Determination of the Construction Method for the Young Dong Tunnel by Risk Assessment

위험도 분석기법에 의한 영동선 터널의 굴착공법 결정사례

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Keywords : *Young Dong Tunnel, Risk assessment, Drill and blast, Mechanical excavation, Shielded TBM*

Abstract

The construction method for the Young Dong Tunnel has been chosen following detailed risk assessment. In this paper, the specific risks to the project programme, associated with adopting either mechanical excavation in the form of a shielded TBM, or drill and blast excavation methods, are assessed. From the risk assessment results, and taking other important factors into account, such as project sensitivity and local experience, the recommendation is made that the relatively low risk drill-and-blast method is the most appropriate for construction of the Young Dong tunnel

주요어 : *영동터널. 위험도 분석, 천공 및 발파, 기계화굴착, 실드 TBM*

요 약

영동터널의 굴착골법은 다음과 같은 세밀한 위험도 분석기법을 통하여 결정되었다. 본 논문에서는 실드 TBM 과 같은 형태의 기계화 굴착공법과 천공 및 발파에 의한 굴착공법에 따른 공사중 특정의 위험도를 분석 하였다. 공사 민감도 및 현장 경험등의 가타 중요 인자를 고려한 위험도 분석결과에 따라 본 현장여건을 고려하면 천공 및 발파공법이 영동선 터널의 굴착공법으로 가장 적합하다고 제안 되었다.

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1. Introduction

The major part of the Young Dong Railroad Relocation Project proposed by Korean National Railways (KNR) consists of the construction of a tunnel in rock approximately 16.3

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km long with a span of approximately 8 m, it will be the longest tunnel in Korea (Fig.1). The tunnel is designed to carry a single-track railway in a large radius loop below mountainous terrain in eastern Korea. The maximum depth of the tunnel is approximately 400 m with most of the alignment being at depths in excess of 100 m

Fig. 1 Young Dong Railroad Relocation Project

2. Geology of the site

The proposed tunnel alignment passes through geological formations ranging from Cambrian to Triassic in age. Expected lithologies intercepted by the alignment include conglomerates, quartzite, sandstones, shales, limestone and coal measures. Cretaceous volcanics also outcrop in the area but these are expected to be well above the proposed invert level. (Fig. 2)

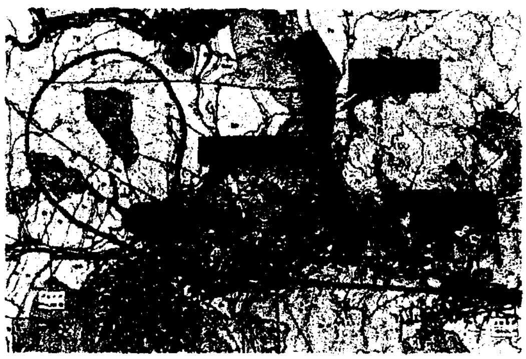

Fig. 2 Geology of the Site

The key geological factors recognized for assessing appropriate construction methods for the tunnel are as follows

● potentially high water pressures, up to 40 bars (40 kgf/cm2) pressure

● fault zones, possibly associated with significant groundwater inflows
● highly sheared and closely jointed rocks
● some rocks with high strength and abrasively
● possible karstified (cavernous) limestone with groundwater
● coal measures rocks and old mine workings

3. Risk Assessment Method

A risk assessment method has been developed to make a quantitative and objective assessment of the construction methods of Young Dong Tunnel. The risks associated with tunnel excavation are dependent on the hazards encountered and are defined with respect to programme (rather than other issues such as safety or cost).

The likelihood of a hazard occurring is assumed to be at one of three levels, thus:1. Proba ble, 2.Occasional, 3. Remote
In turn, the degree of consequence of each hazard is assumed to be at one of five levels, namely : 1. Catastrophic, 2. Critical, 3. Serious, 4. Marginal, 5. Negligible
The description and scale of the above levels of likelihood and consequence are given in Table 1 below.

Table 1 Definition of Risk to Programme

LIKELIHOOD			CONSEQUENCE		
TITLE	DESCRIPTION	SCALE	TITLE	DESCRIPTION	SCALE
Probable	Likely to occur during the construction of the tunnel, possibly on more than on occasion	3	Catastrophic	Total loss of a Section of tunnel	5
			Critical	Major damage or delay to tunnel or majorenvironmental impact affecting programme	4
Occasional	Likely to occur at least once during construction of the tunnel	2	Serious	Some damage or delay to tunnel or some environmental impact affecting programme	3
Remote	Unlikely to occur during construction of the tunnel	1	Marginal	A routine maintenance repair to tunnel or minor hindrance	2
			Negligible	Of little consequence to programme	1

The level of risk for each hazard can be determined by finding its likelihood of occurrence and considering its consequence. The level of risk associated with the hazard is then established conventionally as follows:

Level of Risk = Likelihood x Consequence

Once the level of risk has been ascertained, it can be compared with Table 2 below to identify the action that should be taken to mitigate the risk.

Table 2 Risk Classification

Likelihood \ Consequence	Catastrophic	Critical	Serious	Marginal	Negligible
Probable	15	12	9	6	3
Occasional	10	8	6	4	2
Remote	5	4	3	2	1
Score					
10-15	Very High Risk-not acceptable for tunnel construction need to apply mitigation measures to eliminate or reduce risk				
6-9	High Risk-apply mitigation measures to eliminate or reduce risk. Residual risk at this level indicates need for active management control and response plans to be well developed with well trained personnel, materials and plant readily available				
1-5	Low Risk-may be accepted if mitigating measures are in place under active management control				

Having made an assessment of the risk associated with each hazard, appropriate mitigation measures are considered. The residual risk remaining after mitigation is then assessed in the same way to determine acceptability or otherwise.

4. Risk Assessment

The assessment of risks associated with the use of a shielded TBM to excavate a hard rock tunnel is presented in Table 3, and that for drill and blast excavation is presented in Table 4.

Table 3 Programme Assessment for Excavation by Shielded TBM with Segmental Lining

(L : Likelihood, C : Consequence, R : Risk)

No	HAZARD	RISK	RISK LEVEL			MITIGATION MEASURES	RESIDUAL RISK LEVEL		
			L	C	R		L	C	R
1	Highly jointed rock mass	Raveling grand, roof falls	3	4	12	1. Shielded TBM 2. Probing and preinjection grouting	2	2	4
2	Fault zones	Soft ground with potential roof falls	3	4	12	1. Drag bits on cutter head 2. Shielded TBM	3	3	9
3	Sequeezing ground	Ground "comes on" to the TBM	3	4	12	1. Provision of enlarging cutters 2. Provision of adequate thrust	3	3	9
4	Cavities in the rock	Instability of tunnel face, roof falls	3	4	12	1. Provision of TSP 2. Provision for probe drilling	2	3	6
5	High strength rock	High UCS for rock mass	3	3	9	1. Shallow cutting head 2. Double shield TBM with grippers	3	2	6
6	Abrasive rocks	Iincreased rate of disk cutter wear.	3	3	9	1. Shallow cutting head 2. Back-loaded disk cutters	3	2	6

No	HAZARD	RISK	RISK LEVEL			MITIGATION MEASURES	RESIDUAL RISK LEVEL		
			L	C	R		L	C	R
7	Variable quality rock mass	Mixed face conditions causing mucking difficulties.	3	4	12	1. Provision of drag bits to excavate "soft" ground 2. Shielded TBM with grippers	3	3	9
8	Mechanical failure	Failure of mechanical component .	3	4	12	1. Shallow cutting head 2. Provision of variable speed drive 3. *Reversable cutting head*	2	3	6
9	Water ingress, possibly	Water in cavaties, entering face during excavation	3	4	12	1. Bolted segmental lining provided with compression gaskets 2. Probing and preinjection grouting	2	3	6
10	Fire in TBM	Fire in TBM	1	5	5	1. Fire suppression system 2. Non-flammable hydraulic oils and lubricants	1	4	4
11	Segmental lining erection	Risks of segments drop	3	5	15	1. Fail-safe segment erector 2. Safe segment handing system	1	5	5
12	Tunnel ventilation	Possible *occurrence of* explosive gases	3	5	15	1. Fresh air to the TBM and face 2. Atmospheric monitoring system.	1	4	4
13	*Broken drill*	*Cutterhead damage.*	2	4	8	1. Provide retrieval equipment.	1	4	4

Table 4 Programme Risk Assessment for Excavation by Drill and Blast

(L : Likelihood, C : Consequence, R : Risk)

No	HAZARD	RISK	RISK LEVEL			MITIGATION MEASURES	RESIDUAL RISK LEVEL		
			L	C	R		L	C	R
1	Highly jointed rock mass	Ravelling ground, roof falls andsidewall and/or face instability	3	4	12	1. Reduce length of excavation advance 2. Reduce powder factor to lessen blast damage	2	2	4
2	Fault zones	*Soft ground or mixed face* conditions	3	4	12	1. Increase rock support 2. Probe drilling ahead of the excavation face	3	2	6
3	Water ingress,	Water in cavities entering excavation	3	4	12	1. Pre-injection grouting 2. Provision of pumps to cope with high flows	2	2	4
4	Cavities in the rock mass	Instability of tunnel face, roof fall and side wall instability.	3	4	12	1. Provision of TSP to identify cavities in advance of excavation 2. Provision of probe drilling	2	3	6
5	Tunnel Ventilation	Explosion risk.	3	5	15	1. Provision of adequate fresh air 2. Atmospheric monitoring system.	1	4	4
6	Mechanical breakdown	Failure of key item of plant	3	3	9	1. Planned maintenance strategy 2. Maintain spare plant items.	3	1	3
7	Use of Explosives	Premature detonation	2	5	10	1,. Use non-electric detonators 2. Comply with safety regulation	1	5	5

5. Results and Discussion

It can be seen from an initial inspection of Tables 3 and 4 that the number of hazards associated with a shielded TBM at Young Dong would be much greater than for the drill and blast method. The principal reasons for this include the :

- the sophistication of modern TBMs which require a high level of technological input for their successful operation and maintenance
- the relative inflexibility of mechanised excavation and lining systems to deal with conditions for which they may not have been specifically designed
- the dependence of the tunnel progress entirely on the performance and reliability of a single item of mechanical plant.

Table 3 identifies a total of 13 significant hazards connected with the TBM method. The risk calssifications can be summarised as follows:

	Number of Hazards	
	Before Mitigation	After Mitigation
Very high risk	9	0
High risk	3	8 (Average score 6.9)
Low risk	1	5

Thus, although it can be seen that the areas of very high risk can be successfully eliminated, the majority of the residual risks are classified as high, with an average score of 6.9 (in a high risk range of 6 9, see Table 2).

Table 4 identifies a total of 7 significant hazards connected with the drill and blast method. The risk classifications in this case can be summarised as follows:

	Number of Hazards	
	Before Mitigation	After Mitigation
Very high risk	7	0
High risk	0	2 (Average score 6.0)
Low risk	0	5

Again it can be seen that all areas of very high risk can be successfully eliminated, but in this case slightly more than 70% of the residual risks are classified as "low. The residual risks in the high risk category have an average score of 6.0 (in a high risk range of 6 9, see Table 2).

The average level of risk of all hazards after mitigation in each case can be summarised thus:

- TBM method
  - 13 No. hazards in total
  - average risk classification after mitigation 6.00 (marginally high)
- Drill and blast method
  - 7 No. hazards in total
  - average risk classification after mitigation 4.60 (low)

It is recognised that the above assessment of programme risk is largely qualitative and to a certain extent subjective. Also, the differences in the numerical scores are not large, although this is partly due to the simple scoring system adopted. However, a general trend is apparent which indicates that

- there are likely to be for more significant risks which may impact on programme associated with the use of a TBM than with the drill and blast method a total of 13 No. for TBM compared with 7 No. for drill and blast
- the level of residual risk after mitigation is likely to be generally higher with a TBM than with drill and blast.

6. Conclusion

1. A risk assessment method has been developed and applied to make a quantitative and objective assessment of the construction methods of Young Dong Tunnel.
2. The risk assessment results show that the drill - and - blast method would be a relatively low risk approach, whereas a shielded TBM would provide a generally higher risk approach in Young Dong area with the hazards of coal measures rock, old mine workings, and fault zones.

7. References

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