Mine Tunnel Drivage by Roadheader

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Abstract: This paper discusses the influence of geological and mining factors on the performance and stability of coal mine tunnels driven by roadheaders.

Key Words: roadheader, longwall mining, gateroad, drivage rate, floor heave

Introduction

Mechanized tunneling technique using roadheaders or full-facers, has become a predominant method of tunnel drivage. Especially, roadheaders have been used to an increasing extent to drive both mining and civil engineering tunnels. Compared to drill-and-blast method, mechanized tunneling technique offers major advantages such as continuity of operations, reduction of manual content of the tunnel operations and improved advance rates with reduced manpower. It also offers improved ground control and an environment leading to safer working conditions.

In underground coal mining, longwall mining method is more productive in comparison to other methods but requires particular conditions for its effective use. One of these requirements is that the longwall gateroads are driven rapidly and are also well supported in order to withstand high abutment strata stresses created by a retreating longwall face. In a mine using a high production longwall mining system, gateroads should be developed more rapidly and maintained effectively to achieve high levels of mine productivity and economy.

This paper discusses the influence of geological and mining factors related to the performance of coal mine tunnel drivage by roadheaders and discusses some improvements in the heading drivage operation in Japanese underground coal mines.

Geological and Rock Engineering Aspects

Detailed geological information is necessary in mine tunnel drivage to select the most appropriate efficient excavation technique and selection of ground control method. Properties of coal and coal measure rocks have implications in the selection of drivage and support method in underground coal mines. Geological disturbances such as
presence of discontinuities, faulted zones and presence of ground water usually cause problems during mine tunnel drivage. Stress conditions also affect the stability of tunnel and safe drivage. Therefore, when selecting drivage method, the following geological and rock engineering factors should be taken into consideration.

Properties of Coal and Coal Measure Rocks

The coal measures in Japan are of Paleogene and consist primarily of sandstones, shales, sandyshales, mudstones, tuffs, conglomerates and coals. Figure 1 shows the relation between tangent Young's modulus at 50% of peak stress, E50 and uniaxial compressive strength (UCS), Sc of the coal measures at Mieke and Ikushima Collieries. These values of intact rock specimens were obtained by uniaxial compression testing under dry and wet conditions. The results shows that the UCS and the Young's modulus occupy a wide range. According to the intact rock classification of ISRM using UCS, the strength of the coal measures goes from low, moderate, medium to high ranges. It means that a roadheader should be capable of cutting wide-range strength rocks.

It is generally believed that of the intact rock properties, the UCS provides the single most useful index for predicting machine performance. However, the performance of a roadheader depends on the intact rock and rock mass properties, the installed cutterhead power and thrust, its size and rotation speed and the cutting pick size, spacing, number, type and quality. Therefore, the drivage rate is based on these parameters.

The quantity and quality of the rock property values that were obtained from the rock mass are much lower than for an intact rock sample. Small specimens of intact rocks are easy to collect and test under various laboratory conditions. Test data for large-scale rock mass characterization are very difficult. For these reasons, the majority of

![Figure 1: Relation between Young's modulus and uniaxial compressive strength.](image)
suggested predictive methods rely on the use of small specimens of intact rock. UCS or uniaxial tensile strength (UTS) of intact rock used as an index for criterion or prediction is not so good because the fragmentation mechanism is not taken into consideration sufficiently. It is more important to consider the consumed energy value in fragmentation, such as the rock impact hardness number (RIHN) instead of the strength failure value such as UCS or UTS for criterion or prediction for cutting machine performance (Shimada et al., 1994). In addition, in a fractured rock mass, cutting efficiency is more influenced by the spacing and orientation of fractures than by intact rock properties. The combination of the RIHN of the intact rock and the RQD of the rock mass can predict the roadheader performance precisely (Shimada et al., 1994).

Since the success of a roadheader is more site sensitive, application should be made after the proper evaluation of geological conditions and rock characteristics in order to predict the machine performance, pick consumption, and other related factors. Geological conditions have significant effects on the cuttability of rock.

Two other factors also affect the cuttability of rock:

1) Cutting tools
2) Cutting mode

Drag bits are the most efficient cutting tools. They require low thrust and break rocks in tension due to existence of free surface. High quality point attack bits have recently been developed and marketed, and capable of cutting over 100 MPa UCS.

The machine cutting mode is very important to achieve high cutting efficiency. During tunnel drivage, the following modes of excavation are employed: sumping, traversing, undercutting, and overcutting. It was found that under identical rock conditions, sumping is an inefficient method of excavation and requires higher specific energy that is three times higher than that of traversing (Fowell et al., 1976). With the under cutting mode, cutting is assisted as the fractures and bedding planes open. For overcutting with a roadheader, cutting is assisted by the weight of the cutting drum and the boom.

The abrasivity of a rock depends on its quartz content, grain size and crystalline habit. These effect tool wear and dust production. Abrasivity can be efficiently estimated by using the Cerchar abrasivity index (West, 1989). Rock with a high abrasivity value shows high abrasivity, leading to large bit consumption. Coal measure sandstones generally show high abrasivity.

**Faulted Zones**

A tunnel should never be driven along a fault as displacements of rock on each side of the fault frequently take place, and may lead to the destruction of the tunnel. If a tunnel intersects a fault, little can be done to protect the structure and it is best, if possible, to shift the alignment to avoid it. However, in in-seam drivage, it is difficult to do so. In general, almost small offset faults are passed through by roof ripping or floor brushing. In this situation, the problem is whether a heading machine is capable of cutting hard- and-strong roof or floor rock. In some cases, blasting is used for inducing some
fractures in the hard-and-strong rock mass in order to cut it easily.

Faulted zones, due to their intense geological disturbance will produce hindrances in heading operations and might even cause imruses into the tunnel in the presence of water.

**Ground Water**

Ground water influences the tunnel stability and working conditions. Water bearing strata can be very unfavorable to tunnel heading operations. Even a small amount of water collects at the heading face. If the floor rock is soft and a heavy duty heading machine is used, the machine sinks into the floor rock and is difficult to keep to the required gradient and safe working conditions. Any appreciable amount of water at the heading face will interfere with progress, regardless of the grade of the tunnel. Therefore, it is of the greatest importance before heading starts, to have accurate information about the ground water conditions likely to be encountered.

Water also tends to lubricate the joints in the rock mass, particularly the softer rocks, and weakens its ability to stand without support. Coal measure rocks are affected remarkably by the presence of water. Some shales deteriorate and lose almost all their mechanical properties by slaking or cracking.

In case of high water head, the rocks may fail and fall into the tunnel. Drainage of the heading is necessary to ensure dry and safe working conditions.

**Floor Heave**

The floors of mine tunnels usually remain unsupported after their excavation. Therefore, the weaker the floor rock and the greater stress is, the more excessive the floor heave occurs. The key to the control excessive closure is to control the floor heaves themselves.

The floors of the coal seams are usually shales and naturally weak due to the way in which they were formed geologically. Moreover, the shale is generally highly slickensided which promotes the floor even under relatively low strata stress conditions. The shale contains clay minerals such as kaolinite, montmorillonite and illite. The first two minerals react with water and cause a substantial deterioration in the shale strength with resulting swelling, cracking and disintegration of the rock mass.

Understanding and knowing the causes of excessive floor heaves is of significance in order to control and reduce the problem appropriately. The detailed studies from laboratory tests and several underground observations and measurements carried out at M i i k e and Ikeshima Collieries have revealed that the excessive floor heaves are caused by the following factors (Matsui et al., 1994):

1) Weak rock and coal
2) Ground water
3) Faults
4) Roadway formation method
roadway. The MRH S-65 that is used at Miike Colliery has twin cutting drums that are capable of cutting up to 60 MPa UCS. The MRH S-100 with a single cutting drum at Ikeshima Colliery is able to cut hard rocks up to 100 MPa UCS. The Joy 12CM10 continuous miner is used at Kushiro Colliery. This machine is not used at Miike and Ikeshima Collieries, because of the difficulties in cutting the hard-and strong roof strata and in operating on the poor floor strata that are prone to deterioration with water. Table 1 lists the basic machine specifications.

Table 2 lists the performance of the roadway drivage at Ikeshima Colliery. Almost drivage is carried out using roadheader. The drivage rate with roadheader MRH S-100 is much greater than one with drill-and-blast method.

The following sequence in heading drivage was used during each 1.05 m cut out by the MRH S-100:

1) Excavate upper roadway profile.
2) Forepole.
3) Place roof arch section and lag using timber.
4) Complete mining of remaining lower roadway section.
5) Stand arch legs and lag ribsides.

In gateroad heading operation, the installation of supports causes a maximum delay and makes the heading operations cyclic. An analysis of the time spent in the heading operation at Miike Colliery showed that the cutting machine was utilized 30% of its available time for actual cutting operation, 40% for support installation and 30% for machine stoppage due to external reasons. This trend is almost the same in German coal mines, using the same drivage system (Hlarrmann et al., 1979).

Table 1 Specification of heading machine.

<table>
<thead>
<tr>
<th>Item</th>
<th>S-65</th>
<th>S-100</th>
<th>12CM10</th>
<th>S-200</th>
<th>S-300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total length (m)</td>
<td>11.5</td>
<td>12.2</td>
<td>10.1</td>
<td>10.50</td>
<td>11.4</td>
</tr>
<tr>
<td>Total height (m)</td>
<td>1.5</td>
<td>1.6</td>
<td>1.0</td>
<td>2.1</td>
<td>2.3</td>
</tr>
<tr>
<td>Total width (m)</td>
<td>2.6</td>
<td>2.8</td>
<td>2.5</td>
<td>3.6</td>
<td>3.8</td>
</tr>
<tr>
<td>Total weight (t)</td>
<td>28</td>
<td>37</td>
<td>40</td>
<td>45</td>
<td>40</td>
</tr>
<tr>
<td>Cutting height (m)</td>
<td>4.3</td>
<td>5.8</td>
<td>5.6</td>
<td>5.8</td>
<td>5.8</td>
</tr>
<tr>
<td>Cutting width (m)</td>
<td>4.7</td>
<td>5.1</td>
<td>2.6</td>
<td>6.3</td>
<td>6.7</td>
</tr>
<tr>
<td>Cutting motor (KW)</td>
<td>65</td>
<td>100</td>
<td>100 x 2</td>
<td>200</td>
<td>300</td>
</tr>
<tr>
<td>Ground pressure (MPa)</td>
<td>0.10</td>
<td>0.15</td>
<td>0.16</td>
<td>0.15</td>
<td>0.16</td>
</tr>
<tr>
<td>Advance (m/d)</td>
<td>12.0</td>
<td>15.0</td>
<td>8.1</td>
<td>2.4</td>
<td>3.3</td>
</tr>
</tbody>
</table>

*Note: re-including the bridge conveyor length*

Table 2 Performance of roadway drivage at Ikeshima Colliery.

<table>
<thead>
<tr>
<th>Fiscal year</th>
<th>Total drivage (m)</th>
<th>Drivage with drill-and-blast (%)</th>
<th>Percent</th>
<th>Efficiency (m²/day)</th>
<th>Drivage rate (m²/day)</th>
<th>Drivage with roadheader (%)</th>
<th>Percent</th>
<th>Efficiency (m²/day)</th>
<th>Drivage rate (m²/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1988</td>
<td>6.459</td>
<td>5.076</td>
<td>60.0</td>
<td>4.92</td>
<td>6.3</td>
<td>3.38</td>
<td>45.0</td>
<td>9.10</td>
<td>12.8</td>
</tr>
<tr>
<td>1989</td>
<td>6.551</td>
<td>2.491</td>
<td>30.0</td>
<td>4.14</td>
<td>6.5</td>
<td>4.56</td>
<td>62.0</td>
<td>7.53</td>
<td>11.0</td>
</tr>
<tr>
<td>1990</td>
<td>7.545</td>
<td>4.967</td>
<td>67.7</td>
<td>5.12</td>
<td>7.2</td>
<td>6.58</td>
<td>81.3</td>
<td>8.49</td>
<td>12.2</td>
</tr>
<tr>
<td>1991</td>
<td>6.210</td>
<td>2.316</td>
<td>37.5</td>
<td>5.25</td>
<td>7.3</td>
<td>5.13</td>
<td>62.5</td>
<td>8.54</td>
<td>10.9</td>
</tr>
<tr>
<td>1992</td>
<td>5.211</td>
<td>7.86</td>
<td>85.5</td>
<td>5.65</td>
<td>7.0</td>
<td>8.49</td>
<td>91.5</td>
<td>10.11</td>
<td>12.2</td>
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<tr>
<td>1993</td>
<td>3.581</td>
<td>7.81</td>
<td>91.1</td>
<td>5.71</td>
<td>6.8</td>
<td>7.66</td>
<td>96.0</td>
<td>10.42</td>
<td>12.1</td>
</tr>
<tr>
<td>1994</td>
<td>3.760</td>
<td>156</td>
<td>2.6</td>
<td>4.43</td>
<td>5.0</td>
<td>7.83</td>
<td>98.0</td>
<td>10.16</td>
<td>11.1</td>
</tr>
<tr>
<td>1995</td>
<td>6.177</td>
<td>245</td>
<td>4.0</td>
<td>4.69</td>
<td>5.2</td>
<td>5.82</td>
<td>96.0</td>
<td>13.30</td>
<td>14.8</td>
</tr>
<tr>
<td>1996</td>
<td>3.443</td>
<td>418</td>
<td>6.2</td>
<td>6.16</td>
<td>6.9</td>
<td>6.99</td>
<td>93.6</td>
<td>13.10</td>
<td>16.1</td>
</tr>
</tbody>
</table>
5) Support system

Several measures have been tried in an attempt to control the floor heave in mine tunnels. Most of them have worked markedly well when properly applied, but all are too costly. Therefore, the cost effectiveness must be considered thoroughly when introducing the measures. Present practice is to remove heaved floor rock and restore the required cross section using diniting machines or manual diniting. This process is not efficient and is interceptive to the supply system serving the heading.

Strata Stresses

The strata stress factor is one of the main factors that causes tunnel instability. The excessive closure is mostly encountered in relatively deep mine tunnels that have 600 m of cover depth. This is due to the increased level of strata stresses. Moreover, longwall mining creates an abutment stress zone around the excavated longwall panel. Gateroads are always located along the solid ribsides of the panel. Consequently gateroads are subjected to great ground movements and stresses; this leads to unstable tunnel conditions. Mine tunnels located under or above the remnant pillars or rib edges also experience substantial closure due to the presence of high strata stress zones.

The presence of faults also creates abnormal levels of stresses leading to severe unstable conditions.

Current Mine Tunnel Heading Practice

Gateroad drivage with a roadheading machine is flexible and can be combined with conventional method or the drill-and-blast method. The choice of the most suitable machine is of crucial importance to the success of machine drivage. The use of a machine of insufficient power or cutting capability will result in increased downtime, increased maintenance, and, consequently, higher operating costs.

In-Seam Drivage

Retreat longwall mining system in underground coal mines requires the preparation of a longwall panel before starting extraction. The productivity and economy of this mining system depend upon longwall panel size and total roadheading requirements. In order to meet these requirements, the required advance rate for the gateroads is dependent upon the longwall retreat rate and the drivage system (Barrett, 1989; Lama et al., 1991). However, the complicated and difficult geological conditions in Japan have always restricted mining layout. In general, the panel size is relatively small compared to those in Australia and the USA. For example, the face length is 80 m-250 m with an average of 150 m, and the panel length is 300 m-900 m with an average of 450 m. Therefore, in order to achieve planned coal production, at least two panels are required and the number of annual face change-over needs to increase.

Roadheaders of a MRH S-65 and MRH S-100 of Mitsui Miike Machinery Co. Ltd., and continuous miners of a Joy 12CM10 are used in roadway drivage in Japanese collieries. The roadheader is capable of cutting an arched or a rectangular profile
The most desirable situation is where the strata are self-supporting. If so, they can support and maintain a tunnel. However, a mine tunnel driven in poor strata conditions needs special attention in regard to cutting and supporting. Standing supports such as steel arches or three-piece sets (props and bars) have been traditionally used in Japanese coal mines. The collieries have their own supporting method which is based on their own experiences and needs.

**Stone Drifting**

The existing coal mines in Japan are typically undersea and they are land-or-island based, but all their working area are beneath the sea. Therefore, main roadways are very important for running underground mines.

Heavier duty roadheaders such as the MRH S-200 or S-300 are used in stone drifting in Miike and Kushiro Collieries (see Table 1). They are capable of cutting hard-and-strong rock.

**Improving Gateroad Heading Performance**

The need to drive gateroads with adequate size and to keep these roadways stable in the environment that is adjacent to a longwall face cannot be compromised. It is only with roadways that have been formed and supported according to high standards that a longwall face can achieve and sustain its full potential. To achieve optimum performance in drivage, a system is required that allows all of the functions involved in drivage to be performed simultaneously and continuously. This ideal system has been researched and the systems in use today are compromises that make use of available equipment and technology. Our final goal is to establish an integrated drivage system to optimize all of the functions that are involved in longwall gateroad drivage. The most important functions to be considered are as follows:

1) Heading machine
2) Roadway support system
3) Ventilation system

These functions will be discussed in the following sections.

**Heading Machine**

An ideal heading machine for gateroad heading must allow simultaneous cutting, loading, and tunnel support. Up-to-date heading machines that are capable of cutting, loading, and roof-bolting simultaneously, such as Voest Alpine ABM 20, Joy Sump Shearer, Joy 12CM20/30, Dosco RAM 3 or Kcmcoal Beaver are being used in Australia to improve heading operation (Barrett, 1989). These machines are continuous miner type except for Joy Sump Shearer.

Even if this kind of machine is used, the drivage rate would not be significantly improved as long as the standing support system is used. With a machine like this and a suitable support system, as will be mentioned later, the drivage rate would be
improved remarkably.

The problem in continuous miner heading is the ability of cutting the hard-and-strong rock in passing through a fault.

On the other hand, a roadheader is capable of cutting hard-and-strong rocks. The only means to solve the rapid support problem left in roadheader heading operation is simultaneous cutting, loading and tunnel support. A roadheader mounted with drilling machines is now being developed for rapid installation of roof bolts or rib bolts at the heading face.

**Support System**

Standing support systems cannot improve the drivage rate and tunnel stability. In order to overcome these problems, field trials of strata bolting along with the standing supports have been conducted in certain collieries (Matsui, et al., 1997). The application of strata bolting is based on the principles of stabilizing and confining strata movement around an excavation. If applied successfully, strata bolting minimizes ground movement, maintains clearance, and improves mining operations and safety. There are of course other benefits to be gained such as reduction in materials, transportation, and manpower costs as well as a potential improvement in drivage performance. Bolting system is now used in metal mines or underground plants in limestone quarries in Japan. Presently, however, bolting is considered to be a supplementary support system to the conventional standing support system in underground coal mines. The results obtained from field trials of strata bolting in combination with the standing supports show that roof conditions were greatly improved by roof bolting. However, floor heave and side closure were not effectively controlled under poor strata conditions (Matsui, et al., 1997). The accumulation of experience will lead to the extension of standing support setting intervals and, finally, to the elimination of standing supports.

**Ventilation System**

With greatly increased drivage rates, it may be necessary to increase fan capacities to contend with the increase in gas emissions and dust at the heading face. Dust collectors are available and can reduce the dust at the face. The amount of gas and dust could be reduced by decreasing the cutting rate of the heading machine to more closely match the support or drivage rate.

Simple forcing and exhausting auxiliary ventilation systems suffer from a number of drawbacks. The simple forcing systems have been mainly used in Japanese coal mines. The main problem with the forcing system is that it aggravates dust problems at the heading face.

Simple exhausting systems also have a number of disadvantages: methane dilution at the heading face is less efficient and methane made outbye is carried toward the face. So, rigid ducting is required, and this creates transportation and storage problems, particularly in rapidly advancing headings. In addition, the relatively slow velocity of the air moving inbye allows it to pick up heat from the ground. This is a disadvantage if
high temperatures are a problem.

In order to overcome these drawbacks in the simple ventilation systems, a forcing/exhaust overlap system has been introduced into UK coal mines (Sykes, 1989). The development of a new dust suppression system improves dust suppression by confining dust laden air to an area inbye the operator’s position.

Conclusions

Tunnelheading is affected by unpredicted geological conditions, especially faults and sudden inflow of water. Rock properties and methods of cutting also control the drivage rate and the economy of drivage.

The productivity and the economy of longwall mining can be improved by refining the current heading drivage system. An integrated drivage system that takes into account geological and mining factors contributes to the economic and safety benefits of heading drivage operations and mine tunnel maintenance.

An optimum drivage system is one where simultaneous cutting, loading, and roof and rib supporting are achieved in order to provide rapid drivage rate and flexibility.

Strata bolting support system is superior to the conventional standing support system in many respects. More research and field data must be obtained in order to establish an optimum design method for strata bolting as a sole support system in underground coal mine.

The training and cooperation of the heading drivage team should also be of the highest standard so that satisfactory results can be achieved.

Problems associated with heading in coal measure rocks can be reduced through detailed geological and rock engineering investigations, forward planning, proper selection of equipment and strict supervision.

Acknowledgments

Miike Colliery, the largest coal mine in Japan, closed down due to adverse market conditions in March, 1997.

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Any opinions stated in this paper are those of the authors themselves and are not necessarily those of the collieries.
References


