Multi-seam coal mining

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Paper written on project work carried out in partial fulfilment of Bachelor of Science in Engineering (Mining)

Synopsis

The project report is based on vacation work done by the writer at the Khutala Colliery during December/January 2009–2010. The purpose of this report is to explain and describe the design process in a multi-seam mine design for coal extraction at the Khutala Colliery. The multi-seam design will focus on the No. 2 and No. 4 seams as these are the seams that are currently being mined by underground methods at Khutala Colliery. The seam thicknesses and the parting thickness between the seams provide suitable conditions for designing a multi-seam mine design.

An investigation into the pillar design aspects is carried out followed by a numerical modelling analysis of various scenarios. This analysis validates the first principles approach provided by multi-seam design guidelines. The design results from the analysis of the selected pillar design indicate sufficient parting for primitive conditions between seams, thus illuminating the need for superimposing in-panel pillars.

This multi-seam mine design confirms the potential for the extraction of coal in a new panel. The design indicates that significant amounts of power station coal are present and suitable for extraction by room and pillar mining methods. The panel block indicates 401 625 tonnes of ROM coal. This block has a life of panel that will be mined just over a 4-month period. This 4-month period is assumed to mined at a production rate of 48 000 tonnes per month. The total capital cost required for the new panel is R48 281 127.05.

Keywords

Multi-seam mining, panel design, ventilation flow, superimposition.

Introduction

The problem statement of the project was to design a multi-seam mining layout for Khutala Colliery taking cognizance of the following:

- Panel design
- Ventilation flow
- Superimposition
- Infrastructure
- Men, material and product flow.

Khutala Colliery is a mining operation headed by BHP Billiton Energy Coal South Africa (BECSA). The colliery is located in the Mpumalanga province within the Kendal district. It has the sole purpose of supplying Eskom's Kendal power station with run of mine coal (ROM). The mining methods used are a mechanized bord and pillar method that utilizes continuous miners (CM) and a small-scale contractor operated opencast which utilizes trucks and shovels[1].

There are 5 accepted coal seams in the Witbank coalfield named numerically from 1 to 5 from the bottom[2]. Mining at Khutala Colliery takes place at 3 of those seams: No. 2, No. 4, and No. 5. This panel design will focus on the No. 2 and No. 4 seam.

Multi-seam mining

The mining of multiple seams has long been practised at the Khutala Colliery. By definition, 'multi-seam coal mining' is the mining of coal seams that overlay each other in a vertical depositional sequence. The seams are separated by rock strata known as parting[3].

The area of investigation for the new panel design is located in the No. 2 seam. It is directly overlaid by a previously mined-out area in the No. 4 seam. The area of investigation is located south of the graben fault towards the south-western part of the mine boundary (see Figure 1).

The proposed mining layout for the new panel is to develop a series of secondary developments westwards from the primary development towards the mine boundary. This would be followed by tertiary production panels being driven northwards (see Figure 2).

Borehole data

Borehole core data was collected on the new area of investigation. These borehole cores were drilled vertically from surface. Thirteen boreholes within the panel area were analysed. The data obtained from these borehole cores are analysed to assess the following:

- The coal quality
- The ground conditions
- Parting thickness
- Surrounding rock mass

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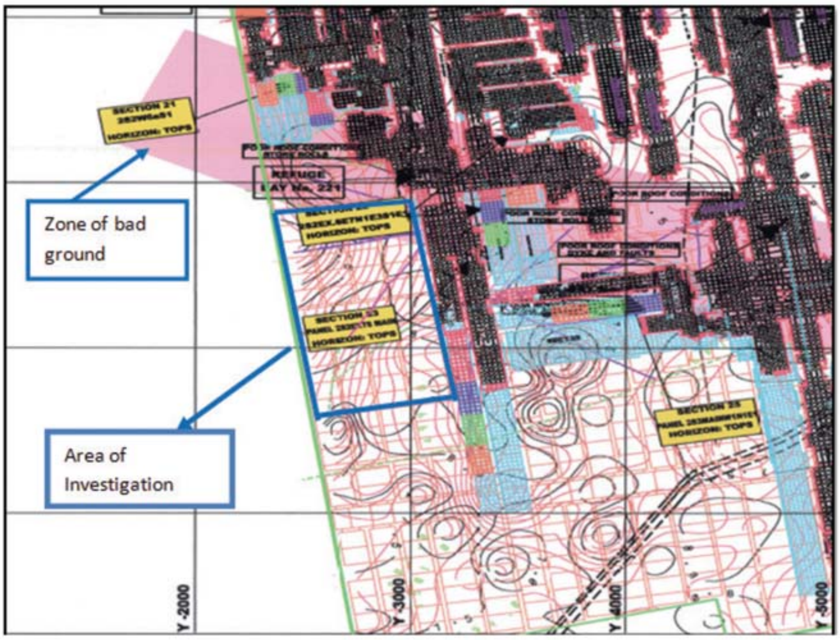

Figure 1—Area of investigation

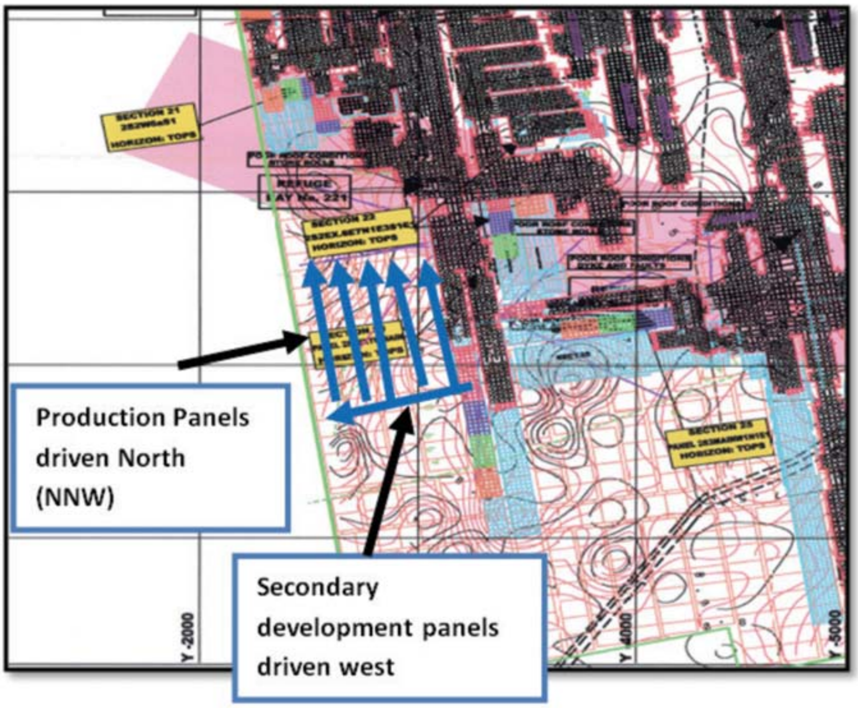

Figure 2—Plan view of panel layout

- Depth of the seams
- Seam thicknesses.

Cross-Sections

From the borehole data, cross-sections of the area were created which provided a general understanding of the seam topography as well as the distance relation between the two seams. Two north-south cross-sections and two east-west cross-sections of the panel area were taken (see Figures 3–6).

The general trend indicated by the cross-sections is that the seams are horizontal and continuous. The seam thicknesses and parting thicknesses remain relatively constant throughout the panel area.

Coal quality and Kendal specifications

Eskom requires that the coal product sent from Khutala Colliery satisfy Kendal's specifications. A summary of the specifications required by Kendal is indicated by Table I.

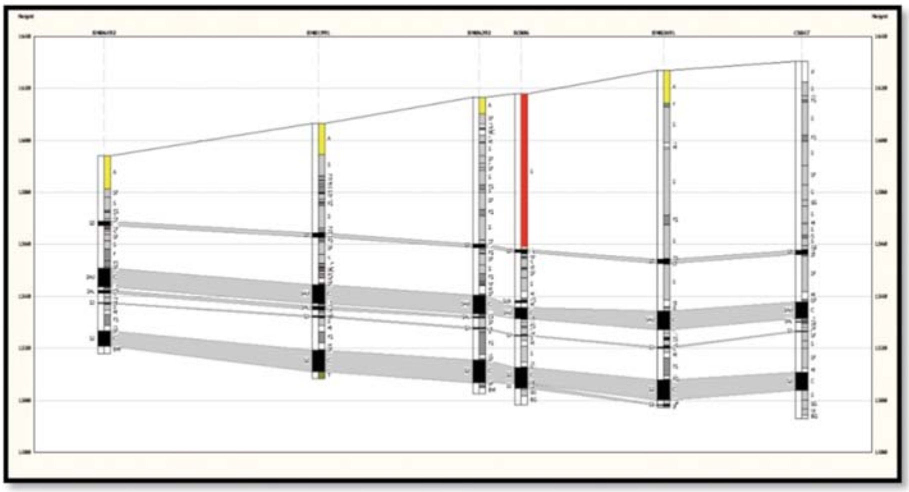

Figure 3—North-south cross-section No. 1

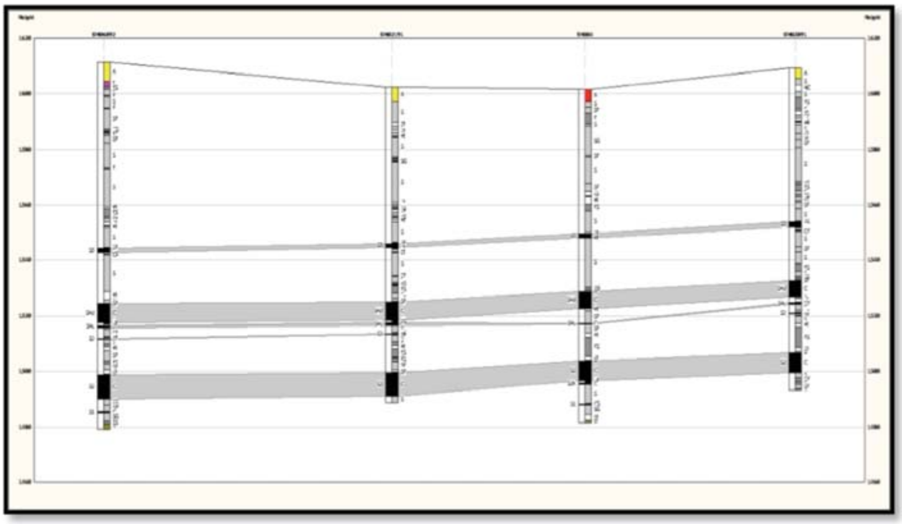

Figure 4—North-south cross-section No. 2

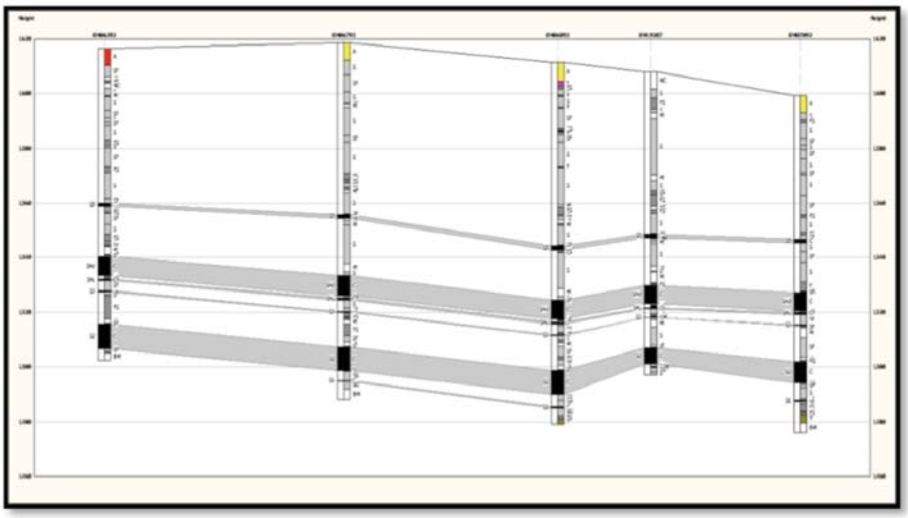

Figure 5—West-east cross-section No. 1

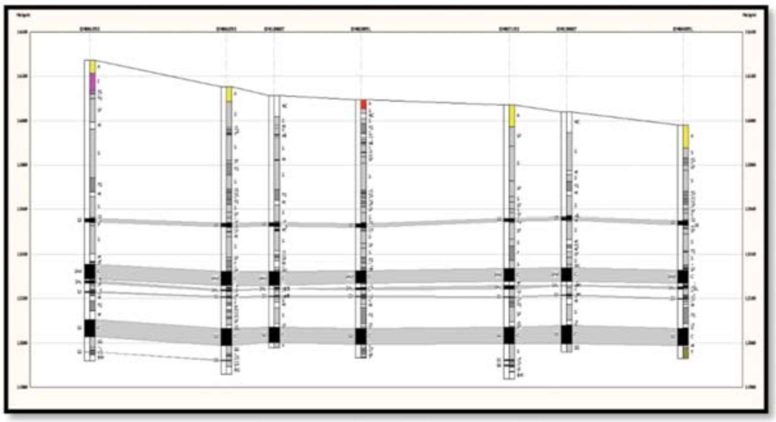

Figure 6—West-east cross-section No. 2

Table II

Borehole qualities

		CV (MJ/kg)	Ash (%)	S (%)	IM (%)
SM111092	Average	21.54	24.64	0.62	2.4
	Std Dev	7.2	16.6	0.57	0.7
SM19707	Average	18.33	17.21	0.22	3.18
	Std Dev	9.89	12.56	0.19	1.68
SM04491	Average	18.5	25.87	0.47	3.48
	Std Dev	8.78	20.07	0.38	1.47
SM04791	Average	24.42	19.46	0.61	3.9
	Std Dev	9.89	12.56	0.19	1.68
BC011	Average	24.46	17.21	0.26	3.2
	Std Dev	7.33	12.56	0.25	1.68
ZFN0778	Average	22.72	23	0.47	3.94
	Std Dev	3.97	9.58	0.24	0.44
SM03691	Average	19.34	22.26	0.27	3.48
	Std Dev	7.95	13.41	0.37	1.32
SM06792	Average	23.36	20.34	0.75	2.92
	Std Dev	6.73	14.93	0.49	0.69
SM01991	Average	21.21	26.18	0.43	4
	Std Dev	5.33	13.61	0.34	0.87
SM11092	Average	21.54	24.64	0.58	2.39
	Std Dev	7.19	16.6	0.42	0.69
Total average		**21.542**	**22.081**	**0.468**	**3.289**

Table I

Product specification summary[4]

Size	50 mm
Ash fusion temp	+1325 C
Ash content	<33.0 %
Abrasive index	300 mg-Fe
CV-calorific value (dry base)	19.6 MJ/kg
Grind ability	50
Total moisture	<8.0 %
Sulphur content	<1.0 %

Table II is a summary of the borehole qualities obtained from the boreholes taken from the panel area. Using the borehole data, the average values for the qualities in each borehole were calculated. When the above qualities in Table II are compared to the Table I, they do not violate any of Kendal's quality requirements.

Seam thickness, depth and parting thickness

Table III is a summary of the seam thickness, seam depth, and parting thickness from the 13 boreholes. The averages and standard deviations for these are calculated. The depth below surface to the seams varies throughout the panel area; however, this is due to the differences in surface topography. These differences in surface topography are relatively small and will be ignored in the panel design. The average values calculated in Table III are used in the design process.

Pillar design

The panel parameters were calculated using the CSIR Mining-Tek programme. The programme uses the Salamon and Munro formula to calculate various panel parameters. The safety factor for square pillars may be determined by dividing the strength of the pillar by the load on the pillar.

The desired safety factor, bord width, mining height, and mining depth are inputted into the CSIR Mining-Tek programme which then calculates the pillar width, pillar strength, pillar load and extraction ratio. The average values calculated in Table III are inputted into the programme.

Table III

Summary of the seam depth, seam thickness and parting thickness

Bhid	Depth to No. 4 seam	No. 4 seam thickness	Depth to No. 2 seam	No. 2 seam thickness	Parting thickness
BC03681	54.5	6.42	70.5	3.76	9.58
BC04181	88.3	7.28	115.42	8.77	19.84
BC04281	95.02	5.54	124.54	8.58	23.98
BH011	49.75	7.16	74.22	7.39	17.31
SM01991	69.2	7.14	95.5	8.04	19.16
SM03691	99.88	7.24	126.85	7.73	19.73
SM04491	81.74	7.29	107.5	7.27	18.47
SM04791	41.92	6.9	68.11	6.59	19.29
SM06492	50.32	7.08	73.25	5.69	15.85
SM06692	92.23	6.6	119.02	7.89	20.19
SM11092	66.16	7.22	91.31	8.14	17.93
SM19707	94.22	6.41	118.7	6.82	18.07
ZFN0778	91.79	7.02	118.98	8.84	20.17
Average	**75**	**6.87**	**100.3**	**7.35**	**18.43**
Std dev	**20.54**	**0.51**	**22.46**	**1.41**	**3.27**

Table IV

Panel parameters calculated using CSIR Mining-Tek

W/H ratio: 2.2	B-Bord width: 6.8			
Design No.	H-Mining height	W—pillar width	C—centre to centre distance	W/H ratio
1	8.5	20.6	27.4	2.42
2	8	19.7	26.5	2.46
3	7.5	18.8	25.6	2.51
4	7	17.9	24.7	2.56
5	6.5	17	23.8	2.62
6	6	16	22.8	2.67
7	5.5	15.1	21.9	2.75
8	5	14.1	20.9	2.82
9	4.5	13.2	20	2.93
10	4	12.2	19	3.05
11	3.8	11.8	18.6	3.11

Various panel parameters were calculated for different mining heights (see Table IV). These panel parameters were assessed to check for compliance with the Khutala COP 'Code of Practice to Combat Rock Falls'. In Khutala's COP, a standard W/H ratio of 2.2 is used. The bord width at Khutala Colliery also is excavated to a standard width 6.8. Also, the COP requires that all in panel pillars be designed to safety factor of 1.7.[5]

Panel design parameters:

SF—Safety Factor: 1.7
B—Bord width: 6.8 m
D—Mining Depth: 100 m

Superimposing multiple seam layouts

Superimposition occurs when the bord and pillar layouts in multiple seams are developed such that they overlay each in a vertical sequence. The next obvious question is determining whether superimposing of pillars will be necessary when designing the panel layout.

To assess this, a simplified multi-seam design flowchart was used in determining whether superimposition would be necessary or not (see Figure 8). This flowchart was used to assess superimposing of all the various panel parameters calculated in Table IV (see Table V).

Numerical modelling

Numerical modelling was carried out to back check the validity of the multi-seam design guidelines mentioned before. Two computer programs used for the modelling process were Examine 2D and LaModel. These two modelling programs were both selected because Examine 2D gives model results from a side view perspective wereas the LaModel gives the model results from an aerial view perspective (plan view). The results from both programs will give an almost 3-dimensional perspective of the panel area providing a richer appreciation of the conditions that are expected to occur in this new panel.

The panels are modelled under superimposed state and under a non-superimposed state to compare the conditions. Both the stress distributions and vertical displacements are assessed.

The two different mining heights modelled are the lowest and the mid-high. The average seam height is 7 m therefore there is little value in modelling a mining height greater than this.

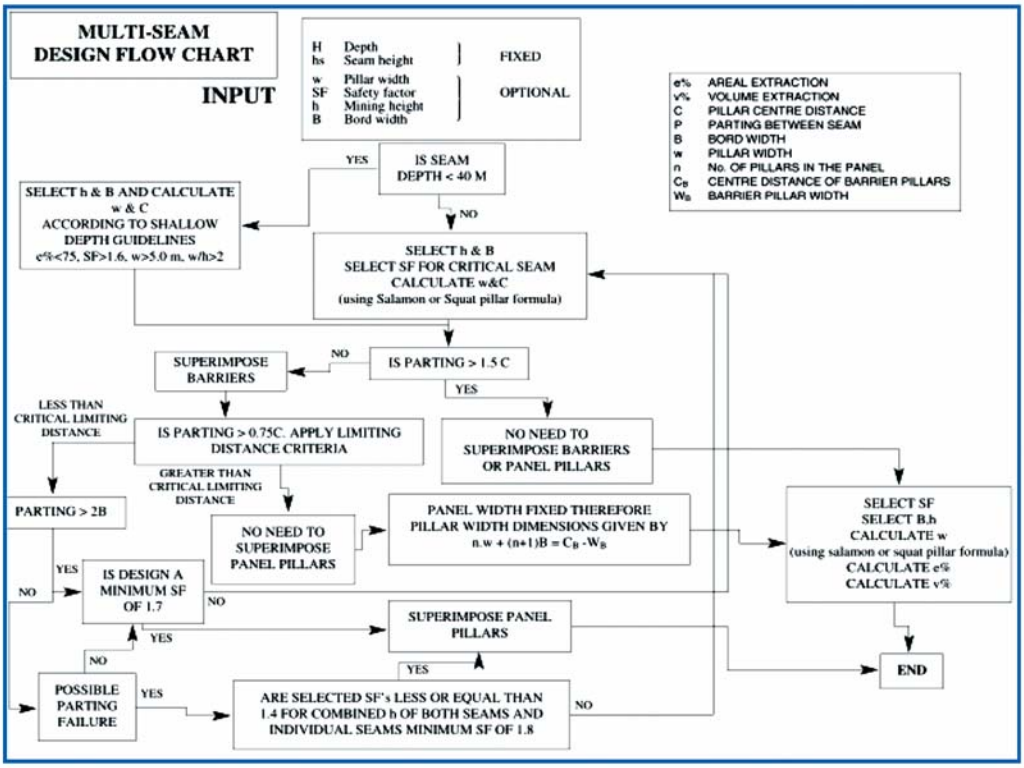

Figure 8—Multi-seam design flow chart[6]

Table V

Panel parameters for various mining heights

W/H ratio: 2.2	B-bord width: 6.8 (m)			P(aver)= 18.43	Std dev =3.2	P-parting<1.5C
Design no.	**H-mining height (m)**	**Safety factor**	**Extraction ratio (%)**	**0.75P (aver)**	**Superimpose pillars P<0.75C**	**Superimpose barriers**
1	8.5	1.7	43.48	20.55	yes	yes
2	8	1.7	44.74	19.88	yes	yes
3	7.5	1.7	46.07	19.2	no	yes
4	7	1.7	47.48	18.53	no	yes
5	6.5	1.7	48.98	17.85	no	yes
6	6	1.7	50.75	17.1	no	yes
7	5.5	1.7	52.46	16.43	no	yes
8	5	1.7	54.49	15.68	no	yes
9	4.5	1.7	56.44	15	no	yes
10	4	1.7	58.77	14.25	no	yes
11	3.8	1.7	59.75	13.95	no	yes

(note: this Table is linked to Table IV)

Examine 2D

The following parameters were used in Examine 2D:

Overburden consists of sandstone and mudstone variations

Density sandstone[7]	2 323 kg/m3
Density mudstone	1 746 kg/m3
Overall unit weight	0.0399 MN
Horizontal/vertical stress ratio	2.0

Rock mass properties

Elastic Modulus	15 Gpa
Possion's ratio	0.25

Mining parameters

Mining height	4 m
Pillar width	12.2 m
Bord width	6.8 m

Figure 9 and Figure 10 indicate the stress distribution and vertical displacement respectively of superimposed workings.

In Figure 9 there are low stress levels in the workings for both seams. This is due to the shallow depths in which these workings occur. There is minimal interaction between drives of the two seams, indicating near primitive ground conditions in the parting. The stresses around the drives in the No. 2 seam are slightly higher than the stresses around drives in the No. 4 seam due to their differences in depth.

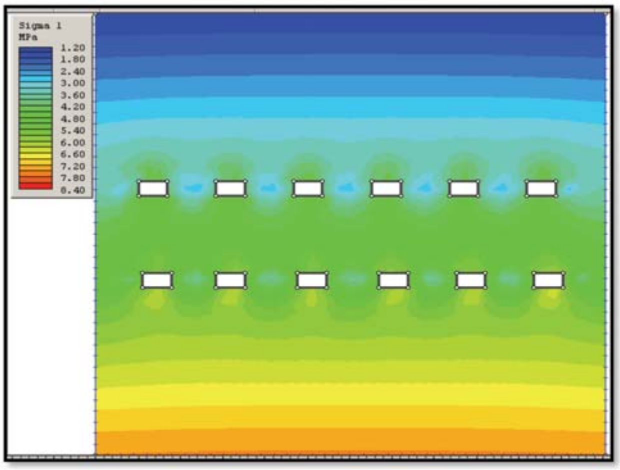

Figure 9—Vertical stress in superimposed multiple seam workings

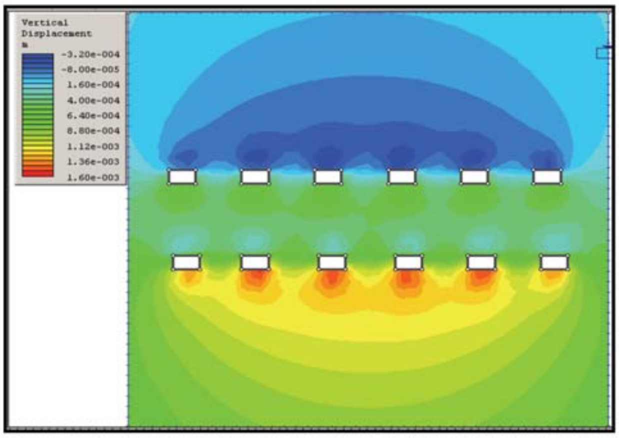

Figure 10—Vertical displacement in superimposed multiple seam workings

Figure 10 indicates low level vertical displacements in roofs of the drives in both seams. The displacement is tensile in the No. 4 seam roof and in compression in the No. 2 seam roof. Both seams have a compression vertical displacement in the floor of the drives.

Figure 11 and Figure 12 indicate the stress distribution and vertical displacement respectively of non-superimposed workings.

In Figure 11 and Figure 10 there are no significant changes in the conditions when workings are under a non-superimposed state. There are minute increases in stress levels and vertical displacements that can be ignored. There is minimal interaction between drives of the two seams, indicating near primitive ground conditions in the parting.

Mining Parameters

Mining height	6 m
Pillar width	16 m
Bord width	6.8 m

Figure 13 and Figure 14 indicate the stress distribution and vertical displacement respectively of superimposed workings.

The conditions in Figure 13 and Figure 14 remain relatively the same as those in Figure 9 and Figure 10. There are slight increases in the stress levels and vertical displacements; however, nothing significant. In Figure 10, the roof of the No.4 seam drives are in compression rather than tension.

Figure 15 and Figure 16 indicate the stress distribution and vertical displacement respectively of non-superimposed workings.

In Figure 15 and Figure 16 there are again no significant changes in the conditions when workings are under a non-superimposed state. There are minute increases in stress levels and vertical displacements that can be ignored. There is minimal interaction between drives of the two seams indicating near primitive ground conditions in the parting.

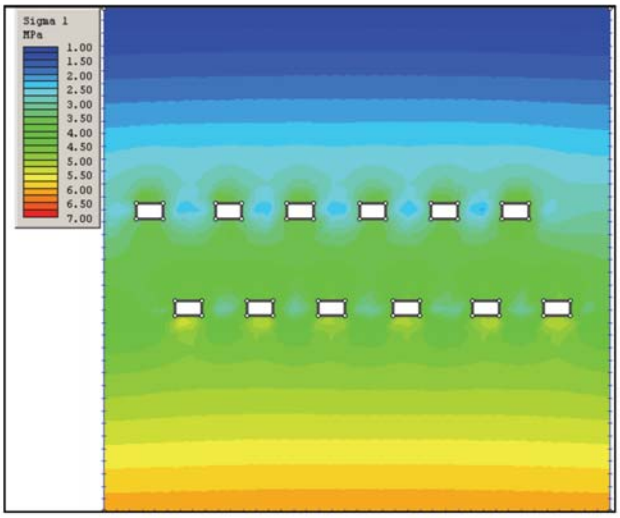

Figure 11—Vertical stress distribution in non-superimposed multiple seam workings

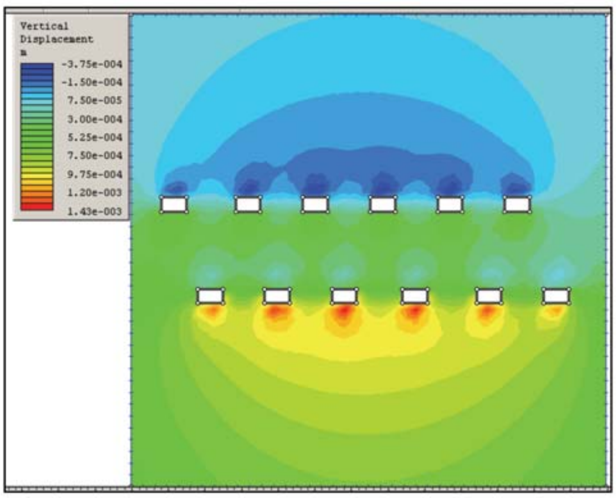

Figure 12—Vertical displacement in non-superimposed multiple seam workings

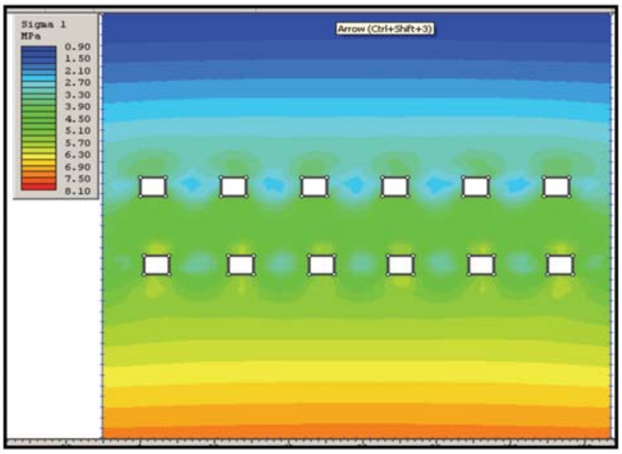

Figure 13—Vertical stress distribution in superimposed multiple seam workings

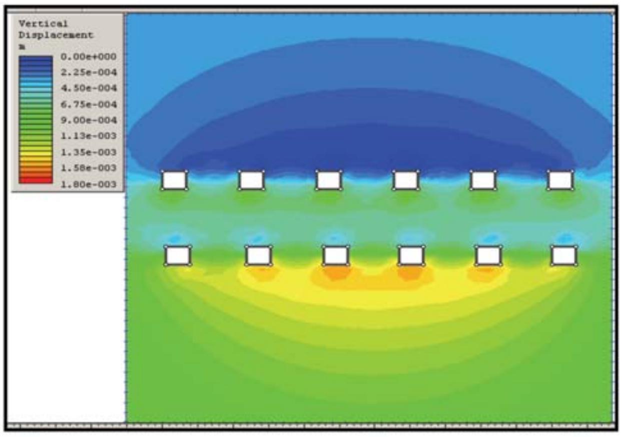

Figure 14—Vertical displacements in superimposed multiple seam workings

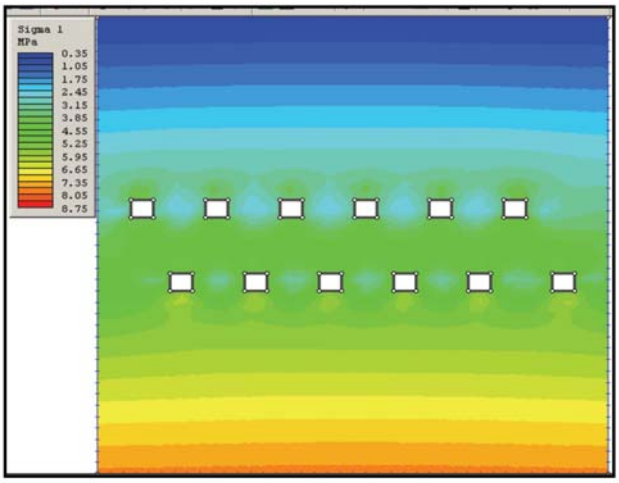

Figure 15—Vertical stress distribution in non-superimposed multiple seam workings

LaModel

LaModel was used to model the two seams overlaying each other. The workings in both seams have the same panel parameters. Only the total vertical stress was analysed on both seams. This was done for when the panels were perfectly superimposed and also for different misalignment positions when the seams were not superimposed. The panel were shifted out in 2 m increments. This was done to assess how the stress conditions in the panel changed with increasing degree of misalignment.

The following parameters were used in the LaModel:

Mining height	6 m
Pillar width	16 m
Bord width	6.8 m
E_{seam}	4 Gpa
$E_{overburden}$	15 Gpa

Figure 17 and Figure 18 indicate the total vertical stress on the No. 2 seam and No. 4 seam workings respectively under superimposed conditions.

In Figure 17, the total vertical stress values are relativly low. The greatest amount of vertical stress is towards the centre of the panels. The lower stress values area located around the edges of the panel.

In Figure 18, the stress values remain relatively low; however, there is a slight increase in stress levels due to its greater depth. The greater stress levels are still found towards the centre of the new panel, with lowest values located towards the edges.

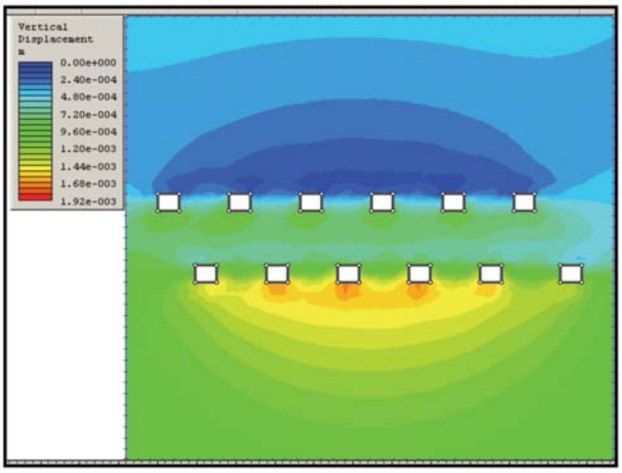

Figure 16—Vertical displacement in non-superimposed multiple seam workings

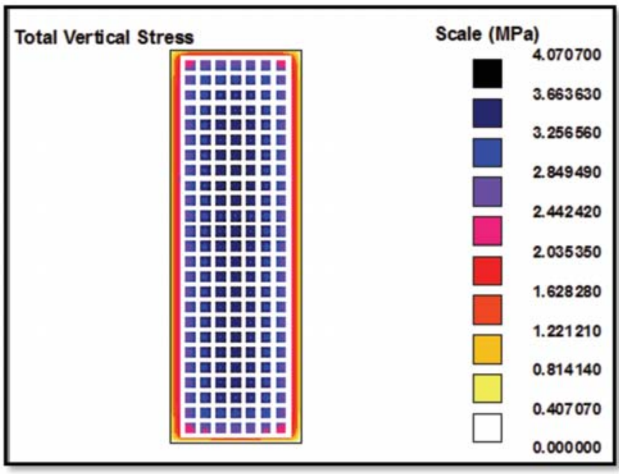

Figure 17—Total vertical stress on superimposed No. 4 seam workings

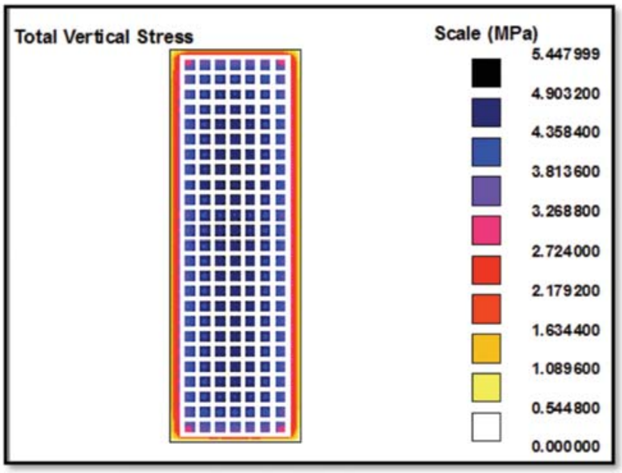

Figure 18—Total vertical stress on superimposed No.2 seam workings

Figure 19 and Figure 20 indicate the total vertical stress on the No. 2 seam and No. 4 seam workings respectively under misalignment 1.

Figure 19 and Figure 20 indicate a slight increase in the stress levels in both seams for the first misalignment. However, the stress levels in both seams still remain relatively low. The greatest amount of vertical stress is still towards the centre of the panels, with lower stress values located around the edges of the panel.

The same trends are experienced for misalignment 2 and misalignment 3. Stress levels increase slighlty with increasing degree of misalignment. However, the stress levels in both seams still remain relatively low. The greatest amount of vertical stress is still towards the centre of the panels, with lower stress values located around the edges of the panel.

Analysis of the numerical modelling

The multi-seam guidelines suggest that superimposing in-panel pillars is not necessary in most cases. When all the mining heights were modelled under superimposed conditions, the workings were relatively stable. These conditions showed little change when workings were modelled under non-superimposed conditions. The writer believes the numerical modelling motivates the validity of this multi-seam design guideline. There is little if no interaction of induced stresses created by the drives in both seams. This thus means that a near primitive ground condition exists between the parting.

Panel evaluation

Tonnage estimation

New panel surface area = 38 250 m^2
Coal density = 1.5 t/m^3
Average seam thickness = 7 m
Total tons = 38 250 × 7 × 1.5 = 401 625

Table VI is a comparison between various mining parameters.

The next questions is which panel parameters should be selected?

Recommended panel design parameters

In the writer's opinion, a mining height of 6 m is suitable for the new panel. This is a compromised selection based on the following key observations:

- ➤ No superimposing of pillars is necessary
- ➤ Mining height does not exceed minimum seam thickness (1 m of coal left in the roof)
- ➤ A relatively good extraction ratio is achieved
- ➤ Effective utilization of coal reserves (coal is not left unmined in pillars)
- ➤ Sufficient room for ventilation flow.

Production rate

Recent data from producing sections at Khutala indicated that CM operated sections were producing between 20 000 t/month and 60 000 t/month, averaging 48 000 t/month with a standard deviation of 10 000 t/month[8].

Average monthly tonnage per section = 48 000 t/month
Actual ROM tonnes = 203 101 (see Table VI)
Life of panel = 203 101/ 48 000 = 4.2 months.

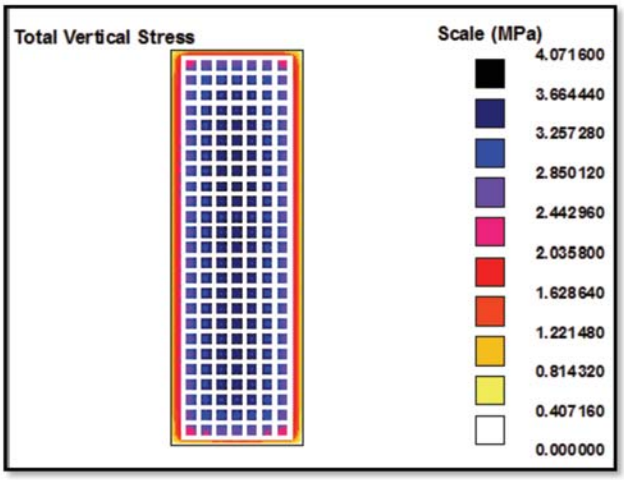

Figure 19—Total vertical stress on non-superimposed No. 4 seam workings (2 m misalignment)

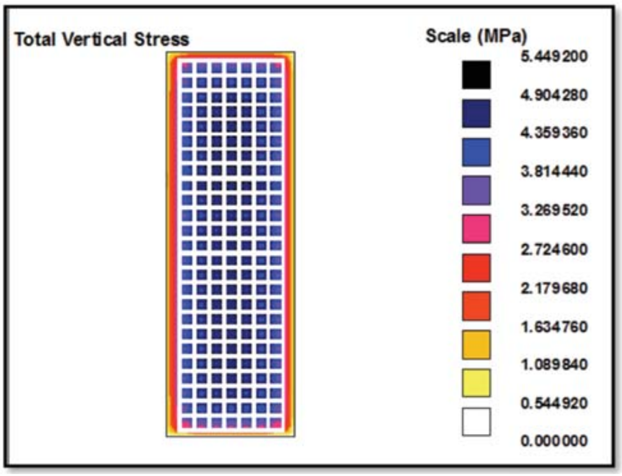

Figure 20—Total vertical stress on non-superimposed No.2 seam workings (2 m misalignment)

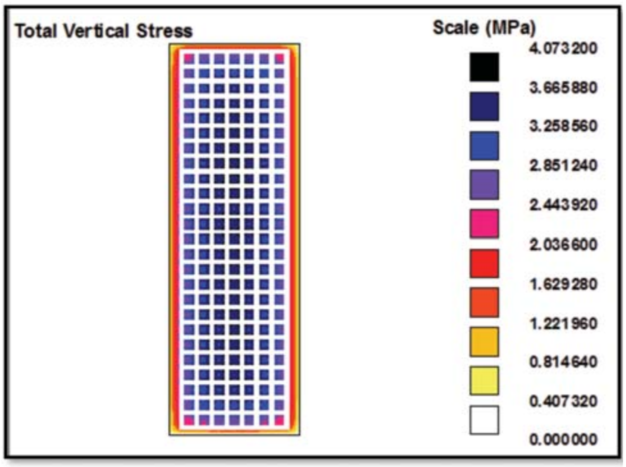

Figure 21—Total vertical stress on non-superimposed No. 4 seam workings (4 m misalignment)

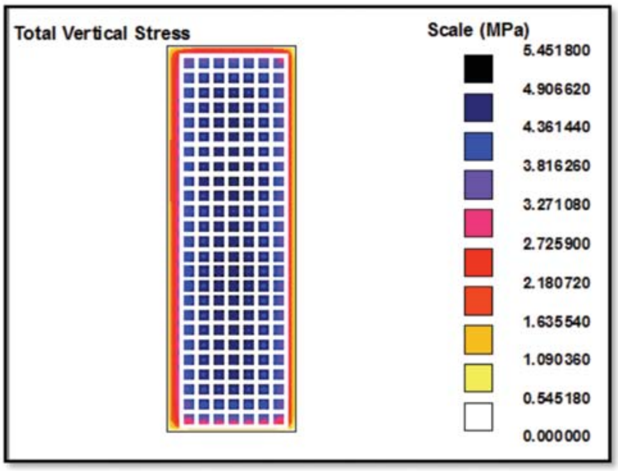

Figure 22—Total vertical stress on non-superimposed No. 2 seam workings (4 m misalignment)

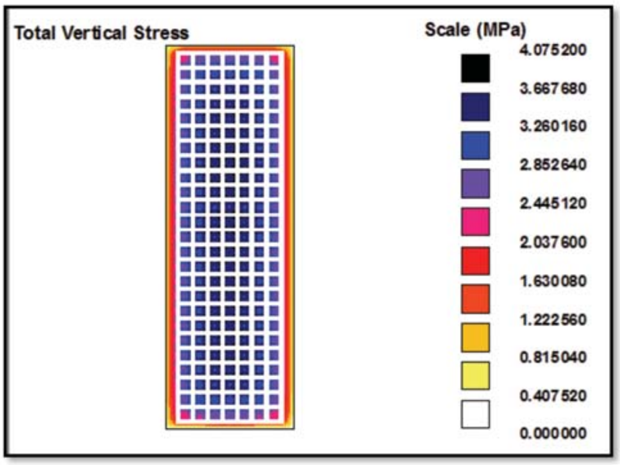

Figure 23—Total vertical stress on non-superimposed No. 4 seam workings (6 m misalignment)

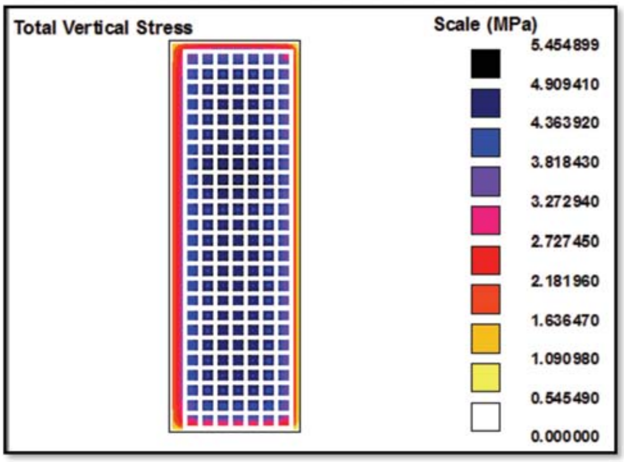

Figure 24—Total vertical stress on non-superimposed No. 2 seam workings (6 m misalignment)

Table VI

Extraction ratios and coal reserves to be extracted for different mining heights

Mining height (m)	Extraction ratio (%)	Total tonnes in panel area (t)	Actual tonnes extracted (t)
4	58.77	401 625	236 035
6	50.57	401 625	203 101
8	44.74	401 625	179 687

Infrastructure

Infrastructure that has to be excavated for mining operations to be carried out include:

- Workshops
- Refuge bays
- Sub-stations
- Airway crossings/crossover.

Improving men, material and product flow

Strategy: installation of a new storage bunker system for No. 2 seam. A bunker system is proposed to be installed along the main conveyor belt of the southern workings (see Figure 25).

Advantages of new surge bin installation

- Continuous production from production panels despite breakdowns on the main belts
- Access from #2 seam to #4 seam
- Improves supply of services
- Provides ventilation flexibility.

Problems to be expected:

- High construction and infrastructural costs (R12 000 000).
- Installation process will result in deviations from the designed mine layout.

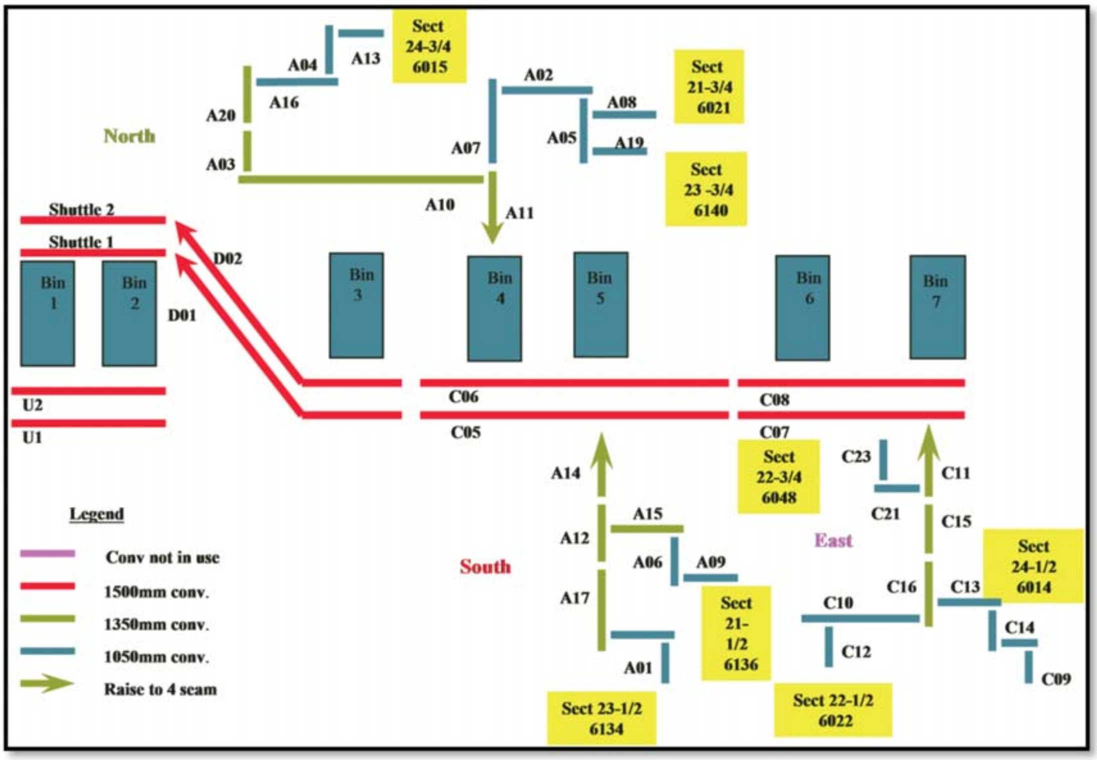

Figure 25—No. 2 seam conveyor belt layout[9]

Ventilation requirements

Panel air requirements

V—air velocity = 1 m/s
B—bord width = 6.8 m
H—mining Height = 6 m
Q—quantity = 1 × 6.8 × 6 = 41 m^3/s
Assume 2 throughroads
Panel quantity = 41 m^3/s × 2 = 82 m^3/s
AU—air utilization = 80 per cent
Panel quantity = 82 × 80 per cent =102 m^3/s

Regulation 10.8.1 suggests that a panel should be provided with 0.025 m^3/s of air per ton mined. At Khutala, the typical production figures for a panel average 770 tonnes/panel/shift to a maximum of 1 200 tonnes/panel/ shift[35]. Therefore the quantity required per panel is 30 m^3/s. The estimated panel quantity of 102 m^3/s is considerably higher than this and thus sufficient. The energy required to supply this air flow is supplied by the main mine fans on surface.

Ventilation layout

A panel will have an intake and a return on its side extremities whereby a coursing system is used to ventilate the panel. This is where air flows in one side of the panel, courses across the panel face and returns out on the opposite side. Mined-out areas in between the intake and return roadways are sealed off and separated by walls and brattices. The panel's ventilation layout will be integrated into the mine's ventilation layout. Mined-out areas are sealed out so as to avoid ventilating needlessly. Air crossings are also installed to ensure contaminated return air does not mix with fresh intake air (see Figure 26).

Financial valuation

In the financial valuation the capital costs associated with developing the new panel are determined. The costs are based on past capital costs for developing panels.

The past development costs in March 2007 are assumed to increase at an escalation (factoring in interest and inflation) of 11 per cent per annum. This translates to the following capital cost in 2010 monetary terms:

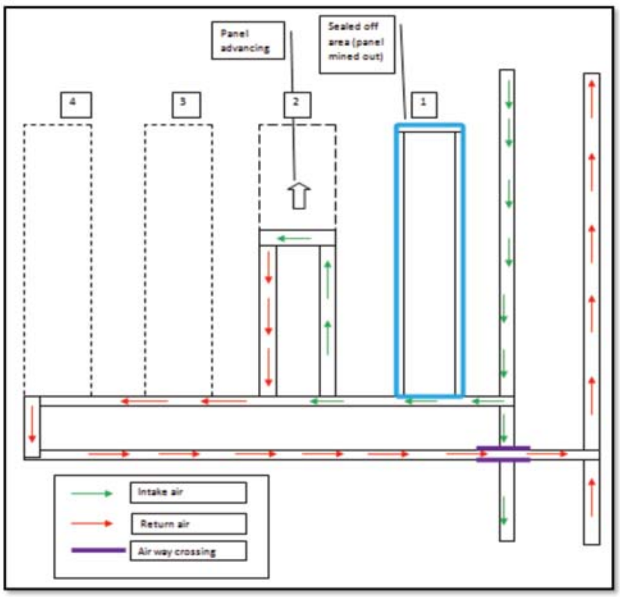

Figure 26—Panel ventilation system integrated with the mine ventilation system

Table VII

Development capital escalated at 11%[10]

Conveyor equipment purchase	
1050 Drive	1 367 631.00
1050 Tail end	136 763.10
General equipment	547 052.40
General equipment	547 052.40
Belt transformer	1 025 723.25
Flitting panels	547 052.40
Starter panels	547 052.40
Transformer	2 051 446.50
Trailing cables	R 547 052.40
Switches	1 641 157.20
Mobile sub	1 367 631.00
Conveyor and structure	683 815.50
Electrical equipment	
Belt transformer	1 025 723.25
Flitting panels	547 052.40
Starter panels	547 052.40
Transformer	2 051 446.50
Trailing cables	547 052.40
Switches	1 641 157.20
Mobile sub	1 367 631.00
Conveyor and structure	683 815.50
Total development capital	**19 420 360.20**

Table VIII

Mining equipment major overhaul escalated 11%[10]

Extra Section Mach - CM No.18	12 035 152.80
2#Shuttle Car No.29 (New Sect)	1 500 000.00
2#Shuttle Car No.37 (New Sect.)	1 500 000.00
2#Shuttle Car No.38 (New Sect.)	1 500 000.00
2#Feeder Breaker (New Sect.)	1 200 000.00
2#Roof bolter (New Sect.)	800 000.00
Total major overhaul	**18 535 152.80**

Table IX

Replacement capital escalated at 11%[10]

Section transport	547 052.40
Toro and tractor	6 496 247.25
Maintenance car	1 094 104.80
Stone duster	2 188 209.60
Total replacement capital	**10 325 614.05**

Table X

Total costs

Total development capital	19 420 360.20
Total major overhaul	18 535 152.80
Total replacement capital	10 325 614.05
Total panel cost	**R 48 281 127.05**

Interest: 6.50 per cent
Inflation: 4.20 per cent
Escalation = (1+0.065) (1+0.042) – 1
= 10.9 per cent, say 11 per cent

Tables VII to Table X indicate the capital requirements for the new panel.

Comments (findings)

The design that goes into developing a new panel requires prior knowledge from various departments such as rock engineering, planning, geology, mining, and ventilation. All the concepts from these departments must be integrated to form a coherent panel design. The panel design must done in line with the existing mine design. It must be aimed at extracting as much of the reserve as possible. The overall design must ensure that production begins in a safe and economical way.

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