CETRA 2016

4th International Conference on Road and Rail Infrastructure
23–25 May 2016, Šibenik, Croatia

Road and Rail Infrastructure IV

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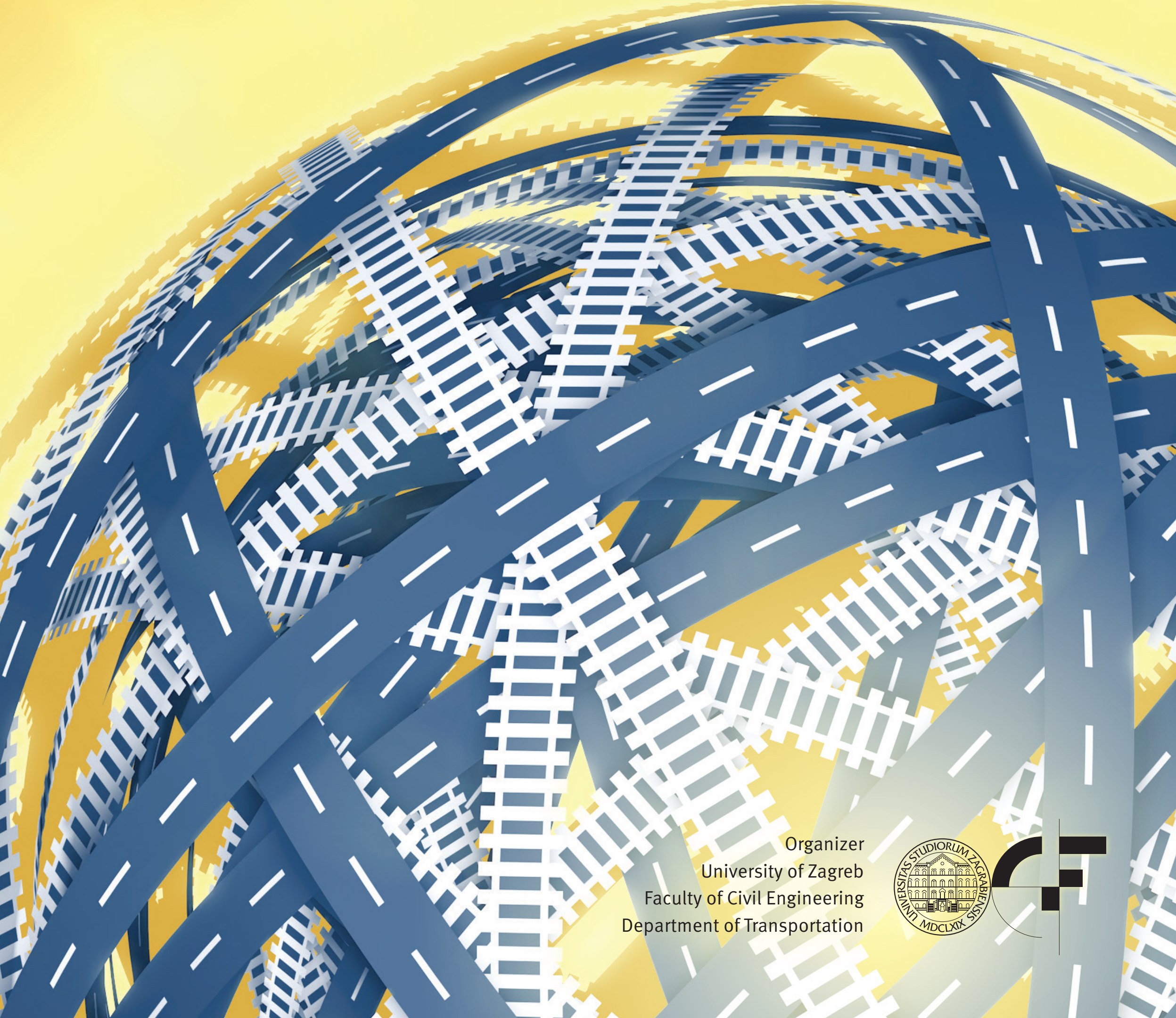

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MONITORING OF INFLOW GROUNDWATER INTO SUBWAY STATION IN SOUTH KOREA

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Abstract

This research carried out investigations on the hydrogeological characteristics of inflow groundwater into subway station in South Korea. It is well known that the behaviour of groundwater around urban area has greatly affected risks on ground subsidence as well as underground structures. Especially, there are many cases of urban sinkhole due to a large volume of groundwater generated during the construction and operation of subway system in South Korea. There are 16 lines of subway with 481 stations in 6 cities in South Korea, and the half of them are placed in Seoul, the capital of South Korea. About 10,000 m^3/day of groundwater was inflow into subway stations in Seoul. In order to investigate the characteristics of inflow groundwater, a test-bed station was monitored for several parameters such as the volume of inflow, water temperature, and electric conductivity, etc. for several months, With geological properties of ground and environmental factors such and rainfall and surface water near the station, the station, the monitoring data was analysed to estimate their correlation and abnormal behaviour. Further studies are ongoing to setup a real-time inflow groundwater monitoring and risk assessment and risk assessment system, which would prevent risks on the underground near subway and its infrastructures.

Keywords: inflow groundwater, subway, ground subsidence, monitoring, tunnel

1 Introduction

In recent years, there has been increased accidents related to ground subsidence in urban area, so called “urban sinkholes”, around the world. A sinkhole is basically formed by a void under the ground which can be induced naturally and/or by human activities. Areas of ground that has the rock easily dissolved by water, such as limestone, salt bed, carbonate rock, etc., could have sinkholes naturally. For example, it has been well known Florida’s peninsula in United States is made of carbonated rock, resulting in karst terrain and many cases of sinkholes has been found in Florida. Otherwise, human activities can also trigger ground failure and subsidence, such as heavy pumping of groundwater, investigative drilling, excavation, and construction/operation of underground facilities. In 2015, there was an accident where two pedestrians swallowed by sinkhole in Seoul. The place was cited in the middle of downtown, and it was found just next to a construction site where 39-story building are being built. It has been assumed the cause of collapse was water coming out of the retaining wall which resulted in drain of soil. It was reported that ground failure and subsidence events had been yearly increasing in South Korea. According to National Disaster Management Institute in Korea, there has been 36 sinkholes happened in Korea for 10 years since 2015. Among them, 32 cases (78.8%) were occurred by human activities, such as deterioration of sewer pipelines, construction of subway, excavation, etc. [1].

During the construction and operation of massive facilities such as subway, underground structures, it is possible that a large volume of groundwater is discharged. Unlike groundwater discharged from localized underground facilities, inflow groundwater into subway system influenced on much wider area due to its net-like structures. It may occur serious decrease of groundwater level, which followed by ground subsidence and adverse effect on the stability of underground facilities. We have studied on technologies to monitor the characteristics of inflow groundwater into subway and to assess its risks on ground subsidence.
In this paper, investigations on the hydrogeological characteristics of inflow groundwater into subway station were overviewed and its status for South Korea was described. In addition, data from a test-bed study of inflow groundwater into a subway station was discussed.

2 Characteristics and effect of inflow groundwater into subway

2.1 Amount of inflow groundwater and related parameters

When the subway tunnel was constructed under the groundwater level, the void in tunnel has atmospheric pressure and groundwater tend to inflow into tunnel. Goodman et al. [2], Lei [3], Park et al. [4] conducted studies on analytical formulations. Equation (1) shows the rate of inflow groundwater per unit length of tunnel, where the tunnel discharges as steady state [2].

$$Q_0 = \frac{2\pi K H_0}{2.3 \mathrm{Log}(2H_0 / r)} \tag{1}$$

Where:
Q_0 – amount of inflow groundwater;
K – hydraulic conductivity;
H_0 – groundwater level measured from the head of tunnel;
r – tunnel's diameter.

When the discharged amount of groundwater is large enough to change groundwater level, that is, transient state, Q(t) at any time can be predicted by equation (2).

$$Q(t) = \sqrt{\frac{8C}{3} K H_0^3 S_y t} \tag{2}$$

Where:
C – arbitrary constant;
S_y – specific yield.

The report of Korean Ministry of Construction and Transportation [5] figured out several parameters which may affect inflow groundwater into subway. It conducted the research for collecting wells in some subway stations in Seoul. Parameters considered were surrounding groundwater level, depth and elevation of the collecting well, length of range, river, geological properties, etc. It showed that the volume of inflow has been correlated with the depth and elevation of collecting well. Also, the amount of rainfall has positive relationship with the volume of inflow groundwater.

2.2 Effect of inflow groundwater on surrounding environment

The inflow groundwater into subway tunnel could gradually decrease the groundwater level. When the groundwater level is decreased, the ground can be weakened and cavities are formed, which result in urban sinkholes. Kim investigated the causes of urban sinkhole [6] and indicated the decreased groundwater level in urban area was one of the main cause of ground subsidence. Also, Kim recommended that most of sinkhole spots in Seoul and Pusan in South Korea were sited on the subway line, that is, subway was working as a huge Line Sink for groundwater.

Yoo and Kim investigated the relationship between groundwater flow and ground subsidence for various ground conditions by numerical approach [7]. A parametric study was conducted on the influencing factors, and indicated that tunnelling-induced groundwater drawdown causes ground-surface settlement (Figure 7).

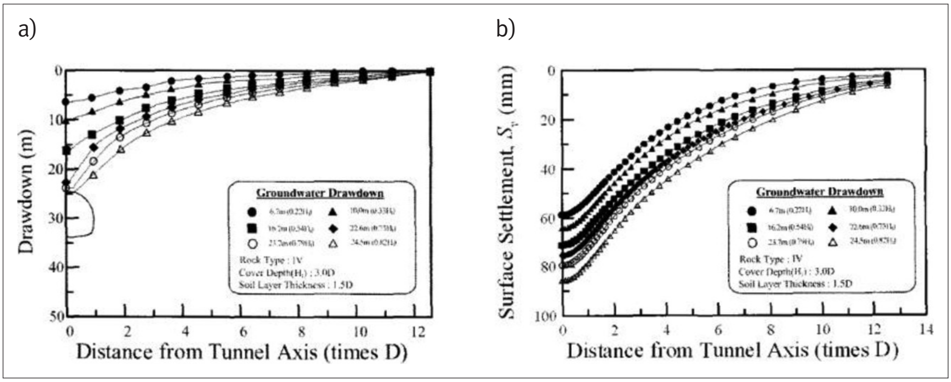

Figure 1 a) Groundwater drawdown, b) Surface settlement with groundwater drawdown [7]

The decreased groundwater level by subway tunnel also can affect the stability of its structures. Jung et al. [8] studied that lowered groundwater level could increase effective stress, which followed by ground subsidence and overstress for underground facilities.

It has been reported that subway tunnel in Shanhai in China was constructed on the weak layer of sediment. This sedimentary layer has high moisture content and compressibility and low hydraulic conductivity. According to Shen et al. [9] urbanization of Shanhai and excessive pumping of groundwater brought problems including lowered groundwater level and surface settlement, as well as the deformation of subway tunnel.

3 A Test-bed study on monitoring of inflow groundwater

Including Seoul, the capital, there are 6 cities which has subway system, total of 16 lines and 505 km of operational route in South Korea. According to the report by K water [10], the total amount of inflow groundwater into subway in South Korea was 142,991 m^3/day, 52,193,000 m3/year. Table 2 shows the status of inflow groundwater into subway for different cities in South Korea.

Table 1 Status of inflow groundwater into subway in South Korea.

City	Line	Station	Length (km)	Inflow Groundwater [m^3/day]
Seoul	8	268	287	97,308
Busan	3	92	96	15,030
Daegu	2	56	54	18,054
Inchon	1	23	24	2,719
Daegeon	1	22	23	7,920
Kwangju	1	20	21	1,960
Total	16	481	505	142,991

According to the report by Seoul city, between 1997 and 2014, the amount of inflow groundwater for line 1 to 5 of subway in Seoul has been decreased by 39.5% [11]. It assumed that the decrease of groundwater near subway has been occurred for a long time.

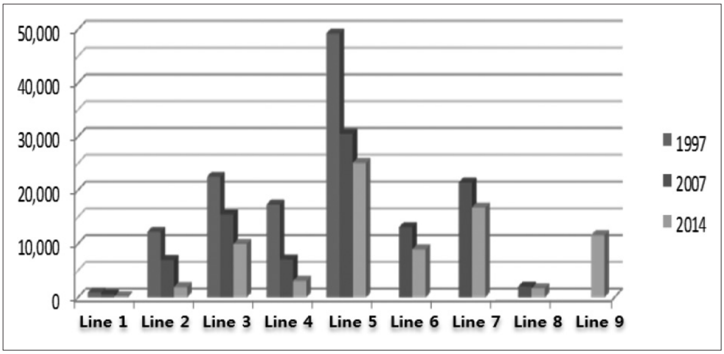

Figure 2 Changes of inflow groundwater into subway in South Korea

For the test-bed study to monitor the behaviour of inflow groundwater, one station in Daejeon city was investigated in this research. The characteristics of groundwater in collecting well such as volume of inflow, electric conductivity and temperature, etc. were measured for several months and surrounding environmental data related to rainfall, river, etc. were collected and analysed at the same period.

3.1 Target area for monitoring of inflow groundwater

In Daejeon city, there is 1 line of subway which is operated 22.7 km with 22 stations since 2006. Inflow groundwater is collected and discharged in 8 stations, and total amount of it is ca. 7,920 m^3/day.

The target station, Jungangro station, has the largest volume of inflow groundwater in Daejeon city, which amount is 3,620 m^3/day. Most of inflow groundwater has been discharged to river, and only about 16 m^3/day of it has been reused. Figure 3 showed the geological properties of area near the target station. Around the station, the layer of soil was depth of 1.5~7 m for sediment, 1.5~12 m for weathering residual soil, 3.5~24.5 m for withered rock. The groundwater level was -3.9 ~ -9.8 m under the surface. The target station was excavated from 2001 to 2003, and it was reported that there was about 6.6 m ~ 15.7 m of decrease in groundwater level during the construction.

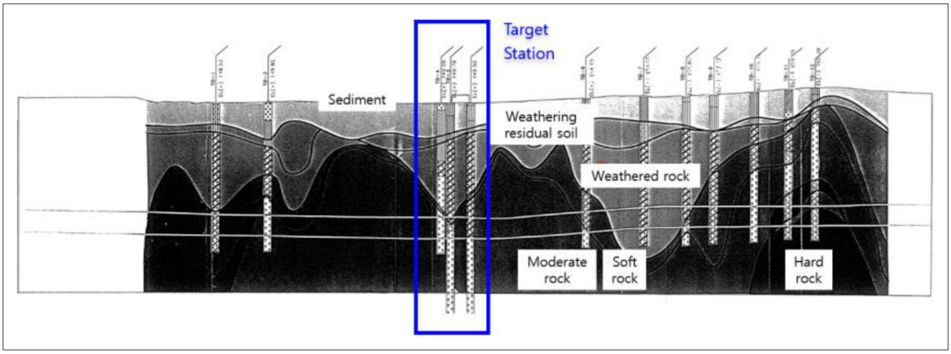

Figure 3 Geological layer of area near the target station

3.2 Monitoring method of inflow groundwater at test-bed station

In order to establish database for risk assessment of inflow groundwater using time series analysis, some parameters for groundwater in collecting well were measured. LTC levelogger and barologger (Solinst, USA) were installed in collecting well and in the pupping room, respectively (Figure 4).

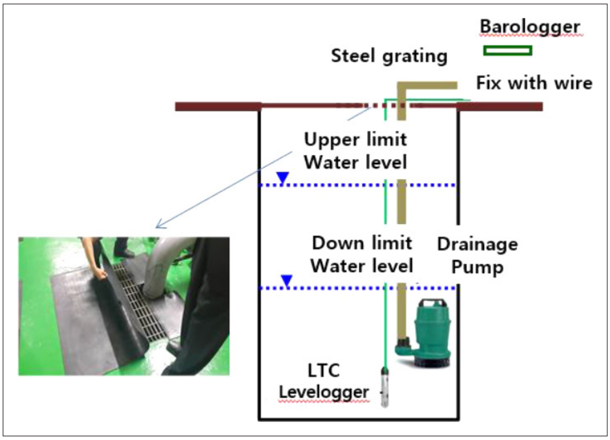

Figure 4 Installation of monitoring sensors in collected well

Using LTC levelogger, the water level in collecting well was measured every minute, which transferred to the amount of inflow groundwater by the area of well. Temperature and electric conductivity are also measured using LTC levelogger in every 3 minutes. The data of atmospheric pressure from barologger was measured to correlate the water level. The area of collecting well was 42.4 m^2.

3.3 Results and Discussion

In order to investigate the characteristics of inflow groundwater, a test-bed station was monitored for several parameters such as the volume of inflow, water temperature, and electric conductivity, etc. Figure 5 shows the behaviour of each parameter for inflow groundwater for about 3 months. The increase of water level in collection well was ranged from 39.2 to 64.3 m/day, with average of 56.5 m/day. This meant 2,396 m^3/day of groundwater was flowed into this collection well. The amount of inflow groundwater was increased during the monitoring period, which was about 2.8 m^3/day. On the other hand, electrostatic conductivity was increase about 0.15 uS/cm/day, where it changed from 347 to 372 uS/cm. The factors including rainfall, river stage, and groundwater level near the station were also investigated based on the data open in public.
The mesured time-series data was analyzed by auto-correlation method to estimate their characteristics. Auto-correlation analysis is conducted with equation (3), where x_t is time-series data, k is time lag, n is the length of time, μ is the averge of x, c_k is autocovariene function, and γ_k is auto-correlation coefficient.

$$C_k = \frac{1}{n}\sum_{t=1}^{n-k}(x_t - \mu)(x_{t+k} - \mu), \quad \gamma_k = \frac{c_k}{c_0} \tag{3}$$

In Figure 6, time-series data for 6 parameters were analysed with auto-correlation analysis. The amount of inflow groundwater, electrical conductivity, temperature and the groundwater level have auto-correlation coefficients which are decresed gradually, while rainfall, river stage shows low auto-corrlation. Cross-correlation analysis was also conducted for these 6 parameters to estimate their relationship (Dara now shown). On the results, rainfall affects the level of river distinctly and EC. The amount of inflow groundwater, EC and temperature were related to each other with 7 to 14 days of time lag.

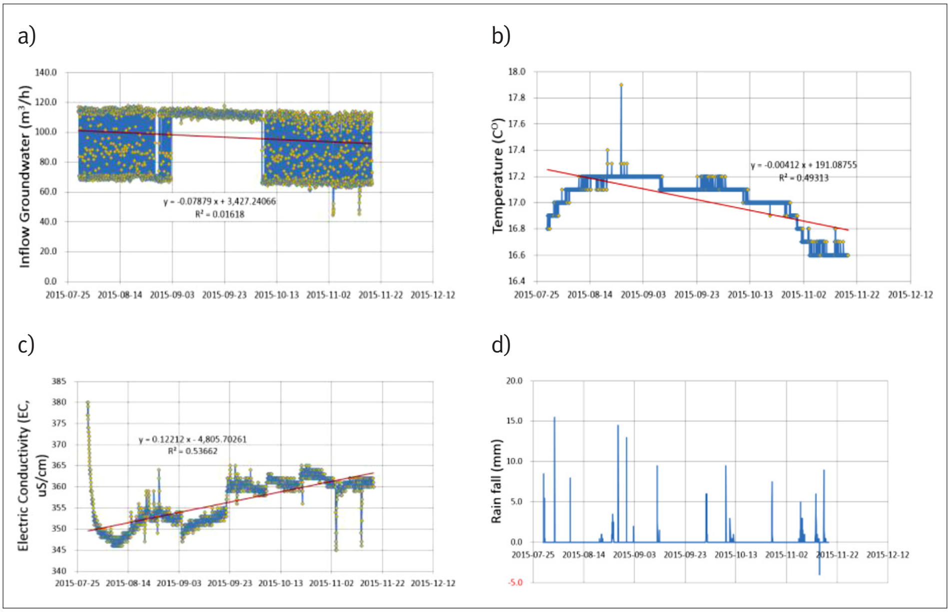

Figure 5 Measured data for a) inflow groundwater, b) water temperature, c) electric conductivity, and d) amount of rain fall

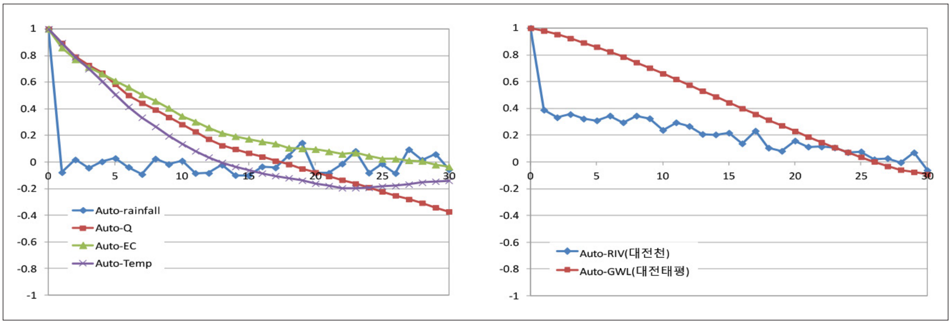

Figure 6 Auto-correlation analysis of inflow groundwater and surrounding factors, such as rain fall, Q(inflow groundwater), EC(electrical conductivity), temperature, RIV(river stage), and GWL(groundwater level)

Acknowledgement

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