INTERNATIONAL CONFERENCE ON SLOPE ENGINEERING

8-10 December 2003

Hong Kong, China

VOLUME I

Department of Civil Engineering
The University of Hong Kong

Evaluation of the Effectiveness of Landslide Remedial Work

Miau-Bin Su[1], I-Hui Chen[2]
[1]Professor, Department of Civil Engineering, National Chung-Hsing University, Taiwan, R.O.C.
[2] PhD Candidate, Department of Civil Engineering, National Chung-Hsing University, Taiwan, R.O.C.

Synopsis

Remedial works including wells and drainage gallery were applied to stabilize a large landslide in Li-shan area. 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 easily and can be judged more precisely from the intervention modeling analysis.

Keywords

landslide, remedial work, evaluation

1.Introduction

General information in regards to background and remediation work for Li-shan landslide can be found in another paper titled “On the failure mechanism and remediation of the Li-shan landslide in Taiwan” coauthored by K.J. Shou and M.B. Su in this proceeding.

2.Monitored data

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 1.
Remedial work for this stage lasts for six years. In the mean time, monitored data are reduced. Parts of the data collected are presented and discussed hereafter.

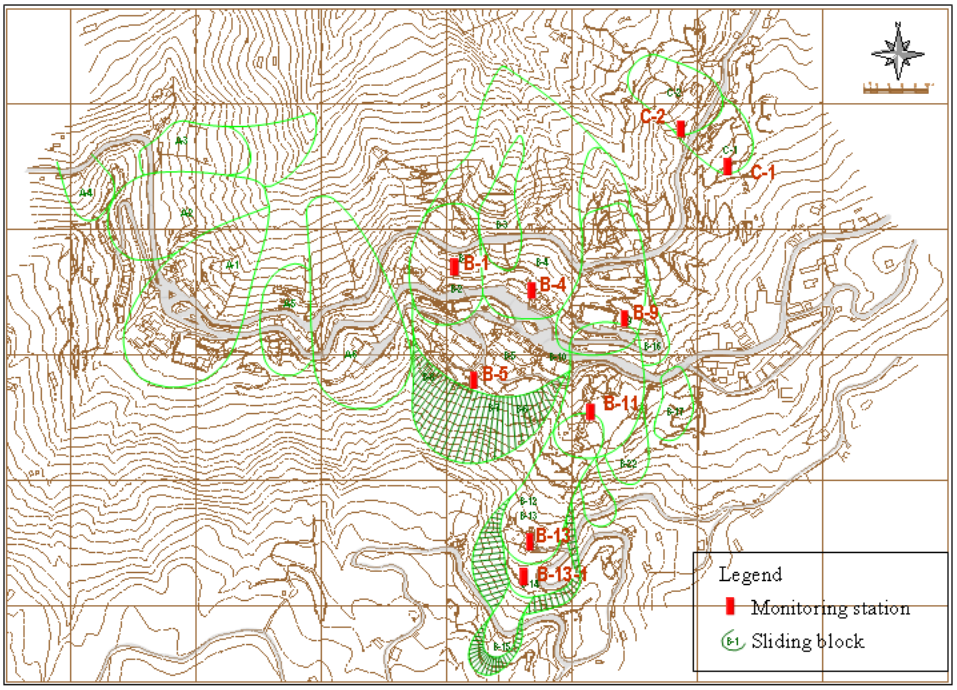

Fig. 1 Locations of monitoring stations in Li-shan landslide area

2.1 B1 station

B1 station located at west side 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 2 for comparison. As can be seen from Fig. 2 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.

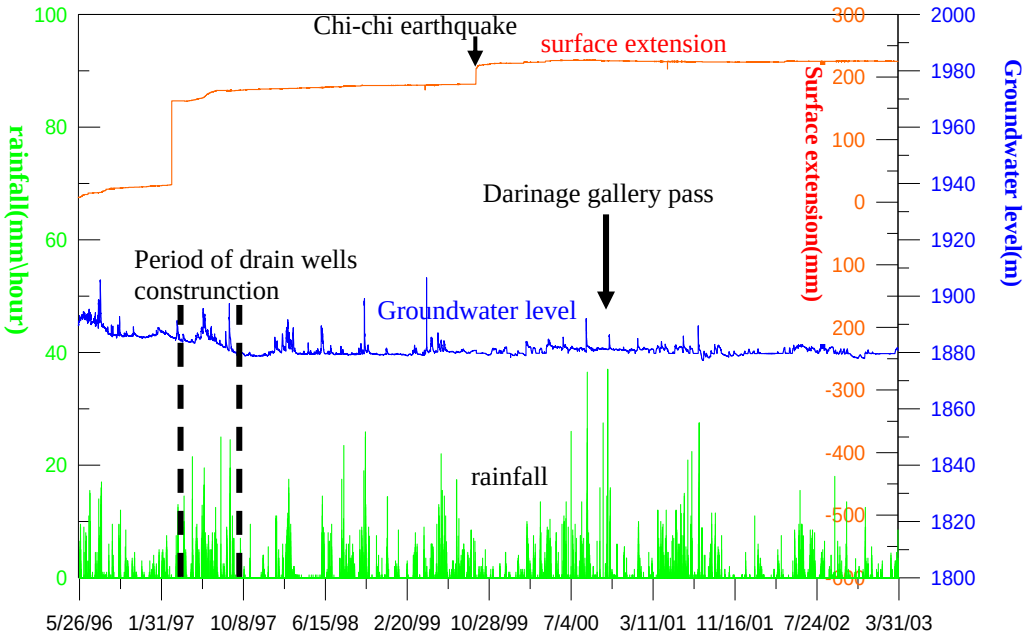

Fig 2 Records for B1 monitoring station

2.2 B5 station

B5 sliding block is located uphill of B1 which has many important building on it. In Fig. 3 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 didn't show significant change is maybe because of the location of fixed point turn out to be on another sliding block.

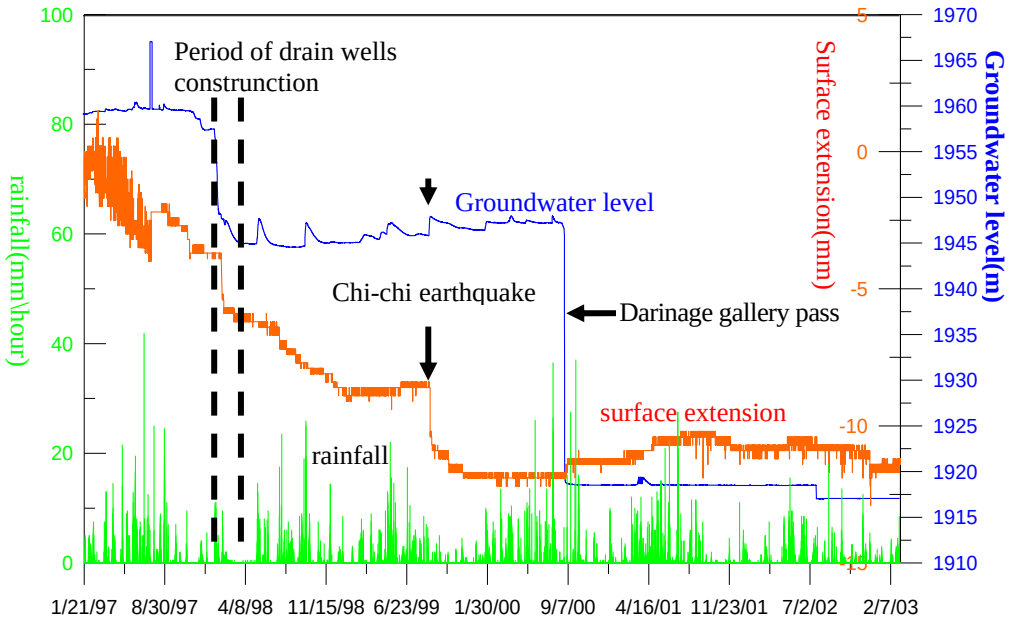

Fig.3 Records for B5 monitoring station

2.3 Chi-chi earthquake 1999

Chi-chi earthquake hitted central Taiwan at 1999. And caused many slope failure. As can be seen from Figure 2 & 3, it caused groundwater level change and ground movement significantly but the slope remained stable. No significant movement observed afterward.

3 TDR Monitoring

TDR monitoring for slope deformation were applied. TDR monitoring utilize radar theory and coaxial cable as the transmission and sensing device (Su and Chen, 2000). Coaxial cables were grouted into borehole to detect shearing and extension along the cable which represents the action of sliding surface of the monitored slope. Results are presented in Figure 4 to show waveform change at different time. A major sliding at 14m deep can be judged clearly from the graph.

4.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 5 shows simulation of transfer applied to year 2000's data.

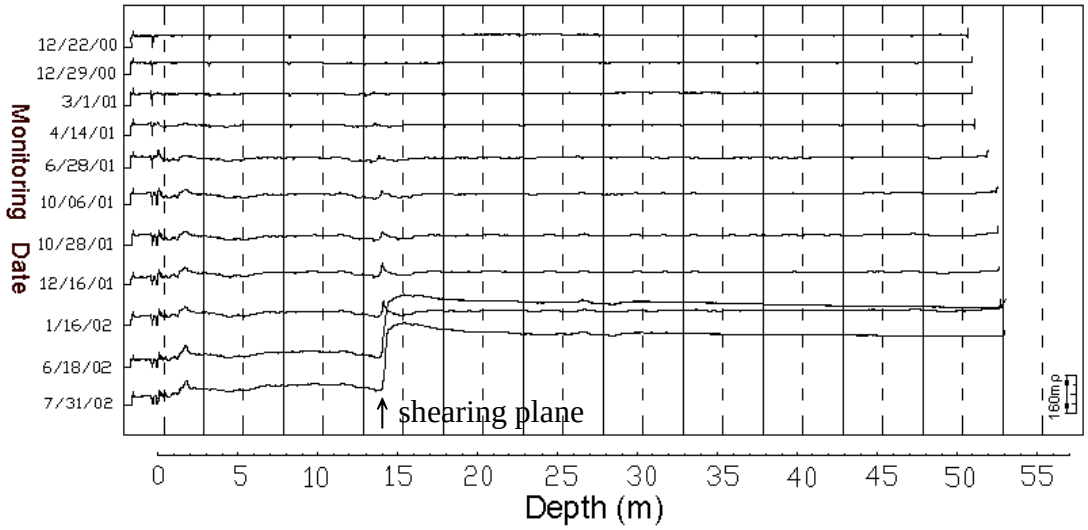

Fig.4 Waveform recorded at B5 TDR monitoring

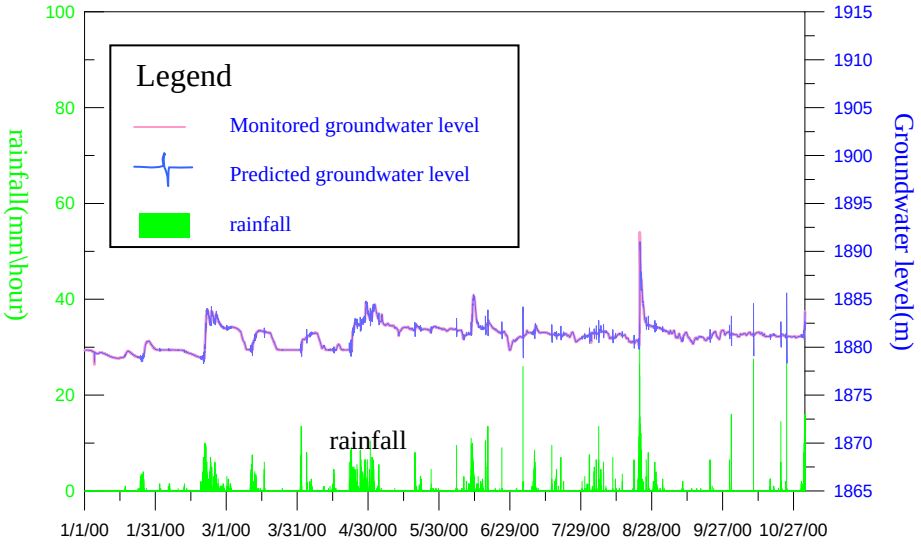

Fig.5 Simulation of transfer function in 2000 (Monitoring station B1)

Table 1 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	$Y_t^* = \frac{0.001686 + 0.00266B + 0.00215B^2 + 0.00155B^3}{1 - 0.67375B} X_{t-8}^*$

5.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. The result reflected field hydrogeological conditions and the role the remedial work play 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.

Table.2 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 3 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)

6.Conclusions

Monitoring systems for an unstable slope under remedial work were helpful. It can provide evidence in judging the effectiveness of the remediation. From data of rainfall and groundwater level change, its optimal transfer function reflected certain hydrogelolgical conditions represents its characteristics. The optimal transfer functions change calculated using intervention modeling technique provides a very good tool in evaluation of achievement and planning for future needs in remedial work. Together with real time data retrevial, it can be organized to a forecast system in safety management plan for the endangered area.

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)