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Environmental problems of groundwater around the longest expressway tunnel in Korea

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ABSTRACT: Long tunnels are usually located in mountainous areas with limited infrastructure. Therefore very little is known about the geological, hydrogeological and geotechnical conditions: the longer the tunnel, the higher the probability of encountering adverse conditions for tunneling ; the greater the cost and duration for tunnel construction. Inje tunnel will be the longest expressway tunnel in Korea. In case of Inje tunnel, Special problems related to the length of the tunnel are for example typically the logistics, ventilation and environmental impacts. Even though modern excavation methods of tunnels have been developed, various types of problems such as change in groundwater distribution and transformation of geographical features still remain. It is not uncommon that private wells and small streams are used for daily life in the regions where mountain tunnels are located. Then serious social problems such as well water level fall, being attributable to tunnel excavation occurs. In the design stage, we evaluated that the quantity of leakage water into tunnels and groundwater drawdown area was simulated using numerical modeling such as MODFLOW and MAFIC to reduce adverse effects on life environment around tunnels.

1 INTRODUCTION

Nowadays road construction projects in Korea have shown a tendency toward linear route designs, for the purpose of increasing running speed and reducing transportation time. Moreover, a growing number of projects are designed with tunnels and bridges in order to minimize damage to the natural environments, which can be caused by slope cutting.

However, some road construction projects, which were started after the year 2000, provoked the delay of projects and creating a lawsuit battle. Such a problem precipitated because the impacts of groundwater outflow during tunnel excavation were dealt with superficial experiences rather than scientific verification. Since 1998, there have been four important environmental conflicts related to tunnel groundwater outflow in Korea. Every tunnel construction that was mentioned above has passed legal environmental impact assessment (EIA) procedures. Nevertheless, these construction projects were delayed or stopped, within a span of 2 or 3 years on average, due to strong objections from civil environmental NGOs and local residents near the project sites. The NGO insisted that the groundwater outflow during tunnel excavation accompanied more serious secondary environmental impacts such as abrupt changes 4 Mitigation Plan for Environmental Impacts of Groundwater in Tunnels in the fauna and flora ecology near the upper part of the tunnel sites. (Lee, J. et al 2005).

Generally speaking, the movement of groundwater is based on meteorology conditions, surface vegetation, hydrogeological conditions and so on. Because a tunnel is a linear structure, the possibility of changing hydrogeology conditions is high and it is difficult to avoid adverse effects to life environment in regions where small-scale water usage remains. Therefore, many studies on the quantity of leakage water into tunnels and groundwater drawdown area are executed to reduce adverse effects on life environment around tunnels as well as retain safety and workability in tunnel constructions.

In this study, we performed the following investigation and numerical analysis to evaluate the environmental influence of groundwater with excavation of tunnel in mountainous area;

- Ground Investigation: Borehole logging, geophysical survey, BIPS, Lugeon test, groundwater level monitoring, water well survey and so forth
- Numerical Analysis for groundwater flow: Continuous and fracture media model
- Evaluation of influence: drawdown of groundwater level, groundwater inflow rate into tunnel Etc.

2 OVERVIEW OF THE TUNNEL

The longest tunnel in Korea will be the Inje tunnel with the length of 11 km. The tunnel consists of two parallel double-lane tube each with a width of 14.5 m. The tubes are connected by cross tunnel as emergency facility every 250 m and 750 m. The gradient of the tunnel from Chuncheon to Yangyang is 1.95% downward. An Incline tunnel with the length of 1.5 km was designed on the purpose of access for excavation face and escape tunnel in emergency. Table 1 shows general overview of the tunnel.

3 GROUND INVESTIGATION

3.1 *General overview on the topology and geological conditions*

The dominant topographic features of the area are rugged mountains and a few of streams. The western part of the area is lower altitude and more relief than the eastern part. This area shows early mature stage in geomorphologic cycle.

This area consists of Pre-Cambrian porphyroblastic gneiss, banded gneiss, and Jurassic biotite granite, two-mica granite, Cretaceous basic and acidic dikes, and Quaternary alluvium and diluvium as shown in Figure 3.

3.2 *Ground investigation*

We carried out geological and geotechnical survey as shown in Figure 2.

4 NUMERICAL ANALYSIS

4.1 *General aspects of groundwater flow model*

The environmental assessment of tunnel groundwater aims to forecast the drawdown and variation of domestic groundwater near planned routes due to tunnel excavation. As usual, numerical methods of groundwater flow modeling are used for the environmental impact assessment of tunnel groundwater.

The program packages used for the modeling of tunnel groundwater outflow are different from each other, depending on the regional groundwater level variation in whole tunnels or small-scale groundwater level variation in narrow fracture zones. Normally, continuous numerical model packages are commonly used for modeling large-scale groundwater flow variations, while fracture media models are applied for

Table 1. Layouts of Inje Tunnel.

Length	10,965 m
Alignment	R = 2000 ~ R = 4991.3
Gradient	−1.95%
Shape of Portal	Arch wall type
Traffic Type	2 tube (2- lane)
Ventilation	Jet Fan : 80 Ventilation Shaft : 4
Excavation Method	Drill and Blast
Emergency Facilities	Escape connecting tunnel : 44 – Interval : 750 m for vehicle : 250 m for human

Figure 1. Location of Inje tunnel and its vertical section profile.

groundwater flow modeling in smaller zones composed of jointed rock aquifers.

Similarly, when we carry out the modeling of groundwater outflow, the MODFLOW package is commonly used for numerical analysis of regional groundwater flows in whole areas of tunnel and drainage, and MAFIC is applied for detailed groundwater modeling in small discrete zones in tunnel areas.

In this study, two representative models are used to forecast the tunnel groundwater outflow pattern as following Table 2.

The ground conditions of modeling section are Very-good(rock type 1)~ Moderate(rock type 3) grade in rock classification and the rock covers of tunnel under stream and valley area are about 100 m or higher.

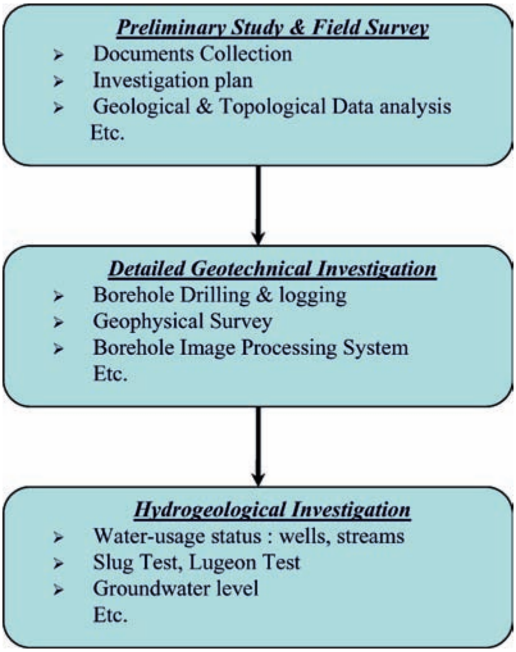


Figure 2. Flow chart of Ground Investigation.

4.2 *Continuous media modeling*

4.2.1 *Setup of the model*

MODFLOW was used to simulate groundwater flow as continuous media model in the studied area. The whole area is 4 km × 3.5 km.

The boundary of the model is set at the summit of northern mountains and southern mountains in the upper and lower end, respectively.

Hydraulic conductivities are classified into fifteen groups according to the permeability of the regions from Lugeon test. The range of value is 4.5E-5 cm/sec ~ 7E-6 cm/sec.

4.2.2 *Steady state simulation*

We calibrated the value of groundwater head between the calculated and observed one in order to modify

Table 2. Layout of groundwater flow modeling.

Program	MODFLOW	MAFIC
Model	3D-Continuous Model	3 D-Discontinuous Model
Section	Sta. 2 + 500 ~ 6 + 500	Sta. 4 + 000 ~ 4 + 500

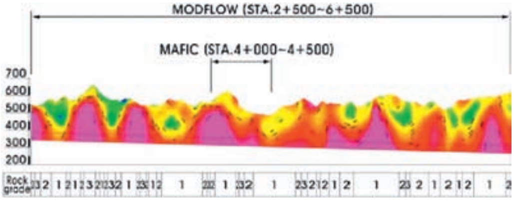


Figure 4. Ground condition and modeling section.

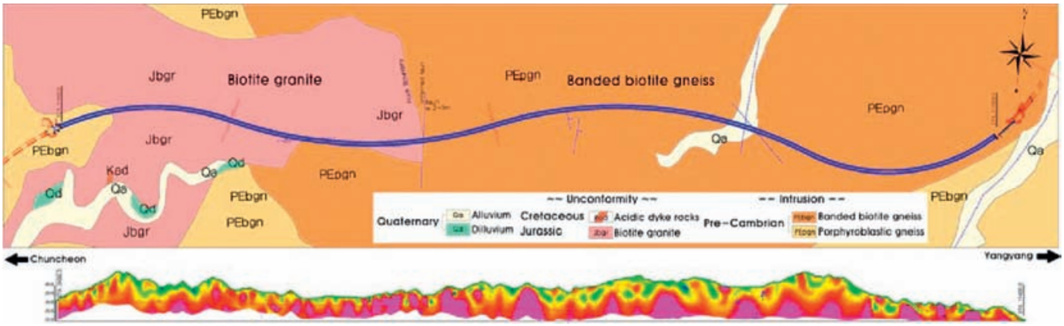


Figure 3. Geological features of Inje tunnel.

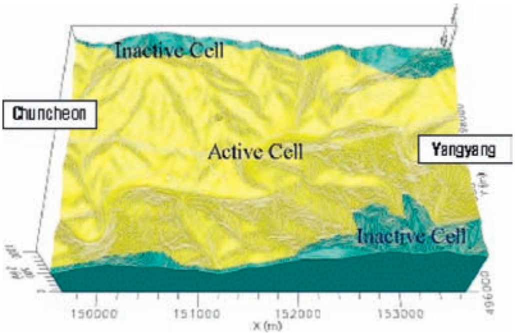


Figure 5. Boundary condition of the model.

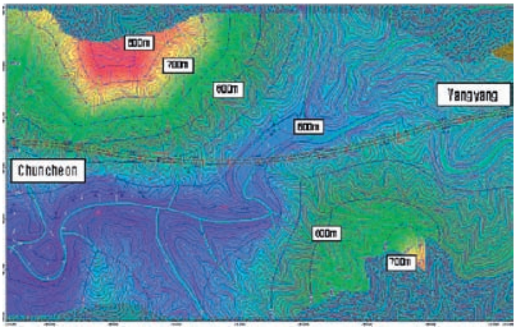


Figure 6. Distribution of equivalent head in steady state condition.

the hydraulic model. Figure 6 shows distribution of equivalent head in steady state condition.

We can see that groundwater inflow was concentrated at tunnel alignment and flow from the summit areas of northern and southern mountain to Bangtae stream.

4.2.3 *Transient state simulation*

Result of Transient flow simulation is used to evaluate variation of groundwater level with tunnel excavation. We can know that the change of groundwater level with time is very small amount of 0.008 m ~ 0.015 m before tunnel excavation.

4.2.4 *Change of groundwater level due to tunnel excavation*

We can see the distribution of groundwater level and drawdown at the check point due to the tunnel excavation as following Figure 8 and Table 3. The check points in model are located every 500 m from Sta. 3 + 000 to Sta. 6 + 500.

The drawdown of groundwater due to tunnel excavation is 1.92 m ~ 3.29 m as you can see the Figure 8. It is small amount in general, but we worried about the influence on groundwater systems around tunnel. Therefore, we carried out simulation for waterproof grouting with the aim of reducing water inflow into tunnel in rock mass.

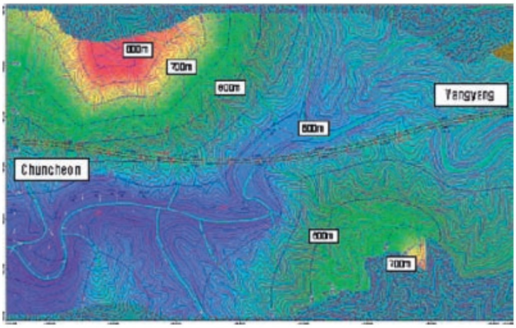
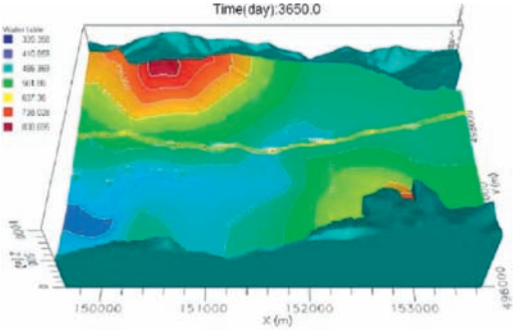
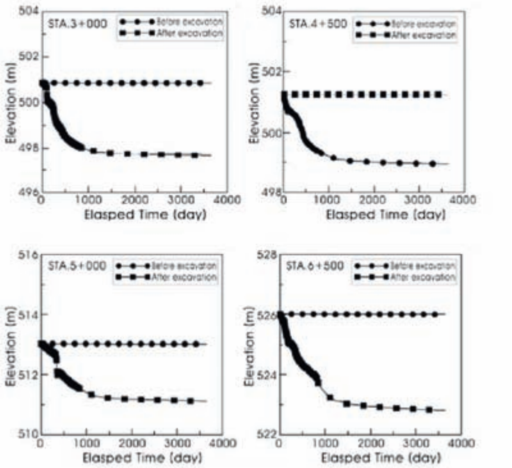


Figure 7. Distribution of equivalent head in transient state condition.



(a) 3650days after tunnel excavation



(b) drawdown of groundwater at each check points

Figure 8. Distribution of groundwater level.

Groundwater level at Sta. 5 + 000 will fall down to 2.03 m after tunnel excavation and water inflow rate per km is 0.127 m^3/min. In case of using waterproof grouting to the ground near tunnel, drawdown of groundwater level is 0.79 m and water inflow rate

Table 3. Groundwater level and water inflow rate into the tunnel.

Check point	Drawdown of groundwater level (m) (without grouting)	Drawdown of groundwater level (m) (with grouting)
Sta. 3 + 000	3.20	0.94
Sta. 3 + 500	2.94	0.87
Sta. 4 + 000	2.32	0.58
Sta. 4 + 500	1.92	0.73
Sta. 5 + 000	2.03	0.79
Sta. 5 + 500	2.98	1.04
Sta. 6 + 000	3.20	0.77
Sta. 6 + 500	3.29	1.05
Water inflow rate per km	0.127 m^3/min (730.75 m^3/day)	0.060 m^3/min (343.27 m^3/day)

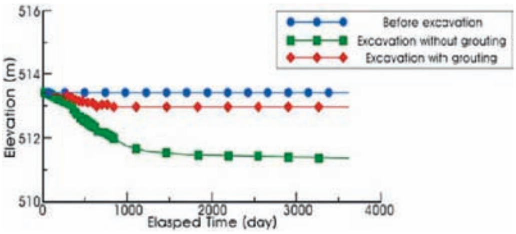


Figure 9. Drawdown groundwater level in case of applying waterproof grouting at Sta. 5 + 000.

per km is 0.060 m^3/min. It can be notified that if waterproof grouting into the ground is performed in advance, the amount of groundwater inflow into the tunnel will decrease as shown in Figure 9 and Table 3.

4.3 *Fracture media modeling*

MAFIC (Matrix And Fracture Interaction Code) determines solutions of flow and pressure by conjugate gradient finite element methods, and solves solute transport by particle tracking discrete fracture network models. Finite element meshes are based on fracture network analysis and geometric modeling.

4.3.1 *Set up of the fracture model*

Using the package of MAFIC, we simulated groundwater flow through fracture model in the studied area (Sta. 4 + 000 ∼ 4 + 500). Input data was estimated based on joint data from detailed surface and borehole survey. In facture model, three of major joint set was estimated as following Table 4.

Figure 10 shows three dimensional fracture network and tunnel.

4.3.2 *Steady state condition*

As the stage of setting boundary condition in steady state simulation, we estimated groundwater level and transmissivity(T) based on results of MODFLOW in steady-state flow condition, water well survey and borehole test and so on.

Table 4. Major joint set and fault in this area.

Joint set	Orientation	Length (m)	S.D of Length (m)	Distribution of length
Set 1	80/194	15.36	10.38	Lognormal
Set 2	78/264	12.93	9.63	Lognormal
Set 3	30/124	34.47	13.18	Lognormal
Fault	85/105			

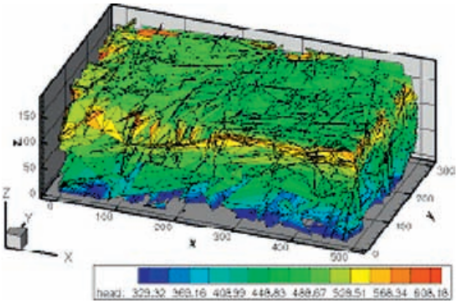
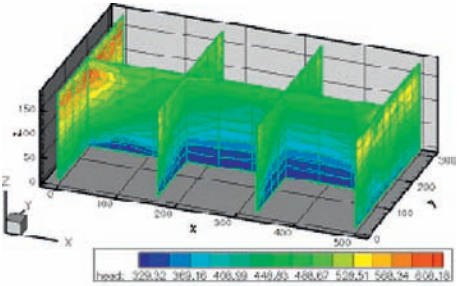
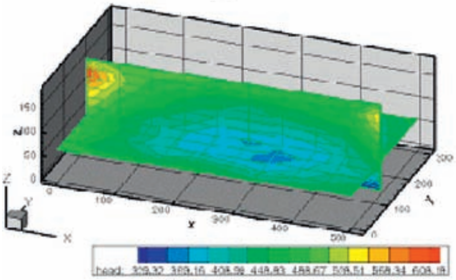


Figure 10. three dimensional model of fracture network and tunnel for steady state simulation.



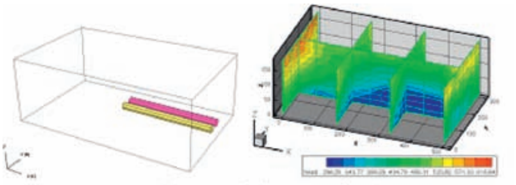
(a) cross section



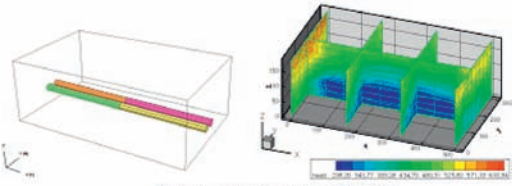
(b) tunnel bottom section

Figure 11. Distribution of water head in steady-state condition before tunnel excavation.

Especially, average transmissivity evaluated from the result of Legeon test and BIPS is 1.24 m^2/sec.



(a) tunnel advance of 250m



(b) tunnel advance of 500m

Figure 12. Distribution of water head in transient-state condition before tunnel excavation.

Figure 11 shows distribution of water head in steady-state condition before tunnel excavation. It was set as the value of initial water head in transient flow condition.

4.3.3 *Transient state condition*

We simulated the groundwater flow due to tunnel excavation in the condition of transient state. As tunnel excavation was performed, groundwater flowed into tunnel and water head fell down suddenly and afterward gradually.

In the case of 500 m tunnel advance, water inflow rate per km into tunnel is 0.10 m^3/min. That was similar to the result of MODFLOW (0.127 m^3/min).

5 CONCLUSIONS

In spite of the difficulty for estimation of water flow characteristics into tunnel before excavation, it is very important to predict the variation of hydraulic system due to the tunnel.

In this study, two representative models are used to forecast the tunnel groundwater outflow pattern such as MODFLOW and MAFIC.

Based on the result of numerical modeling, it can be notified that if waterproof grouting into the ground is performed in advance, the amount of groundwater inflow into the tunnel will decrease compared to non-grouting case.

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