Railway Tunnel Blasting Design adjacent to the Existing "Live" Tunnel
운행중인 철도 터널에서의 근접 발파 설계

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요약

현대건설㈜은 중앙선 (덕소 ~ 양수) 복선 전철공사 실시설계 턴키 입찰을 위한 일련의 조사 및 설계를 수행하였다. 본 논문은 사업 구간에 속해 있는 월문터널에 대한 설계를 수행하는 과정에서 현재 기존 노선이 운행되는 있는 단선 터널에 근접한 지역에서 공사 중에 운행되고 있는 열차의 안정성을 확보하기 위한 기초 조사를 선행하였다. 본 논문의 목적은 현재 국내에서 시행되고 있는 근접 터널 시공 문제에서 (특히, 화약 발파에 의한 터널 설계 및 시공) 문제시 되고 있는 적절한 진동제어에 대한 수치가 필요 이상으로 적용되고 있다는 점에 대하여 향후, 경제적이고 도전적인 설계를 위한 제시를 하기 위함에 있다.

1. Introduction

Hyundai Engineering and Construction Co Ltd (HDEC) prepared a turnkey tender submission to Korea National Railroad (KNR) for the design and construction of a section of the Joong Ang Railway Project in central Korea. The section includes the Wolmoon Tunnel. The Wolmoon Tunnel is approximately 210 metres in length and approximately 12 metres excavated span. The tunnel was designed to be concrete lined and to contain twin railway tracks on a ballasted trackbed.

The key feature of the new tunnel is that is to be driven on an approximately parallel alignment to an existing single track tunnel in which trains run at very frequent intervals. The tunnels will be at their minimum separation in the vicinity of the west portal, with the separation increasing towards the east portal. Figs. 1 & 2 show the general plan and typical sections. It can be seen that:

- there is a section of open cut to be excavated alongside the existing tunnel where the minimum rock clearance is approximately 4.5 metres;
- at the point where the new tunnel commences, at the west portal, the rock pillar between the tunnels is approximately 11 metres wide (increasing to approximately 16 metres at the east portal).

The existing tunnel is approximately 50 years old. It is horseshoe shaped with a span of approximately 4.5 metres and a height of approximately 6.5 metres. It has an unreinforced concrete lining which is 30 cm minimum

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thickness. The tunnel has a ballasted trackbed, and there is no concrete invert slab. The tunnel is reported to be in generally good condition.

The proximity of the existing 'live' railway tunnel to the proposed major excavations in rock, both above and below ground level, clearly presents a major constraint and source of risk during construction of the new railway. An assessment of all aspects of the potential impact of blasting on the existing tunnel, and to make recommendations in respect to:

- blasting methods and vibration control criteria;
- procedures to manage the risks from blasting, including, as appropriate, inspection, instrumentation and monitoring, and/or protective measures.

There are a number of key criteria and constraints which influence the approach to managing the risks associated with the proposed works. At the time of preparation of this report these are understood to include the following

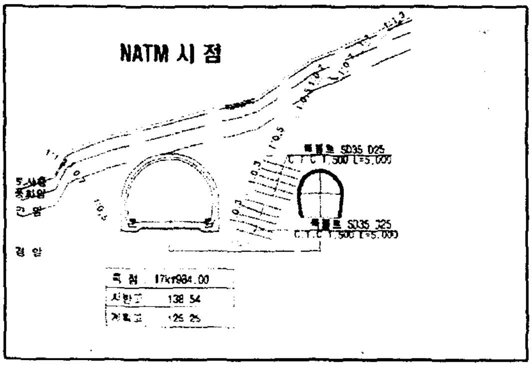

Fig. 1. Cross-sectional view of NATM Tunnel

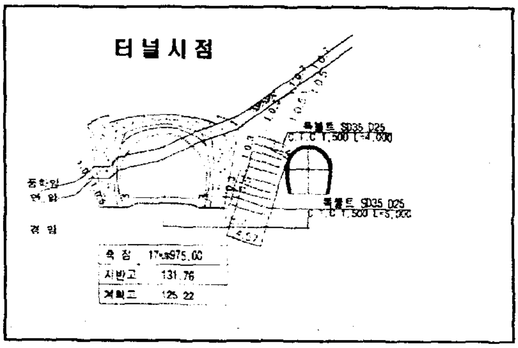

Fig. 2. Portal adjacent to the existing tunnel

- blasting will be restricted to daytime hours only;
- track possession in the existing tunnel will only be possible between midnight and 2 a.m.;
- train movements through the tunnel are scheduled to be at frequent intervals, possibly as close as 5 minutes at certain times of the day; there is a general requirement by KNR to avoid disruption to its existing schedules as far as possible;

These criteria and constraints are severe, but not dissimilar to those applied to similar works in recent years in Hong Kong, for example. However, it should be noted here that it is essential, in the interests of railway safety in such cases, for the Contractor and railway Operator to work very closely together. Disruption to schedules can only be minimised, and safety standards maintained, by this very close cooperation.

2. Engineering Rock Mass

Based on drillhole data and geological profile, the area of steeply dipping ground at the portal area comprises a sequence of soil, weathered rock and rock, comprising from gneissic bedrock to granitic. A fault is mapped at some 130m from the gneiss/granite contact. Ground conditions could vary significantly across the tunnel section. Thicknesses of the "soft" rock are similar in both drillholes at between 4.5 and 6m respectively.

Since rockhead is believed to rise approximately parallel to the existing ground surface the excavation at the portal area is likely to be in mixed conditions of soil, weathered rock, and "soft" and "hard" rock. The proposed tunnel section is shown to be entirely within "hard" rock. However, the variability shown in the drillholes suggests the possibility of encountering weathered rock beyond this chainage.

Typical rock properties for the "soft" and "hard" rocks have been supplied as indicated below.

Engineering Properties	"Soft" Rock	"Hard" rock
Unconfined Compressive Strength (MPa)	40 ~ 50	130 ~ 160
RQD (%)	0 ~ 22	7 ~ 72
Rock Mass Rating	29 ~ 39	42 ~ 73
Joint Spacing (cm)	3 ~ 20	20 ~ 42
Seismic Velocity (km/s)	0.7 – 2.9	

The rock mass of the "soft" rock can therefore be classified as "Poor Rock". Although blasting is likely to be required in much of the "hard" rock areas, the RMR and seismic velocity data, infer that, in the portal area, much of the rock, including some of the "hard" rock is likely to be rippable.

3. Case Histories

A review of comparable case histories has been undertaken in order to provide an appreciation of international practice, with particular reference to:

- approaches to risk management when blasting in the vicinity of existing "live" railway tunnels
- acceptable vibration control criteria appropriate to railway structures and tunnel linings
- inspection, instrumentation and monitoring procedures
- protective measures.

Summaries of key matters arising from the most relevant case histories reviewed, and with particular reference to the Wolmoon Tunnel, are given below.

Case Study I -- Producing the Mass Transit Rail (MTR) tunnels at Lai King in Hong Kong consisted of excavating a number of openings in close proximity to existing MTR tunnels in which trains were operating. After trial blasts and consultation with the MTR Corporation, realistic ground vibration limits were imposed on the live tunnels. No damage was observed.

Initially, trial blasts in the Up Tsuen Wan Line Deviation Tunnel were carried out at distances of 5m to 8m from the live tunnels. Recorded PPVs were 110mm/s to 130mm/s. Following these trials, Nitro Consult AB (Swedish blasting consultants) recommended the following PPV limits:

Higher PPVs were permitted for smaller separation distances, because of the lower damage potential of the higher frequency vibrations produced by closer blasts. A detailed account of these events is given in a paper by Mr. Alan Morris, published by the Hong Kong Institution of Engineers in 1998.

Separation Distance (m)	PPV limit (mm/s)	
	95% Confidence	90% Confidence
3 ~ 10	115	75
10 ~ 20	95	60
20 ~ 30	75	50

Case Study II -- The Hemriksdals Sewage Treatment Plant (Sweden) was built underground. It consists of 24 major rock caverns, each with a width of 10m and a height of 13m, and with lengths of 80m to 130m. In all caverns, the roof is supported by a thin (less than 20mm) layer of shotcrete plus rock dowels.

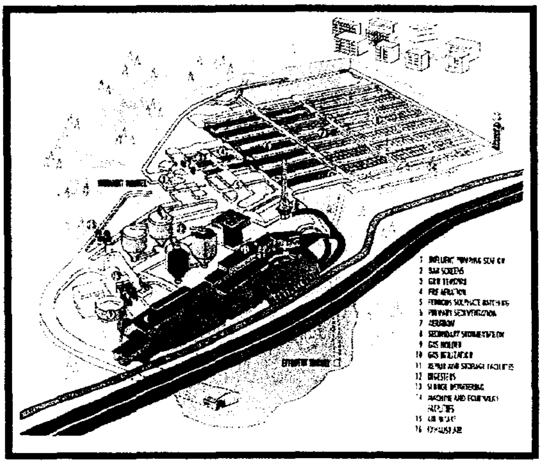

Fig. 3. Underground sewage treatment plant in Viikinmaeki wastewater

In 1992, an extension to the treatment plant started with the excavation (by blasting) of new rock caverns (volume 250,000m^3) and the deepening of 12 of the existing caverns (volume 100,000m^3). All caverns are supported by 10m wide pillars of rock. The plant consists of concrete structures, pumps, power supply, computers and relay equipment, all of which needed to be in operation during the blasting operations.

The guide values for PPV limits for the concrete structures and rock caverns were:

Distance (m)	PPV (mm/s)	Distance (m)	PPV (mm/s)
0 ~ 5	120	15 ~ 20	70
5 ~ 10	100	20 ~ 30	60
10 ~ 15	80	30 ~ 40	50

In general, the Contractor had no problems in keeping within the vibration limits for the main excavation. Each of the new caverns was excavated with a pilot drive, side stripping, and a horizontal bench. When blasting the new caverns, the highest recorded PPV was 167mm/s. This PPV was experienced by the nearest concrete structure, which was in direct contact with the rock wall. No damage to the concrete structure was reported, and no rock or concrete spall occurred. For the entire job, the highest vibration was recorded during blasting of the raise shafts. During breakthrough of one of these shafts, a PPV of more than 255mm/s was recorded on the concrete foundation. No damage occurred.

4. Blasting

A recommended drilling and blasting for surface and tunnel excavations at the Wolmoon site is illustrated in Figs. 4 & 5. The specialist report deals with the following principal issues:

- flyrock
- ground vibration control criteria
- recommended initial blast designs (surface, portal and tunnel)
- predicted ground vibrations
- cost and time incentives to avoid the use of ground vibration limits that are excessively conservative
- precedent practice in the form of a review of case histories

5. Protective Features

- the design of blasting operations to limit flyrock and within agreed vibration control criteria
- implementation of a risk management approach
- the risk management strategy document

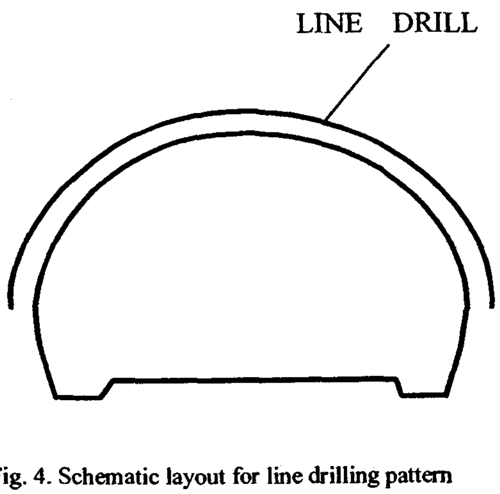

Fig. 4. Schematic layout for line drilling pattern

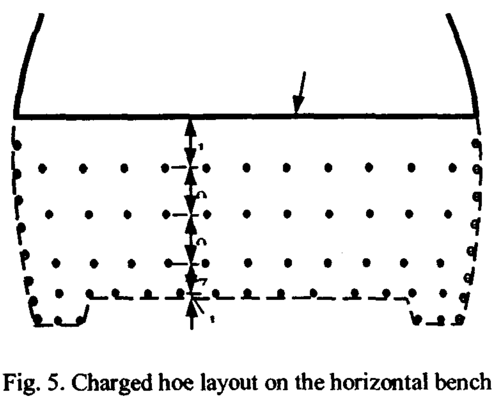

Fig. 5. Charged hoe layout on the horizontal bench

- risk register
- blast records, tunnel inspection record, and instrumentation records

- precise survey records

It is also proposed that physical protective measures should be deployed. The purpose of these measures is to minimize the risk of a major disruption of the rail services due to damage to railway infrastructure arising from flyrock (in the open cut excavation), or spalled concrete or more significant structural damage in the tunnel.

Blast Mats -- Blast mats or other screening measures, should be used for all surface blasts and for tunnel blasts in the portal area.

Protective Measures in Existing Tunnel -- Protective measures in the existing tunnel should take account of the:

- short night time possession periods (2 hours per night) available for installation
- overhead line and its support
- uncertain condition of the concrete lining and the surrounding rock mass.

6. Summary

The conclusion of this report is that the necessary technology exists to construct the new Wolmoon Tunnel using explosive methods within the key criteria and constraints relating to the safety, integrity, and continued operation of the existing tunnel. Similar works have been successfully completed elsewhere and it is proposed to draw on this experience to achieve a successful result at Wolmoon.

Although the probability of occurrence of identified risks should be very low, the consequences of the risks, should they occur, are very significant. Consideration of the risks to the infrastructure, and users of, the existing railway leads to the following fundamental conclusions:

(i) blasting cannot be allowed at any time when trains may be in the existing tunnel, or in the immediate vicinity;

(ii) the existing tunnel and rails must, as a basic minimum, be inspected visually by a qualified engineer after each blast, and before trains are again allowed to pass through the tunnel.

(iii) blasting trials to establish acceptable vibration control criteria for each phase of the work (open cut, portal and tunnel)

(iv) instrumentation and precise survey (during night-time possessions) to monitor:

(v) relatively simple and easily installed physical protective measures and reinforcement in the form of blast mats for surface and portal excavations

References

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2. Hyundai Engineering & Construction Co., Ltd. (2000), "Turnkey proposal documents for detail design report of Jooang Railway civil work", October.