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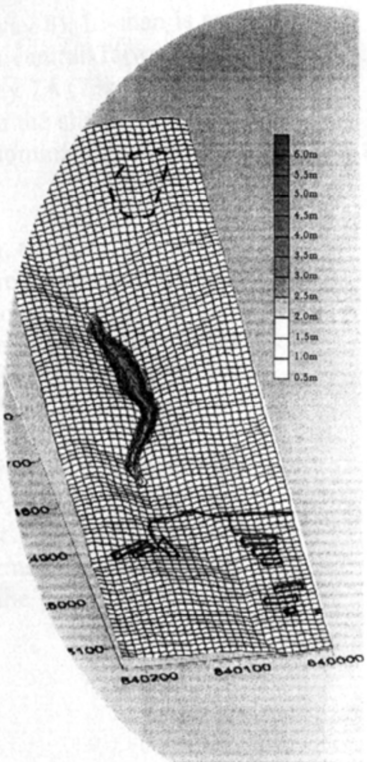

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Landslide Hazard Monitoring and Warning System for Li-shan Area

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Abstract:*Due to heavy rains, the sites near the highway 7A (73k+150) and the highway 8 (82k) in the Li-shan township began to subside in mid April 1990. In this study, topography, geology, and groundwater condition of this area were first reviewed. Based on this review, together with field investigations, a general hypothetic model was established to illustrate the Li-shan landslide. Then, a series of limit equilibrium back analyses were performed to understand the failure mechanism of this landslide area. In addition, the performance of the remediation treatment was reviewed. Finally, by combining the automatic monitoring station with internet embedded controller, real time monitoring results can be accessed through internet.*

Keywords:*Li-shan landslide, failure mechanism, remediation, groundwater, monitoring system*

Introduction

Located at the midway of the east-west cross-island highway (the highway 8), Li-shan is an important small town not only for transportation but also for tourism in central Taiwan (see Picture 1). In mid April 1990, due to heavy rain, the sites near the highway 7A (73k+150) and the highway 8 (82k) began to subside as their foundations are located on the sliding block of the landslide. It is generally suggested that the Li-shan landslide is predominantly caused by heavy rain together with the poor drainage condition.

In order to keep the highway functioning and secure the town for living, the government had executed the first phase emergency treatment followed by the second remediation treatment since July 1990. A dewatering system including surface ditches, drainage wells and two drainage galleries, was constructed and completed in early 2003. And the effectiveness of the remediation treatment has been strongly revealed as the Li-shan landslide survived the Chi-Chi earthquake (ML=7.3) in 1999.

In view of the characteristics of the sliding area, it is of great interest to understand to the complicated failure mechanism, which motivates this study. In this study, topography, geology, and groundwater condition of this area were first studied with field investigations. A series of limit equilibrium back analyses were performed to understand the failure mechanism of this landslide for different phases. In addition, the performance of the remediation treatment is also discussed with risk estimation.

Picture 1. A bird eye view of the Li-shan Landslide area (looking to the southwest).

Picture 2. The rejuvenation in the Tachiachi river makes the toe steeper than the head.

Geology Conditions

In western Taiwan, the westward thrust front due to the compression of the Phillipine Sea Plate is obstructed by the rigid basement Peikang High (part of the Eurasian Plate) and result in a series of Quatenary thrust faults trending north-south and diping towards the east [1,2]. The 1999 Chi-Chi earthquake is considered as reactivating of one of the Chelungpu thrust fault. However, the Li-shan fault, a major ridge fault of Taiwan island also generated by the above tectonic activity, is located few kilometers west of the Li-shan landslide.

Topographically, Li-shan area is located in the valley of the Tachiachi river. Geologically, Li-shan is not far from the Li-shan fault, and it is suggested the geological conditions is more complicated than expected in this area. And it is evident that the Li-shan is located at colluvial formations originally from the Miocene Lushan slate formation. The testing results show that the Lushan slate is about 2.76 ton/m3 of unit weight. And the mechanical properties for different weathering conditions can be summarized in Table 1.

TABLE 1. Mechanical properties of the geo-material in Li-shan area.

geomaterial type	unit weight (ton/m^3)	cohesion c(ton/m^2)	friction angle φ(°)
colluvium	2.06	0.75	30
medium to highly weathered slate	2.69	3.00	28
fresh to medium weathered slate	2.70	30.00	33
sliding plane	2.69	3.00	28

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. Pictures of schematic of automatic monitoring system is given in Fig. 1-1 and Fig. 1-2.

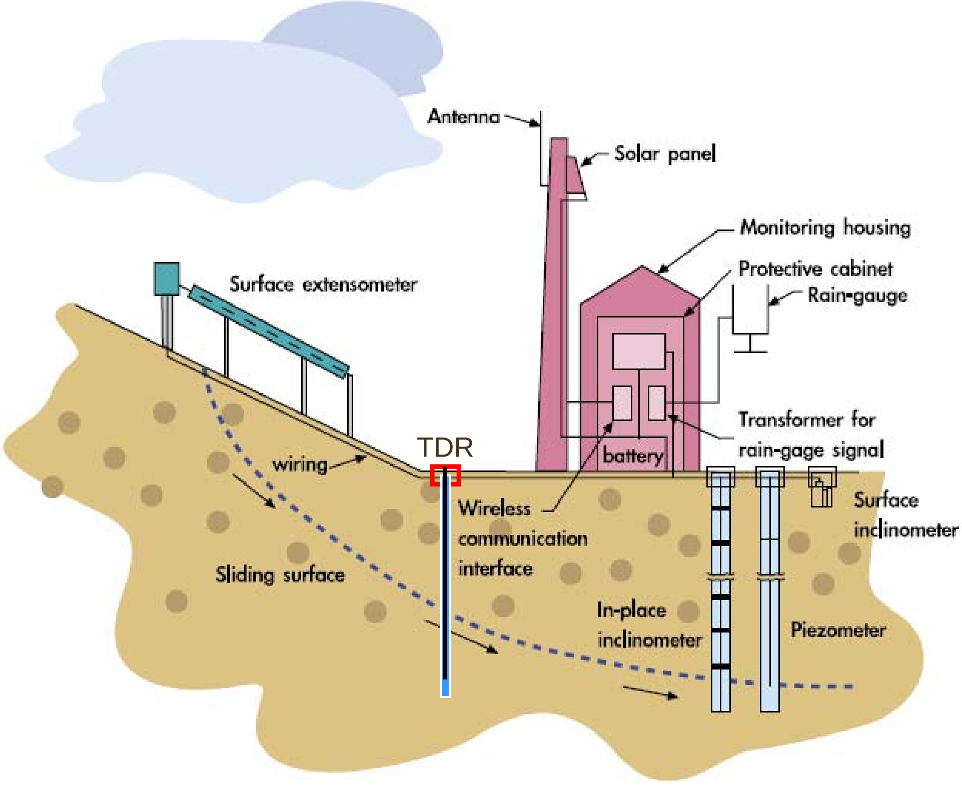

Fig. 1-1 Schematic of automatic monitoring system applied in Li-shan landslide area

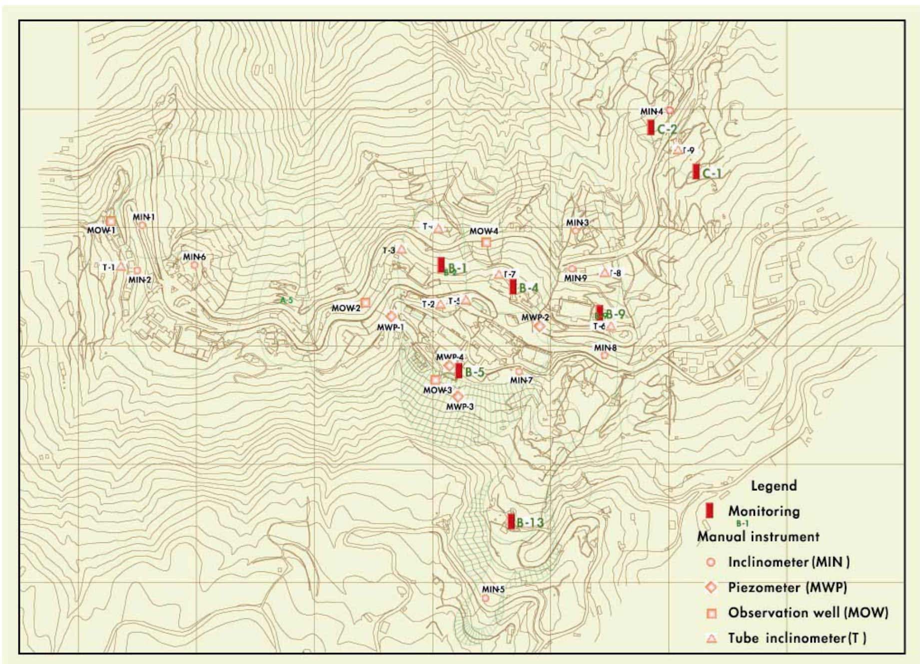

Fig. 1-2 Location map of monitoring station

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.2. 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 15o and 30o , and the precision is 0.01°.

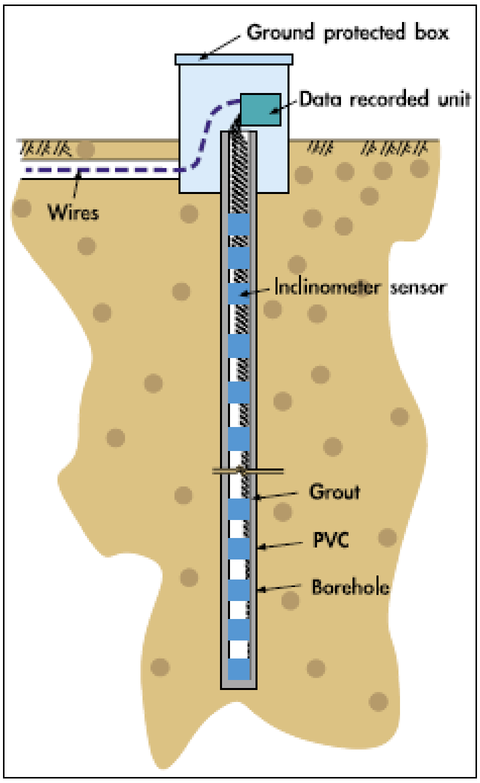

Fig.2 Setup of probe inclinometer

(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 . 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.

Fig.3 is the result of recorded data by the automatic monitoring system.It can be see that the relation between rainfall, groundwater level and ground surface movement.

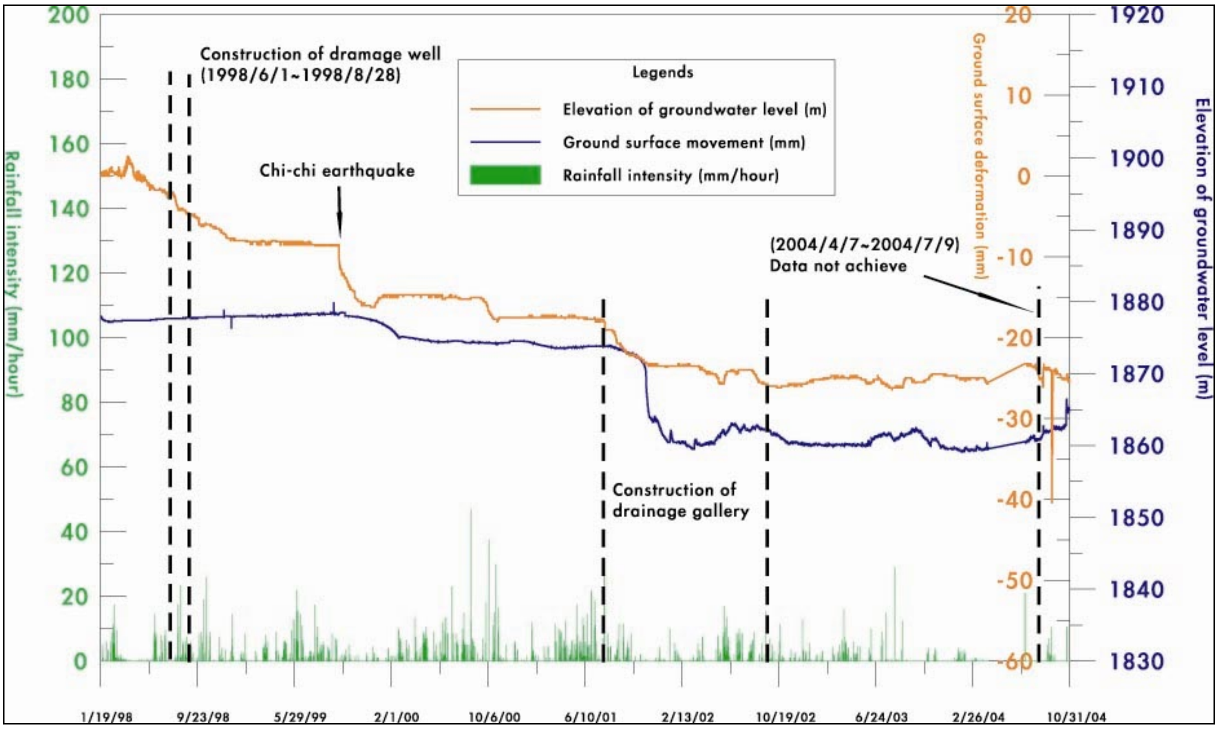

Fig.3 Result of recorded data by the automatic monitoring system

(3)TDR monitoring system

TDR(Time Domain Reflectometry) technique when applied to monitor sliding within slopes.(Fig.4) When a coaxial cable is embedded in the borehole 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. The recoreded waveform shows as fig.5. 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. 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(Fig.6), in which the sliding surface was found at the interface between the highly weathered slate and the intact rock.

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.

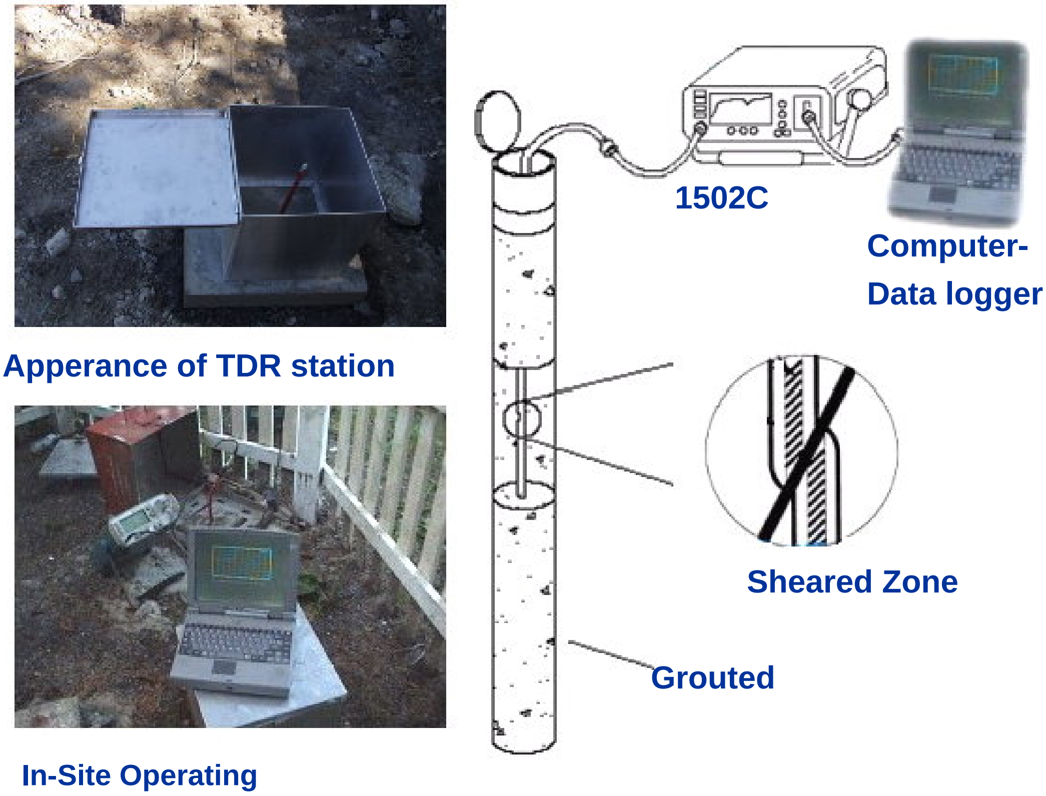

Fig.4 TDR monitoring system

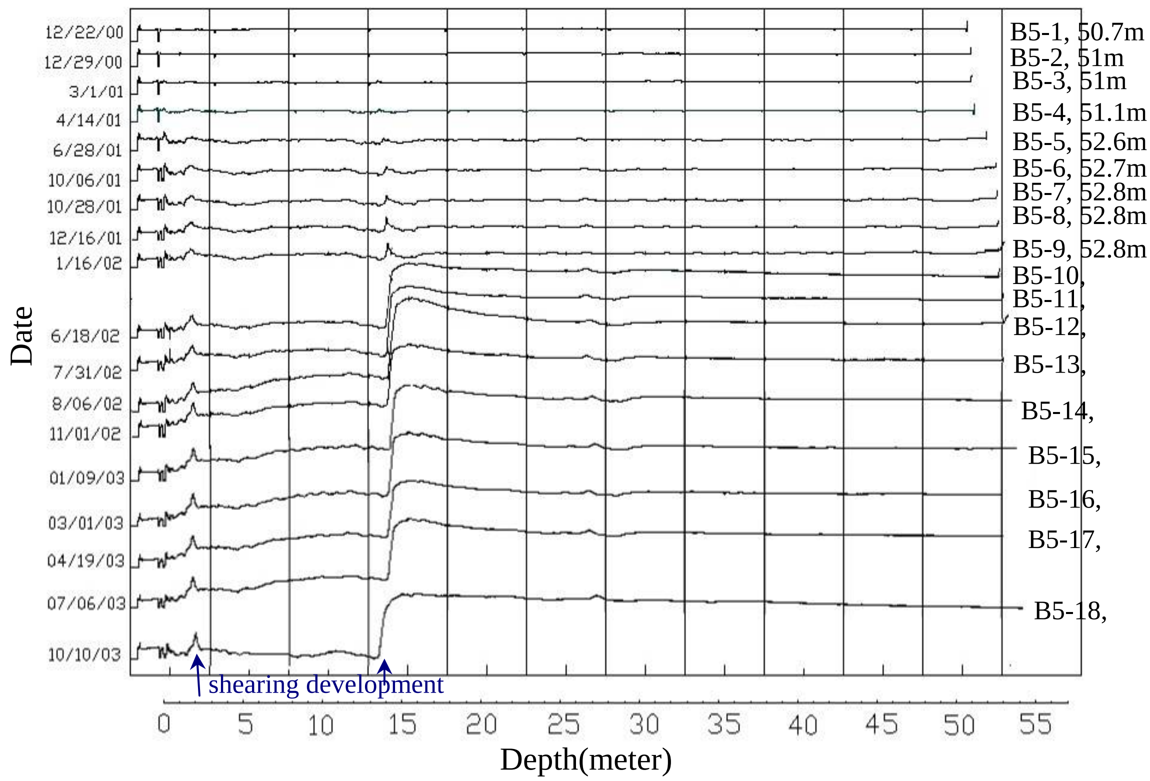

Fig.5 Recorded waveform of TDR monitoring station

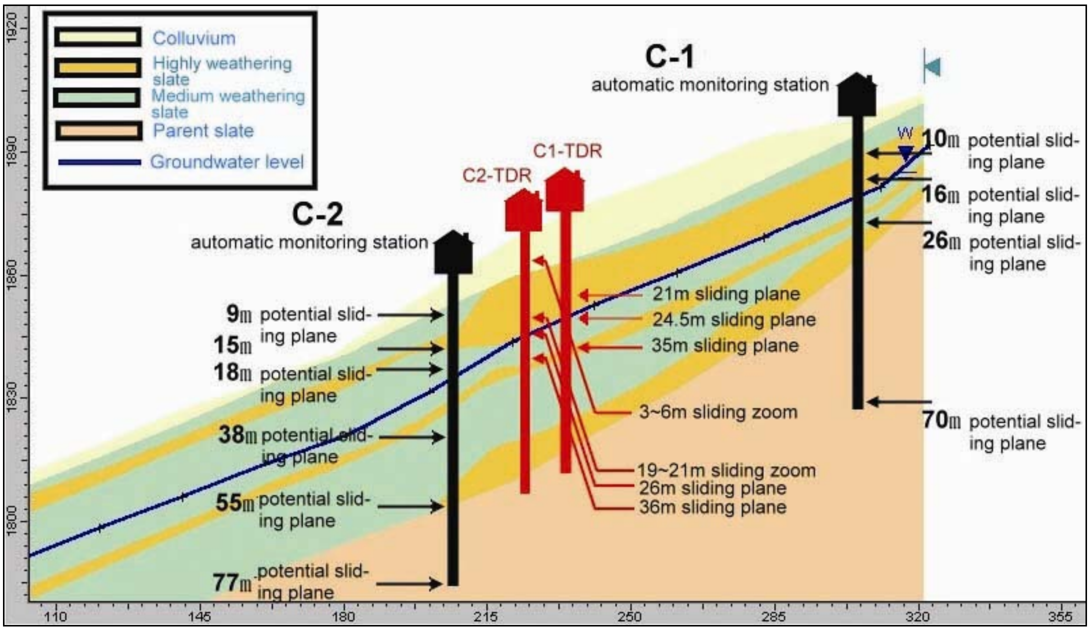

Fig.6 Searching for possible sliding surface by TDR monitoring techniques

Failure Mechanism

Based on the field investigations together with the topographical and geological information, a general hypothetic model was established to illustrate the Li-shan landslide. This model comprises major factors as below: (1) the sliding planes is basically along the lower boundary of the regolith, about 20m below the surface, (2) there is a major old landslide at the center of the town, (3) the high erosion rate makes the slopes by the streams more dangerous than the others.

The landslide area can be divided to three regions, i.e. the west, northeast, and southeast regions (see Figure 7). Except the southeast region, most of the unstable slopes possess shallow sliding planes about 9-26 m below surface. However, there is an old landslide within the southeast region, of which boundary subdivides the southeast region to two subregions. According to the core logs and the records of drainage gallery construction, the old sliding plane is more than 40-60 m below surface. The rest of the southeast region is more or less located at a valley of a small branch of the Tachiachi river. Due to the tectonic activities, there is rejuvenation in the Tachiachi river. Thus the erosion rate of this branch is quite high, which generate higher hazard potential of this subregion (see Picture 2).

Based on the study of topography, the profiles AA', BB' and CC' (see Figure 8) were adopted and analyzed by the limit equilibrium analysis model PC-STABL [3]. The slopes are fairly stable for dry condition as the safety factor is 1.21-1.35; but they become critical with high groundwater level as the safety factor drops to 0.99-1.15. This finding might reveal there are more than one activities in this area, as the precipitation is quite high in this area, about 2340 mm annually. Therefore, it is essential to have remediation treatment in this area (see Table 2). Besides, during the Chi-Chi earthquake, the horizontal acceleration was estimated 0.15-0.20g. With this impact, this area survived except minor damages near the profile BB'. It somehow reveals the effectiveness of the remediation.

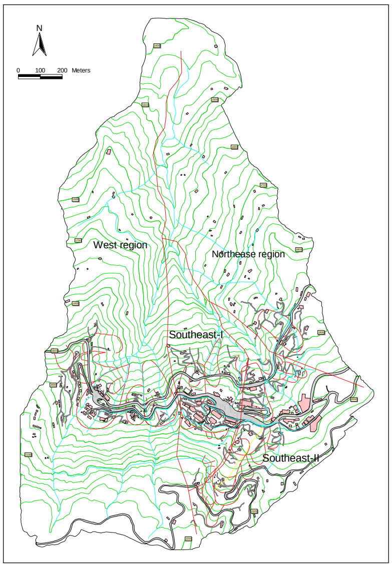

Figure 7. The topography and divisions of the Li-shan landslide area.

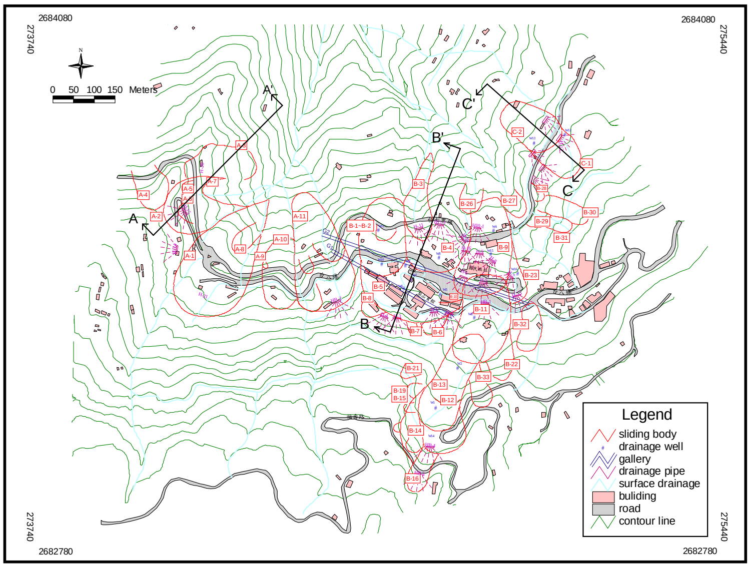

Figure 8. Illustration of the remediation treatment in the Li-shan landslide area.

TABLE 2. Safety factors for the residual slopes in Li-shan area.

profile analyzed	A-A’	B-B’	C-C’
dry(no groundwater)	1.23	1.21	1.35
wet (high GWL)	1.11	0.99	1.15
wet (with remediation)	1.23	1.18	1.22

Remediation

As the landslide is closely related with the rainfall and groundwater, groundwater control is essential to for slope stabilization in this area. A drainage system, composed of surface and subsurface drainage components, was designed to be a remediation treatment. For the surface drainage system, existing ditches were integrated as a system to divert the water undesirable surface flows into non-problem areas, as well as to prevent excessive water infiltration near tension cracks. In order to more efficiently control the groundwater level, a subsurface drainage system is also applied, which is consisted of three major components, i.e., horizontal drainage pipe, drainage well, and drainage gallery. There are (1) 15 horizontal drainage sites, 7-9 pipes (30-60m in length) in each site, (2) 13 drainage wells, located major in the heads of slopes, and (3) 2 drainage galleries, excavated below the sliding planes. The surface and subsurface drainage systems are illustrated in Figure 7.

From the preliminary results of groundwater level monitoring, the groundwater level has been successfully reduced about 10-20m after the drainage gallery #1 in operation. By this improvement, the stability of slopes is reasonably improved as expected with safety factors around 1.18-1.23.

Internet Embedded Prewarning System

By combining the automatic monitoring station with internet embedded controller(Fig. 9), the system is reconfigured into an internet server based system. Real time monitoring results can be accessed through internet(Fig. 10). A GIS database server collect data from field station to calculate factor of safety for slope against sliding. Using the criterion discussed in above, the judgement can be made easily. And, decisions for response in regard to local residents' safety can be made by computer automatically.

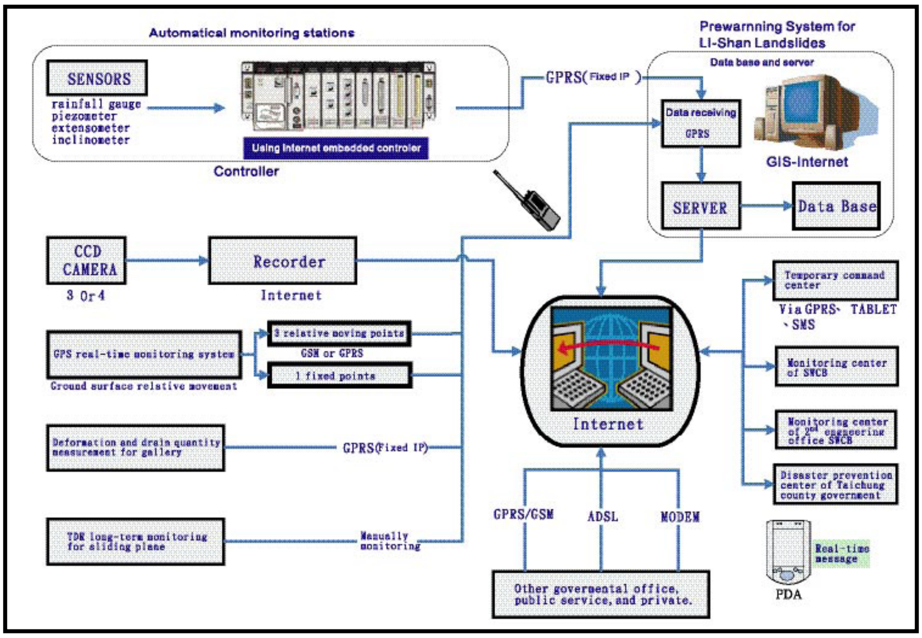

Figure 9. Automatic monitoring system

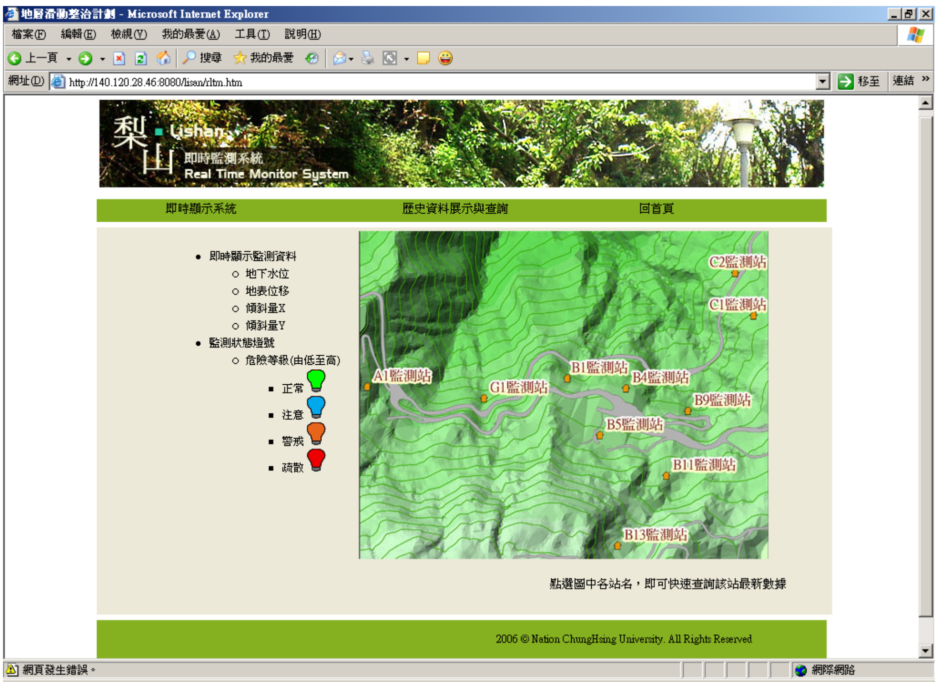

Figure 10. Internet page(Real time monitoring and prewarning)

Conclusion

Stability analyses were employed to study the behavior of the slope and the failure mechanism of the Li-shan landslide. The slopes are quite stable for dry condition, but become critical for fully saturated condition. The remediation treatment is essential as the precipitation in this area is quite high in this area. According to the renovation proposal "Investigation and Renovation Planning for Landslides in Li-Shan Area" by Industrial Technology Research Institute, the groundwater level could be lowered 8.3 m after the remediation work is accomplished. In fact, the groundwater level was dropped an average of 12 m, measured by the 2nd Engineering Office of Soil and Water Conservation Bureau on the monitoring stations, which was better than the previous estimation. The risk reduces to 1.0 % when count on the contribution of the remediation treatments.

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