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Evaluation of the Effectiveness for Remedial Works applied to Li-shan Landslide

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ABSTRACT

In Li-shan landslide area, six monitoring stations equipped with real-time record for the rainfall, groundwater level and ground deformations were set during the proceed of the remedial work. Data collected were analyzed using the ARIMA model to establish the relation between rainfall and groundwater level change. Then, intervention model were used to analyze the effect of remedial work Finally, estimation were made complete with the representative transfer function after the operation of the drainage system.

The result shows that time series analysis are applicable in verifying the effectiveness of the remedial work. And, the representative transfer function achieved for each sloping block can be used as the tool for pre-warning purpose if real-time monitoring data can be retrieved remotely.

1.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. 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(SWCB 1994). 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. Monitoring work is continued (SWCB 2011).

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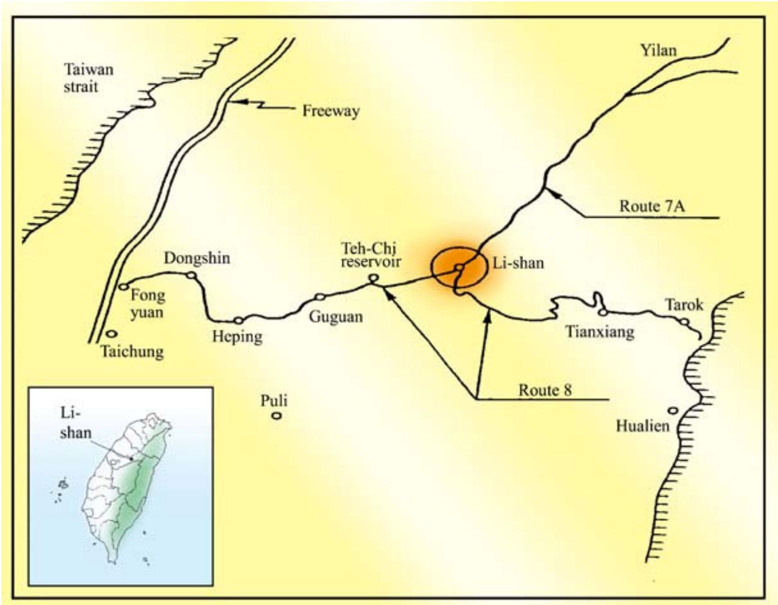

Fig. 1. Location of Li-shanarea

2.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 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 executed 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.

3.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.

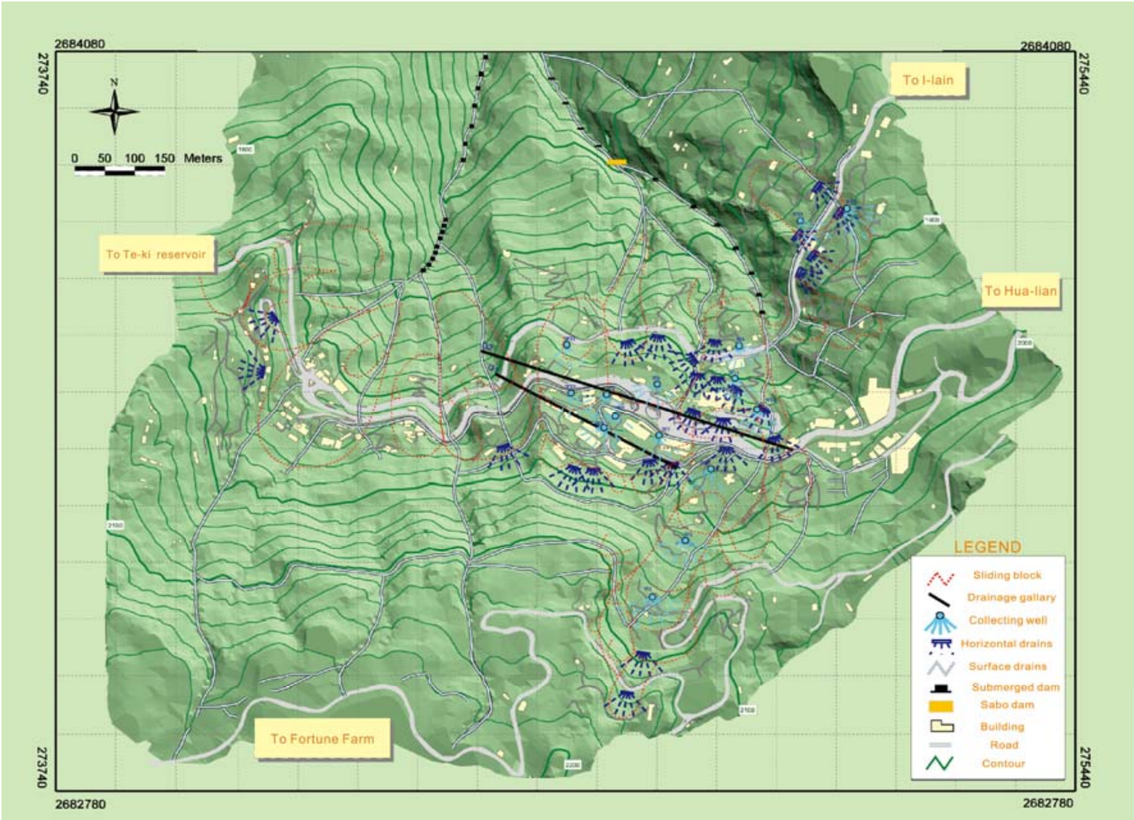

Fig. 2. Distribution of remediation works in Li-shan landslide area

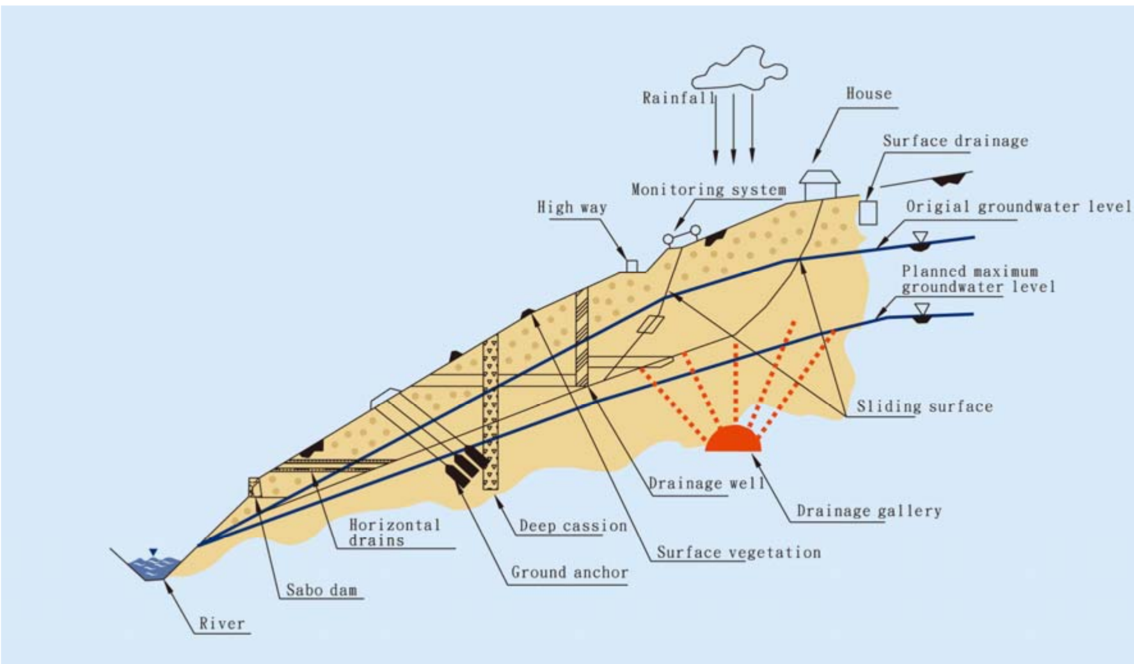

Fig. 3. Content of remediation plans for landslide

4.MONITORING SYSTEM

4.1.Purpose

Starting from 1995, monitoring instruments for Li-Shan area were installed to measure the ground deformation and the ground water level fluctuation. Subsequently, the automated recording systems were established for the purpose of long-term monitoring.

4.2.Content

Monitoring systems for a few significant sliding block areas were set up, and the contents of the facilities are listed as follow.

Table 1. List of monitoring system

<table>
<tr><th>Year</th><th>Content</th><th>Remark</th></tr>
<tr><td>1995</td><td>Automatic monitoring stations (B-1, B-9)</td><td rowspan="6">1.each station were equipped with rain gage, piezometer for groundwater level, inclinometer on the surface and into the borehole for monitoring the ground deformation and extensometer for surface movement.
2.manual monitoring systems include:
9 inclinometers;
9 mechanical tiltmeters;
4 piezometers; 4 water level tubes.</td></tr>
<tr><td>1996</td><td>Automatic monitoring stations (B-4, B-6)</td></tr>
<tr><td rowspan="2">1997</td><td>Automatic monitoring stations (B-13, C-1)</td></tr>
<tr><td>Manual monitoring systems</td></tr>
<tr><td rowspan="2">1999</td><td>Automatic monitoring stations (B-1, C-2)</td></tr>
<tr><td>Semi-antomatic monitoring within deainage wells</td></tr>
</table>

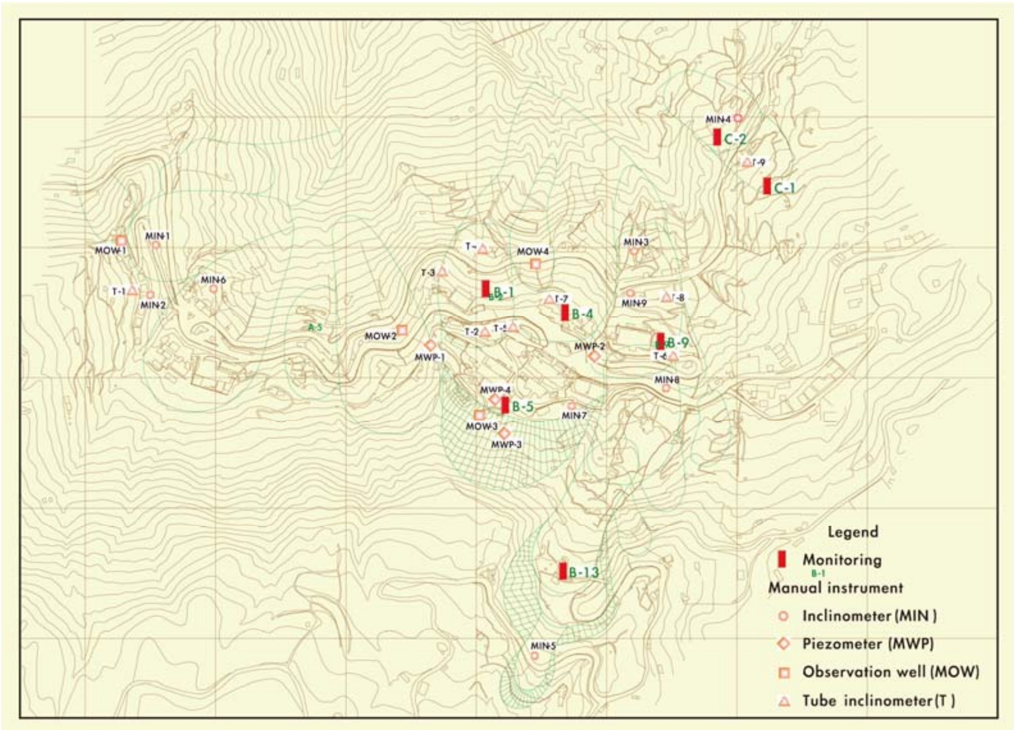

Fig. 4. Location map of monitoring station

5.RESULTS OF MONITORING SYSTEM

Data collected through the monitoring system are presented in yearly report (Su 2000, Su 2002, Su 2003, SWCB 2011).

5.1. 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.

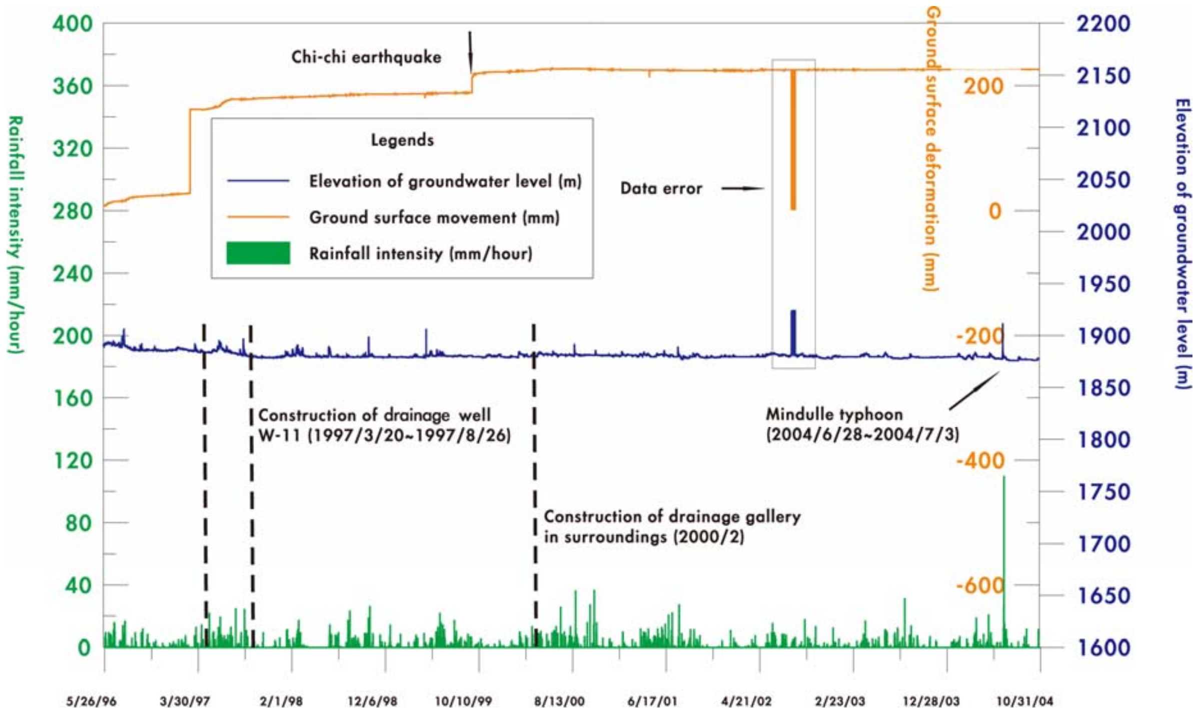

Fig. 5. Relation between rainfall intensity and groundwater level in B1 station

5.2. B4 station

Sliding block B4 monitoring station was located in the front part of the central region. The recorded data indicate that the ground water level changed a little at the beginning of the construction of the drainage wells, however, a significant water level drop was observed at the end of the construction. After the drainage well construction was completed, the water level keeps at an elevation of 1887 m thereafter.

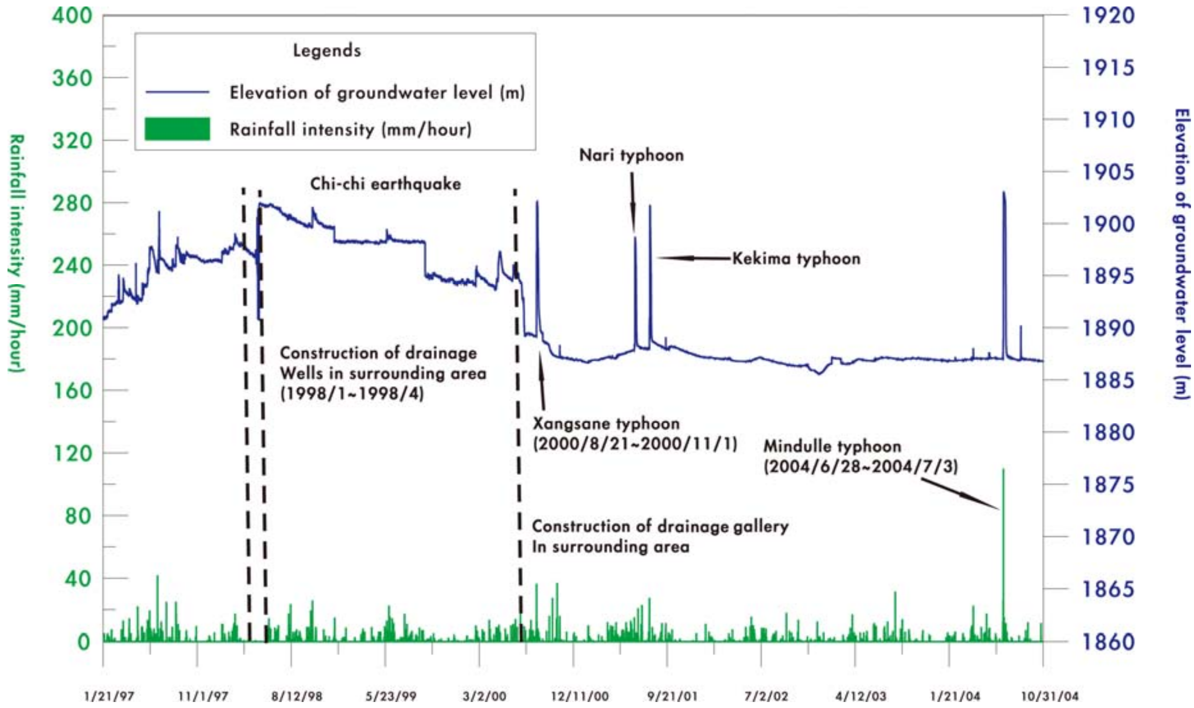

Fig. 6. Relation between rainfall intensity and groundwater level in B4 station

5.3. 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.

5.4. B9 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. The results of the graph 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.

5.5. B11 station

Sliding block B11 monitoring station was located just right above the B9 block. The monitoring station was installed late in 2000. The results of the graph show that the rainfall intensity is strongly correlated with the ground water level.
Relation between

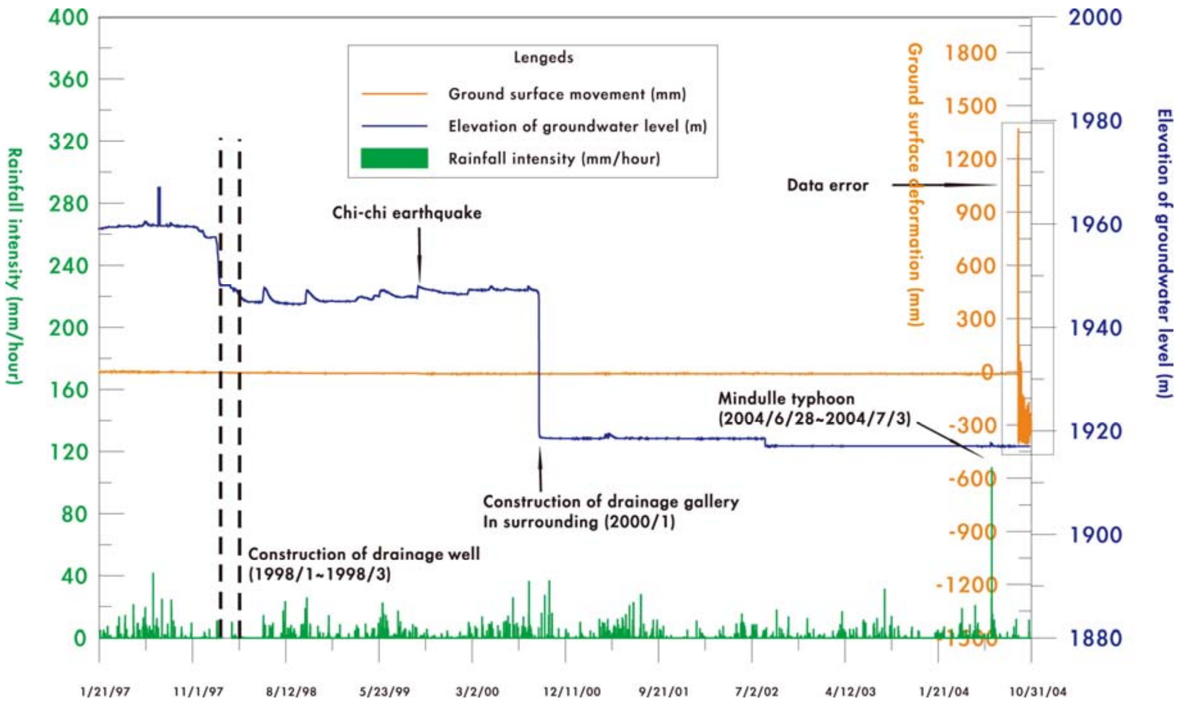

Fig. 7. Relation between rainfall intensity and groundwater level in B5 station

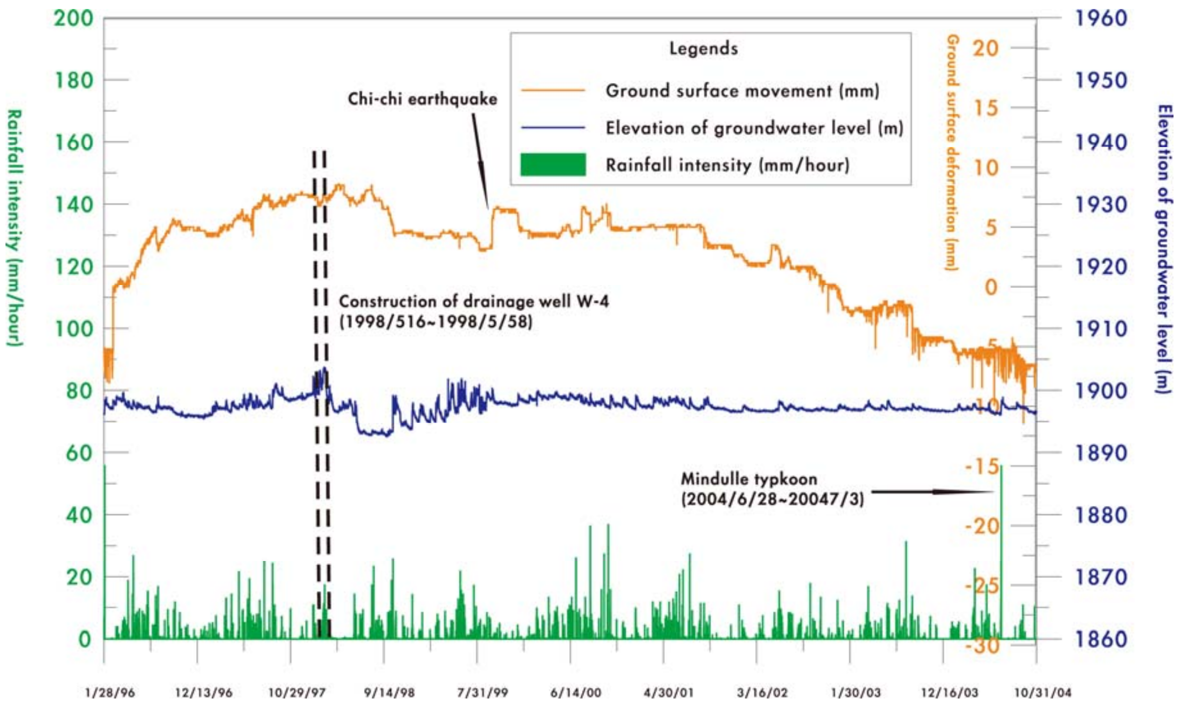

Fig. 8. Relation between rainfall intensity and groundwater level in B9 station

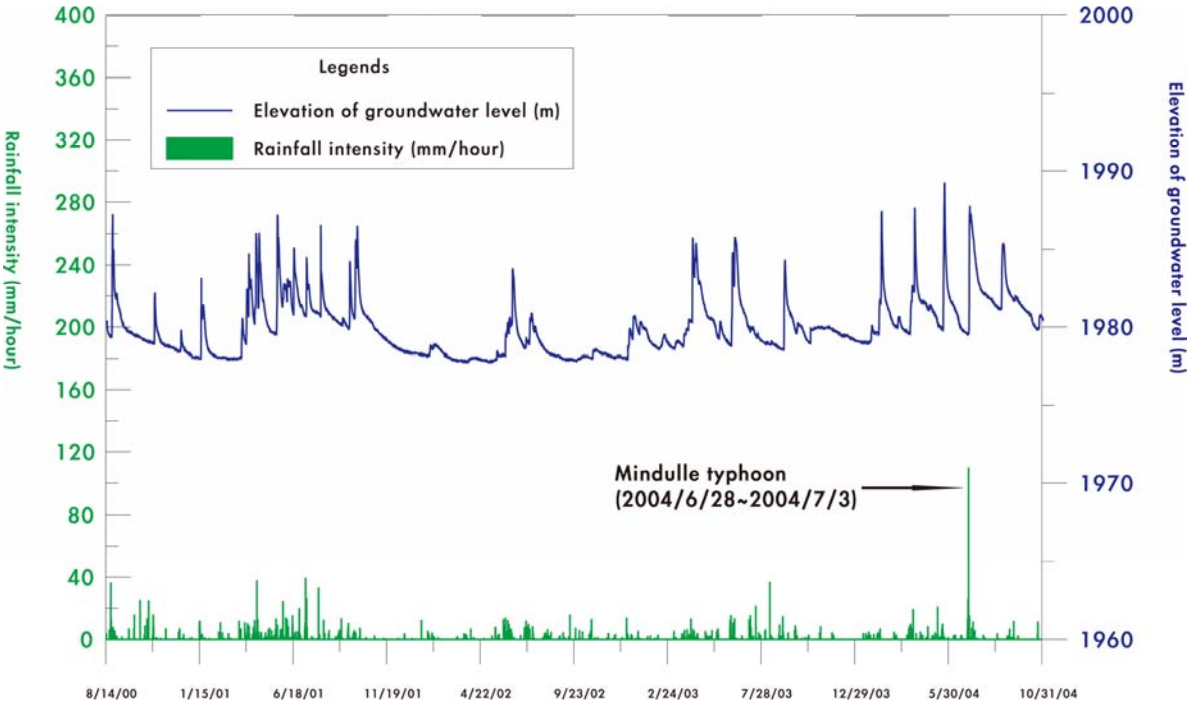

Fig. 9. Relation between rainfall intensity and groundwater level in B11 station

5.6. B13 station

Sliding block B13 monitoring station was located just right above the blocks B9 and B11. Recorded data indicate that little correlation between the ground water level and the rainfall intensity was observed. Besides, only a slight drop of the water level occurred during the Chi-Chi earthquake hitting. It might be suggested that the layer of the weathered slated rock was located in between the two layers of clay stratum, which indicates that the inflow of the rainfall did not affect the ground water level. Still, the long-term investigation is needed.

5.7. C1 & C2 stations

Sliding block C1 and C2 monitoring stations were located on the northeastern part of the central region. Both blocks are connected together, with block C1 on the uphill side and block C2 on the downhill side, respectively. Recorded data show that more than 10 meters drop of the ground water level was observed after the completion of the horizontal drains. However, little change of the ground water level was found on C2 station. Further monitoring on the ground water level is under way.

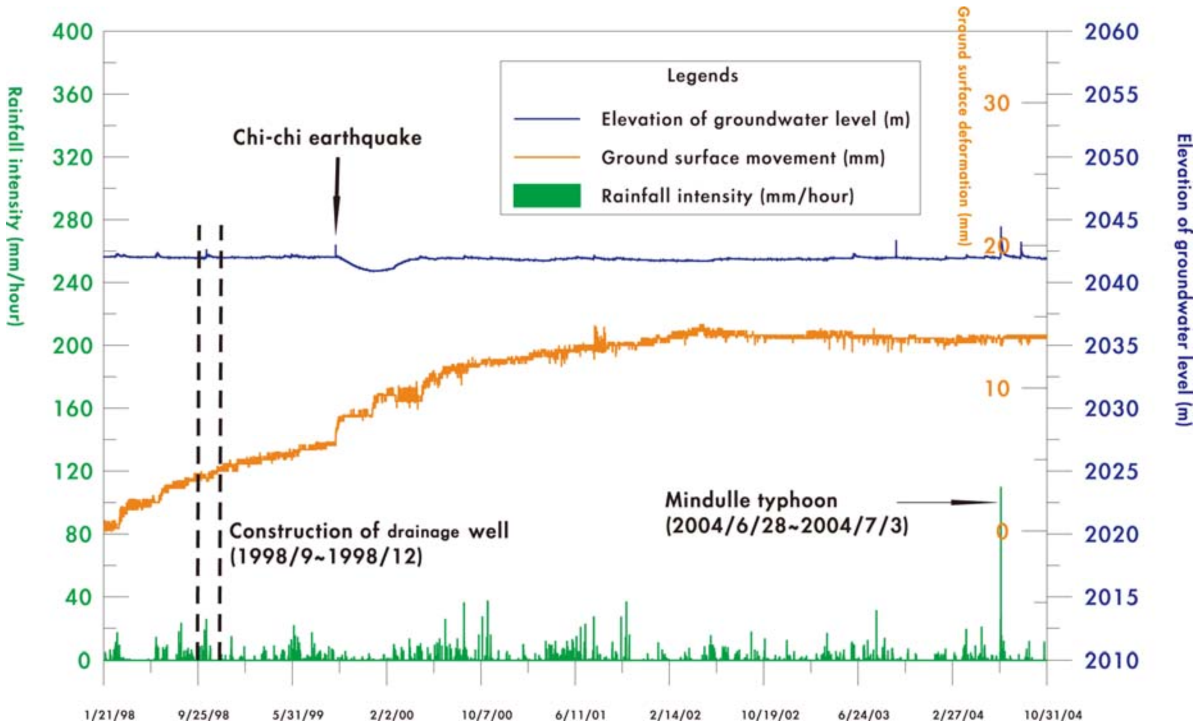

Fig. 10. Relation between rainfall intensity and groundwater level in B13 station

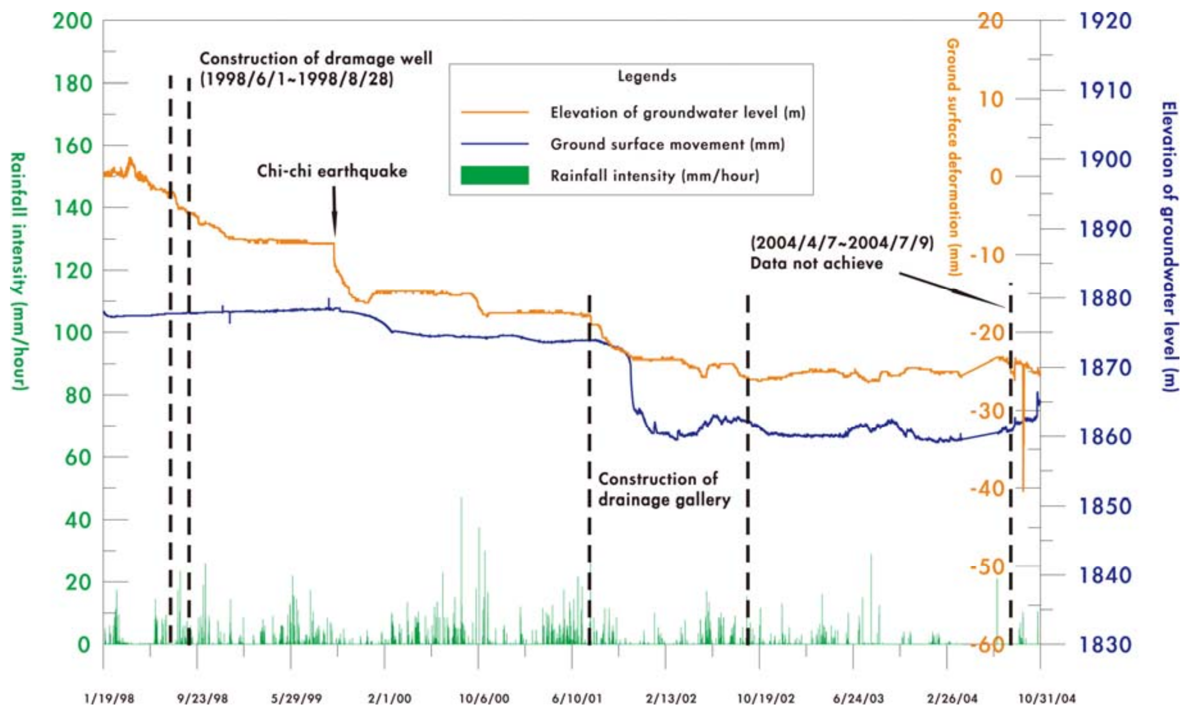

Fig. 11. Relation between rainfall intensity and groundwater level in C1 station

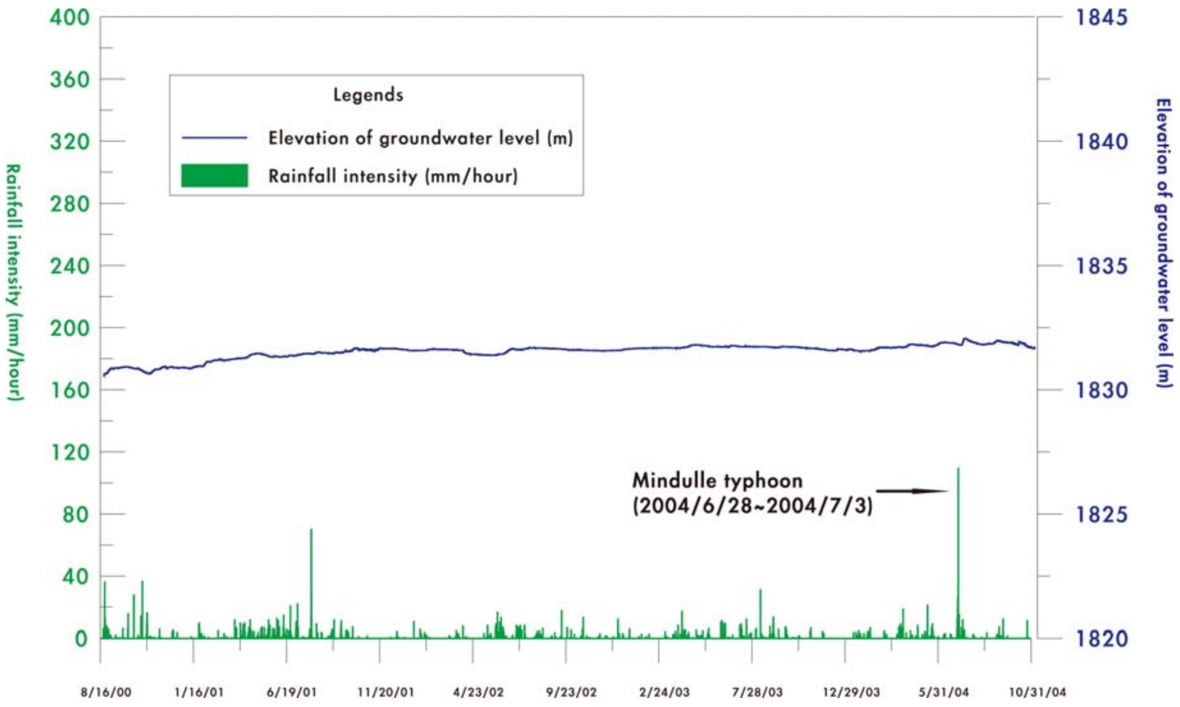

Fig. 12. Relation between rainfall intensity and groundwater level in C2 station

6.ANALYSIS OF DATA MONTORED

After collecting the data from each monitoring station, the software ARIMA (Auto Regressive Integrated Moving Average) was applied to obtain the best fit for the transfer function of the relationship between the intensity of rainfall and the change of the ground water level for that station. The developed model of the transfer function for predicting the renew relationship between rainfall intensity and water level change will be continuously modified and updated through the Time Series Analysis as well as the Neural Network Analysis after the subsequent monitoring results being substituted into the data base.

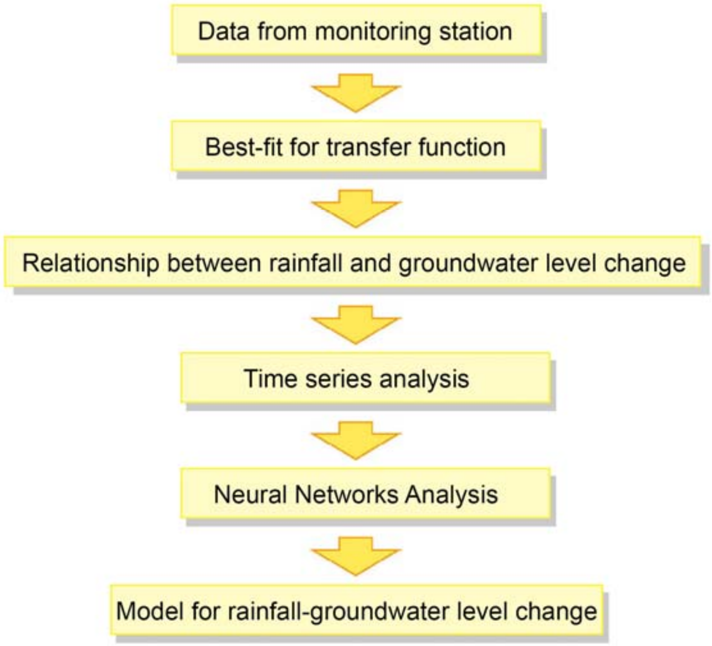

Fig. 13. Process of data analysis

6.1. Transfer functions

Through the analysis of the software ARIMA which was based on the Time Series Analysis, the optimum transfer function for the relationship between the intensity of the rainfall and the change of the ground water level could be obtained.

Table 2. representative transfer function for each sliding block

sliding block	Cumulative rainfall (mm)	Maximum groundwater level changes (m)	representative 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	$Y_t^* = \frac{0.0086788 - 0.0028266B^6}{1 - 0.95385} X_t^*$
B5	304.2	2.52	$Y_t^* = \frac{0.0005824 - 0.0003949B^7}{1 - 0.97955} X_{t-7}$
B9	304.2	5.95	$Y_t^* = \frac{0.05127}{1 - 0.74822B} X_{t-5}^*$
B13	304.2	0.68	$Y_t^* = \frac{0.001686 + 0.00266B + 0.00215B^2 + 0.00155B^3}{1 - 0.67375B} X_{t-8}^*$

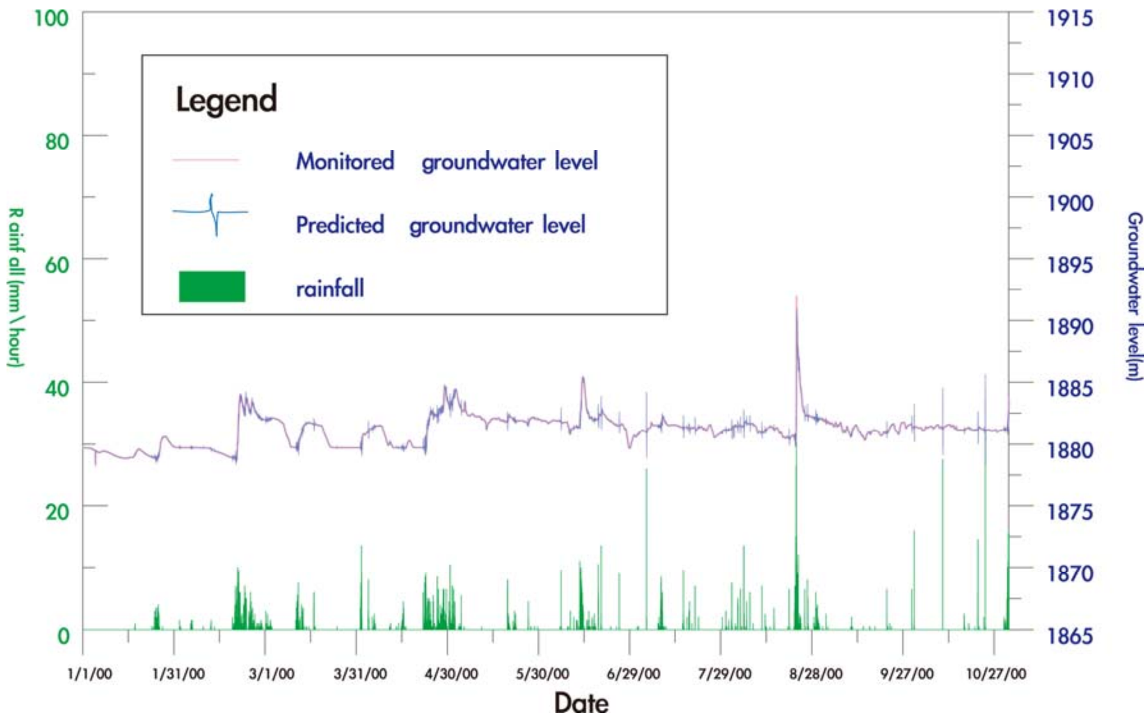

Fig. 14. Simulation of transfer function in 2000 (Monitoring station B1)

6.2. Intervention Modeling

The Intervention Model was formed through the combination of the ARIMA model of single variable as well as the model of the transfer function. It was used to investigate the effect of outside factor intervening on the specific performance behavior. In this investigation, the Intervention Model was applied to study the effect of the construction of the drainage wells on the variation of the ground water level. The analytical prediction indicates that the drainage well construction did have the significant effect on the ground water level. The results are consistent with the field observation that the ground water level dropped an average of 10 meters on B1 station after the construction of the drainage wells was completed.

Table 3. Relative data of Intervention Model

Monitoring station	Period of drain wells construction	Beginning time of intervention model	Period of data analysis	ARIMA model of roundwater 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 4. 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)

CONCLUSIONS

Rainfall induced groundwater fluctuation is similar to surface water hydrograph. They all have a steeper rising part and a clear recessing part. If long term monitoring data can be obtained, statistical analysis can be applied to find representative characteristics for local hydrogeology. Relation between rainfall and groundwater level change can be applied to find the best fit transfer function.

Intervention model analysis can be used to make judge on subsurface drainage measure. Subsurface drainage facilities had influence in drain capability for the specific slope which will change the hydrogeological characteristics. In Li-shan landslide case, back analysis showed the effectiveness for the remedial work performed.

The result shows that time series analysis are applicable in verifying the effectiveness of the remedial work. And, the representative transfer function achieved for each sloping block can be used as the tool for pre-warning purpose if real-time monitoring data can be retrieved remotely.

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