Case Study
Full Face Tunnel Blasting within Environmental Constraints
Sungnam-Yeoju City Railway Project, South Korea

Site Profile
The Sungnam-Yeoju City Railway Project No.2 is a section of railway tunnel located in the City of Sungnam, South Korea. The project included the excavation of 2.9 km’s of tunnel length.

A 165m section of the tunnel length passes below residential buildings area at an average depth of 32m. For this section of tunnel excavation authorities have set a strict environmental limit on ground vibration.

The Situation
Adherence to the strict vibration limits set for the 165m tunnel section in close proximity to residential dwellings, was found to be very challenging using conventional delayed electric initiating systems.

Initially five trial blasts using conventional electric Long Period dets did not deliver promising results and in fact increased the safety hazard and lowered productivity. As a result of this the blasting operation in the tunnel was stopped for three months.

The Principle Contractor for the tunnelling Project, Hanjin Heavy Industries and Construction, conducted a series of trials to determine the best drill & blast techniques to meet the strict vibration limits.

In order to comply with the strict ground vibration limits Hanjin Heavy Industries and Construction contacted Orica Mining Services to discuss other potential solutions and alternative initiating systems to overcome the vibration limit challenge. Orica proposed the use of eDev™ Electronic Tunnelling System for the excavation of the 165 m section of the tunnel length.

Hanjin Heavy Industries and Construction’s tunnel manager approved three (3) trial blasts with the use of eDev™ Electronic Tunnelling System.

The trials were approved based on the following key performance indicators –

• Ground vibration at the residential dwellings as determined by regression analysis, should not exceed 0.2cm/sec, and
• Full-face blasting above the bench should be possible (the full tunnel face is divided into an upper face blast and a lower bench blast).

Blasting Issues
Hanjin Heavy Industries and Construction used the following techniques and technologies for the trials with conventional initiating systems:

• Full face sectioned into four (4) separate blasts;
• Four 362mm void holes drilled to 10m in advance of the face, to improve void ratio in the cut;
• Blasthole depth changed from 1.1m to 0.8m;
• Increase number of blastholes to 235 to improve explosive distribution and reduce confinement;
• Multi-blower machine and LP Electric Detonators used to achieve individual delay assignment at each hole.

Each of the initial five trial blasts with conventional electric system used the sectional firing approach, as described below:

The full face was sectioned into four (4) separate blasts; each prepared, loaded and fired at four separate firing times. The face sectioned has been shown in Figure 2.
Segmenting and firing the face in smaller sections was done to limit ground vibration but the approach was unsuccessful and the method introduced the following adverse factors to the project:

- Increased the safety risk to the blast crew reworking the pre-fired face;
- Number of blasting events increased, limiting full face advance to one face per day;
- Additional site preparation for each blast;
- Poor utilisation of earth moving fleet;
- Apart from the initial blast near the void holes all other blasting events exceeded the vibration limit.

The sectional approach not only failed to reduce vibration to acceptable levels, but also introduced safety and operational issues that generally made progress slow and unacceptable. The five conventional trial blasts required five days to complete and resulted in one serious injury.

**Technical Solutions**

To investigate the potential benefits of using the eDev™ Electronic Tunnelling System and to collect vibration data for analysis three eDev™ trial blasts were undertaken.

For the trials with eDev™ Electronic Tunnelling System, the tunnel faces where drilled and charged as they had been during the trials with the conventional electric initiating system, except for

- Reduction of no of void holes from four to two (362mm x 10m).
- Full face firing of blast face instead of sectional firing.

The eDev™ Electronic Tunnelling System offers fully programmable electronic detonators and a unique “timing by numbers” approach to delay assignment at the working face. This means:

- Electronic accuracy of 0.1% of assigned delay time;
- Single hole initiation, with unique eDev™ approach to delay assignment;
- Potential to have as many individual delay numbers as required, with delay offsets within each delay number, huge potential to manage MIC and to optimise blast designs;
- Easy to learn system and use at the face;
- Improved safety, security and testability of completed work.

For Hanjin Heavy Industries and Construction, this would mean that for the first time, they would have true single hole firing. Energy released within the blast to deliver optimum breakout progression, not compromised by delay limitations inherent in pyrotechnic initiating systems.
Results

The face design used for the eDev™ blasts and the vibration results are shown below.

![Figure 3: Full-face design for the eDev™ trial blasts](image)

The Vibration monitoring positions are shown below on the topographic sectional view of the project site. Positions A and B are mountain – non residential locations on the tunnel approach to the residential monitoring positions at C, D and E.

It can be seen from the results in Table 1 that the eDev™ trial blasts have been taken while the tunnel face is still a short distance away from the area directly under the residential dwellings.

![Figure 4: Sectional view showing vibration monitoring positions during eDev™ trial-blasting](image)

<table>
<thead>
<tr>
<th>Trial Blasts</th>
<th>Monitor Position</th>
<th>Distance (m)</th>
<th>PPV Max (cm/Sec)</th>
<th>Monitor Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Trial (202 holes) 16/03/10</td>
<td>A</td>
<td>41.6</td>
<td>0.206</td>
<td>Mountain</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>40.3</td>
<td>Error</td>
<td>Mountain</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>45.3</td>
<td>0.127</td>
<td>1st houses</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>70.4</td>
<td>0.0476</td>
<td>middle houses</td>
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<td></td>
<td>E</td>
<td>91.5</td>
<td>0.0318</td>
<td>last houses</td>
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<tr>
<td>2nd Trial (180 holes) 17/03/10</td>
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<td></td>
<td>B</td>
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<td></td>
<td>C</td>
<td>45.2</td>
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<td>59.9</td>
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<td>E</td>
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<td>3rd Trial (202 holes) 17/03/10</td>
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<tr>
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<td>0.173</td>
<td>Mountain</td>
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<td></td>
<td>E</td>
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<td>0.0302</td>
<td>last houses</td>
</tr>
</tbody>
</table>

Table 1: The results of full-face blasting using eDev™

The vibration records collected for the conventional electric initiation and the eDev™ trial blasts have been subjected to regression analysis to determine the likely vibration outcomes when the working face is 32m directly below the residential dwellings.

Trial results and observations are summarised as follows:
Sectioned face blasting approach using conventional electric detonators:

- Vibration compliance was only achieved when firing the cut section. All other fired sections consistently exceeded vibration limits.
- Regression analysis of the results suggested that environmental compliance would not be possible.
- The sectional blasting technique introduced unacceptable levels of risk and compromised acceptable safety standards.
- Tunnel advance rate was reduced due to poor equipment utilisation, increased preparation time and re-drilling of damaged blastholes.
- Excavation Cycle-time was increased: One day to load fire and excavate one full face.

Full face firing of the Blast tunnel faces using the eDev™ Tunnelling System:

- All three trial blasts complied with the ground vibration limits set at all monitoring locations.
- Regression analysis suggested that blast design optimisation and use of eDev™ Electronic Tunnel system would most likely result in achievement of environmental compliance when tunnelling directly below the residential dwellings.
- Worker safety was greatly improved.
- Cycle-times would improve allowing for an estimated three full face firings per day.
- The blast design could deploy reduced void holes by using the flexibility of eDev™ to enable the blasting engineers to adjust and optimise the relief and breakout sequence.

The three eDev™ Electronic Tunnelling System blasts were successful in terms of environmental compliance, while allowing the contractor to achieve full-face tunnel blasting. Regression analysis suggests that eDev™ and design optimisation will deliver environmental compliance, as the tunnel passes under the residential dwellings. Hanjin Heavy Industries and Construction have determined that the eDev™ Electronic Tunnelling System is going to be a key tool in efforts to manage the environmental risk posed by blasting in the Sungnam-Yeoju Railway tunnel.

Acknowledgements

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