Construction of twin tunnel in weak and blocky rock mass by using arch supporting method

Un Chol Han¹*, Chung Il Kim² Gun Ui Hong² and Il Yong Kang¹

¹ School of Science and Engineering, Kim Chaek University of Technology, Pyongyang 999093, Democratic People’s Republic of Korea
² Faculty of Mining Engineering, Kim Chaek University of Technology, Pyongyang 999093, Democratic People’s Republic of Korea

* Corresponding Author. Tel.: 0085023811811; Fax: 0085023814410
E-mail address: huch8272@star-co.net.kp ; P.O. Box: 60 Kyogu Pyongyang

Abstract. Design of tunnel excavation and support system in weathered and blocky rock mass is usually a principal challenge in tunneling. In this study, the excavation method of twin tunnel was newly taken into consideration in the condition of weak rock mass, the section size of tunnel was reasonably determined, and new supporting method was established. Firstly, the mechanical characteristics of the project rock mass were determined in each section of tunnel using in-situ point load test (PLT) and RocLab software. Then, design of twin tunnel excavation from mono-tunnel excavation in the weak parts of rock mass was proposed and section of twin tunnel joint was reasonably determined based on the safety and stability of the twin tunnel joint by FLAC3D. Finally, the sequential excavation method of combining top heading and benching with arch supporting method (ASM) was newly proposed and the validity of this method was determined by the numerical simulation modeling. Introducing ASM for the support system ensured the support strength in the excavation tunnel. Advanced excavation scheme and the support system have been successfully applied to ensure the safety and convenience of the target tunnel construction, with about twice reduction of construction time and 1.5 times raising of stability factor. As a result, proposed method in this paper can be used to all manual tunnelling and underground structures in weak and blocky rock mass.

Keywords: Weak and blocky rock mass, Twin tunnel, Point load test (PLT), Finite difference method, Arch supporting method (ASM).

1. Introduction
Design of excavation method and its support system in weathered and incompetent rocks is a primary challenge in tunneling. The ultimate selection of excavation and sequencing schemes for a specific condition should be typically based on complicated interactions occurring between several factors such as safety, cost and schedule considerations [1,2].

Jonchon-Riman road tunnel connects the Jonchon town and Liman village of Zagang Province
DPR of Korea and it has been built since 2011 to improve the traffic situations in mountainous area. Geological features of the specific area are seriously affected by two structures of destroyed orogenic zones. The tunnel was originally designed in arch type with the height of 5.2 m and the width of 10.9 m. A pilot tunnel for tunneling was built 10 years ago, with the width of 2.5 m and the height of 2 m. The main tunneling has been done simultaneously at both sides but it couldn’t progress more from 160 m at Jonchon town side and 180 m at Liman village side due to the several times of caving.

To overcome this difficulty, one can select two methods. First, it is to improve the tunnel design and excavation method and second, it is to improve the supporting system.

In this paper, by using point load test (PLT) and RocLab software, we proposed the tunnel design as the twin tunnel excavation method based on the mechanical characteristics of the target rock mass and set the reasonable section size of twin tunnel and established the supporting system by FLAC3D. Finally, the sequential excavation method of combining top heading and benching with arch supporting method (ASM) was newly proposed and this method was verified by in situ construction.

2. Geotechnical investigation

2.1. Determination of axial strength index by PLT

2.1.1. PLT apparatus. The PLT has often been reported as an indirect measure of the compressive or tensile strength of rock. It has been used widely in practice due to its testing ease, simplicity of specimen preparation, and field applications [3,4].

In this study, we used the point load tester to decide the uniaxial compressive of the rock, because of the weakness of the rock and the lack of instruments. The instruments used for PLT are 5-ton hydraulic press, a tensometer “MODEL SDB-410C”, deformation sensor and slide caliper (Figure 1).

![Figure 1. PLT apparatus](image)

2.1.2. Sampling in pilot tunnel and PLT results. We took total 225 specimens with 10–50 specimens for every blocks where the rock conditions were seriously changed and resized them with respect to the method suggested by International Society of Rock Mechanics and Rock Engineering [4]. PLT results are given in Table 1.

| Chainage, m | Rock type       | No. of specimens | Diameter, mm | Axial strength index, MPa |
|------------|-----------------|------------------|--------------|--------------------------|
|            |                 |                  | Mean         | Min. | Max. | Mean | Min. | Max. | Mean |
| 160-220    | quartz schist   | 22               | 25           | 42   | 32.0 | 5.47 | 14.26 | 8.92 |
| 220-275    | altered rocks   | 16               | 28           | 37   | 32.1 | 0.41 | 1.11  | 0.77 |
| 275-305    | carbonaceous    | 21               | 30           | 40   | 33.3 | 0.51 | 3.43  | 1.80 |
| 305-360    | shale           | 39               | 20           | 40   | 31.6 | 1.87 | 8.51  | 3.48 |
| 360-440    | quartz schist   | 33               | 24           | 45   | 32.2 | 2.40 | 9.28  | 4.34 |

Table 1. Size of nonstandard specimens and PLT results.
440-450 quartz schist (fractured zone) 10 35 37 36.6 1.82 3.68 2.25
450-680 chlorite schist 50 22 41 29.4 5.37 27.1 17.07
680-695 graphite schist (fractured zone) 16 35 38 36.8 1.38 4.11 2.46
695-820 quartz schist 48 25 41 34.3 8.64 26.4 15.5

As you can see in Table 1, the strength of the rock sample is obviously different according to the blocks and it is very low. This shows the basic cause of the carving is that the supporting ability of the rock itself is very low.

2.2. Determination of mechanical characteristics for rock mass by RocLab

We determined the geological strength index (GSI) for target rock mass using the image processing method proposed by Hong et al. [5, 6] and the mechanical characteristics of rock mass by RocLab software presented by Rocscience Inc [7] and it was shown in Table 2.

Table 2. Mechanical characteristics of rock mass in pilot according to chainage.

| Chainage, m | GSI | Uniaxial compressive strength $\sigma_{uc}$, MPa | Tensile strength $\sigma_t$, MPa | Young’s modulus $E_{\text{min}}$, MPa | Cohesion $c_r$, MPa | Internal friction angle $\phi$, ° |
|------------|-----|-----------------|-----------------|-----------------|-----------------|-----------------|
| 160-220    | 16.7| 3.8              | 0.4             | 16361           | 4.77            | 54.94           |
| 220-275    | 18.2| 3.8              | 0.4             | 17930           | 4.99            | 54.88           |
| 275-305    | 20.3| 3.9              | 0.5             | 17945           | 5.1             | 54.91           |
| 305-360    | 22.3| 4.0              | 0.6             | 16938           | 5.04            | 54.83           |
| 360-440    | 20.4| 9.8              | 0.8             | 16868           | 5.12            | 54.96           |
| 440-450    | 13.6| 1.05             | 0.01            | 12979           | 5.3             | 55.11           |
| 450-680    | 39.8| 9.1              | 1.0             | 20950           | 5.09            | 55.04           |
| 680-695    | 14.5| 1.4              | 0.09            | 13986           | 5.25            | 55.10           |
| 695-820    | 35.3| 2.1              | 0.3             | 19023           | 5.26            | 55.12           |

As shown in this table, the mechanical characteristics of the rock mass are very low so its supporting ability is obviously low and it appears that the carving happens very often.

3. Selection of excavating scheme for twin tunnel

3.1. Selection of reasonable section for tunnel

We investigated the stability of the following two cases by using FLAC3D [8]; initial tunnel (the height of 5.2 m and the width of 10.9 m) and twin tunnel with width of 6.1 m and height of 5.2 m as shown in Figure 2. The section size of the twin tunnel is determined with respect to road tunnel design standard in our country and the space between the tunnels are simulated as 5~20 m.

Figure 2. Solid models of twin tunnel; (a) part to be separated from initial tunnel to twin tunnel and (b) twin tunnel

From Table 2, we used the parameters of rock mass for numerical simulation. Besides for the rock
mass, the Poisson's ratio and volume mass are 0.28 and 2900 kg/m$^3$, respectively and for the concrete, 0.17, 2500 kg/m$^3$, respectively. We used the Mohr-Coulomb model as the material model. And the load condition was dead weight and the boundary condition was that the bottom was full restraint and the both sides were normal direction restraint.

From numerical simulation results, for the single tunnel and twin tunnel case, the maximum tensile stress of the rock mass surrounding tunnel and concrete support are 1.566 MPa, 0.69 MPa and the maximum deformation of the tunnel are 8.2 mm and 4.7 mm. At this time when the distance between tunnels is above 15m, the tunnels don’t affect each other. As result, if we deform the tunnel as a twin tunnel, the stability will be increased 2.25 times and the displacement will be decreased to 60%.

3.2. Determination of excavation method

From the 3-D numerical simulation by FLAC3D, under the weak condition of the rock mass, the reasonable excavation method is to combine the method of top heading and benching that precede the high face and ASM providing that the current conduct gallery has been advanced.

ASM is to first excavate the advancing pilot at both sides of the arch and then the rest of the arch to complete the top heading face. And cover the arch part with the unitary armored concrete and excavate the bench face and at the supporting sides there should be column in the zigzag form and between them we form the unitary armored concrete.

In Figure 3, when we excavate the advancing pilot tunnel with excavating cycle of 1.5 m and 3.0 m respectively at both sides of the arch, it was shown the vertical displacement result of the rock mass around the tunnel.

![Figure 3](image)

**Figure 3.** Vertical displacement result after tunneling of upper pilot faces at both sides of the arch; (a) excavating cycle of 1.5 m, (b) excavating cycle of 3.0 m
In FLAC3D simulation, when we excavate the upper pilot of 3 m, the maximum vertical displacement is 100 mm so it is about 1.6 times as that of 1.5 m. Thus, the advancing distance of the upper working place for the target tunnel excavation should not be beyond 3 m and cover with unitary armored concrete after digging not to ruin the arch part. When the arch part is in danger, we should cover the arch lining after putting the temporary timber supports in circulator sector.

As shown in Figure 4, when we set 30 cm of unitary armored concrete after excavation of arch block, the maximum displacement of tunnel lining is below 7 mm so we can fully guarantee the safety of tunnel. So we built the tunnel of the target area according to this approach.

![Figure 4. Vertical displacement result after 3 m tunneling of upper faces](image)

### 3.3. Design and application of support system to ensure the stability of tunnel

#### 3.3.1. Setting of batch armored concrete anchor bolt

We drill every 1.5 × 1.5 m on the tunnel wall with the bit head of 38–42 mm diameter and then put three concrete iron of 16 mm diameter in batch. And we put cement mixture with the ratio of 0.4–0.5 and plaster the wedge with gray loam not to flow out of the hole. At this time the length of the anchor bolt is set to 2–4 m in consideration of depth of sidewall corruption. We installed 5800 batch armored concrete anchor bolt all over the tunnel.

When the tunnel walls have height of 4 m, we set the anchor bolts of 38–42 mm diameter with every 2.5 m interval. At this time the length of the rod is determined by drilling depth more than 50 cm in rock mass through the tunnel lining. Using this method, we have established the 71 anchor bolt to ensure the stability of twin tunnel in dangerous sections.

#### 3.3.2. Construction of arch supporting pillar

Under the weak rock mass conditions, after upper tunnel excavation we design and build the arch supporting pillar.

First, we excavate the middle block of down tunnel and build two columns apart from 3 m with the length of 50 cm and width of 1.5 m in zigzag form on both side walls. Then we excavate the rest part and cover the armored concrete between the arch supporting columns. Using this method, we build the twin tunnel in weak rock mass with safety.

### 4. Discussion

By introducing the twin tunnel excavation method and arch supporting column, the displacement of the weak target rock mass after operation is kept constant. And the actual displacement in the caved part is similar to the expected result through analysis.

When we excavate the heading pilot and the first part, the displacement of the side wall and upper part of the tunnel is increased. This mechanical behavior of the base is expressed as the response to the
tunnel excavation from the view point.

As a result, by introducing twin tunnel excavation approach and arch supporting pillars, this kind of abnormal behavior is related to the cone type collapse on the right side of the view point.

5. Conclusion

In this study, we proposed the excavation method of twin tunnel in the condition of weak rock mass by using arch supporting method (ASM).

While, we determined the mechanical characteristics of the project rock mass in each section of tunnelling using in-situ point load test (PLT) and RocLab software. Also, by using FLAC3D, the reasonable section size and the supporting system for twin tunnel is established.

After all, applying this approach, we can achieve the following economic benefits.

Firstly, we reduce the duration of the project half by the tunneling method under the weak rock mass conditions.

Secondly, we increase the safety of the tunnel 2.25 times.

Therefore, we believed that the proposed method could be successfully applied to construct by hand tunnels and underground cavities in the weak and blocky rock mass.

6. Acknowledgement

This study was financially supported by National High Technical Development Program of DPR of Korea. The authors appreciate the help of many people on this project including the geotechnical staff.

References

[1] Sharifzadeh M, Daraei R and Broojerdi MS, 2012 Design of sequential excavation tunneling in weak rocks through findings obtained from displacements based back analysis. Tunn Undergr Space Technol. 28: 10-17.
[2] Lia Zhao, Luoa Zujiang, Xua Chenghua, Tanb Jinzhong, 2019 3D fluid-solid full coupling numerical simulation of soil deformation induced by shield tunnelling. Tunn. Undergr. Space Technol. 90: 174-182.
[3] Paraskevopoulou C and Diederichs M 2018 Analysis of time-dependent deformation in tunnels using the Convergence-Confinement Method. Tunn. Undergr. Space Technol. 71, 62–80.
[4] ISRM Suggested Methods 1985 Suggested method for determining point-load strength. Int J Rock Mech Min Sci 22: 53–60.
[5] Hong KU, Han EC and Kang KS 2017 Determination of geological strength index of jointed rockmass based on image processing. Journal of Rock Mechanics and Geotechnical Engineering, 9: 702-708. DOI: 10.1016/j.jrmge.2017.05.001.
[6] Kang KS, Hu NL, Sin CS, Rim SH, Han EC and Kim CN 2017 Determination of the mechanical parameters of rock mass based on a GSI system and displacement back analysis. Journal of Geophysics and Engineering, 14: 939-948. DOI: 10.1088/1742-2140/aa6e78.
[7] Rocscience Inc., 2010 RocLab user’s manual, Toronto.
[8] Itasca 2011 FLAC3D user’s manual (Version 3.0) [M]. Minneapolis, USA: Itasca Consulting Group, Inc.