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Landslide Remediation Work and Treatment in Taiwan

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ABSTRACT

Landslides are involved in many human activities. Especially in Taiwan, natural environment is not favor to development of sloping lands. A case study is presented here to show the procedure of a landslide remediation work. Drainage method are employed to fulfill both the ecologic and safety requirement. At the end, field monitored data are presented to verify the achievement of this work.

Introduction

Natural environment of Taiwan can be characterized as rapid topography, fragile geological conditions, short and rapid rivers. Peoples living in this island are always threatening by natural hazards like earthquake, typhoon and torrential rain. But, on the other hand, utilization of the sloping lands impose a great burden on the natural resources. Landslide hazards caused by geological processes or induced by human activities have become a major threatening issue for the safety of residences.

Landslides are involved in many engineering fields like road, railway, dam, river engineering, watershed management, regional development for residential or industrial use. These phenomena and consequences have draw the attention from geologist, civil engineers, forest engineers to deal with the disaster and remediation work.

Classification of landslides

Landslides are commonly classified by its type of material movement. There are five types named falls, topples, slides, spreads and flows as schematically illustrated in Fig.1 as proposed by Varnes 1978. This classification is widely accepted and adopted by the International Geotechnical Societies UNESCO working party on world landslide inventory. This classification system is easy to use in field investigation based on visual judgment for possible type of motion. In Taiwan, landslides are divided five groups including falls, slides, erosions, creeps and debris flows to emphasized in their type of damage. Remediation work can then be planned.

Choice of a remediation method

As described by Broomhead (1992) in his book titled"The Stability of Slopes",the first response to a slope stabilization problem should always be use of regrading or cuts and fills as the main element of the scheme because of the effect of fills at the toe of a slope are immediate. It is only in the comparatively uncommon cases where regrading is impossible that other stabilization measures have to be considered as the principal element of the treatment.

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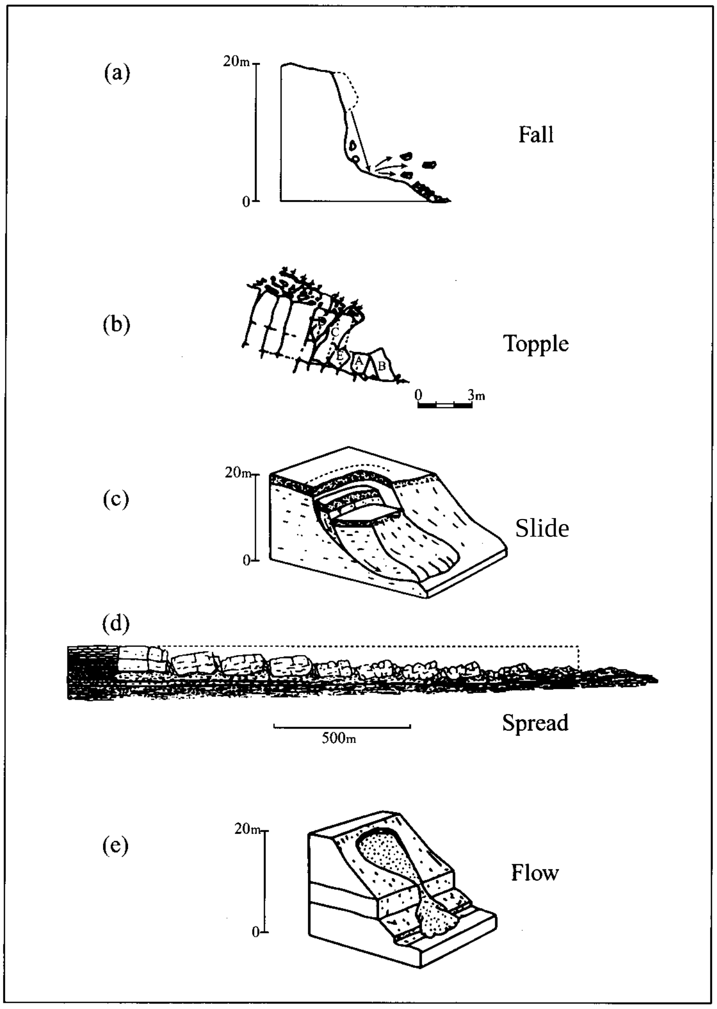

Fig.1 Types of landslides(Fig.3-19, Cruden & Varnes, 1996)

Drainage can be considered as the sole stabilization method where stabilization by regrading is impractical. It becomes immediately effective where large flows in permeable strata can be intercepted. Drainage method must be considered as a longer term work and not a method of bringing slides to rest. On the other hand, treatment of surface water flows is essential in controlling many mudslides and mudflows in fine grained soils. In stiffer deposits, the excavation of trenches for shallow drains can decrease porewater pressures and have immediate effect in regards to its stability.

The long-term susceptibility of drainage measures to blockage makes the use of drainage method as the main treatment subject to caution. Regular follow up maintenance programme is a must.

Retaining structures constructed in an unstable slope are the third measures of primary stabilization. These structures can be divided into two main categories: active measures like stressed ground anchors, rock bolts, soil nailing, etc. and passive measures like retaining walls, unstressed dowels, piling, etc. Both measures can be used successfully, but to become effective, passive measures rely on further movement of the slide to mobilize the full resistance of the built structure. These further deformation maybe undesirable and can cause some unexpected effect.

The digging out of slide geomaterials and their replacement can be effective in some cases, notably when small slides masses are involved. Debris from landslide can be piled up or replaced after certain suitable treatment. Cavity can be refilled with certain imported materials

with intrinsically better properties. Lime stabilization, compaction in thin layers between drainage blankets and the use of reinforced techniques with geofabrics and geogrids are the others treatment can be considered.
After the selection of a primary stabilization measure, secondary treatments may be required to preserve the long term effectiveness of the primary measure, or to prevent deterioration of untreated portion of the surroundings. Drainage is always the key element of this, both surface and underground drains.
In the following, a case studied is presented to see the effectiveness of drainage as the main stabilization measure for a large scale landslide remediation plan.

A case study – Li-Shan landslide

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. 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 severe settlement and deteriorated crack. 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 renovating the landslide was officially approved after an intensive investigation between 1991 and 1993. 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.

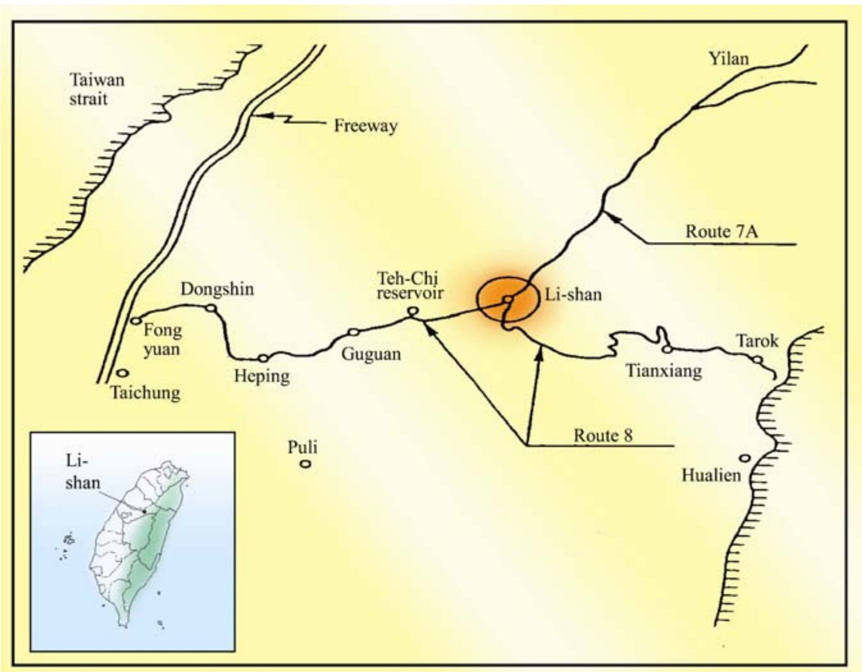

Fig.2 Location of Li-Shan area

Disaster of Landslide in 1990

A continuous heavy rain hit Li-Shan area on April 11, 1990. Consequently, the slope, near the highway 7A(73K+150) started to slide down on April 15. The sliding body measured about 100m wide, 150m long, and 20m in thickness. About 300,000 cubic meters of the total debris were sliding down to an erosion trench which is a branch of Ta-Chia river flowing down to the Teh-Chi Water Reservoir. As the sliding body crossing highway 8 and 7A, all the communication and transportation were interrupted.

Fig.3 Landslide at route 7A 73k+150

Fig.4 View of landslide from Tachiachi river

Landslide along Route 7A

The damage on highway route 7A is near 73K+150, which includes cracking and failing of retaining walls and uneven cracks on the floor. The affected area extended from the west side of Li-Shan Grand Hotel to the east side of Li-Shan Civil Hotel. About 320 m pavement in length along highway route 7A was destroyed. The destruction of nearby buildings was serious. Reports of soil-boring indicate that the damage area was mainly located on the upper part of sliding blocks.

Fig.5 Landslide causing destruction on route 7A

Fig.6 Subsidence of pavement on route 7A

Fig.7 Top view of landslide along route 7A

Failure Mechanism of Li-Shan Landslide

Based on the investigations, it could be recognized that Li-Shan has experienced more than one landslide activity in the history. The horseshoe shape of topography (scarp behind the Li-Shan Grand Hotel) with a convex ridge (front of sliding body) to the north is a strong evidence for a major previous landslide.

Fig. 8 View of Li-Shan landslide

Analysis of Rainfall Record

The rainfall record in April, 1990 was shown in the figure. It could be found that the maximum daily rainfall recorded during the landslide disaster is not very large compared to the previous record in the history. However, the accumulated rainfall of 585 mm from April 10th to 20th and the monthly rainfall of 957.5 mm in April show that both rainfalls exceeded the record of 50 years return period based on the frequency analysis. The continuous rainfall could cause a tremendous amount of water infiltrate and accumulate inside the slope. The infiltrated water could increase the pore water pressure, subsequently decrease the effective stress in the rock mass and resulted in the instability of the slope. Based on this, it could be confirmed that the rainfall induced the increase of water pressure is the main factor which triggers the landslide of the highly weathered rock slope.

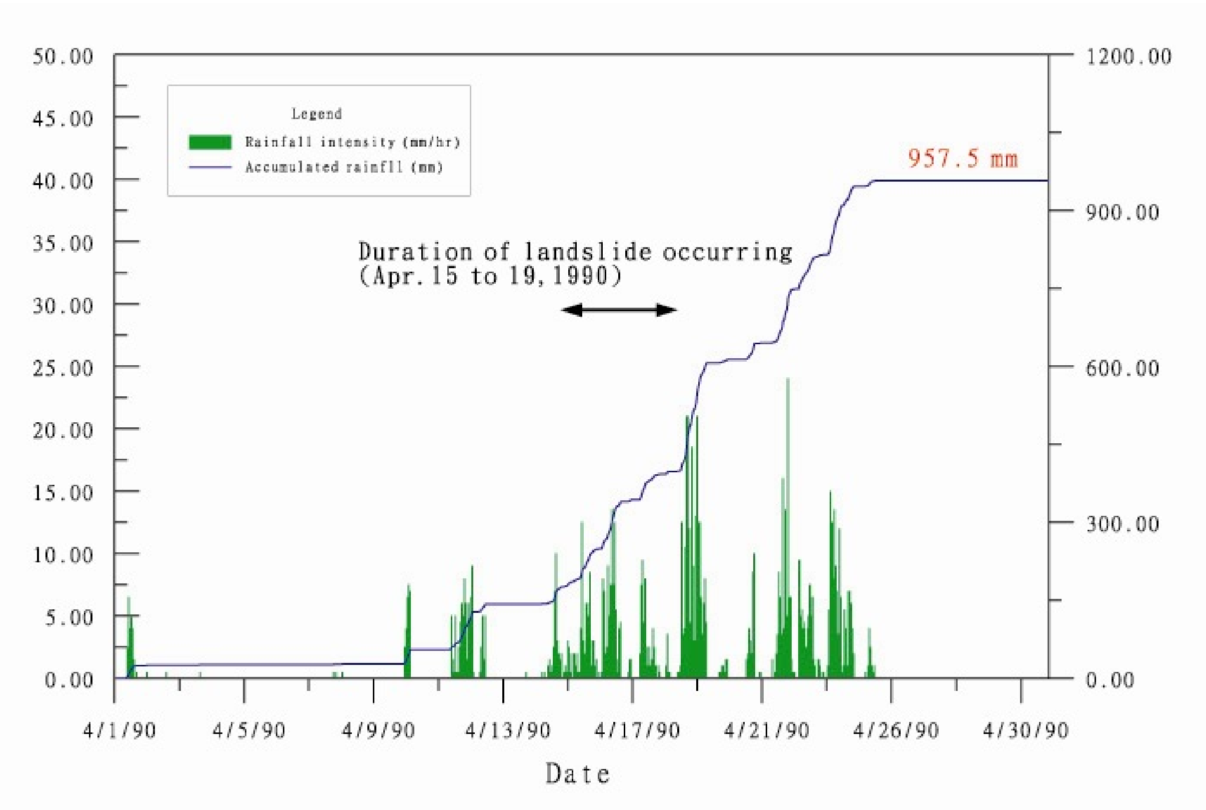

Fig.9 Precipitation record at Taipower Li-Shan station in April 1990

Remediation Plan

Objectives

The primary remediation work conducted for landslide stabilization in Li-Shan area is 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 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 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 executed for the period of 1995-2000. However, the project was extended from 2000 to 2002 due to the complicated features 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.

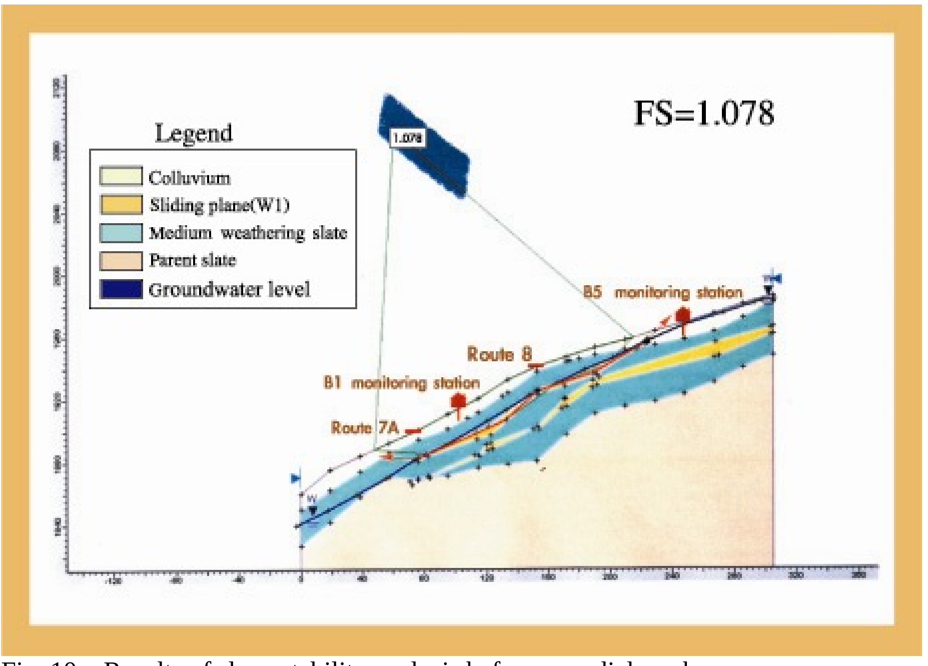

Fig. 10 Results of slope stability analysis before remedial work

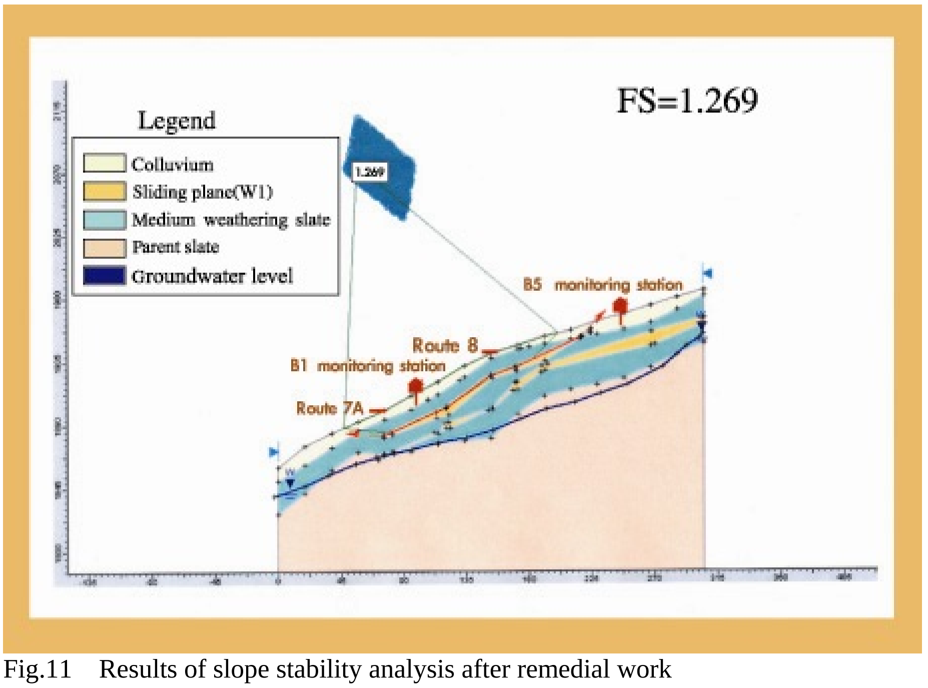

Fig.11 Results of slope stability analysis after remedial work

Contents of Remediation Work

All items in regard to the remedial work planned and conducted are listed in the following.
(1)Complete the surface drainage work by installing the drainage ditches and infiltration ditches with a total length of 8,170 m.
(2)Installation of 38 sets of horizontal drains (180 drilling holes) with a total length of 10,890m.
(3)Installation of 15 sets of drainage wells (diameter of 3.5 m with depths ranged between

15m to 40 m, besides, a total length of 16,960-m collecting pipes were installed inside the wells).
(4)Installation of drainage gallery G1 with 350 m in length including the installation of the 4,863-m collecting pipes inside the gallery; and the 550m long drainage gallery G2 which includes the installation of collecting pipes with 10,700 m in length inside the gallery.
(5)Remediation work for route 7A had been accomplished by Highway Bureau.
(6)Sliding block A-3 has been stabilized by using the 130-m buttress to provide the sufficient dead weight near the toe of the unstable mass to prevent slope movement, besides, 8 sets of drop structures were also constructed.
(7)Completion of 3 sets of sediment restored dams as well as 62 sets of submerged dams for sediment restoring work.
(8)Completion of 8 sets of automated monitoring systems and the following monitoring system maintenance.
(9)Field investigations had been carried out twice before the design was undertaken.
(10)Provide five progressively synthesized reports about remediation work on Li-Shan landslide.
(11)Immediate mitigation measures were taken for hazard remediation.
Total expenditure approved by the government is NT$ 1,068,274,000 by the end of year 2002.

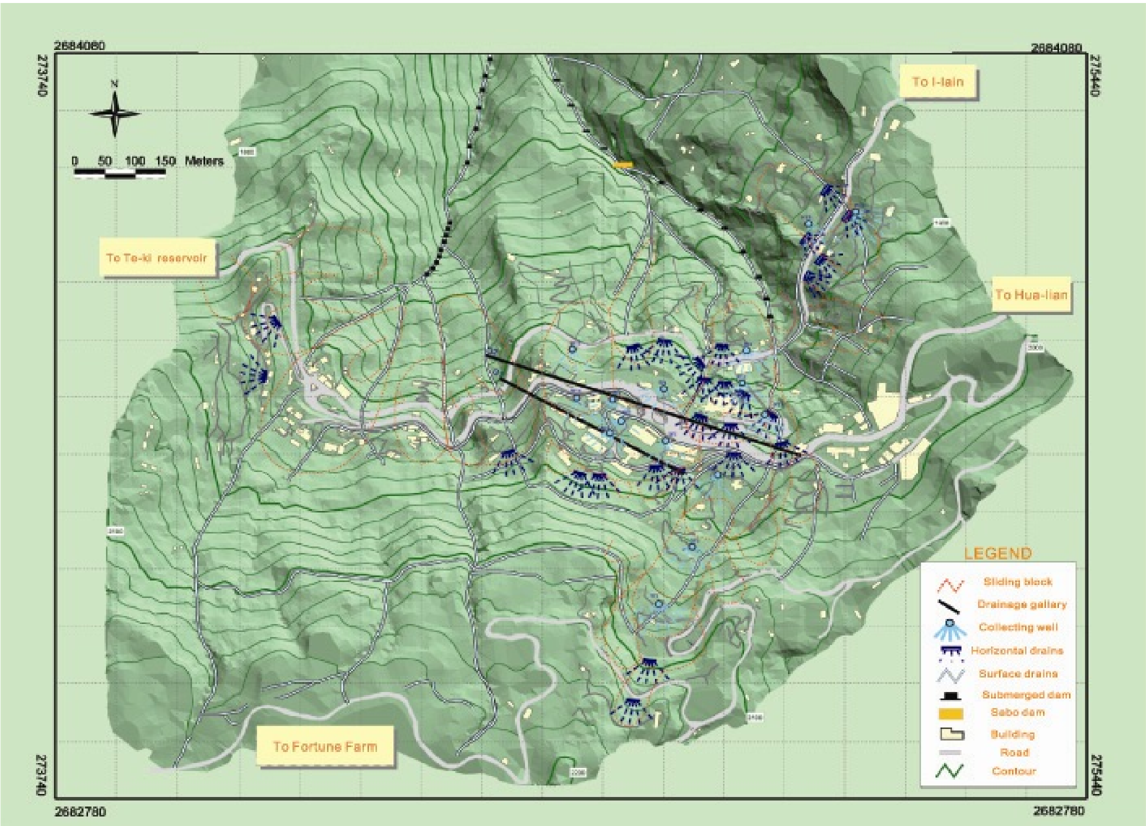

Fig. 12 Distribution of remediation works in Li-Shan landslide area

Remediation Measures

The primarily physical measures for Li-Shan landslide were the drainage of the surface water and groundwater. The objective was to lower the pore water pressure which was developed inside the landslide-prone soil mass, and thereby enhance the slope stability. After analyzing the field observation data from the installed monitoring station, the pertinent remediation plans will be implemented.

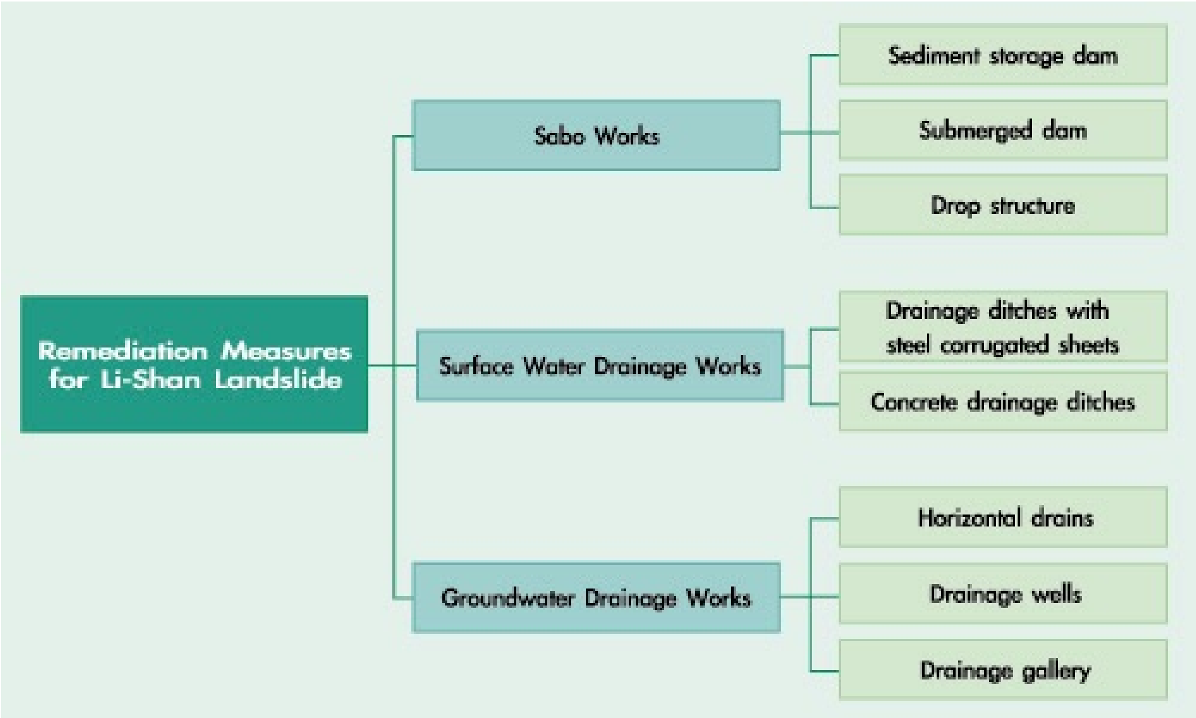

Fig.13 Flow chart of remediation work

In Fig. 14, contents of the drainage system are presented graphically in a profile of slopes. The chief goal is to control the maximum groundwater level. The effect can be explained using Fig. 15 to see their functions.

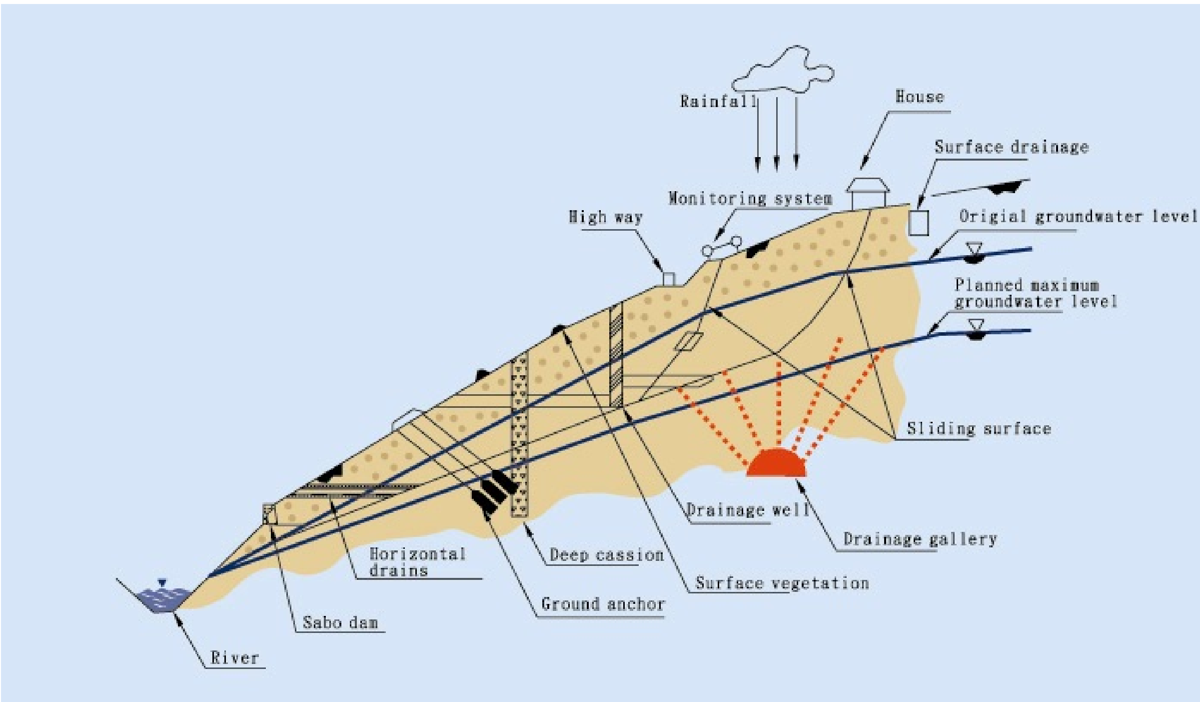

Fig.14 Content of remediation plans for landslide

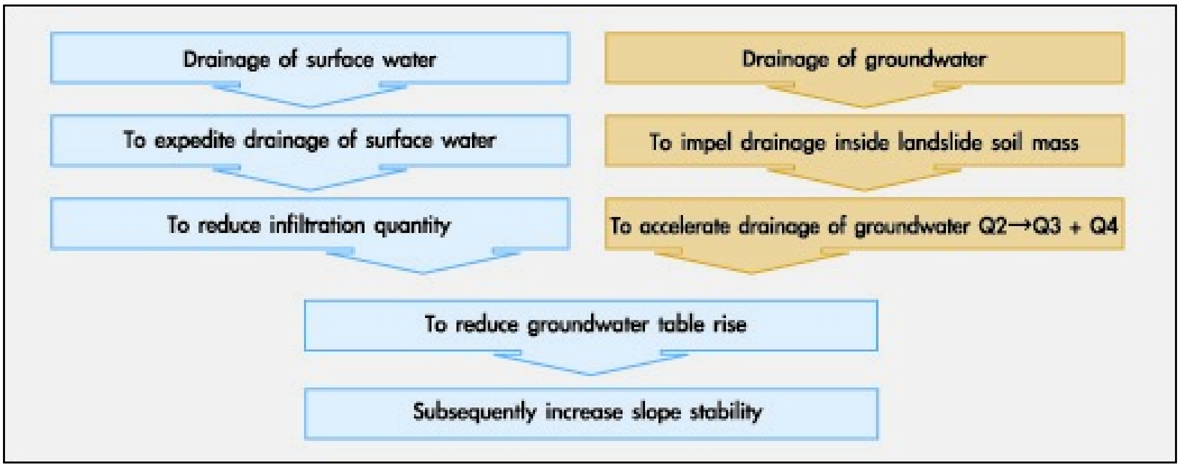

Fig.15 Function of drainage system

Fig. 16 is a diagram explaining the effect of drainage to the fluctuation of groundwater level so as its stability within a slope. Drainage can reduce infiltration and delaying of groundwater level rise during rainfall season. Lowering the maximum height of groundwater level during rainfall can keep the stability of the slope. In order to realize the effect of installation of drainage system, field monitored data are applied to simulate groundwater level change with or without drainage system, the result is presented in Fig.17.

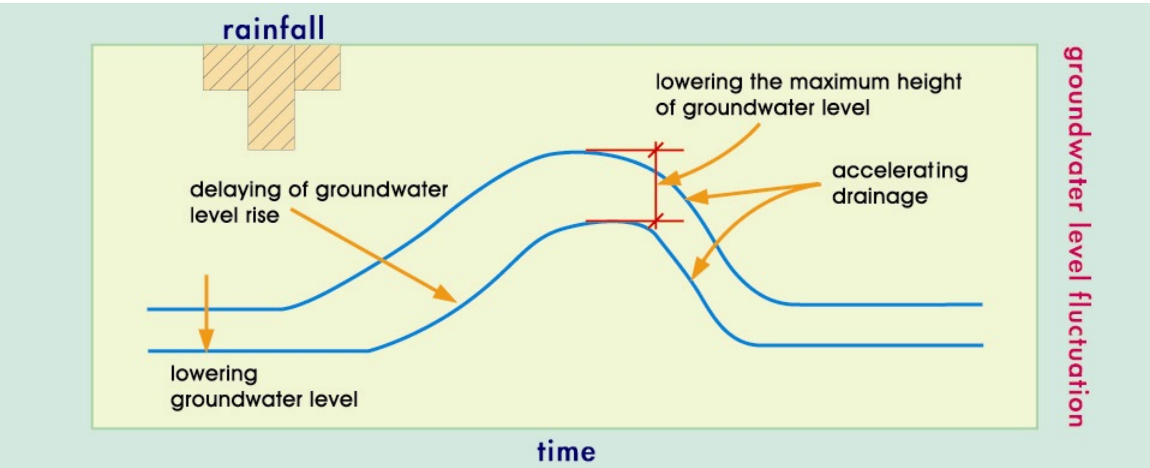

Fig.16 Groundwater level in slope area responds to installation of drainage system

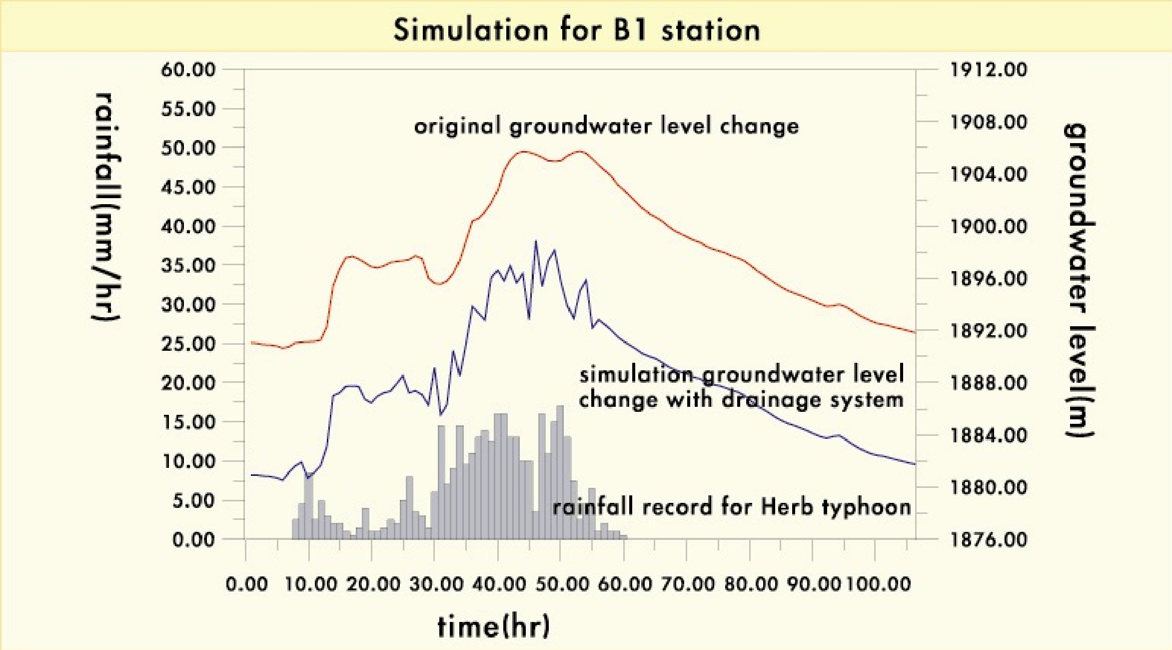

Fig.17 Comparisons between observed data and simulated result after construction of drainage system

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.

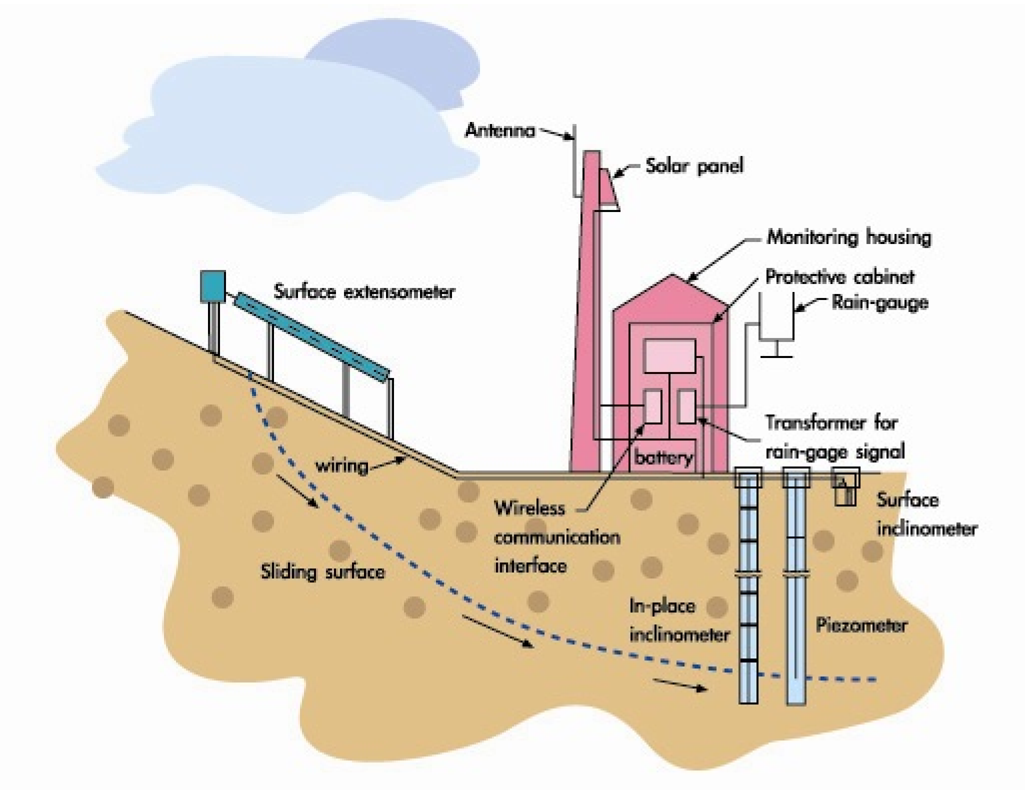

Fig. 18 Schematic of automatic monitoring system applied in Li-Shan landslide area

Evaluation of Remedial works

Results of monitoring system

B1 station

Sliding block B1 monitoring station was located at the western side of the central region. Collected data of rainfall, ground water level, and the surface movement are placed together and plotted in the same graph. As can be seen from the graph, the ground water level drops an average of 10 meters and the surface deformation moves an amount of 20 cm, respectively during the construction period of the drainage wells. In the meantime, the heavy rainfall usually accompanies the rise of the ground water level. However, the water level remained unchanged after the construction of the drainage wells was completed.

B5 station

Sliding block B5 monitoring station was located just right above the block B1. The graph shows that the 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.

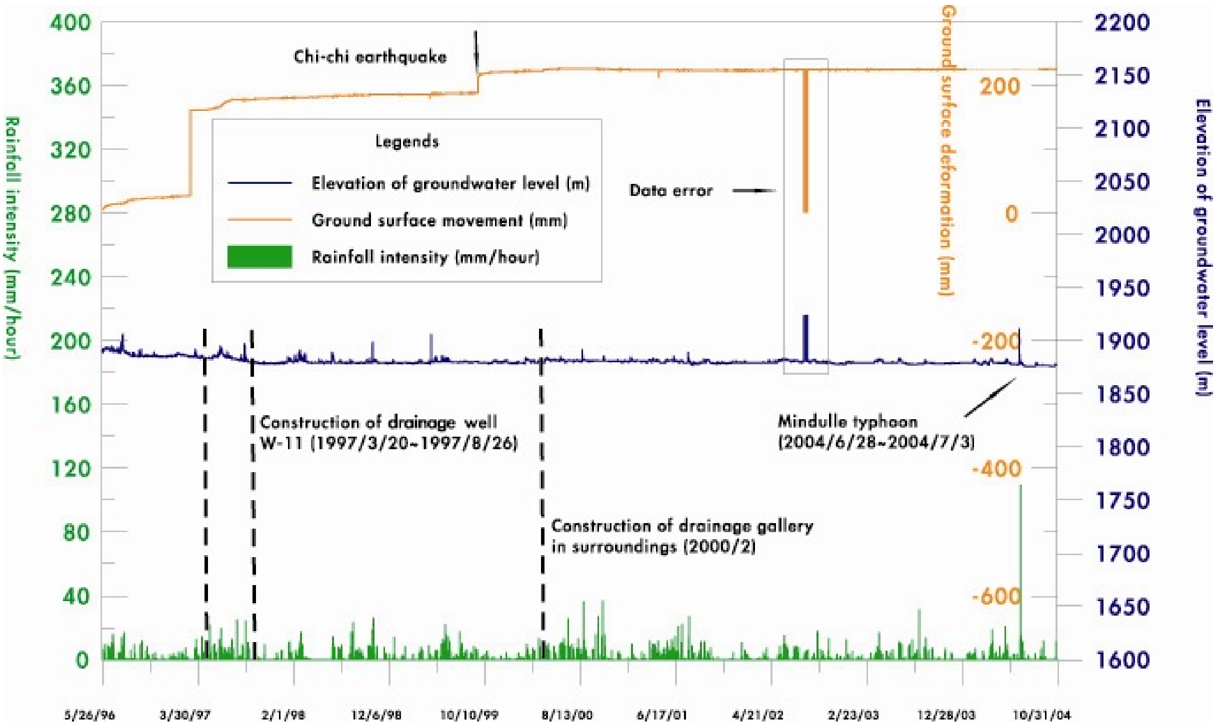

Fig.19 Relation between rainfall intensity, groundwater level and surface deformation in B1 station during 1996/5 - 2004/10

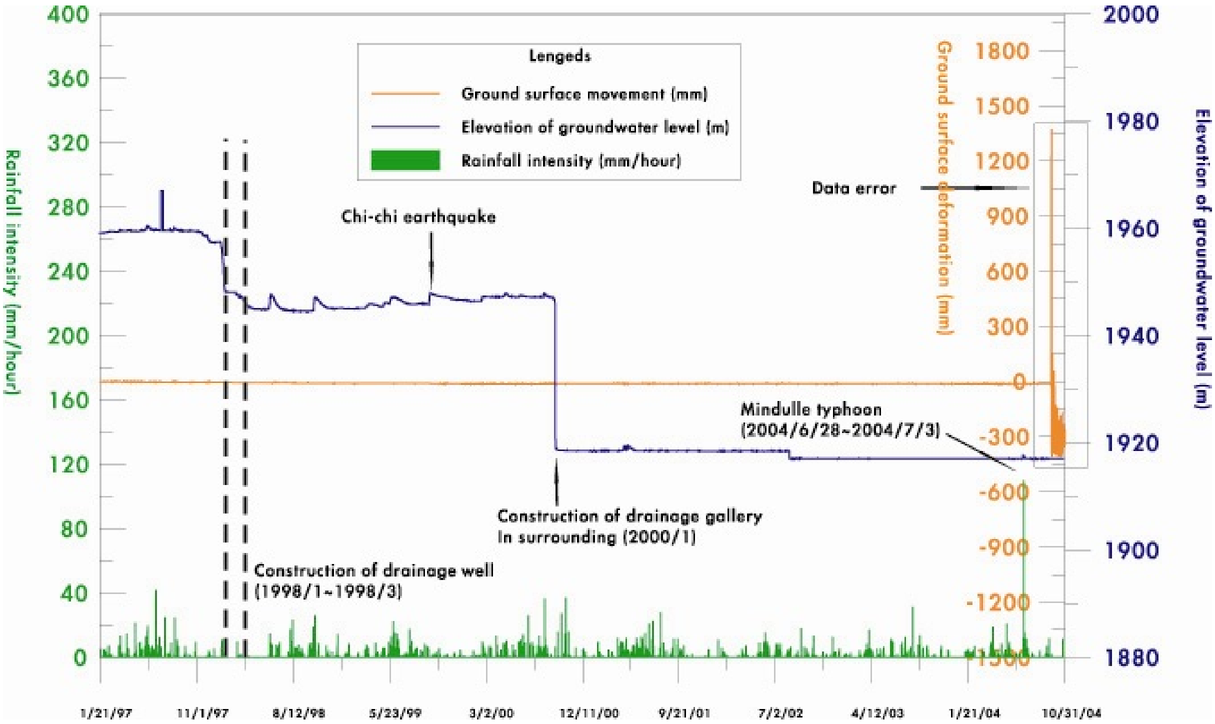

Fig.20 Relation between rainfall intensity, groundwater level and surface deformation in B5 station during 1996/5 - 2004/10

Conclusions

Landslides remediation work are important in Taiwan in regards to the natural resources and to the requirement of slope land development. In the consequences of choice of a remediation method, regrading the landform should be first to consider, drainage method and retaining structure both can help in slope stability. The case study presented proved the effectiveness of drainage method especially it exert no harm to local ecology. Factor of safety for Li-Shan landslide has improved by using surface and underground drainage system.

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