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The mining of South African thick coal seams: rock mechanics and mining considerations

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2015-03-16
http://hdl.handle.net/10539/17289

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A slot is cut along a plane of weakness in the coal roof and rib-sides immediately in front of the monitor and is then progressively widened towards the goaf until either all the coal is extracted or goafing occurs. The monitor is then withdrawn some distance down dip and the whole process is repeated. The water used to cut the coal also serves to wash the coal to the feeder breaker and thence to transport it along flumes to the slurry reticulation network located in the main development. The necessity to drive secondary developments to the rise at a minimum of 5 degrees results in coal not being recovered from the floor. In order to minimise this coal loss, panel length rarely exceeds 80 m. Often primary development is also achieved utilizing water monitors.

5.3.6 Stope mining

Stope dimensions are selected in the light of the characteristics of the roof strata to ensure either non-caving (open stoping) or caving (sublevel caving and drawing) of the roof strata during stoping operations. In the case of open stoping the roof strata usually caves sometime after the completion of stoping operations, hence the classification of the method as one which results in 'caving' of the roof strata. Depending on seam thickness, one or more sublevels are developed through the seam. Typically, entries comprising each sublevel are 5 m wide and 3 m high and are spaced at lateral intervals of 8 to 15 m, Fig. 5(b). The vertical distance between sublevels also ranges from 8 to 15 m. A vertical slot is developed through the total seam thickness and slices of coal are sequentially blasted from each sublevel into this slot. In open stoping coal is recovered from drawpoints in the lowest sublevel, whilst in sublevel caving and drawing coal is usually recovered from all sublevels.

5.4 Geologic Conditions Associated with Thick Seam Mining Methods

5.4.1 Approach to tabulating conditions

Cochrane (1972) noted that 'thick coal seams occur in an infinite number and complexity of natural and geological environments'. Therefore, whilst a thick seam mining method may have been developed for use under a specific set of geologic conditions, application of this method to other locations has introduced new combinations of conditions to which the method is suited. It is impractical to define all these various combinations and only the more important geologic conditions associated with thick seam mining methods are tabulated.

Three categories of geologic conditions have been identified, namely:

i) Requirements - regional geologic features which must be satisfied in order for a method to be considered potentially suitable. These features are usually specified within a given 'range' of values.

ii) Limitations - site specific features which may jeopardise the success of a mining method and which cannot be changed. Therefore, the 'influence' of these features on mining methods must be assessed.

iii) Considerations - regional or site specific features which require careful 'consideration' to reduce the risk they present to the success of a mining method. This may involve changing the nature of a feature or planning the mining operation such that the adverse influence of a feature is minimised.

Four geologic zones of influence pertaining to a thick coal seam have also been identified, namely:

i) floor strata,
ii) coal strata,
iii) immediate roof strata,
iv) upper roof strata.

A convenient means of recording the conditions associated with each of these zones is in matrices of the form devised to classify thick seam mining methods (Table 3). Such matrices enable information to be presented logically and concisely and permit quick and accurate comparisons to be made between geologic conditions associated with each of the various mining methods. In addition, the recording of the information relating to the geology of South African thick coal seams in a similar form (Chapter 6), enables quick and accurate identification of any thick seam mining methods potentially suited for the mining of these seams.

To be of most value, particularly in view of the rather unique combination of local conditions, matrices should be presented in a quantitative form. However, it has already been noted that many publications only discuss the geologic conditions associated with thick seam mining methods on a qualitative basis. Therefore, rating systems have been devised to quantify some of the more common qualitative descriptions of geologic conditions.

5.4.2 Floor strata

Rarely is reference made in publications to the floor strata other than to the 'competence' of the strata, a term usually implying the ability of the floor strata to withstand load. Factors contributing to this 'competency' such as strength, friability, jointing and

susceptibility to weathering, as well as other factors, such as the water bearing capacity and evenness of the floor strata, which influence the selection of mining methods, mining horizons and mining equipment, are only noted occasionally.

Consequently, the recording of geologic conditions pertaining to the floor strata is limited to a qualitative assessment of 'competency', although an attempt has been made to identify the influence of the more important factors contributing to this 'competency'. The 'quantitative' rating system which has been applied to qualitative descriptions of 'competency' and of 'contributing' factors is recorded in Table 4. The influence of these geologic properties on each of the thick seam mining methods is tabulated in Tables 5(A), 5(B) and 5(C).

It should be noted that mining methods do not always operate on a stone floor. In particular, a number of slicing mining methods commonly operate on a coal floor or a floor comprised of stowed material. However, the possibility usually exists to manipulate floor strata properties, for example, by leaving a layer of coal on top of an incompetent stone floor, by locating all sublevel entries in the more competent coal horizons within the seam, or by laying matting on top of the stowed material. Therefore, geologic conditions pertaining to the floor strata have been categorised as 'considerations'.

Furthermore, it should also be noted that the properties required of the parameters recorded in Tables 5(A), 5(B) and 5(C) are dependent on the type of mining equipment used and on the final function of the floor strata. Track mounted equipment usually requires a much more competent floor strata than rubber typed equipment. Similarly, more stringent limits must be placed on

TABLE 4. Rating system applied to qualitative descriptions of floor strata geologic conditions associated with thick seam mining methods.

Cat.	Parameter \ Rating	0	I	II	III	IV
SOLID MATERIALS	Competency	very competent	competent	moderately competent	incompetent	very incompetent
	Strength	very strong	strong	moderately strong	weak	very weak
	Friability	negligble	slightly friable	moderately friable	friable	very friable
	Rate of deterioration upon exposure to i) mine atmosphere ii) water	negligible to slow (years)	moderately quick (months)	quick (weeks)	rapid (days)	very rapid (hours)

TABLE 5(A) Typical floor strata geologic conditions associated with thick seam full face mining methods.

CATEGORY	Parameter \ Mining Method	ROOF STRATA CONTROL			
		Maintain	Limited Subsidence	Cave	
		Bord and pillar	Longwall mining with stowing	Bord and pillar with pillar extraction	Longwall mining
CONSIDERATIONS	Competency	≤II	≤II	≤II	≤II
	Strength	≤II	≤II	≤II	≤II
	Friability	≤II	≤III	≤II	≤III
	Rate of deterioration upon exposure to i) mine atmosphere	≤I	≤III	<I	≤III
	ii) water	≤I	≤III	<I	≤III

TABLE 5(A) Typical floor strata geologic conditions associated with thick seam full face mining methods.

CATEGORY	Parameter \ Mining Method	ROOF STRATA CONTROL			
		Maintain	Limited Subsidence	Cave	
		Bord and pillar	Longwall mining with stowing	Bord and pillar with pillar extraction	Longwall mining
CONSIDERATIONS	Competency	≤ II	≤ II	≤ II	≤ II
	Strength	≤ II	≤ II	≤ II	≤ II
	Friability	≤ II	≤ III	≤ II	≤ III
	Rate of deterioration upon exposure to i) mine atmosphere	< I	≤ III	< I	≤ III
	ii) water	≤ I	≤ III	< I	≤ III

TABLE 5(B) Typical floor strata geologic conditions associated with thick seam slicing mining methods.

CATEGORY	Mining Method / Parameter	ROOF STRATA CONTROL											
		Maintain				Limited Subsidence			Cave				
		Bord and pillar				Non-simultaneous multi-slice longwall			Bord and pillar				
		In a number of slices	With top- or bottom-coaling.	With top- or bottom- coaling followed by stowing	With repeated cycles of stowing and top-coaling	In descending slices with stowing	In ascending slices with stowing,	Simultaneous multi-slice longwall in ascending slices with stowing	Multi-slice with pillar extraction	Pillar extraction and top- or bottom-coaling	Non-simultaneous multi-slice longwall in descending slices	Simultaneous multi-slice longwall in descending slices.	Non-integrated longwall mining with sublevel caving
CONSIDERATIONS	Competency	≤II	≤II	≤II	≤II	≤II	≤II	≤II	≤II	≤II	≤II	≤II	≤II
	Strength	≤II	≤II	≤II	≤II	≤II	≤II	≤II	≤II	≤II	≤II	≤II	≤II
	Friability	≤III	≤II	≤II	≤III	≤III	≤III	≤III	≤II	≤II	≤III	≤III	≤III
	Rate of deterioration upon exposure to i) mine atmosphere ii) water	 <I <I	 <I <I	 <I <I	 ≤I ≤I	 ≤III <I	 ≤III ≤II	 ≤III ≤II	 <I <I	 <I <I	 ≤III <I	 ≤III ≤I	 ≤III ≤III

TABLE 5(C) Typical floor strata geologic conditions associated with thick seam caving and drawing mining methods.

CATEGORY	Mining Method / Parameter	ROOF STRATA CONTROL					
		Maintain	Limited Subsidence	Cave			
						Stope mining	
				Integrated long-wall mining and sublevel caving	Hydraulic mining	Open stoping	Sublevel caving and drawing
CONSIDERATIONS	Competency			≤ II	≤ I	≤ II	≤ II
	Strength			≤ II	≤ II	≤ II	≤ II
	Friability			≤ III	≤ II	≤ II	≤ II
	Rate of deterioration upon exposure to: i) mine atmosphere			≤ III	≤ I	≤ I	≤ I
	ii) water			≤ III	≤ I	≤ I	≤ I

factors such as friability and deterioration of floor strata upon exposure to water when the floor strata has to fulfill a later function as the roof strata of a lower slice mining operation. These factors have been taken into consideration when assessing parameters.

5.4.3 Coal strata

The rating system applied to qualitative descriptions of various geologic conditions pertaining to thick coal seams is recorded in Table 6. Actual geologic conditions are tabulated in Tables 7(A), 7(B) and 7(C).

A number of points concerning the values assigned to parameters require clarification. These are:

i) Requirements.

Depth - bord and pillar mining methods which maintain the integrity of the roof strata are restricted usually to a maximum depth of 300 m by percentage extraction considerations (refer Fig. 1). When the roof strata is caved practical considerations associated with the formation and extraction of very large pillars limit these methods to a maximum depth of about 500 m. Caving methods, in general, are not employed at a depth of less than 50 m because of practical problems associated with weathered roof strata, surface cracking and surface subsidence, and the greater economic viability of surface mining techniques.

Seam thickness - the recorded seam thickness represents the total seam thickness potentially mineable by a method. Often an upper limit cannot be specified since it is a function of

TABLE 6. Rating system applied to qualitative descriptions of coal seam geologic conditions associated with thick seam mining methods.

CATEGORY	Parameter \ Rating	0	I	II	III	IV
STRUCTURE	Degree of cleating	negligible	sparse	moderate	dense in one direction	dense in more than one direction
	Friability	negligible	slightly friable	moderately friable	friable	very friable
LIMITATIONS	Influence on method of: Slips Faults Stone partings Stone lenses	not adverse	moderately adverse	adverse	very adverse	excludes use of method
CONSIDERATIONS	Suitability of method to: i) a high gas content i) a high proneness to spontaneous combustion.	high	good	fair	poor	cannot be utilized

TABLE 7(A) Typical coal seam geologic requirements, limitations and considerations associated with thick seam full face mining methods.

CATEGORY	Parameter \ Mining Method	ROOF STRATA CONTROL: Maintain — Bord and pillar	Limited Subsidence — Longwall mining with stowing	Cave — Bord and pillar with pillar extraction	Cave — Longwall mining
REQUIREMENTS	Range in				
	Depth (m)	<300	>50	50-500	>50
	Seam thickness (m)	>4	4-5(1)	4-5	4-6
	Variation in seam thickness (m)				
	i) over 10m	NC(2)	<2-(3)	NC	<2-
	ii) over 1000m	NC	<2-	NC	<2-
	Variation in dip (degrees)				
	i) over 10m	<±15	<±10	<±15	<±10
	ii) over 1000m	<±15	<±15	<±15	<±15
	Degree of cleating	NC	NC	NC	NC
	Friability	NC(≤II)(4)	NC(≤II)	NC(≤II)	NC(≤II)
LIMITATIONS	Influence of				
	Slips(5)	II	III	III	III
	Faults(5)				
	throw - 0,2 - 1,0m	I	II - III	I	II - III
	1,0 - 3,0m	II - III	III - IV	II - III	III - IV
	>3m	III - IV	IV	III - IV	IV
	Stone partings				
	thickness - <0,3m	I - II	I - II	I - II	I - II
	0,3 - 0,7m	II - III	II - III	II - III	II - III
	0,7 - 1,5m	III - IV	III - IV	III - IV	III - IV
	1,5 - 4,0m	III - IV	IV	III - IV	IV
	Stone lenses	II - III	II - III	II - III	II - III
CONSIDERATIONS	Suitability to				
	i) a high gas content	II	II - III	II - III	II - III
	ii) a high proneness to spontaneous combustion	I	I - II	III - IV	III - IV

Footnotes

1) Range represents total seam thickness potentially mineable by method

2) N C - not critical

3) - (-Ve) - indicates parameter should not decrease by more than this value.

4) ( ) - a preferable but not essential value for this parameter

5) Refer to discussion of this parameter, section 5 4 3

TABLE 7(B) Typical coal seam geologic requirements, limitations and considerations associated with thick seam slicing mining methods.

CATEGORY	Parameter \ Mining Method	ROOF STRATA CONTROL: Maintain: Bord and pillar: In a number of slices	Maintain: Bord and pillar: With top- or bottom-coaling	Maintain: Bord and pillar: With top- or bottom- coaling followed by stowing	Maintain: Bord and pillar: With repeated cycles of stowing and top-coaling	Limited Subsidence: Non-simultaneous multi-slice longwall: In descending slices with stowing	Limited Subsidence: Non-simultaneous multi-slice longwall: In ascending slices with stowing	Limited Subsidence: Simultaneous multi-slice longwall in ascending slices with stowing	Cave: Bord and pillar: Multi-slice with pillar extraction	Cave: Bord and pillar: Pillar extraction and top- or bottom- coaling	Cave: Non-simultaneous multi-slice longwall in descending slices	Cave: Simultaneous multi-slice longwall in descending slices	Cave: Non-integrated longwall mining with sublevel caving
REQUIREMENTS	Range in Depth (m)	<300	<300	<300	<300	>50 (1)(2)	>50	>50	50-500	50-500	>50	>50	>50
	Seam thickness (m)	>4	>4	>4	>4	>4 [4-12]	>4 [4-8]	>4 [4-8]	>4	>4 [4-6]	>4 [4-8]	>4 [4-8]	>4 [4-8]
	Variation in seam thickness (m) i) over 10m	Δ -(3) (<4-)	NC	NC	<1-	<1-	<1-	<1-	<1-	NC	<1-	<1-	NC
	ii) over 1000m	(<4-)	NC	NC	(<2-)	(<2-)	(<2-)	<2-	(<2-)	NC	(<2-)	<2-	NC
	Variation in dip (degrees) i) over 10m	<±15	<±15	<±15	<±15	<±10	<±10	<±10	<±15	<±15	<±10	<±10	<±10
	ii) over 1000m	<±15	<±15	<±15	<±15	<±15	<±15	<±15	<±15	<±15	<±10	<±15	<±15
	Degree of cleating	NC (5)	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	≥III
	Friability	NC (≤II)	NC (≤III)	NC (≤III)	NC (≤II)	NC (≤II)	NC (≤I)	NC (≤I)	NC (≤II)	NC (≤II)	NC (≤II)	NC (≤II)	≥III
LIMITATIONS	Influence of Slips (6)	II	II	II	II	II	II	II-III	II	II	II-III	II-III	II
	Faults (6) throw - 0,2 - 1,0m	II	I	I	I	II-III	II-III	III-IV	II	I	II-III	III-IV	II-III
	1,0 - 3,0m	III-IV	II-III	II-III	II-III	III-IV	III-IV	IV	III-IV	II-III	III-IV	IV	III-IV
	>3m	IV	III-IV	III-IV	III-IV	IV	IV	IV	IV	III-IV	IV	IV	III-IV
	Stone partings thickness - <0,3m	+ (7)	I	I	I	+	+	+	+	II	+	+	II-III
	0,3 - 0,7m	+	II	II	II	+	+	+	+	III	+	+	III-IV
	0,7 - 1,5m	+	III	III	III	+	+	+	+	III-IV	+	+	IV
	1,5 - 4,0m	+	IV	IV	IV	+	+	+	+	IV	+	+	IV
	Stone lenses	I-II	I-II	I-II	I-II	II-III	II-III	II-III	I-II	I-II	II-III	II-III	II-III
CONSI-DERATIONS	Suitability to i) a high gas content	II	II	II	II	II-III	II-III	II-III	II-III	II-III	II-III	II-III	III-IV
	ii) a high proneness to spontaneous combustion	I	I	I	I	I-II	I-II	I-II	III-IV	III-IV	III-IV	III-IV	III-IV

Footnotes

1) Range represents total seam thickness potentially mineable by method

2) [ ] - a range of values common for this parameter

3) -(-Ve) - indicates parameter should not decrease by more than this value.

4) ( ) - a preferable but not essential value for this parameter

5) N C - not critical

6) Refer to discussion of this parameter, section 5.4.3.

7) + - rated as an advantage - see discussion on 'stone partings'

TABLE 7(C) Typical coal seam geologic requirements, limitations and considerations associated with thick seam caving and drawing mining methods.

CATEGORY	Parameter \ Mining Method	ROOF STRATA CONTROL					
		Maintain	Limited Subsidence	Cave			
				Integrated long-wall mining and sublevel caving	Hydraulic mining	Stope mining: Open stoping	Stope mining: Sublevel caving and drawing
REQUIREMENTS	Range in						
	Depth (m)			>50	>50	>50	NC[3]
	Seam thickness (m)			>4 [8 - 14][1],[2]	>4 [6-16]	>6	>6
	Variation in seam thickness (m)						
	i) over 10 m			NC	NC	NC	NC
	ii) over 1000 m			NC	NC	NC	NC
	Variation in dip (degrees)						
	i) over 10m			≤ ± 10	*[4]	NC	NC
	ii) over 1000 m			≤ ± 15	*	NC	NC
	Degree of cleating			≥ III	≥ III	NC	NC
	Friability			≥ III	≥ III	NC (≤ II)[5]	NC (≤ II)
LIMITATIONS	Influence of						
	Slips[6]			II	I - II	I - II	I II
	Faults[6]						
	throw - 0,2 - 1,0m			II - III	I - II	I - II	I - II
	1,0 - 3,0m			III - IV	II - III	II - III	II - III
	>3m			III - IV	III - IV	III - IV	III - IV
	Stone partings						
	thickness - <0,3m			II - III	III - IV	I	I
	0,3 - 0,7m			III - IV	III - IV	I - II	I - II
	0,7 - 1,5m			IV	IV	II - III	II - III
	1,5 - 4,0m			IV	IV	III - IV	III - IV
	Stone lenses			II - III	II - III	I - II	I - II
CONSI-DERATIONS	Suitability to						
	i) a high gas content			II - III	II - III	II - III	II - III
	ii) a high proneness to spontaneous combustion			III - IV	III - IV	III - IV	III - IV

Footnotes

1) Range represents total seam thickness potentially mineable by method.

2) [ ] - a range of values common for the parameter

3) NC - not critical

4) * - each situation to be individually assessed - see discussion on 'variation in dip'

5) ( ) - a preferable but not essential value for this parameter

6) Refer to discussion of this parameter, section 5 4 3

other parameters such as depth and the coal winning technique.

Variation in seam thickness - the effect of this parameter is difficult to rate quantitatively since it often depends on whether advance knowledge is known of variation in seam thickness and whether this variation is due to a change in the floor elevation or the roof elevation of a seam, or both. The parameter influences slicing mining systems the most. When rating this influence a distinction has been made between the maximum variation tolerable over a lateral distance of 10 m and that tolerable over a distance of 1 000 m. The flexibility of most slicing methods to cope with sudden local variations in seam thickness is much less than in the later case where panel layouts can be designed to uniformly reduce the mining height in slices or to increase or decrease the number of slices to accommodate regional variations in seam thickness.

Variation in dip - similar to variations in seam thickness, both local and regional variations in dip (from the horizontal) have been recognised. The primary considerations when evaluating dip were the maximum gradient at which equipment could tram and the flexibility of longwalling equipment. No quantitative evaluation of the influence of dip on hydraulic mining has been made in view of flexibility associated with this method for artificially manipulating 'apparent' dip. With this method each situation must be assessed individually.

Degree of cleating - A cleat is a discontinuity within a coal seam along which no relative

displacement in any direction parallel to the plane of the discontinuity has occurred. Whilst well defined cleating can be utilized to advantage in coal cutting operations it is not essential. In drilling and blasting operations it may be of little importance. Consequently, the degree of cleating has only been rated for those methods which depend upon a well-cleated coal for success.

Friability - as far as can be ascertained there is no universally acceptable quantitative measure of friability. Qualitatively, the term has been taken to mean the ease at which a coal seam crumbles. Similar to cleating this parameter has only been rated for those methods which depend upon a friable coal for success. It is interesting to note that ratings do not contradict those preferred of a coal floor strata.

ii) Limitations.

Slips - a slip is considered to be 'a fault along which a displacement of less than 200 mm has occurred'. The influence of slips on a mining method is a function of, amongst other parameters, the mining height, support procedures, and the time and area of mine workings over which slips are exposed. Ratings are based on a consideration of the degree to which these parameters are associated with each mining method.

Faults - since the significance of faulting is a function of seam thickness this parameter has been evaluated in terms of the potential effect which a change in seam elevation may have on a

mining method. No consideration has been given to fault density or to other effects of faulting such as poor ground stability.

Stone partings - by the definition of a thick coal seam (section 2.2) stone partings may be up to 4 m thick and separate seams which are at least 2 m thick. Rather than having an adverse effect on mining operations such partings may be utilized to great advantage in some slicing methods. For example, partings can function as competent floor or immediate roof strata, protect mining operations from overlying goaf, and limit adverse interaction between mining operations in adjacent slices. In Table 7(B) a '+' rating has been assigned to those methods where the potential exists for stone partings to be utilized to such advantages.

Stone lenses - stone lenses are considered to be non-continuous stone bands, usually of variable thickness and elevation, which occur within a seam. Where the possibility exists to win coal by either drilling and blasting or coal cutting this parameter has been evaluated in terms of its influence on coal cutting operations, since this mining technique will be most adversely affected by the presence of stone lenses in a seam.

iii) Considerations.

Gas - whilst this parameter must always be taken into consideration it causes most concern when present in high concentrations. Therefore, the parameter has been evaluated in terms of the suitability of a method for use in a very gassy coal seam. Recognised ventilation procedures are assumed to be practiced.

Spontaneous combustion - similar to gas, this parameter has been evaluated in terms of the suitability of a method for use in a coal seam which is highly prone to spontaneous combustion and in which recognised ventilation procedures are enforced.

A number of geologic 'limitations' and 'considerations' have not been tabulated since they can only be quantified in the light of specific site conditions. For example, the influence which variation in rank throughout the seam thickness has on the potential of each mining method can only be assessed in the light of specific washing costs and market requirements. Similarly, the significance of the direction and spacing of faults can only be quantified after panel length and panel width have been determined on the basis of other site specific geologic and economic considerations.

5.4.3 Immediate Roof Strata

Similar to floor strata, reference is rarely made in publications to the immediate roof strata other than to the 'competence' of the strata. In these instances the term 'competence' usually implies the capacity of the strata to span underground excavations. As such, the degree of competence assigned to the immediate roof strata is relative to the size of the excavation, the time period that the excavation has to remain open for, and the type of roof support employed. For example, strata that is classified as competent because it spans a 6 m wide bord for an indefinite period of time without need of artifical support may be classified as incompetent when considering open stoping because it is incapable of spanning in excess of 15 m. Therefore, two 'quantitative' systems have been devised for rating the competency of the immediate roof strata. The first system rates the competency of the strata in terms of

the width of the excavation which the strata must be able to span before caving of the roof strata is induced. The second system rates the competency of the strata in terms of the maximum tolerable distance which the strata can overhang into the goaf after caving has been induced. These two systems are presented in Table 8 and have been applied to the various thick seam mining methods in Table 9.

Numerous means exist to change the competency of the immediate roof strata and/or its influence on mining operations. For example, the degree of competence may be improved by leaving a layer of coal in the roof to prevent weathering due to exposure to the mine atmosphere, or by restricting bord width. The adverse influence of incompetent immediate roof strata in bord and pillar mining with pillar extraction may be limited by utilizing a form of pillar extraction on the advance whereby pillars are extracted almost immediately after formation. In longwall mining, supports may be 'contact' advanced to limit displacement of an incompetent immediate roof strata. Thus, the 'competency' of the immediate roof strata has been categorised as a 'consideration'. However, the support of a large roof area in open-stoping operations may be impractical and so the degree of competence of the immediate roof strata constitutes a 'limitation' in this special case.

5.4.5 Upper roof strata

The upper roof strata primarily determines the manner in which stresses are distributed around the mine workings. Stress distribution is dependent upon the total thickness of the upper roof strata as well as on the rigidity and disposition of the various stratum comprising the upper roof strata. As such, it is not possible, either qualitatively or quantitatively to evaluate those geologic properties of the upper roof

Table 8 Rating system applied to record the competency of immediate roof strata associated with thick seam mining methods.

CATEGORY	Parameter \ Rating	0	I	II	III	IV
CONSIDERATIONS	Competency					
	i) No caving-spans in excess of:	30 m (with local rock-bolt support if necessary)	15 m (with local rock-bolt support if necessary)	6 m (with local rock-bolt support if necessary)	6 m only with dense rockbolt and/or truss support	6 m only with arched and/or girdered support
	ii) Caving-Overhangs up to:	30 m	15 m	10 m	5 m	face support line

TABLE 9 Typical immediate roof strata behaviour associated with thick seam mining methods.

(A) Full face mining methods

CATEGORY	Parameter \ Mining Method	ROOF STRATA CONTROL			
		Maintain	Limited Subsidence	Cave	
		Bord and pillar	Longwall mining with stowing	Bord and pillar with pillar extraction	Longwall mining
CONSIDERATIONS	Competency i) no caving ii) caving	≤III (≤II)(1) N.A	N A(2) ≥II	≤II ≥III	N.A ≥III

(B) Slicing mining methods

CATEGORY	Parameter \ Mining Method	ROOF STRATA CONTROL												
		Maintain				Limited Subsidence			Cave					
		Bord and pillar				Non-simultaneous multi-slice longwall			Bord and pillar					
		In a number of slices	With top- or bottom- coaling	With top- or bottom- coaling followed by stowing	With repeated cycles of stowing and top- coaling	In descending slices with stowing	In ascending slices with stowing	Simultaneous multi-slice longwall in ascending slices with stowing	Multi-slice with pillar extraction	Pillar extraction and top- or bottom- coaling	Non-simultaneous multi-slice longwall in descending slices	Simultaneous multi-slice longwall in descending slices	Non-integrated longwall mining with sublevel caving
CONSIDERATIONS	Competency i) no caving ii) caving	≤II NA	≤II NA	≤II NA	≤II NA	N A II-III	N A II-III	N A II-III	≤II ≥III	≤II II-III	N A ≥III	N A ≥III	NA >III+(3)

(C) Caving and drawing mining methods

CATEGORY	Parameter \ Mining Method	ROOF STRATA CONTROL					
		Maintain	Limited Subsidence	Cave			
				Integrated longwall mining and sublevel caving	Hydraulic mining	Stope mining	
						Open stoping	Sublevel caving and drawing
CONSIDERATIONS	Competency(4) i) no caving ii) caving			N A ≥III +	≤IV II-III	0 - I N R(5)	≤II ≥II

Footnotes

1) ( ) - preferable but not essential value for the parameter
2) N A - not applicable
3) + - refers to stone roof not top-coal
4) A 'limitation' for open stoping
5) N R - not relevant since caves only after completion of mining operations.

strata which influence the selection of thick seam mining methods. In any case, these properties often do not influence the selection of a method so much as the mine design associated with a method.

5.5 Economic Characteristics of Thick Seam Mining Methods

Well defined economic characteristics are associated with most thick seam mining methods. For example, mechanised simultaneous multi-slice longwall methods are noted as extremely capital intensive, low working cost, inflexible, high risk, low productivity, high percentage extraction methods, whilst most bord and pillar methods are noted as low capital intensive, high working cost, very flexible, low risk, high productivity methods which only achieve a high percentage extraction at shallow depth. However, an accurate quantitative tabulation of these characteristics is impractical since actual values associated with a mining method can vary significantly from one economy to another, one geologic location to another, one coal winning technique to another, and one mine layout to another.

For presentation purposes and to facilitate comparisons between methods, a 'quantitative' rating system, Table 10, has been devised for describing the qualitative economic characteristics of the various thick seam mining methods. These characteristics are tabulated in Tables 11(A), 11(B) and 11(C). In addition, a typical range in the present day capital cost of each method has also been recorded. Since this capital cost is, amongst others, a function of parameters such as face length, panel length, working height and percentage extraction, a typical range in annual production and panel percentage extraction achieved by the mining operations on which the present-day capital cost was based is also recorded.

TABLE 16 Rating system applied to qualitative descriptions of economic conditions associated with thick seam mining methods.

Parameter \ Rating	0	I	II	III	IV
Capital costs Working costs— i) Engineering ii) Labour iii) Mining iv) Provisions	low	moderate	high	very high	extremely high
Rate of Production Productivity	very high	high	moderately high	low	very low
Flexibility of method	extremely flexible	flexible	moderately inflexible	inflexible	extremely inflexible
Versatility of equipment	extremely versatile	versatile	moderately unversatile	unversatile	extremely unversatile
Risk	very low	low	moderately high	high	very high

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Versatility of equipment	extremely versatile	versatile	moderately unversatile	unversatile	extremely unversatile
Risk	very low	low	moderately high	high	very high

TABLE 11(A) Typical economic characteristics of thick seam full face mining methods.

CATEGORY / Parameter \ Mining Method	ROOF STRATA CONTROL			
	Maintain	Limited Subsidence	Cave	
	Bord and pillar	Longwall mining with stowing	Bord and pillar with pillar extraction	Longwall mining
Capital cost	0 - I	III - IV	0 - I	III - IV
Working costs				
i) Engineering	0 - I	II - III	0 - I	II - III
ii) Labour	I - II	I - II	II - III	0 - I
iii) Mining	I - II	0	II - III	0
iv) Provisions	0	I	0	I
Rate of production	II	II	II	II
Productivity	I - II	II - III	II	II - III
Flexibility (of method)	0 - I	III	I - II	III
Versatility (of equipment)	I	IV	I	III - IV
Risk	I	III	I	II - III
Actual capital cost (R x 10^6)	1,0 - 2,5	10 - 12	1,0 - 2,5	10 - 12
Annual production (t x 10^6)	0,4 - 0,8	0,5 - 0,6	0,4 - 0,8	0,6 - 0,8
Typical panel % ext (6m)	30 - 40	70 - 95	50 - 70	70 - 95
Typical overall % ext (6m)	15 - 25	55 - 85	45 - 55	55 - 85

TABLE 11(B) Typical economic characteristics of thick seam slicing mining methods.

CATEGORY	Parameter \ Mining Method	ROOF STRATA CONTROL: Maintain: Bord and pillar: In a number of slices	Maintain: Bord and pillar: With top- or bottom- coaling	Maintain: Bord and pillar: With top- or bottom- coaling followed by stowing	Maintain: Bord and pillar: With repeated cycles of stowing and top. coaling	Limited Subsidence: Non-simul aneous multi-slice longwall: In descending slices with stowing	Limited Subsidence: Non-simul aneous multi-slice longwall: In ascending slices with stowing	Limited Subsidence: Simultaneous multi-slice longwall in ascending slices with stowing	Cave: Bord and pillar: Multi-slice with pillar extraction	Cave: Bord and pillar: Pillar extraction and top- or bottom- coaling	Cave: Non-simultaneous multi-slice longwall in descending slices	Cave: Simultaneous multi-slice longwall in descending slices	Cave: Non-integrated longwall mining with sublevel caving
IN-SLICE	Capital cost	0-I	0-I	0-I	0-I	II-III	II-III	I[1]	0-I	0-I	II-III	IV	III-IV
	Working costs i) Engineering ii) Labour iii) Mining iv) Provisions	0-I I-II I-II 0	0-I I-II I-II 0	0-I II-III I-II 0	0-I II-III I-II 0	III-IV I-II 0-I I	III-IV I-II 0-I I	I-II III-IV II-III I	0-I II II-III 0	0-I II-III II-III 0	II-III 0-I 0-I I	II-III 0-I I-II I	II-III II-III I I
	Rate of production	II	II	II	II	I-II	I-II	III-IV	II-III	II	I-II	II-III	III
	Productivity	I	I	I	I-II	II-III	II-III	III-IV	II	I-II	I-II	III-IV	II-III
	Flexibility of method	II	I	I	I	III	III	IV	II	I	III	IV	III
	Versatility of equipment	I	I	I	I	III-IV	III-IV	III-IV	I	I	II-III	II-III	IV
	Risk	I	I	I	I	II-III	II-III	III-IV	I	I	II-III	III-IV	III
IN-PANEL	Actual capital cost (R x 10^6)	1,0-2,5	1,0-2,5	1,0-2,5	1,0-2,5	8-10	8-10	1-3	1,0-2,5	1,0-2,5	8-10	14-16	7-11
	Annual production (t x 10^6)	0,4-0,8	0,4-0,8	0,4-0,8	0,4-0,8	0,8-1,2	0,8-1,2	0,3-0,7	0,4-0,8	0,4-0,8	0,8-1,4	0,55-0,8	0,45-0,8
	Typical panel % ext (6m)	30-40	30-40	35-45	40-50	75-90	75-95	75-90	80-95	50-70	70-95	70-90	50-80
	Typical overall % ext (6m)	15-30	15-25	20-30	25-40	60-85	70-85	50-70	50-75	40-55	60-85	70-90	40-70

Footnote

1) Only partially mechanised

TABLE 11(C) Typical economic characteristics of thick seam caving and drawing mining methods.

Mining Method / Parameter	ROOF STRATA CONTROL					
	Maintain	Limited Subsidence	Cave			
			Integrated long-wall mining and sublevel caving	Hydraulic mining	Stope mining: Open stoping	Stope mining: Sublevel caving and drawing
Capital cost			II-III	0-I	0-I	0-I
Working costs i) Engineering ii) Labour iii) Mining iv) Provisions			II-III II-III I I	0 0-I 0-I 0	0-I I-II I-II 0	0-I I-II I-II 0
Rate of production			III	I	II	II
Productivity			II-III	I	I-II	II
Flexibility of method			III	I-II	I-II	I-II
Versatility of equipment			IV	IV	I-II	I-II
Risk			III	II-III	II-III	I-II
Actual capital cost ($R \times 10^6$)			4 - 6	1,0 - 2,0	1,0 - 2,0	1,0 - 2,0
Annual production ($t \times 10^6$)			0,15-0,35	0,6 - 0,9	0,2 - 0,3	0,2 - 0,3
Typical panel % ext (6m)			50 - 80	75 - 90	80 - 95	60 - 85
Typical overall % ext (6m)			40 - 70	60 - 80	60 - 80	55 - 75

TABLE 11(C) Typical economic characteristics of thick seam caving and drawing mining methods.

Mining Method / Parameter	ROOF STRATA CONTROL					
	Maintain	Limited Subsidence	Cave			
			Integrated long-wall mining and sublevel caving	Hydraulic mining	Slope mining: Open stoping	Slope mining: Subkevel caving and drawing
Capital cost			II-III	0-I	0-I	0-I
Working costs i) Engineering ii) Labour iii) Mining iv) Provisions			II-III II-III I I	0 0-I 0-I 0	0-I I-II I-II 0	0-I I-II I-II 0
Rate of production			III	I	II	II
Productivity			II-III	I	I-II	II
Flexibility of method			III	I-II	I-II	I-II
Versatility of equipment			IV	IV	I-II	I-II
Risk			III	II-III	II-III	I-II
Actual capital cost (R x 10^6)			4 - 6	1,0 - 2,0	1,0 - 2,0	1,0 - 2,0
Annual production (t x 10^6)			0,15-0,35	0,6 - 0,9	0,2 - 0,3	0,2 - 0,3
Typical panel % ext (6m)			50 - 80	75 - 90	80 - 95	60 - 85
Typical overall % ext (6m)			40 - 70	60 - 80	60 - 80	55 - 75

A number of points pertaining to Tables 11(A), 11(B) and 11(C) require brief clarification. These are:

i) Provisions - that component of working costs associated with longwall mining which provides for large sub-assemblies and longwall face moves.

ii) Flexibility of a method - is a measure of the adaptability of a method to varying and/or unexpected mining conditions.

iii) Versatility of equipment - is a measure of the suitability of equipment under different conditions to those for which it was selected.

iv) Risk - is a combined measure of both the possibility of a loss and the magnitude of this loss.

v) Annual production - is based on three shifts/day for methods involving mechanised longwall mining and two shifts/day for all other methods.

vi) Percentage extraction - represent typical panel and overall percentage extraction rates currently achieved by each method. In the case of bord and pillar methods which maintain the integrity of the roof strata these figures are typical for a depth of 150 m.

5.6 Conclusions

A considerable number of thick seam mining methods are in use throughout the world. Most of these methods have been adapted from mining methods utilized to mine 2 to 4 m thick seams although a few, such as longwall mining with sublevel caving and hydraulic mining, have been developed specifically for thick seams. Well-defined geologic and economic

characteristics and requirements are associated with many of the methods. For example, hydraulic mining is noted to require a well cleated, friable coal seam, an immediate roof which caves at frequent and regular intervals behind the face soon after being undermined but not during the undermining operation, and a reasonably competent floor which does not deteriorate excessively in the presence of water. The method is also noted to be a non-capital intensive, low working cost, highly productive method. Under the rather unique combination of geologic and economic conditions existing in South Africa these characteristics and requirements need to be quantified in order to assess the suitability of the method to South African conditions. However, because quantitative classification systems have yet to be developed for many such paramters and since very little of the literature relating to thick seam mining is concerned with evaluating the potential of thick seam mining methods under a specific set of conditions, many of the characteristics and requirements of these methods could not be quantified.

Nevertheless, the information which has been tabulated, especially that categorised under geologic 'requirements' of a mining method and that pertaining to the economic characteristics of a mining method, should enable the potential of thick seam mining methods under local conditions to be assessed reasonably accurately. For example, the requirements of a well cleated, friable coal strata for hydraulic mining are sufficient to rule out its application in those South African coalfields where shearers of, typically, twice the kilowatt rating of those employed elsewhere in the world are required to mine poorly cleated thick seam coal horizons. Similarly, the fact that simultaneous longwall mining methods require at least double the capital outlay of conventional longwall mining in order to achieve the same annual production, but are not as productive, rules out the use of such methods in the light of the economic uncertainty associated with existing conventional longwall mining operations in South Africa.

In general, it may be concluded that a high percentage extraction (>60 per cent) from thick coal seams, particularly at depth, requires the utilization of capital intensive mining methods. The productivity associated with many of these methods is low.

Author Galvin J M
Name of thesis The mining of South African thick coal seams - rock mechanics and mining considerations 1981

PUBLISHER:
University of the Witwatersrand, Johannesburg
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