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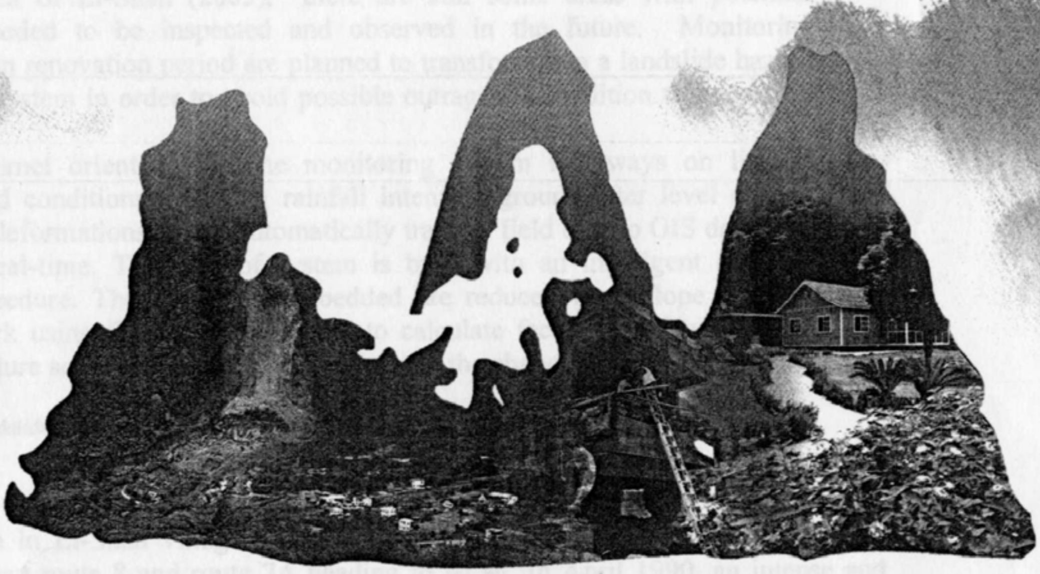
論文集



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Landslide Hazard Prewarning System for Li-Shan Area

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ABSTRACT

In April 1990, an intense and spectacular landslide hazard occurred in Li-Shan area triggered by a prolonged torrential rain. The catastrophe leads to destroying of many public facilities in surrounding area. An investigation program for renovating the landslide was conducted from 1991 to 1993. After that, remediation works were performed starting from 1995 and finished the project at the end of 2002.

According to the report "performance evaluation on renovation works in landslide area of Li-Shan (2003)," there are still some areas with potential landslide needed to be inspected and observed in the future. Monitoring systems set in renovation period are planned to transform into a landslide hazard prewarning system in order to avoid possible outrageous condition to happen in the future.

An internet oriented real-time monitoring system is always on line to monitor field conditions including rainfall intensity, groundwater level change and ground deformations. It can automatically transfer field data to GIS data base system in real-time. The core of system is built with an intelligent decision making procedure. The procedure embedded are reduced from slope stability analysis work using field monitored data to calculate factor of safety so as to announce future action automatically in regards to the change of field condition.

Key Words: landslide, prewarning system, Hazard mitigation

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Introduction

The 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 April 1990, an intense and spectacular landslide hazard occurred in this area triggered by a prolonged torrential rain. The catastrophe lead to destroy the pavement foundation on route 7A, disrupted the transportation facilities, and caused the nearby buildings such as Li-Shan Hotel to severe settlement and deteriorative crack. After the disaster, the then 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 area was officially approved between 1991 and 1993. The Energy Research Organization of Industrial Technology Research Institute was requested to submit the proposal and accomplish the task, “Investigation and Renovation Planning for Landslides in Li-Shan Area” in 1994.

Rainfall record

Background analysis of rainfall record for April 1990 is presented in Figure 1. In the duration of landslide occurring, maximum daily rainfall record was 155.5 mm at 19th, which is not very large compared to history record. But, accumulated rainfall between 10th to 20th of April arrived 585 mm and total rainfall in April of that year arrived 957.5 mm both exceed 50 years return period from rainfall frequency analysis. It can be seen as continuous rainfall caused large amount of infiltrated water to accumulate inside slopes so as to induce landslides. Water infiltrate from ground surface and uphill area and flow into the endangered slope can cause porewater pressure to raise, effective stress within slope to decrease, and break the stability of slope. So, rainfall and groundwater level change are concluded as the main triggering factors for this highly weathered rock slope.

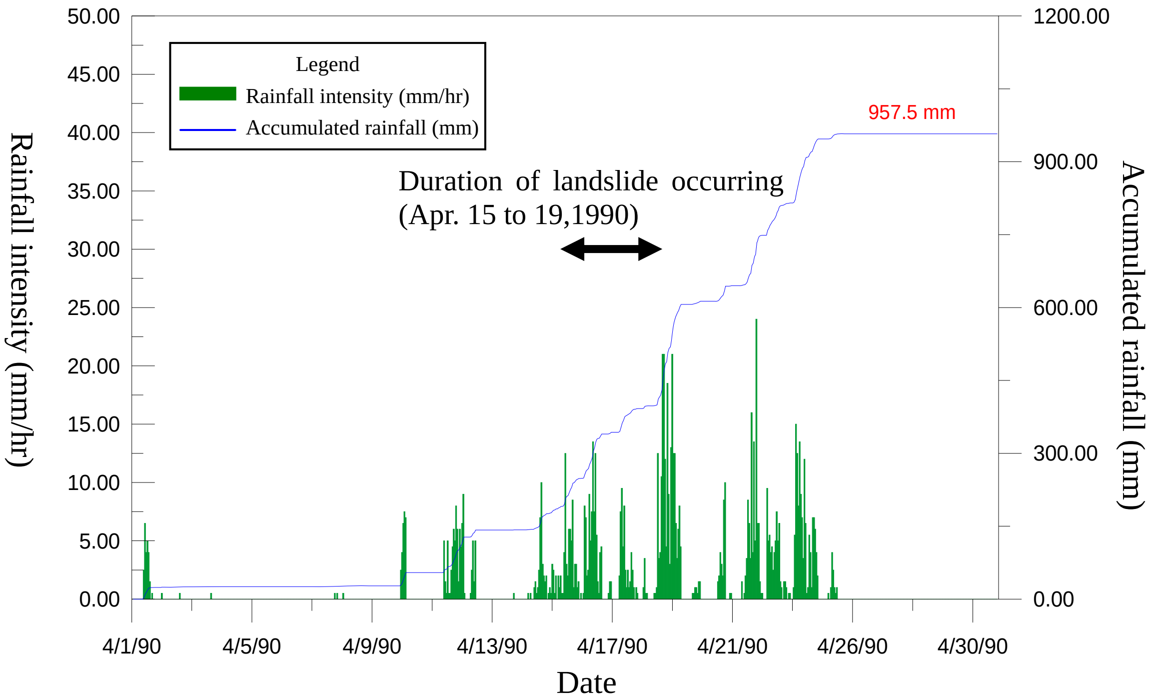

Fig. 1 Precipitation record at Taipower company’s Li-Shan station in April 1990

Renovation Work

The primary renovation work for landslide in Li-Shan area is to lower the groundwater level and drain the surface rainfall. 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 to normal condition.

On June 25, 1994, the renovation project for remediation work on Li-Shan landslide was officially approved by Executive Yuan. It was originally planned to be executed for the period 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 more detailed field investigation process to deduce the properties of naturally occurring materials before the detailed design for renovation work was undertaken.

All items for renovation project include:

1. Complete the surface drainage work by installing the drainage ditches both lateral and longitudinal direction with a total length of 8,170 m.
2. Installation of 38 sets of horizontal drains (180 drilling holes) with a total length of 10,890 m.
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 which includes the installation of the 4,863 m collecting pipes inside the gallery; and the 550 m 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. Construction of 3 sets of sediment restored dams as well as 62 sets of submerged dams for sediment restored work.
8. Installation of 8 sets of automated monitoring systems and 3 sets of monitoring system maintenance.
9. Field investigations had been carried out twice before the design was undertaken.
10. Provide five progressively synthesized reports about renovation 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.

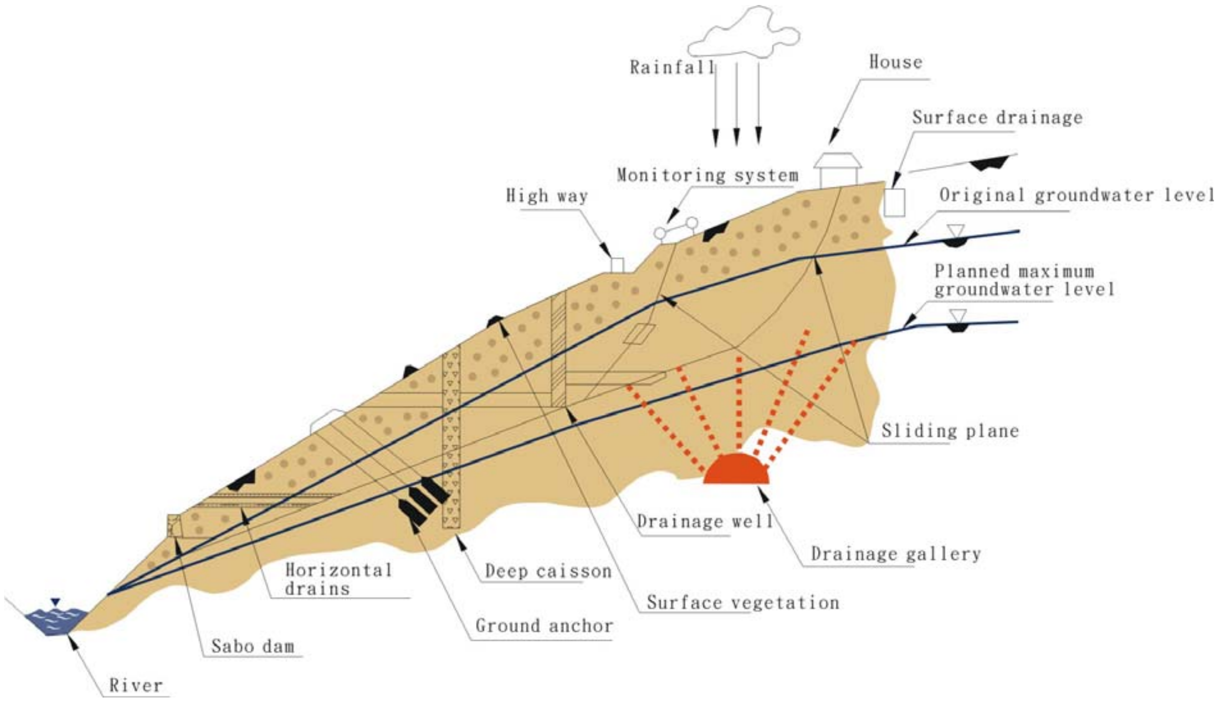

Fig. 2 Sketch diagram to show different remedial works

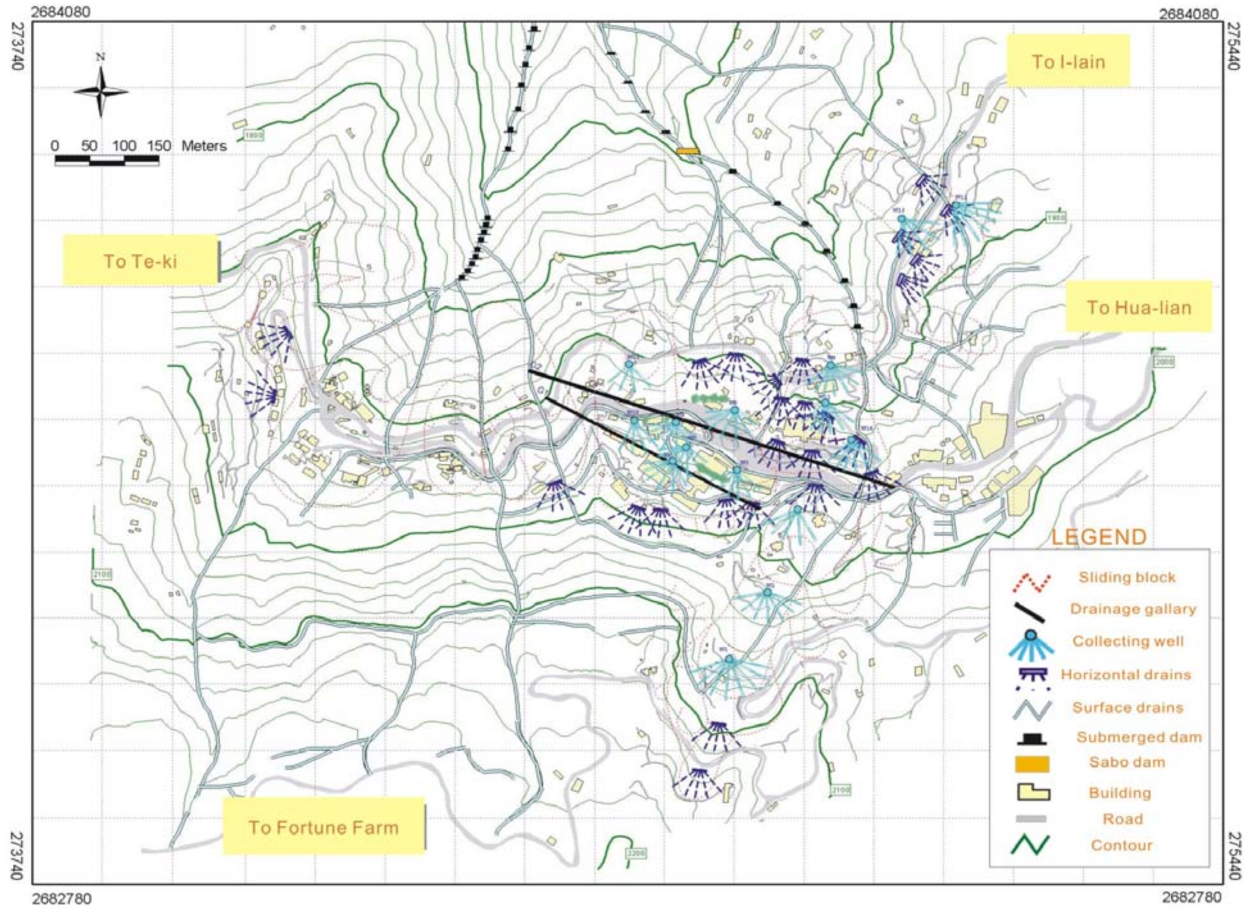

Fig. 3 Distribution of engineering works in Li-shan area

Description of Li-Shan's Geology Conditions

In western Taiwan, the westward thrust front due to the compression of the Philippine Sea Plate is obstructed by the rigid basement Peikang High (part of the Eurasian Plate) and result in a series of Quaternary thrust faults trending north-south and dipping towards the east. The 1999 Chi-Chi earthquake is considered as reactivating of one of the active thrust fault, Che-Lung-Pu 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. From the geologic map of Taiwan as shown in Figure 4, she can be broadly divided into these major geologic provinces namely, central range, coastal range, and western foothills.

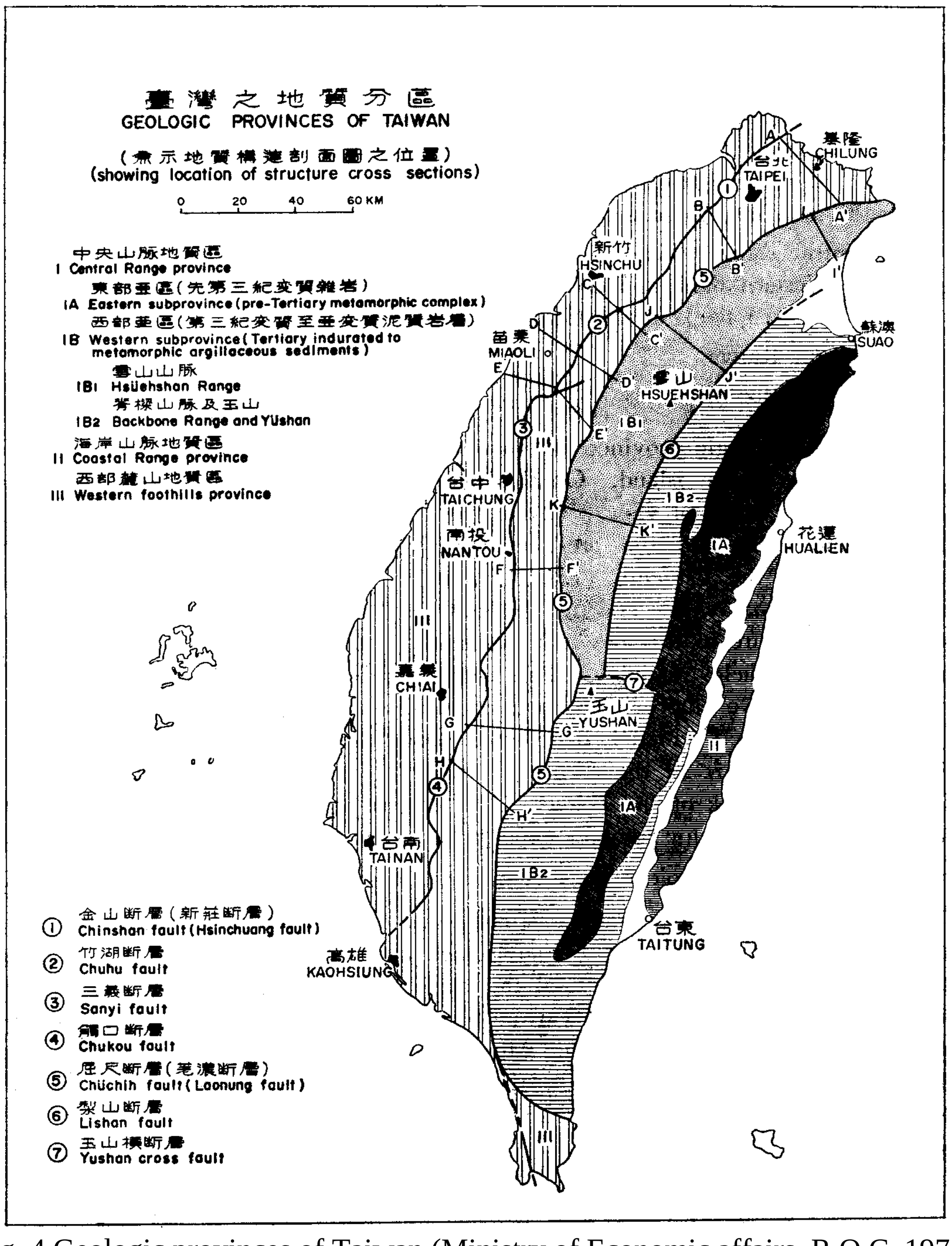

Fig. 4 Geologic provinces of Taiwan (Ministry of Economic affairs, R.O.C, 1975)

Topographically, Li-Shan area is located in the valley of the Ta-Chia-Chi river, and there is an old sliding body located in the center of the Li-Shan area. Through the field investigations, smaller sliding bodies can be identified and classified.

Geologically, Li-Shan village is not far from the Li-Shan fault, and it is suggested that the geological conditions is more complicated than expected in this area. It is evident that Li-Shan village is located at colluvial deposits originally from the Miocene Lu-Shan formation. Due to the high erosion rate of the Lu-Shan Formation, together with the heavy rain during April 15-19, 1990, it is generally concluded suggested that the Li-Shan landslide is predominantly caused by heavy rain and poor drainage condition.

According to the investigations, the Lu-Shan formations can be classified to three different types by their condition of weathering: the colluvium soil (highly weathered), the weathered slate, and the fresh slate.

The landslide area can be divided into four regions, namely central, west, northeast, and southeast regions as shown in Figure 5. Except the southeast region, most of the unstable slopes possess shallow sliding planes at about 9-26 m below surface. However, there is an old landslide within the central region, of which boundary divides the southeast region from central region. According to the core logs and the records of drainage gallery construction, the old sliding plane is located more than 40-60 m below surface. The southeast region is more or less at a valley of a small branch of the Ta-Chia-Chi river. Due to the tectonic activities, there is rejuvenation in the Ta-Chia-Chi river. Thus the erosion rate of this branch is quite high, which generate higher landslide hazard potential for this subregion.

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 plane is basically along the lower boundary of the regolith at about 20m below the surface, (2) there is a major old landslide at the center of the village, (3) the high erosion rate makes the slopes beside the streams more dangerous than the others.

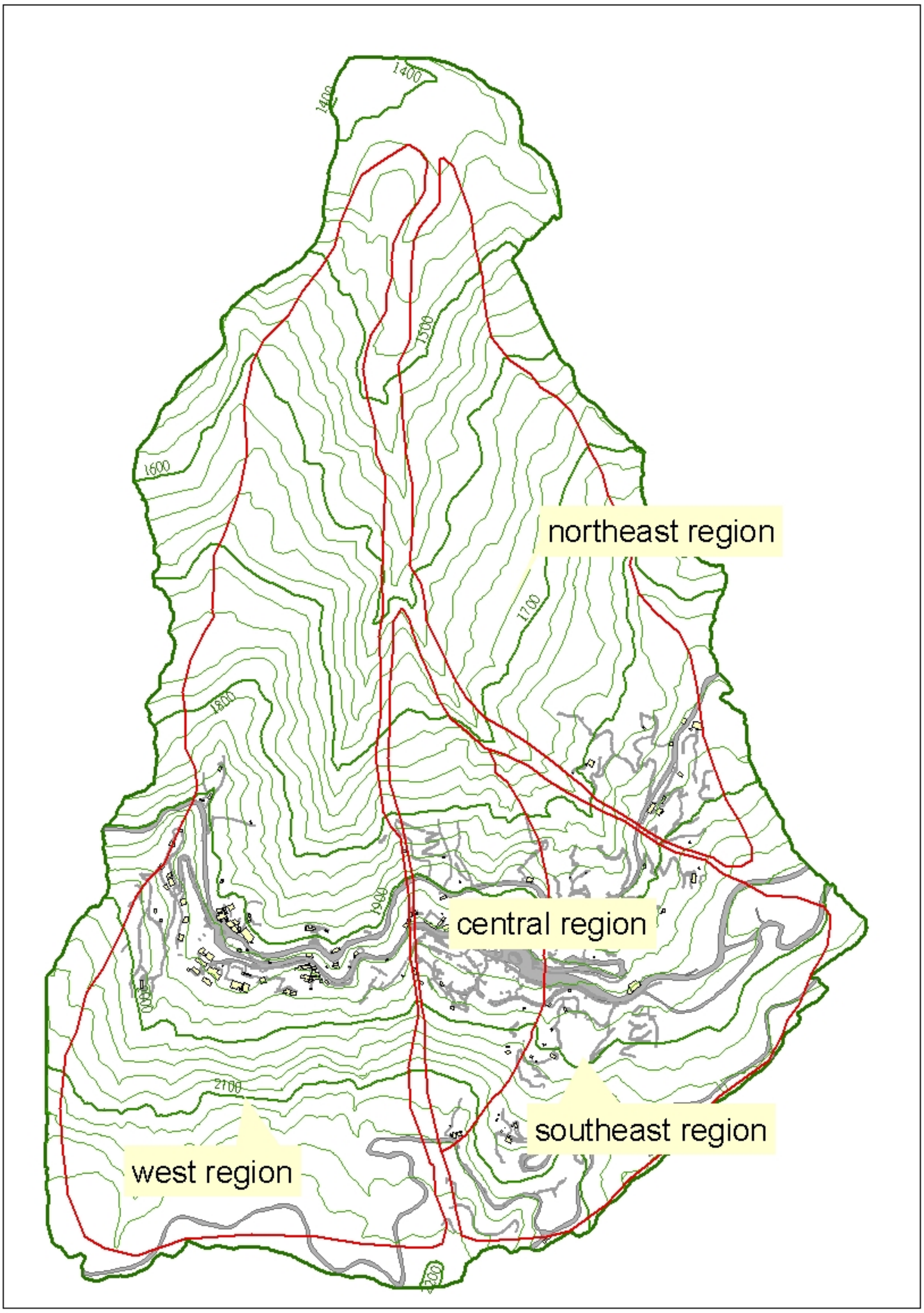

Fig. 5 Division of the four regions in Li-shan landslide area

Monitoring system

Eight monitoring stations were set up in this area. Each station was equipped with raingage, piezometer for groundwater level, inclinometer on the surface and into the borehole for monitoring the ground deformation and extensometer for surface movement. System configuration is shown in Figure 6. Locations of the stations are given in details in Figure 7.

Remedial work for this stage lasts from 1995 to 2002. In the mean time, monitored data are reduced. Automatic monitoring system is reduced to evaluate effectiveness of remedial work. Complete data set can be found in the reports listed in the references. At present time, monitoring results are transfer into management criterion for safety as discussed in the followings.

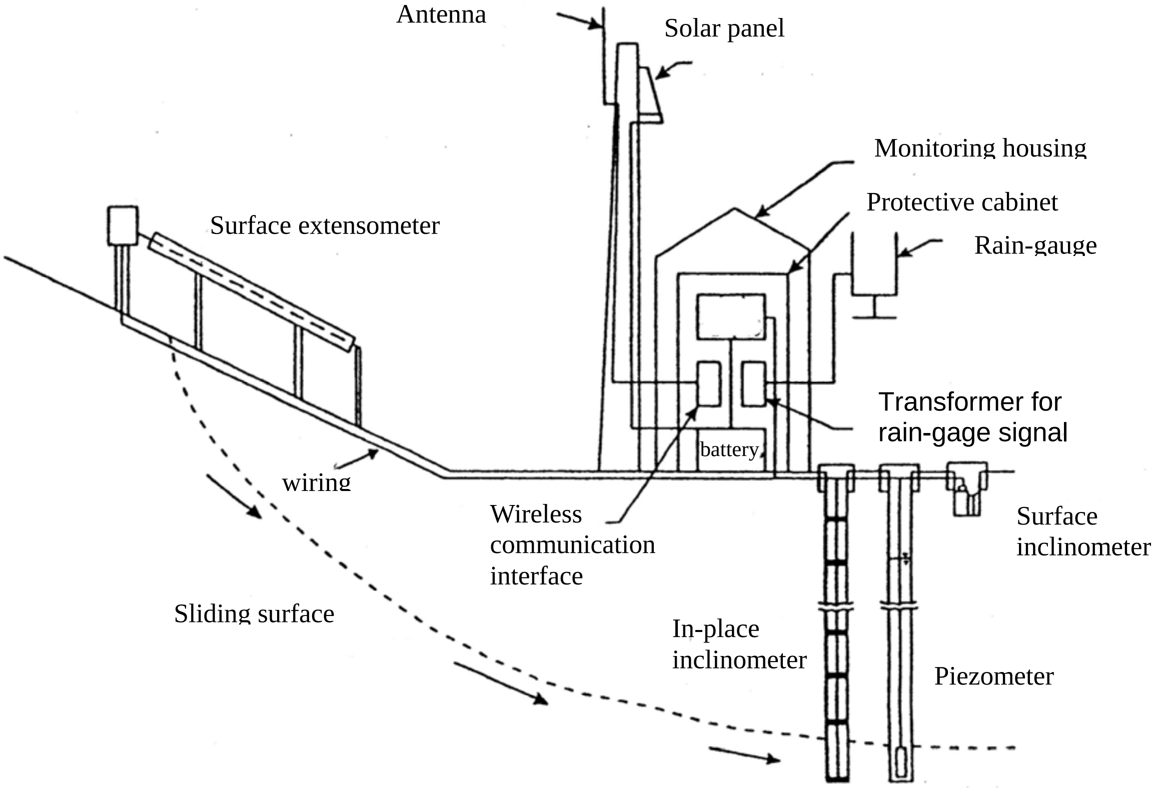

Fig. 6 Schematic of automatic monitoring system applied in Li-shan landslide area

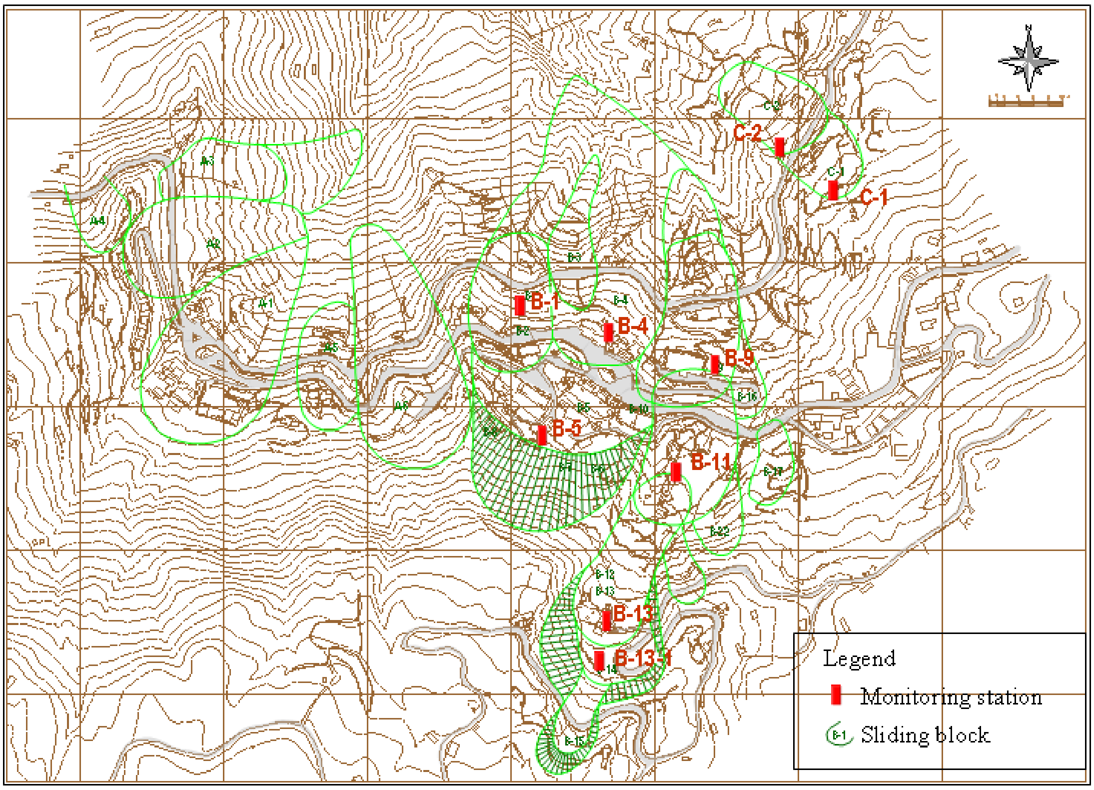

Fig. 7 Locations of monitoring stations in Li-shan landslide area

Management criterions for safety in regards to landslide

In order to set up the safety managing mechanism, field monitored data are applied to set up criterions using rainfall record, groundwater level, and surface deformation individually. Degrees of risk are separated into 4 grades, namely normal, attention, warning, and dangerous. In "normal" situation that means in daily life nothing happen could induce danger. When there are something detected which could enlarged into a dangerous condition, people who are in charged should be noticed and moved to "attention" situation. When the factors influencing the stability of slopes are getting worse, there are possibility for the landslide be triggered, the commander should move into a "warning" stage and be highly alerted. If the stability of the slopes getting worse, there are quite certain that slopes keep on guarded having high possibility to slide, citizens who are living in affecting area should be evacuated for the sack of safety, the system should move into "dangerous" stage.

Criterion for rainfall amount

Rainfall causes infiltration then groundwater level to raise then affects the stability of slopes. Based on data recorded previously, different return period rainfall intensity for LI-Shan area are summarized in Table 1 and Table 2.

Table 1 24 hrs rainfall intensity(in mm) versus return period for Li-Shan area

Return period	Extreme type-1 distribution	Log-normal distribution	Log-pearson type-3 distribution	Mean value from above
2.33	178.0	178.6	178.6	178.4
5	223.1	224.5	224.5	224.0
10	259.7	261.3	261.3	260.8
25	306.0	307.2	307.3	306.8
50	340.4	341.0	341.3	340.9
100	374.5	374.6	375.1	374.7

Table 2 48 hrs rainfall intensity(in mm) versus return period for Li-Shan area

Return period	Extreme type-1 distribution	Log-normal distribution	Log-pearson type-3 distribution	Mean value from above
2.33	254.96	254.62	248.31	252.63
5	327.06	321.77	318.55	322.44
10	385.7	375.85	380.71	380.75
25	459.78	443.55	465.85	456.39
50	514.75	493.62	534.24	514.2
100	569.3	543.46	607.03	573.26

Rainfall intensity for 10 years return period are suggested as the criterion for safety. By using B-9 rain gauge's data, the criterion chosen are put together with the record in the monitored duration as shown in Figure 8, 9 and 10 for hourly, daily and bi-daily rainfall amount.

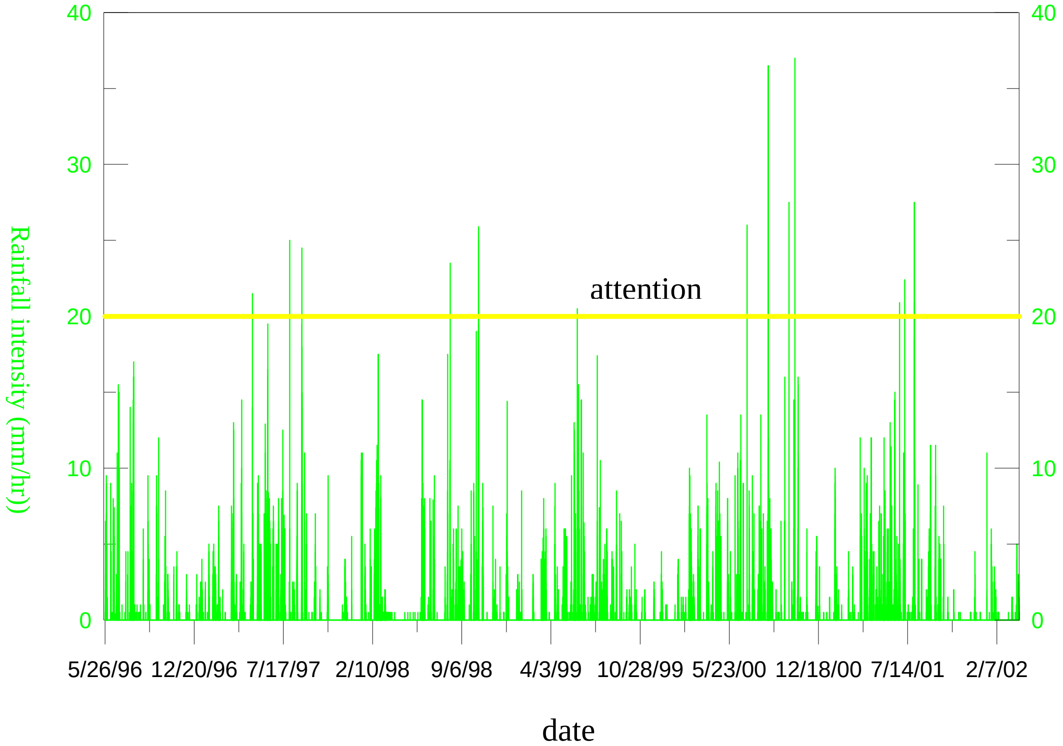

Fig.8 Precipitation record in B9 monitoring station

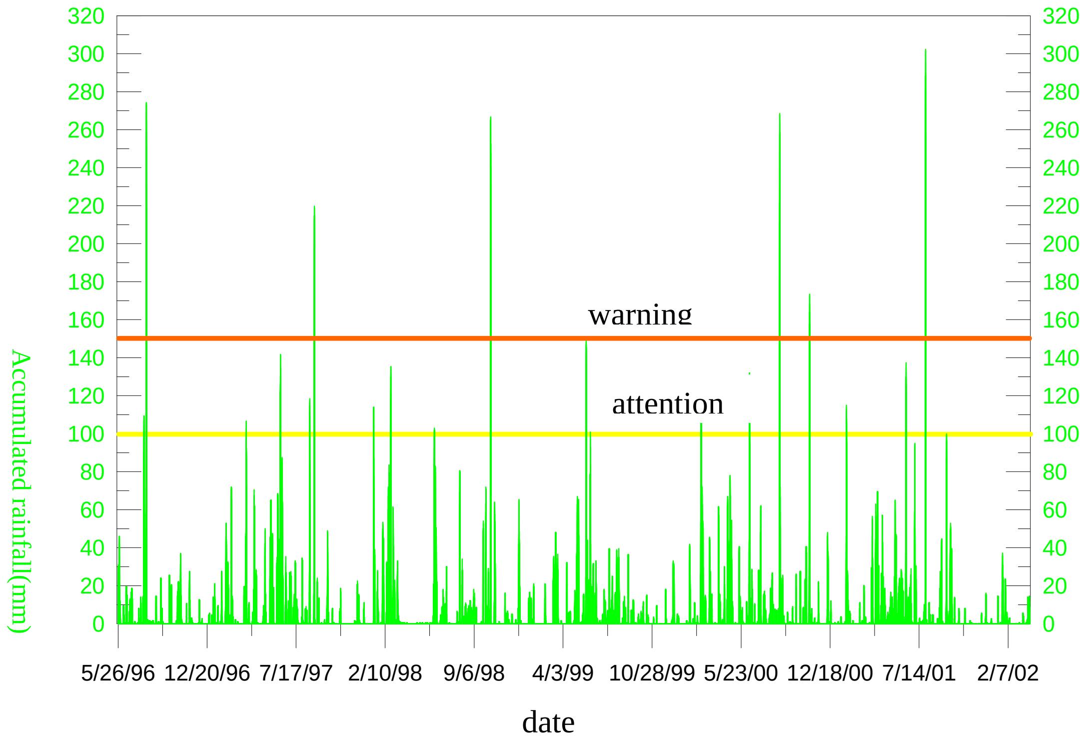

Fig.9 Precipitation record of 24hr duration in B9 monitoring station

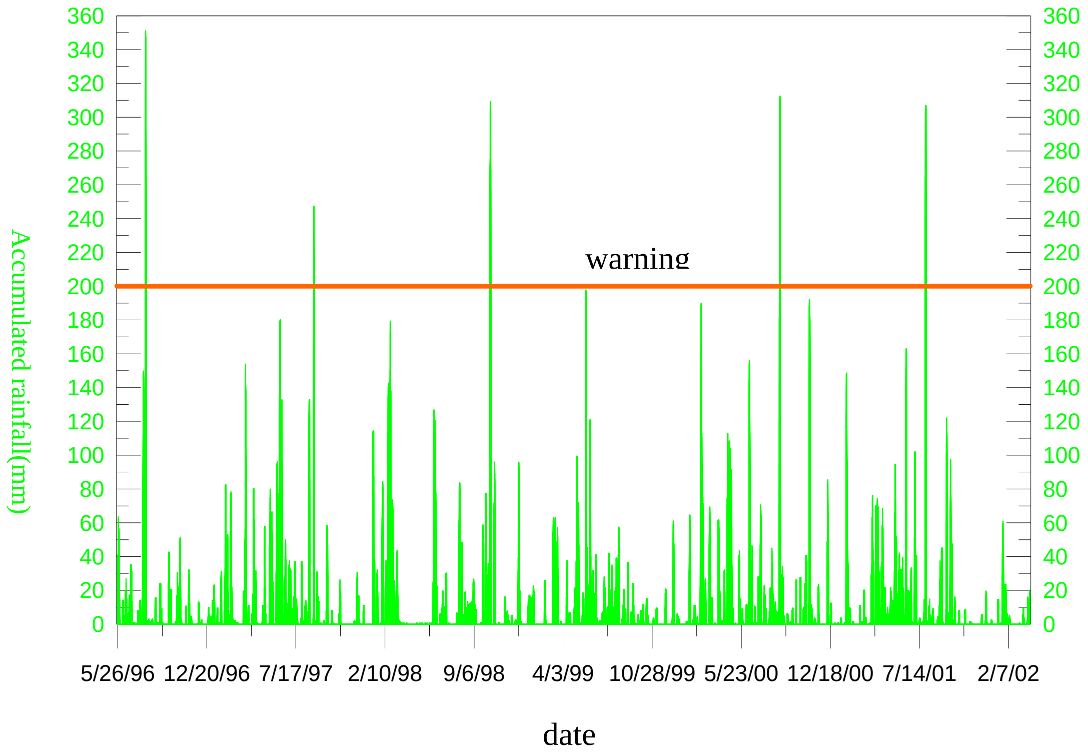

Fig.10 Precipitation record of 48hr duration in B9 monitoring station

For hourly rainfall, maximum intensity during recording period was 37 mm/hr. But its affect on stability rely on saturation degree of soil and groundwater level in slopes. In performing prediction using Analogous Neural Network technique, it is concluded that for rainfall intensity larger than 20mm/hr could cause significant groundwater surface raising. So 20mm/hr rainfall intensity is chosen as the “attention” criterion, and because long term rainfall affects stability more significant, no “warning” criterion are set for hourly rainfall. 24 hrs and 48 hrs accumulated rainfall are chosen using analyzed result on Table 1 and 2. It is chosen as a little bit less than 2.3 years return period. No rainfall criterion evacuation action was set because of the uncertainty. Criterions for rainfall intensity are verified continuously from Herb typhoon in 1996, Cass in 1997, Zeb in 1998, Bilis and Xangsane in 2000 and Toraji in 2001. The results are acceptable and can be found in more detail from previous report.

Criterion for groundwater level

Groundwater level charge is the most important factor that affects the stability of a slope from inside. Pore water pressure change will alter the effective stress within a slope so as to change it factor of safety. In order to find safety criterion for groundwater level, slope stability analysis based on bore log and strength testing are performed. Then, analysis result are put together with monitoring data to back calculating critical groundwater level based on pre-defined factors of safety.

8 profiles are chosen for slope stability analysis as shown in Fig 11. A among them, S2 and C1 are presented here in Figure 12 and 13. Commercial program “SLIDE” based on 2-D limit equilibrium method are utilized. Parameters for material properties and shear strength are condensed from laboratory tests results are presented in Table 3, 4 and 5.

After finishing the slope stability analysis, groundwater level elevation for different predefined factor of safety based on monitoring. Station located are calculated to set up criterions for each slopes monitored as listed in Table 6.

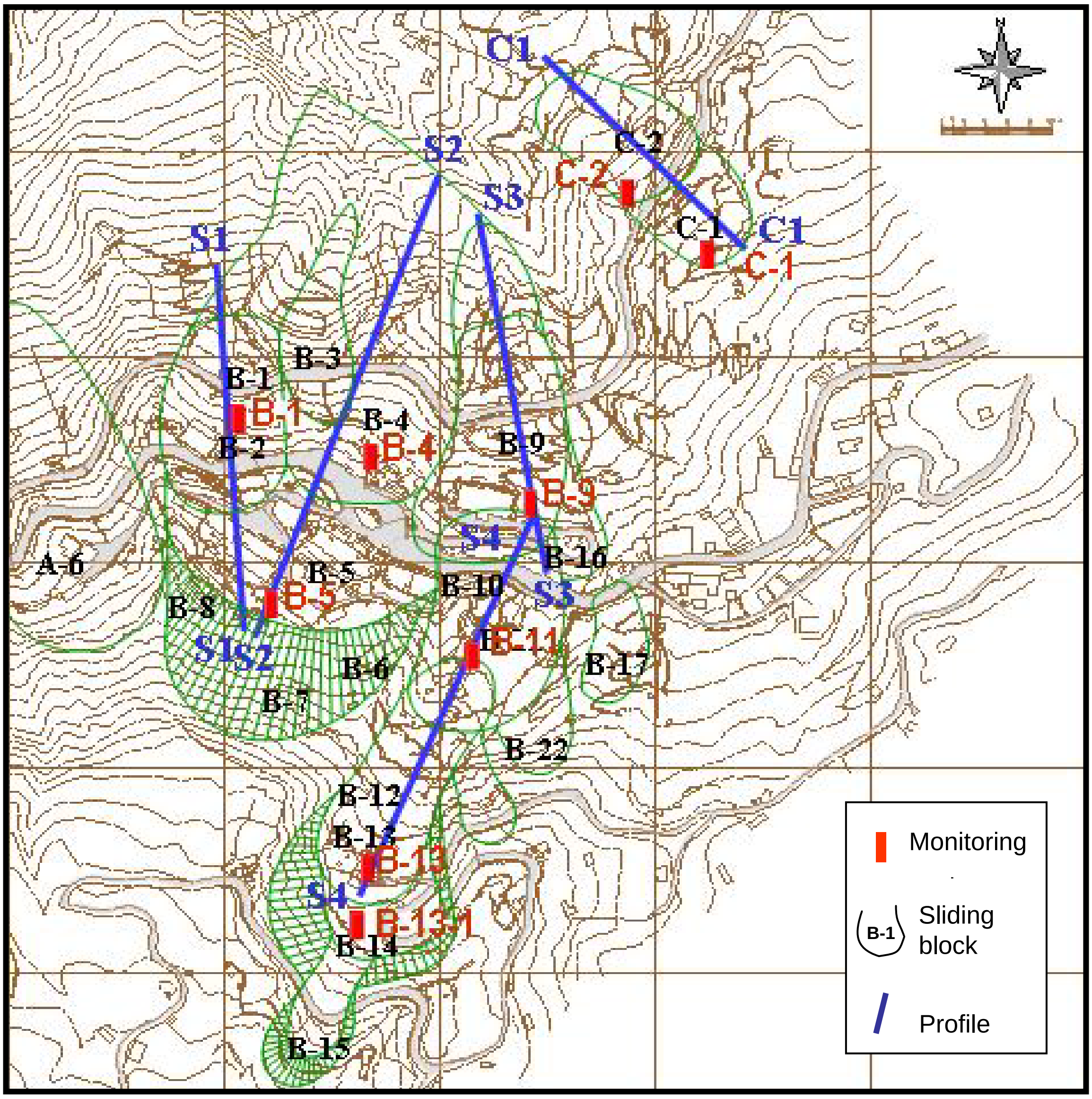

Fig. 11 Location of profile and its corresponding monitoring station

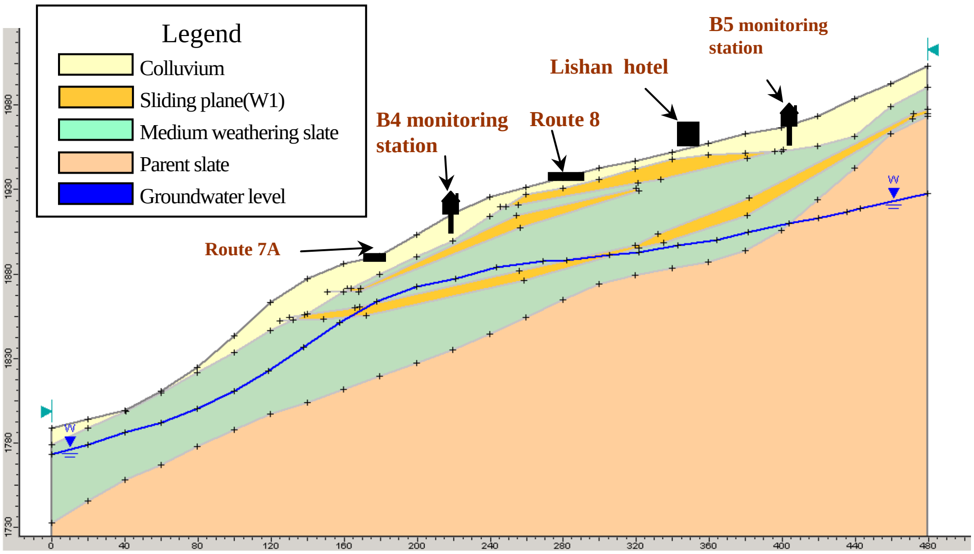

Fig. 12 Identification of potential sliding plane on S2 profile

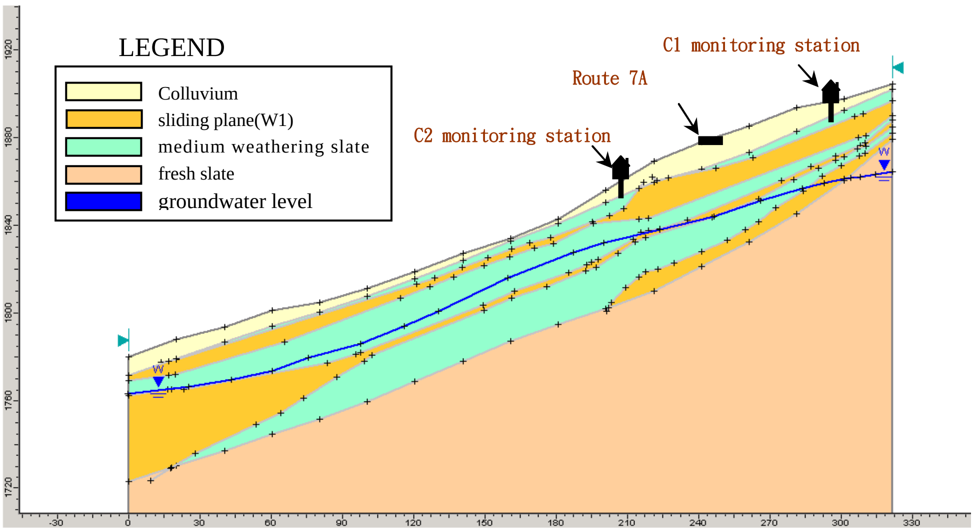

Fig .13 Identification of potential sliding plane on C1 profile

Table3 Properties of geomaterial in Li-Shan area

Type of geomaterial	G	γ_t(t/m^3)	C(T/M^2)	φ (degree)
Colluvium	2.73	2.06	0.50	28
Medium to highly weathered slate	2.76	2.69	3.00	33
Fresh to medium weathered slate	2.76	2.70	30.00	37
Sliding plane	2.76	2.69	1.00	16.7

Table 4 Result of analysis using Slide program for S2 profile

F.S / condition	Shallow sliding plane	Medium depth sliding plane	Deep sliding plane
No loading(present groundwater level)	1.66	1.18	1.33
Extra loading (present groundwater level)	1.65	1.18	1.33
No loading (highest groundwater level)	1.65	1.11	1.06
Extra loading (highest groundwater level)	1.59	1.10	1.06
No loading (lowest groundwater level)	1.71	1.24	1.35
No loading (slope filled up with groundwater)	------	------	1.01

Table 5 Result of analysis using Slide program for for C1 profile

F.S / condition	Shallow sliding plane	Deep sliding plane
present groundwater level	1.11	1.18
highest groundwater level	1.10	1.16
lowest groundwater level	1.21	1.23
slope filled up with groundwater	0.63	------

Table 6 Criterion for elevation of groundwater level for monitoring station

Degree of risk	Normal	Attention	Warning	Dangerous
Corresponding factor of safety	>1.15	1.10	1.05	1.0
B1 Elevation of G.W.L.(m)	1890	1892	1897	1902
B4 Elevation of G.W.L. (m)	1891	1897	1903	1908
B5 Elevation of G.W.L. (m)	1945	1948	1953	1962
B9 Elevation of G.W.L. (m)	1893	1902	1907	1913
B11 Elevation of G.W.L. (m)	1978	1987	1991	2004
B13 Elevation of G.W.L. (m)	2040	2045	2050	2060
C1 Elevation of G.W.L. (m)	1874	1878	1882	1885
C2 Elevation of G.W.L. (m)	1830	1835	1838	1843

Criterion for ground surface deformation

Distribution of ground surface deformation reflects the sliding zone and block. Monitoring of ground surface deformation in a landslide area can apply to detect small deformation before large completely failure. Relationship between strain of ground surface and time for creeping are applied in estimating triggering of major failure. As presented by Saito(1965), slope will creep before complete failure. Creeping of slope can be divided into three stages based on its strain rate, i,e., slope of the line for strain and time graph. In first order of creeping slop of the line is decreasing. The line will develop steadily in a fixed slope until it moves into third stage. Slope of the line increase dramatically when it is approaching totally slope failure as shown in Figure 14.

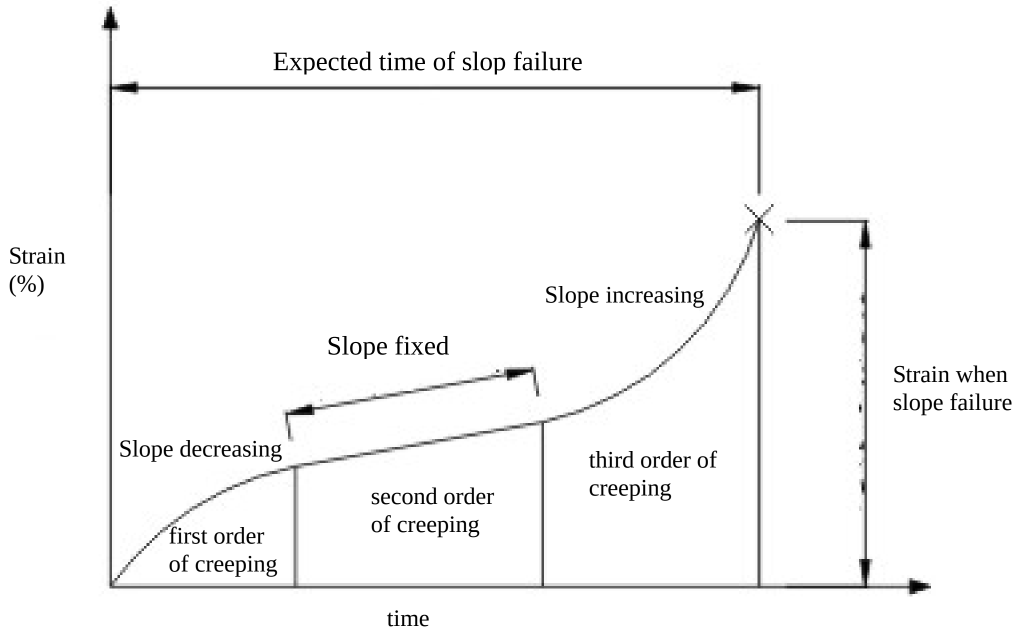

Fig. 14 Strain and time relation in creep phenomenon (Saito,1965)

Fukuzoni (1985) proposed a concept of reverse of deformation rate approaching zero when complete failure occurred. As shown in Figure 15, graph of reverse of deformation rate to time is drawn, extrapolation of line intercept zero can be applied to calculate Tr, expected time of failure from now.
In considering the effectiveness of strain rate, 10^{-6} %/min is chosen as the criterion for entering warning stage. This decision is made based on Saito’s collect of many case study. Time for evacuating act is chosen as 5 hrs expecting time of slope failure from the time judge is made. This suggestion is based on considering the time needed to give order to citizens and preparing and action. This is summarized in Table 7.

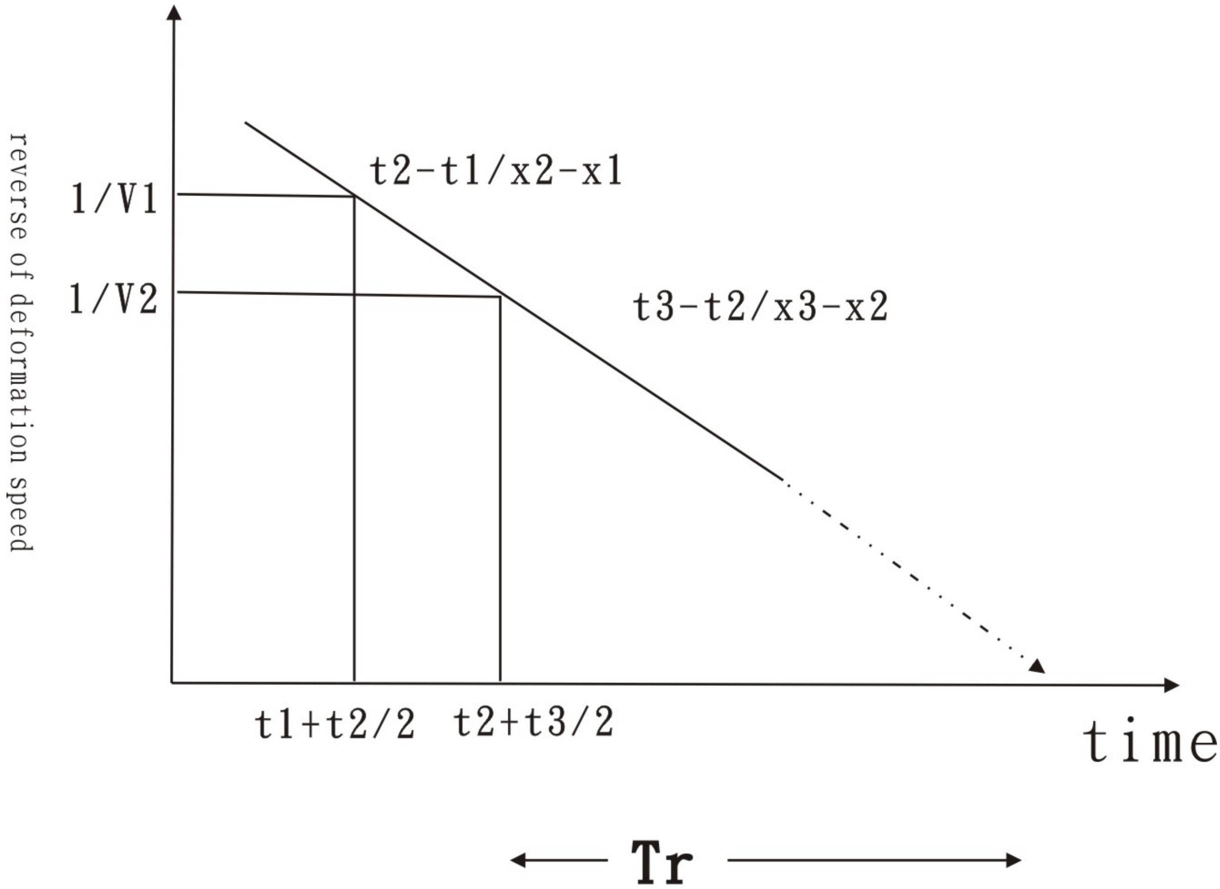

Fig.15 Use of curve of reverse deformation speed to predict expected time of slope failure

Table 7 Criterion for ground deformation

Degree of risk	Warning (%/min)	Evacuation (hour)
Criterion for deformation speed	10^{-6}	--------
Expected time of slope failure	------	T_r<5(disaster expect ed to occurr within 5 hours)

Recorded data

Ground surface deformation can be read from surface extensometer which had long term record from monitoring stations in Li-shan area. A brief description is given in the following in regards to each station.

B1 monitoring station

B1 station located at west side of central region which is the bottom of a series of sliding blocks. There are B2, B5, and B8 block in above.

Data for ground surface deformation together with major events are presented in Figure 16.As can be seen, ground keep on moving from the beginning construction of drainage well and drainage tunnel both caused the ground to move. But, after all the remediation work finished at the end of 2002, the ground remained stable until present time.

B5 monitoring station

B5 sliding block is located uphill of B1 which has many important building on it.

Data showed the influence of construction work in Figure 17. But, after all the remediation work finished at the end of 2002, the ground remained stable until present time .

B9 monitoring station

B9 sliding block is located to the east of B4 and B5 block. It is the front block of a series sliding block on southeast region. It has a major building called citizen Hotel sitting on it. The building was quite huge and has a very good view looking into Da-cha-chi river, but building had evaluated unsafe right after the major Li-shan landslide occurred on April 1990. And now (2004), the building was torn down and the site remolded into a rural garden.

In Figure 18, data of ground deformation showed the effect of construction work. After construction of drainage gallery, ground surface showed small amount of compression rather than extension. During the time for destruction of citizen Hotel, data showed fluctuating. In the future, more attention should be paid here to evaluate its long term stability.

B13 monitoring station

B13 block is located uphill of B11 and B9 block and formed a headward sequence more like retrogressive sliding in a complex form and was judged still unstable and developing headward.

Data for ground surface deformation showed the slope is stable in regard to sliding in Figure 19. But, by observing the field condition, headward erosion problem is significant here.

C1 monitoring station

C1 station located at Northeast region. C1 is on uphill of route 7A. Date of ground surface deformation showed close relationship with construction work of remedial plan in Figure 20.

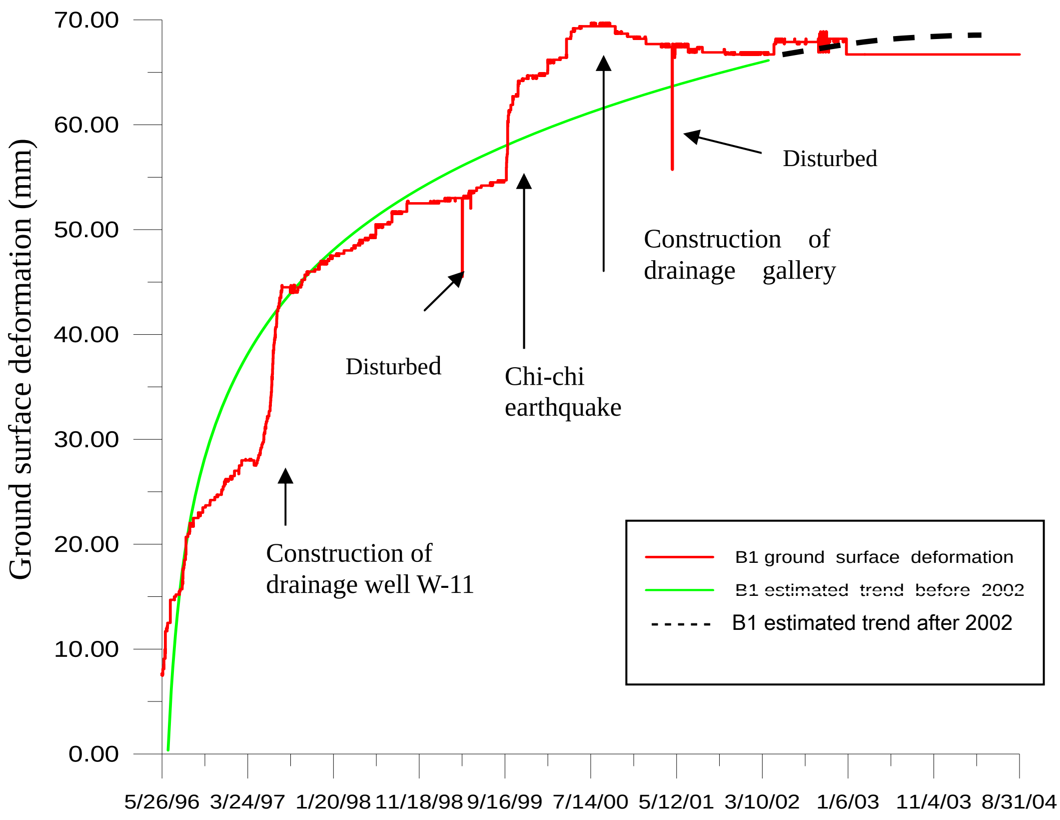

Fig.16 ground surface deformation and its estimated trend for B1 station

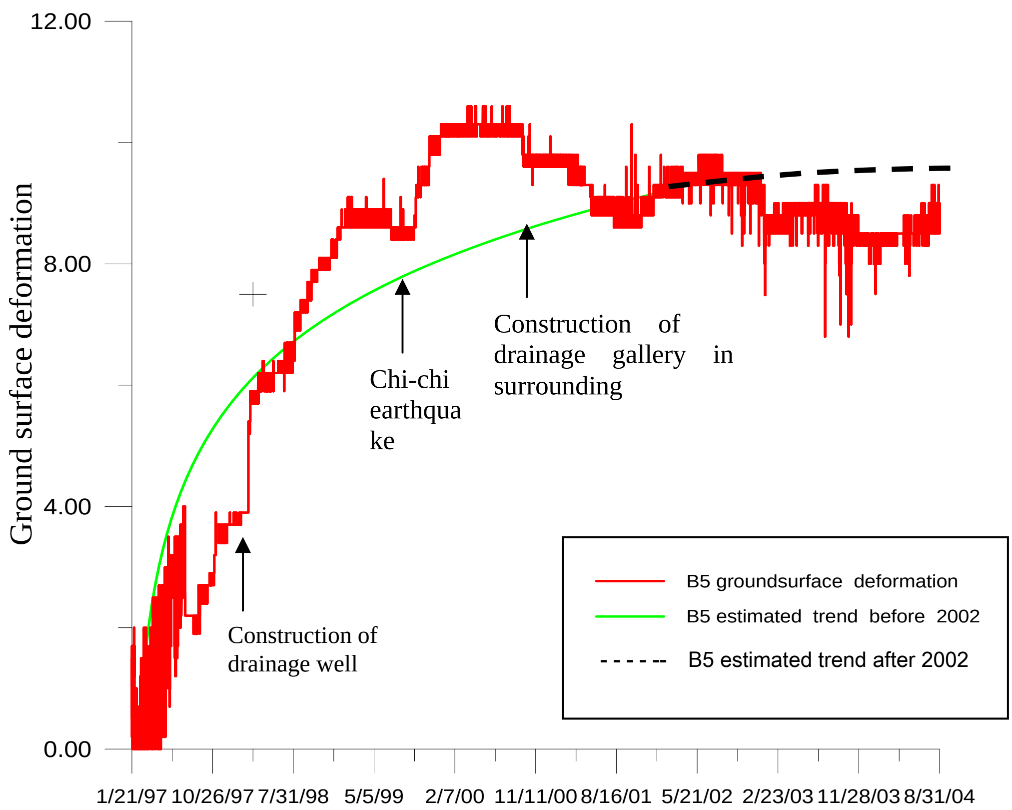

Fig.17 Ground surface deformation and its estimated trend for B5 station

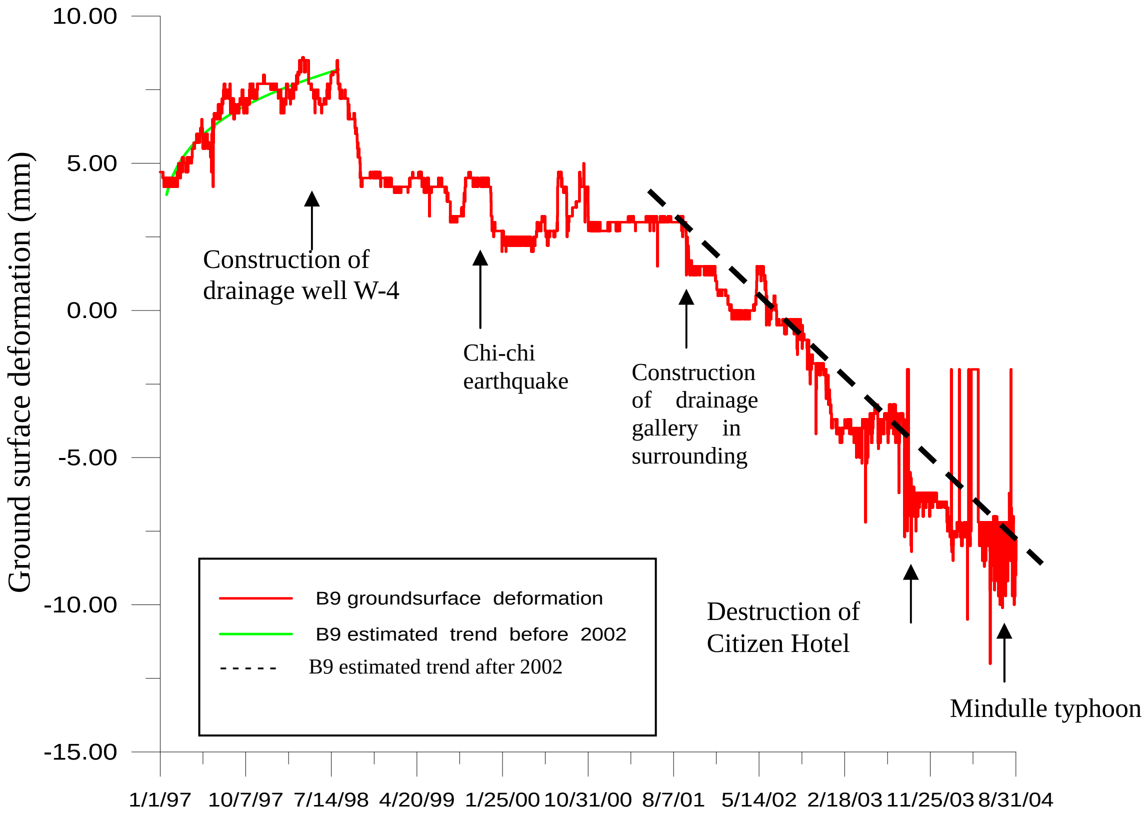

Fig.18 Ground surface deformation and its estimated trend for B9 station

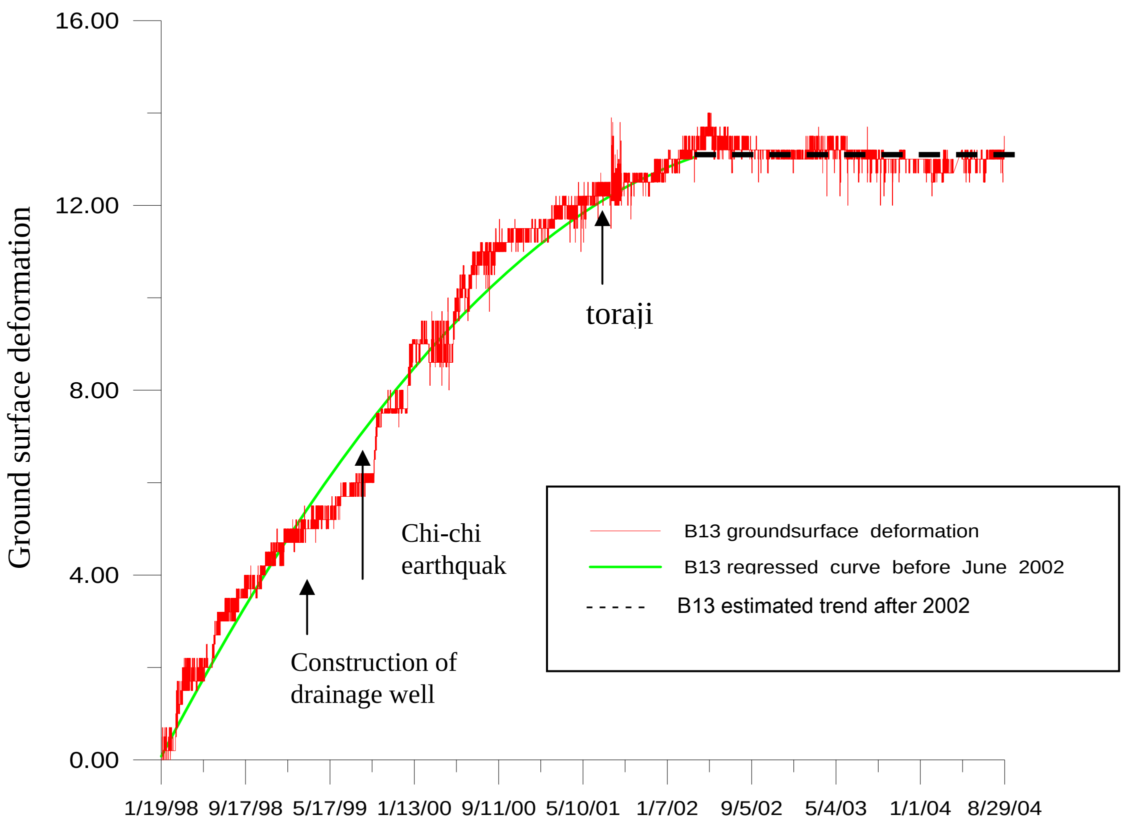

Fig.19 Ground surface deformation and its estimated trend for B13 station

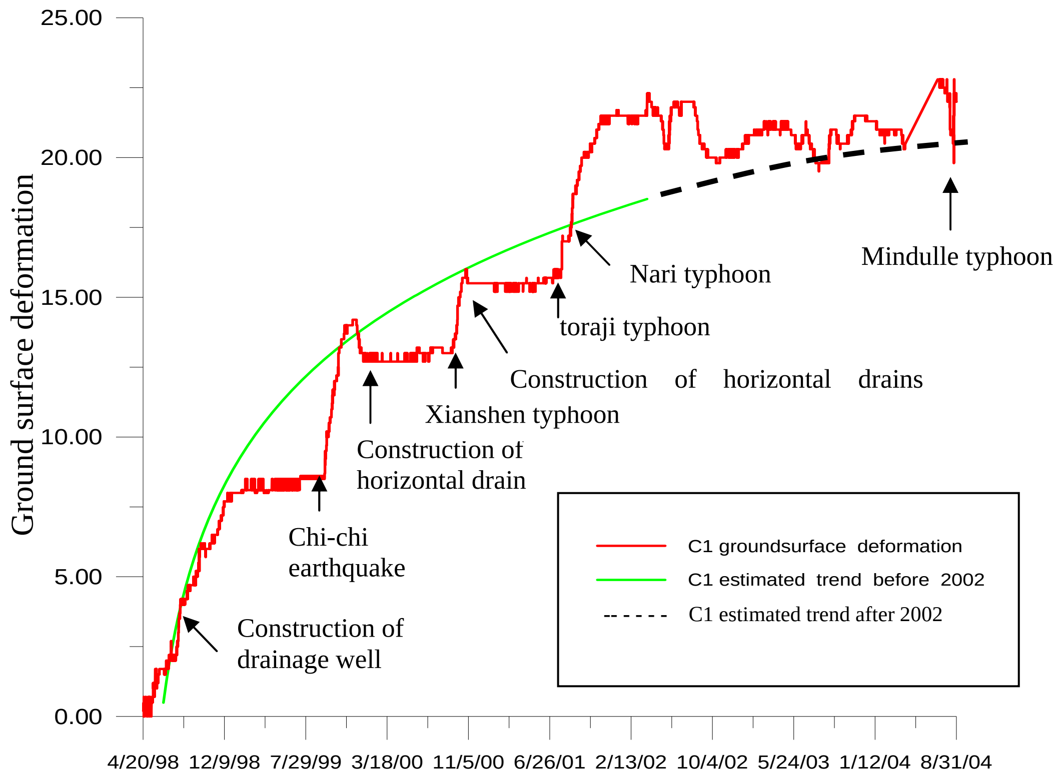

Fig.20 Ground surface deformation and its estimated trend for C1 station

Internet embedded prewarning system

By combining the automatic monitoring station with internet embedded controller, the system is reconfigured into an internet server data based system as shown in Figure 21. Data are communicated within internet. Gis database server receive 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, command for response in regard to local residents' safety can be made by computer automatically.

Concluding Remarks

According to the report "Performance Evaluation on Renovation Work in Landslide Area of Li-Shan (2002)", there are still some areas with potential landslide needed to be inspected and observed. Besides, the current monitoring systems also require continuous data recording and transmission, as well as field instruments maintenance. Therefore, the subsequent working projects were proposed and approved by "Technical Counseling Committee on Renovation Work of Li-Shan Landslide Area, Agricultural Commission, Executive Yuan" through the 4th committee meeting. The items of the project will be arranged and listed by the Water and Soil Conservation Bureau, and the performance evaluation on each item will also be periodically and perspectively reviewed year by year.

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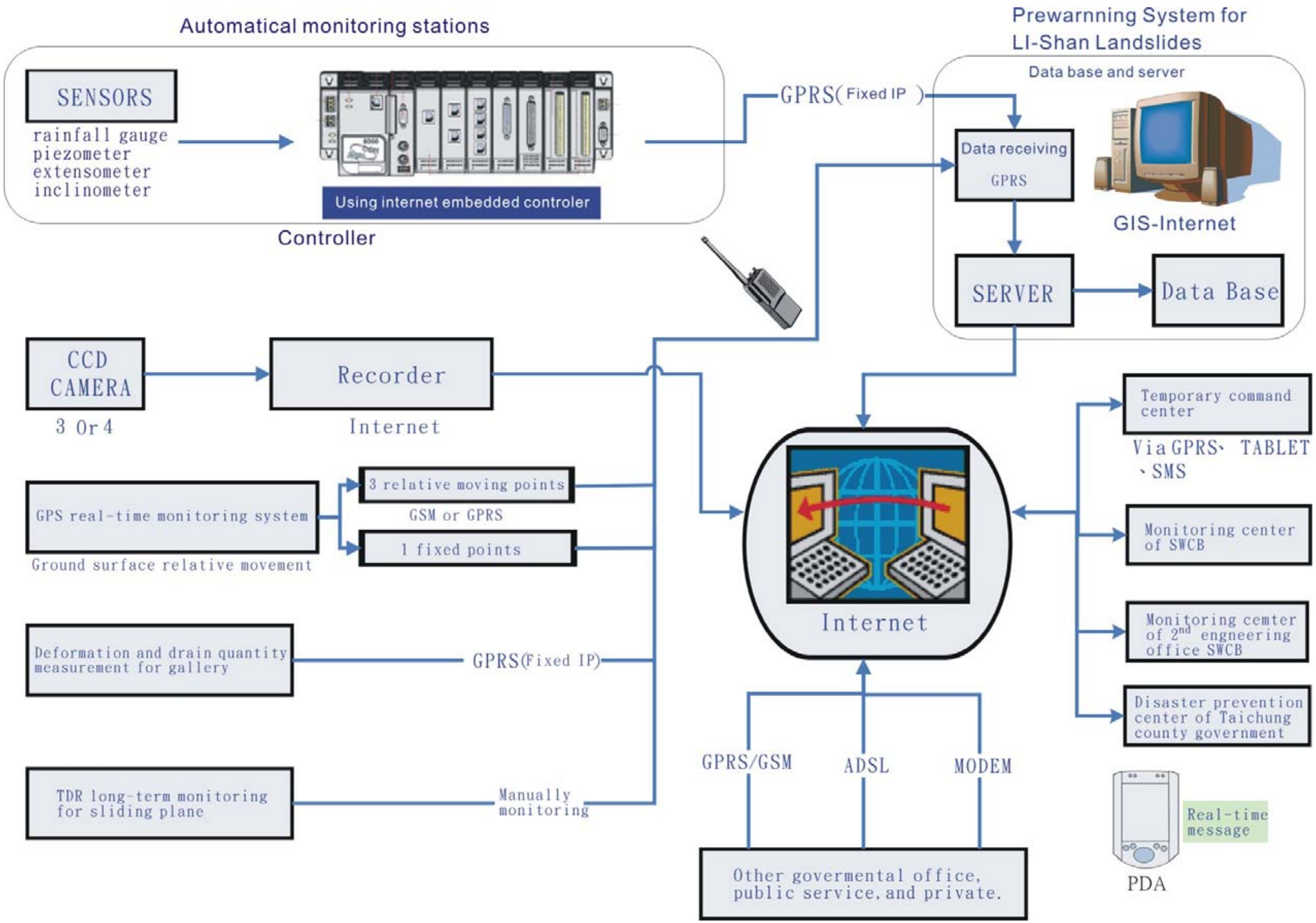

Fig. 21 Internet embedded prewarning system