Chapter 5.0

Evaluation of geotechnical classification techniques to design coal mine roofs

5.1 Introduction

Rock mass classification systems have constituted an integral part of empirical mine design for over 100 years, Ritter (1879). The use of such systems can be either implicit or explicit. They are traditionally used to group areas of similar geotechnical characteristics, to provide guidelines of stability performance and to select appropriate support. In more recent years, classification systems have often been used in tandem with analytical and numerical tools. There has been an increase of work linking classification indexes to material properties such as modulus of elasticity, the m and s parameters in the Hoek and Brown (1988) failure criterion, etc. These values are then used as input parameters for numerical models. Consequently, the importance of application of rock mass characterization methods has increased over time. The primary objective of all classification systems is to quantify the intrinsic properties of the rock mass based on past experience. The second objective is to investigate how external loading conditions acting on a rock mass influence its behaviour. An understanding of these processes can lead to the successful prediction of rock mass behaviour for different conditions.

The earliest reference to the use of rock mass classification for the design of tunnel support is by Terzaghi (1946) in which the rock loads, carried by steel sets, are estimated on the basis of a descriptive classification. Since Terzaghi (1946), many rock mass classification systems have been proposed, the most important of which are as follows:

- Lauffer (1958)
- Deere (1970): Rock Quality Designation, RQD
- Wickham et al. (1972): Rock Structure Rating (RSR – Concept)
- Bieniawski (1973): Geomechanics Classification, Rock Mass Rating
- Barton et al. (1974): Q- System
- Buddery and Oldroyd (1992): Impact splitting Test
- Molinda and Mark (1994): Coal Mine Roof Rating

Most of the multi-parameter classification schemes by Wickham et al. (1972), Bieniawski (1973, 1989) and Barton et al. (1974) were developed from civil engineering case histories in which most of the components of the engineering geological character of the rock mass were included. Studies of these systems have shown that their main application is for both hard and soft jointed rock masses. Several classification systems have been developed and modified for underground coal mining. Many mines locally and abroad have been using locally developed classification systems to determine the roof qualities and support systems that are in most cases not well documented and are restricted to the developer of such systems or the mine on which the system was developed. Furthermore, these systems cannot be compared with one another or results converted to an equivalent rating in another mine. In this Chapter, the application of CMRR in South African collieries is reviewed and evaluated against locally used impact splitting test developed by Oldroyd and Buddery (1992). The aim of this assessment is to evaluate rating system that is most appropriate for South African coal mines to design roof support systems.

Several authors in the past summarised the widely used rock mass rating systems, which are utilised in Civil Engineering tunnelling and in gold and platinum hard rock mines. These summaries can be found in the following references:

- Hoek, (2007)
- Swart (2005)
- Guler et al. (1998)
- Singh and Goel (1992)
- Milne et al (1998)
- Milne (1988)

5.2 Coal Mine Roof Rating (CMRR)

Molinda and Mark (1994) have developed the Coal Mine Roof Rating (CMRR) classification system to quantify descriptive geological information for use in coal mine design and roof support selection. This system results from years of geologic ground control research in longwall mines in the United States. The CMRR weights the geotechnical factors that determine roof competence, and combines them into a single rating on a scale from 0-100. The characteristics of the CMRR are that it:

- Focuses on the characteristics of bedding planes, slickensides, and other discontinuities that weaken the fabric of sedimentary coal measure rock.
- Applies to all U.S. coalfields, and allows a meaningful comparison of structural competence even where lithologies are quite different.

- Concentrates on the bolted interval and its ability to form a stable mine structure.
- Provides a methodology for geotechnical data collection.

The principle behind the CMRR system is to evaluate the geotechnical characteristics of the mine roof instead of the geological description. CMRR emphasizes structurally weak or strong units instead of geologic divisions. The structure of the system is similar to RMR (Bieniawski, 1973) system in that the important roof parameters are identified, their influence on roof strength is quantified and the final rating is calculated from the combination of all the parameters. Figure 5-1 shows the parameters that compose the CMRR system. The system is also designed such that the final rating/unsupported span/stand-up time relationship is comparable to that of the RMR. However, the CMRR is intended to be a universal system for coal mining and to initially exclude time-consuming and expensive laboratory analyses. Later, Molinda and Mark (1999) documented a revised approach that takes into consideration the Point Load Test.

An important attribute of the CMRR is its ability to rate the strength of bedded rocks in general, and of shales and other clay-rich rocks in particular. Layered rocks are generally much weaker when loaded parallel to bedding, and the CMRR addresses both the degree of layering and the strength of the bedding planes. In addition, the CMRR has been modified by Molinda and Mark (1999) to retain its ability to identify those rocks that are most susceptible to horizontal stresses.

Data gathering for the system relies only on observation and simple contact tests using a ball peen hammer, a 9 cm mason chisel, a tape measure and sample bags. All the data is recorded in a designed data sheet that is used to calculate the final rating. The calculation is based on rating the exposed roof that is divided into structural units. Each unit is rated individually, mainly on an evaluation of the discontinuities and their characteristics. Next, the CMRR is determined for the mine roof as a whole. The ratings of the units within the bolted interval are first combined into a thickness-weighted average. Then a series of roof adjustment factors are applied with the most important being that of the strong bed. It was found by the developers of the system that the structural competence of a bolted mine roof is largely determined by its competent member. All the parameters are then combined to calculate the final CMRR.

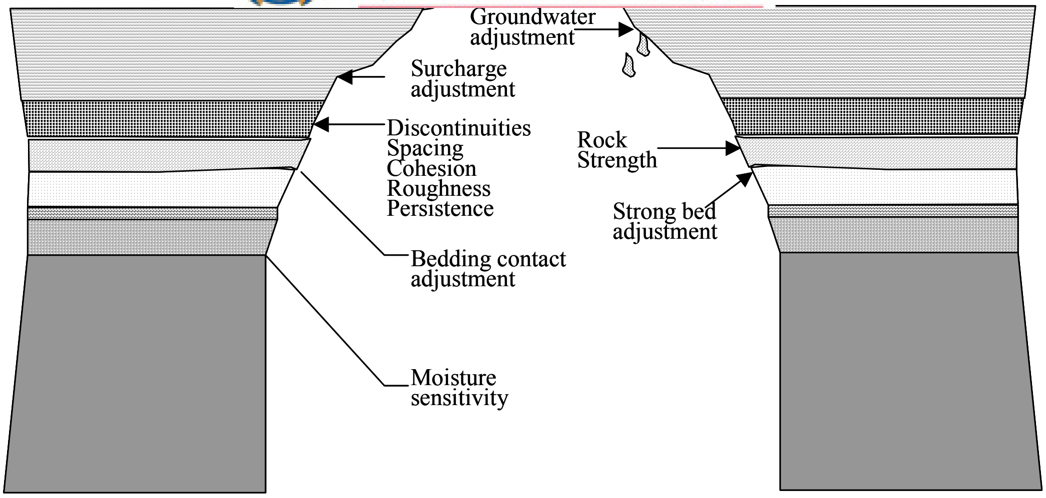

Figure 5-1 Components of the CMRR system (after Mark and Molinda, 1994)

The following is a summary of the factors that contribute to the final unit rating value:

a) Compressive strength of intact rock: The ball peen hammer test is used to place rock into five classes, depending on the nature of the indentation.
b) Cohesion of discontinuities: The strength of the bond between the two faces of a discontinuity is estimated by observation of roof behaviour, assisted by the chisel test.
c) Roughness of discontinuity: The surface of the discontinuity is classified as “rough”, “wavy”, or “planar” by observation.
d) Intensity of discontinuities: The average observed distance between discontinuities within a unit.
e) Persistence of discontinuity: The observed areal extent of a discontinuity plane.
f) Moisture sensitivity: Estimated from an immersion test, and only considered if significant inflows of groundwater are anticipated or if the unit is exposed to humid mine air.

After the individual unit ratings have been determined, they are summed into a single rating for the entire mine roof and adjustments are applied from the tables by taking account of the following:

- Strong beds in the bolted interval
- Number of lithologic units contacts
- Groundwater and
- Surcharge

Mark et al. (2002) modified the original CMRR described above because it could not be applied before any mining has taken place i.e. for pre-planning, as it requires underground observations. An entirely new system was developed to determine the CMRR from exploratory drill core using the Point Load Tests (PLT) to determine the strength parameters that account for approximately 60% of the final rating. The new system uses both diametral (parallel to bedding) and axial (perpendicular to bedding) PLT's. The diametral tests allow the estimates of bedding plane cohesion and rock anistrophy, both of which are critical to estimating susceptibility to horizontal stresses. Traditional core logging procedures are used to determine discontinuity spacing and roughness. To ensure compatibility with the original CMRR, the new rating scales were verified by comparing drill core results with nearby underground mining exposures.

A large database of strength ratings of rocks has been assembled through extensive point load testing and logging in the United States. Over 2000 PLT (both axial and diametrical) have been made on common coal measure rock types from mines representing most U.S. coal fields.

The CMRR has been determined for 97 roof exposures from 75 coal mines across the United States by Molinda and Mark (1994). All of the major U.S. coal basins are represented, with sizes ranging from small new mines to some of the largest longwall operations. The data has been partitioned to reflect the following three broad classes of roof based on a scale of 0-100: weak (0-45), moderate (45-65), and strong (65-100). Table 5-1 shows the CMRR classes with corresponding geological conditions.

Table 5-1 CMRR classes in the U.S. (after Mark and Molinda, 1994)

CMRR Class	CMRR Region	Geological Conditions
Weak	0-45	Claystones, Mudrocks, Shales
Moderate	45-65	Siltstones and Sandstones
Strong	65-100	Sandstones

CMRR has been integrated into support design programs such the "Analysis of Longwall Pillar Stability (ALPS)" program in calculation of safety factors for given coal pillar sizes based on applied loads and strength of the pillar. A similar case study in Australia by Colwell et al. (1999) has used the CMRR to develop a new methodology for chain pillar design called the "Analysis of Longwall Tailgate Serviceability (ALTS)". In both cases, statistical analysis from case histories of CMRR values have been used in conjunction with existing pillar design formulae to develop a relationship between the stability factor and roof qualities. The combination of CMRR with empirical formulae has improved the accuracy of design of gate road systems in the U.S. by integrating case histories developed through in-mine data collection techniques with numerical modelling and empirical pillar design formulae.

Mark (1999) documented the application of the CMRR to South African strata conditions since it was first introduced to the coal mining industry in 1998. Since that time, the system has been used on a limited basis owing to the fact that South African coal operations have generally been conducted in good geotechnical conditions compared to other parts of the world.

Geotechnical site investigations were conducted (van der Merwe et al. 2001) at 20 falls of ground incident sites in South African coal mines. The CMRR classification system was used to classify the roof conditions at the fall sites. In addition to that, Bieniawski's Rock Mass Rating and Laubscher's Mining Rock Mass Rating were used as comparisons with the CMRR. A stress damage survey was also undertaken to relate rock mass damage to the horizontal stress regime. In addition, a coal cleat damage was done to relate maximum horizontal stress direction to cleat orientation. All CMRR values obtain from the underground mapping sites fell in the weak class i.e. on a scale 0-100, between 0-45. Many observations from the fall of ground site mappings in South Africa were found to collate with experiences gained in the United States. However, a wide range of CMRR values were noted in some areas where roof conditions deteriorated in close proximity to major dykes or sills.

In another study by van der Merwe et al. 2001, further CMRR classification studies were carried to create a geotechnical database of the South African coal fields. The following conclusions with respect to CMRR values for South African coal mines were made:

- Roof shale's were generally within the range of 0-45 (weak)
- Sandstones were generally above the CMRR value of 45 (moderate to strong)
- Siltstones generally fell in the moderate CMRR range (45-65)

These observations correlate closely to Mark's (1994) work that siltstones and sandstones in the U.S. were moderate to strong. The CMRR has been found to be robust enough to classify and describe the roof conditions that are found in South Africa and that it was easy to learn the technique.

However, despite these advantages, in some cases the CMRR values gave a wide range in areas of high horizontal stresses and in proximity of major geological features. In one case the method over rated roof conditions (CMRR=55) in an area where orientation of major/minor geological features resulted in roof collapses due to its inability to cater for these in the unit contact adjustment van der Merwe et al. (2001).

5.2.1 Evaluation of CMRR

Both CMRR underground and drill core CMRR have been tested as part of this study at three South African collieries.

During this study, the greatest difficulty experienced underground with the trials of CMRR was to find nearby roof exposures with sufficient height. It was sometimes possible where there were air crossings, however, most of the time in most of the sections, CMRR could not be applied. Therefore, the underground visits suggested that for quick and comparative results, a detailed rating system that requires data on roof stratification can only be used in the planning stage on borehole cores.

One other problem experienced underground was the effect of a single discontinuity which could cause significant damage to the roof. Because CMRR only took sets of discontinuities into account, it was observed that the effect of single joint together with the direction of it should be included in a coal mine roof rating system. Van der Merwe et al. (2001) showed that 37 per cent of 182 falls of ground in South African collieries, which were investigated during the course of the project, were caused by mainly single joints. It is also found that the blasting damage in the roof should be included in a coal mine roof rating system. In addition, van der Merwe et al. (2001) also highlighted that less than 10 per cent of 182 falls of ground in South African collieries were caused by high horizontal stress. Although it is not a major cause of falls of ground, an adjustment factor in a rating system to account for high horizontal stress is required.

Other important shortcomings of CMRR were the rated height into the roof and the stratigraphic position of weak layers. The first 2.0 m into the roof is usually rated in South Africa collieries. One advantage of this is that, if the rating system is used for comparison purposes, it is important to compare the same height in each rating. Also, the effect of soft layers high into the roof, even if significantly thinner than those lower in the sequence, can affect the stability of roof.

During this evaluation study, there was difficulty in comparing underground CMRR with locally developed systems owing to the fact that in the collieries visited, their systems were not developed for rating the roof, but for planning purposes. Therefore, a direct comparison between the locally used colliery-based systems and CMRR could not be carried out. However, impact splitting testing and CMRR were compared on surface using drill cores. This highlighted the shortcoming of CMRR with respect to the relative positions of stiff and soft layers in the roof. Figure 5-2 shows three different 0.9 m long cores. Each core contains three different 0.3 m long layers, namely, sandstone, shale and siltstone, but set up in different sequences, e.g. sandstone is positioned at the top, middle or bottom of the different core runs respectively.

The results obtained from the CMRR were exactly the same for all three cores. This indicated that the CMRR does not consider the position of soft or stiff layers within the roof strata. However, impact splitting tests resulted in three different ratings based on the position of stiff sandstone layer into the roof that affects the stability of the roof. This indicates that the CMRR rates the quality of roof as a whole without considering the positions of different layers in the roof, and hence the likelihood and potential severity of the instability. This has major implications in South African collieries, since in many cases the support design is based on the stiffness of the immediate roof layer. Lastly, CMRR requires skilled personnel and some degree of training.

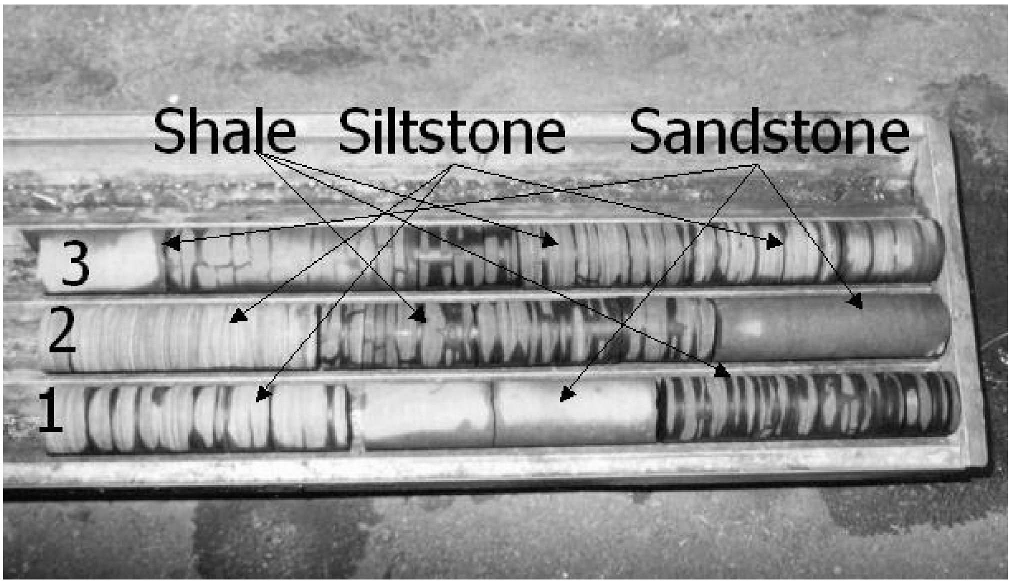

Figure 5-2 Cores used for CMRR and impact splitting testing

In summary, the shortcomings of CMRR, which were identified during the evaluation study of CMRR, are summarized below:

- Exposure into the roof is required (underground CMRR only)
- Only the bolted height is rated. In South Africa, 2.0 m into the roof is the height that is usually rated. Typical bolted heights in South Africa are less than 2.0 m.
- Although sets of joints have been considered in CMRR, single joints should also be included.
- Joint orientation is not taken into account (underground CMRR only).
- Stress adjustment is required in the rating system to account for the influence of high horizontal stress (underground CMRR only)

- No adjustment is made for the effects of blasting (underground CMRR only)
- The position of soft or hard layers into the roof is not taken into account (both underground and borehole core CMRR)
- Skilled personnel are required to carry out ratings (both underground and borehole core CMRR)
- Subjectivity in the rating is not entirely eliminated

5.3 Rating systems being used in South African collieries

5.3.1 Rating systems developed for planning purposes

Van der Merwe (2001) developed the first roof rating system in South Africa in 1980, using Rock Quality Designation (RQD). In this rating system the critical height into the roof was taken as 2.0 m. This height of the roof was initially rated with RQD. Following a splitting test conducted with a chisel at regular distances along the core, RQD was re-applied and final results were compared with the initial results. The final rating was then obtained based on the difference between the initial and final RQDs. Due to possible discrepancies resulting from the use of chisels with different geometries and forces, van der Merwe (1989) developed a standard chisel for all roof rating tests. A summary of the rating systems that have been documented for use in coal mining in South African is given in Table 5-2.

Jermy and Ward, 1988 conducted an investigation into relating geotechnical properties of various sedimentary facies to their observed underground behaviour to quantify geological factors that affect roof stability in coal mines. Twenty-four distinct facies types were determined from borehole cores from a number of collieries throughout South Africa. A database of 10 000 tests from core samples was compiled from the Waterberg, Witbank, Highveld, Eastern Transvaal, Klip River, Utrecht and Vryheid Coalfields. The results from the tests have shown that those facies with lower direct tensile strengths generally gave rise to unstable roof conditions. Furthermore, the low direct tensile strengths of the argillaceous facies were found to be very important when considering the behaviour of these rocks underground. The arenaceous facies were found to have higher average direct tensile strengths. However, the authors found that this can be reduced dramatically by the presence of argillaceous or carbonaceous partings within the rock which can affect the roof stability. Other tests that were included in the assessment were the Brazilian Strength Tests (BTS) and the Uniaxial Compressive Strength (UCS). Descriptions of sedimentary facies and a summary of their underground properties are given in Table 5-3.

Table 5-2 A summary of some classification systems used in South African coal mining and their main applications

Name of classification system	**Form and Type****	**Main Applications**	**Reference**
Roof and floor classification for collieries	Descriptive form	For quantification of geological factors that affect roof stability	Jermy and Ward, 1988
Duncan Swell and Slake Durability tests	Numerical and behaviouristic form Functional type	Quantification of floor conditions	Buddery and Oldroyd, 1992
Impact splitting test	Descriptive and behaviouristic form Functional type	Coal roof characterization and support design	Buddery and Oldroyd, 1992
CMRR	Descriptive and behaviouristic form Functional type	Coal roof characterization and support design.	Molinda and Mark, 1994
Section physical risk and performance rating	Descriptive Functional type	Classification of adherence to mine standards and physical rating	Oldroyd and Latilla, 1999

∗∗Definition of the Form and Type:
Descriptive form: the input to the system is mainly based on descriptions
Numerical form: the input parameters are given numerical ratings according to their character
Behaviouristic form: the input is based on the behaviour of the rock mass.
General type: the system is worked out to serve as a general characterization
Functional type: the system is structured for a special application (for example for rock support recommendation)

Table 5-3 Description of sedimentary facies and summary of their underground properties

FACIES	DESCRIPTION	PROPERTIES OF ROCK STRATA UNDERGROUND
1	Massive dark grey to black carbonaceous siltstone.	Very poor roof and floor strata due to low tensile strength and deteriorates rapidly upon exposure. Roof falls common and floor heave occurs when depth of mining exceeds 150 m.
2	Lenticular-bedded siltstone with discontinuous ripple cross lamination. Resembles lenticular bedding of Reineck and Wunderlich (1986).	
3	Alteration of 1 cm thick layers of flat laminated siltstone and fine grained sandstone.	
4	Flaser bedded siltstone and fine grained sandstone as described by Reineck and Wunderlich (1968).	Reasonable roof strata which deteriorates upon exposure giving rise to spalling from the roof.
5	Ripple cross laminated fine-grained grey feldspathic sandstone.	Reasonable roof strata, although localised roof falls do occur due to parting along silt drapes. Durability good.
6	Ripple cross laminated fine-grained grey feldspathic sandstone with silt drapes and grit bands.	
7	Massive fine grained greyish white feldspathic sandstone.	Very competent floor and roof strata due to low porosity and high tensile strength.
8	Fine grained greyish white feldspathic sandstone with planar/trough crossbeds.	
9	Massive medium grained white feldspathic sandstone.	Good roof and floor strata with fairly high tensile strengths. Sometimes creates problems due to poor goafing ability in stooping areas.
10	Medium grained white feldspathic sandstone with planar/trough crossbeds	
11	Massive coarse grained white feldspathic sandstone.	Good roof and floor strata. Decomposes under prolonged saturation giving rise to stability problems.
12	Coarse grained white feldspathic sandstone with planar/trough crossbeds.	
13	Intensely bioturbated carbonaceous siltstone or fine-grained sandstone.	Deteriorates rapidly upon exposure and saturation to give roof and floor instability.
14	Medium to coarse-grained feldspathic sandstone with irregular carbonaceous drapes and slump structures.	No information available.
15	Highly carbonaceous silty sandstone.	No information available.
16	Whitish brown calcrete.	Not applicable.
17	Highly weathered creamy orange to grey Beaufort (?) mudstone.	
18	Unweathered grey Beaufort (?) mudstone.	
19	Massive khaki to grey mudstone associated with diamictite.	
20	Dark greyish black gritty diamictite with angular 0-4 mm matrix supported clasts	
21	Dark greyish black pebbly diamictite with , angular matrix supported clasts > 4 mm diameter.	
22	Coal mixed dull and bright.	More stable roof rock than facies 1-3.
23	Mixed coal and mudstone.	Not applicable.
24	Massive greyish black carbonaceous mudstone associated with coal seam middling.	

Buddery and Oldroyd (1992) developed a roof and floor classification system for collieries. The following philosophy was applied in devising a suitable classification system:

- The rock property tests should be related to the expected mode of failure of the strata.
- The whole spectrum of strata should be tested with particular emphasis being placed on obtaining the properties of the weakest material.
- Large numbers of tests should be able to be conducted simply, quickly, at low cost and in-house.

Roof failure in South African coal mines is strongly related to the frequency of laminations or bedding planes. In their roof classification, Buddery and Oldroyd (1992) considered a Coal Rock Structure Rating (CRSR) system to classify the roof condition. Tests to indicate the propensity of the laminations or bedding planes to open and separate will therefore be ideal for planning. The tests should indicate the mode of failure of the roof and it should be easy for a large number of the tests to be conducted. This was initially based on three parameters: RQD, the results of impact splitting tests, and a parameter related to joint condition and groundwater. Due to the impracticality of satisfactorily distinguishing between drilling-induced and natural fractures in the coal measures strata, the RQD parameter was discarded from the system. The third parameter proved to be difficult to determine irrespective of the roof type. It was, therefore, decided to confine the determination of roof ratings to the results of impact splitting tests.

The impact splitting test involves imparting the same impact to the core at 20 mm intervals. The resulting fracture frequency is then used to determine a roof rating. The instrument shown in Figure 5-3 consists of an angle iron base which holds the core. Mounted on this is a tube containing a chisel with a mass of 1.5 kg and a blade width of 25 mm. The chisel is dropped onto the core from a constant height according to core size, 100 mm for a 60 mm diameter core and 64 mm for 48 mm diameter core. The impact splitter caused weak or poorly cemented bedding planes and laminations to open, thus giving an indication of the likely *in situ* behaviour when subjected to bending stresses.

Figure 5-3 The Impact splitting equipment

It is suggested that, when designing coal mine roof support, 2.0 m of strata above the immediate roof should be tested. If the roof horizon is in doubt, then all strata from the lowest likely roof horizon to 2.0 m above the highest likely roof horizon are tested so that all the potential horizons may be compared. In this classification system, the strata are divided into geotechnical units. The units are then tested and the mean fracture spacing for each unit is obtained. An individual rating for each unit is determined by using one of the following equations:

$$\begin{aligned} &\text{For } fs \leq 5 \quad \text{rating} = 4fs \\ &\text{For } fs > 5 \quad \text{rating} = 2fs+10 \end{aligned} \qquad [5\text{-}1]$$

Where fs = fracture spacing is in *cm*

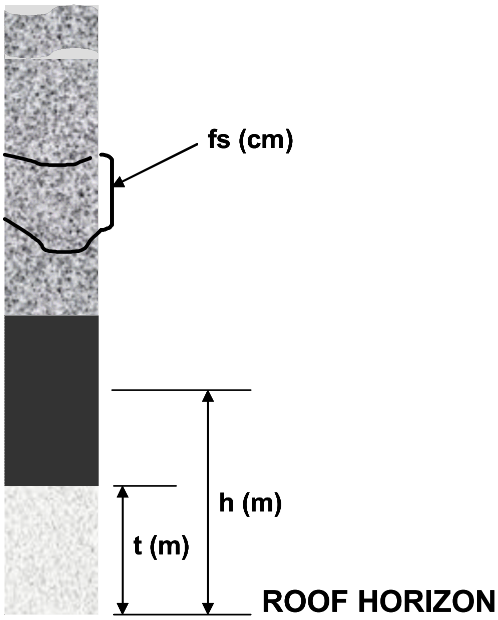

Figure 5-4 Impact splitting unit rating calculation

This value is then used to classify the individual strata units into rock quality categories as shown in Table 5-4. For coal mine roofs, the individual ratings are adjusted to obtain a roof rating for the first 2.0 m of roof. It was stated that the immediate roof unit will have a much greater influence on the roof stability and consequently the unit ratings are weighted according to their position in the roof by using the following equation:

$$\textit{Weighted rating} = \textit{rating} \ x \ 2(2-h)\ t \qquad [5\text{-}2]$$

Where h is mean unit height above the roof in metres and t is thickness of unit in metres (Figure 5-4).

The weighted ratings for all units are then totalled to give a final roof rating. Buddery and Oldroyd (1992) concluded that good agreement between expected and actual roof conditions has been found when using this rating system.

Latilla et al. (2002) revised the unit and coal roof classification system, and recommended the following Table for classification of coal mine roofs:

Table 5-4 Unit and coal roof classification system (after Latilla et al, 2002)

Unit Rating	Rock Class	Roof Rating
< 9	Very poor	< 34
10 – 13	Poor	35 – 51
14 – 19	Moderate	52 – 75
20 – 28	Good	76 – 113
29 – 42	Very good	114 – 167
> 42	Excellent	> 167

In addition, Latilla et al. (2002) suggested an adjustment factor to take into account areas where the immediate roof is coal. The unit rating is multiplied by 1.56, which is the density of sandstone (2500 kg/m3) divided by coal density (1600 kg/m3).

Based on this rating system the support patterns listed in Table 5-5 are adopted together with a special “current-with-mining assessment” technique to adapt to changing roof conditions, Latilla et al. (2002).

Sasol Coal also developed a roof rating system based on fall of ground accidents. Analyses of fall of ground (FOG) accidents in group collieries indicated that almost all such accidents occurred near dykes and underneath rivers. The collieries have been divided into three groups indicating the roof conditions based on these two criteria. These areas are marked on mine plans as Class 'C', Class 'B' and Class 'A'. The worst and the best ground conditions are expected in Class 'A' and Class 'C' respectively. In Class 'C' areas, a spare roofbolter and tell-tales should be available to cater for and identify possible roof deterioration.

Table 5-5 Estimated support requirements for different roof classifications (after van Wijk, 2004)

Roof condition	**Bord width (m)**	**Typical systematic support**			
		Type	**Length (m)**	**Pattern**	**Distance between rows of bolts (m)**
Excellent	7	M16 point anchor	0.9 or 1.2	Spot bolting false roof	N/A
Very Good	6.5 to 7	M16 point anchor	1.2	Spot bolting and 5 bolts per intersection only	N/A
Good	6 to 6.5	M16 point anchor	1.2 or 1.5	5 bolts per intersection and 2 per row in bords	2 to 2.5
Moderate	5.5 to 6	M16 or M20 full column resin	1.5 or 1.8	9 bolts per intersection and 3 per row in bords	1.5 to 2
Poor	5 to 5.5	M20 full column resin	1.8	16 bolts per intersection and 4 per row in bords. Steel straps may be necessary	1 to 1.5
Very Poor	<5	Specialised support, e.g. 1.8m M20 full column resin bolts and/or cable anchors with steel straps. Cable trusses, cluster stick packs or shotcrete may also be required	≥1.8	As dictated by conditions. Typically 5 bolts per row with steel straps. Often 9 cables in intersections.	<1

On each special area plan, a borehole log is also attached to indicate to mining personnel the roof conditions in the area. This also assists mining personnel in determining what length of roof bolt to use in the area. The same mining group has also developed a rating system to be used on borehole cores in greenfield areas, called Percentage Lamination Plan. This plan assists mining personnel in determining;

- the thickness of laminated material,
- whether the laminated stratum is high or low in the roof,
- whether the lamination is such that intersection failure can occur,

- whether the section is approaching ground where drastic changes in roof conditions can occur.

This plan indicates the percentage laminated strata in the direct roof and is available in the following ranges: the first metre of roof, the second metre of roof and the first two metres of roof.

There are also rating systems used in South Africa that are empirical correlations between particular features and roof behaviour based on the local geology. These systems are usually based on experience of mining personnel or especially geologists. If a specific layer or the position of a layer caused problems underground, these layers and/or position of these layers usually formed the rating systems. Experienced geologist identifies the significant layer and its position in the roof, during the logging of boreholes. This information is then marked on mine plans and its position referred to as Roof Hazard Plans. In geology based rating systems, the thickness of particular layers is also found to be important. Therefore, for some mines, the roof rating is based on the thickness of particular layers, such as sandstone, shale or siltstone, and the roof support pattern is determined by the assessed quality of the roof. It was also found that geological discontinuities are important and play a major role in the quality of roof, therefore, some mines adapted rating systems based on these features.

As the mines had problems with a certain rock type or with the thickness of certain rock type, they extended their rating systems by including them in their systems. Because these systems were purely based on years of experience, an appropriate universal system should correlate well with these experienced-based systems.

A review of the rating systems being used in South Africa highlighted that roof rating systems are being used mainly for planning purposes, and not to determine the changing conditions underground. However, rating systems have also been developed in South Africa by Ingwe Coal (Oldroyd and Latilla, 1999), in which support systems are changed based on on-going evaluation of changing underground conditions.

5.3.2 Proactive rating systems developed to identify changing conditions

Mechanised mining allows sections to be developed at a rapid rate, typically more than 1000 m per month for most sections, this can result in a variety of conditions being encountered in a single section in a very short time. Van Wijk et al. (2002) identified a number of accidents in Ingwe Coal (a division of BHP Billiton Energy Coal) mines that were caused primarily by the inability to recognise changing conditions and therefore failing to apply necessary counter measures timeously.

In order to identify the changing ground conditions, van Wijk et al. (2002) documented two underground rating systems: the “Section Physical Risk Rating” for measuring the physical conditions and the “Section Performance Rating” for determining how well the underground section personnel response to these conditions. Both forms are essentially risk matrices defining various scenarios, each with a certain weighting.

The section physical risk rating form is a basic questionnaire requesting information regarding geological conditions relevant to roof and sidewall stability, the mining method, and the support system, together with other geological information to determine a physical ranking that ensures the total system is examined. The section performance rating form is designed to measure how conditions determined by the section physical risk rating are being addressed. Furthermore, the form also measures compliance with the support rules and strata control standards. Both forms can be easily adapted for specific conditions. Should geological discontinuities, for example, represent a major problem in a particular area or for a specific mining method, then the importance of these features may be highlighted as a separate item with its own sub-divisions or by changing the weighting.

In summary, the following are some of the benefits of using the section physical and performance risk ratings:

- The rating forms enable quantification of previously subjective observations.
- Different auditors, i.e. shift supervisors, mine overseers and rock engineers, use the same format. This allows meaningful comparisons to be made in individual sections.
- A visit (audit) is structured such that people observe and record all potential hazards. It enables trends to be monitored and forms an integral part of the section management plan.

Van Wijk et al. (2002) describes the impact splitting tests, section performance rating and physical risk ratings as a system that can be used during the planning stage and assigning appropriate support patterns; for identifying changing conditions while mining; determining the best reaction to those conditions.

5.3.3 Colliery specific systems being used in South Africa

A number of hazard rating systems are used by the coal mines in South Africa. Some of these have already been documented but in most cases the systems are designed and implemented by the individual mines themselves. In light of this, it was necessary to investigate these different hazard systems by conducting visits to the coal mines. It was decided that this task would be approached in three stages:

1. Documenting the colliery's hazard rating system;
2. Applying an existing system to test it against the colliery's system.
3. Comparison of results of the existing systems to the colliery's rating system.

One of the initial tasks for this study was to devise an effective method to directly compare the different rating systems used in different collieries. The reason for this is that most of the systems are not documented and as already mentioned and differ from one mine to another. It is for this reason that impact splitting was considered as the most effective system to apply at each mine in order to test it against the mine's system and also to test one mine's results against another mine. The section performance rating and physical risk ratings were also conducted underground to test their applicability at each colliery.

The research was conducted at eight collieries in the Witbank and Highveld Coalfields. This section of this thesis presents the results of the investigations at each colliery.

5.4 Geotechnical testing at different collieries

As mentioned above, a number of rating systems are used by the coal mines in South Africa. These systems are usually based on experience of local mining personnel, and implemented by the individual mines themselves. A series of impact splitting tests were therefore conducted and compared against the mines individual systems in order to determine the reliability and repeatability of impact splitting tests against the systems that are developed over many years of experienced on the mines. Tests were conducted at six different mines.

The following lithological codes are used in the following tables:

C	: Coal
F	: Shale
S	: Sandstone
S/f	: Sandstone with shale bands

S/F : Sandstone/Shale interlaminated
S/s : Sandstone/Siltstone (Predominantly Sandstone)
SC : Sandstone/Coal (Predominantly Sandstone)
SF : Shaley sandstone/siltstone

5.4.1 Colliery 'A'

At this colliery, a rating system implemented by the geology department is used to predict the anticipated underground conditions for planning. The plan used for support design is based on the thickness of the gritstone (coarse grained sandstone), which is a strong stratum that can act as a self-supporting beam and is referred to as the Roof Grit Plan. The grit plan was divided into four-thickness categories and classified. Support recommendations are then made as shown in Table 5-6. The underlying principle in terms of support recommendations is that the thinner the grit, the longer should be the anchorage length. The density of support is also increased as the grit thickness reduces. The geology department also makes use of a Point Load Tester to measure the strength of the rock types in the roof and the floor. This information is then used mainly for contamination and floor cutability purposes more than classification of the grit strength.

Table 5-6 Roof grit hazard classification used at Colliery 'A'

Roof Grit	Classification	Typical Support
No Grit	Very Poor	W-straps with cable anchors
< 0.5 m Grit	Poor	1.8 m Full Column Resin, with W-straps for Slips
0.5 m - 1.0 m Grit	Moderate	1.2 m – 1.5 m Full Column Resin
1.0 m to 2.0 m Grit	Good	1.2 m Full Column Resin
> 2.0 m Grit	Very Good	0.9 m Full Column Resin

The roof grit plan is demarcated in different colours representing different roof grit thicknesses and the information is superimposed on the underground mining plan. At each section, a separate underground section plan is provided that incorporates the anticipated roof conditions from the Roof Grit Plan, as well as geological structures, mining parameters, methane contents and horizontal stress mapping. The underground section plan is approved by the mine surveyor, mine geologist, assistant manager, planning officer and environmental officer to ensure that all parameters are correctly represented on the plan.

A comparative study was conducted on three borehole drill cores, about 100 m from each other on the No 2 Seam.

Table 5-7 to Table 5-9 show the results of impact splitting of the three borehole drill cores. The mine geologists classified borehole drill core ARN 4968 as Roof Grit of 2.19, i.e. “Good” roof. From, Table 5-7 the final rating of 232 from impact splitting classifies the borehole drill core as “Excellent” roof.

Figure 5-5 shows a unit from the roof before impact splitting. The initial fractures are counted before the impact splitting, i.e. one on this case. Figure 5-6 shows the same unit after impact splitting with 3 final fractures.

Figure 5-5 A fine to medium grained sandstone or “grit” unit before impact splitting, taken from borehole ARN 4968

Figure 5-6 A fine to medium grained sandstone or “grit” unit after impact splitting, taken from borehole ARN 4968

Table 5-7 Impact splitting results at Colliery 'A', No 2 Seam, borehole ARN 4968

Depth (m)	Thickness (cm)	Lithology	Initial Fractures	Final Fractures	Fracture Spacing (cm)	Unit Rating	Weighted Rating	Remarks
46.5	13.2	S/F	1	6	2.2	8.8	0.1	Very Poor
46.7	20	S/F	1	2	10.0	30.0	2.4	Good
47	25.2	S	1	4	6.3	22.6	5.4	Moderate
47.3	34.5	S	1	2	17.3	44.5	22.3	Very Good
47.6	24.5	S	1	1	24.5	59.0	31.2	Very Good
47.8	24	S	1	2	12.0	34.0	20.9	Very Good
48.4	61.6	S	1	2	30.8	71.6	149.3	Very Good
							Final Rating	
							232	**Excellent**

Table 5-8 and Table 5-9 show the results from impact splitting of the other two borehole drill cores. The final ratings of borehole drill cores ARN 4974 and ARN 4975 are 274 - "Excellent" roof - and 199 - "Excellent" roof. The mine geologists classified the borehole drill cores as Roof Grit of 1.95 – 2.09 "Good" roof. These results show a good correlation between impact splitting tests and the roof grit plan classification. The advantage of impact splitting is that it quantifies the roof condition as opposed to the mere description of the thickness of the gritstone. Moreover, where grit layer is not so obvious, the mine's system may result in errors due to the subjectivity of the assessment technique.

Table 5-8 Impact splitting results at Colliery 'A', No 2 Seam, borehole ARN 4974

Depth (m)	Thickness (cm)	Lithology	Initial Fractures	Final Fractures	Fracture Spacing (cm)	Unit Rating	Weighted Rating	Remarks
43.6	32.5	S/F	1	5	6.5	23.0	3.6	Moderate
43.9	36	S/F	1	5	7.2	24.4	9.1	Moderate
44.3	41.8	S	1	2	20.9	51.8	38.6	Very Good
44.8	45.3	S	1	2	22.7	55.3	68.8	Very Good
45.2	44	S	1	1	44.0	98.0	153.5	Very Good
							Final Rating	
							274	**Excellent**

Underground visits were also conducted to assess adherence to the underground anticipated physical conditions and mine standards using physical rating system and performance rating system. These systems were successful in identifying possible hazards but because they originated from a different mine, some parameters could not be recorded owing to different specifications e.g. Colliery 'A' standards of support spacing are not included in the rating systems.

Table 5-9 Impact splitting results at Colliery 'A', No 2 Seam, borehole ARN 4975

Depth (m)	Thickness (cm)	Lithology	Initial Fractures	Final Fractures	Fracture Spacing (cm)	Unit Rating	Weighted Rating	Remarks
44.86	15.5	F/S	1	4	3.9	15.5	0.4	Very Poor
44.96	10	F/S	1	3	3.3	13.3	0.5	Very Poor
45.20	24.2	F/S	1	6	4.0	16.1	2.9	Very Poor
45.31	11.5	F/S	1	3	3.8	15.3	2.0	Very Poor
45.89	57.5	S	1	4	14.4	38.8	40.1	Poor
46.10	21	S	1	2	10.5	31.0	16.8	Poor
46.33	23.2	S	1	2	11.6	33.2	23.3	Poor
46.70	37	S	1	1	37.0	84.0	112.8	Very Good
							Final Rating	
							199	**Excellent**

5.4.2 Colliery 'B'

At Colliery 'B', a roof hazard plan only exists for the No 5 Seam. The hazard plan is based mainly on geological structures, roof type above the coal seam (from boreholes), horizontal stresses, and surface structures e.g. pans. Geological structures include dykes and sills with associated burnt coal areas. The roof type above the coal seam is described from exploration boreholes and is classified from the lithological description of the borehole as shown in Table 5-10.

Horizontal resistivity measurements are carried out on surface to determine the depth of weathering to assist in mine planning, considering that weathering allows increased water content which can affect the strength of the roof. Individual boreholes were analysed and the classification of normal, poor and bad roof is identified according to the composition of the immediate roof and the overlying strata.

Table 5-10 Roof hazard classification at Colliery 'B'

Classification	Roof type
Normal roof	Shale or siltstone of more than 30 cm thick overlain by sandstone
Poor	Interlaminated, laminated, fissile and micaceous sandstone, siltstone and shale less than 30 cm
Bad roof	Dolerite intrusions, deep weathering of the roof and faults

The hazards identified in the roof hazard plan are included in all section plans issued by the survey department. When mining towards an area that has been demarcated in the roof hazard plan, various procedures come into effect in terms of personnel awareness and roof support.

A comparative study was conducted on a total of five borehole drill cores, three from the No 5 Seam and two from the No 2 Seam. These borehole cores were mainly drilled for future planning and thus their numbers are the temporal numbers used by the drillers. The results of impact splitting of the five borehole drill cores from No 5 Seam and No 2 Seam are presented from Table 5-11 to Table 5-15.

Figure 5-7 shows an example of the borehole drill core of the Sandstone/Shale interlaminated roof from the No 5 Seam. In Figure 5-8 the weaker roof composed mainly of shale is shown.

Figure 5-7 Borehole drill core from Colliery 'B', No 5 Seam

Figure 5-8 Borehole drill core from Colliery 'B', No 2 Seam

Table 5-11 Impact splitting results at Colliery 'B', No 5 Seam, borehole H45S5

Depth (m)	Thickness (cm)	Lithology	Initial Fractures	Final Fractures	Fracture Spacing (cm)	Unit Rating	Weighted Rating	Remarks
38	14.5	S	1	2	7.3	24.5	5.2	Moderate
38.1	12.7	S/F	1	5	2.5	10.2	2.2	Poor
38.3	14.5	S/F	1	5	2.9	11.6	3.5	Poor
38.4	16.4	S/F	1	4	4.1	16.4	6.0	Poor
38.6	12.5	S	1	1	12.5	35.0	11.7	Very Good
38.7	14.2	S	1	1	14.2	38.4	15.6	Very Good
38.8	12	S/F	1	2	6.0	22.0	8.1	Moderate
39	14.5	S/F	1	2	7.3	24.5	12.3	Moderate
39.1	11.5	S/F	1	2	5.8	21.5	9.1	Moderate
39.2	11	S	1	1	11.0	32.0	13.7	Very Good
							Final **87**	**Good** **Moderate**

The final rating from impact splitting of borehole drill core H45S5 is 87, which is classified as "Good" roof. A similar classification of "Good" was obtained from the final ratings of drill cores H49S5 and H50S5 i.e. 87 and 84. These results from the three borehole drill cores could not be directly compared to the colliery's rating system due to the fact that the borehole drill cores were done for future planning purposes by a drilling contractor. Furthermore, due to staff changes during the course of this study at the mine, the new geologist had difficulty in learning their rating system. However, impact splitting results show a good correlation between each of the three tests, which were taken in maximum possible proximity i.e. were spaced at less than 500 m.

Table 5-12 Impact splitting results at Colliery 'B', No 5 Seam, borehole H49S5

Depth (m)	Thickness (cm)	Lithology	Initial Fractures	Final Fractures	Fracture Spacing (cm)	Unit Rating	Weighted Rating	Remarks
37.9	14.5	S	1	1	14.5	39.0	3.7	Very Good
38.1	17	S/F	1	6	2.8	11.3	2.0	Poor
38.2	10.5	S/F	1	3	3.5	14.0	1.9	Poor
38.3	12	S/F	1	3	4.0	16.0	2.8	Poor
38.5	17.1	S/F	1	4	4.3	17.1	5.3	Moderate
38.6	11.5	S/F	1	4	2.9	11.5	2.8	Poor
38.8	18	S/F	1	4	4.5	18.0	7.8	Moderate
39	22	S	1	4	5.5	21.0	12.8	Moderate
39.4	35.2	S	1	4	8.8	27.6	33.5	Good
39.5	15	S	1	3	5.0	20.0	11.6	Moderate
							Final Rating	
							84	**good**

From Table 5-14 and Table 5-15, the final ratings obtained from the No 2 Seam are 21 and 15 which indicate "Very Poor" roof in each case. The weakness of the shale in this case made it difficult to rate up to 2 m into the roof due to the shale being easily broken by merely picking it up from the borehole drill core box. However, the results show the advantage of impact splitting over the colliery's system in its ability to readily quantify the roof instead of a mere description that can change from one persons perception to another.

Table 5-13 Impact splitting results at Colliery 'B', No 5 Seam, borehole H50S5

Depth (m)	Thickness (cm)	Lithology	Initial Fractures	Final Fractures	Fracture Spacing (cm)	Unit Rating	Weighted Rating	Remarks
37.6	15	S	1	2	7.5	25.0	3.9	Moderate
37.8	14.7	S/F	1	7	2.1	8.4	1.8	Very Poor
37.9	16	S/F	1	5	3.2	12.8	3.4	Poor
38.1	12.6	S/F	1	5	2.5	10.1	2.6	Poor
38.2	10.5	S/F	1	2	5.3	20.5	4.9	Moderate
38.3	12.4	S	1	1	12.4	34.8	10.7	Very Good
38.5	20.8	S/F	1	2	10.4	30.8	17.9	Good
38.7	19.5	S/F	1	4	4.9	19.5	12.2	Moderate
38.8	16.4	S/F	1	2	8.2	26.4	14.9	Moderate
39	15.4	S/F	1	2	7.7	25.4	15.0	Moderate
							Final Rating	
							87	**Good**

Table 5-14 Impact splitting results at Colliery 'B', No 2 Seam, borehole P4S2

Depth (m)	Thickness (cm)	Lithology	Initial Fractures	Final Fractures	Fracture Spacing (cm)	Unit Rating	Weighted Rating	Remarks
59.3	12.2	F	1	6	2.0	8.1	2.5	Very Poor
59.4	10.1	F	1	5	2.0	8.1	2.2	Very Poor
59.5	14.5	F	1	8	1.8	7.3	3.0	Very Poor
59.6	12.3	F	1	5	2.5	9.8	3.7	Very Poor
59.8	11.5	F	1	6	1.9	7.7	3.1	Very Poor
59.9	11.2	F	1	6	1.9	7.5	3.1	Very Poor
60	13	F	1	7	1.9	7.4	3.7	Very Poor
							Final Rating	
							21	**Very Poor**

Table 5-15 Impact splitting results at Colliery 'B', No 2 Seam, borehole P3S2

Depth (m)	Thickness (cm)	Lithology	Initial Fractures	Final Fractures	Fracture Spacing (cm)	Unit Rating	Weighted Rating	Remarks
54.6	12.5	F	1	6	2.1	8.3	3.2	Very Poor
54.8	13	F	1	6	2.2	8.7	3.9	Very Poor
54.9	10.5	F	1	4	2.6	10.5	4.1	Poor
55.0	12.5	F	1	6	2.1	8.3	4.0	Very Poor
							Final Rating	
							15	**Very Poor**

5.4.3 Colliery 'T'

At Colliery 'T', hazard plans are based on analyses of fall of ground accidents. The sections have been divided into three groups depending on the position of the section relative to dykes and surface rivers. These areas are marked on mine plans as Class 'C', Class 'B' and Class 'A'. The guidelines for maximum bord width and cut-out distance are given in Table 5-16. A support recommendation is given for each class. All this information is transferred to the section plans issued by the survey department.

Table 5-16 Guidelines used in hazard plan at Colliery 'T'

Guideline	**Maximum Bord width**	**Maximum Cut-out distance**
Class A	6.0m	9.0m
Class B	6.6m	18.0m
Class C	7.2m	24.0m

A comparative study was done on a total of four borehole drill cores from the No 4 Seam and the results are presented from Table 5-17 to Table 5-20.

Table 5-17 Impact splitting results at Colliery 'T', No 4 Seam, borehole G293584

Depth (m)	Thickness (cm)	Lithology	Initial Fractures	Final Fractures	Fracture Spacing (cm)	Unit Rating	Weighted Rating	Remarks
153	23	S/s	1	8	2.9	11.5	-0.6	Poor
153.2	22	S/s	1	5	4.4	17.6	0.7	Moderate
153.4	20	S/s	1	3	6.7	23.3	2.8	Moderate
154.1	70	S	1	2	35.0	80.0	84.0	Very Good
154.4	26	S	1	2	13.0	36.0	23.8	Very Good
154.7	36	S	1	4	9.0	28.0	30.6	Good
155	27	S	1	1	27.0	64.0	64.5	Very Good
							Final Rating	
							206	**Excellent**

Table 5-18 Impact splitting results at Colliery 'T', No 4 Seam, borehole G293585

Depth (m)	Thickness (cm)	Lithology	Initial Fractures	Final Fractures	Fracture Spacing (cm)	Unit Rating	Weighted Rating	Remarks
156.2	27	S/s	1	6	4.5	18.0	0.6	Moderate
156.4	26	S/s	1	8	3.3	13.0	1.8	Poor
157.3	85	S	1	6	14.2	38.3	57.0	Very Good
157.6	26	S	1	4	6.5	23.0	17.6	Moderate
157.7	11	S	1	1	11.0	32.0	11.6	Very Good
157.8	10	S	1	1	10.0	30.0	10.5	Good
158	24	S	1	3	8.0	26.0	23.5	Moderate
							Final Rating	
							123	**Very Good**

The final rating of 206 from impact splitting classifies the borehole drill core as "Excellent" roof. Final ratings of 123 ("Very Good"), 240 ("Excellent") and 224 ("Excellent") were obtained from the other three impact splitting tests. The results show a good correlation in quantifying the expected roof conditions. Even though the colliery's system did not quantify the roof conditions, the geologist's description of the expected conditions was also a "Good" roof.

Table 5-19 Impact splitting results at Colliery 'T', No 4 Seam, borehole G293587

Depth (m)	Thickness (cm)	Lithology	Initial Fractures	Final Fractures	Fracture Spacing (cm)	Unit Rating	Weighted Rating	Remarks
162.2	14	S/s	1	2	7.0	24.0	0.9	Moderate
163	79	S/s	1	3	26.3	62.7	59.9	Very Good
163.1	10	S	1	2	5.0	20.0	4.2	Moderate
163.9	80	S	1	3	26.7	63.3	152.0	Very Good
164	15	S	1	1	15.0	40.0	23.1	Very Good
							Final Rating	
							240	**Excellent**

Table 5-20 Impact splitting results at Colliery 'T', No 4 Seam, borehole G293588

Depth (m)	Thickness (cm)	Lithology	Initial Fractures	Final Fractures	Fracture Spacing (cm)	Unit Rating	Weighted Rating	Remarks
163.6	10	S	1	1	10.0	30.0	3.3	Good
163.7	10	S	1	2	5.0	20.0	2.6	Moderate
163.9	10	S	1	2	5.0	20.0	3.4	Moderate
163.4	30	S	1	1	30.0	70.0	10.5	Very Good
163.7	30	S	1	1	30.0	70.0	23.1	Very Good
163.9	20	S	1	1	20.0	50.0	16.0	Very Good
164.1	30	S	1	1	30.0	70.0	39.9	Very Good
164.3	20	S	1	1	20.0	50.0	24.0	Very Good
164.9	60	S	1	3	20.0	50.0	96.0	Very Good
165	10	S	1	3	3.3	13.3	5.2	Poor
							Final Rating	
							224	**Excellent**

5.4.4 Colliery 'K'

At Colliery 'K', a roof hazard plan has been developed for the No 4 Seam by rating the roof lithology (e.g. Sandstone) and thickness of coal left in the roof (shown in Figure 5-9) to form a Composite Roof Hazard Plan with the ratings shown in Table 5-21. Due to changes of personnel, the new geologists could not describe how the scores, rating and ranking numbers were obtained. The classifications in Table 5-21 are coloured differently and demarcated in the composite roof hazard plan together with areas of floor roll and sill transgression.

Table 5-21 Composite roof hazard plan classification at Colliery 'K'

Score	Rating	Rank
5	21 - 25	Strong
4	16 - 20	Moderate
3	11 - 15	Weak - Moderate
2	6 - 10	Weak
1	1 - 5	Very Weak

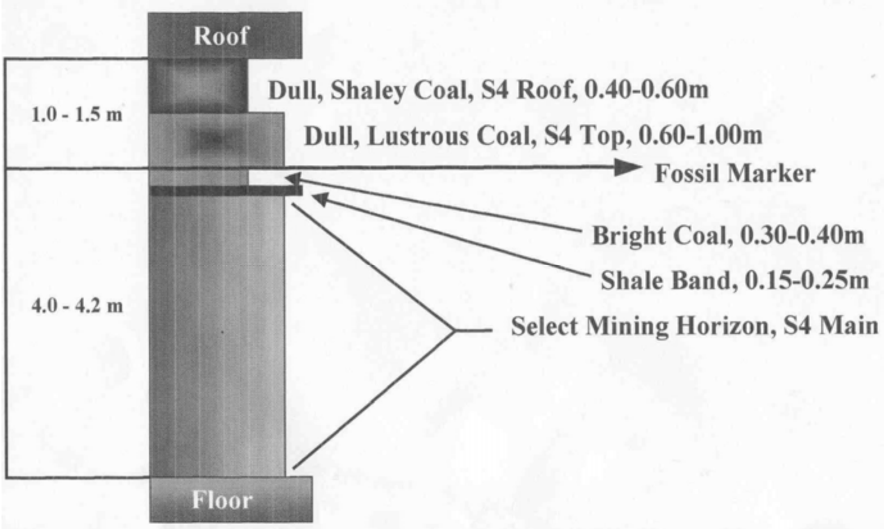

Figure 5-9 Typical Colliery 'K' No 4 Seam roof lithology

During this investigation, there was no drilling taking place at Colliery 'K' and thus only one impact splitting test was conducted on borehole drill core KRL3811 and the results are presented in Table 5-22.

When plotted on the composite roof hazard plan, the borehole drill core was on the border of the areas demarcated "Moderate" and "Good". Based on the colliery's system, without underground observations, any of the rankings between Moderate to Weak-Moderate could classify this borehole. However, the impact splitting tests rated it as "Good". The results presented in Table 5-22 are before a coal adjustment factor of 1.56 was applied as explained in the literature review.

Table 5-22 Impact splitting results at Colliery 'K', No 4 Seam, borehole KRL3811

Depth (m)	Thickness (cm)	Lithology	Initial Fractures	Final Fractures	Fracture Spacing (cm)	Unit Rating	Weighted Rating	Remarks
44	19.5	S/f	1	1	19.5	49.0	17.2	Very Good
44.3	25.5	S/f	1	2	12.8	35.5	21.2	Very Good
44.5	18.5	C	1	7	2.6	16.5	8.6	Poor
44.6	12.5	C	1	5	2.5	15.6	6.0	Poor
44.8	20.5	C	1	7	2.9	18.3	12.7	Moderate
45	20	C	1	8	2.5	15.6	11.9	Poor
							Final Rating	
							78	**Good**

5.4.5 Colliery 'N'

The Roof Hazard Plan has been established to indicate potential hazards that may affect the safety of the employees. The hazards that are identified are:

- Dykes and sills with associated burnt coal areas
- Laminations, partings and shale from surface
- Sudden change in floor gradient
- All areas of poor roof identified from roof sounding
- Excessive bord widths
- All bord widths exceeding 9 m due to over cutting or scaling
- Horizontal stress concentrations and historical roof fall problems

This plan is constantly revised depending on the identification of new hazardous areas. A separate plan is included in all section plans issued by the survey department. When mining towards an area that has been demarcated in the hazard plan, various procedures come into effect in terms of personnel awareness and roof support. A comparative study was done on Borehole 321, No 4 Seam to test the mines classification of the immediate roof against the results from Impact Slitting Tests. Table 5-23 presents the results of rating of the borehole drill core which has a final rating of 116 (i.e. "Very Good" roof). The geologists also classified the area as good roof on the Roof Hazard Plan.

Table 5-23 Impact splitting results at Colliery 'N', No 4 Seam, borehole 321

Depth (m)	Thickness (cm)	Lithology	Initial Fractures	Final Fractures	Fracture Spacing (cm)	Unit Rating	Weighted Rating	Remarks
229.8	66	S	1	7	9.4	28.9	17.9	Good
230.2	36	SF	1	10	3.6	14.4	10.6	Poor
230.6	39	S	1	3	13.0	36.0	39.5	Very Good
230.8	19	S	1	2	9.5	29.0	18.8	Good
230.9	13	S	1	1	13.0	36.0	17.2	Very Good
231	10	S	1	1	10.0	30.0	11.7	Good
							Final Rating	
							116	**Very Good**

5.4.6 Colliery 'S'

The hazard plan used at this colliery is same as that of Colliery 'T'. A comparative study was done on borehole drill core V118043 from the No 4 Seam and the results are presented in Table 5-24 and Table 5-25.

Table 5-24 Impact splitting results at Colliery 'S', No 4 Seam, Borehole V118043

Depth (m)	Thickness (cm)	Lithology	Initial Fractures	Final Fractures	Fracture Spacing (cm)	Unit Rating	Weighted Rating	Remarks
84.1	15.0	C	1	5	3.0	12.0	6.9	Poor
84.2	10.0	C	1	2	5.0	20.0	7.2	Moderate
84.5	29.0	C	1	4	7.3	24.5	22.8	Moderate
84.8	26.5	C	1	4	6.6	23.3	16.4	Moderate
84.9	10.0	C	1	4	2.5	10.0	2.3	Very Poor
85.0	11.0	SC	1	2	5.5	21.0	4.8	Moderate
85.1	10.0	SF	1	3	3.3	13.3	2.5	Poor
85.3	19.0	SF	1	6	3.2	12.7	3.8	Poor
85.4	13.0	SF	1	2	6.5	23.0	3.8	Moderate
							Final Rating	
							70	**Moderate**

Table 5-25 Impact splitting results, borehole V118043 after coal adjustment factor

Depth (m)	Thickness (cm)	Lithology	Initial Fractures	Final Fractures	Fracture Spacing (cm)	Unit Rating	Weighted Rating	Remarks
84.1	15	C	1	5	3.0	18.8	3.5	Moderate
84.2	10	C	1	2	5.0	31.3	4.7	Good
84.5	29	C	1	4	7.3	38.3	21.2	Very Good
84.8	26.5	C	1	4	6.6	36.3	24.4	Very Good
84.9	10	C	1	4	2.5	15.6	4.5	Poor
85	11	SC	1	2	5.5	21.0	7.1	Moderate
85.1	10	SF	1	3	3.3	13.3	4.4	Poor
85.3	19	SF	1	6	3.2	12.7	8.7	Poor
85.4	13	SF	1	2	6.5	23.0	11.6	Moderate
							Final Rating	
							90	**Moderate**

A comparative study between the results obtained from impact split tests and mine's roof hazard plan could not be conducted at Colliery 'S' due to unavailability of mine personnel. However, according to mine geologist the expected conditions were moderate.

5.5 Application of proactive systems

A series of underground visits also conducted at above given collieries to determine the applicability of the section performance rating and physical risk rating (van Wijk et al., 2002) The results from application of these systems showed that these systems are mine specific and therefore they need to be updated according to different mine standards (e.g. difference in systematic support types and spacing). Furthermore, it was evident that the systems needed someone with a strata control background, as most of the ratings are strata control related and constitute a big weighting in the final rating. The following is a summary of the points to note about the underground section rating systems:

- A structured check list ensured that the user observed and recorded all potential hazards. It also ensures that they are re-evaluated again for improvement in the conditions.
- Different inspectors, i.e. shift supervisors, mine overseers and rock engineers, use the same format. This allows meaningful comparisons to be made in individual sections.
- Systems need to be applied by someone who has a strata control understanding.

- The systems could be used on any mine with small modifications to the control instructions (e.g. support types)
- These systems cannot give a quantification of the required support.

5.6 Conclusions and recommendations

The purpose of this task was to evaluate and compare existing roof rating system that are used in South Africa and others that have been developed in other countries, and proposing the way forward for the development of a system that could be used universally on South African collieries to determine the roof conditions and quantitatively required support. The results showed that although many collieries have hazard plans, these plans do not readily quantify the mechanistic behaviour of the roof strata, they are mostly descriptive and are subject to different opinions. Therefore, they cannot be used for roof support design purposes. Furthermore, there is no uniform methodology behind the development of these plans, which makes it difficult for another person to apply them.

The CMRR could overcome most problems associated with the application of rock mass classification systems to coal mining. Also, in principal, the borehole core CMRR is a very similar system to impact splitter. However, due to its origin from case histories from the United States, certain modifications need to be applied to the system for the different conditions in South African coal mines. In the context of the South African coal mining industry, the following summary can be drawn regarding future improvements in the system:

- Requires exposure into the roof (underground CMRR only)
- Only the bolted height is rated. In South Africa, 2.0 m into the roof is the height that is usually rated.
- Although sets of joints have been considered in CMRR, single joints can have an influence and should thus also be included.
- Joint orientation is not included (underground CMRR only).
- Stress adjustment is required in the rating system to account for the influence of high horizontal stress (underground CMRR only)
- Blasting adjustment is not considered (underground CMRR only)
- Does not consider the position of soft or hard layers into the roof (both underground and borehole core CMRR)
- Requires skilled personnel to carry out ratings (both underground and borehole core CMRR)

Rating systems will continue to play an important role in coal mining practice. These systems should relate to the expected mode of failure of the strata for design and planning purposes. Underground rating and performance systems need to be incorporated with the roof rating systems into the overall ground control management to ensure adherence to design and overall mine standards. However, these systems cannot quantitatively determine the required support system in a given condition.

Although most collieries studied had some form of hazard identification systems in place, these systems are mostly descriptive in nature and therefore tend to be subjective. Moreover, these rating systems are used mainly for planning purposes, and not to determine the changing conditions underground. The systems have worked in some cases where one person had extensive experience at one mine. However, due to movement of personnel, there has been a loss of knowledge, insufficient documentation and a lack of updates of the local systems.

Impact splitting test has been found to be an appropriate system to eliminate human error in core rating. The advantage of impact splitting over the individual colliery‘s geology based rating systems is its ability to readily quantify the roof instead of a mere description that can change from one person to another. Geology based systems have been developed from experience by mine personnel that certain soft or hard layers in the roof were a major cause of instability. During this study, impact splitting has shown a very good correlation with the geology based rating systems. The system can therefore be used during planning for good prediction of conditions ahead of mining. Furthermore, the system requires minimal training time and therefore does not require skilled personnel.

In conclusion, impact splitting tests, section performance rating and physical risk ratings systems developed in South Africa can be described as the most effective and appropriate for South African conditions. Impact splitting can readily quantify the roof conditions during planning with minimum subjectivity. Section performance and physical risk rating can be used for identifying changing conditions while mining and determining the best response to the different conditions.

It must however be noted that as shown in the previous chapters of this thesis that the roof lithology, stress regime and roof characteristics can change within meters in a production section. Therefore, in order to predict these changing conditions many boreholes are required for a section, which would be very expensive and time consuming. In addition, borehole core based systems like the impact splitting are dependent on the quality of the core. Layers that are very weak or have very low cohesion can easily break during the drilling process. Geophysical techniques may therefore be more accurate in such cases for identification of these layers.