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A Case study on the excessive displacement of rear face under construction road tunnel in Korea

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ABSTRACT : NATM (New Austrian Tunneling Method) has been widely used in Korea for tunnel construction. The main feature of NATM is to utilize all available means to develop the maximum self-supporting capacity of the surrounding rock or soil itself, and to undertake investigation and monitoring during construction to provide the stability of the tunnel. If undetected worse ground condition is encountered, the strengthening works will be carried out to ensure safety. In this case study, the ground at the entrance of tunnel was revealed to be silty sand contained a lot of core stones during portal excavation, not just as the weathered and soft rocks as originally predicted before design. Thus the tunnel face collapsed with water spouting, and the upper ground surface was also sunk at the same time. The remediation measures including ground grouting, tunnel reinforcing and invert lining were then implemented and completed successfully. It could be a useful reference to the design and construction of tunnels with soil entrance.

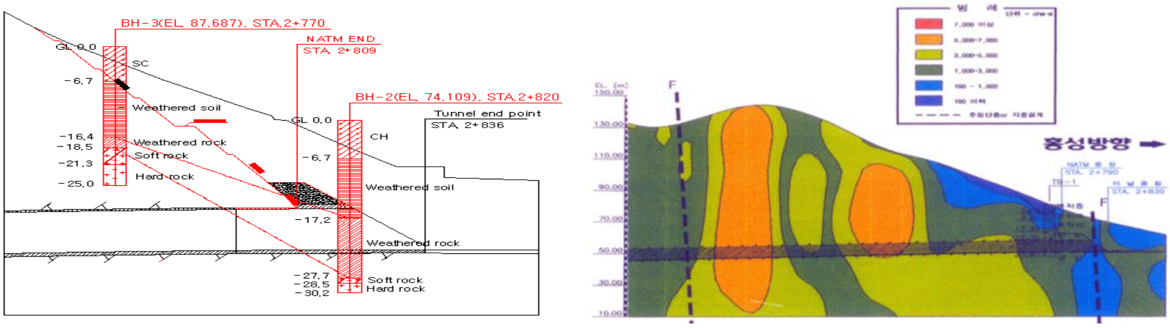
1. INTRODUCTION

NATM has been widely used in Korea for tunnel construction. The main feature of NATM is to utilize all available means to develop the maximum self-supporting capacity of the surrounding rock or soil itself, and to undertake investigation and monitoring during construction to provide the stability of the tunnel. If undetected worse ground condition is encountered, the strengthening works will be carried out to ensure safety. The length of Bong-whang tunnel is 1,178m. Collapse of tunnel face and sinking of upper ground happened at about 19m from tunnel entrance during construction. Additional investigation using boring test and elastic wave exploration was then undertaken before reinforcement. It was found that ground condition was actually worse than expected in design stage. Proposed remediation measures included ground grouting, tunnel reinforcing, and invert constructing. First, the upper ground of tunnel was reinforced by Micro Silica-Cement Grouting Method. Then, the tunnel reinforcement was implemented using Reinforced Grouting Method. Finally, invert was constructed by steel-reinforced concrete lining. These strengthening works completed successfully.

2. ORIGINAL DESIGN INFORMATION

2.1 Geological and ground survey

The strata around the tunnel were formed at Mesozoic Jurassic period. Boring test revealed the strata, from top to bottom, were sandy clay, silty-clay sand, weathered soil, weathered rock, soft rock, and hard rock, respectively. Near tunnel entrance the rock was deep weathered. Soil layer and weathered rock were both quite thick. The elastic resistivity survey showed that soft and hard rocks had a resistivity from 1,000 to 3,000(Ω·m).



(a) Ground profile (b) Result of elastic resistivity survey

Figure 1. Ground profile and elastic resistivity survey

2.2 State at portal of tunnel

The silty sand at the tunnel end contained a lot of core stones. The core stones could be easily disintegrated in dry, and was assumed having some apparent cohesion in moisture state. The arching effect of surrounding ground cannot be mobilized enough in such a tunnel where NATM was employed. Therefore, it is necessary to use reinforcement method during tunnel advancing.

(a) Core stone of slope (b) Cut of portal in slope (c) Ground state (Easily fractured)

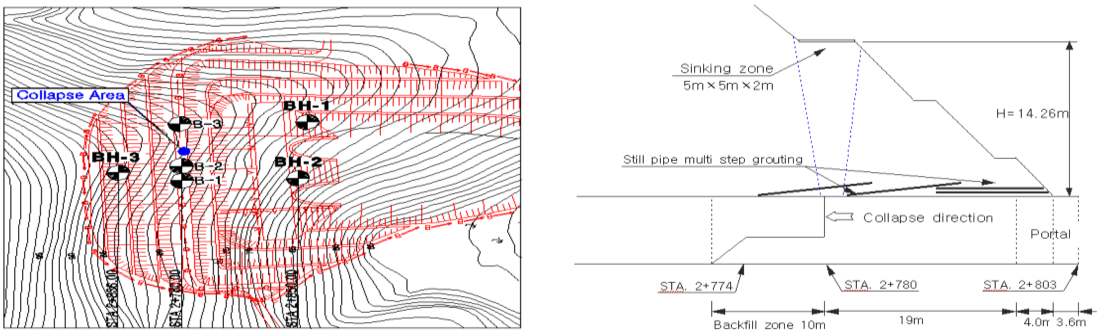
Figure 2. State of portal of tunnel

3. INFORMATION ON COLLAPSES

Tunnel collapse and upper ground sinking happened at the same time in STA.2+780. The wallside at the left crown zone had a deformation of about 80cm. Surrounding ground was prone to the second progressive failure due to stress release. Therefore, 10m backfill was carried out from face, and vinyl was covered to prevent rainfall infiltration into sinking zone.

(a) Upper part of tunnel (b) Front view of tunnel (c) Displacement of tunnel inside

Figure 3. State of collapse zone

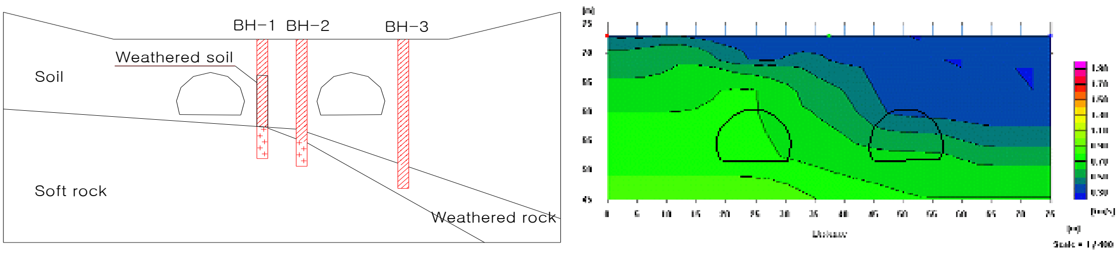


(a) Contour of collapse zone (b) Collapse zone of cross section

Figure 4. Ground profile and tunnel cross section

4. ADDITIONAL GROUND SURVEY OF SINKING ZONE

Additional boring tests for ground profiles of sinking zone were carried out. The zone was confirmed to be composed of decomposed granite soil and weathered rock. Elastic wave exploration was executed and showed that the sinking zone contained unexpected soils.



(a) Ground profile (b) Result of elastic wave exploration

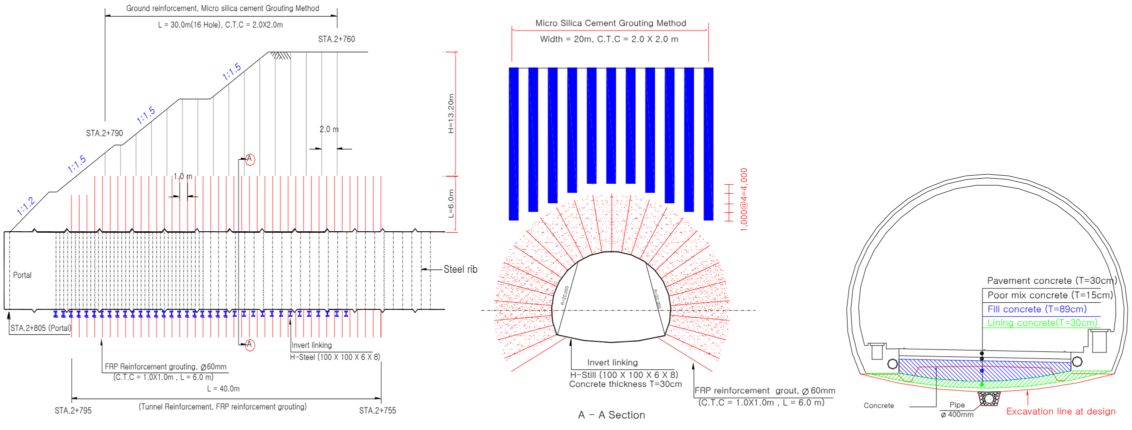
Figure 5. Ground profile and elastic wave exploration

5. REINFORCEMENT MEASURES

The ground strength and impervious properties of rocks in collapse area were expected to be increased at the same time. The ground disturbance also should be minimized during construction. Upper ground was strengthened by Micro Silica-Cement Grouting Method, tunnel reinforcement was undertaken using radiation FRP Reinforced Grouting Method, and invert was constructed using steel-reinforced concrete lining. Reinforcement measures are summarized in table 1.

Table 1. Summary of proposed remediation measures

Order	Item	Reinforced area	method	size
1	Upper ground grouting	Sta. 2+760 – Sta. 2+799	Micro silica-cement grouting method	length 30m, width 20mC.T.C 2.0x2.0m
2	Tunnel reinforcing	Sta. 2+755 – Sta. 2+795	Radial FRP reinforced grouting	length 40m C.T.C 1.0x1.0m
3	Invert reinforcing	Sta. 2+760 – Sta. 2+799	Steel-reinforced concrete lining	length 45m invert spacing 0.5m



(a) Cross section of tunnel reinforcement (b) Invert lining

Figure 6. Reinforcement of collapsed area

6. TESTS ON REINFORCEMENT EFFECT

6.1 Reinforcement effect test of ground

Ground strengthening effect was evaluated by Standard Penetration Test, Field Permeability Test, and Borehole Loading Test. The N-value of the Standard Penetration Test increased 18 – 41, permeability reduced about 100, and the deformation and elastic modulus increased more than 200%.

Table 2. Results of reinforcement test (ground)

	Test item	Depth (m)					
		1.5	3.0	4.5	6.0	7.5	9.0
After	SPT	N = 6/30	-	N =1/30	N = 1/30	N = 11/30	N = 3/30
	FPT	-	-	-	k = 5.2×10^{-3} cm/sec		-
	BLT	-	-	-		*D*=15.98 MPa *E*=21.18 MPa	
Before	SPT	N = 24/30	N = 28/30	N = 27/30	N = 42/30	N = 47/30	-
	FPT	-	-	-	k = 5.5×10^{-5} cm/sec		-
	BLT	-	-	-		*D*=41.29 MPa *E*=48.35 MPa	

Notes : SPT=Standard Penetration Test; FPT=Field Permeability Test; BLT=Borehole Loading Test;
N=N-value(blow/cm) ; *E*=Elastic modulus; *D*=Deformation modulus; *k*=coefficient of permeability

6.2 Reinforcement effect test of tunnel

The reinforcement effect of tunnel by FRP Reinforced Grouting Method was evaluated using borehole loading test. 2 tests were executed after grout curing of 8 days and 44 days, respectively. Results of borehole loading tests were listed in table 3.

Table 3. Results of Borehole loading test (Inside of tunnel)

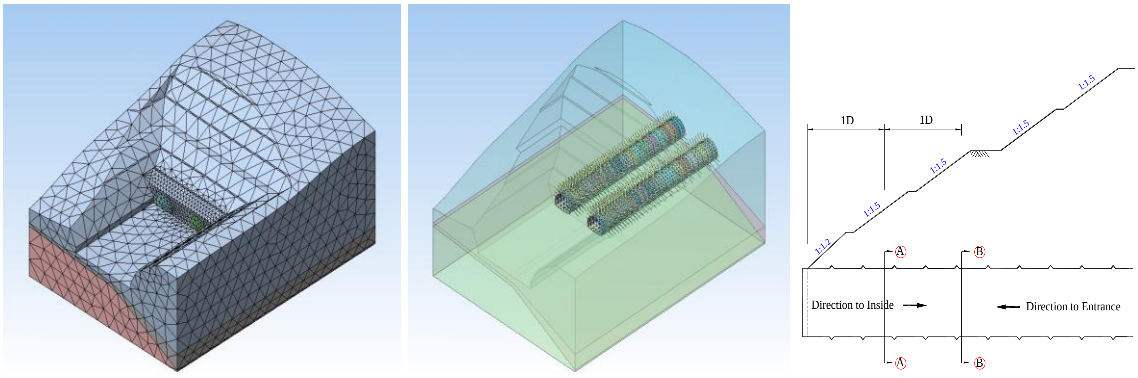
Hole	State	E* (MPa)	Test result		Curing period
			E (MPa)	E/E* (%)	
PB-1	Sta. 2+790.0	294.20	228.49	78 %	8 days (The first test)
PB-2	Sta. 2+785.0	294.20	196.52	67 %	
PB-3	Sta. 2+780.0	294.20	225.75	77 %	
PB-4	Sta. 2+787.5	294.20	299.20	102 %	44 days (The second test)
PB-5	Sta. 2+782.5	294.20	306.06	104 %	

Notes : E* =Standard elastic modulus; E = Elastic modulus by an test;

7. FINITE-ELEMENT ANALYSIS

7.1 Modelling

Stability of tunnel was analyzed using a commercial numerical program (MIDAS GTS Ver.1.10). 4-node tetrahedron element was used for soil and rock, shell element for shotcrete lining, and beam element for FRP reinforcing member. The analyses considered two different driving directions, that is, driving from entrance and toward entrance, as shown in Figure 7(c). Table.4 showed necessary input data for numerical analysis.



(a) Finite element mesh (b) Support modelling (c) Measure Sections

Figure 7. 3-D FEM analysis

Table 4. Material Properties Examined in Finite Element Analyses

Material	c (kPa)	ϕ (°)	γ (kN/m^3)	E (MPa)	υ	K_o
Soil	39.23	20	15.68	29.42	0.35	0.5
Weathered rock	2.45×10^2	35	22.15	4.90×10^2	0.30	0.7
Soft rock	6.86×10^2	40	24.50	2.94×10^3	0.30	1.0
Primary Shotcrete	-	-	23.52	4.90×10^3	0.20	-
Secondary Shotcrete	-	-	23.52	1.47×10^4	0.20	-
Rock Bolt	-	-	76.93	2.06×10^5	0.30	-

Notes: c=Cohesion; ϕ=Internal friction angle; γ=Total unit weight; υ=Poisson's ratio
E=Elastic modulus; K_o=Lateral earth pressure coefficient

7.2 Result of Numerical Analysis

Stability of tunnel was evaluated under 2 driving directions. Analysis results showed that the support effort was much better in the case of entrance driving direction. Typically, Stress relaxation was converged on front of face due to longitudinal arching effect. But, in the case of driving toward entrance, the longitudinal arching effect cannot be formed.

Section	Item	Direction to inside of tunnel		Direction to entrance of tunnel			
		Bench cut	All face cut	Bench cut		All face cut	
A-A'	Crown settlements (cm)	4.35	5.16	5.54	**(27%increase)**	6.37	**(23% increase)**
	Convergence (cm)	2.13	3.71	2.20	**(3% increase)**	3.91	**(5% increase)**
	Bottom displacement (cm)	2.23	2.67	2.45	**(10% increase)**	3.73	**(40% increase)**
	Shotcrete compression Stress (MPa)	7.07	8.61	9.50	**(34% increase)**	9.04	**(5% increase)**
	Rock Bolt axial force (kN/ea)	87.28	120.62	13.29	**(57% increase)**	156.91	**(30% increase)**
B-B'	Crown settlements (cm)	6.55	6.83	7.83	**(20% increase)**	8.39	**(23% increase)**
	Convergence (cm)	2.13	2.83	2.44	**(15% increase)**	2.91	**(3% increase)**
	Bottom displacement (cm)	2.23	3.10	3.60	**(61% increase)**	3.73	**(20% increase)**
	Shotcrete compression Stress (MPa)	9.53	9.56	12.06	**(27% increase)**	10.68	**(12% increase)**
	Rock Bolt axial force (kN/ea)	169.66	192.21	235.36	**(39% increase)**	333.43	**(74% increase)**

8. SUMMARY AND CONCLUSIONS

The actual ground state of Bong-whang tunnel was worse than predicted in design. The remediation measures included ground and tunnel reinforcing by Micro Silica-Cement Grouting Method and FRP Reinforced Grouting Method, respectively, and invert constructing using steel-reinforced concrete lining. The major findings can be summarized as follows:

(1) Upper ground at tunnel entrance contained unexpected soils. Therefore, face collapse and ground sinking near tunnel entrance took place at the same time.
(2) Standard penetration test, field permeability test, and borehole loading test were executed to check the reinforcement effects. The effects of ground strength improvement and permeability decrease could both be confirmed through indicator reaction test.
(3) RPUM method was applied to reinforce the collapsed area. The FRP reinforced grouting method can get the tunnel reinforcing and ground improving effects at the same time.
(4) Numerical analysis results show that it was not desirable driving toward entrance, especially in the case of weakness ground.
(5) FRP reinforced grouting method is proved to be very useful in the case of stress relaxation and fractured zone.

REFERENCES

Korea highway cooperation., 2002 Development of the design methodology of reinforcement grouting using FRP pipe.
Korea Geotechnical Society., 2000 Development of the design methodology of reinforcement grouting using FRP pipe. and Geotechnics, 35(3) : 436-449.