Proceeding of
International Symposium on Landslide and Debris Flow Hazard Assessment
2004 Oct 7th~8th

Performance Evaluation on the Renovation Work for Li-Shan Landslides

M.B. Su[1] H.L. Wu[1] L.C. Chan[2]
[1]Civil Engineering Dept. National Chung-Hsing University
[2]Soil and Water Conservation Bureau, Council of Agriculture,.

ABSTRACT

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 following a prolonged torrential rain. Remedial works including wells and drainage gallery were applied to stabilize this landslide. Eight field monitoring stations were set during the construction period of the remedial work. For the purpose of predicting rainfall effect to the stability of slopes, ARIMA model was applied to study the relation between rainfall record and groundwater level change. Transfer functions for each pair of monitored data were established for simulation. In order to evaluate the effect of individual remedial work, intervention modeling was conducted to study the influence on transfer function before and after construction. Effect of the remedial measures to the monitored slopes can be seen from records of groundwater level change directly and can be judged more precisely from the intervention modeling analysis.

KEYWORDS: evalution, renovation, landslide

INTRODUCTION

As shown in Figure 1, 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 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 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 was officially approved after an intensive investigation between 1991 and 1993. Accomplish the task, "Investigation and Renovation Planning for Landslides in Li-Shan Area" at the end of year 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.

RAINFALL RECORD

Background analysis of rainfall record is presented in Figure 2. In the duration of landslide occurring, maximum daily rainfall record was 155.5mm at 19th, which is not very large compared to history record. But, accumulated rainfall between 10th to 20th of April arrived 585mm and total rainfall in April of that year arrived 957.5mm both exceed 50 years return period from rainfall frequency analysis. It can be seen as continuous rainfall can cause large amount of infiltration water to accumulate inside slopes so as to induce landslide. 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 the main triggering factors for this highly weathered rock slope.

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 a few kilometers west of the Li-Shan landslide. Geological provinces of Taiwan is shown in Figure 3 as published by governmental agency.

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

Geologically, Li-Shan is not far from the Li-Shan fault. It is suggested that the geological conditions is more complicated than expected in this area. And, it is evident that Li-Shan 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 that the Li-Shan landslide is predominantly caused by heavy rain and insufficient drainage capability.

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

The landslide area can be divided into four regions, namely central, west, northeast, and southeast regions as shown in Figure 4. 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 is adjacent to the southeast 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 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 village, (3) the high erosion rate makes the slopes beside the streams more dangerous than others.

RENOVATION WORK

The primary renovation 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 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 designed 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 appropriate field investigation process to deduce the properties of naturally occurring materials before the detailed design for renovation work was undertaken.

All items in regard to the remedial work planned and conducted are listed in the following, its distributions are given in Figure 5.

(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 10,890 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 including 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)Completing of 3 sets of sediment restored dams as well as 62 sets of submerged dams for sediment restoring work.

(8)Completing 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)rovide 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.

MONITORING SYSTEM

Eight monitoring stations were set up in this area. Each station were 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. Locations of the stations are given in details in Figure 6.

Remedial work for this stage lasts from 1955 to 2002. In the mean time, monitored data are reduced. Parts of the data collected are presented and discussed hereafter.

B1 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 rainfall, groundwater level change together with surface movement are put together in Figure 7 for comparison. As can be seen from the Figure, during construction of drainage wells, groundwater level dropped for more than 10 meters and certain amount of surface deformation happened. After that, ground showed quite stable. But, rise of groundwater level were large during rainstorm seasons until drainage gallery pass through this area. After that, groungwater level remained quite stable.

B4 station

B4 sliding block is located in front of the colluvium of the central region which is very close to the major highway. Monitored data showed fairly large variation. In the early time, construction of drainage well showed no effect in lowering the groundwater level. But, when construction work approaching surrounding area, groundwater level dropped significantly. After that, it kept stable in elevation 1887m(m.s.l) till now.

B5 station

B5 sliding block is located uphill of B1 which has many important building on it. In Fig. 9 groundwater level monitored showed a minor drop during drainage well construction but had a very large drop when drainage gallery pass underneath. Extensometer on the ground surface showed no significant change is maybe because of the location of fixed point turn out to be on another sliding block.

B9 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 river, but building had evaluated unsafe right after the major li-shan landslide occurred on april 1990. And now (2004), the building was teared down and the site remolded into a rural garden.
As can be seen for graph of the recorded data, construction of drainage well did showed effects on groundwater level. Drainage tunnel seems didn't lowered the groundwater level but limited the magnitude of fluctuation of groundwater level. Removing of the building was believed can improve the stability of the sliding block.

B11 station

B11 block is located uphill of B9 block. The monitoring station was set lately on year 2000. Groundwater elevation has great correlation to rainfall intensity. No significant effect on construction work observed.

B13 station

B13 block is located uphill of B11 and B9 block and form a headwater sequence more like retrogressive sliding in a complex form and was judged still unstable and developing headward. Groundwater level recorded showed very little connection to the rainfall. It kept groundwater level dropped during Chi-Chi earthquake and recovered gradually. It was judged that the groundwater here is in confined situation and more investigation showed be performed to study it characteristics.

C1 & C2 station

C1 & C2 blocks located at northeast direction of the central region and are connected to each other. C1 is on uphill and C2 downhill.
Record presented in Figure 11 for C1 station showed great influence of groundwater level to the remedial work. Total drop of groundwater level was more than 10 meters especially after construction of horizontal drains and Nari typhoon hitted. C2 station showed no significant fluctuation of its groundwater level. More study showed be conducted here.

PERFORMANCE EVALUATION ON RENOVATION WORK

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 renovation work is accomplished. In fact, the groundwater level was dropped an average of 12 m, measured by the 2nd Engineering Office of Water and Soil Conservation Bureau on the monitoring stations, which was better than the previous estimation.
The Li-Shan area was subsequently hit by a series of typhoons such as Herb, Wenni, and Amber during the construction period of renovation work. Still, the whole region was safe, no hazards occurred. Even for the front sliding block B1 of the sliding region, the

groundwater levels were estimated by statistics analysis with an average drop of 10 m.

According to report "Performance Evaluation on Renovation Work in Landslide Area of Li-Shan (2002)", the factor of safety against slope failures will be increased from an average value of 0.9 to the values ranged between 1.10 and 1.30. Besides, the factor of safety will be estimated and risen up to 1.12 during the period of typhoon storms hitting. It indicates that the renovation works are well performed.

The tendency of sliding in Li-Shan area becomes decreasing, according to the measured recordings on the monitoring stations. Moreover, no significant phenomenon of sliding was observed even during the time when the powerful 921 Chi-Chi earthquake with a magnitude of 7.2 on Richter scale hit Taiwan in 1999.

STABILITY ANALYSIS

Slope stablility analysis to estimate factor of safety for each sliding block were performed using material's parameters obtain from field investigation and laboratory testing.

TRANSFER FUNCTIONS

Time domain ARIMA models for rainfall and groundwater level change are studied. Then, transfer functions for each stations were established between rainfall and groundwater level change. Table 1 showed the optimal transfer function for each station. Time series analysis showed good correlation. Figure 15 shows simulation of transfer applied to year 2000's data for data from monitoring station B1.

INTERVENTION MODELING

Intervention modeling for hydrologic data was applied here to study the effect of remedial work to slope stability. By combining single variable ARIMA model and transfer function, it can be applied to verify the effect by checking the optimal transfer function before and after the intervention occurred. The result reflected field hydrogeological conditions and the role the remedial work played in regard to its draining capability. Drainage well was judged to be a one order step function with decending tail and long term groundwater level drops was around 10 meters with the construction of wells in around. Significances were applied for judgement. Table 2 showed the result of modeling. Parts of the monitored data did show the influence of the remedial work. Table 3 list the complete end result for intervention modeling. Meaning for each parameters in the equation can be found from references.

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.

ACKNOWLEDGEMENTS

The work presented was made possible through the support of the Soil and Water Conservation Bureau, committee council of agriculture Taiwan, R.O.C., efforts of many researcher and work group in the field are also thanked.

REFERENCES

[1]Box and Jenkins, Time Series Analysis Forecasting and Control prentice-hall inc., (1994)

[2]Adamowski K., "A Stochastic systems Model of Groundwater level Fluctuations," Journal of Hydrology, No.62 (1983)

[3]Maidment, D.R., and S.P. Miaou, "Transfer Function Models of Daily Urban Water Use," Water Resources Research, Vol.21, No.4 (1985)

[4]Su, M.B. and Chen, Y.J., "TDR Monitoring for Integrity of Structural Systems", Journal of Infrastructure Systems, Vol.6, No.2, pp.67-72, June (2000)

[5]Su, M.B., and I.H. Chen, "Evaluation of the effectiveness of landslide remedial work", proceedings of the international conference on Slope Engineering, H.K. China (2003)

[6]"Investigation and Renovation planning for landslides in Li-Shan Area," Report, 2nd Engineering Office, SWCB (1994)

[7]"Performance Evaluation on Renovation work in landslide area of Li-Shan," Report, 2nd Engineering Office, SWCB (2002)

[8]"A pictorial Guide of remediation plans for Li-Shan Landslides," Report by Yen, Soil and Water Conservation Bureau, Council of Agriculture, Executive Yuan, Taiwan(R.O.C.) (2003)

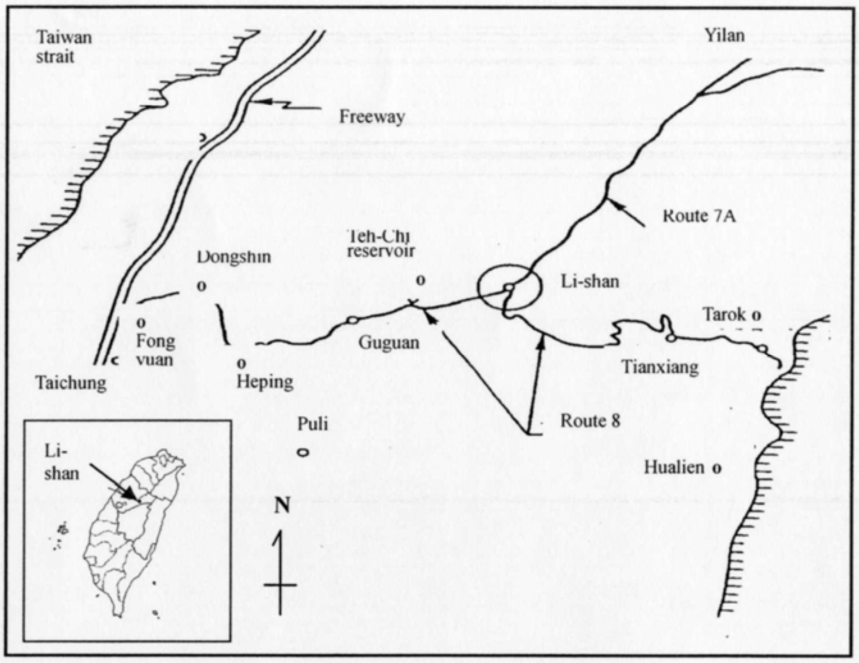

Fig. 1 Location of Li-shan area

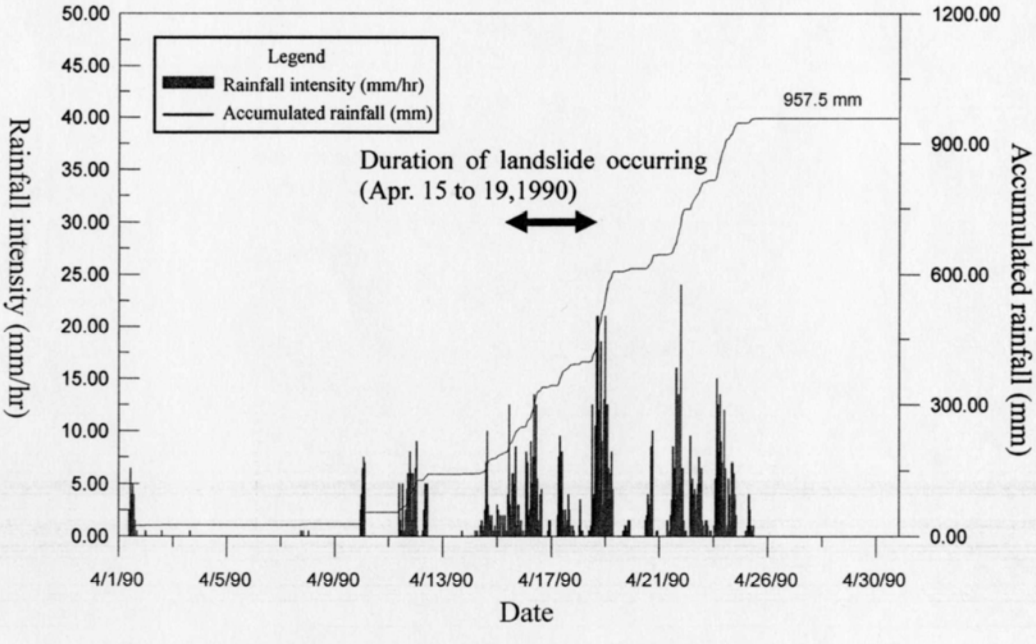

Fig. 2 Precipitation record at Taipower Li-Shan station in April 1990

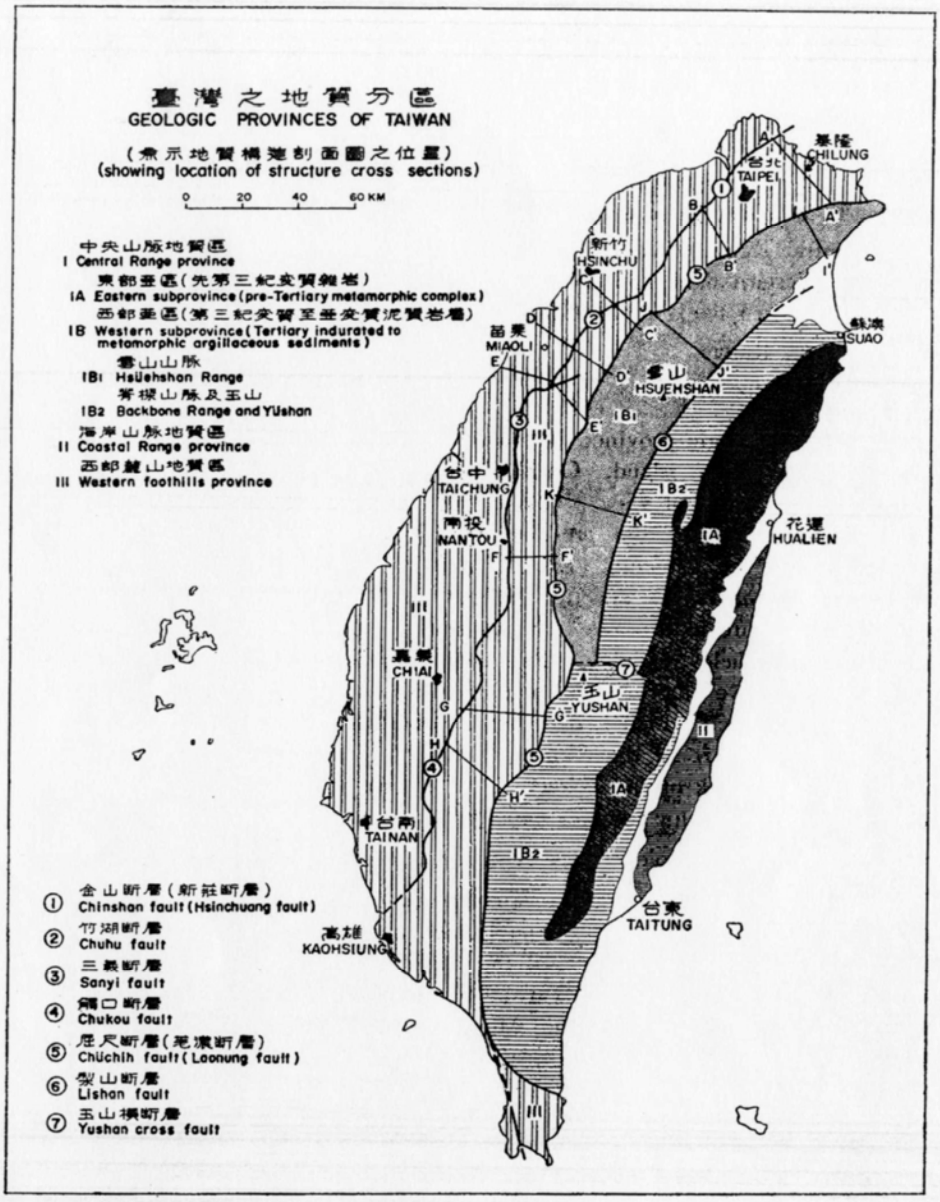

Fig. 3 Geologic provinces of Taiwan(Ministry of Economic affairs, R.O.C, 1975)

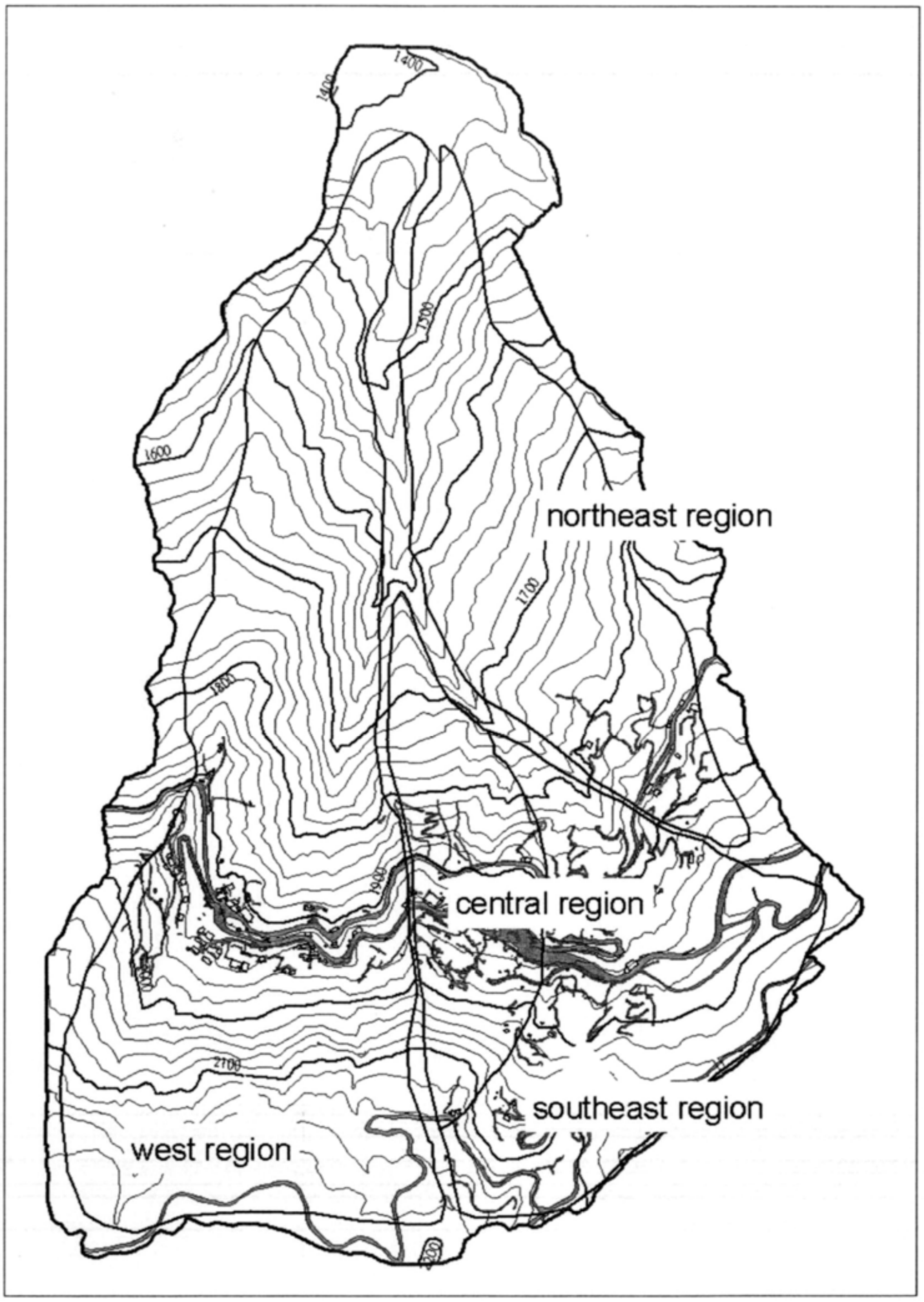

Fig. 4 Division of the four regions in Li-shan landslide area

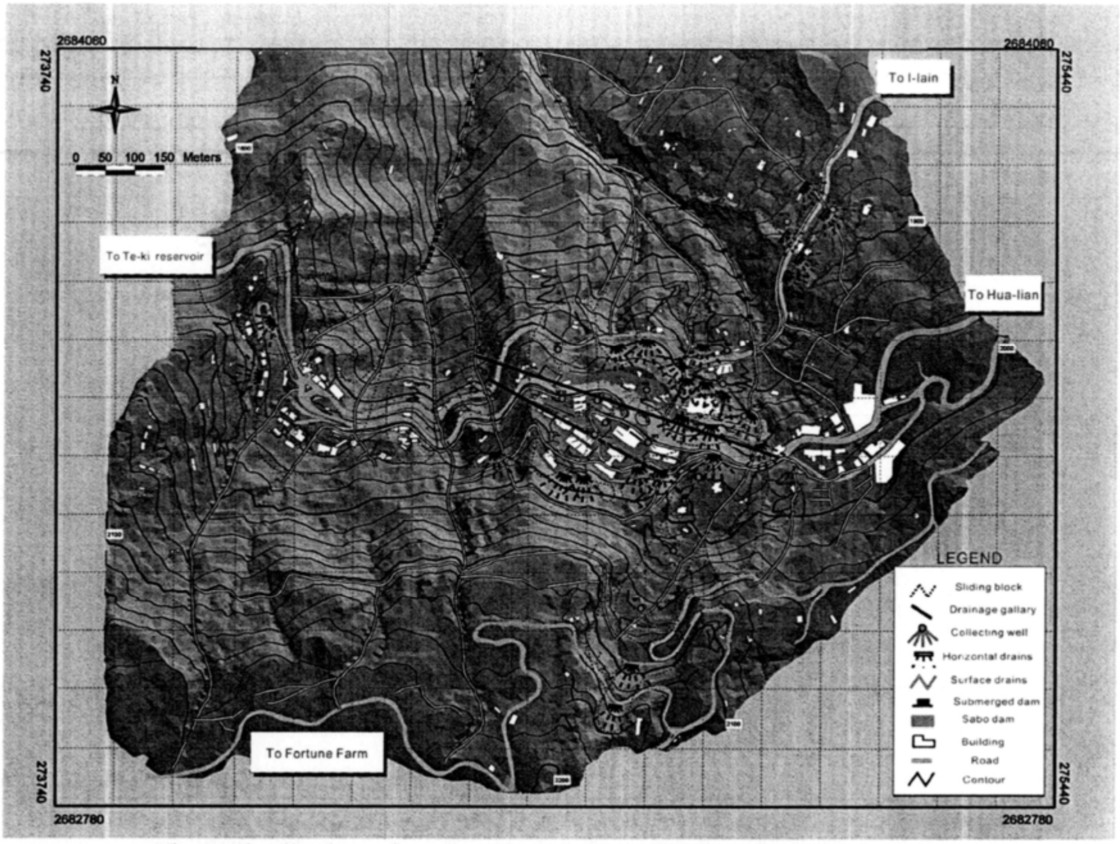

Fig.5 Distribution of engineering works in Li-shan landslide area

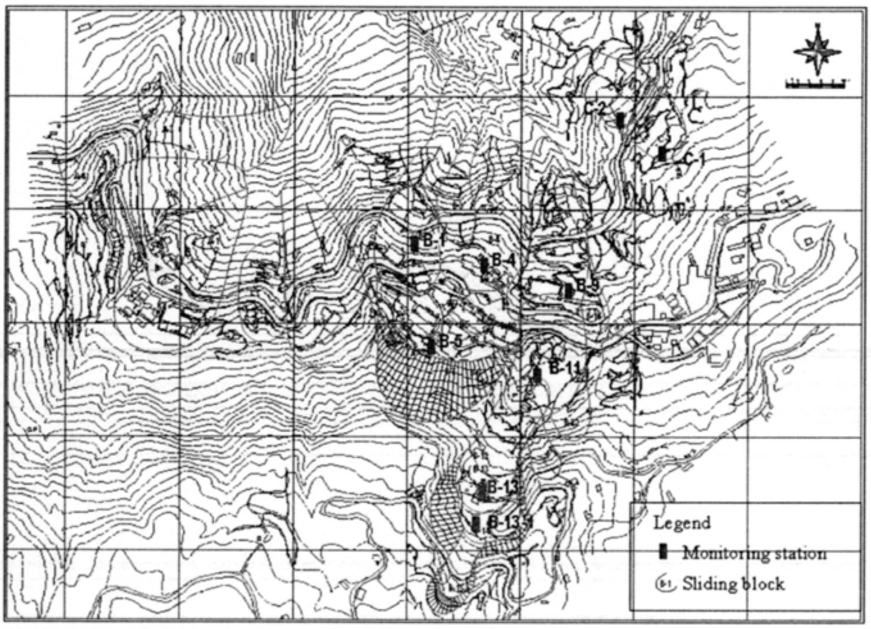

Fig. 6 Locations of monitoring stations in Li-shan landslide area

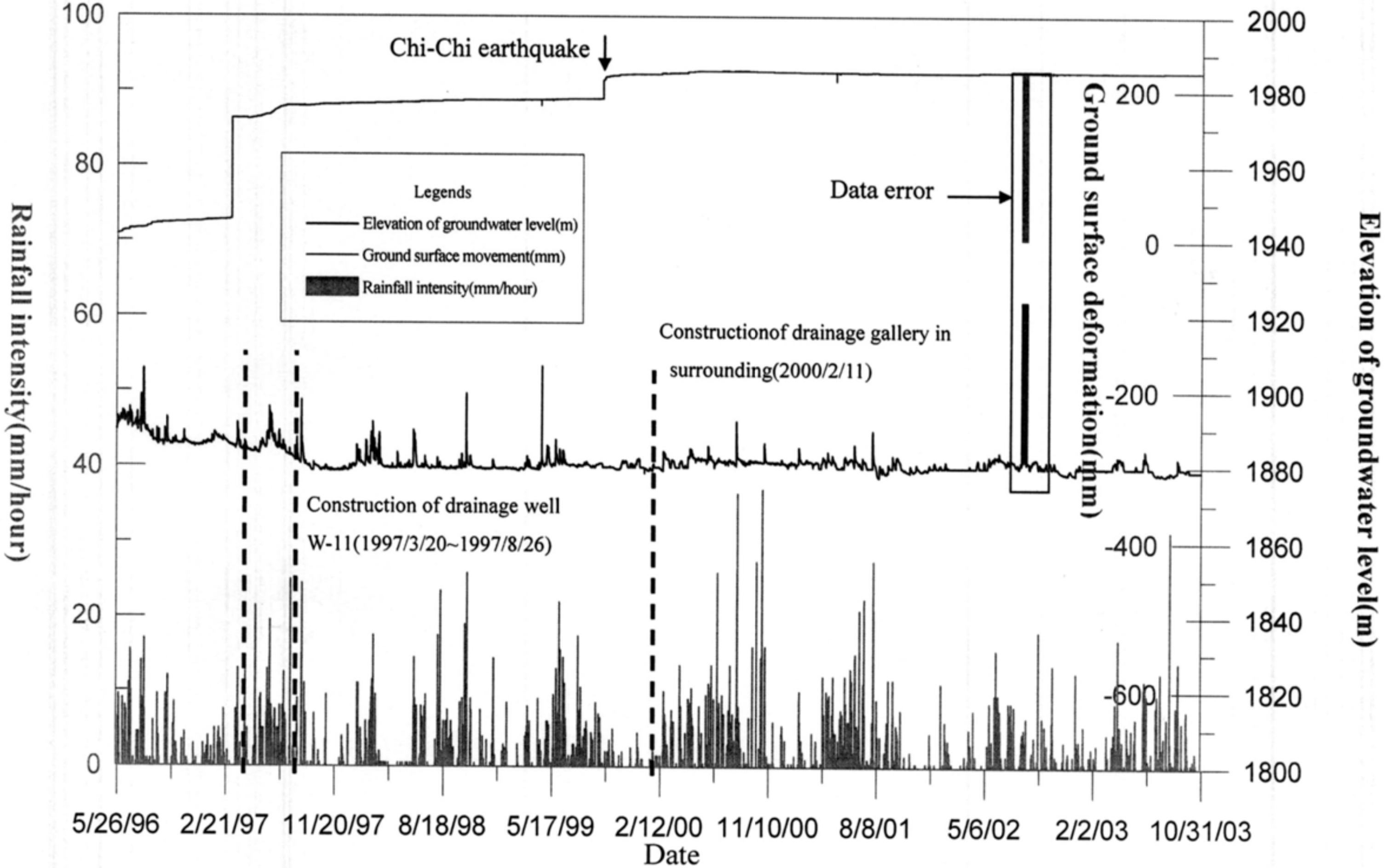

Fig. 7 Relation between rainfall intensity, groundwater level and surface deformation in B1 station during 1996/5~2003/10

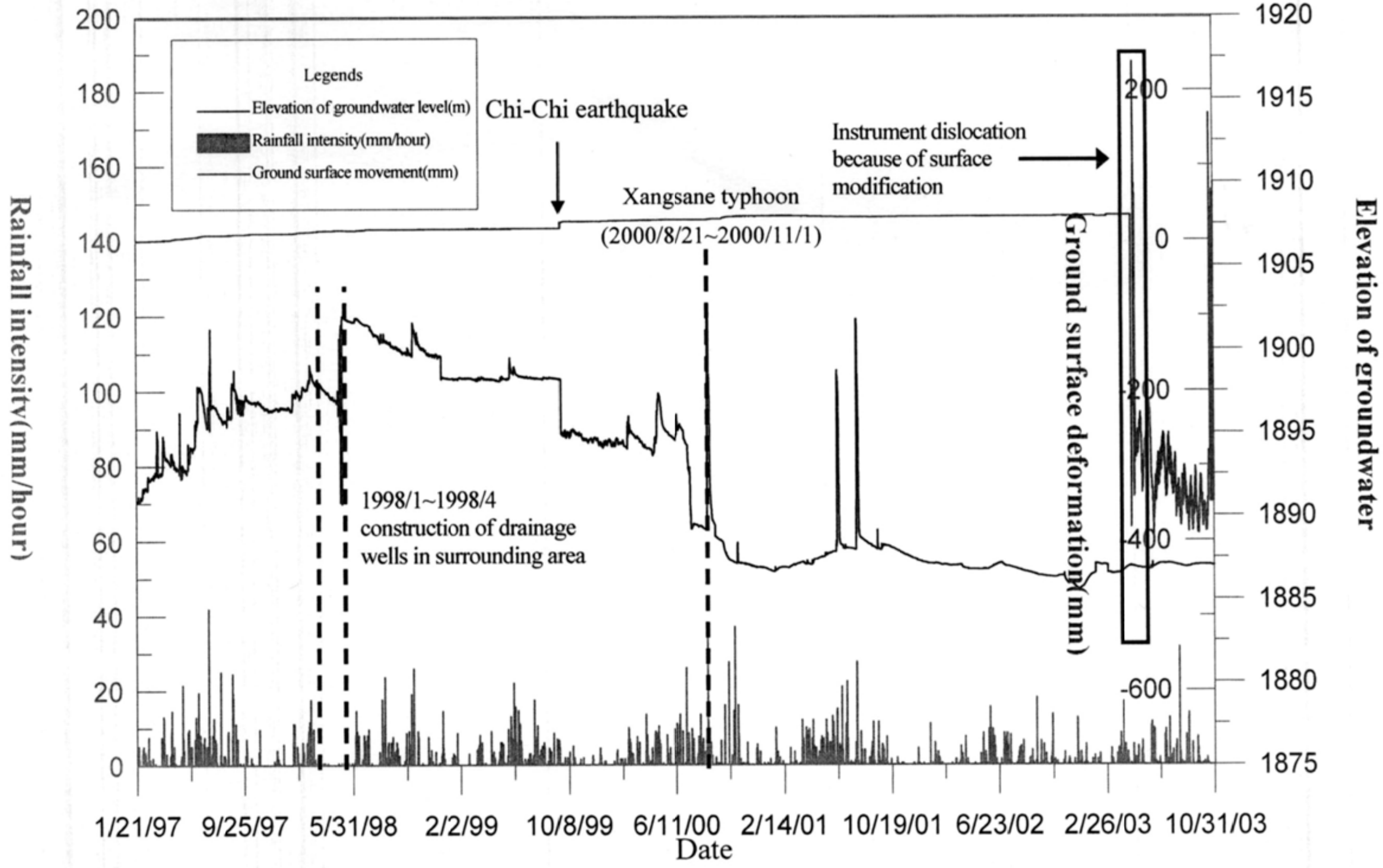

Fig. 8 Relation between rainfall intensity, groundwater level and surface deformation in B4 station during 1997/1~2003/10

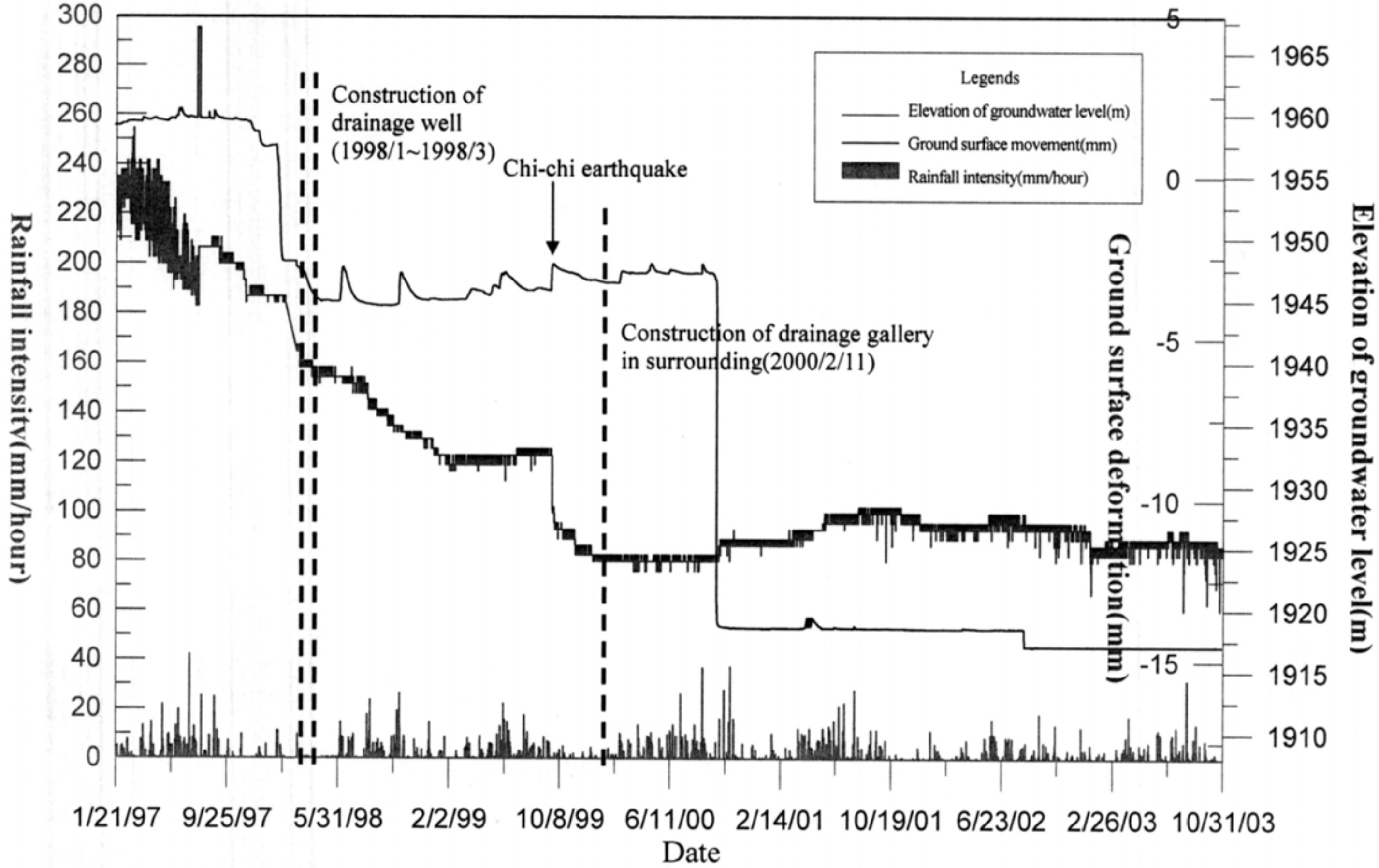

Fig. 9 Relation between rainfall intensity, groundwater level and surface deformation in B5 station during 1997/1~2003/10

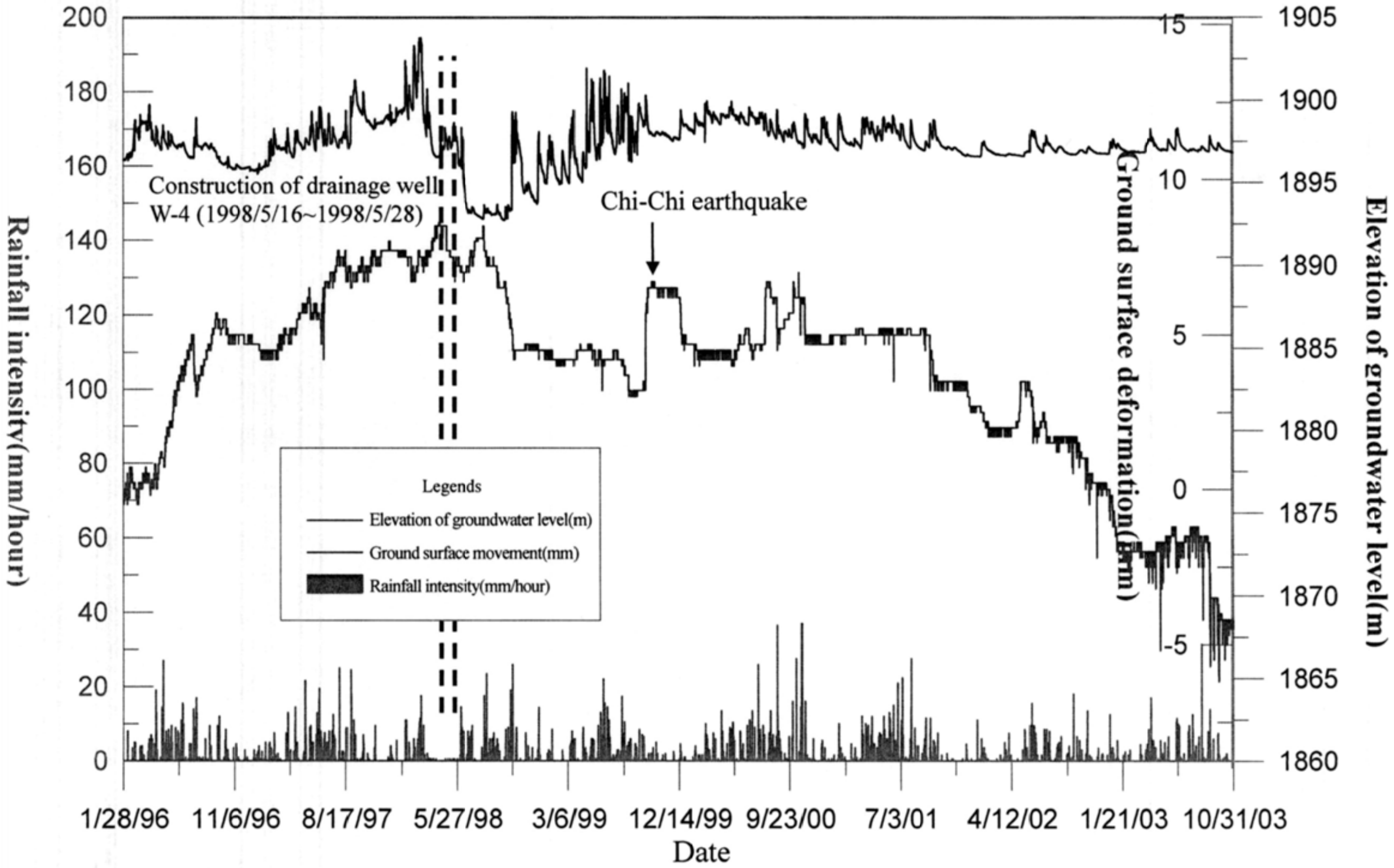

Fig. 10 Relation between rainfall intensity, groundwater level and surface deformation in B9 station during 1996/1~2003/10

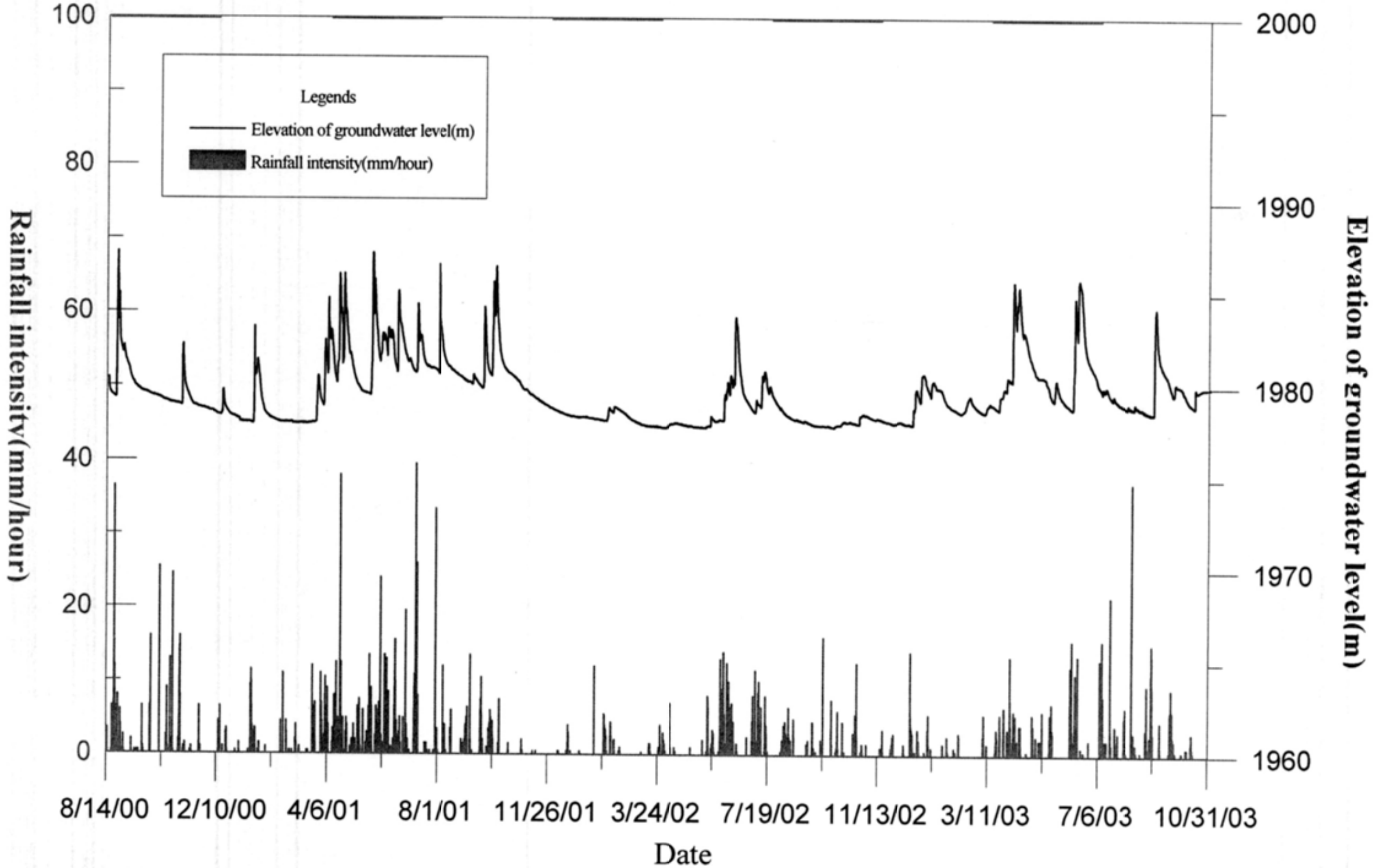

Fig. 11 Relation between rainfall intensity, and groundwater level in B11 station during 2000/8~2003/10

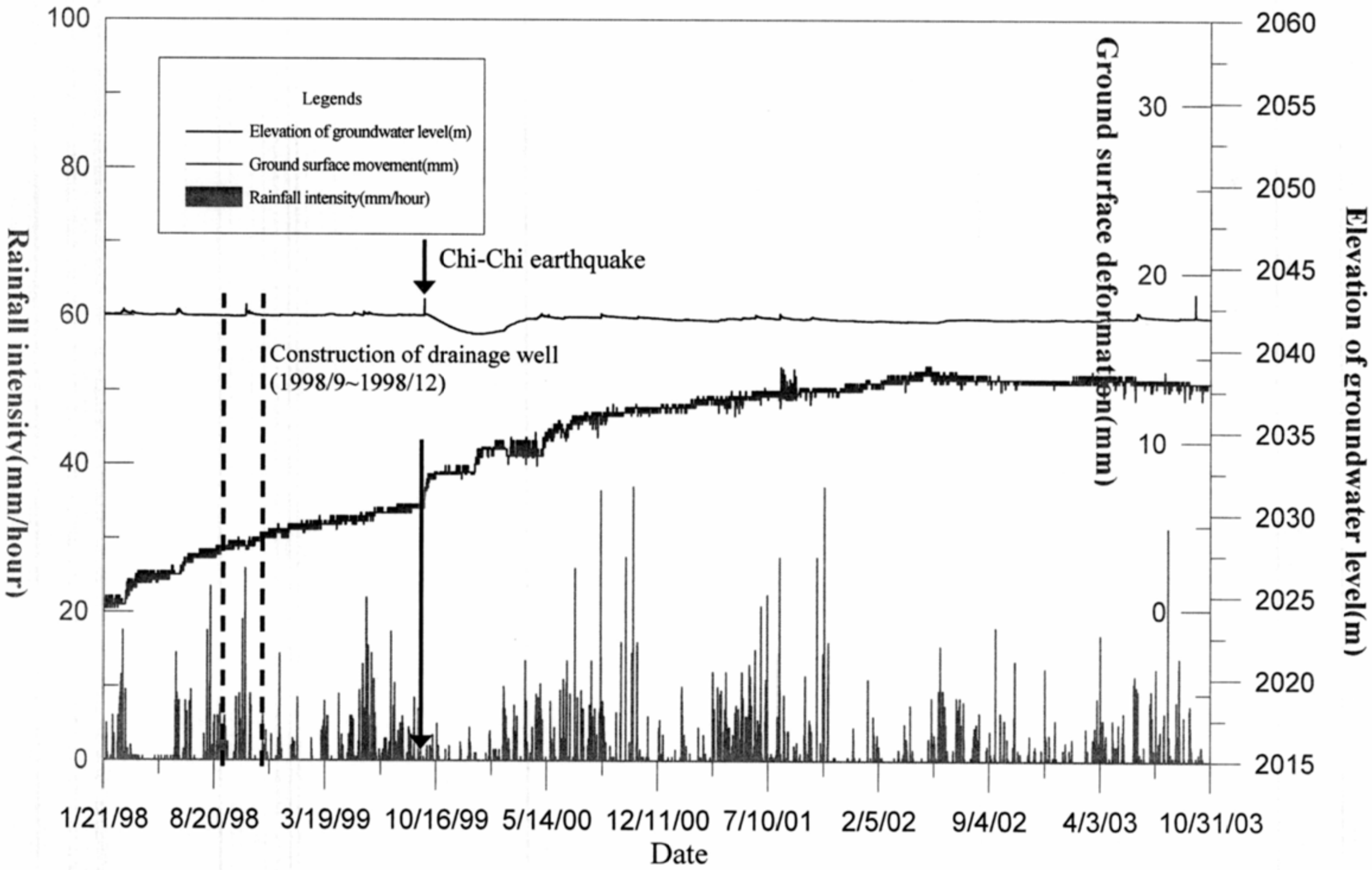

Fig. 12 Relation between rainfall intensity, groundwater level and surface deformation in B13 station during 1998/1~2003/10

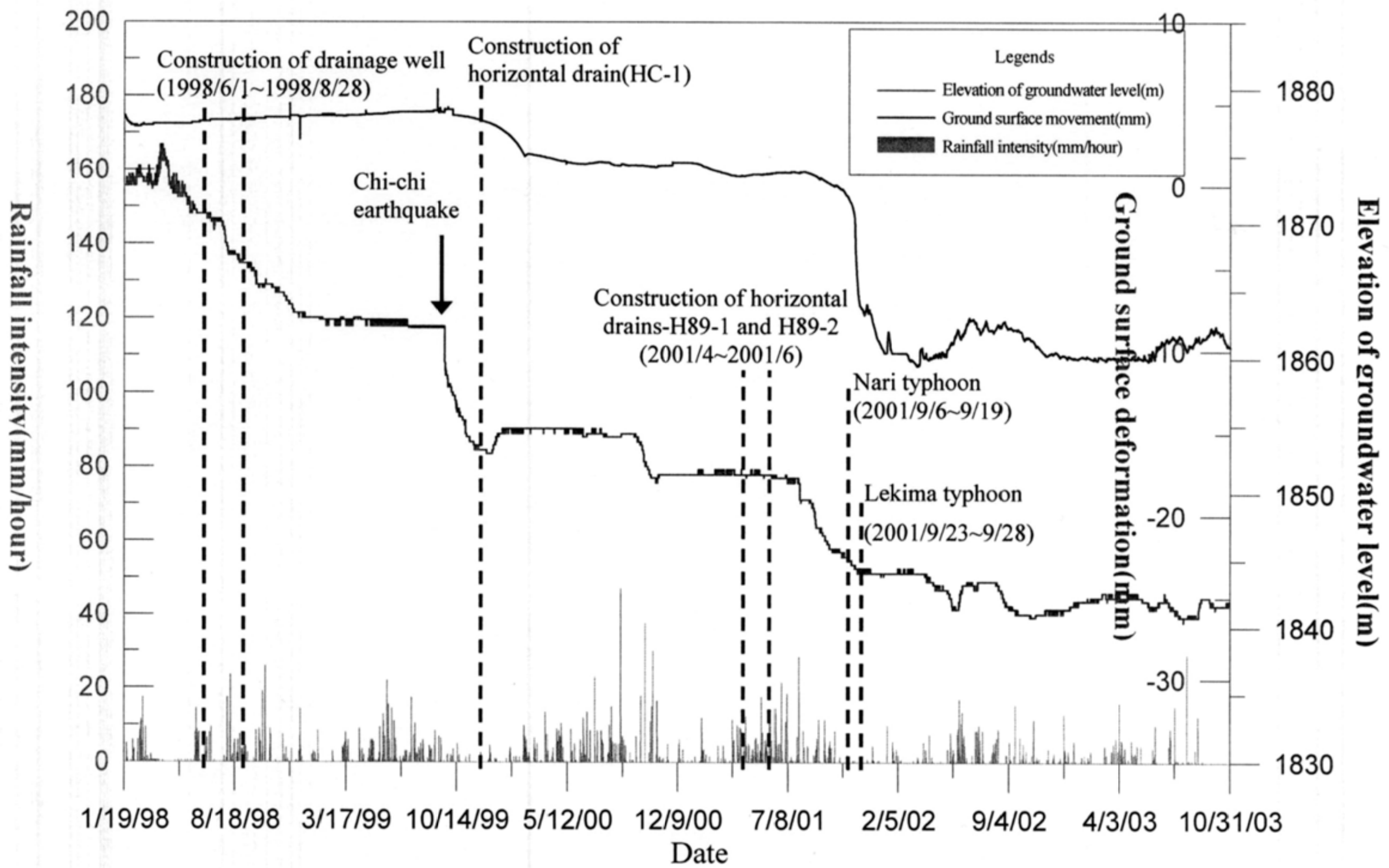

Fig. 13 Relation between rainfall intensity, groundwater level and surface deformation in C1 station during 1998/1~2003/10

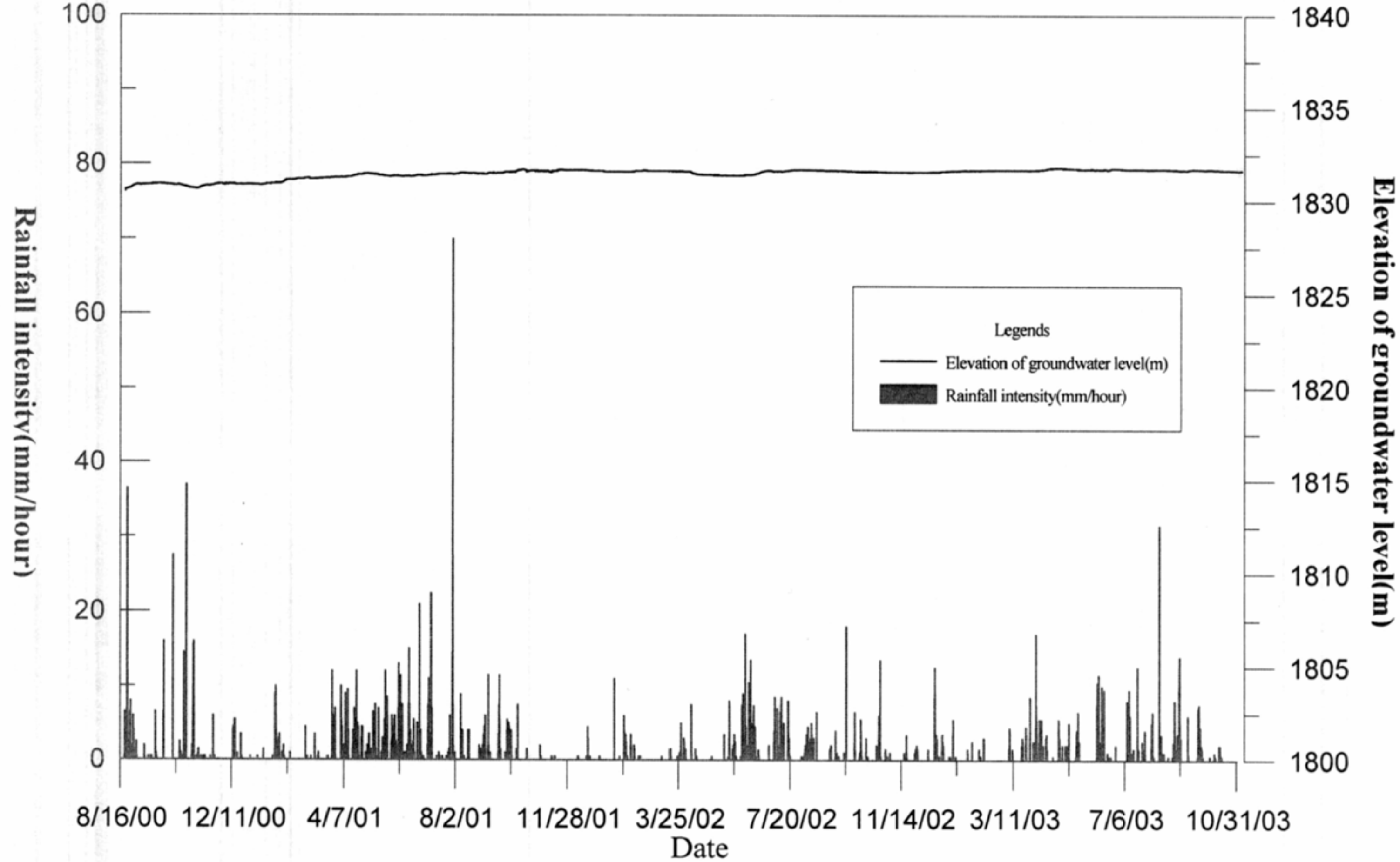

Fig. 14 Relation between rainfall intensity, and groundwater level in C2 station during 2000/8~2003/10

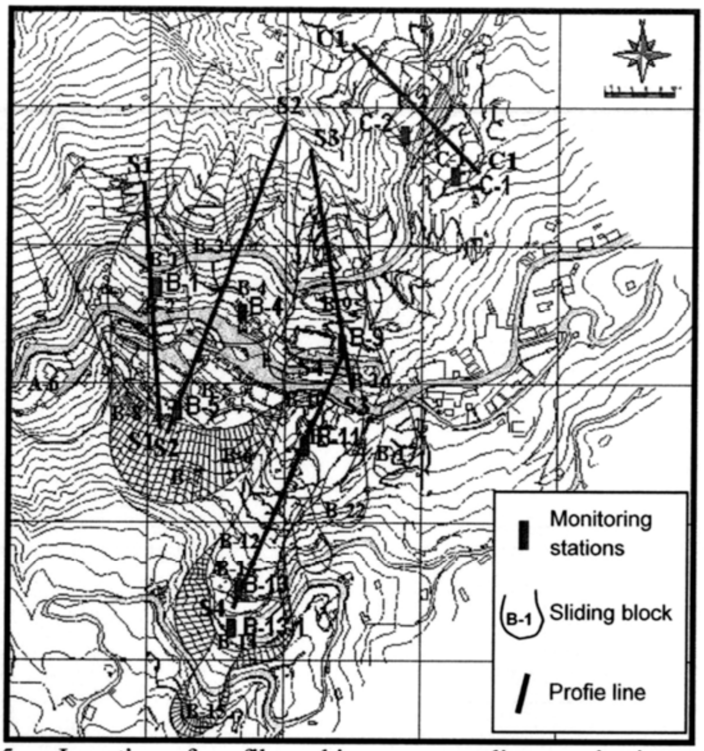

Fig.15 Location of profile and its corresponding monitoring station

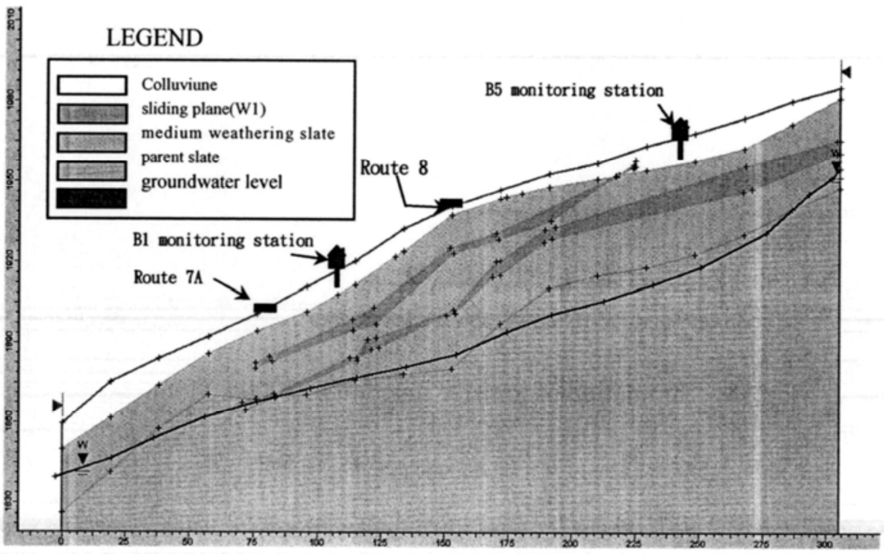

Fig.16 Identification of potential sliding plane on S1 profile

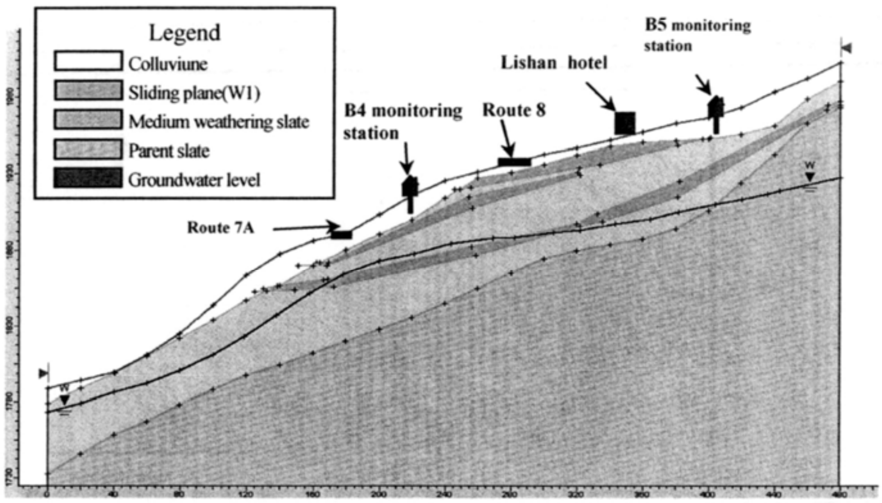

Fig.17 Identification of potential sliding plane on S2 profile

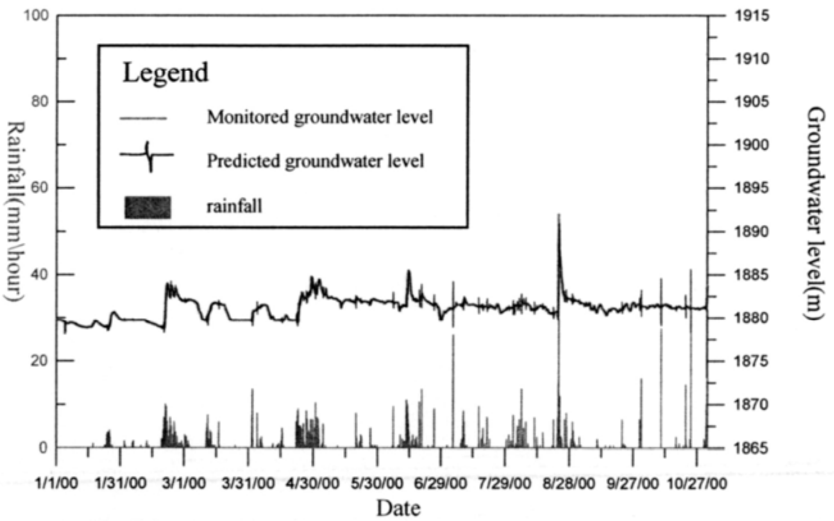

Fig.18 Simulation of transfer function in 2000 (Monitoring station B1)

Table 1 Properties of geomaterial in Li-Shan area

Type of geomaterial	G	$\gamma_t(t/m^3)$	$C(T/M^2)$	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 2 Result of analysis using Slide program for S1 profile

	Shallow sliding plane	Deep sliding plane
unloading(present groundwater level)	1.27	1.16
loading (present groundwater level)	1.27	1.15
unloading (highest groundwater level)	1.08	1.04
loading (highest groundwater level)	1.08	1.03
unloading (lowest groundwater level)	1.46	1.35
unloading (slope filled up with groundwater)	------	0.77

Table 3 Result of analysis using Slide program for S2 profile

	Shallow sliding plane	Medium depth sliding plane	Deep sliding plane
unloading(present groundwater level)	1.66	1.18	1.33
loading (present groundwater level)	1.65	1.18	1.33
unloading (highest groundwater level)	1.65	1.11	1.06
loading (highest groundwater level)	1.59	1.10	1.06
unloading (lowest groundwater level)	1.71	1.24	1.35
unloading (slope filled up with groundwater)	------	------	1.01

Table 4 Results of optimum transfer function

Monitoring station	Accumulative precipitation (mm)	Variation of Maximum groundwater (m)	optimum transfer function
B1	304.2	19.62	$Y_t^* = \frac{0.12297 + 0.07676B}{1 - 0.82564B} X_{t-1}^*$
B4	304.2	2.02	$Y_t^* = \frac{0.0086788 - 0.0028266B^6}{1 - 0.95385B} X_t^*$
B5	304.2	2.52	$Y_t^* = \frac{0.0005824 - 0.0003949B^7}{1 - 0.97955B} X_{t-7}$
B9	304.2	5.95	$Y_t^* = \frac{0.05127}{1 - 0.74822B} X_{t-5}^*$
B13	304.2	0.68	$Y_t^* = \frac{0.001686 + 0.00266B + 0.00215B^2 + 0.00155B^3}{1 - 0.67375B} X_{t-8}^*$

Table 5 Relative data of Intervention Model

Monitoring station	Period of drain wells construction	Beginning time of intervention model	Period of data analysis	ARIMA model of groundwater before drainage	Model calibration
B1	1997.3.20~1997.8.26	1997.7.7	1997.1.01~1997.12.31	(1，0，3)	significant
B4	1997.3.06~1998.5.01	--	--	--	not significant
B5	1998.1.11~1998.2.12	1998.1.16	1997.7.01~1998.2.01	(1，0，5)	significant
B9	1998.5.20~1998.5.28	1998.6.8	1998.1.01~1998.9.30	(1，0，1)	significant
B13	1997.4.09~1997.12.27	--	--	--	not significant
C1	1998.06.12~1998.7.24	--	--	--	not significant

Table 6 Results of Intervention Model

Monitoring station	Function ofIntervention Model
B1	$G = \frac{-0.12773}{1 - 0.9832B} S_t + \frac{1 + 0.17945B - 0.17575B^2 - 0.14922B^3}{1 - 0.89155B} a_t + 1886.2$
B5	$G = \frac{-0.72847}{1 - 1.006B} S_t + \frac{1 + 1.18B + 1.1B^2 + 0.921B^3 + 1.17B^4 + 0.73B^5}{1 - 0.4464B} a_t + 1959.6$
B9	$G = \frac{-0.37085}{1 - 1.1351B} S_t + \frac{1 + 0.55925B}{1 - 0.99907B} a_t + 1899.2$

(Note: G:groundwater level，S_t:step function，a_t :disturbance term，B:Backward shift operator)