한국지하수토양환경학회 추계학술발표회
2003년 9월 26~27일 제 주 대 학 교

Correlation analysis and time series analysis of Groundwater inflow rate into tunnel of Seoul subway system

김성준*, 이강근, 염병우**

서울대학교 지구환경과학부 · *현 삼성건설기술연구소 · **지질자원연구원

Abstract

Statistical analysis is performed to estimate the correlations between geological or geographical factor and groundwater inflow rates in the Seoul subway system. Correlation analysis shows that among several geological and geographical factors fractures and streams have most strong effects on inflow rate into tunnels. In particular, subway line 5~8 are affected more by these factors than subway line 1~4. Time series analysis is carried out to forecast groundwater inflow rate. Time series analysis is a useful empirical method for simulation and forecasts in case that physical model can not be applied to. The time series of groundwater inflow rates is calculated using the observation data. Transfer function-noise model is applied with the precipitation data as input variables. For time series analysis, statistical methods are performed to identify proper model and autoregressive-moving average models are applied to evaluation of inflow rate. Each model is identified to satisfy the lowest value of information criteria. Results show that the values by result equations are well fitted with the actual inflow rate values. The selected models could give a good explanation of inflow rates variation into subway tunnels.

Key word : subway tunnel, inflow rate, correlation analysis, time series analysis

1. Introduction

A large amount of groundwater is pumped out under construction and in operation process of subway(Forth and Thorley, 1997). Groundwater over 108,630 m^3 per day seeped into subway tunnels in 2000, and most of them are pumped out to streams nearby (annual report Seoul metropolitan rapid transit corporation(SMRT) and Seoul metropolitan subway corporation(SMSC). 2000). The information about groundwater inflow into subway tunnels can be useful information in subway construction and operation, recycle planning of groundwater and groundwater protection and management.

Generally, physical models are used for long-term estimation. But in metropolis like Seoul city, it is impossible to obtain hydrogeological parameters. In addition it's own characteristics of urban environment like impermeable surface, underground structures, a number of authorized or unauthorized pumping well and supply and sewage system make impossible to apply deterministic models. In this case, time series analysis is useful tool for predicting and forecasting(Salas and Obeysekera, 1982).

In this study, correlation analysis using collected data is performed to estimate the effect of geological, geographical factors on groundwater inflow rate and time series analysis is applied to forecasting inflow rate.

2. Correlation analysis

For correlation analysis, Various existing data about factor that can be affect groundwater inflow rate are collected from SMSC and SMRT, These factor include artificial factors like tunnel's size, depth, elevation, grouting method and geological factors like fault, fissure, rock species, stratigraphy. To analyze the effect of these various factors in Seoul subway systems, the correlation analysis is performed. The correlation of groundwater inflow rate and these various factors are summarized in table 1.

Table 1. Relation of groundwater inflow rate and various factors

Variable		Correlation
Location of collection tank	Depth of collection tank	/
	Elevation of collection tank	++
Length of drainage zone	Line 2	+
	Line 5	++
Stratigraphy		+
Stratigraphy(Inflow rate pre zone		+
Tectonic structure		++
Land use		/
Water level in near well		/

Codes : +++ strong correlation ; ++ moderate correlation ; + weak correlation

***/**/* strong/moderate, weak correlation, non numerical variable / no clear correlation

Generally, depth of collector tank and presence of fault, drainage zone are affected groundwater inflow into subway tunnel strongly relative to other factors.

And the effect of these factors is more strong in line 5～8 than line 1～4, which this result is supposed that the effect of the depth of tunnels than other characteristics of line 5~8. And the area which show high groundwater inflow rate is located most in Jungrang stream, which large scale fault is located in. As a results, the presence of fault affect groundwater inflow rate into tunnel strongly. But other tectonic line like joint, folder does not investigated for shortage of data. To understand the effect of tectonic lines to groundwater inflow, it is needed to the investigation of tectonic lines in Seoul area.

3. Time series analysis

Long-term observation of inflow rate is operated in 6 collector tanks of subway lines with approval of SMRT and SMSC for 9 month. Groundwater inflow rates are calculated using these long-term observation data. And time-series analysis is performed for long-term estimation of inflow rate and groundwater inflow rate is calculated in each collector tank. On the result of statistical data like autocorrelation function, partial autocorrelation function using difference of inflow rate, proper transfer function-noise models are selected by Box and Jenkins method. The transfer function-noise model is applied for estimation of groundwater inflow rate this research using precipitation and groundwater inflow rate as input and output respectively. For the stationarity of input and output variable, pre-whitening and differences are computed respectively, and prediction is performed in 3 collector tanks located at Gilum, Garibong, and Sadang stations using selected transfer function-noise model, but results obtained from only first two stations are presented here.

Considering principle of parsimony, each models are identified to satisfy the lowest value of Akaine's Information Criterion(AIC) and Schwartz's Bayesian Criterion(SBC). The resulting transfer function-noise models for Gulum and Garibong stations are as follows.

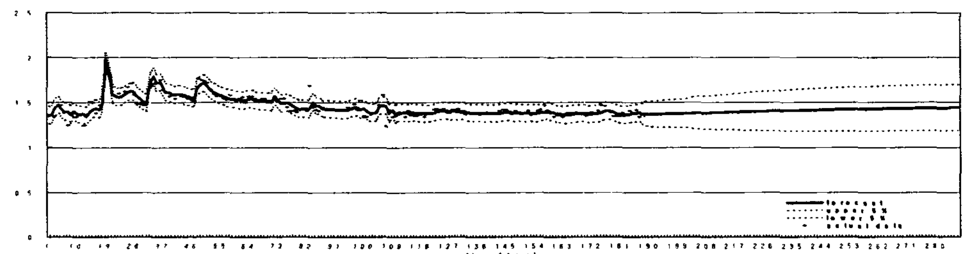
Gilum station :

$$L_t = 1.2811 + \frac{0.0015 + 0.0004B^2}{1 - 0.3974B} P_t + \frac{1}{1 - 0.5756B - 0.3922B^2} a_t$$

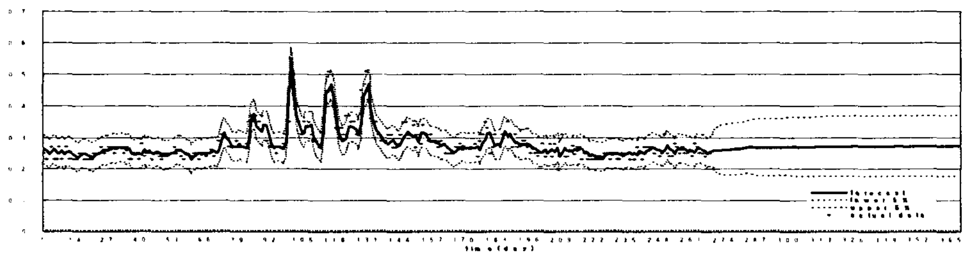
Garibong station :

$$L_t = 0.6484 + \frac{0.0017 - 0.0003B - 0.0007B^2}{1 - 0.9616B} P_t + \frac{1}{1 - 0.2845B - 0.1013B^2 - 0.1341B^3} a_t$$

The time series of estimate value, actual observed value of groundwater inflow rate, 95% confidence interval and residual in Gilum, Garibong stations are shown in Figure 1.



Garibong



Gilum

Figure 1. Time series of forecasts, observed data in Garibong, Gilum stations

4. Conclusion

For estimation of groundwater inflow rate into subway tennel, we performed a statistical analysis to examine the relation between geological or artificial factors and groundwater inflow rates. Results show that line 5~8 are affected more by geological and geographical factors for their depth of subway, compared to line 1~4 tunnels.

Long-term observations are operated in 6 collection tank for 6~9 months and groundwater inflow rate is calculated in each collector tank. The transfer function-noise model is applied for estimation of groundwater inflow rate this research using precipitation and groundwater inflow rate as input and output respectively. For the stationarity of input and output variables, pre-whitening and differences are computed respectively. Predictions in Gilum and Garibong using selected transfer function-noise model show that the selected models are in agreement with observation data.

5. References

Annual report, 2000, Seoul metropolitan rapid transit corporation

Annual report, 2000, Seoul metropolitan subway corporation

Groundwater observation annual report, 2000, Ministry of construction and transfortation.

Box, G.E.P., Jenkins, G.M. and Reinsel., G.C., Time series analysis : Forecasting and control, 3rd Edition., New Jersey : Prentice Hall

Cesano, D., B. Olofsson and A.C. Bagtzoglou, 2000, Parameter regulating groundwater inflows into hard rock tunnels - a statistical study of the Bolmen Tunnel in Sounthern Sweden., Tunneling and Underground Space Technology, Vol. 15, No. 2, pp. 153-165.

Cesano, D., and B. Olofsson, 1997, Impact on groundwater level when tunnelling in urban area., Groundwater in the urban environment, Vol. 1, pp. 231-236.

Forth, R.A. and Thorley, C.B.B, 1997, Construction dewatering in Hong Kong., Groundwater in the urban environment, Vol. 1, pp. 231-236.

Salas, J.D. and Obeysekera, J.T.B., 1982., ARMA model identification of hydrological time series. Water Resources Research, vol 29, 2011-2026.