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A study on behavior of 2-arch tunnel by a large model experiment

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ABSTRACT: It is tendency that the parallel tunnels are constructed close to each other in order to diminish civil complaints and environmental damage. The 2-Arch tunnel is similar to two parallel tunnels with very short centre-to-centre distance. Recently, construction of 2-Arch tunnel is increasing. However, it is executing without enough studies for behavior of the 2-Arch tunnel. In this research, a study for behavior of 2-Arch tunnel is examined using large model test machine. At first we make the model ground with horizontal joint-set. Then embody in-situ stress by applying pressure to boundary of model ground. Then excavate model ground according to construction steps of the 2-Arch tunnel. As a result, during excavation of pilot tunnel, measured ground displacements are about 40~50% of whole displacement, which is concentrated in 0.25D (D: diameter of tunnel) region around tunnel. Height of loosen area by construction of the 2-Arch tunnel is 0.15w (w:centre-to-centre distance between left and right tunnel). These results are compared with DEM to conform the reliability of results.

1 INTRODUCTION

The 2-Arch tunnel is similar to two parallel tunnels with very short centre-to-centre distance. The 2-Arch tunnel has been increasing in order to diminish environmental damage and ensures linking with structure close by tunnel. There have been a series of researches on the behavior of 2-Arch tunnel in soil and weathered rock. However, the use of 2-Arch tunnel in korea has been rapidly increasing in hard rock. So, researches of 2-Arch tunnel in hard rock are urgently needed. The stability of center upper part of 2-Arch tunnel is weak comparing with other parallel tunnels; therefore it is necessary to install pillar and secure structural stability. In 2-Arch tunnel, mutual effect of precedence and afterward tunnel is bigger than general parallel tunnel. The stability of pillar and mutual effect are very important in research of the 2-Arch tunnel.

Therefore, this study is conducted to model characteristic of sedimentary rock that similar with ground condition of prototype tunnel. Step in different stage displacement tendency, precedence tunnel stress transition by excavate afterward tunnel, pillar and lining behavior examine by achieving an experiment according to carrying out construction steps of 2-Arch tunnel. With this, compare with numerical analysis (DEM) in same condition and confirm the reliability of results.

2 SUMMARY OF EXPERIMENT

2.1 *The model package*

The dimensions of the model ground were 3 m × 3 m × 0.27 m (B × H × T). The main characteristic of the test machine is application of both the vertical and lateral loading system to embody in-situ stress.

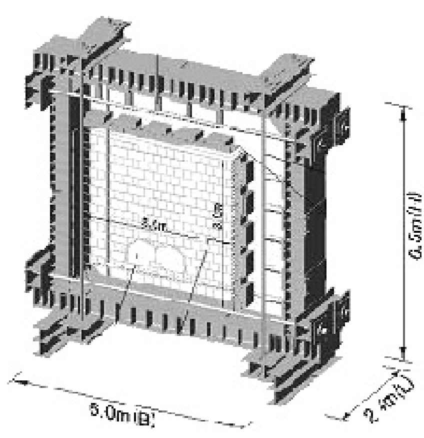


Figure 1. Large model test machine.

Table 1. Property of model ground.

Block					Joint surface	
E (MPa)	ν	γ (KN/m^3)	C (MPa)	φ (°)	C (MPa)	φ (°)
980	0.25	19.8	2.55	35	0	32

The inside of the model container was coated with grease to reduce side friction so that shear stress transfer at the ground and the container interface could be minimized.

2.2 *The model ground*

It has been well known that rock mass is not homogeneous and exists discontinuities. The behaviour of tunnels and surrounding ground are heavily dependent on the characteristic of the rock mass. In this study to model characteristic of sedimentary rock, the model ground was made of a number of concrete bricks. The model ground was classified by Rock Mass Rating (RMR) used in tunnel design in Korea widely. The model ground used in the model tests had slightly rough surface with aperture thickness less than 1 mm. Overall the model ground had total RMR rating of 67 and hence the model ground was classified as class number II, i.e., Good rock.

2.3 *Tunnel cross section and stiffness reduction rate*

There is a problem in problem in passing of equipment and construct of pillar, because center tunnel is small and narrow (Fig. 2). Therefore, an experiment achieved into improved 2-Arch tunnel section that considers equipment exit and entrance center tunnel of approximately enlarge, and improve waterproof sheet establishment location and carrying out order (Fig. 3).

Usually, the property of the material and size are decided by through the suitable stiffness reduction rate when achieve a model experiment. The property of model tunnel was decided by the method of Duddeck and Erdmann (1985) that use stiffness ratio (α) of lining. Actuality stiffness ratio of research object tunnel and model tunnel depended on stiffness of each ground and property of tunnel lining. Those are expressed with below way. The reduction rate applications are same with table 2.

Stiffness ratio of prototype tunnel
: $\alpha = (E_k \cdot R^3)/(E_b \cdot I_b)$
Stiffness ratio of model tunnel
: $\alpha = (E_{km} \cdot R_m^3)/(E_{bm} \cdot I_{bm})$

$E_k(E_{km})$: Modulus of elasticity of ground (MPa)
$R(R_m)$: Diameter of prototype(model) tunnel (cm)

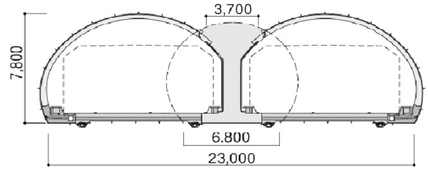


Figure 2. The exist 2-Arch tunnel cross-section.

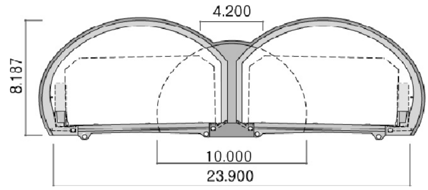


Figure 3. Improved 2-Arch tunnel cross-section.

Table 2. Application of reduction ratio.

Tunnel	E(ground) (MPa)	E(lining) (MPa)	Diameter (m)	Thickness lining (cm)
Prototype tunnel	$9.8*10^3$	$1.96*10^5$	23	40
Model tunnel	$9.8*10^3$	$1.96*10^5$	1.2	0.6

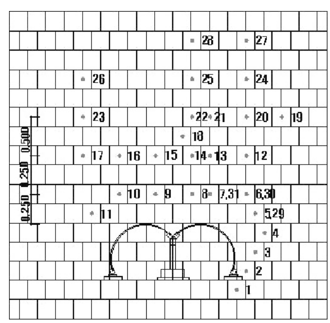
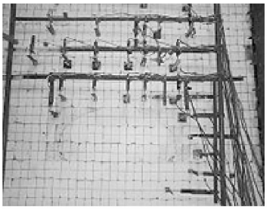


Figure 4. Measure point of ground displacement.

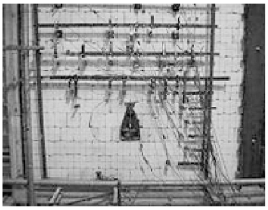
$E_b(E_{bm})$: Modulus of elasticity of lining (MPa)
$I_b(I_{bm})$: Second moment of area lining
$t(t_m)$: Thickness of prototype(model) tunnel lining (cm)

2.4 *Instrumentation*

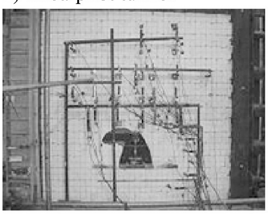
In the model test the behaviour of the tunnel and the ground due to excavation was monitored using LVDT (Linear Variable Displacement Transducer, ground displacements) and load cell (pillar load). The locations of LVDTs are shown in Figure 4.



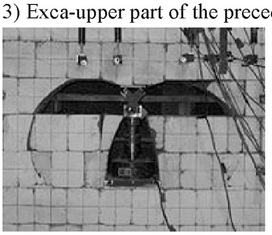
1) Make a ground



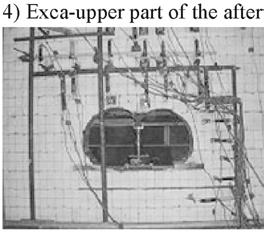
2) Exca-pilot tunnel



3) Exca-upper part of the precedence tunnel.



4) Exca-upper part of the afterward tunnel.



5) Completion of the tunnel excavation.

Figure 5. The test procedures.

2.5 *The center pillar*

In order to measure the rock load acting on the centre pillar, load cell was installed prior to the formation of the model ground. In the real tunnel excavation, the centre pillar is to be installed after completion of the pilot tunnel. However, to measure loosening load during the pilot tunnel excavation the centre pillar was installed prior to the assembly of the model ground. Thereafter the pillar load has been arranged to zero to measure rock load, exclusively associated with the main tunnel excavation.

2.6 *Experiment condition and method*

The model test was conducted under a uniform surface loading of 980 kPa. An achieved experiment considers actual construction step as follows.

1. Made up horizontality being stratiform rock mass by the use concrete block of fixed size.
2. The model test was conducted under a uniform surface loading of 980 kPa with lateral earth pressure of 1470 kPa and hence the earth pressure coefficient was 1.5.
3. Excavation of upper part of the pilot tunnel.
4. Excavation of lower part of the pilot tunnel.
5. Arrangement of load cell reading to zero.
6. Excavation of precedence tunnel.
7. Excavation of afterward tunnel.

3 THE RESULTS OF THE EXPERIMENT

This research is that investigate behavior of 2-Arch tunnel that is conducted through a large model test and DEM analysis from the stratified rock. The main examination contents are same as follows.

1. Displacement tendency at different steps
2. Precedence tunnel stress transition by afterward tunnel excavation
3. Estimate of behavior of center pillar and loosen area rock load.

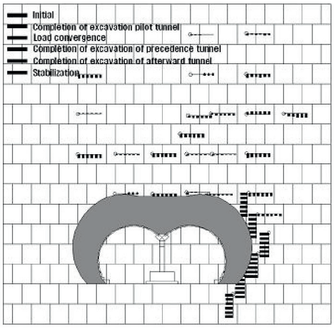
3.1 *Displacement tendency of different steps*

The ground displacement is the main factor for tunnel and adjacent structure's stability judgment by tunnel excavation. The displacements that appear in experiment results are compared with numerical analysis (DEM) in equal condition and analyzed. Boundary condition of this numerical analysis set limits to horizontality displacement in side wall and lower part set limits to perpendicular displacement. Input data of numerical analysis is decided by axial compression test, direct shear test and RMR value of model ground.

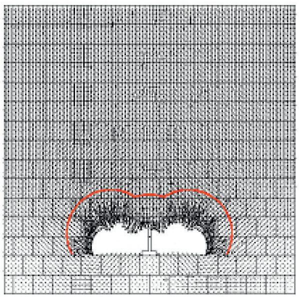
3.1.1 *Displacement concentration region*

In the model test, most of the ground displacement was examined by large model test and numerical analysis occurred within 0.25D. Experiment consequences and numerical analysis consequences of displacement were variance more or less.

This is judged by joint action that is happen vertically joint between block and block that can produce cause and experiment special quality upper that did



(a) Result - model test



(b) Result – UDEC

Figure 6. Displacement concentration region.

not accord with correctly properties value of actuality model ground in numerical analysis.

But, a model experiment and numerical analysis result of displacement concentration extent and tendency are similar, therefore in identical branch result was judged that it is meaning that compare mutual and analyzed displacement to different steps.

3.1.2 *Horizontal displacement of different steps*

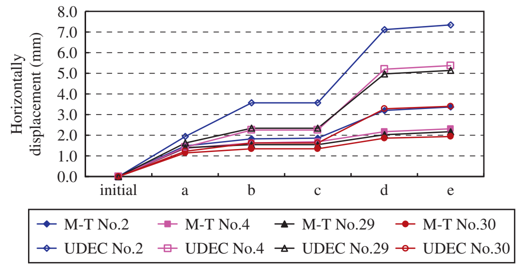
In order to evaluate stability of the side wall, the lateral ground displacements at the right part of the tunnel have been monitored using LVDTs. The direction of displacement is positive to tunnel and displacement of opposite direction is negative.

a. Excavation upper part of the pilot tunnel.
b. Excavation lower part of the pilot tunnel.
c. Installation of pillar.
d. Excavation of the precedence tunnel.
e. Excavation of the afterward tunnel.

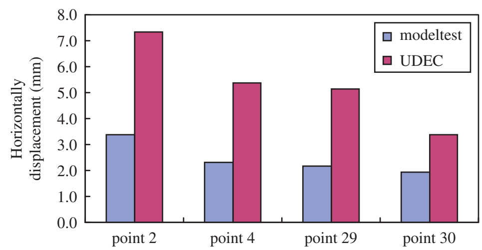
During excavate to pilot tunnel, most of displacement occurred. In general the stress condition of the ground after tunnel excavation may be different from the in-situ condition. In particular, direction and magnitude of the principle stresses will be changed due to stress re-distribution through the arching effect, hence the measured results are indicate that majority of the stress change occurred during stage b after the stress condition may not be changed much. Also, The measured results show that the longer the distance from the tunnel base the smaller the lateral ground displacement.(measure point 2,4's horizontal displacement > measure point 29,30's horizontal displacement). Overall the measurements suggest that the stability of the 2-arch tunnel depends mainly on the excavation of the pilot tunnel. Therefore, the pilot tunnel should be stabilized prior to excavation of the other part of the tunnel. A large model experiment and numerical analysis result is same with table 3.

Table 3. H-displacement of different steps (mm).

Measure point		Horizontal displacement (mm)				
		a	b	c	D	e
Large model test	2	1.49	1.83	1.85	3.21	3.38
	4	1.36	1.62	1.69	2.18	2.31
	29	1.4	1.54	1.55	2.02	2.17
	30	1.14	1.33	1.33	1.87	1.94
UDEC	2	1.943	3.578	3.577	7.127	7.349
	4	1.423	2.254	2.254	5.203	5.382
	29	1.617	2.344	2.344	4.984	5.141
	30	1.231	1.618	1.618	3.280	3.387



(a) H-displacement of different steps



(b) Completion of tunnel excavation

Figure 7. H-displacement.

3.1.3 *Vertical displacement of different steps*

In order to measure vertical ground displacements during the tunnel excavation at different steps, ground

Table 4. V-displacement of different steps (mm) – M.T.

Measure point		a	b	c	d	e
7	0.25D	−1.05	−1.53	−1.55	−1.84	−2.33
13	0.50D	−0.82	−1.21	−1.16	−1.38	−1.89
8	0.25D	−1.24	−1.66	−1.67	−2.01	−2.99
14	0.50D	−0.99	−1.25	−1.35	−1.59	−2.38
9	0.25D	−1.32	−1.72	−1.74	−2.52	−2.74
15	0.50D	−0.99	−1.31	−1.39	−1.94	−2.11
10	0.25D	−1.2	−1.59	−1.59	−1.94	−2.21
16	0.50D	−0.86	−1.24	−1.3	−1.51	−1.81

Table 5. V-displacement of different steps (mm) – UDEC.

Measure point		a	b	c	d	e
7	0.25D	−0.95	−1.44	−1.45	−1.75	−4.39
13	0.50D	−0.95	−1.63	−1.63	−1.95	−4.26
8	0.25D	−1.43	−2.01	−2.01	−2.60	−5.89
14	0.50D	−1.29	−2.05	−2.05	−2.67	−5.41
9	0.25D	−1.8	−2.43	−2.43	−3.99	−6.14
15	0.50D	−1.43	−2.22	−2.22	−3.66	−5.63
10	0.25D	−0.95	−1.44	−1.44	−3.26	−4.09
16	0.50D	−0.97	−1.65	−1.66	−3.09	−4.05

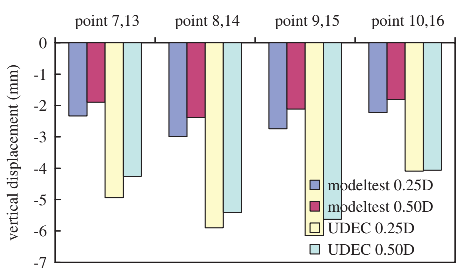
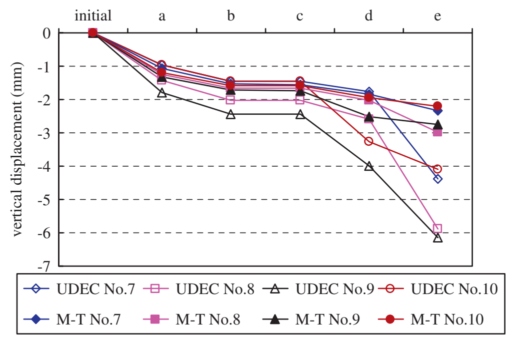


Figure 8. V-displacement (completion of excavation).

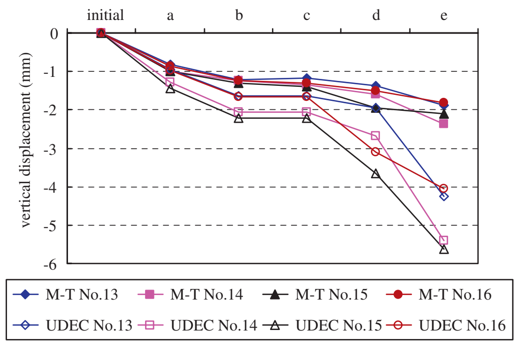
displacements at 0.25D and 0.5D above the tunnel crown have been monitored (0.25D: points 7–10 0.5D: points 13–16), where D is the width of the tunnel (Table 4).

The majority of the displacements occurred at excavation of pilot tunnel after insignificant changes of the ground displacement had developed. The Vertical displacement in 0.25D was observed greatly 120% when compare with displacement in 0.5D and most displacement was concentrated on 0.25D extent.

Horizontal displacements more than 40% of whole displacements and vertical displacements more than 20% are occurred during excavation of pilot tunnel. The displacement of model test is larger than numerical analysis result (Table 5) at pilot tunnel excavation steps. The displacement was concentrated on



(a) 0.25D from upper part of tunnel



(b) 0.5D from upper part of tunnel

Figure 9. V-displacement of different stages.

0.25D extent. Such result means that stability of whole tunnel is dominated by stability of pilot tunnel excavation in 2-Arch tunnel. This suggests that rock bolt length should be longer than 0.25D to prevent the rock loosening.

3.2 *Precedence tunnel stress transition by afterward tunnel excavation*

Precedence tunnel stability by afterward tunnel excavation is main concerns to establishment 2-arch tunnel that parallel tunnel is very near. In the case of precedence tunnel, displacement is converged at completion of excavation and establishment of support. But ground displacement and additional loading to support is increased by excavation of afterward tunnel. Additional load that happen to precedence tunnel at afterward tunnel excavate is 10∼30% of whole load to the tunnel. (Lee and kim – 2001, The consideration of improve 2-Arch tunnel Design and construction method).

At the large model test result, displacement of precedence tunnel is occurred 8∼12% of whole displacement by excavation of afterward tunnel. And 20∼35% of UDEC analysis result increased at the same point. It is considered similar result if take into

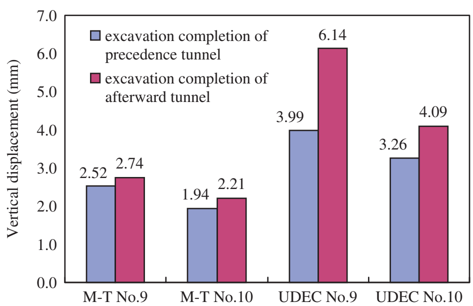


Figure 10. Displacement of precedence tunnel by excavation of afterward tunnel.

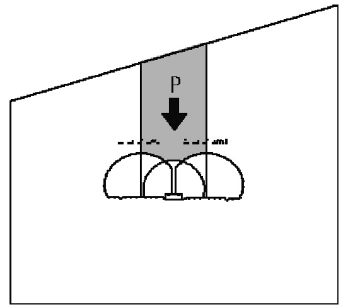


Figure 11. The load acting on pillar of 2-Arch tunnel in soil and weathered rocks (Matsuda, 1998).

account difference in behavior of joint that happen in experiment and joint properties value that apply in analysis. This is similar with suggested result by Lee, kim. This result means that effect to support of precedence tunnel by excavation of afterward tunnel. It can become problem in stability secure of precedence tunnel or support amount excess of afterward tunnel that such conduct has precedence tunnel support and afterward tunnel supports equally. Therefore hereafter designs need to establish suitable support pattern plan in conduct of 2-Arch tunnel.

3.3 *Behavior of the center pillar*

Matsuda (1998) proposed an empirical equation of rock load for a tunnel in soils and weathered rocks by considering soil depth (H) and tunnel centre-to-centre distance (B). However, to date studies of rock load that can be used in preliminary tunnel design for 2-arch tunnel in rock is rather limited. In the current study, an empirical relation for rock load based on the measurement is proposed for the rock when RMR is greater than 60.

- The load width act on pillar is distance apart two tunnel. (W)
- When distance of tunnel to ground surface (H) is longer than tunnel width (D)

  $P = \gamma \times D \times W$

  γ : unit weight of ground
- When distance of tunnel width (D) is longer than tunnel to ground surface (H)

  $P = \gamma \times H \times W$

1. Initial stage
2. Excavation completion of upper part of pilot tunnel.
3. Excavation completion of lower part of pilot tunnel
4. Load convergence
5. Excavation completion of precedence tunnel
6. Excavation completion of afterward tunnel

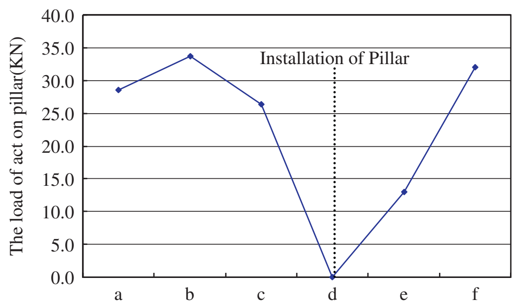


Figure 12. Change of the load acting on pillar at different steps.

Table 6. The load acting on pillar (KN).

a	b	c	d	e	f
28.6	33.0	26.4	0	13.2	31.2

The maximum load acting on pillar of 2-Arch tunnel is 33.0 KN (Table 6). In Figure 12, the load of until converge step that act on pillar of 2-Arch tunnel is supported by rock bolt and shotcrete. The final load of about 31.2 KN is the actual rock load to be supported by the center pillar. In the current study, an empirical relation for rock load based on the measurement is proposed for the rock when RMR is greater than 60. The empirical equation proposed from the current research is $H = 0.15$ W, where W is the centre-to-centre distance between left and right tunnels. Although more study is obviously required, this relation may be used for the preliminary design of the centre pillar for the 2-arch tunnel.

4 CONCLUSIONS

The 2-Arch tunnel is similar to two parallel tunnels with very short centre-to-centre distance. However, it is executing without enough studies for behavior of the 2-Arch tunnel. In this research, a study for behavior of the 2-Arch tunnel is examined using large model test machine. Then embody in-situ stress by applying pressure to boundary of model ground.

1. The ground displacements mainly occurred within 0.25D, where D is the tunnel width. Horizontal displacements more than 40% of whole displacements and vertical displacements more than 20% occurred during excavation of pilot tunnel. Such result means that stability of whole tunnel dominated by stability of pilot tunnel excavation in the 2-Arch tunnel. This suggests that rock bolt length should be longer than 0.25D to prevent the rock loosening.
2. Based on the limited information obtained from the measurement, the rock load acting on the centre pillar may be $H = 0.15\,W$, where W is the centre-to-centre distance between left and right tunnels when RMR is more than 60. However, obviously more research is required to generalize the proposed relation.

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