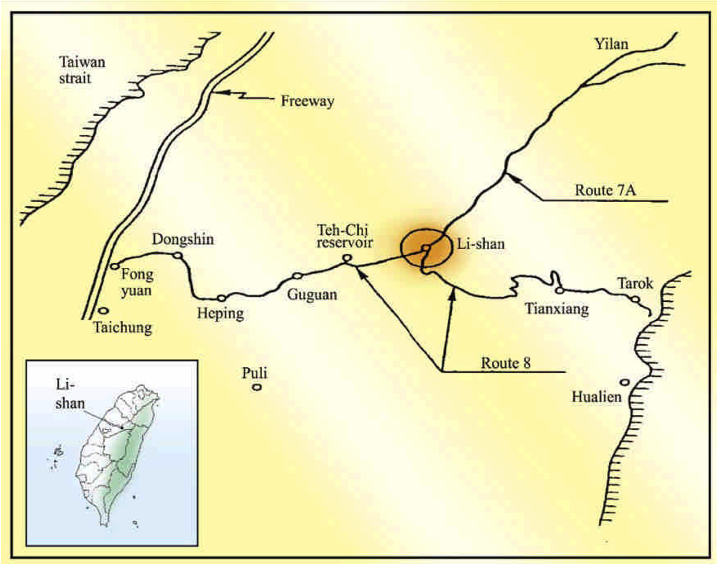

Fig. 1 Location of Li-shan area

Due to the high precipitation, the erosion rate in this area is high. Therefore there are different extent weathered slate formations covering the slope surfaces. For the purpose of stability study, rock are classified into 5 types, namely colluvium, strongly weathered slate, medium weathered slate, weakly weathered slate, and fresh slate. Fig.2 gives a picture of the geo-materials.

Slot no.	no.1	no.2	no.3	no.4	no.5
material classification	colluvium (Dt)	strongly weathered slate (W1)	medium weathered slate (W2)	weakly weathered slate (W3)	fresh slate (Rf)
content	brown/ sandy silt with broken rock	Black/ clay shape	Black/ fine plate	Black/ round plate to blocky	Black/ RQD>75
ISRM classification	VI	V	III,IV	II	I

Fig. 2 Classification of Geo-materials

Remediation Plan

The primary remediation work conducted for landslide stabilization in Li-Shan area is to lower the groundwater level and safely drain the surface runoff. It was estimated that the factor of safety against landslide could be increased up to 1.2 after the groundwater level was lowered down approximately 8.5 m. In the collapsed and sliding zone, the slope-geometry modification by removing part of the landslide mass was undertaken to ensure the slope stability is safe before the transportation facilities on route 7A was resumed to normal condition.

On June 25, 1994, the remediation project for Li-Shan landslide was officially approved by Executive Yuan. It was originally designed to be conducted for the period of 1995-2000. However, the project was extended from 2000 to 2002 due to the complicated features of hydrogeology in Li-Shan existing slide area, which consequently needed an appropriate field investigation process to deduce the properties of naturally occurring materials before the detailed design for remediation work was undertaken[2].

Systematic Structure of Monitoring System

Eight monitoring stations were set up in this area. Each station was equipped with facilities such as the piezometer for measuring the groundwater level, the inclinometer for monitoring the ground deformation, and the extensometer for detecting the surface movement. A picture of schematic of automatic monitoring system is given in Fig. 3.

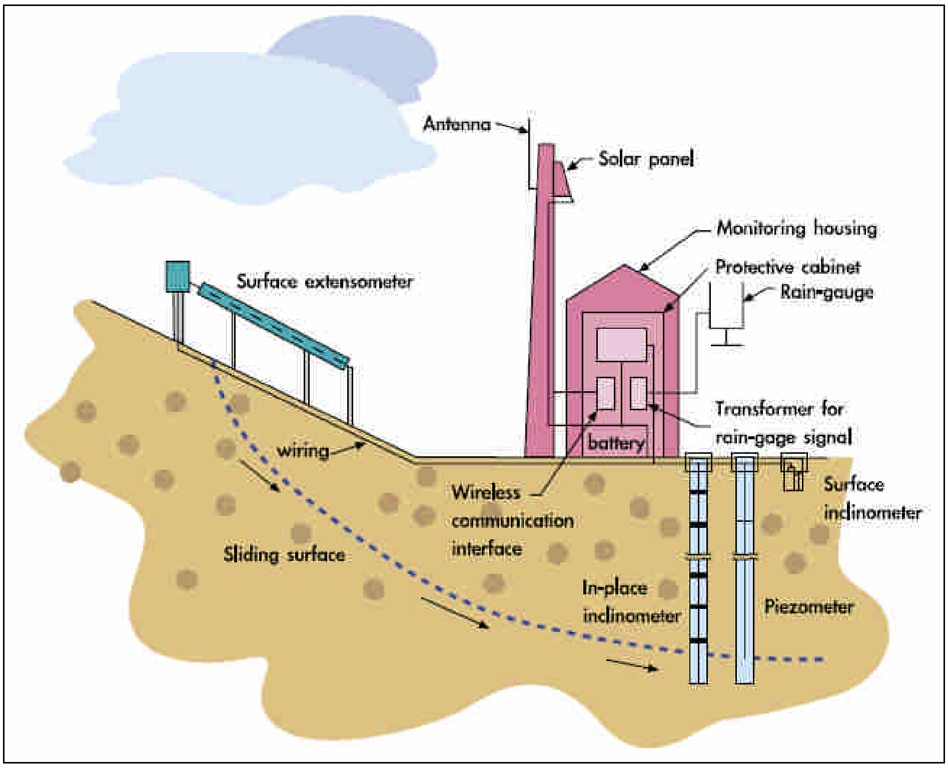

Fig. 3 Schematic of automatic monitoring system applied in Li-shan landslide area

Sliding Surface Monitoring

Inclinometers are the devices which are used to detect the location of the slip surfaces in unstable slopes. Two types on inclinometer are used in this study.

(1)In-place inclinometer

The sensor packages are spaced along a standard grooved inclinometer as shown in Fig.4. The sensors are aligned and secured in the casing by spring-loaded wheels, which fit the casing grooves. Readings could be obtained by measuring the change in tilt of the sensor, and then multiply it with the gauge length or spacing between sensors. The results are expressed as the relative displacement of each sensor; and these relative displacements can be summed to determine the total displacement at each sensor. The maximum deflection range is between 15^{o} and 30^{o} , and the precision is 0.01^{o}.

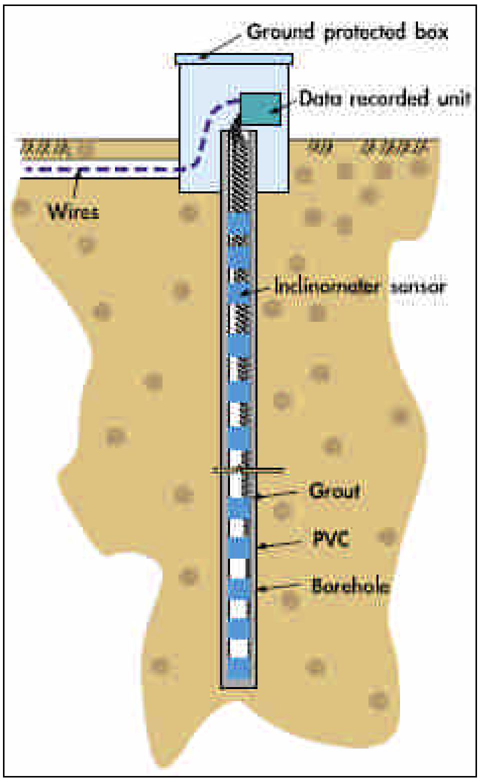

Fig.4 Setup of probe inclinometer

(2)Probe inclinometer

The probe inclinometer consisted of four components, which includes the guide casing, probe sensor, control cable or wire, and the portable control and readout unit as shown in Fig. 5. The probe sensor is lowered on an accurately marked cable, its wheels following the oriented slots of the guide casing. The response to slope changes in the casing could be monitored and recorded on the readout unit manually or automatically.

TDR(Time Domain Reflectometry) for Displacement Measurement using Coaxial Cable

TDR was developed by electrical engineers as a method to locate discontinuities in coaxial transmission cables . The technique has been extended to measurement of the properties of materials in which conductors are embedded, such as soil water content and evaluation of material dielectric behaviour. In rock mechanics, the technique has been employed to identify zones of rock mass deformation and blasting performance[3,4] .

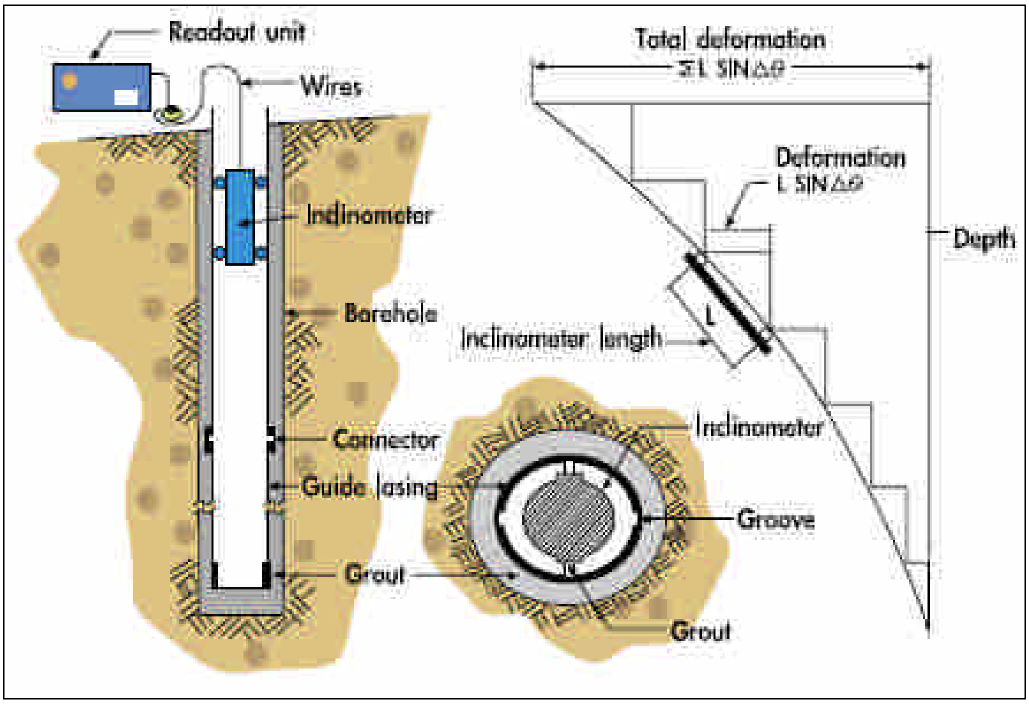

Fig.5 Sketch of probe inclinometer with manual readout

This technique can be applied to monitor sliding within slopes[5]. When a coaxial cable is embedded in a borehole it works like a continuous sensor which can detect fracturing and relative movement at any location along its length. An electromagnetic pulse is launched down the cable and reflection from points of cable deformation can be located precisely. TDR monitoring provides a viable tool when location of deformation are not known in advance. This is the major advantage for TDR compared with other monitoring systems[6]. Telemetric monitoring based on TDR theories has been proven to be applicable.

TDR has been applied to monitor the landslide region in Li-Shan. The findings indicate that the sliding surface location detected by using this technique was compared fairly well with the report of the boring-log exploration, in which the sliding surface was found at the interface between the highly weathered slate and the intact rock.

Results and Interpretation

(1) TDR signatures

Five TDR coaxial cable were installed in bore-hole in some of the monitoring station. Fig. 6 shows the location for the monitoring stations. Waveforms recorded from 4 stations are presented in here for discussing(see Fig. 7, 8, 9, 10). Cables were grouted within a PVC pipe as the protective sleeves. The PVC pipes had multiple hole predrilled so grout can fill up the space between bore hole and PVC pipe as well as the space between PVC pipe and coaxial cable.

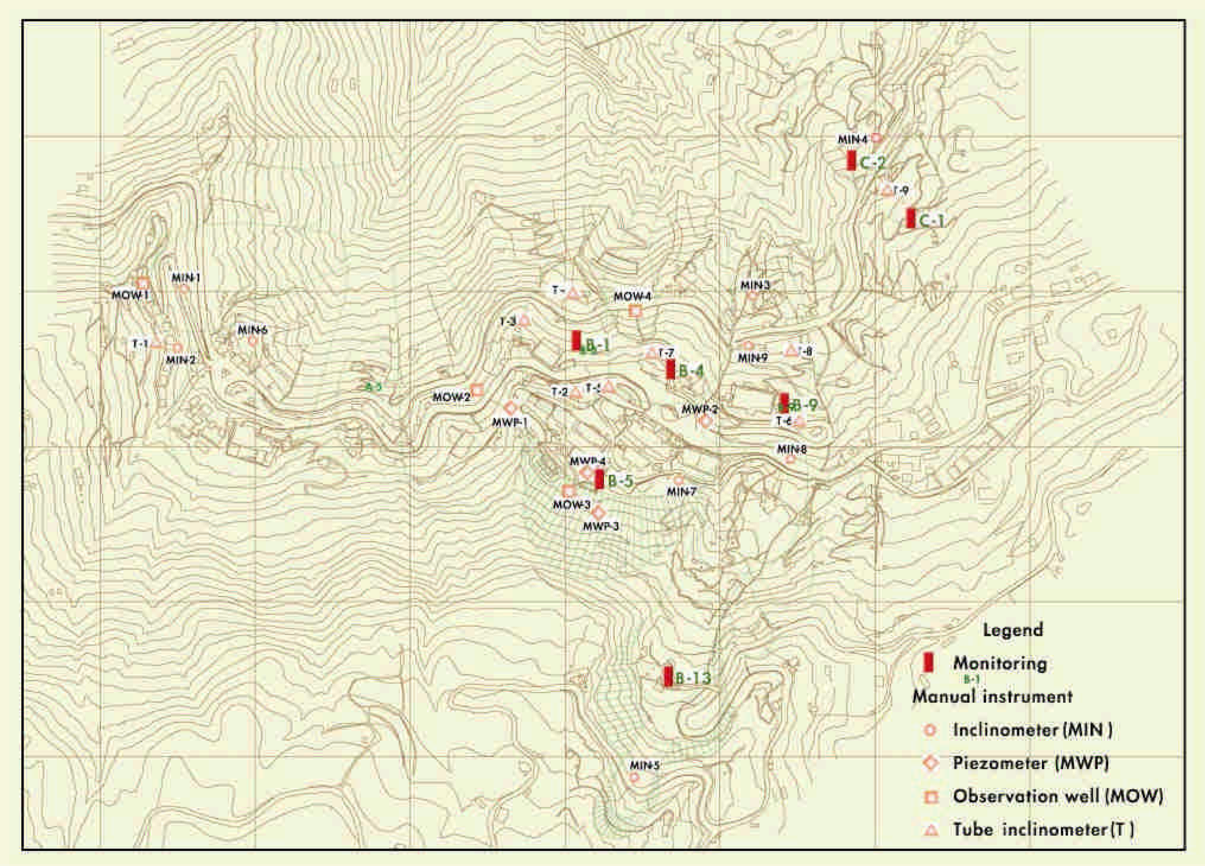

Fig. 6 Location map of monitoring station

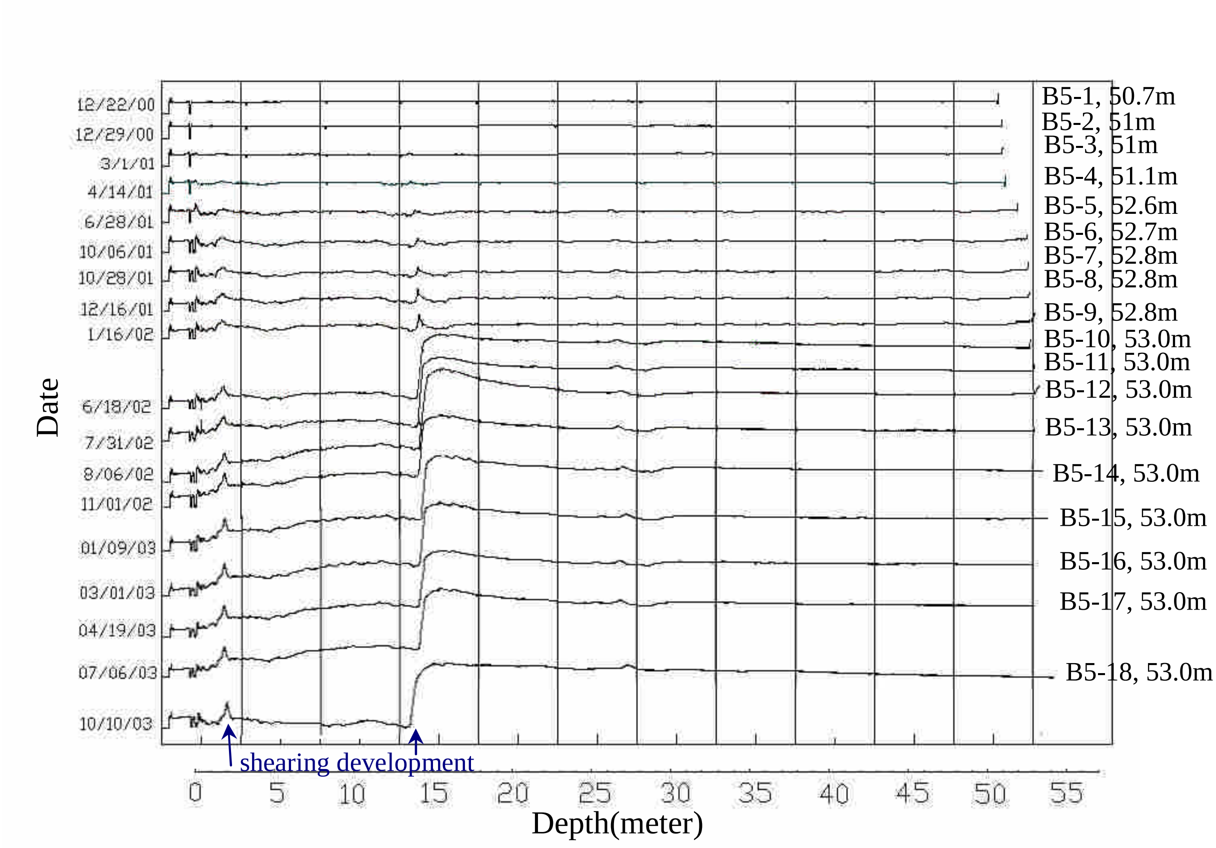

Fig.7 Recorded waveform at B-5 TDR monitoring station

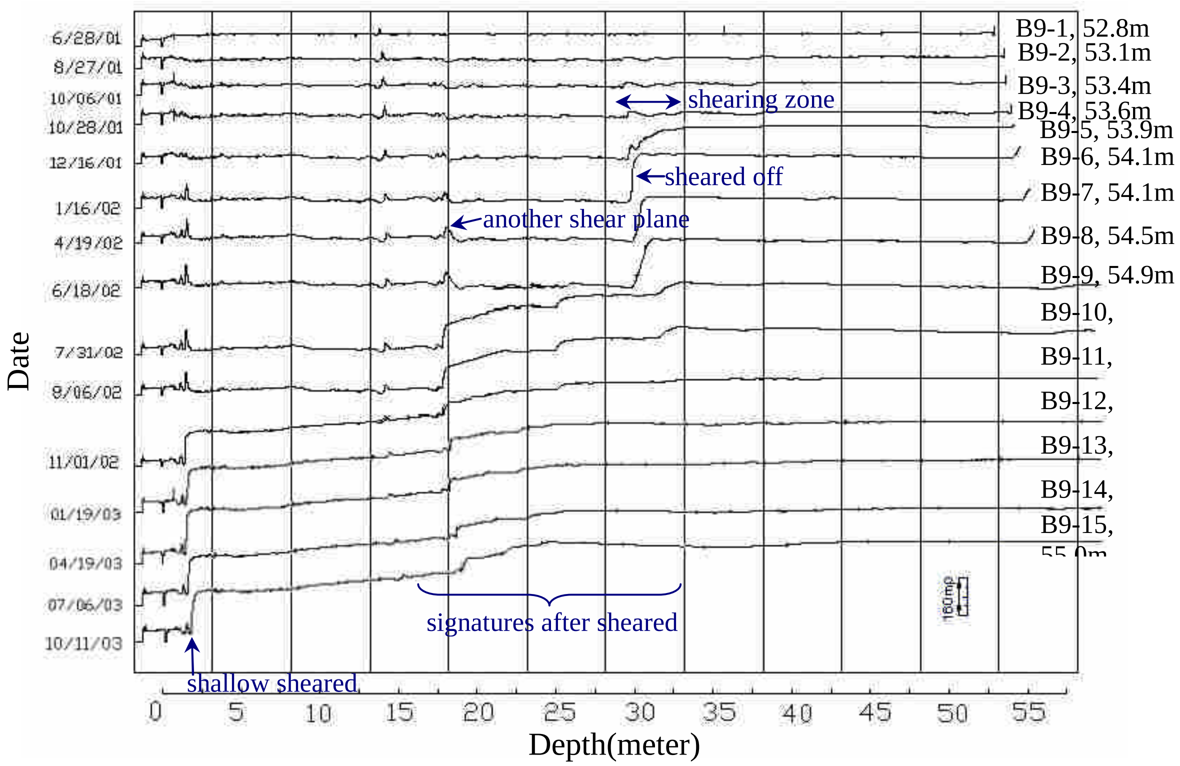

Fig.8 Recorded waveform at B-9 TDR monitoring station

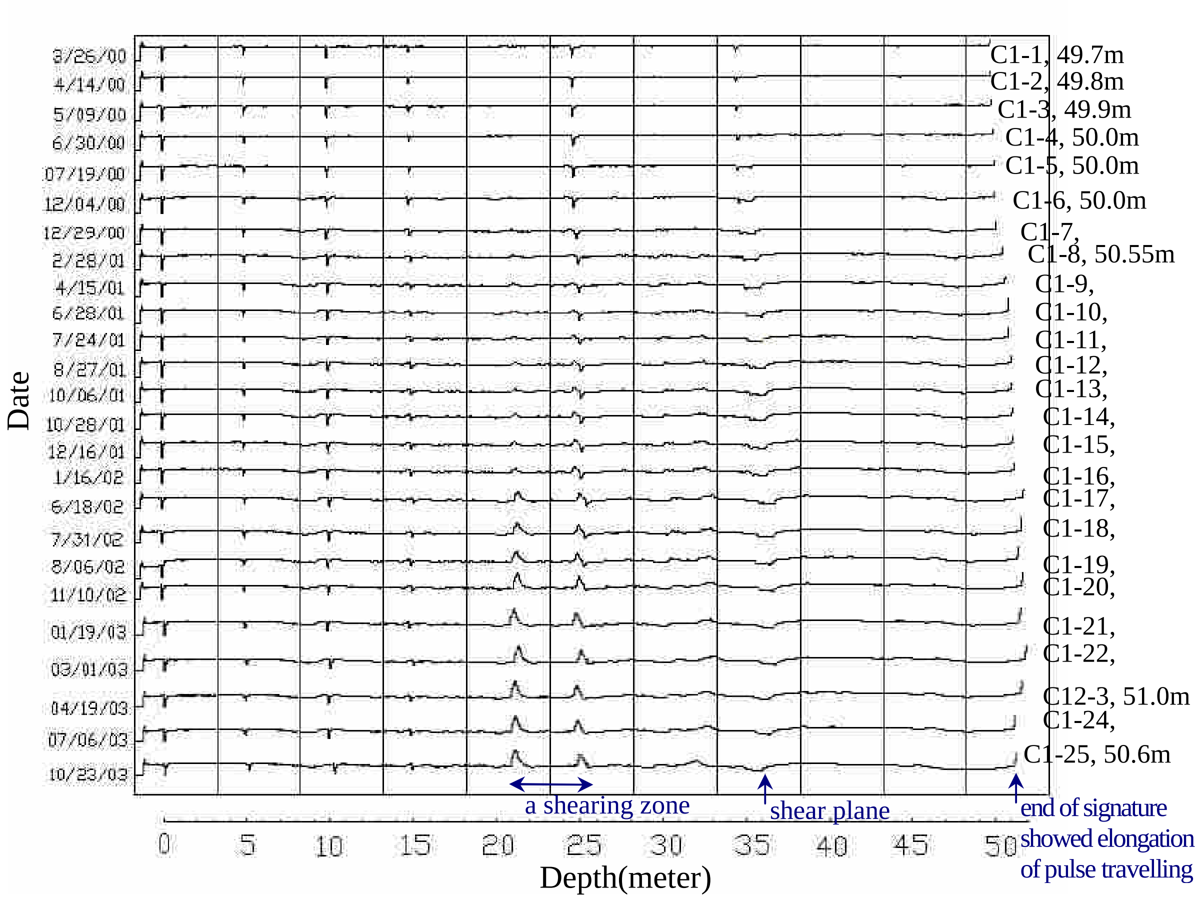

Fig.9 Recorded waveform at C-1 TDR monitoring station

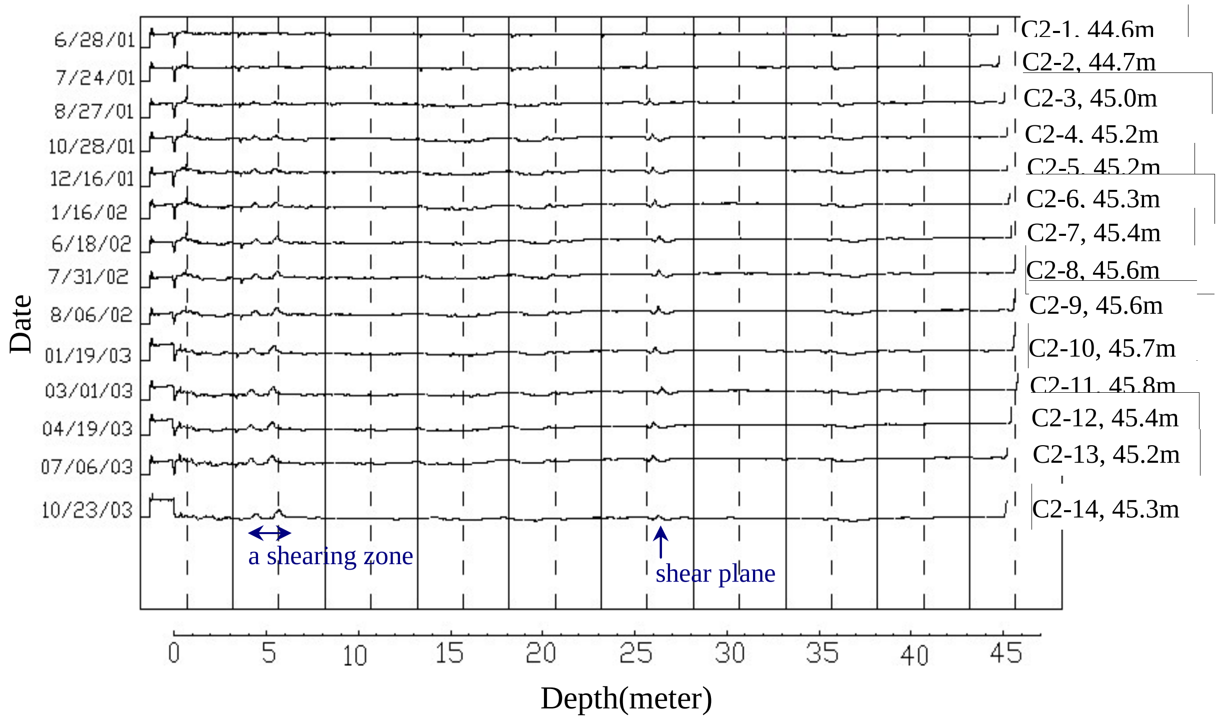

Fig.10 Recorded waveform at C-2 TDR monitoring station

(2)B5 monitoring station

Sliding block B5 monitoring station was located just right above the block B1. Ground water level drops approximately an amount of 15 meters during the construction period of drainage wells, and an extra 28 meters drop was recorded when the underground drainage gallery was excavated and approached to this region. The results also display that little change of surface movement was observed on the wire extensometer, which indicate that the fixed anchoring point of the extensometer might be installed on another sliding block. In Fig. 11, location of monitoring instruments are put together using projected location on the slope profile. Potential sliding planes are judged using the properties of geo-materials.

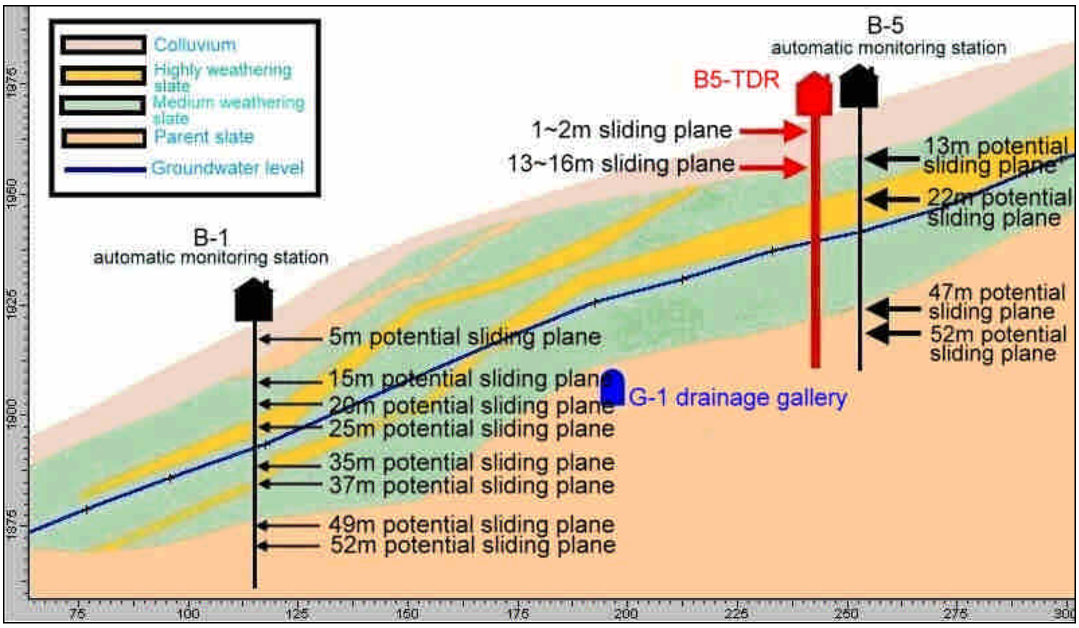

Fig.11 Profile of slope including B5-TDR cables

(3)B9 monitoring station

Sliding block B9 monitoring station was located just on the eastern side of the blocks B4 and B5. A huge building of Citizen Hotel was constructed on the top of block B9 in 1970. Unfortunately, it was eventually torn down in 2004 after the malfunctions of the building were evaluated, following the landslide in 1990. Monitored results show that the construction of drainage wells has significant effects on lowering the ground water level. Besides, it could be believed that the stability of this sliding block B9 could be improved after the building of Citizen Hotel was removed. A profile is given in Fig. 12 to compare sliding plane judged from TDR monitoring with potential sliding plane from geo-material.

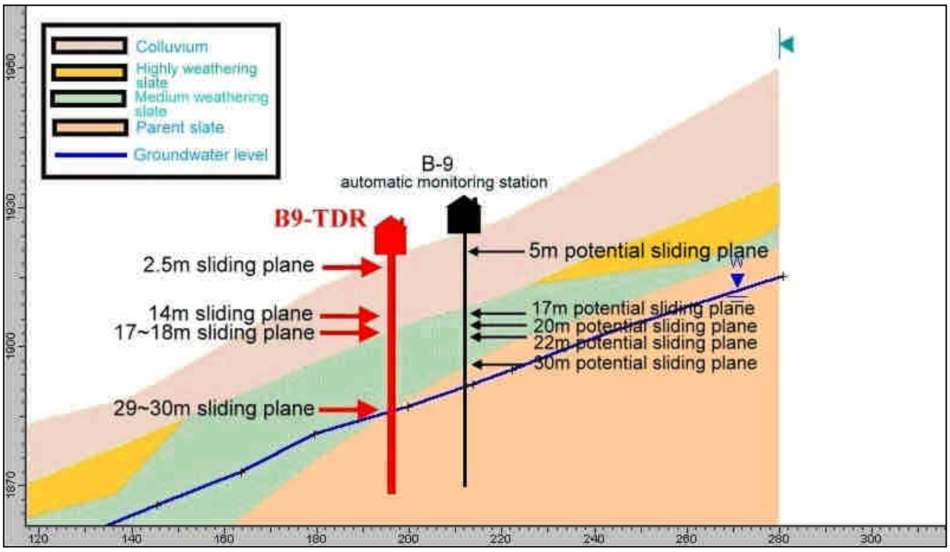

Fig.12 Profile of slope including B9-TDR cables

(4)C1 monitoring station

C1 station located at Northeast region. C1 is on uphill of route 7A. Fig. 13 gives the profile of TDR cable installed and monitoring station. As shown in Fig. 14 and 15, date of ground surface deformation showed close relationship with construction work of remedial plan.

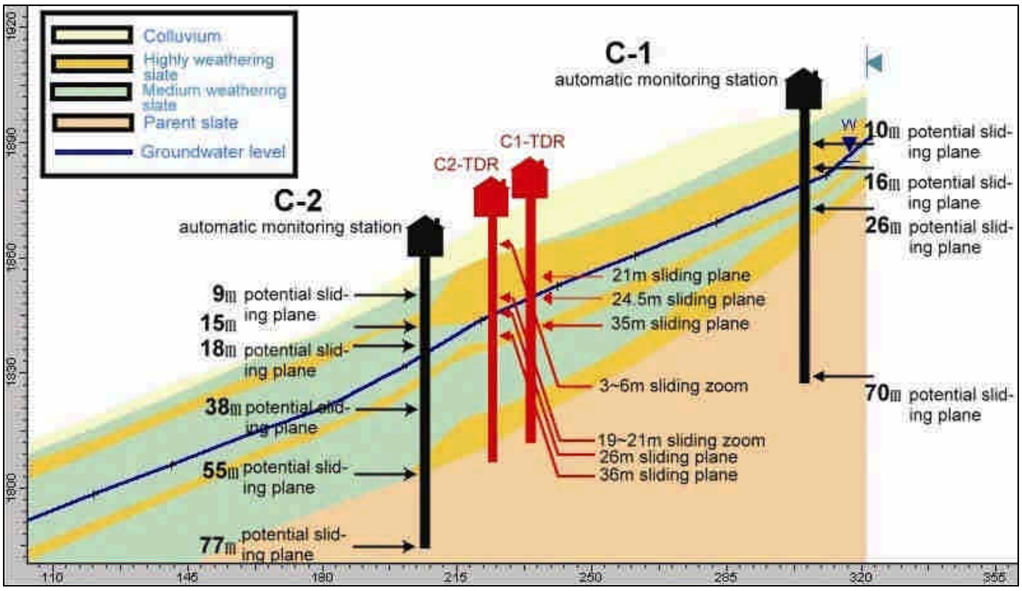

Fig. 13 Profile of slope including C1-TDR and C2-TDR cables

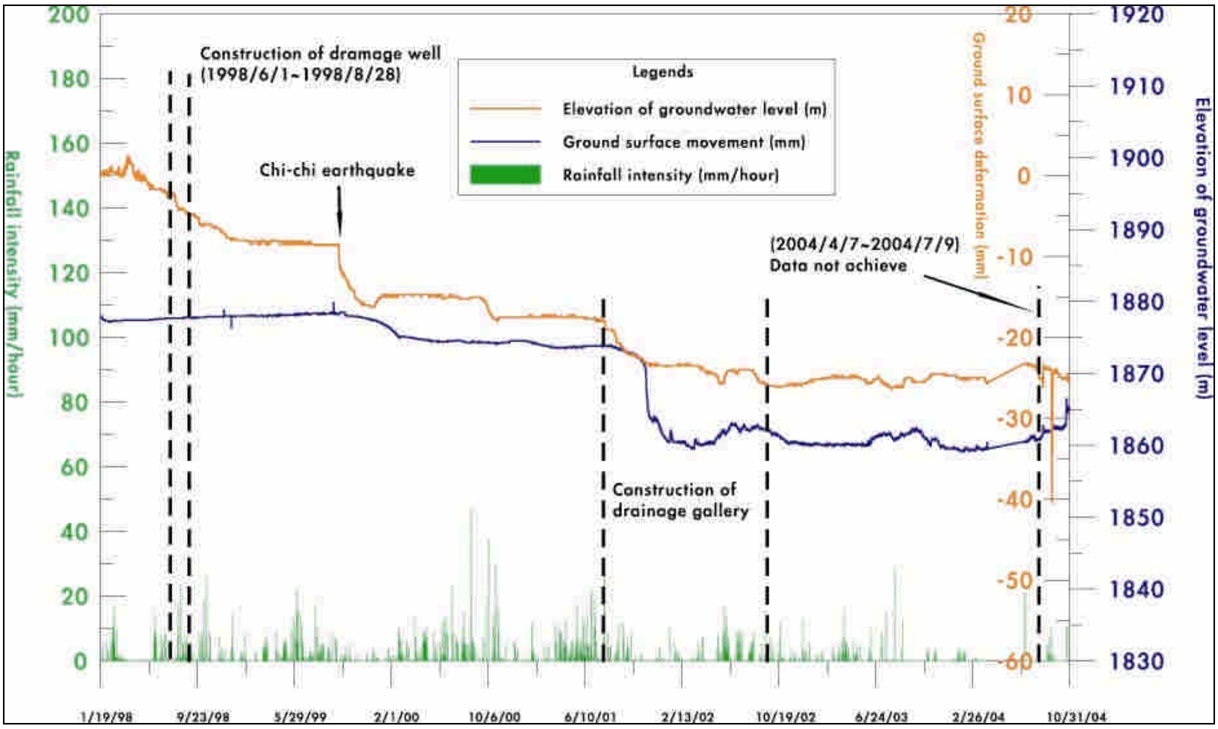

Fig.14 Relation between rainfall intensity, groundwater level and surface deformation in C1 station

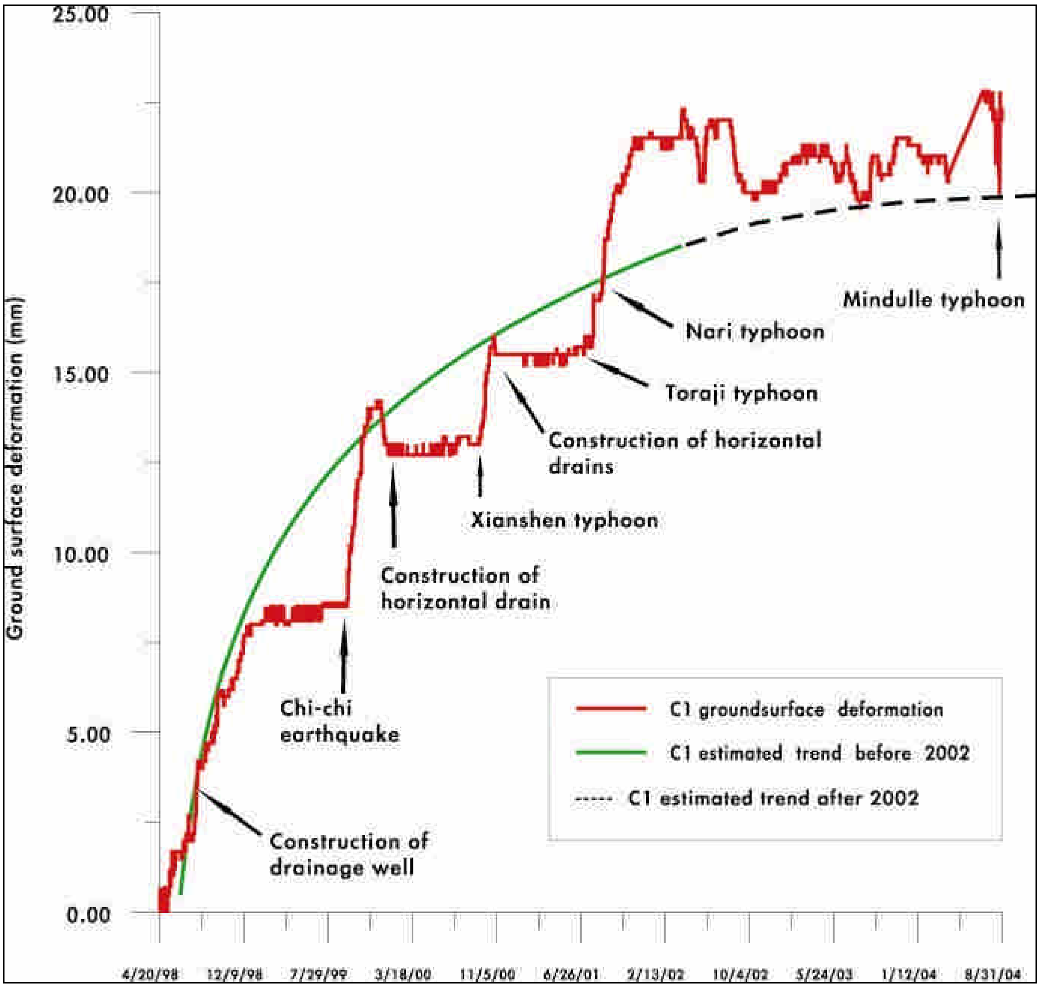

Fig.15 Ground surface deformation and its estimated trend for C1 station

Discussion

(1) Development of a shear plane

As can be seen from recorded waveforms, shearing development at different depth are quite clear from a small change to total reflection of transmitted wave. Locations of shear plane are compared with boring-log. Highly weathered slate were always presented as the potential sliding surface as in all four record.

(2) Development of a shearing zone

Some special phenomena are observed which are not discussed in previous research. As shown in Fig.9, waveforms show a pair of waveform rise in very close location. By simulating the possible reason for this type of waveform change, it is concluded that it may caused by the bending effect of a section of grouted coaxial cable. Bending causes the cable be teared to break at both upper and lower limit. These damage showed increase in its inductance and caused a spike in the waveform.

(3) Extension of the cable length

As marked at the end of each waveform, length of the waveform presented showed extension of the cable length as shearing occurred. These increase all coming from cable deformation or there's some kind of electrical effect caused by change of cable characteristic impedance after cable deformation.

(4) Signatures after sheared off

Multiple reflection can be observed from the graphs. TDR showed good applicability in slide monitoring. Waveform change all along the depth can be monitored even after major sheared off.

Concluding Remarks

Using TDR coaxial cables to monitor sliding plane proved to be effective. For landslide happened in highly weathered rock slope in steep mountainside, which is very common in Taiwan island, there are significant sliding zones or planes existed. Grouted coaxial cables inside bore hole can detect sliding much better than traditional inclinometer including in-place type and probe type.

References

[1] Soil and Water Conservation Bureau, "Remediation plan and Hazard Prewarning system for Li-Shan Landslide", Council of Agriculture (COA) Executive Yuan, Taiwan, R.O.C., 2005.

[2] M.B. Su, H.L. Wu, and L.C. Chen, "Performance Evaluation on the Renovation Work for Li-Shan Landslides," Proceeding of international symposium on Landslide and Debris Flow Hazard Assessment, Taipei, 2004.

[3] Dowding C. H., M. B. Su, K. M. O'Connor, “Principle of Time Domain Reflectometry Applied to Measurement of Rock Mass Deformation”, Int. Journal of Rock Mech., Mining Sci., and Geomechanical Abst., Vol.25 No.5, pp.287-297, 1988.

[4] Dowding C. H., M. B. Su and K. M. O'Connor, “Measurement of Rock Mass Deformation with Grouted Coaxial Antenna Cables,” Journal of Rock Mechanics and Rock Engineering. Vol.22, pp.1-23, 1989.

[5] M.B. Su, and Y.J. Chen, “Multiple Reflection of Metallic Time Domain Reflectometry,” Journal of Experimental Techniques, Vol.22, No.1, pp26-29, 1998.

[6] Miau-Bin Su, and Yuh-Jyh Chen, “MTDR Monitoring for the Integrity of Infrastructures”, Journal of Intelligent Material Systems and Structures, Vol.10, No.3, pp.242-247, 1999.