Economical aessesment of long tunnel route in complex geological formations

복잡한 지질구조암반층에서의 장대터널노선 선정을 위한 경제성 평가에 대한 연구

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Abstract

A new railway line of about 17km length was planned between Dongbaeksan and the neighboring town Dokye to improve the existing decrepit railway system. New line about 17km of the distance will almost be in circular alignment tunnels owing to the difference of elevation about 380m. Since the geology of the area is rather unusual compared to the normal in South Korea, extensive geological investigations have been carried out to prepare geological maps and profiles along the planned tunnel routes. The tunnel will almost be in sedimentary rock formations, such as limestone, sandstone, shale, coal etc and be near abandoned mines. Various rock formations have the complicated, altered those rocks, but are well developed with laminated formations. Each rock formations have been classified using the Q-system and the cost of tunnel excavation, support has been estimated and compared for three alternative routes in the design stage. Based on these estimates, the final route of the railway line was chosen.

Keywords: Long tunnel design, complex geological formations, Q-system, cost rate

요 지

강원도 동백산과 도계구간의 기존 노후 된 철도를 개량하기 위하여 새로운 장대터널을 계획하였다. 신설되는 터널은 두 지역의 표고차가 380m로 고저차가 심해 철도운영시설기준을 만족시키기 위하여 17km연장의 장대원형터널노선으로 계획하였다. 본 지역은 국내의 일반적인 지역에 비해 지질구조가 매우 복잡하기 때문에 계획한 터널노선의 지질 및 지층 상태를 규명하기 위하여 보다 정밀하고 광범위한 지질 및 지반조사를 실시하였다. 또한 계획된 터널은 석회암, 사암, 혈암 및 석탄층 등의 퇴적암층을 통과하며 근접하여 폐갱들이 존재하였다. 이들 암반층은 매우 다양한 형태의 서로 다른 암 종류로 혼재 되어 있어서 각 노선별 통과 암반층에 대하여 Q값에 의한 지반분류를 실시하고 터널의 굴착, 지보 등에 대한 시공성 및 경제성등을 3개의 제안노선들에 대하여 제안한 평가 기법에 따라 평가를 실시하였다. 결과적으로 노선별 경제성 분석 결과에 따라 최적의 노선을 최종 선정하여 현재 시공 중에 있다.

주요어: 장대터널설계, 복잡한 지질구조 암반층, Q값, 시공비비율

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1. Introduction

A new railway line of about 17 km length named as "Solan Tunnel" was planned between Dongbaeksan and the neighboring town Dokye to improve the existing decrepit railway system in the Youngdong Railway located at Taeback City, Kangwon-Do in South Korea as shown in Figure 1. New line about 17km of the distance will almost be in circular alignment tunnels owing to the difference of elevation about 380 m. New tunnel was designed to increase the transportation capacity of the existing railway to 35 trains per day by changing the old switch-back system in the existing railway. (Tunnelling korea, 2003)

Since the geology of the area is rather unusual compared to the normal in South Korea and the tunnel was located in a complex geological region with faults, cavities and coal mines, extensive geological investigations have been carried out to prepare geological maps and profiles along the planned tunnel routes.

The tunnel will almost be in sedimentary rock formations, such as limestone, sandstone, shale, coal etc and be near abandoned mines. Various rock formations have the complicated, altered those rocks, but are well developed with laminated formations. In the design stage, each rock formations have been classified using the Q-system and the cost of tunnel excavations, support has been estimated and compared for three alternative lines. Based on these estimates, the final route of the railway line was chosen.

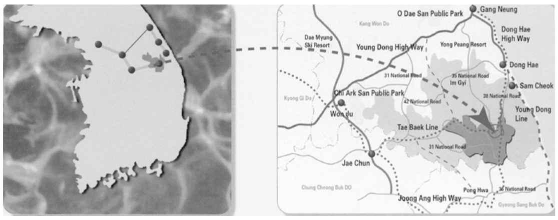


Fig. 1 Location

2. Regional geologcal formations

All proposed tunnel alignments pass through geological formations ranging from Cambrian to Triassic Age as illustrated in an outline geological map by Korean Institute of Geology and Mining (KIGAM) and shown in Figure 2. One of the proposed tunnel alignments chosen as the construction plan in this project also presents in this figure. The historical description for rock formation developed in the project area is given in Table 1.

As described above, Cretaceous rocks also outcrop in the area and some quaternary alluvial deposits are present. Lithologies are mostly sedimentary, consisting of conglomerates, sandstones, shales, limestones and coal measures. There are outcropped Cretaceous volcanics but are believed to be well above proposed invert level. The areas of concern are potentially formed of cavernous limestone in the Cambro-Ordovician Great Limestone Group, mining in the Carboniferous Gamcheon formation and Permian Jangseoug formation.

Figure 3 shows the composition rate of rock types for each geological formation encountered in the project area.

The proposed tunnel lines have quite complex geological conditions developed from Cambrian to Triassic Age and there are several major uncon-

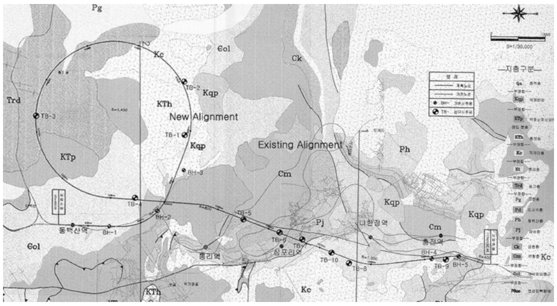


Fig. 2 Geological map in the project area

Table 1. Historical description for rock formation in the project area

Geologic Time		Super Group	Formation	Symbol	Rock Descriptions
Era	Period				
Cenozoic	Quaternary		Alluvium	Qa	Sand and gravel
Mesozoic	Cretaceous	Kyonsang	Quartz porphyry	Kqp	Quartz porphyry (fine muscovite granite)
			Paebungsan Volcanic rock	KTP	Basalt, andesite rhyolite, extrusive rock and tuff
			Heungjun	KTh	Tufficeous classic rock, tuff
			Jukgakri	Kc	Conglomeratic lower sandstone, mudstone, conglomerate alternation of beds
			T'ongi	Kt	Coarse sandstone, tuff (thickmess = 2 m)
	Triassic	P'yongan	Tonggo	TRd	Green and red sandstone plus siltstone
Paleozoic	Permian		Kohan	Pg	Gray~light Medium Sandstone, dark gray~greenish gray sandstone and siltstone
			Tosagok	Pd	Red and green coarse sandstone or pebbly sandstone
			Hambaeksan	Ph	Alternation of white coarse grained sandstone (quartzite at glance), gray shale
			Changsong	Pj	Alternation of sandstone and shale, shale has intercalations of two to three coal beds, among which one bed is workable quality and thickness
	Carbonifer-ous		Kumchon	Ck	Alternation of dark gray sandstone, dark gray shale, gray limestone (lentricular shaped coal beds)
			Manhang	Cm	Red or greenish gray shale and sand stone, mottled coarse sandstone, fine-pebble conglomerate with intercalations of white or light colored limestone
	Cambrian-Ordovician	Choson	Great Limestone.	∈ol	Limestone, quartzite or thinned Shale (Makdong limestone)

Legend: ········ Unconformity ═══ Intrusion or Extrusion

formities. Major strike-slip, thrust and other fault are also developed in the region as shown in Figure 4.

3. Engineering geological analysis

As mentioned above the geological history in this

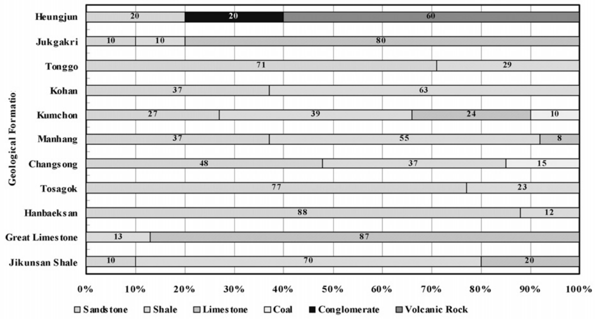


Fig. 3 Composition rate of rock types for geological formations

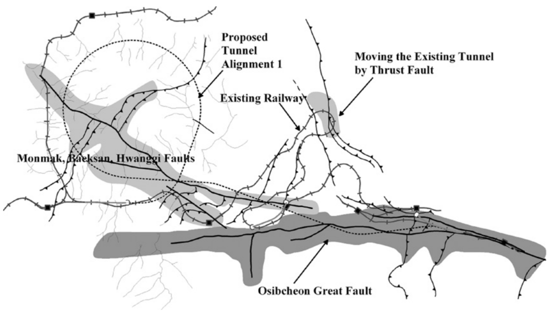


Fig. 4 Discontinuities in the project area

area is complicated. Another complication is that the rock exposures found at the surface along the tunnel line often not be of the same rocks as those at the tunnel level. These conditions have warranted a special mapping technique. The technique has been to describe the exposures where available and in this way arrive at a statistical evaluation of the different rock formations which are likely to be met in the tunnels. The different rock formations have been characterized according to the Q-system of rock mass classification. Based on an evaluation of the data obtained from field mapping, cores logging and experience from existing field information, the different rock formations encountered in the project area were estimated according to the percentages in different Q-intervals as shown in Figure 5.

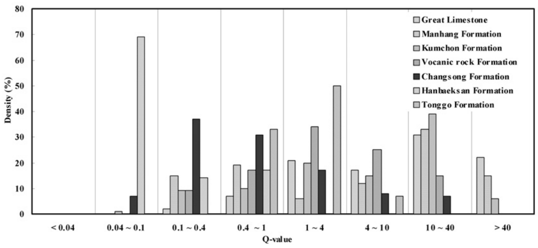


Fig. 5 Q-value distribution of the different geological rock formations.

4. Estimation of construction cost rate

Based on the support recommendation in the Q-system (Rost, 199) the cost rate per meter for tunnel support was calculated for the different Q-intervals (see Table2). With the help of Figure 5 and the available geological sections the tunnel length in each of the Q-intervals can be estimated. The cost rate for tunnel support can then be calculated for the three alternatives. The meter cost rate for water tightening is also calculated based on the distance in each tightening category and Than the costs are determined. The base of cost evaluation for the excavation is the price per meter for drill and blast and transport of musk out of the tunnel. For distances with low Q-values, extra costs for spiling volts and reduced length of the blast rounds are added. In the way the cost rate for excavation and support and water tightening can be compared for the different alternatives. The cost rate is defined as the ratio of construction cost for the given Q-intervals relative to that for Q-interval of 1 to 4. At this stage of planning the intention is that the costs should be given with an accuracy of ±20%.

Table 2. Calculation of support quality and construction cost rate for a tunnel with 12m span width (The cost rates are given per meter of tunnel in different Q-intervals)

Q-value	Concrete Lining	Reinforced ribs of shotcrete	Fibre reinforced	Shotcrete	Bolts	Spiling bolts	Cost Rate/m(CR/m)
<0.01	20 m^3		4.0 m^3			14.0	6.624
0.01-0.04		0.5 number	11.0 m^3		24	13.0	6.402
0.04-0.1			8.0 m^3		17	8.4	4.261
0.1-0.4			5.6 m^3		13	6.3	3.137
0.4-1.0			3.3 m^3		9		1.500
1.0-4.0			2.2 m^3		6		1.000
4.0-10.0			1.4 m^3		5		0.706
10.0-40.0				1.4 m^3	3		0.517
>40.0					2		0.118

Note: Costs should be given with an accuracy of ±20% at the stage of planning

Table 3 gives the unit construction cost rate for the different rock formations. The unit construction cost rates are estimated using the results of composition rate of rock type for geological formations (see Figure 3), Q-value distribution of the different geological rock formations (see Figure 5) and unit cost rate given in Table 2.

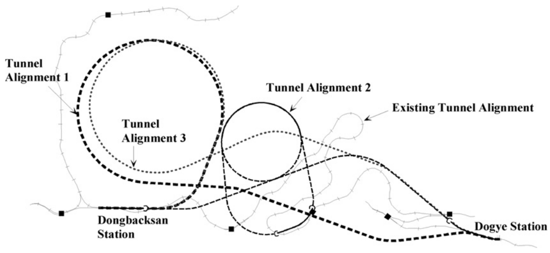


Fig. 6 Three proposed tunnel alignments

5. The proposed tunnel alignment alternatives

Based on the geological conditions in the project area, three alternative tunnel alignments are proposed as possible railway route in the project area (see Figure 6). Details of these alignments are described as follows.

The tunnel alignment 1 was laid out with a single tunnel, total length of 15.76 km. The tunnel makes on big loop and crosses the valley to reach Dokye. The crossing of the valley places the tunnel in a region where coal measures have been worked and will be worked.

Access to the tunnel will be through three ventilation shafts and two portals. A 1-km-long adit will be needed to gain an additional working at the Dokye end because of the very poor ground and likelihood of missing the project completion in the prescribed duration without additional access. A 1-km adit in PD-3 material has been added. The alignment will cross 13 fault zones, 1.8km of coal measures, and includes 1.9km of limestone. Figure 7 shows the geological profile to be passed through this alterative tunnel alignment.

According to the geological profile given in Figure 7, the statistical distribution of geological rock formations for the tunnel alignment 1 is given in Table 4. The unit construction cost rate analyzed by statistical technique is also given in the table.

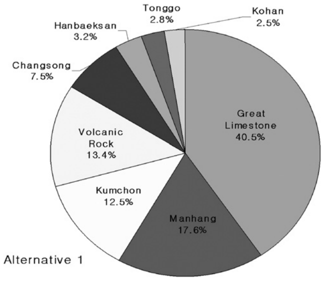
The tunnel alignment 2 is similar to the tunnel alignment 1 and is referred to as Alternative 2. Alternative 2 is laid out with a single tunnel, total

Table 3. Unit construction cost rate for the different rock formations

Cost Rate/m for Q-intervals	6.402	4.261	3.137	1.500	1.000	0.706	0.517	0.118	Unit Cost Rate/m for Rock Formations
Q-intervals	〈 0.04	0.04~0.1	0.1~0.4	0.4~1	1~4	1~10	10~40	40 〈	
Great Limestone			2 %	7 %	21 %	17 %	31 %	22 %	0.684
Manhang			15 %	19 %	6 %	12 %	33 %	15 %	1.089
Kumchon		1 %	9 %	10 %	20 %	15 %	39 %	6 %	0.990
Volcanic Rock			9 %	17 %	34 %	25 %	15 %		1.131
Changsong			7 %	37 %	31 %	17 %	8 %		1.246
Hanbaeksan			69 %	14 %	17 %				2.544
Tonggo				33 %	50 %	17 %			1.115
Kohan		1 %	3 %	4 %	92 %				1.117

Fig. 7 Geological profile for tunnel alignment 1

Table 4. The statistical distribution of rock formations and unit construction cost rate (Alternative 1)

Rock Formations (RF)	Construction Cost Rate/m for RF	Statistical Distribution of RF (%)	Calculated Cost Rate for Alignment	Statistical distribution of rock formations
Great Limestone	0.684	40.5	0.277	
Manhang	1.089	17.6	0.192	
Kumchon	0.990	12.5	0.124	
Volcanic Rock	1.131	13.4	0.152	
Changsong	1.246	7.5	0.093	
Hanbaeksan	2.544	3.2	0.081	
Tonggo	1.115	2.8	0.031	
Kohan	1.117	2.5	0.028	
Evaluation Value for Alternative 1			0.978	

length of 14.59km. The tunnel makes a single loop, slightly smaller than the basic design loop. The Dokye end of the tunnel remains in the west wall of the valley. By do so, same of the main tunnel will avoid the coal measures area and the poor ground conditions. Figure 8 shows the geological profile to be passed through this alterative tunnel alignment.

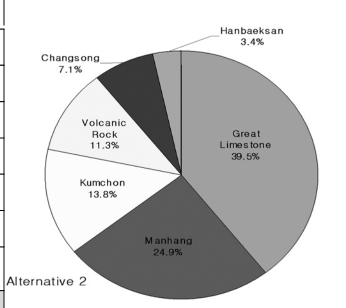
Access to the tunnel will be through three ventilation shafts and two portals. A 1-km-long adit may be needed at the Dokye end because of the very poor ground and likelihood of missing the project completion in the prescribed duration. The alignment will cross 11 fault zones, 0.9km of coal measures, and includes 1.9km of limestone.

According to the geological profile given in Figure 8, the statistical distribution of geological rock formations for the tunnel alignment 2 is given in Table 5. The unit construction cost rate analyzed by statistical technique is also given in the table.

The tunnel alignment 3 is referred to as Alternative 3. Alternative 3 uses the loop concept to pick up the difference in elevation between the two ends. Alternative 3 is laid out with two tunnels, not one - an Upper Tunnel and a Lower Tunnel. The alter-

Fig. 8 Geological profile for tunnel alignment 2

Table 5. The statistical distribution of rock formations and unit construction cost rate (Alternative 2)

Rock Formations (RF)	Construction Cost Rate/m for RF	Statistical Distribution of RF (%)	Calculated Cost Rate for Alignment	Statistical distribution of rock formations
Great Limestone	0.684	39.5	0.270	
Manhang	1.089	24.9	0.271	
Kumchon	0.990	13.8	0.137	
Volcanic Rock	1.131	11.3	0.128	
Changsong	1.246	7.1	0.088	
Hanbaeksan	2.544	3.4	0.087	
Tonggo	1.115	0	0.000	
Kohan	1.117	0	0.000	
Evaluation Value for Alternative 2			0.918	

native has a total length of 17.81km. The tunnel is longer but in better ground conditions. The Upper Tunnel also serves as a pilot tunnel for construction of the Lower Tunnel. The Dokye end of the tunnel, like Alternative 1, remains in the west wall of the valley. By do so, same of the main tunnel will avoid the coal measures area and the poor ground conditions.

Access to the tunnel will be through two ventilation shafts, two emergency stair shafts, and four portals. The two tunnels are positioned above one another. Shafts built for one tunnel are used by the other tunnel. This allows multiple working faces to cover the construction duration. No additional adits are needed. The alignment will cross 11 fault zones, 2.5km of coal measures, and includes 7.8km of limestone. The increased amount of limestone will remove uncertainty of the ground conditions. Figure 9 shows the geological profile to be passed through this alterative tunnel alignment.

According to the geological profile given in Figure 9, the statistical distribution of geological rock formations for the tunnel alignment 2 is given in Table 6. The unit construction cost rate analyzed by statistical technique is also given in the table.

6. Comparison of the three alternatives atives analysis results

The results of the alternative analysis are given in previous section. In the analysis, tunnel length, amount of poor ground, amount of good ground, and numbers of openings are considered. Based on the results, the features of three alternatives are sum-marized in Table 7. It can be seen from the table that the tunnel alignment 1 (Alternative 1) will be

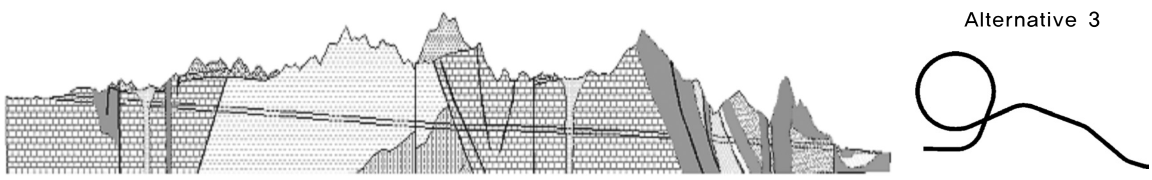
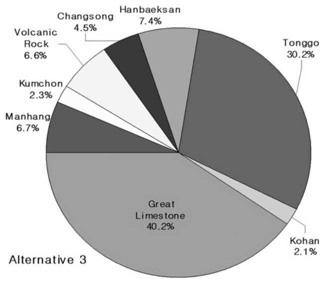


Fig. 9 Geological profile for tunnel alignment 3

Table 6. The statistical distribution of rock formations and unit construction cost rate (Alternative 3)

Rock Formations (RF)	Construction Cost Rate/m for RF	Statistical Distribution of RF (%)	Calculated Cost Rate for Alignment	Statistical distribution of rock formations
Great Limestone	0.684	40.2	0.275	
Manhang	1.089	6.7	0.073	
Kumchon	0.990	2.3	0.023	
Volcanic Rock	1.131	6.6	0.075	
Changsong	1.246	4.5	0.056	
Hanbaeksan	2.544	7.4	0.188	
Tonggo	1.115	30.2	0.337	
Kohan	1.117	2.1	0.023	
Evaluation Value for Alternative 3			1.050	



very good for construction tunnel line in the project area.

7. Conclusion

The determination method of economical and feasible tunnel construction route in the complex geological formations is introduced in this paper. In the study, three possible tunnel alignments are evaluated.

Due to the complicated geology prevalent in the project area, extensive geological investigations have been carried out and reviewed. Relatively accurate geological profiles are estimated from various rock formations developed in the area. Since the bedding is often sub-horizontal, it can be deduced that small changes in the tunnel level and route may lead to serious consequences for the stability of the tunnel.

In order to perform this study, various rock formations have been classified using the Q-system and the cost of tunnel excavation, support has been estimated and compared for three alternative lines in the design stage. Based on these estimates, the final route of the railway line was chosen. In this project, the following tunnel alignment (Alternative

Table 7. Comparison of the three tunnel alternatives

Item	Alternative 1	Alternative 2	Alternative 3
Length of main tunnel	15.76 km	14.59 km	17.81 km
Number of access points	5	5	10
Type of access	Shafts, portals, and adit	Shafts, portals, and adit	Shafts and portals
Length of access	1.47 km	1.47 km	0.9 km
Number of fault crossings	13	11	11
Number of coal measures	7	3	3
Length of coal measures	1.8 km	0.9 km	2.5 km
Length of limestone	1.9 km	1.9 km	7.8 km
Evaluation Value	0.978	0.981	1.050
Evaluation	Very Good	Good	Fair

1) is chosen and under construction by DAEWOO. (Fig. 10)

In order to perform a more detailed evaluation of the geological condition for the proposed tunnel lines, it is also suggested that DAT analysis will be very useful for accurately determining the tunnel route. The DAT program namely Decision Aid in Tunneling was developed by Professor Einstein at MIT. The concept of the program is to identify the geotechnical conditions a tunnel or tunnels will encounter. With each ground class there will be an uncertainty or risk. The ground conditions could be worst than expected. The result is a delay in construction and advance rates reduced. The delays can lead to high costs. The ground conditions can also be better, allowing portions of the tunnels to be completed ahead of schedule.

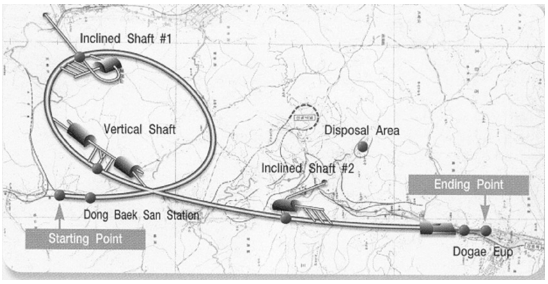


Fig. 10 Alternative 1

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