DEFORMATION OF RETREAT GATROAD IN INTERPANEL-PILLAR SYSTEM

by

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K. Gotoh¹ and T. Tsuru²

ABSTRACT

Since 1989, the Department of Mining Engineering at Kyushu University, in cooperation with the Ikeshima Colliery, Matsushima Coal Mining Co. Ltd., has been conducting a research project into longwall gate road designs applicable to deep and poor strata conditions. During this period, the economic environment has drastically changed the situation of the domestic coal mining industry. Conventionally, the retreat longwall method, with re-use of gate road, has been employed as it achieves higher recovery. However, from the view point of production efficiency, this method is not suitable because it requires intensive work in side packing and roadway maintenance. Therefore an interpanel-pillar system, or a two-entry gate road system, was adopted to identify the factors responsible for excessive vertical closure in longwall gate roads. Field measurements and non-linear finite element analyses were undertaken to confirm the performance of this system. Study results indicate that the stability of the gate road employing the rib pillar system is comparable to that of the conventional system of re-using gate roads.

INTRODUCTION

The retreat longwall method with re-use of gate roads has been conventionally employed in Japan, mainly because of the advantage of higher recovery. However, from the viewpoint of production efficiency, this method is not suitable because it requires intensive work for side packing and roadway maintenance. An interpanel-pillar system, or a two-entry gate road system using more powerful coal winning equipment, has been adopted to increase the productivity of longwall mining at the Mike Colliery (Matsui, Ichinose and Uchino, 1991). The success of this system has accelerated its introduction into the Ikeshima Colliery.

The Department of Mining Engineering, Kyushu University, in cooperation with the Ikeshima Colliery, has, since 1980, been conducting investigation into retreat longwall gate road designs applicable to deep, poor strata conditions. These results have been previously reported (Matsui et al., 1987a, Matsui, Ichinose and Uchino, 1987b, and Matsui, 1989a).

The purpose of this study is to examine the deformational behaviour of the gate road and to assess the stability of the gate road employing the interpanel-pillar system by means of field investigation and non-linear finite element modelling.

MINE HISTORY

The Ikeshima Colliery is one of the major collieries in Japan. It is an underground mine with modern equipment and it produces more than 1.8 million tons of raw coal (1.2 million tons of clean coal) per year. The lease covers a vast mining area of 35,000 ha, in which an estimated 2.3 billion tons of coal reserve exists.

Ikeshima is a small island located 40 km northwest of Nagasaki, Kyushu Island, as shown in Fig. 1. It is an area of 0.86 km² with a circumference of 4 km. Development of the island began in 1952, but coal production has now ceased. At present, coal is mined from the south and north of Ikeshima Island.

The Colliery is equipped with full facilities for coal

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11th International Conference on Ground Control in Mining, The University of Wollongong, N.S.W., July 1992.
Fig. 1 Location map of the Ikeshima Colliery.

production through to loading it out to sea. In addition, the Colliery supplies houses and facilities which enable employees and their families to enjoy life in the community. The total population of Ikeshima Island is about 6,000, of which 700 are employed at the Colliery. As fresh water is scarce, the Colliery has a sea water desalination plant which has the capacity to convert sea water to 2,650 cubic yards of fresh water for use throughout the island.

Although the geological structure of the Colliery is comparatively simple and stable, as shown in Fig. 2, there are many local faults which are mainly of normal type. The formations in the Ikeshima coal fields are of Pre-Tertiary, Tertiary and Quaternary ages. The Pre-Tertiary formations consist of granite and crystalline schists which are overlain unconformably by the Tertiary formations. The latter have a thickness of about 1400 m and comprise beds of sandstone intercalated with shales, mudstones, conglomerates and coal seams. The Quaternary formations overlie the Tertiary formations which form the islands.

Within the Tertiary formations, there are a total of five coal seams, of which three are workable. These are known as the 18 ft. Upper Seam (the Upper Seam), the 18 ft. Lower Seam (the Lower Seam), and the 4 ft. Seam, in increasing order of depth, respectively. The principal dip of the seams is between 30° and 10° to the southeast in the Hikishima area. Nowadays, longwall mining is practised in this area. Each seam is overlain and underlain by shale, but is bounded locally by sandstone or sandy shale.

The mechanical properties of these rocks and coals deteriorate greatly in the presence of water and some shales especially exhibit a slaking phenomenon when they come into contact with water (Izinoe and Matsui, 1987). Fig. 3 shows the mechanical properties of the floor shales of the Lower Seam, which deteriorate greatly in the presence of water. Table 1 lists the mechanical properties of each coal under dry and wet conditions.
PREVIOUS AND PRESENT LONGWALL DESIGN

Gateroads are usually formed by a roadheader of the MRH S-100 from Mitsubishi Miike Machinery Co. Ltd. This machine is able to cut hard rock up to 100 MPa UCS (uniaxial compressive strength). In some cases, the conventional drilling and blasting method is employed. Support in the gateroad is set by using 2.8m x 4.8m three-piece steel arches (cross-section 0.115m x 0.055m), as shown in Fig. 4, and spaced at 0.6m or 1.0m intervals, depending on the bedding and strata conditions. The supports are tied and lagged with wood. A strata bolting technique is planned for introduction into the gateroad supporting.

Fully mechanised retreat longwall mining has been employed. The width and length of each panel are set in the range of 80m to 120m and 300m to 1,000m respectively. The values depend on the mining and strata conditions. Each face is supported by self-advancing powered shield supports, and the coal is extracted using a double ended ranging drum shearer. The roof in the extracted area is allowed to cave fully.

With the conventional system of re-using gateroads behind the face-line, face-side packing (using flyash and cement slurry) was used to protect the gateroad and to prevent the ventilated air leaking into the mined out area, as shown in Fig. 5. The effectiveness of face-side packing in alleviating the excessive vertical closure is identified by means of non-linear finite element analyses (Matsui, 1989b). However, it is difficult to set the most appropriate conditions of the pack for the complicated mining and strata conditions. New packing materials and methods, which exhibit a remarkable effect on roadway stability, have been reported (Clark and Newson, 1981) and Northard, 1986). However, there are economical and technical problems in introducing them into Japanese underground coal mines.

Due to the widening price gap between domestically produced and imported coal, domestic coal mines have made extensive efforts to reduce production costs. The introduction of the new longwall mining system, the interpanel-pillar system, at the Ikeshima colliery is one of the projects introduced to maximise coal face productivity. Optimum design of the interpanel-pillar is of critical importance in achieving safety, economy and efficiency in longwall mining. The optimum pillar must be designed so that it is able to maintain the gateroads until the passage of the second panel longwall face and to collapse soon afterwards. Improper pillars left in place are not only a waste of precious resources, but they create problems such as severe roadway closure and spontaneous combustion.

After discussing the results of the field investigation at the Miike Colliery (Matsui, Ichinose and Uehara, 1991), a 25m wide rib pillar was recommended. However, the Colliery decided to employ a narrower rib pillar in order to increase coal recovery as much as possible. At first, a 15m wide rib pillar was introduced and then a 10m wide rib pillar was also employed. In the two-factory gateroad system employing the rib pillar, the gateroad
of the second longwall panel, located on the side of the first panel, was driven during, or after, the extraction of the first longwall panel. In these cases, the influence of the first panel extraction on the stability of the roadway during, and after, development were examined. Considering the stability of the rib pillar on roadway maintenance and spontaneous combustion, three 1.5m long fully reinforced wood dowels were installed in the pillar at 1.3m spacing after development.

The stability of the gateroad and the possibility of spontaneous combustion in the pillar were examined by monitoring roadway closure and the contents of methane and carbon monoxide gases.

FIELD INVESTIGATION

Site Description

Figs. 6 and 7 show the Beshima Colliery longwall district where field investigation was undertaken. The 18 ft. Upper Seam of the Northern Section, located at a depth of about 430m, as shown in Fig. 6, was extracted by longwall mining employing a 15m wide rib pillar. The extracted height is about 2.5m. The immediate roof and floor of the workings were shales, which tended to deteriorate when wet. In the Southern section of the district, the 2.7m thick 18 ft Lower Seam, situated at a depth of about 420m, used a 10 m wide rib pillar. Because of the poor geological conditions, the dimensions of the longwall panels were restricted, as shown in Fig. 7. The immediate roof and floor in this district were mainly shale with some local occurrence of sandstone in the roof. Again, the strength of the immediate floor and roof rocks deteriorated with the presence of water.

Measuring Technique

Convergence measuring stations were used to measure vertical closure in the gateroads during extraction of adjacent longwall panels. Marks were installed both in the roof and the floor of the roadways. Roadway closure was determined by the following two methods:

1) Telescopic scale measurements (reading to 1mm)

<table>
<thead>
<tr>
<th>Table 1 Mechanical properties of coal.</th>
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<td></td>
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<tr>
<td>Seam (ft)</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>18ft Upper</td>
</tr>
<tr>
<td>18ft Lower</td>
</tr>
<tr>
<td>4ft</td>
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</tbody>
</table>

$S_u$: Uniaxial compressive strength. $S_b$: Brazilian tensile strength. $E_0$: Tangent Young's modulus at 10% of peak stress.

11th International Conference on Ground Control in Mining. The University of Wollongong, N.S.W., July 1992.
2) Dial gauge measurements (reading to 0.001 mm) for a period of between 10 and 60 minutes.

The vertical closure rate on mm/day of gateroad was determined by extrapolation of the results of dial gauge measurements. These measurements were carried out during the roadway drivage and longwall mining.

Results and Discussion

Fig. 8 illustrates a general trend of the vertical closure in gateroad during its operative life. The graph shows a rapid increase in the rate of vertical closure during the initial stage of roadway drivage stage. This rate of closure reduces with time, reaching a total value of $VC_q$.

Fig. 6 Study site of the North Section of the Hikishima area employing a 10-m-wide rib pillar

Fig. 7 Study site of the South section of the Hikishima area employing a 10-m-wide rib pillar
The second increased rate of closure, \( VC_1 \), occurs with the start of the first longwall retreat face. The third and final increased rate of closure takes place with the mining of the second adjacent longwall panel. The total value of \( VC \) of gateroad closure is:

\[
VC = VC_0 + VC_1 + VC_2
\]

After using the passage of the second longwall face, the gateroad cannot be used.

When the roadway is driven under weak strata and high stress conditions, the deformational behaviour of roadway with respect to time cannot be disregarded. The stability of the roadway and support system is estimated by the magnitude of vertical closure or the rate of vertical closure.

Fig. 9 shows the vertical closure rate of the gateroad during development. Roadways driven by a roadheader deform less than those driven by a drilling and blasting method. However, under poor strata conditions, there is no significant difference between them, due to the deterioration of the surrounding strata by the presence of water. The effect of the damaged zone created by blast vibrations is offset by the remarkable strain deterioration with ground water. The effectiveness of machine drivage cannot be seen in the results obtained of deformational behaviour of the roadway. However, if the magnitude of the deformation is within an allowable limit and repair work is not incurred, the validity of employing the heading machine can be found in the rapid drivage rate which reduces costs.

As shown in Fig. 9, gateroads employing the rib pillar show similar behaviour under good and poor strata conditions. It is difficult to find a clear difference in deformational behaviour between the conventional gateroad and gateroad with rib pillar. However, the closure rate of the gateroad driven in the side abutment pressure zone is larger than that of the gateroad driven without interaction from adjacent longwall mining. If the closure rate is less than 10mm/day at 50m behind the heading face, the drivage vertical closure (\( VC_0 \)) would be less than 20cm showing a stable condition. At this stage, there is not clear difference between the results from employing the 10m wide pillar and the 15m wide pillar.

Fig. 10 shows the vertical closure rates during mining of the 1st longwall panel. Although there is a fairly wide scatter in the values plotted, characteristics of the deformation of the gateroad affected by the longwall mining can be seen. Roadway closures increase at 20-30m in advance of the face-line, owing to the front abutment pressure. After the passage of the face, the closure rate increased rapidly with the presence of the side abutment pressure, and then decreased to almost zero within 100m of the face line. In the faulted zone, the roadway suffered...
installation of fully resin-grouted wood dowels. Owing to this measure, the pillar created neither serious spalling nor showed signs of spontaneous combustion.

Fig. 11 illustrates the vertical closure rate during extraction of the 2nd longwall panel. Although there is a wide scatter in the plotted values, the general trend of influence of the approaching 2nd longwall face on the overall gateroad stability is evident. The gateroad was affected within 30-40m ahead of the 2nd face-line, and the vertical closure reached over 1.0m at the face-line. In order to keep the necessary height and width of the gateroad, dining work was carried out.

FINITE ELEMENT ANALYSES

Finite Element Modelling

Finite Element Modelling was used to clarify the effectiveness of an interpanel-pillar system on controlling vertical closure. Fig. 12 shows the details of the model used in this study. CST triangular elements were used under plane strain condition. Due to symmetry, only one half of the model, namely the left hand side of the model, was considered. The width and height of the rectangular gateroad was 5 m and 3 m respectively. The working thickness and panel width was 3 m and 140 m respectively. The initial ground pressure of pre-mining (or in-situ stress existing in the strata where longwall mining is to be conducted) was assumed to be hydrostatic in nature and a hydrostatic stress condition has a magnitude equal to the depth times the unit weight of the strata. Additional stress was applied to the top of the finite element model to represent the additional overburden. The working depth is
The analysis was carried out in three steps. Firstly, the initial stress conditions were set, then the gate road was driven and finally, the longwall panel was extracted. These operations were simulated by evaluating 400m in the analysis.

The stresses along the potential surface of the excavation, computing the equivalent forces at the nodes of the finite elements along the excavated surfaces and reversing the signs of these nodal forces when applying them to the finite element mesh. The forces were applied incrementally.

The coal, roof and floor rocks were assumed to behave in a linearly elastic manner until their failure. Mohr's theory of yielding was adopted as the failure criterion. This theory postulates that the material will fail when:

\[ \tau^2 = (\frac{S_y}{S_t} + 1 - \frac{2}{S_t}) \]  
\[ \sigma \]

is satisfied (\( \tau \) and \( \sigma \) are the shear and normal stress, \( S_y \) and \( S_t \) are the uniaxial compressive and tensile strength). Excessive stresses in the failure zone are redistributed by means of an iterative procedure. All elements in the failure zone were assigned a new Young's modulus with the value equal to one-hundredth of its original value and 0.45 for Poisson's ratio.

In this modelling, two geological conditions were considered. One was with the roof and floor rock, having the same properties, being greater than those of the coal seam. The other was for the weak immediate floor, of 3m thickness, having the same properties as the coal seam. The mechanical properties of the coal and rock used in this analysis are listed in Table 2.

Table 2 Mechanical properties of coal and rock used in the finite element analysis.

<table>
<thead>
<tr>
<th></th>
<th>Young's modulus (GPa)</th>
<th>Poisson's ratio</th>
<th>Compressive strength (MPa)</th>
<th>Tensile strength (MPa)</th>
<th>Unit weight (kN/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>rock</td>
<td>Eᵣ = 1.0</td>
<td></td>
<td>19.9</td>
<td>1.0</td>
<td>25</td>
</tr>
<tr>
<td>coal</td>
<td>Eᵣ = 0.5</td>
<td></td>
<td>5.0</td>
<td>0.5</td>
<td>15</td>
</tr>
</tbody>
</table>

Fig. 13 Failure zone around gate road under different rib pillar condition

Fig. 14 Failure zone around gate road under different rib pillar condition with weak immediate floor
surrounding strata around the gateroad under different pillar widths. Increasing the pillar width reduces the development of the failure zone. As shown in Fig. 13, with \( W_p = 5 \text{m or } 10 \text{m}, \) the rib pillar fails totally after longwall mining. With \( W_p = 10 \text{m or } 15 \text{m under weak floor conditions}, \) Fig. 14 shows that, in addition to a totally failed pillar, a large failure zone develops under the pillar causing excessive floor heave. In order to improve this severe situation, a narrower yield pillar or a wider stiff pillar could be employed as shown in the case of \( W_p = 5 \text{m or } 10 \text{m}. \) When the narrower rib pillar is employed, the gateroad is less stable than one employing the wider pillar. Therefore, severe splitting of the pillar and the coal rib would have to be controlled by using an appropriate support system.

In order to establish the optimum pillar design method support system, the following factors should be taken into consideration. They include the post-failure behaviour of roof, floor rocks and coal seam, the mechanism of caving in the mined-out area, and operational conditions concerning the adjacent longwall panel.

Fig. 15 shows the failure zone developing around the gateroad with a 3-m-wide face-side packing with Young's modulus \( E_{\text{pack}} = 0.5 \). A large failure zone develops in the roof and floor along the ribside, creating severe vertical closure. In order to control the excessive vertical closure, a wider and stronger packing must be employed (Matsui, 1989b). However, this leads to increasing mining cost. As shown in Figs. 13 and 14, the stability of the gateroad is improved by employing the optimum rib pillar.

CONCLUSIONS

Field measurements, observations, and FEM analyses were conducted to assess the stability of longwall gateroads employing the interpanel pillar system. Results showed that the stability of this type of gateroad is comparable to that of the conventional re-use of gateroad system. In order to establish the optimum pillar design method, including a stiff and yield pillar, more experience and field data must be obtained.

ACKNOWLEDGEMENTS

The authors would like to thank all mining engineers of the Keshima Colliery for their assistance in this research project.

REFERENCES


