PREDICTION OF GATE ROADWAY CLOSURE IN LONGWALL ADVANCE MINING

By
Raghu N. Singh and Bahityar Unver

ABSTRACT
Longwall advance mining is still the predominant system of coal extraction in the U.K., contributing to some 70% of underground coal production. Gate roadways providing access to a longwall advancing coal face are maintained adjacent to a rib pillar under high stresses, shaftmen pressures and the caving rock mass. It is very difficult to realistically model such access roadways using mathematical or numerical techniques and hence, predict roadway closure. For the past 15 years, a research group in Nottingham University has engaged in the study of longwall gate roadway stability using observation methods. Gate roadway deformations have been measured in 224 gate roadways and a comprehensive database has been established. The paper describes the statistical analysis of this database and presents some predictive equations which will enable a forecast of the gate roadway closure to be made. Further field work to validate these equations is described together with an error analysis. The results are very promising and indicate that it is possible to predict gate roadway closure in the U.K. within practical limits of accuracy.

INTRODUCTION
The location of gate roadways in the vicinity of highly stressed strata and caving ground behind a longwall face presents the most difficult stability problem in underground coal mining. The stability status of a gate roadway can be evaluated by several techniques, but practical closure measurements are the most useful form of data to predict the deformational behaviour and thus, optimize design. The closure of the gate roadways are not somewhat unexpected, but many roadways fail, in the sense that closure prevents their functioning as intended. A distorting operation may be all that can be done to restore temporarily the full operational capability. Critical deformation of gate roadways has been accepted as a criterion of stability in the U.K. (Whittaker and Batchelor, 1972), West Germany (Remmer, 1977), and in France (Tibérianski, 1979). Statistical prediction from a database as distinct from a theoretical analysis is a method which is purely based on past experience and field work and is capable of giving reliable results in analogous conditions. The purpose of this work is to provide an easy but reliable design tool for mining engineers.

PAST WORK
Researchers have attempted to establish a comprehensive means of closure prediction other than theoretical analyses in France, W. Germany and in the U.K. The formulae developed in France and in W. Germany are difficult to apply in the U.K. because of different mining and geological conditions and different techniques for measurements and analysis of gate roadway closure, (Wells and Singh, 1985). Roof bolting is the basic means of support in France, due to the differences of strata control conditions, the applicability of Tibérianski's predictive equation in the U.K. coal mining conditions seems to be difficult. In W. Germany, the advance heading system of gate roadway formation is predominant (over 60%) and over 95% of roadways are supported by TH arches (German Telescopic Arches). Other geological and roadway design parameters do not change to a great extent. It is, therefore, possible to generalize and establish an empirical relationship representing roadway closure and use it for the roadway design in W. Germany. In the U.K., strata behaviour, roadway design parameters, geological environment, method of roadway formation and support types vary considerably. Hence, it is necessary to develop separate
empirical predictive equations to suit U.K. conditions.

This work is basically a continuation based on the closure measurements and statistical analysis technique presented by Wells and Singh (1985). However, the following points should be further examined to make the closure prediction approach more efficient.

1- Validation of the predictive equations by comparing measured and predicted closures.
2- Adding more data to the database, where the data is not enough to generalize the effect of variables.
3- Examination of the role of individual factors on roadway closure.

DEVELOPMENT OF THE DATABASE:

The present study is based on closure measurements in the Midlands Coalfield of the U.K., originally presented by Whittaker, Singh and Nazine (1978), and has been updated by the authors. Measurements have been taken from 224 gate roadways in 31 different coal seams from 41 coal mines. The roadway deformation measurements are drawn on a graph to observe the real behaviour and to compute various measures of closure. Information regarding various roadway design parameters, support types, geological conditions and abnormal conditions contributing to roadway stability are also recorded. The roadway deformation data analysis sheet includes almost all of the factors affecting the gate roadway closure. Data from this database has been written into a computer file by using indices instead of alphanumerical characters. Data manipulation and retrieval facilities have been incorporated into a sophisticated computer program.

In this paper the method of analysis of the roadway deformation survey data is similar to that proposed by Wells and Singh (1985). A revised summary of the database is presented in Table 1.

STATISTICAL ANALYSIS OF THE DATABASE

The general statistical package Minitab was used for manipulating the data, and elementary statistical techniques may be referred to the Minitab Manual, Minitab Students Handbook, or in a standard statistics text-book (Chatfield, 1978). The entire data was reanalysed using factor analysis. Frequency plots of the each variable have been examined to see the type of the distribution. It was deduced that most of the variables were approximately normally distributed, except rib pillar width which followed a log-normal distribution. Linear relationships, if there was any relationship in reality, were determined by the scatter plots of independent / dependent variable pairs. The coefficient of correlation provides a measure of the degree of relationship.

Table 1. Summary of observations used in roadway deformation surveys.
(Wells and Singh 1985 as modified by authors)

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Continuous Range</th>
<th>Mean</th>
<th>Stan. Dev.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extracted Seam lit.</td>
<td>0.73 - 2.87</td>
<td>1.454</td>
<td>0.414</td>
<td>m</td>
</tr>
<tr>
<td>Depth of Working</td>
<td>59 - 921</td>
<td>492</td>
<td>199.8</td>
<td>m</td>
</tr>
<tr>
<td>Face Length</td>
<td>100 - 298</td>
<td>209</td>
<td>35.4</td>
<td>m</td>
</tr>
<tr>
<td>Rib Pillar Width</td>
<td>0 - 91.7</td>
<td>91.7</td>
<td>28.3</td>
<td>m</td>
</tr>
<tr>
<td>Rib-side Pack Width</td>
<td>0 - 6</td>
<td>1.06</td>
<td>1.52</td>
<td>m</td>
</tr>
<tr>
<td>Face-side Pack Width</td>
<td>0 - 20</td>
<td>3.96</td>
<td>2.75</td>
<td>m</td>
</tr>
<tr>
<td>Roadway Height</td>
<td>1.64 - 4.10</td>
<td>3.15</td>
<td>0.49</td>
<td>m</td>
</tr>
<tr>
<td>Roadway Width</td>
<td>2.60 - 5.10</td>
<td>4.01</td>
<td>0.44</td>
<td>m</td>
</tr>
<tr>
<td>Rate of Advance</td>
<td>155 - 800</td>
<td>489</td>
<td>114</td>
<td>m/year</td>
</tr>
<tr>
<td>Initial Cross-sec. Area</td>
<td>4.90 - 17.7</td>
<td>10.8</td>
<td>2.25</td>
<td>m2</td>
</tr>
<tr>
<td>Face-side Pack Strength</td>
<td>0 - 4</td>
<td>1</td>
<td>-</td>
<td>Index</td>
</tr>
<tr>
<td>Rib-side Pack Strength</td>
<td>0 - 4</td>
<td>3</td>
<td>-</td>
<td>Index</td>
</tr>
<tr>
<td>Roof Strength</td>
<td>4 - 8</td>
<td>6.12</td>
<td>-</td>
<td>Index</td>
</tr>
<tr>
<td>Floor Strength</td>
<td>4 - 8</td>
<td>7.02</td>
<td>-</td>
<td>Index</td>
</tr>
<tr>
<td>Support Spacing</td>
<td>0.6 - 1.25</td>
<td>0.96</td>
<td>0.15</td>
<td>m</td>
</tr>
</tbody>
</table>

*Excluding solid rib pillar cases.

The AusIMM Illawarra Branch, Ground Movement and Control related to Coal Mining Symposium August 1986 160
Closure Prediction by Means of Equations

Recorded data has been analysed by means of statistical techniques to get predictive equations of closure, considering the major effective factors. A continuous independent variable may have a high correlation with a dependent variable, but its effect on that variable is negligible. Similarly, the discrete variables found to have an effect on closure may be necessarily be significant for the purpose of closure prediction. Regression analyses have been carried out on vertical closure and other variables by comparing regression coefficients and constants, correlations and amounts of variance explained among the variables to find the best predictive regression equations. The modified predictive equations and their correlations are shown in Table 2. For example, vertical closure of gate roadways which are formed by the half heading system of gate roadway formation without solid rib pillar can be predicted as follows:

\[ V = 0.354 \times (\text{Extracted Seam Height}) + 0.0022 \times (\text{Depth Below Surface}) - 0.0017 \times (\text{Rib Pillar Width}) + 0.24 \times (\text{Roof Strength Index}) + 0.355 \times (\text{Floor Str. Index}) - 4.35 \] (1)

The rib pillar width has found to be an important variable for the prediction of closure and it has been divided into two groups as normal and solid rib pillars, due to the difficulty of assigning numbers to solid rib pillar widths. The natural logarithm of rib pillar width has given a better correlation in conventional, in-line and mechanised ripping gate roadway formation techniques.

In the case of advance headings, closure was found to be decreasing with increasing extracted seam height and the correlation coefficient between the extracted seam height and vertical closure is -0.19, whereas, it has a value of 0.60 for conventional ripping. The anomaly of this situation may be attributed to the fact that, high stress concentrations on advance headings can not be easily taken into account.

| Table 2. Vertical closure prediction equations obtained by multiple linear regression. |
|---|---|---|---|---|---|---|
| Gate Roadway Formation method | Pillar | Extracted Seam Height | Depth | Rib Pillar Width | Roof Strength Index | Floor Strength Index | Begr. Const. Correlation |
| Advance Heading | Normal Rib Pillar | -0.0270 | 0.0001 | -0.0014 | -- | -0.0619 | 1.960 | 0.60 |
| Solid Rib Pillar | -0.5850 | 0.0006 | -- | 0.0094 | -- | 1.460 | 0.41 |
| Conventional R. | Normal Rib Pillar | 0.7110 | 0.0008 | -0.0145* | 0.0418 | 0.0516 | -0.836 | 0.75 |
| Solid Rib Pillar | 0.6100 | 0.0004 | -- | 0.1210 | 0.0528 | -1.290 | 0.65 |
| Half Heading | Normal Rib Pillar | 0.3540 | 0.0022 | -0.0017 | 0.2400 | 0.3550 | -4.350 | 0.96 |
| Solid Rib Pillar | 0.2760 | -0.0001 | -- | 0.3870 | 0.1500 | -2.590 | 0.48 |
| Mechanised R. | Normal Rib Pillar | 1.0400 | -0.0017 | -0.0020 | -- | 0.3820 | -2.090 | 0.71 |
| Solid Rib Pillar | 0.4580 | -0.0002 | -- | 0.4540 | 0.2760 | -4.130 | 0.56 |
| In-line Ripping | Normal Rib Pillar | 0.0390 | 0.0001 | -0.0294* | 0.1140 | 0.2160 | 0.859 | 0.80 |
| Solid Rib Pillar | 0.3090 | 0.0003 | -- | 0.0849 | -0.0987 | 0.668 | 0.47 |
| Normal Rib Pillar | -0.0397 | 0.0010 | 0.0006 | 0.0470 | -0.6740 | 4.340 | 0.82 |
| Solid Drivage | Solid Rib Pillar | 0.2160 | 0.0023 | -- | -0.1240 | -- | 0.489 | 0.79 |

*Coefficient of \( \ln (\text{Rib Pillar Width}) \)

P.S. Not enough data to make an analysis for re-used roadways.

The AustIMM Illawarra Branch, Ground Movement and Control related to Coal Mining Symposium August 1986

161
VALIDITY OF THE PREDICTIVE EQUATIONS

The validity of predictive equations can be evaluated by the following two methods:

(i) by the comparison of measured and predicted closure values,
(ii) by applying them to real case histories.

Correlation of predicted and actual closure values for the half heading system with normal rib pillar cases is shown in Figure 1. As it can be seen from the figure, predicted results are very promising and close to actual values. The correlation coefficient of points has been found to be 0.96 which is very significant indeed.

It is impossible to obtain the precise value of closure underground even though it is measured by various techniques. Numerous factors, such as the anisotropy of surrounding rock, different geological features and interactive stress conditions, affecting the closure cause underground closure measurements to fluctuate along the roadway. The roadway closure for this purpose has been defined by Mittal and Singh, (1981). The amount of closure is considered as the maximum on the regression line between vertical closure and distance to face line.

Figure 2, shows the results of vertical closure measurements on 406's tailgate in Hem Heath Colliery in the
Midlands Coalfield. It is easy to deduce the nature of the closure from this graph, that the lowest value of vertical closure is around 2.0 m, whereas, the highest value is approximately 2.97 m. This means if the predicted value is between these closure values, it can be marked as a good prediction. The details of 406's tailgate chosen for validation studies are given below:

Colliery = Hem Heath,
Seam = Winghay Seam,
Formation Method = In-line ripping
Depth = 722 m,
Extracted Seam Height = 2.6 m,
Rib Pillar Width = 15 m,
Floor Index = 6

The measured closure was 2.75 metres which is 75% of initial roadway height. The equation for predicting vertical closure for the In-line ripping system with normal rib pillar is given by:

\[ V = 0.839 \times E + 0.0001 \times D + 0.0234 \times \ln(W) + 0.114 \times B - 0.216 \times F + 0.859 \]  (2)

The predicted closure obtained from above equation is 2.75 metres. The lowest point on the graph is about 2 metres, whereas, the actual closure is 2.75 metres. The predicted closure being lower than the actual closure might be due to, firstly, the interaction of remnant pillars in the above seams, or secondly, a narrow width of the rib pillar, thirdly, the use of stilts in soft floor conditions.

Closure in the maingate of the same face, as shown in Figure 3, is considerably smaller than tailgate closure. 406's maingate details at Hem Heath Colliery, Winghay Seam, can be summarised as below:

Formation Method = Half heading
Rib Pillar = Solid rib pillar

The vertical closure prediction equation of the half heading formation method with a solid rib pillar, (Table 2) is given as follows:

\[ V = 0.276 \times E + 0.0001 \times D + 0.387 \times R + 0.150 \times F - 2.59 \]  (3)

The vertical closure is predicted as 1.32 metres by the predictive equation 3, whereas, the measured vertical closure was 0.76 metre. The mean value of vertical closures of 224 cases is 1.071 metres, where the range is 0.15 - 2.80 metres. In fact, the measured amount of closure is quite low when it is compared with mean and predicted closure values. The nature of closure as seen from Figure 3, is very uniform. It might be contributed to the absence of geological abnormalities.

The authors have selected these two extreme cases to show the significance of predicted closure. In most of the cases the predicted and actual closures are surprisingly, very comparable.

ANALYSIS OF IMPORTANT VARIABLES AND THEIR INFLUENCE ON GATE ROADWAY CLOSURE

Method of analysis

The effect of variables was analysed by changing the predictive equation as dependent on only one variable, by assuming the other variables to have their average values. A second analysis was made on the same conditions considering maximum and
minimum values of another variable to
determine the effect range. This method of
analysis is detailed in a subsequent section

Factors Affecting the Closure

1- Strength of Roof

As it has been stated before, the
effect of roof strength is very important on
closure. Referring to Figure 4, the effect
of roof strength on closure is of great
importance in the case of the half heading

![Graph](image)

1- Very weak floor,
2- Mean values of the variables,
3- Strong floor.

Figure 4. Effect of roof strength on vertical closure in different floor
conditions, (Half heading with normal rib pillar)

2- Strength of Floor

Figure 5. is somewhat different to
Figure 4, in such a way that, as far as the

![Graph](image)

1- Very weak roof,
2- Mean values of the variables,
3- Strong roof.

Figure 5. Effect of floor strength on vertical closure in different roof
conditions, (Half heading with normal rib pillar)
half heading is concerned, the effect of roof strength seems to be dominant over the effect of floor strength. When the roof is very strong, the predictive equation does not result in any closure for that particular roadway. In fact, this is an impossible situation. Predictive equations should be accepted to give significant results when the values of variables are close to the mean.

3- Extracted Seam Height

The extracted seam height has a significant effect on closure, except in the case of the advance heading formation method. The influence of extracted seam height can be seen clearly for conventional ripping gate roadway formation system in Figure 6. The relationship is an increasing

![Graph showing the effect of extracted seam height on vertical closure in different depth conditions.](image)

Figure 6. Effect of extracted seam height on vertical closure in different depth conditions, (Conventional ripping with normal rib pillar)

![Graph showing the effect of depth below surface in different roof and floor conditions.](image)

Figure 7. Effect of depth below surface in different roof and floor conditions, (Conventional ripping with normal rib pillar).

The AusIMM Illawarra Branch, Ground Movement and Control related to Coal Mining Symposium August 1986
vertical closure with increasing extracted seam height. The effect of depth below the surface is also shown on the same graph. A difference in closure of 0.8 metre may occur between a mine which is shallow and a mine which is deep.

4- Rib Pillar Width

The rib pillar width is probably the most difficult variable to model, because of so many parameters affecting its influence on closure. Detailed analysis of the rib pillar width on gate roadway closure has been considered by Whittaker and Singh, (1981).

5- Effect of Depth in Various Roof and Floor Conditions

Figure 7, indicates the effect of depth below surface for different roof and floor conditions, for roadways formed by the conventional ripping system with a normal rib pillar. Various combinations of roof and floor conditions are shown on the graph itself. Although it is very difficult to find a situation with extreme cases, such as very strong roof and weak floor or vice versa, they are included on the graph to get a general idea. Lines numbered as 1, 2 and 6 are the most realistic cases in the U.K. Midlands Coalfield.

DISCUSSION

The amount of closure must be taken into consideration by design engineers when designing a support system for a gate roadway. For example, if the closure is thought to be about 7 metres, roadway height should be at least 3.8 metres to leave 1.8 metres of roadway height as stipulated in the U.K. coal mines regulations. If the profile of the roadway becomes unsuitable to continue working, dinting is the only way to gain full operational capability of the roadway again. A gate roadway should be designed in such a way that no dinting is required to make the deformed roadway operational, because dinting operations promote further closure. Some cost analysis studies were done at Nottingham University Mining Engineering Department, proving the cost of repair could exceed the construction cost of the roadway by four times. (Miller, 1981). Accuracy of the predicted closure is, therefore, of great financial importance.

Selection of parameters used in the predictive formulae basically depends on the experience gained from past work, in the U.K. The variation of these parameters are so great within the strata in the immediate vicinity of the underground roadway that, to obtain all of them could be very difficult. Judgement should be made about their values by the designer. Hence, it is basically a result of knowledge of the in-situ stress combined with experience.

In order to increase the significance of predictive equations, roof and floor indices should be determined by using a rock mass classification system. In addition to this, the effect of interactions from other workings should be included in the analysis.

CONCLUSIONS

Main conclusions from this study can be summarised as follows:
- More case histories should be added to database to emphasize the effect of some presently unreliable variables.
- Vertical closure predictive formulae should be accepted to give significant prediction only in cases with variables close to mean values. Significance of prediction of closure with extreme variables should be regarded as low.
- Instead of looking for the effect of depth below surface which is unreliable with present data, the stress conditions around the gate roadways should be thought as more important.
- Correlation coefficients between measured and predicted closure values should be taken into consideration before using a particular formula.

ACKNOWLEDGEMENT

The authors would like to thank Professor T. Atkinson, Head of the Department of Mining Engineering, University of Nottingham, for his encouragement and to all the individuals who contributed to the compilation of this data over the past fifteen years.

REFERENCES

Kremer, M. (1977) Die ausbeulang durch vorausberechnung endkonzentraier in all-us trecken mit einem RV program, Gluckauf 116 3-8