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To: Mr. Pongweni
Company: Total Coal South Africa
From: Dr. B. J. Madden
Date: Monday 26th August 2013
Number of Pages inclusive: (123)
cc   Mr. G. Ponni,
          Mr. D. du Plooy,
          Mr. R. Phadagi.

Dear Mr. Pongweni,

Re.: Geotechnical Report on the Feasibility of Checkerboarding the mined out areas at Tumelo Coal Mine.

Executive Summary

A desktop study investigation has been conducted into the feasibility of secondary extraction on a checkerboard layout of the existing pillars in the 2 Seam workings at the Tumelo.

The findings of the investigation documented in this report suggest that it is feasible to conduct checkerboarding in the following panels at Tumelo:

- East Main North 3
- East Main North 3 West 3
- East Main North 4
- East Main North 5
- East Main North 7
- East Main North 8
- East Main North 8 West 1
- East Main North 8 West 2
- East Main North 8 West 3
- East Main North 8 East 1 & 2

The various investigations detailed in this report including theoretical calculations and numerical modelling indicate that the extraction of alternate pillars in the above panels can be achieved.

The mining layouts at Tumelo were designed for maximum extraction on the advance and therefore additional reserve extraction by means of checkerboard mining must be seen as an unforeseen gain in production tonnages, optimization of the geological resource and extension of the Life of Mine (LOM).

Pillar width to height ratios, in some of the panels in which checkerboard extraction is deemed to be feasible, are lower than the usually recommended ratios for pillars to be considered as potentially extractable which results in the potential for violent pillar failure.

Careful attention should therefore be paid to the selection and sequencing of the pillars to be extracted in each one of the identified panels.

Pillars could, and most likely will, fail with time after the pillar extraction has taken place.

Due to the general nature of the immediate roof at Tumelo, roof collapses could occur and roofbolt breakerlines, timber "Policeman" and a "Tooth Extractor," to be available on site, are suggested.

The findings of this desktop investigation as documented in the report below should only be seen as an initial indication of areas in which checkerboard extraction is potentially viable.

Additional investigations, including but not limited to the following are suggested prior to the commencement with secondary extraction:

- underground mapping;
- drilling of additional geological boreholes to verify the overburden strata;
- identification and installation of monitoring equipment;
- conducting of a risk assessment;
- compilation of the relevant procedures;
- compilation of an extraction sequence for each pillar and panel to be mined.

1. Introduction

At the request of Mr. T. Pongweni, Technical Services Manager, Total Coal South Africa, an investigation was conducted into the feasibility of conducting checkerboard extraction of the pillars in the existing underground workings on the 2 Seam at Tumelo Coal Mine.

Mining at Tumelo Coal Mine commenced in January 2009 and is expected to continue into early or mid 2014 depending on the availability of reserves and mining equipment.
All mining which has been conducted at Tumelo has been done by continuous mining methods on a standard bord and pillar layout.

Pillar centers (designed) range between 14,0 m and 25,0 m at various locations within the mine with a designed bord width of 6,8 m in all panels.

All of the panels which have been mined during this period at Tumelo have been designed for primary extraction only, with the maximum percentage extraction on the advance.
Due, however, to the variability of the 2 Seam within the Tumelo mining area as well as the frequency of dolerite intrusions within the reserve limit, optimal extraction on the advance at Tumelo has been extremely difficult which has resulted in, in some areas, larger than ideal pillars (from the perspective of reserve optimization). This in turn results in higher than required safety factors of the pillars in such areas and the potential to conduct secondary extraction on a checkerboard layout.

For the purposes of this investigation the underground layouts and face positions as at the end of July 2013 have been used.

2. Information Provided

The following information was provided by management and the relevant departments:
- Survey information from Exact Survey as detailed below:
    - 1 in 2500 mine plan of the Tumelo Reserve Area, with the following indicated on it:
        - Existing underground plans,
        - Face positions at the end of July 2013,
        - Geological borehole positions,
        - Surface features and structures,
        - The D/2.7 limit relevant to the above mentioned surface features and structures,
        - Intersected geological intrusions,
        - Anticipated geological intrusions,
        - The 2 Seam reserve limit,
        - Panel names,
        - Boundary pillars.
    - .dxf file containing all of the above information was also provided,
- Geological Borehole Logs were requested and utilized as required,

3. Geotechnical Investigation

An assessment of the surface features and structures within the mining area at Tumelo revealed that there are a number of areas which should not be considered for secondary extraction due to the stipulated mining restrictions which are to be applied when mining beneath such structures, as documented in the undermining application risk assessment.
Such areas should therefore be deemed un-exploitable from a secondary extraction perspective but have still been included to a certain degree in this investigation.

a. Pillar Stability

Safety Factor Calculations

The initial pillar stability assessment was conducted by means of the strength, load and safety factor calculations documented in Table 1 below.

The safety factor calculations indicate all of the panels in question were mined according to the current industry standards designed for maximum extraction on the advance without initially planning for secondary extraction.

Table 1 included below indicates the calculated as-mined pillar strengths, pillar loads and safety factors in all of the existing panels at Tumelo.

A table which includes all of the relevant information used in these calculations is included in APPENDIX 1 of this report.

As can be noted from the information included in Table 1 below there are a number of panels in which either the as-mined Safety Factor, or the minimum as-mined width-to-height ratios of the pillars are below 1,8 and 3,0 respectively.

In such areas secondary extraction may still be possible, however it is more unlikely, and if possible should be conducted with a considerable amount of additional caution.

It is suggested that the panels in which the Safety Factors or width-to-height ratios were noted to be below 1,6 or 2,2 respectively be immediately excluded from further consideration for secondary extraction.

Panel	Salamon Strength (Mpa)	Load (Mpa)	SF	SF (CM)	Width/Height (Min)	Areal % Extraction	Strength (vdM) (Mpa)	SF(vdM)	SF(vdM) CM	SF (CM) After Extraction
East Main Portion 1	9.9	3.5	2.8	3.4	3.0	71.3	10.5	3.0	3.6	1.7
East Main Portion 2	8.7	5.3	1.6	1.9	2.1	68.5	7.3	1.4	1.6	1.0
East Main Portion 3	8.7	4.8	1.8	2.1	2.5	64.9	8.6	1.8	2.0	1.0
East Main Portion 4	8.9	4.9	1.8	2.0	2.9	60.0	10.2	2.1	2.3	1.0
East Main Portion 5	9.9	5.1	1.9	2.2	2.9	55.4	10.3	2.0	2.2	1.1
East Main Portion 6	10.6	5.6	1.9	2.1	3.3	55.4	11.5	2.1	2.3	1.1
East Main North 3 Portion 1	9.1	4.4	2.1	2.3	2.9	60.0	10.1	2.3	2.6	1.2
East Main North 3 Portion 2	8.6	5.0	1.7	2.0	2.6	60.7	9.3	1.9	2.1	1.0
East Main North 3 West 3	9.2	4.4	2.1	2.4	2.9	63.3	10.3	2.3	2.7	1.2
East Main North 4	8.6	5.3	1.6	1.8	2.4	62.9	8.4	1.6	1.8	0.9
East Main North 5	8.7	5.2	1.7	1.9	2.7	61.3	9.4	1.8	2.1	1.0
East Main North 7	10.8	6.2	1.7	2.0	3.8	63.3	13.3	2.1	2.5	1.0
East Main North 8 Portion 1	11.3	5.4	2.1	2.3	3.6	54.9	12.7	2.4	2.6	1.2
East Main North 8 Portion 2	10.7	5.1	2.1	2.3	3.3	54.7	11.6	2.3	2.5	1.2
East Main North 8 West 2	10.6	6.4	1.7	1.9	3.7	61.9	13.0	2.0	2.3	0.9
East Main North 8 West 3	9.6	5.7	1.7	1.9	3.2	58.6	11.2	2.0	2.2	1.0
East Main North 8 East 1 & 2	9.9	6.2	1.6	1.8	2.5	60.8	8.7	1.4	1.6	0.9
East Main South 1	9.0	4.7	1.9	2.2	2.7	66.2	9.5	2.0	2.4	1.1
East Main South 1 East 1	8.1	5.4	1.5	1.7	2.2	64.8	7.9	1.5	1.7	0.9
East Main South 1 East 2	8.4	5.1	1.7	1.9	2.5	67.7	8.7	1.7	2.0	1.0
East Main South 2 Portion 1	8.0	6.1	1.3	1.5	2.3	63.4	8.0	1.3	1.5	0.8
East Main South 2 Portion 2	8.6	5.5	1.6	1.8	2.7	62.0	9.4	1.7	2.0	0.9
East Main South 2 West 3	9.6	4.8	2.0	2.2	3.0	58.6	10.5	2.2	2.4	1.1
East Main South 2 East 1	8.6	6.1	1.4	1.6	2.7	61.3	9.5	1.5	1.8	0.8
East Main South 2 East 2	8.8	5.6	1.6	1.8	2.5	56.8	8.8	1.6	1.8	0.9
East Main South 2 East 3	9.9	5.7	1.8	2.0	3.3	59.4	11.6	2.1	2.3	1.0
East Main South 4	10.1	6.2	1.6	1.8	3.1	59.7	10.9	1.8	2.0	0.9
East Main South 5	11.7	5.8	2.0	2.2	3.8	54.0	13.2	2.3	2.5	1.1

Table 1. As-mined pillar strengths, loads, safety factors, width-to-height ratios and areal % extraction.

The various pillar strengths documented in the above table have been calculated using Salamon's pillar strength formula, included below:

$$Salamon\ Strength = \frac{7{,}176\ w^{0{,}46}}{h^{0{,}66}}\ \text{MPa}$$

Where: w – Effective pillar width
          h – As-mined mining height

Loading on the pillars has been calculated assuming Tributary Area Loading which is a conservative estimate of the load to which the pillars in the majority of the panels in question are subjected as the Tributary Area Loading theory usually only applies when the width of the panel in question exceeds the depth at which mining is to take place within it. This has not always been found to be the case at Tumelo and therefore in some instances a portion of the load of the overburden is expected to span the panel and result in abutment loading of the inter-panel barrier pillars. This is illustrated in the outputs of the numerical modelling included below.

The load has however still been calculated using the following equation:

$$Load = \frac{0.025\ H\ C^2}{w^2}\ \text{MPa}$$

Where: H – Depth to the floor of the mining seam
          C – As-mined pillar centers
          w – Effective pillar width

Safety factors have subsequently been calculated using the following formula:

$$Safety\ Factor = \frac{Strength}{Load}$$

The above calculations do not take into account the adjustment of the pillar strength due to the fact that mining was conducted using a continuous miner.

The following continuous miner adjustment after (Wagner and Madden 1984) has subsequently been applied to the Safety Factor:

$$SF_{cm} = \eta\ (1 + \frac{2\Delta w_o}{w})^{2{,}46}$$

Where: n – Safety Factor calculated above for Drill and Blast mining methods
          w_0 – The blast damage zone assumed to be 0,3 m
          w – The designed pillar width

The pillar width to mining height ratio and estimated areal percentage extraction have subsequently been calculated.

The pillar strength formula of van der Merwe (2005), included below, provides an alternative method for calculating the strength of a pillar:

$$Strength_{vdm} = 3,5 \ x \ \frac{w}{h} \quad \text{MPa}$$

A safety factor has then also been calculated using the van der Merwe (2005) formula to which the continuous miner adjustment has once again been applied.

Numerical Modelling

The 2-dimensional numerical modelling package LAModel (NIOSH) was utilized to calculate the stress regimes to which the pillars within the panels under investigation are currently exposed and would be exposed to was the proposed checkerboard extraction to take place in each panel.

In addition to this the numerical modelling package was used to assess the proposed final pillar layouts for stability / failure as well as to estimate the amount of convergence which can be expected in the immediate roof within the mining panels post checkerboard extraction.

A sensitivity analysis on the effect of different element sizes on LaModel results was conducted by Prof. Van der Merwe (2011).

The following is an extract from Prof. Van der Merwe's report:

A typical coal mining dimensions where the pillars are of the order of 10 m or more wide and roadways of the order of 5,0 m to 10 m wide. The model was infinitely wide and regular in all directions, in order to take the effects of barriers out of the equation.
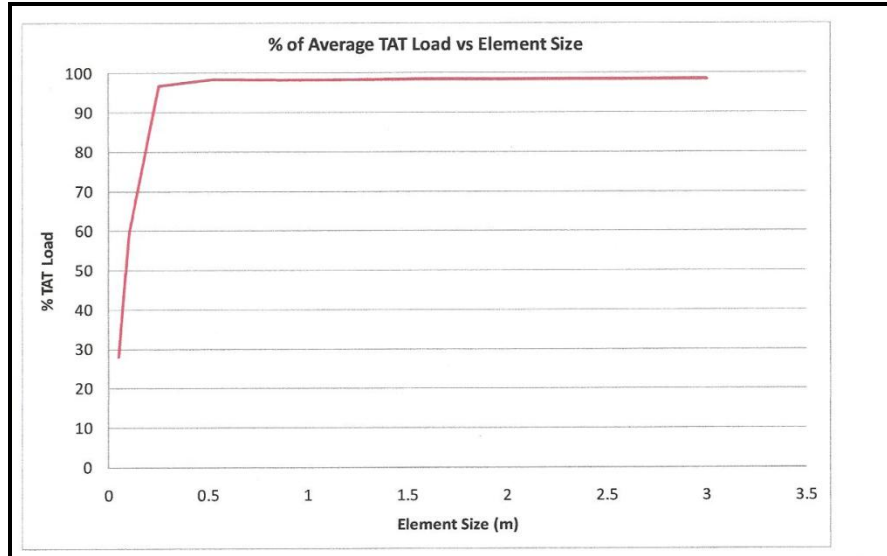
Figure 1 LaModel Load as a Percentage of the Tributary Area Load vs Element Size.

The first issue is the relevance of the average pillar load as compared to Tributary Area Theory loading. Figure 1 shows that acceptable results are obtained provided the element sizes exceed 0.5 m. If the elements are smaller, the results are erratic.

The second issue relates to yielding elements. LaModel elements have no lateral connection to each other, each one acts on its own. Therefore, if the Material Properties specify a certain maximum load, then the element will yield if its load is greater than the specified load, never mind the average pillar load. The whole issue arises because we can only determine the maximum load for an entire pillar, and then we apply it to individual elements.

As known, the load across a pillar is not constant: It is higher at the edges than in the centre. If you model a pillar with just a single element, then the LaModel load is obviously constant across the pillar. The more elements you use, the greater the difference will be between the load at the edges as opposed to the load in the centre of the pillar, see Figures 2 and 3.
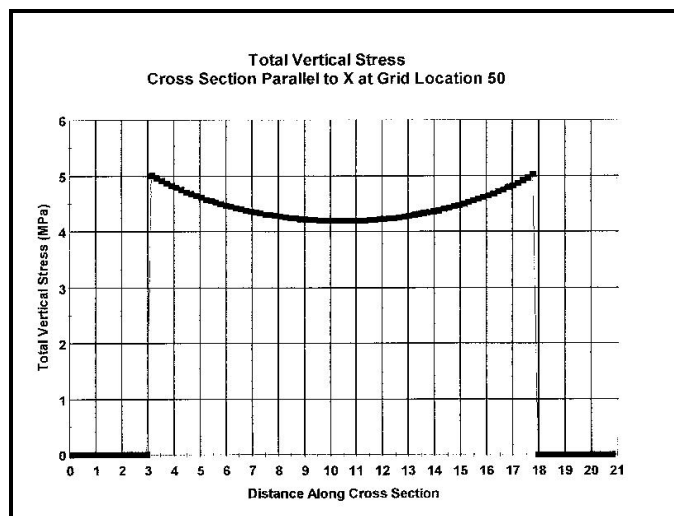

Figure 2. *Stress profile across a pillar using 0.2 m elements – the difference between the maximum and minimum load is approximately 0.9 MPa.*

The material specification is based on the maximum load that a pillar can sustain. Bearing in mind the above, it is thus possible that the average load on a pillar can be below the failure limit, while the load on individual elements at the edges can be greater than the limit. Those elements at the edge will then fail, the load on the adjoining elements will increase and eventually the whole pillar will fail, while the average load was below the failure limit. The smaller the elements, the more pronounced this effect will be.

To counter this effect, it is thus necessary to adjust the failure limit to compensate for the element size effect. The maximum strength should be increased such that the maximum load on an element is equal to the average pillar load that is calculated for any given pillar size at the point of failure.
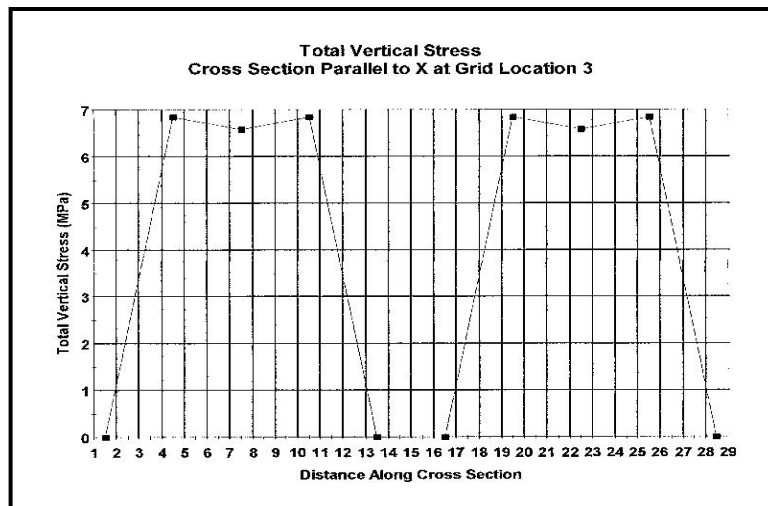

Figure 3. Stress profile across pillars using 3 m elements – the difference between the maximum and minimum loads is approximately 0.4 MPa.

Figure 4 shows by how much the maximum element load exceeds the average pillar load for different element sizes.
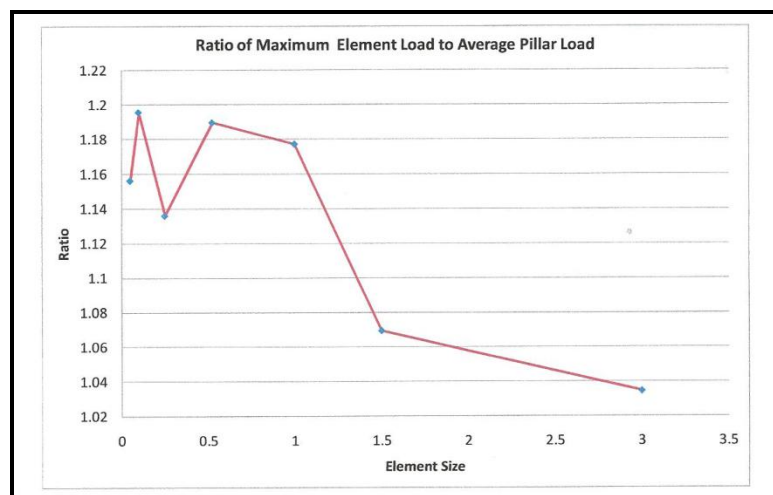

Figure 4. Ratio of maximum element load to average pillar load for different element sizes.

What the figure confirms, is firstly that elements smaller than 0.5 m should not be used in typical coal mining situations. Secondly, it assists in deciding by how much the maximum load specification should be increased if small elements are used. For instance, using an element size of 0.5 m, the maximum element load is approximately 19% higher than the average pillar load and consequently the maximum pillar strength should be increased by 19% to avoid the artificial chain reaction.

When using 3 m elements, the adjustment comes down to about 3.5%. This explains why unrealistic pillar runs are predicted in certain situations. Figure 4 should help with the required adjustments when using small elements.

Model parameters.

For the purposes of the numerical modelling investigation, a total of Thirteen (13) areas were identified to be modelled in individual modelling assessments.

Illustrated in Figure 5 below are all of the areas which were identified and subsequently modelled.
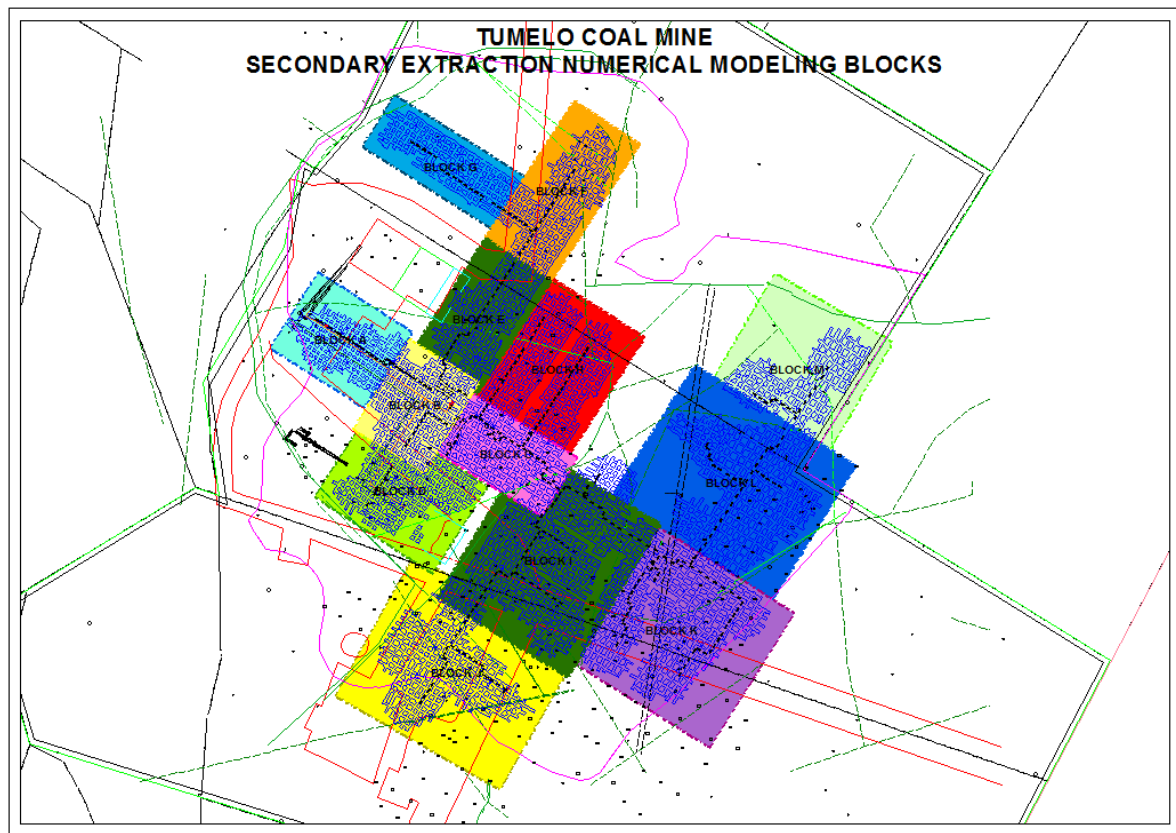
Figure 5. Illustration of the Thirteen (13) individual areas which were identified for and subsequently individually modelled using numerical modelling techniques.

Table 2 below documents the basic details for all of the areas which were modelled in this investigation. The full details of the input parameters for each of the various materials used in each individual model, to simulate the Checkerboard extraction of the various panels under investigation, are included in the tables included in APPENDIX 1 of this report.

Figure 6 below illustrates the concepts of Peak and Residual Stress' and Strains as well as the Elastic and Post Failure Modulus of the pillars.

Figure 6. Conceptual Illustration of a Strain Softening Model.

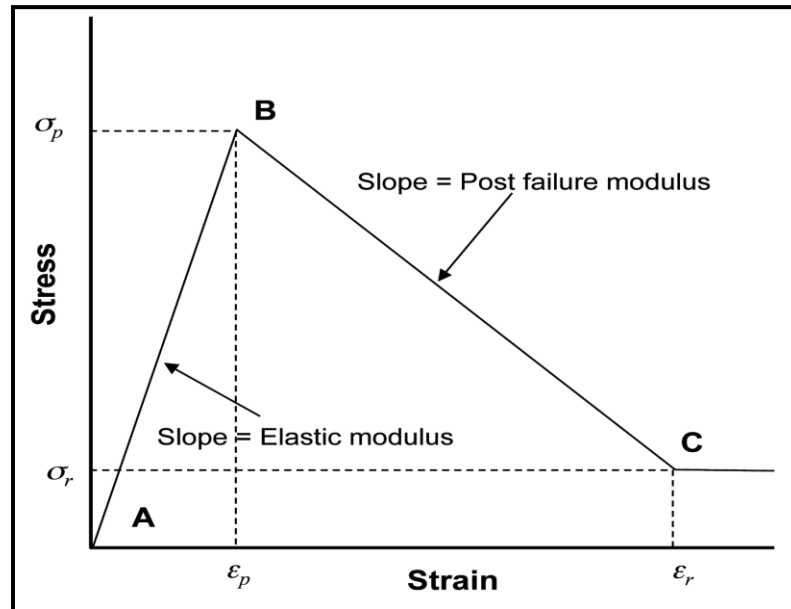| MODEL NUMBER	BLOCK	DIMENSIONS (m)		BOUNDARY CONDITIONS				MINING DEPTH (m)	SEAM THICKNESS (m)	NO. OF MATERIALS
		LENGTH	WIDTH	NORTH	SOUTH	EAST	WEST			
1	A	250	315	Rigid	Rigid	Symmetric	Rigid	50	1.9	3
2	B	270	215	Symmetric	Symmetric	Symmetric	Symmetric	72	3.6	3
3	C	180	310	Symmetric	Rigid	Rigid	Symmetric	78	3.7	3
4	D	285	380	Rigid	Rigid	Rigid	Rigid	72	3.6	3
5	E	365	210	Symmetric	Rigid	Rigid	Rigid	70	3.9	4
6	F	420	210	Rigid	Symmetric	Rigid	Rigid	75	3.8	3
7	G	450	155	Rigid	Symmetric	Rigid	Rigid	65	3.5	3
8	H	380	290	Rigid	Symmetric	Rigid	Rigid	80	4	4
9	I	455	380	Rigid	Rigid	Symmetric	Rigid	90	3.8	5
10	J	435	470	Rigid	Rigid	Rigid	Rigid	90	3.9	4
11	K	420	445	Rigid	Rigid	Rigid	Rigid	100	3.4	4
12	L	410	490	Rigid	Symmetric	Symmetric	Rigid	100	3.1	5
13	M	350	320	Rigid	Symmetric	Rigid	Rigid	92	3.4	4

Table 2. Basic Information for each of the Areas which were Modelled in the Numerical Modelling Investigation.

Note, in the tables included in APPENDIX 1 of this report, that the Peak Stress and Strain as well as the Residual Strain for a Peak Stress increased by 19% as per Prof. Van der Merwe's calculations have been used in the modelling exercise.

LaModel Outputs

Each of the identified areas (blocks) was modelling individually and independent of each other, although the boundary conditions of each model was set to, as far as practically possible, imitate the effect which the subsequent mining of each of the various areas would have on the adjacent areas.

Due to the fact that existing underground workings at Tumelo are relatively small from a geographic perspective, as well as the fact that pillar failure as well as the associated overburden failure is not expected (at least in the short term); the effect that the mining of adjacent panels will have on the remaining mining areas is not expect to be significant.

Included below is a summary of the model results which were generated by the models constructed for each of the identified areas.

<u>Block A</u>

Current Scenario:
Maximum Total Vertical Stress -   4,339 MPa
Maximum Seam Convergence -   3,049 mm

Seam Convergence

Scale (m)

0.003049
0.002746
0.002442
0.002138
0.001835
0.001531
0.001228
0.000924
0.000621
0.000317
0.000013
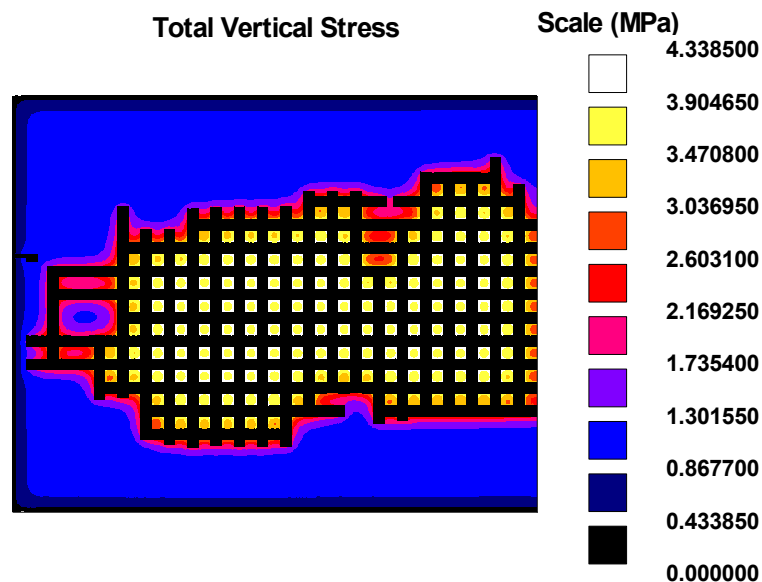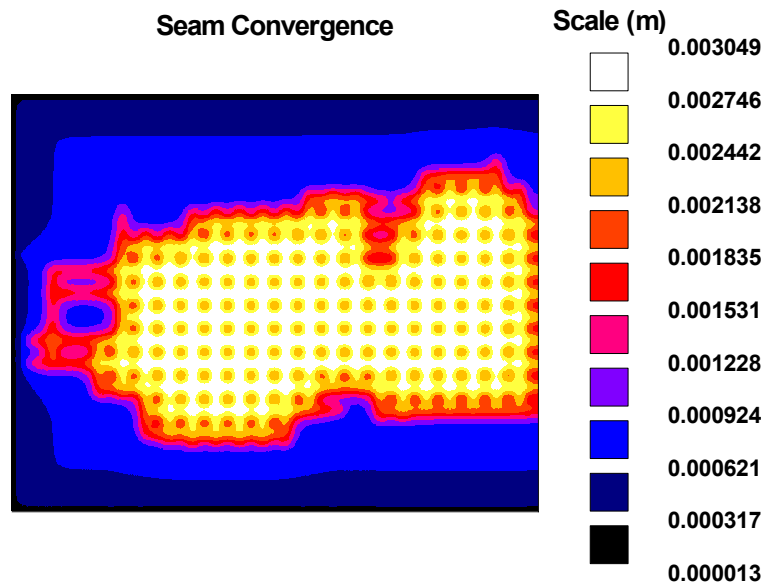
Post Checkerboard Extraction:
Maximum Total Vertical Stress -   8,697 MPa
Maximum Seam Convergence -   6,649 mm

Total Vertical Stress

Scale (MPa)

8.696900
7.827210
6.957520
6.087830
5.218140
4.348450
3.478760
2.609070
1.739380
0.869690
0.000000

Seam Convergence

Scale (m)

⬜	**0.006649**
🟨	**0.005985**
🟧	**0.005322**
🟧	**0.004658**
🟥	**0.003995**
🟥	**0.003331**
🟪	**0.002668**
🟪	**0.002004**
🟦	**0.001341**
🟦	**0.000677**
⬛	**0.000013**
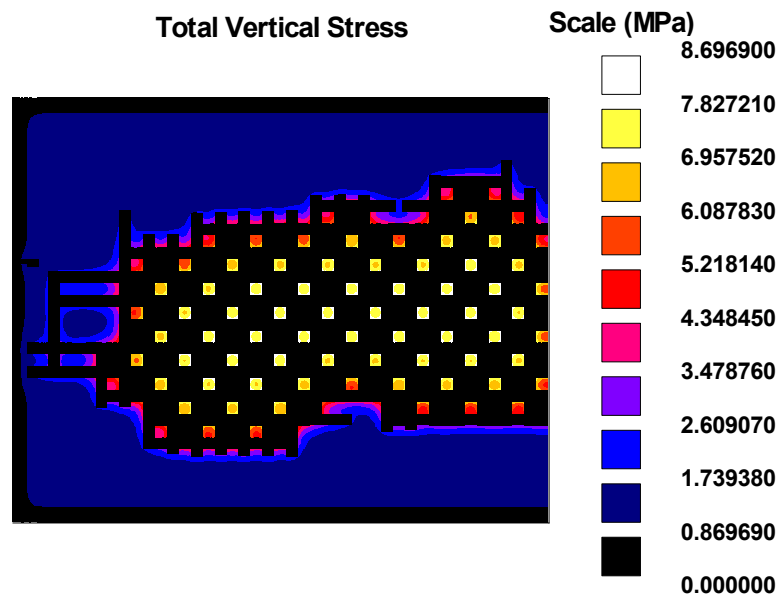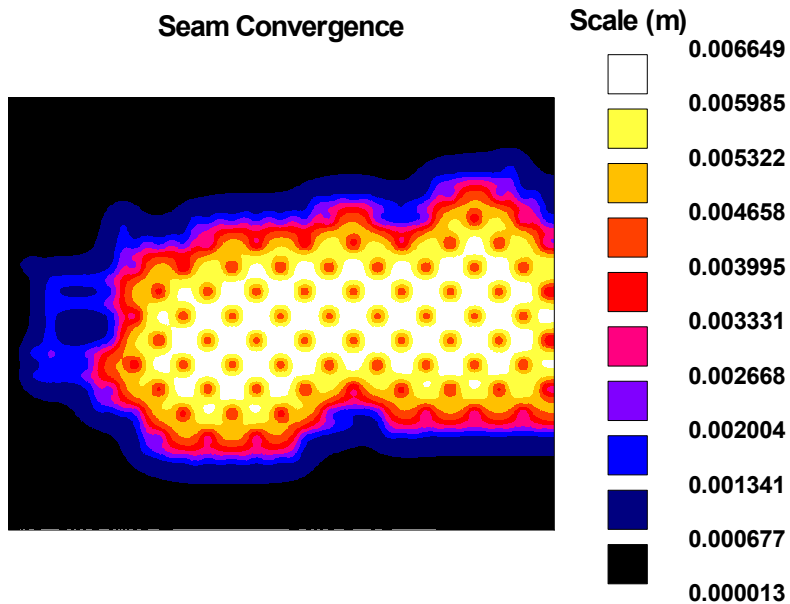
Block B

       Current Scenario:
       Maximum Total Vertical Stress -   8,073 MPa
       Maximum Seam Convergence -   7,098 mm

Total Vertical Stress

Scale (MPa)

⬜	**8.073200**
🟨	**7.265881**
🟧	**6.458560**
🟧	**5.651240**
🟧	**4.843920**
🟥	**4.036600**
🟥	**3.229280**
🟪	**2.421960**
🟦	**1.614640**
🟦	**0.807320**
⬛	**0.000000**

Seam Convergence

Scale (m)

☐	0.007098
🟨	0.006532
🟧	0.005967
🟧	0.005401
🟥	0.004835
🟥	0.004269
🟪	0.003703
🟪	0.003137
🟦	0.002571
🟦	0.002005
⬛	0.001439
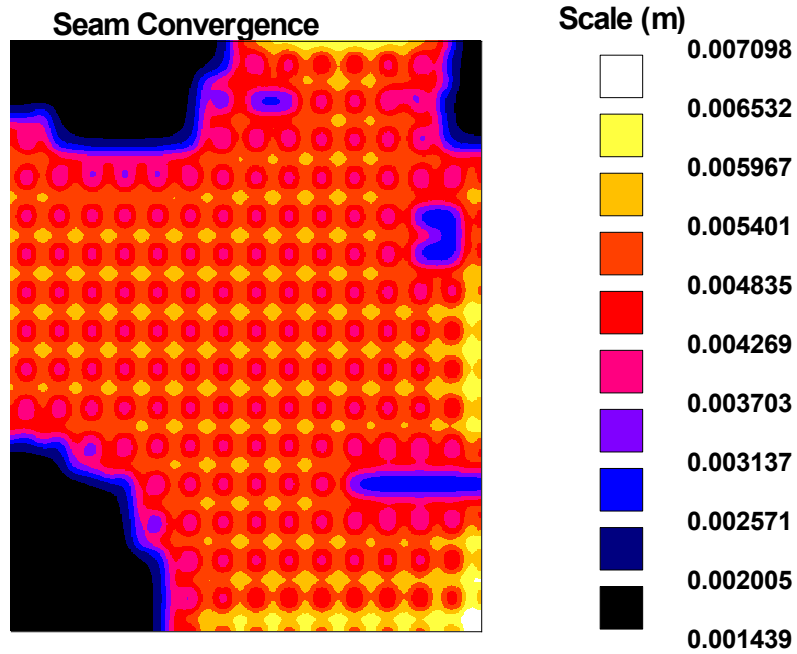
Post Checkerboard Extraction:
Maximum Total Vertical Stress -   95,988 MPa (**Pillar Failure**)
Maximum Seam Convergence -   251,75 mm

Total Vertical Stress

Scale (MPa)

☐	95.987999
🟨	86.389198
🟧	76.790398
🟧	67.191597
🟥	57.592800
🟥	47.993999
🟪	38.395199
🟪	28.796400
🟦	19.197599
🟦	9.598800
⬛	0.000000

Seam Convergence

Scale (m)

⬜	0.251750
🟨	0.226719
🟧	0.201688
🟧	0.176657
🟥	0.151626
🟥	0.126595
🟪	0.101564
🟪	0.076533
🟦	0.051501
🟦	0.026470
⬛	0.001439

Block C

Current Scenario:
Maximum Total Vertical Stress -   5,739 MPa
Maximum Seam Convergence -   5,422 mm

Total Vertical Stress

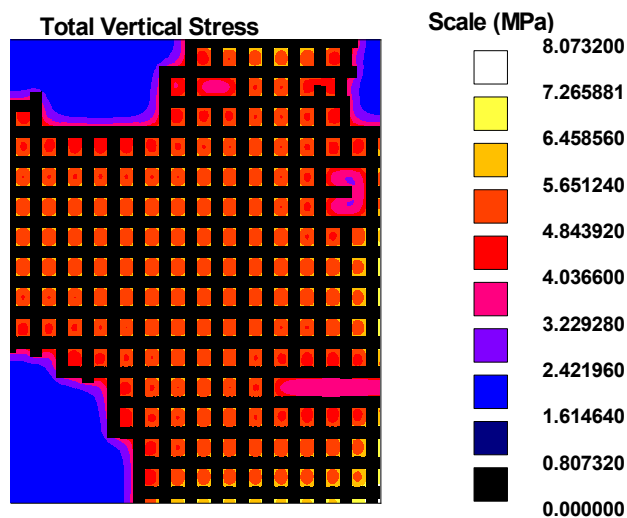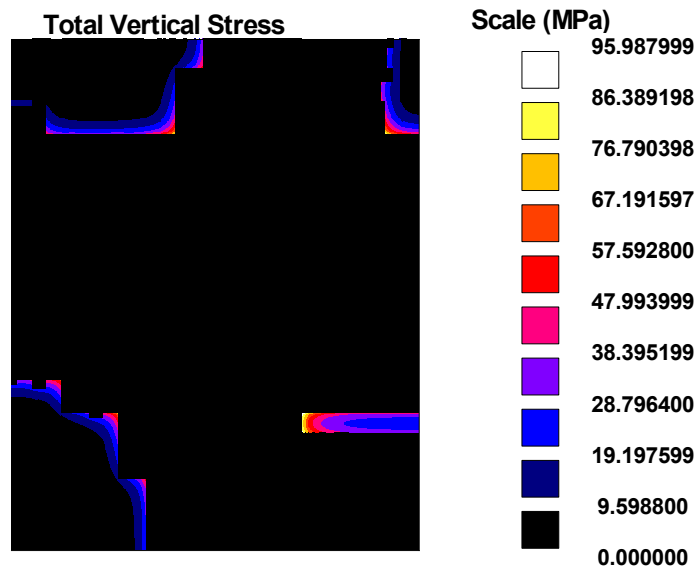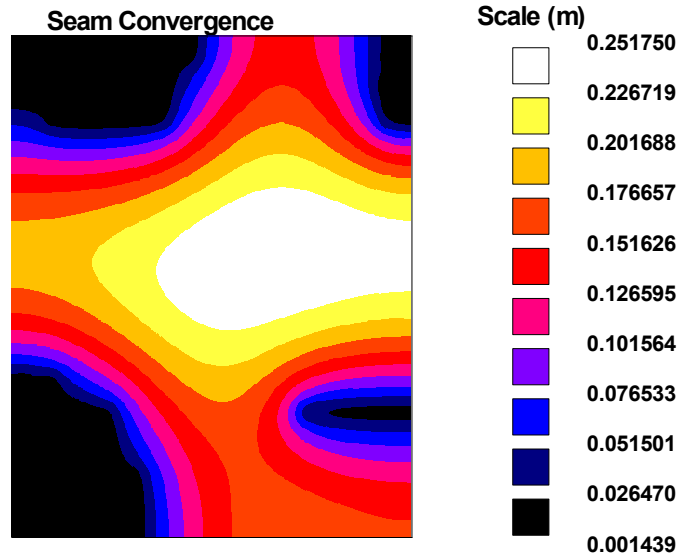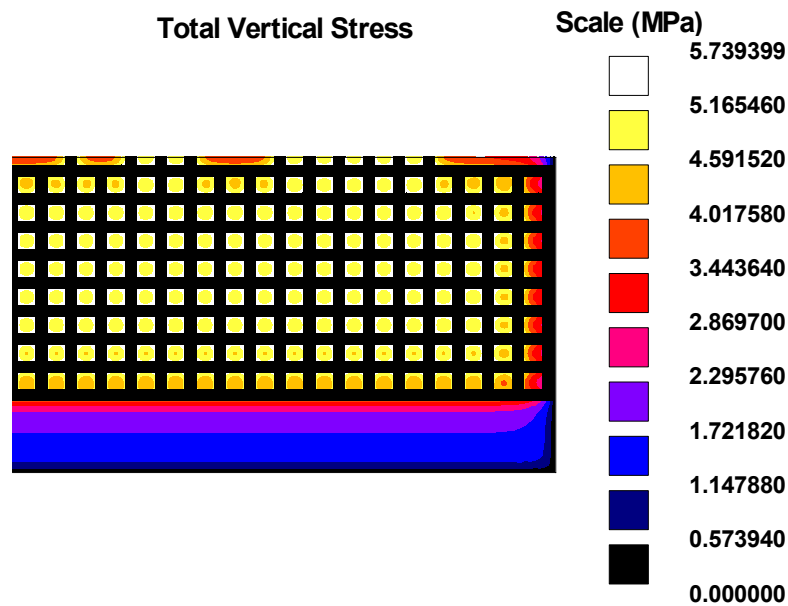**Scale (MPa)**

⬜	5.739399
🟨	5.165460
🟧	4.591520
🟧	4.017580
🟥	3.443640
🟥	2.869700
🟪	2.295760
🟪	1.721820
🟦	1.147880
🟦	0.573940
⬛	0.000000

Seam Convergence

Scale (m)

(white)	0.005422
(yellow)	0.004882
(orange)	0.004342
(orange-red)	0.003802
(red)	0.003263
(pink)	0.002723
(magenta)	0.002183
(purple)	0.001643
(blue)	0.001104
(dark blue)	0.000564
(black)	0.000024
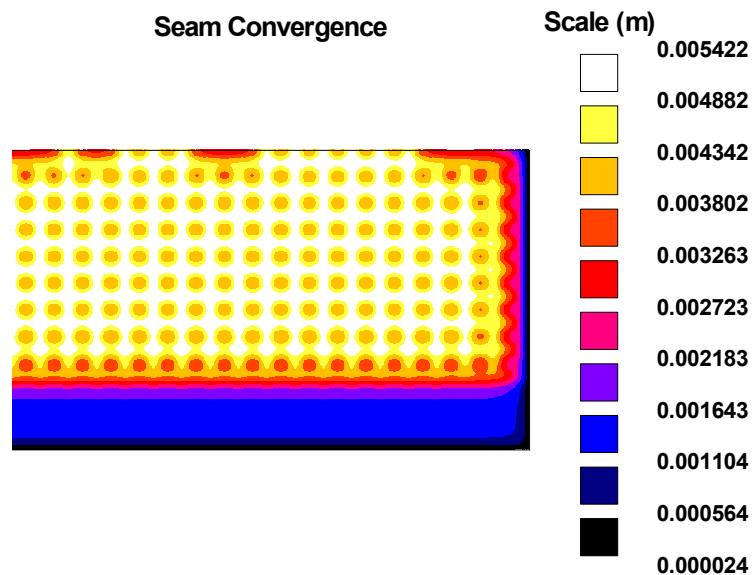
Post Checkerboard Extraction:
Maximum Total Vertical Stress -   11,29 MPa
Maximum Seam Convergence -   13,027 mm

Total Vertical Stress

Scale (MPa)

(white)	11.290000
(yellow)	10.161000
(orange)	9.032001
(orange-red)	7.903001
(red)	6.774001
(pink)	5.645000
(magenta)	4.516000
(purple)	3.387000
(blue)	2.258000
(dark blue)	1.129000
(black)	0.000000

Seam Convergence

Scale (m)

0.013027

0.011727

0.010426

0.009126

0.007826

0.006526

0.005225

0.003925

0.002625

0.001325

0.000024
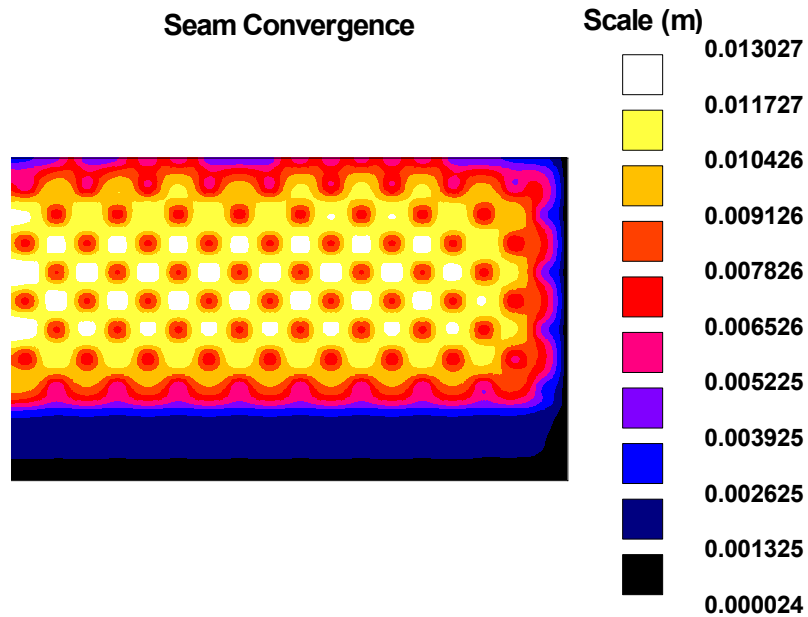
Block D

Current Scenario:
Maximum Total Vertical Stress -   6,25 MPa
Maximum Seam Convergence -   6,213 mm

Total Vertical Stress

Scale (MPa)

6.250000

5.625000

5.000000

4.375000

3.750000

3.125000

2.500000

1.875000

1.250000

0.625000

0.000000

Seam Convergence

Scale (m)

0.006213
0.005595
0.004976
0.004357
0.003738
0.003120
0.002501
0.001882
0.001263
0.000645
0.000026
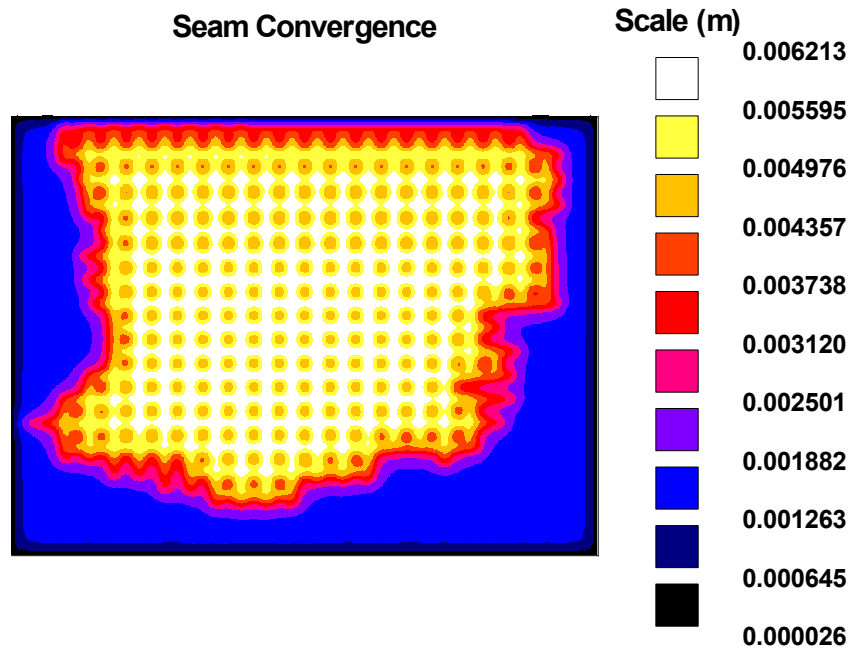
Post Checkerboard Extraction:
Maximum Total Vertical Stress -   63,04 MPa (**Pillar Failure**)
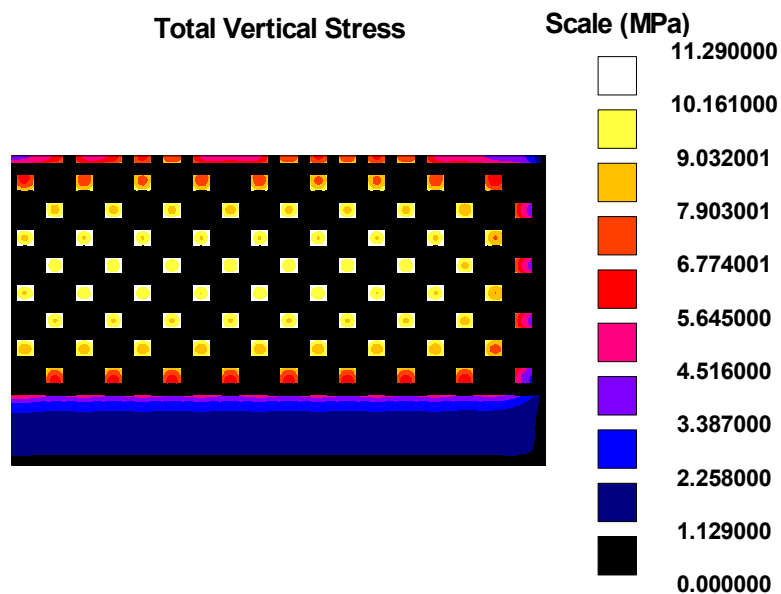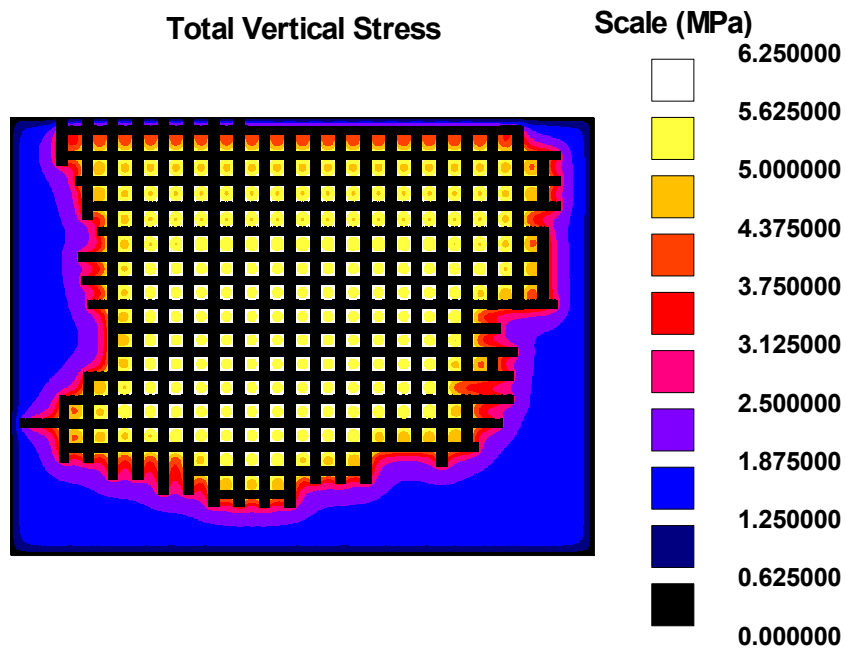Maximum Seam Convergence -   263,01 mm

Total Vertical Stress

Scale (MPa)

63.039009
56.735107
50.431206
44.127304
37.823402
31.519501
25.215601
18.911701
12.607800
6.303900
0.000000

Seam Convergence

Scale (m)

0.263010
0.236712
0.210413
0.184115
0.157816
0.131518
0.105220
0.078921
0.052623
0.026324
0.000026
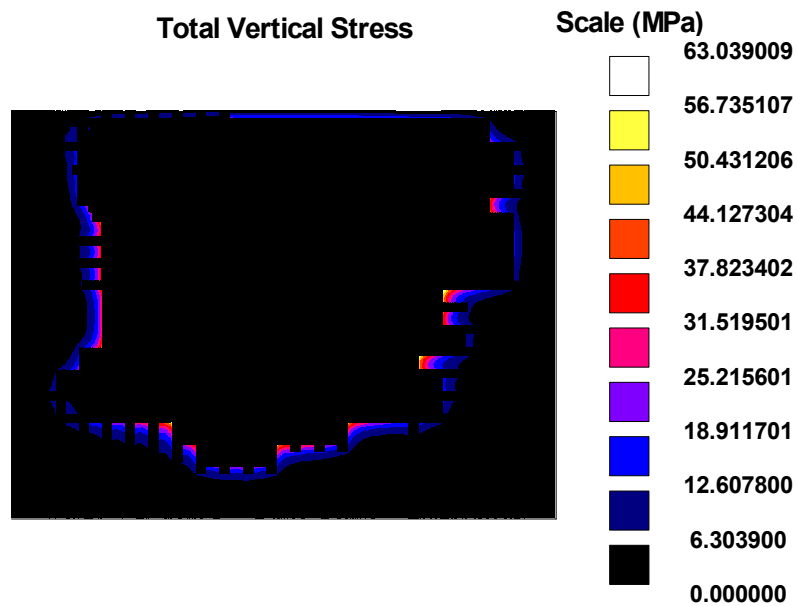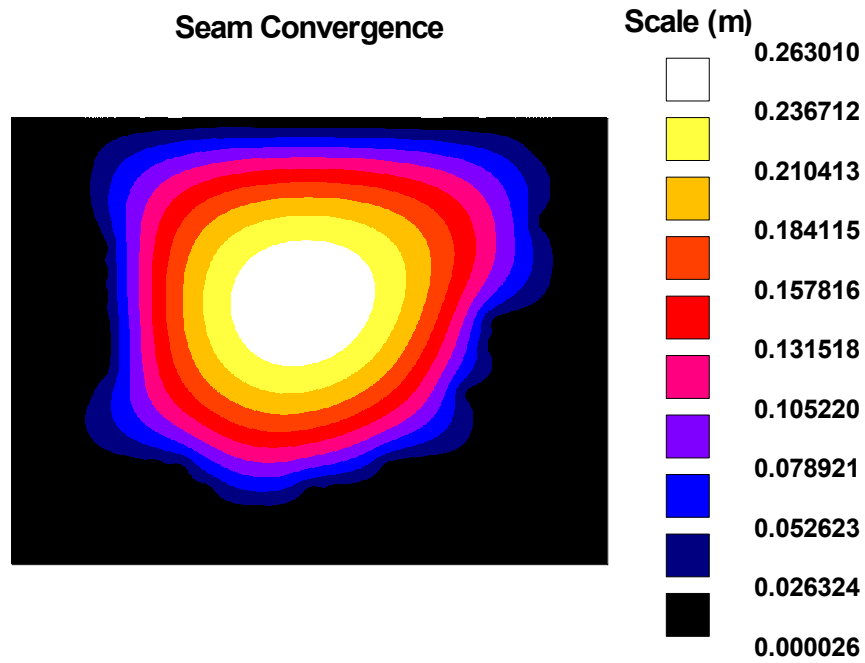
Block E

Current Scenario:
Maximum Total Vertical Stress -   5,17 MPa
Maximum Seam Convergence -   5,58 mm

Total Vertical Stress

Scale (MPa)

5.169100
4.652190
4.135280
3.618370
3.101460
2.584550
2.067640
1.550730
1.033820
0.516910
0.000000

Seam Convergence

Scale (m)

⬜	0.005580
🟨	0.005025
🟧	0.004469
🟧	0.003914
🟥	0.003358
🟥	0.002803
🟪	0.002247
🟪	0.001692
🟦	0.001136
⬛	0.000581
⬛	0.000026
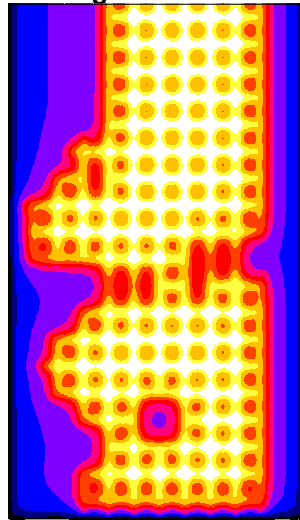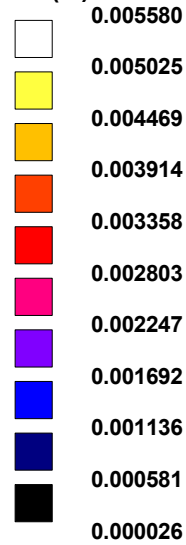
Post Checkerboard Extraction:
Maximum Total Vertical Stress -   10,59 MPa
Maximum Seam Convergence -   12,93 mm

Total Vertical Stress

Scale (MPa)

⬜	10.593001
🟨	9.533701
🟧	8.474401
🟧	7.415100
🟥	6.355800
🟥	5.296500
🟪	4.237200
🟪	3.177900
🟦	2.118600
⬛	1.059300
⬛	0.000000

Seam Convergence

Scale (m)

0.012929
0.011639
0.010348
0.009058
0.007768
0.006477
0.005187
0.003897
0.002606
0.001316
0.000026
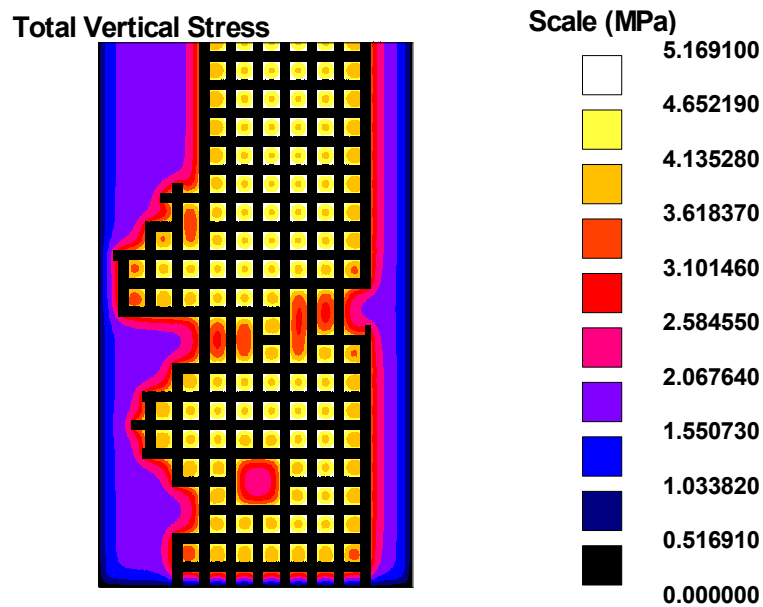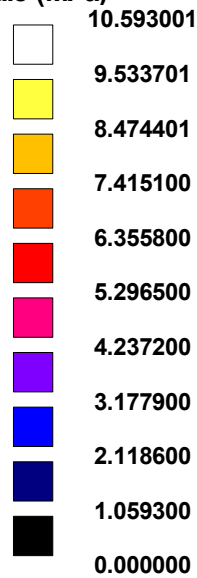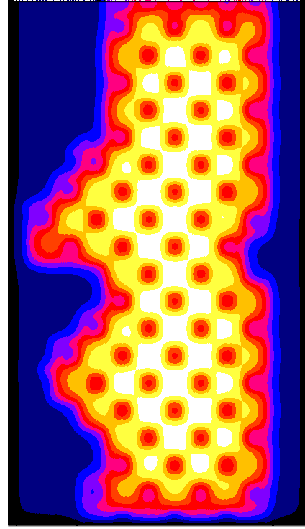
Block F

Current Scenario:
Maximum Total Vertical Stress -   5,73 MPa
Maximum Seam Convergence -   5,98 mm

Total Vertical Stress

Scale (MPa)

5.726700
5.154030
4.581360
4.008690
3.436020
2.863350
2.290680
1.718010
1.145340
0.572670
0.000000

Seam Convergence

Scale (m)

0.005984

0.005389

0.004793

0.004197

0.003602

0.003006

0.002410

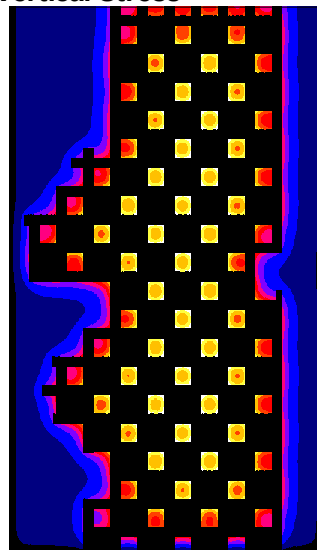0.001814

0.001219

0.000623

0.000027
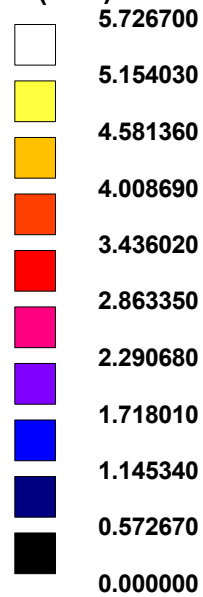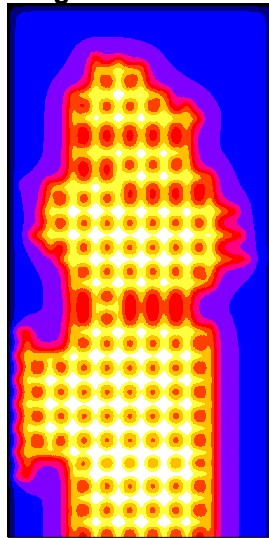
Post Checkerboard Extraction:
Maximum Total Vertical Stress -   11,42 MPa
Maximum Seam Convergence -   13,63 mm

Total Vertical Stress

Scale (MPa)

11.419000

10.277100

9.135200

7.993300

6.851400

5.709500

4.567600

3.425700

2.283800

1.141900

0.000000

Seam Convergence

Scale (m)

0.013627

0.012267

0.010907

0.009547

0.008187

0.006827

0.005467

0.004107

0.002747

0.001387

0.000027
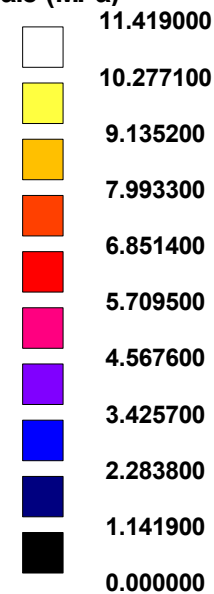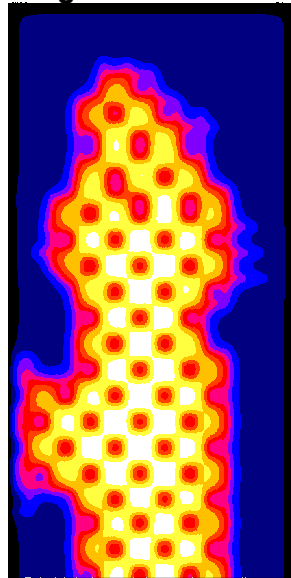
Block G

Current Scenario:
Maximum Total Vertical Stress -   5,78 MPa
Maximum Seam Convergence -   7,743 mm

Total Vertical Stress

Scale (MPa)

5.778100

5.200290

4.622480

4.044670

3.466860

2.889050

2.311240

1.733430

1.155620

0.577810

0.000000

Seam Convergence

Scale (m)

0.007743
0.006970
0.006197
0.005425
0.004652
0.003880
0.003107
0.002334
0.001562
0.000789
0.000017
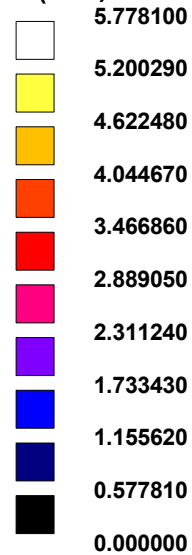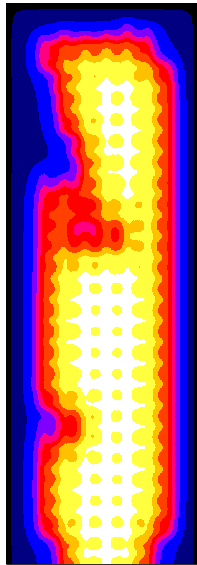
Post Checkerboard Extraction:
Maximum Total Vertical Stress -   8,84 MPa
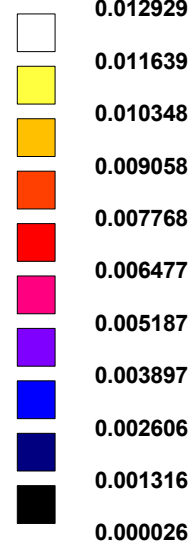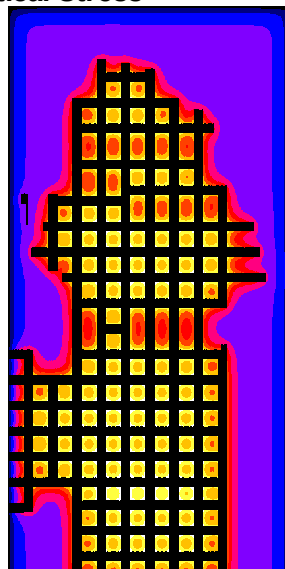Maximum Seam Convergence -   14,96 mm

Total Vertical Stress

Scale (MPa)

8.844600
7.960140
7.075680
6.191220
5.306760
4.422300
3.537840
2.653380
1.768920
0.884460
0.000000

Seam Convergence

Scale (m)

0.014963

0.013468

0.011974

0.010479

0.008984

0.007490

0.005995

0.004501

0.003006

0.001511

0.000017
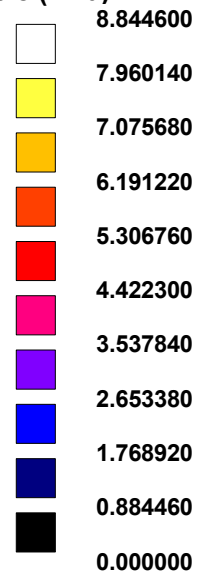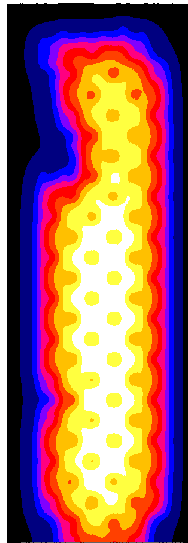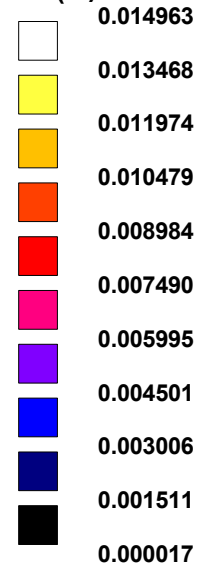
Block H

Current Scenario:
Maximum Total Vertical Stress -   6,15 MPa
Maximum Seam Convergence -   6,77 mm

Total Vertical Stress

Scale (MPa)
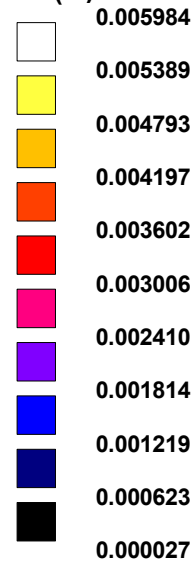
6.153100

5.537790

4.922480

4.307170

3.691860

3.076550

2.461240

1.845930

1.230620

0.615310

0.000000

Seam Convergence

Scale (m)

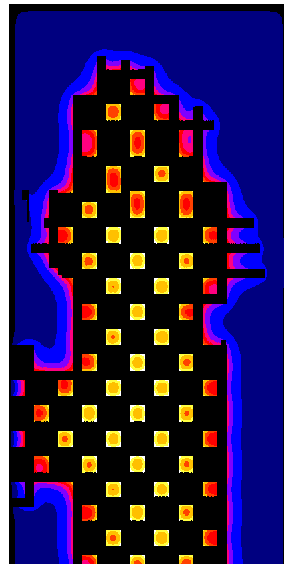|	
⬜	0.006774
🟨	0.006099
🟧	0.005425
🟧	0.004751
🟥	0.004076
🟥	0.003402
🟪	0.002727
🟪	0.002053
🟦	0.001378
⬛	0.000704
⬛	0.000029
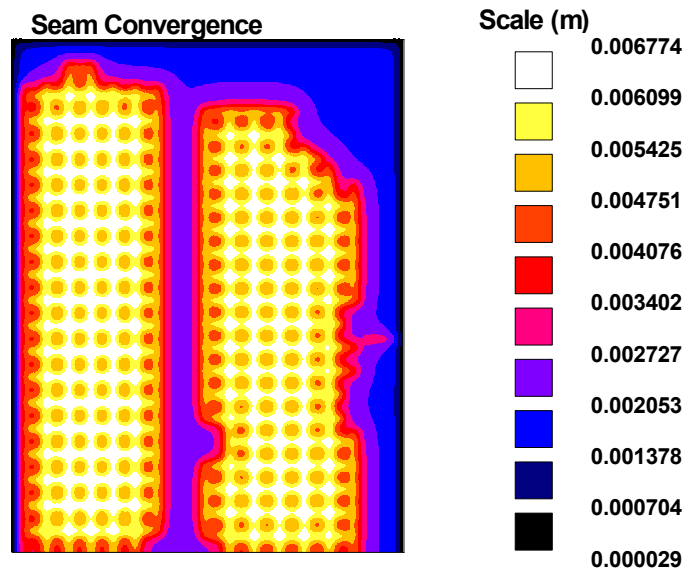
Post Checkerboard Extraction:
Maximum Total Vertical Stress -   11,64 MPa
Maximum Seam Convergence -   15,15 mm

Total Vertical Stress

Scale (MPa)

⬜	11.638000
🟨	10.474200
🟧	9.310400
🟧	8.146600
🟥	6.982800
🟥	5.819000
🟪	4.655200
🟪	3.491400
🟦	2.327600
⬛	1.163800
⬛	0.000000

Seam Convergence

Scale (m)

0.015146
0.013634
0.012123
0.010611
0.009099
0.007588
0.006076
0.004564
0.003053
0.001541
0.000029

Block I

Current Scenario:
Maximum Total Vertical Stress -   8,38 MPa
Maximum Seam Convergence -   11,61 mm

Total Vertical Stress

Scale (MPa)

8.376900
7.539209
6.701519
5.863830
5.026140
4.188450
3.350760
2.513070
1.675380
0.837690
0.000000

Seam Convergence

Scale (m)

0.011614
0.010471
0.009329
0.008186
0.007043
0.005901
0.004758
0.003616
0.002473
0.001330
0.000188
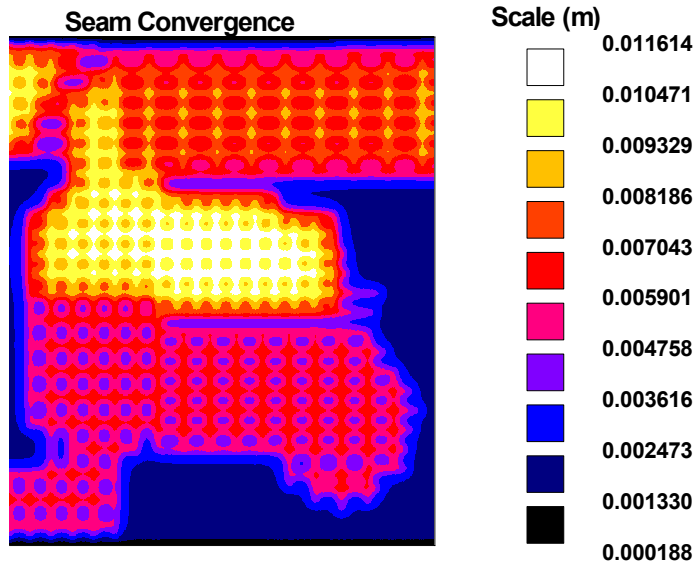
Post Checkerboard Extraction:
Maximum Total Vertical Stress -   15,04 MPa
Maximum Seam Convergence -   24,56 mm

Total Vertical Stress

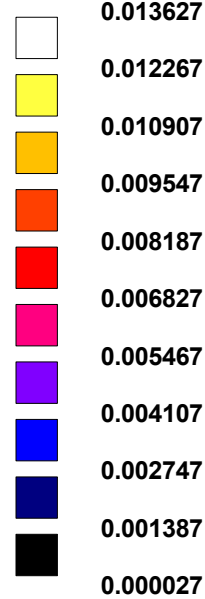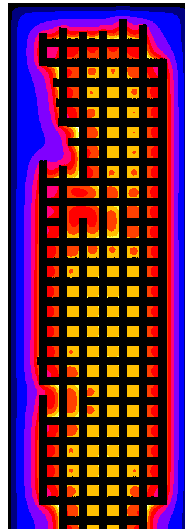**Scale (MPa)**

15.044001
13.539600
12.035200
10.530800
9.026400
7.521999
6.017600
4.513200
3.008800
1.504400
0.000000

Seam Convergence

Scale (m)

☐	0.024557
☐	0.022120
☐	0.019683
☐	0.017246
☐	0.014809
☐	0.012372
☐	0.009935
☐	0.007499
☐	0.005062
☐	0.002625
☐	0.000188
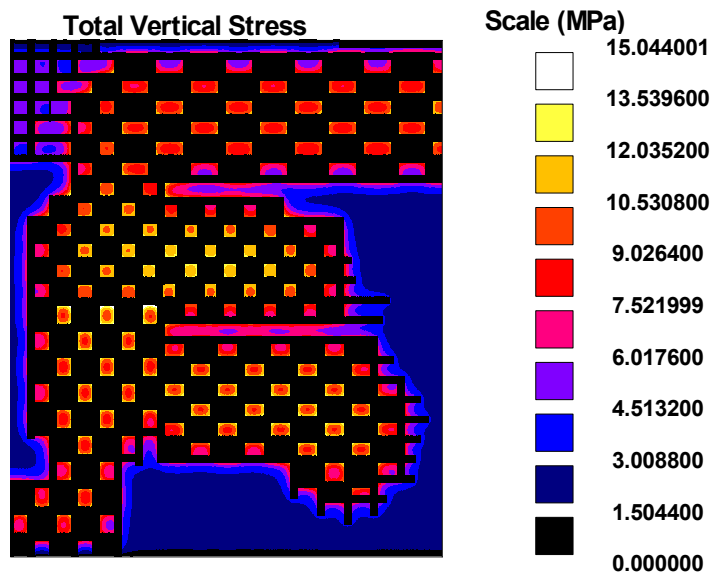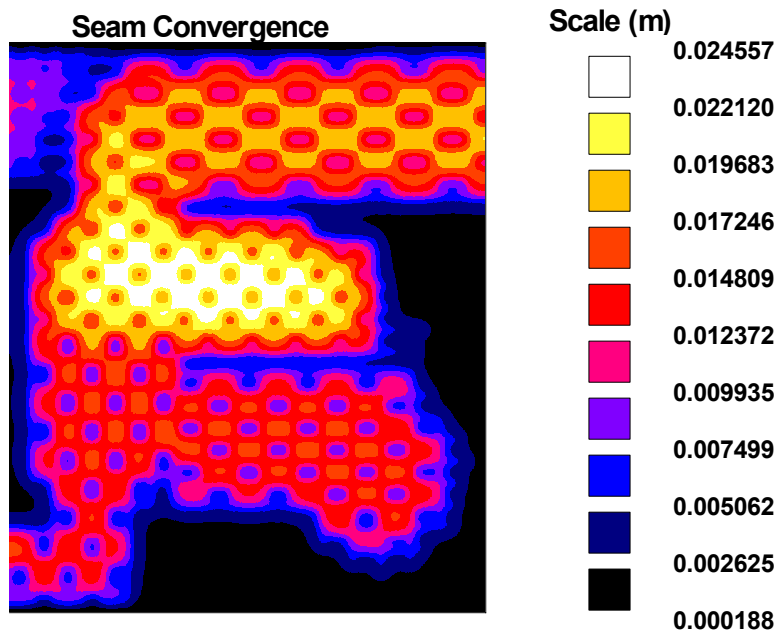
Block J

Current Scenario:
Maximum Total Vertical Stress -   6,82 MPa
Maximum Seam Convergence -   7,35 mm

Total Vertical Stress

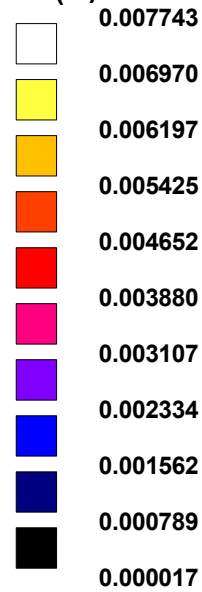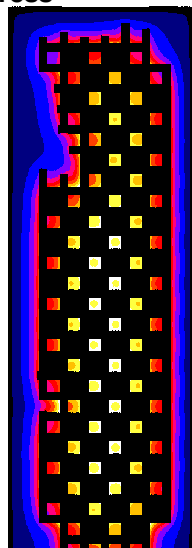**Scale (MPa)**

☐	6.820601
☐	6.138541
☐	5.456481
☐	4.774420
☐	4.092360
☐	3.410300
☐	2.728240
☐	2.046180
☐	1.364120
☐	0.682060
☐	0.000000

Seam Convergence

Scale (m)

0.007350
0.006618
0.005887
0.005155
0.004423
0.003692
0.002960
0.002228
0.001496
0.000765
0.000033
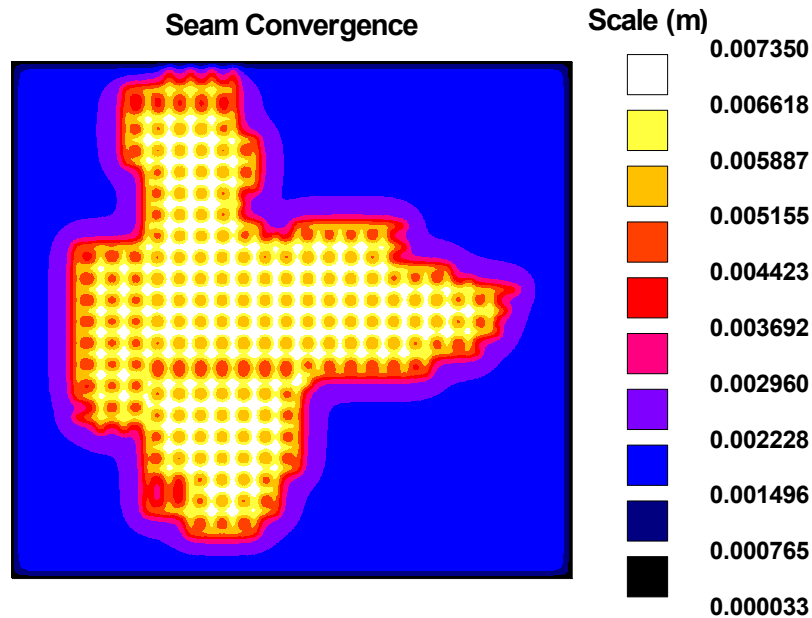
Post Checkerboard Extraction:
Maximum Total Vertical Stress -   72,55 MPa (**Pillar Failure**)
Maximum Seam Convergence -   275,63 mm

Total Vertical Stress

Scale (MPa)

72.554008
65.298607
58.043205
50.787804
43.532402
36.277000
29.021601
21.766201
14.510800
7.255400
0.000000

Seam Convergence

Scale (m)

0.275630

0.248070

0.220511

0.192951

0.165391

0.137831

0.110272

0.082712

0.055152

0.027593

0.000033
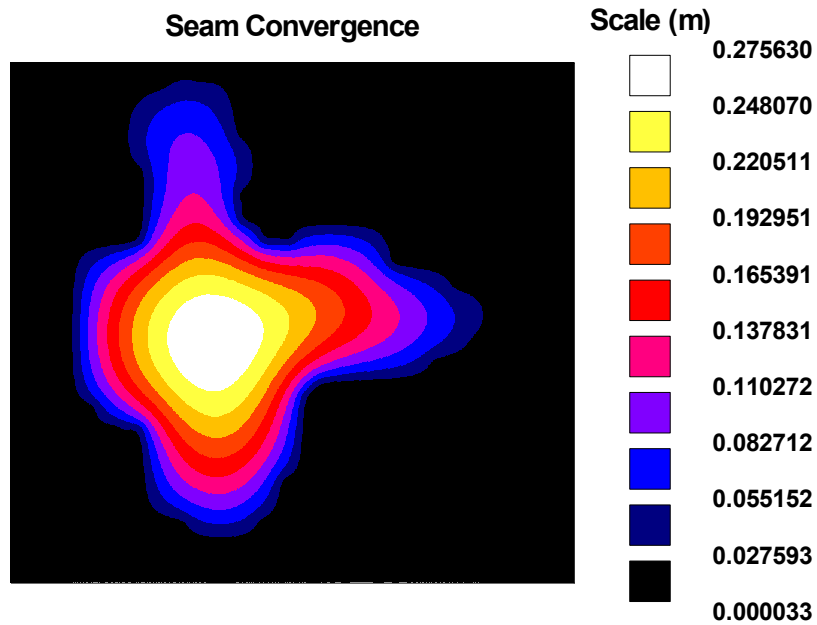
<u>Block K</u>

Current Scenario:
Maximum Total Vertical Stress -   8,14 MPa
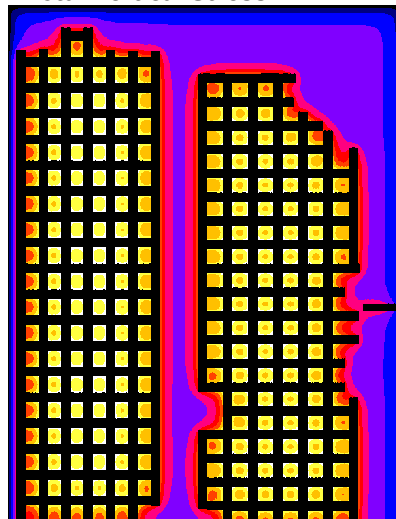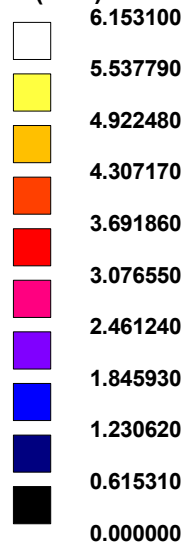Maximum Seam Convergence -   7,71 mm

Total Vertical Stress

Scale (MPa)

8.142800

7.328520

6.514240

5.699960

4.885680

4.071400

3.257120

2.442840

1.628560

0.814280

0.000000

Seam Convergence

Scale (m)

	0.007709
	0.006942
	0.006175
	0.005407
	0.004640
	0.003872
	0.003105
	0.002338
	0.001570
	0.000803
	0.000036
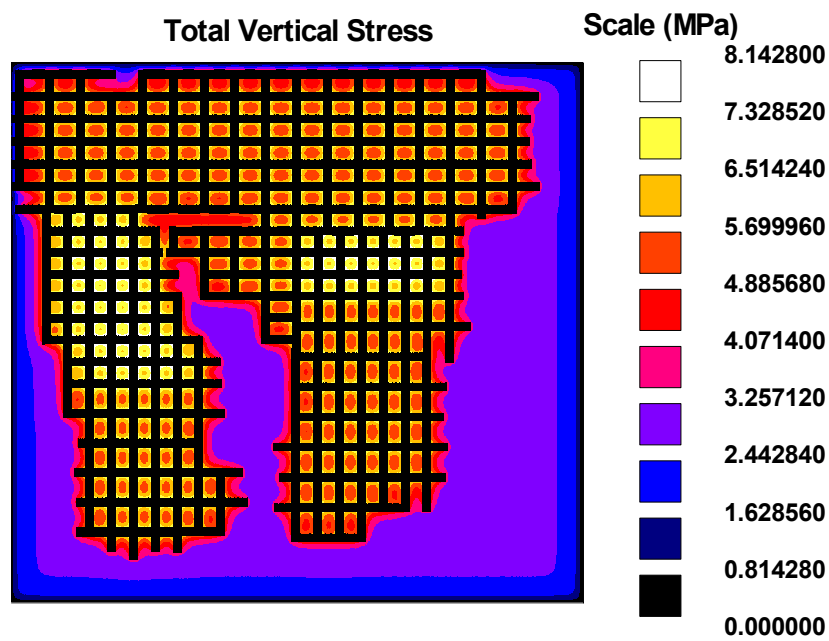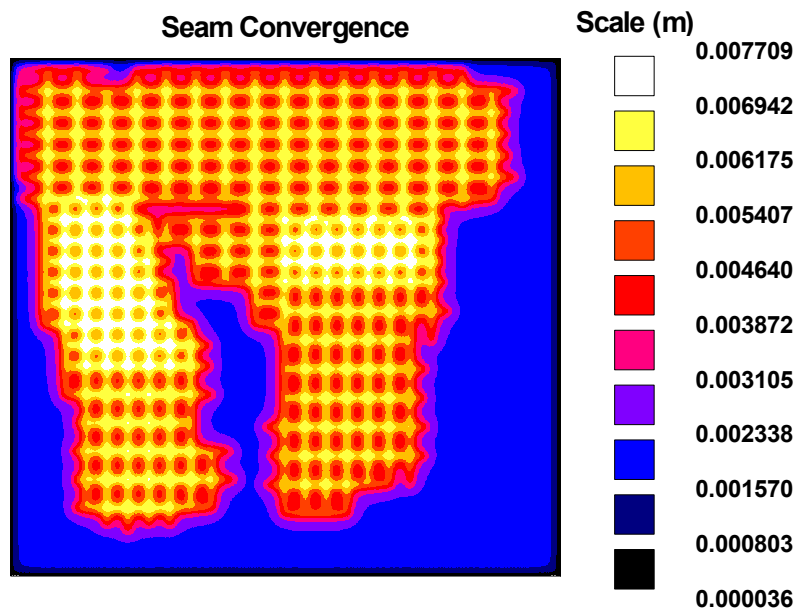
Post Checkerboard Extraction (East Main Panel Only):
Maximum Total Vertical Stress -   14,73
Maximum Seam Convergence -   16,35 mm

Total Vertical Stress

Scale (MPa)

	14.726000
	13.253400
	11.780800
	10.308200
	8.835600
	7.363000
	5.890400
	4.417800
	2.945200
	1.472600
	0.000000

Seam Convergence

Scale (m)

0.016350
0.014719
0.013087
0.011456
0.009824
0.008193
0.006561
0.004930
0.003299
0.001667
0.000036
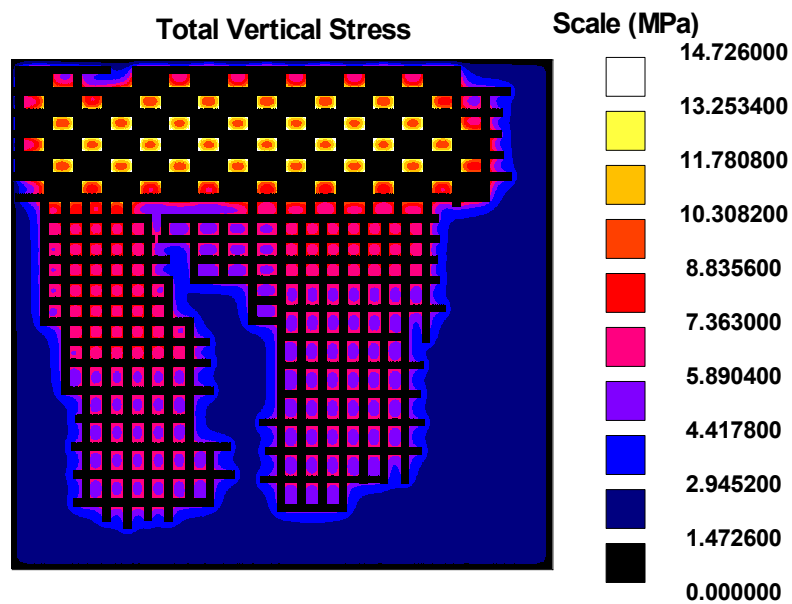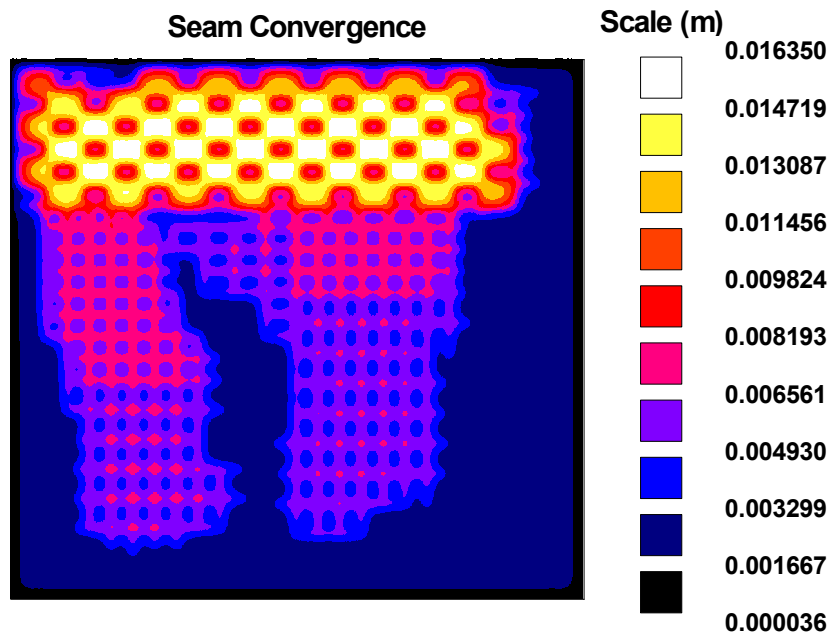
Post Checkerboard Extraction (East Main & South Panels):
Maximum Total Vertical Stress -   113,46 (**Pillar Failure**)
Maximum Seam Convergence -   284.615 mm

Total Vertical Stress

Scale (MPa)

113.459999
102.113998
90.767998
79.421997
68.075996
56.730000
45.383999
34.037998
22.691999
11.346000
0.000000

Seam Convergence

Scale (m)

0.284610
0.256153
0.227695
0.199238
0.170780
0.142323
0.113865
0.085408
0.056951
0.028493
0.000036
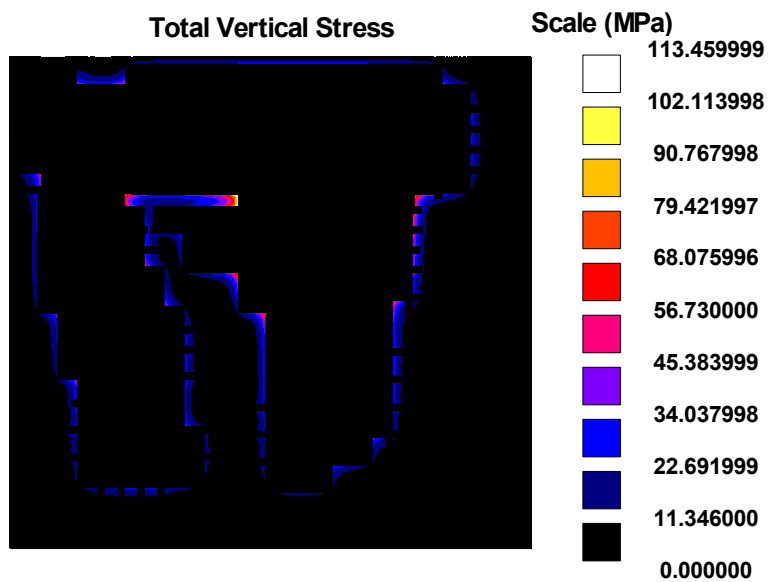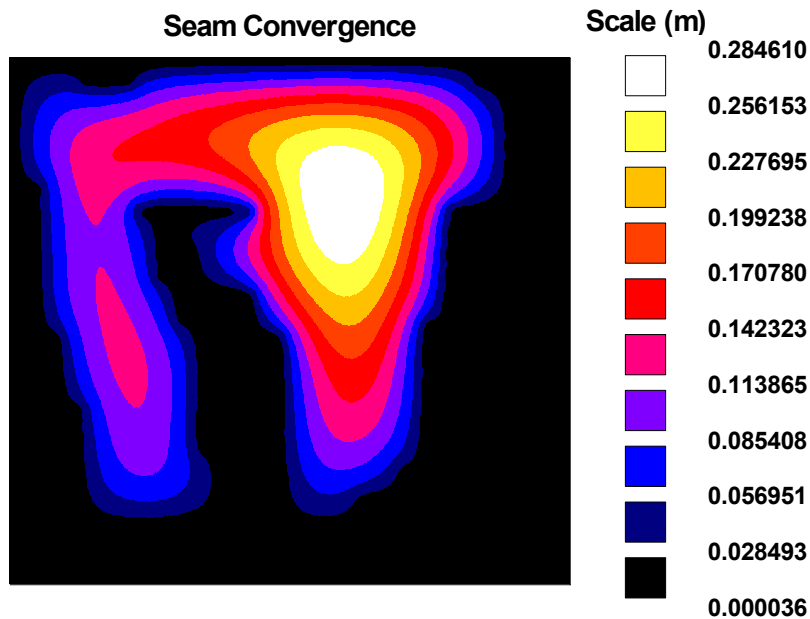
Block L

Current Scenario:
Maximum Total Vertical Stress -   8,05 MPa
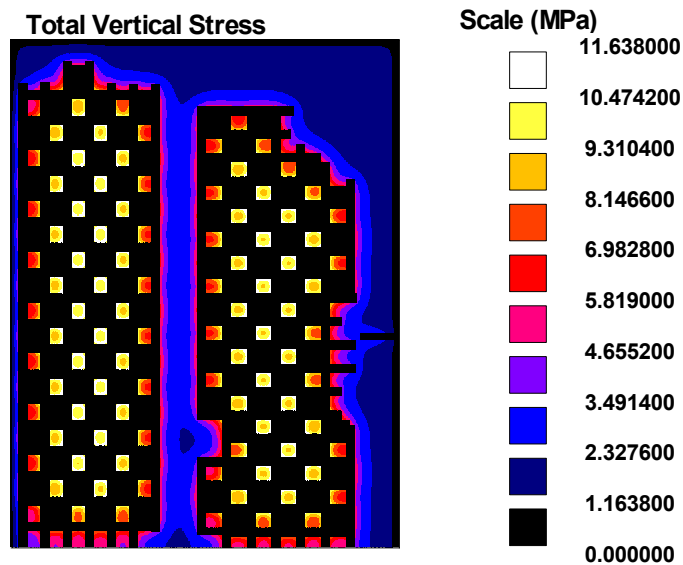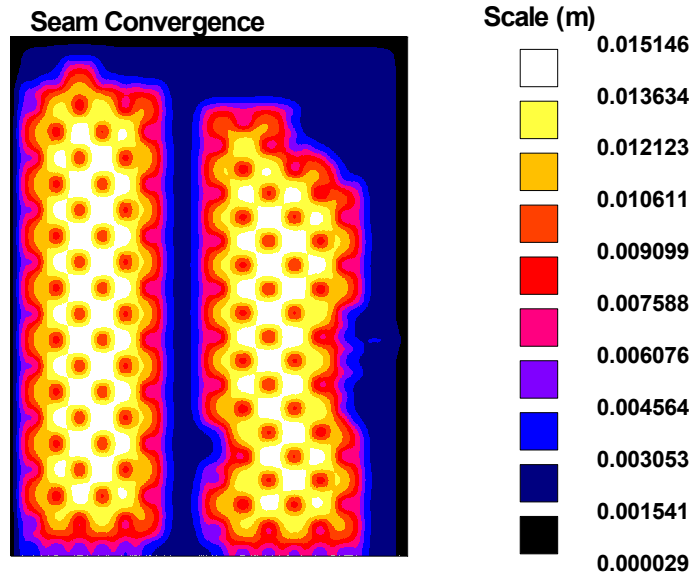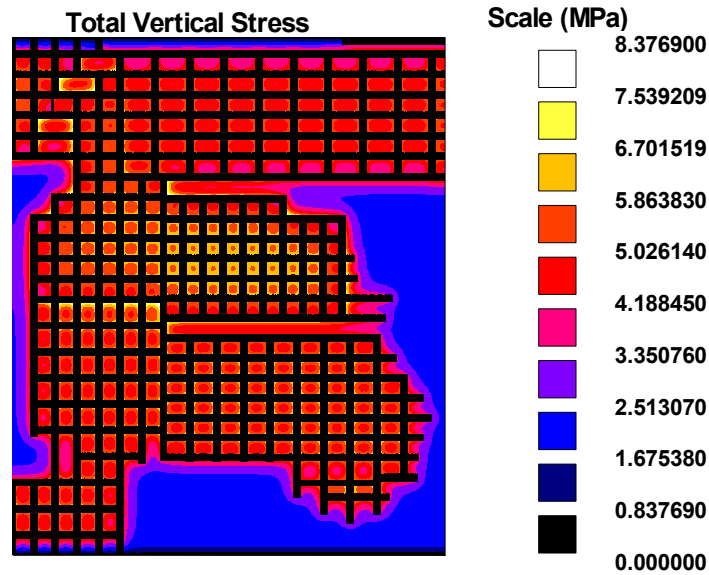Maximum Seam Convergence -   7.008 mm

Total Vertical Stress

Scale (MPa)

8.047500
7.242750
6.438000
5.633250
4.828500
4.023750
3.219000
2.414250
1.609500
0.804750
0.000000

Seam Convergence

Scale (m)

0.007008
0.006311
0.005613
0.004916
0.004219
0.003522
0.002824
0.002127
0.001430
0.000732
0.000035
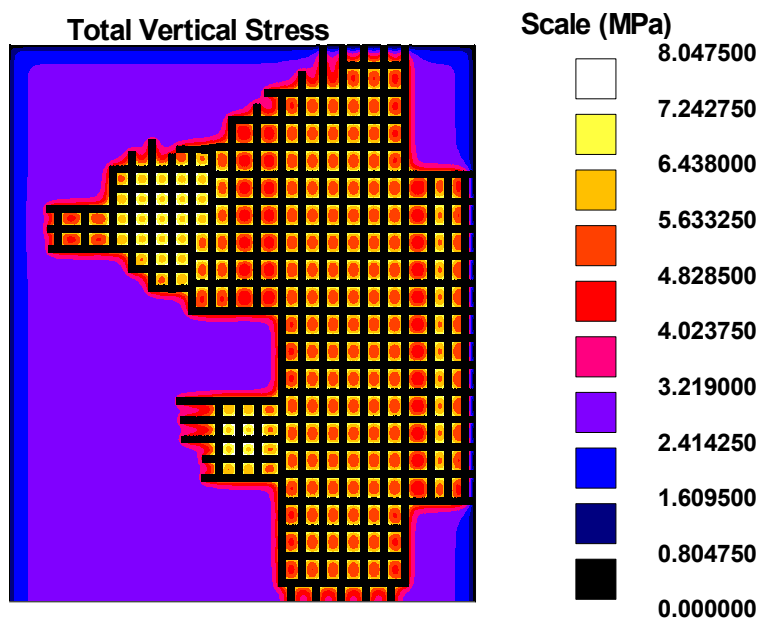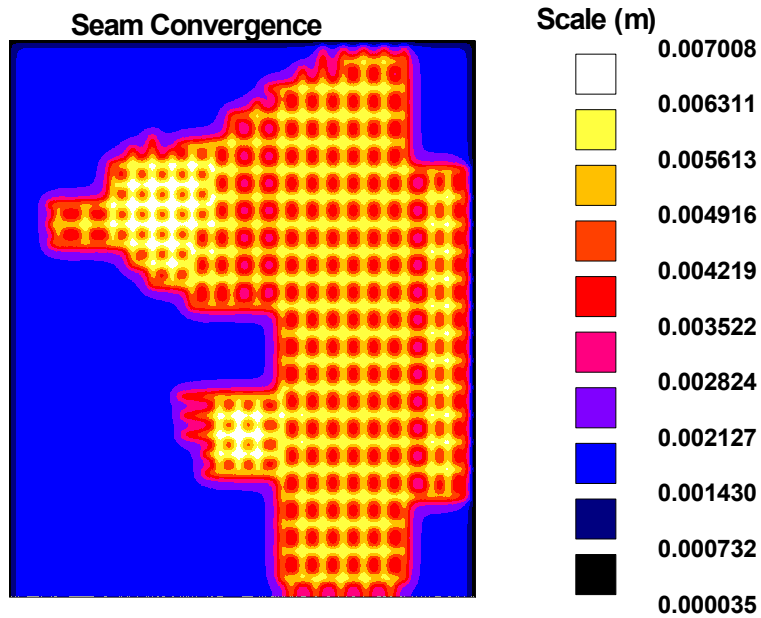
Post Checkerboard Extraction :
Maximum Total Vertical Stress -   16,19
Maximum Seam Convergence -   16,89 mm

Total Vertical Stress

Scale (MPa)

16.190002
14.571002
12.952002
11.333001
9.714001
8.095000
6.476000
4.857000
3.238000
1.619000
0.000000

Seam Convergence

Scale (m)

0.016890
0.015205
0.013519
0.011834
0.010148
0.008463
0.006777
0.005092
0.003406
0.001721
0.000035
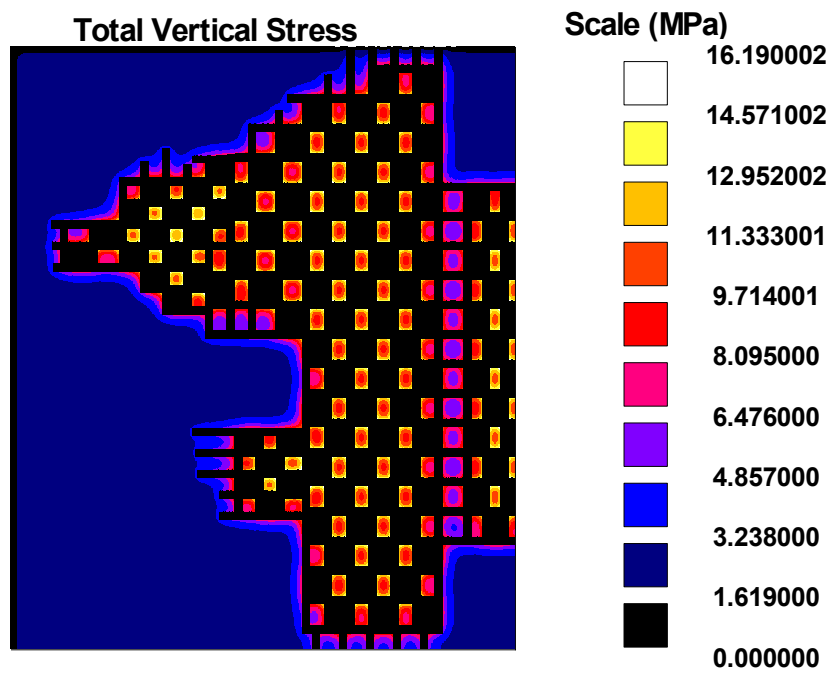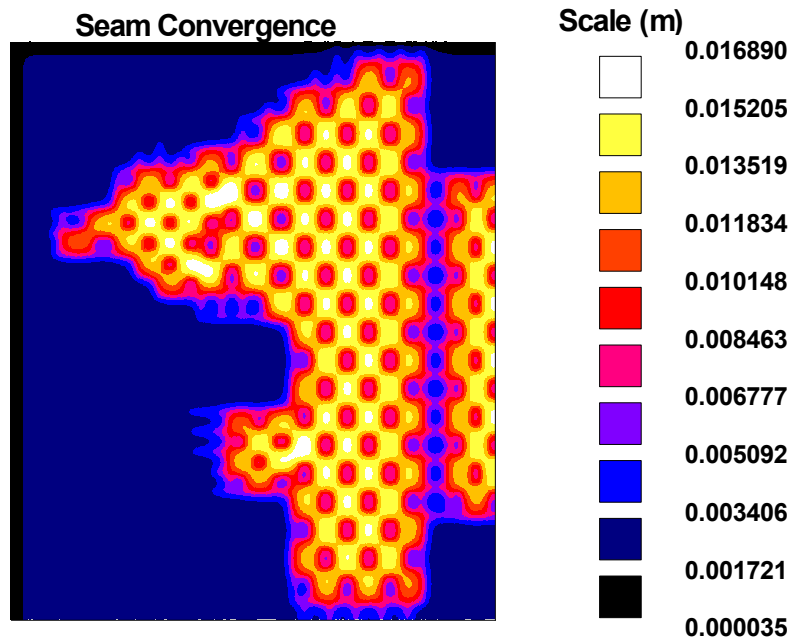
Block M

Current Scenario:
Maximum Total Vertical Stress -   7,05 MPa
Maximum Seam Convergence -   6,7 mm
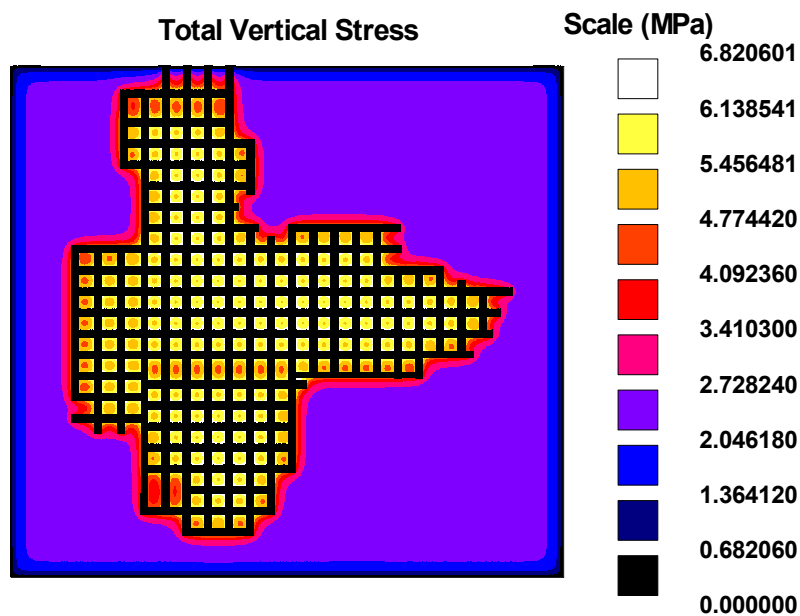
Total Vertical Stress

Scale (MPa)

7.047901
6.343111
5.638320
4.933530
4.228740
3.523950
2.819160
2.114370
1.409580
0.704790
0.000000

Seam Convergence

Scale (m)

0.006700
0.006033
0.005367
0.004700
0.004033
0.003367
0.002700
0.002033
0.001366
0.000700
0.000033
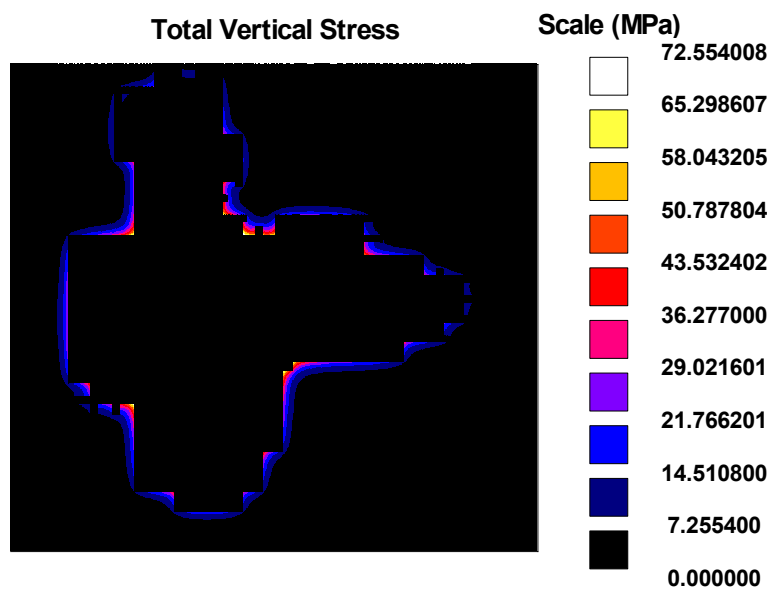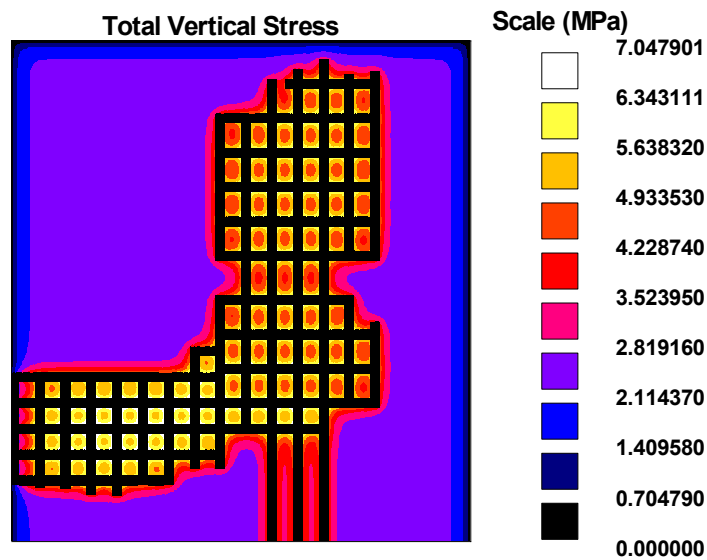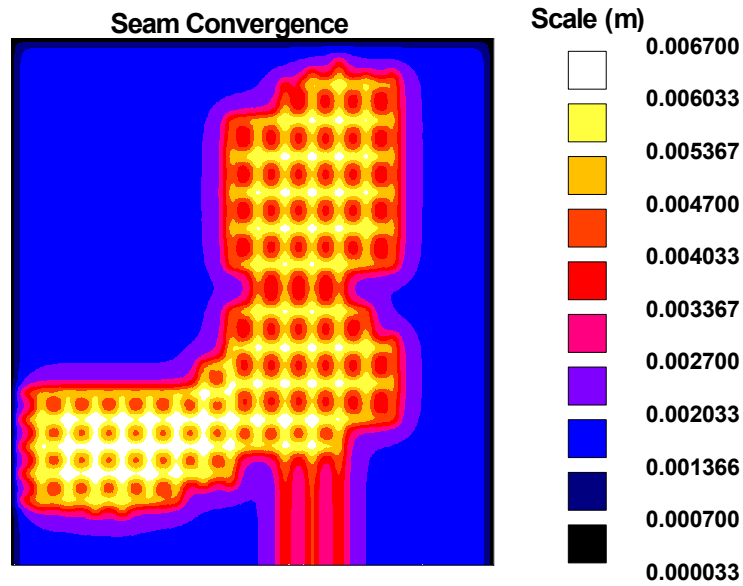
Post Checkerboard Extraction :
Maximum Total Vertical Stress -   13,72 MPa
Maximum Seam Convergence -   15,39 mm

Total Vertical Stress

Scale (MPa)

13.723001
12.350700
10.978400
9.606100
8.233800
6.861500
5.489200
4.116900
2.744600
1.372300
0.000000

Seam Convergence

Scale (m)

⬜	0.015389
🟨	0.013853
🟧	0.012318
🟧	0.010782
🟥	0.009247
🟥	0.007711
🟪	0.006175
🟪	0.004640
🟦	0.003104
🟦	0.001568
⬛	0.000033
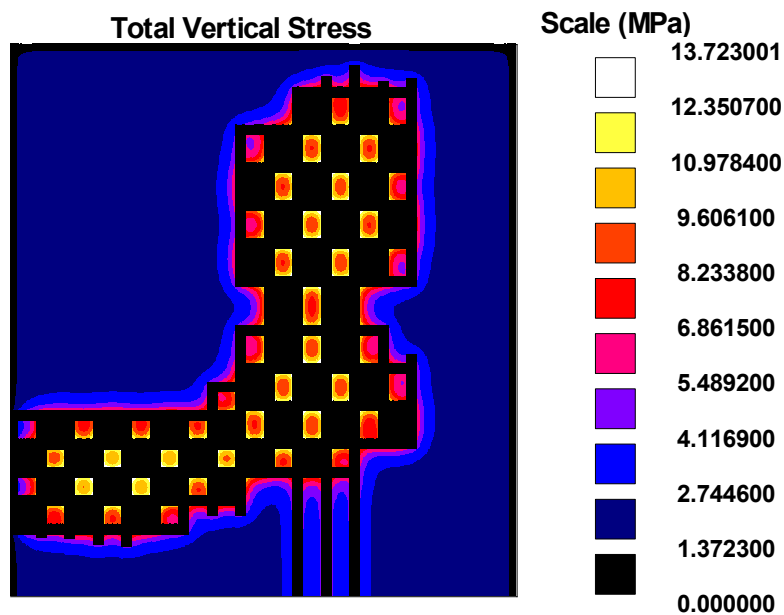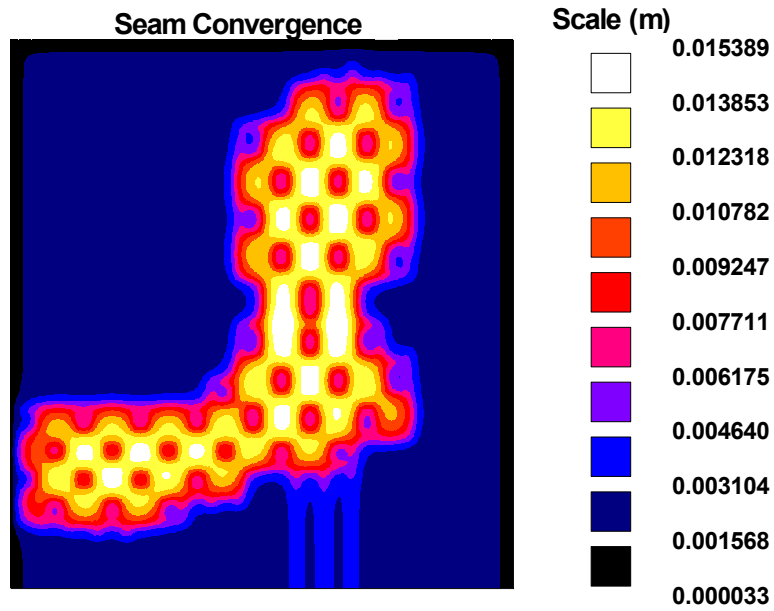
A cross-section plot of the vertical stress has been drawn through the pillars in which the expected vertical stress' were noted to be greatest in each of the identified mining blocks.
A cross-section plot of the seam convergence has also been drawn along the roadway in each of the mining blocks in which the convergence was noted to be expected to be greatest (usually the center roadway).
The various cross-sections are included below per area / block.

Block A
Current Scenario:
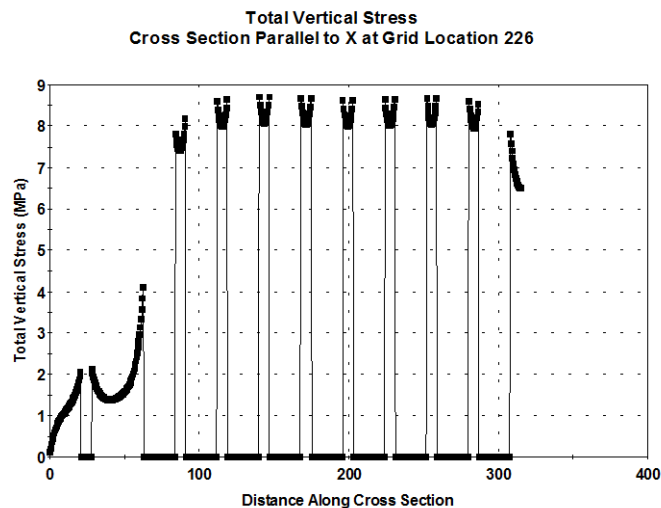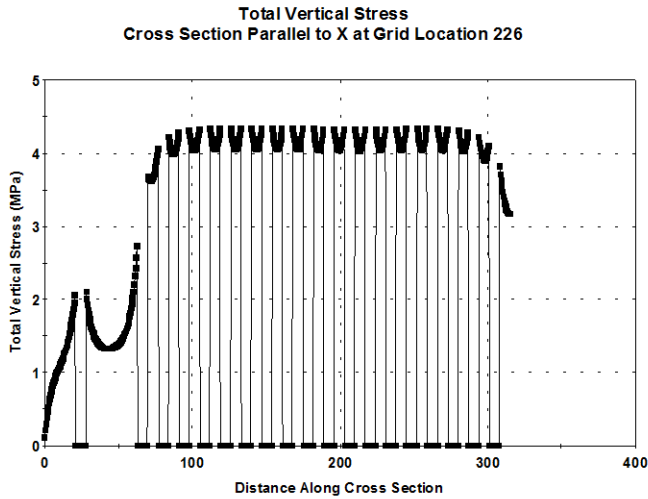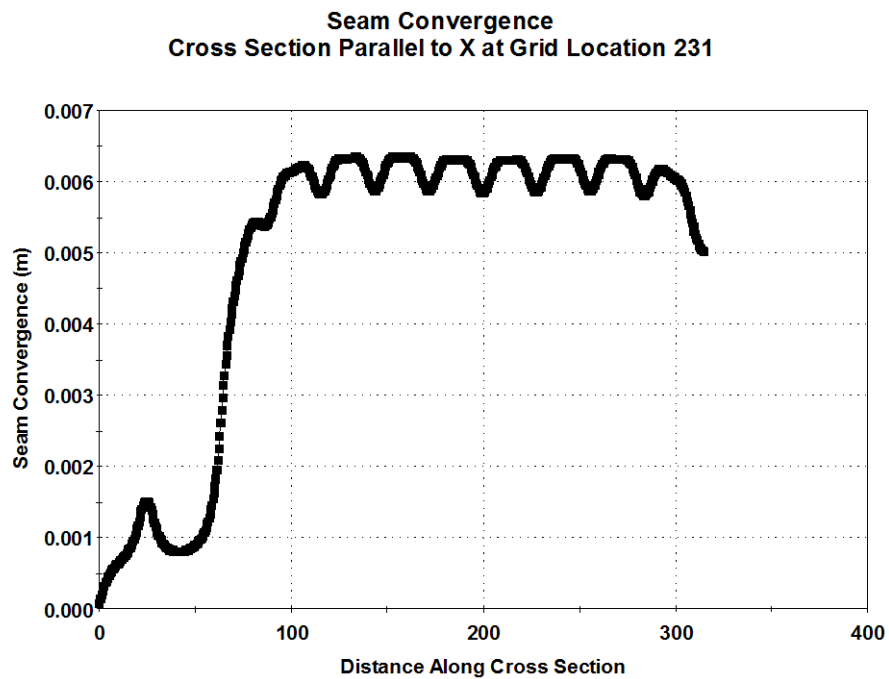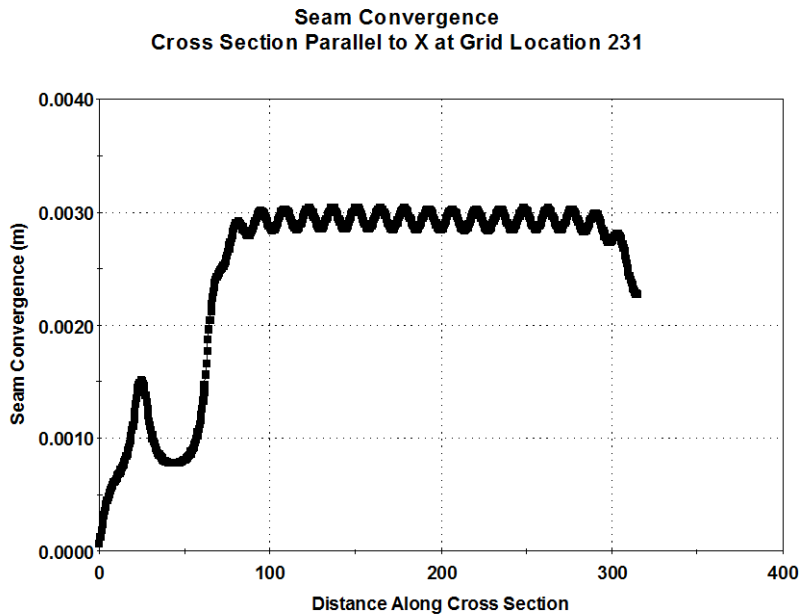
Total Vertical Stress
Cross Section Parallel to X at Grid Location 226

Total Vertical Stress
Cross Section Parallel to X at Grid Location 226

Post Checkerboard Extraction:

Seam Convergence
Cross Section Parallel to X at Grid Location 231

Seam Convergence
Cross Section Parallel to X at Grid Location 231

Block B
Current Scenario:

Total Vertical Stress
Cross Section Parallel to X at Grid Location 268
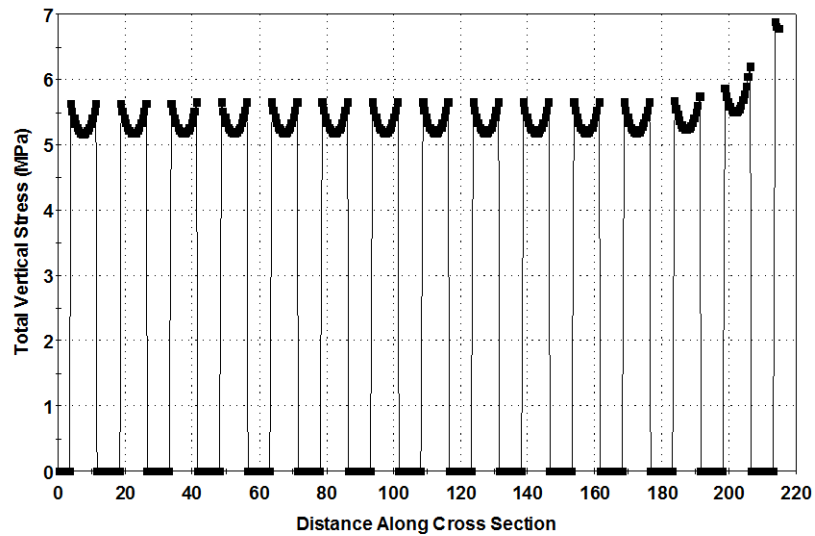
Seam Convergence
Cross Section Parallel to X at Grid Location 264

Post Checkerboard Extraction:

Total Vertical Stress
Cross Section Parallel to X at Grid Location 268

Seam Convergence
Cross Section Parallel to X at Grid Location 264

Block C
Current Scenario:

Total Vertical Stress
Cross Section Parallel to X at Grid Location 130

Seam Convergence
Cross Section Parallel to X at Grid Location 124

Post Checkerboard Extraction:
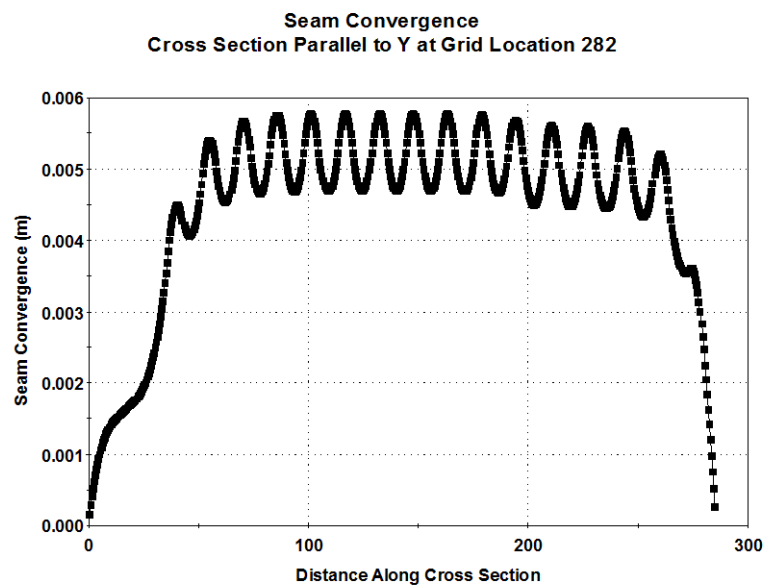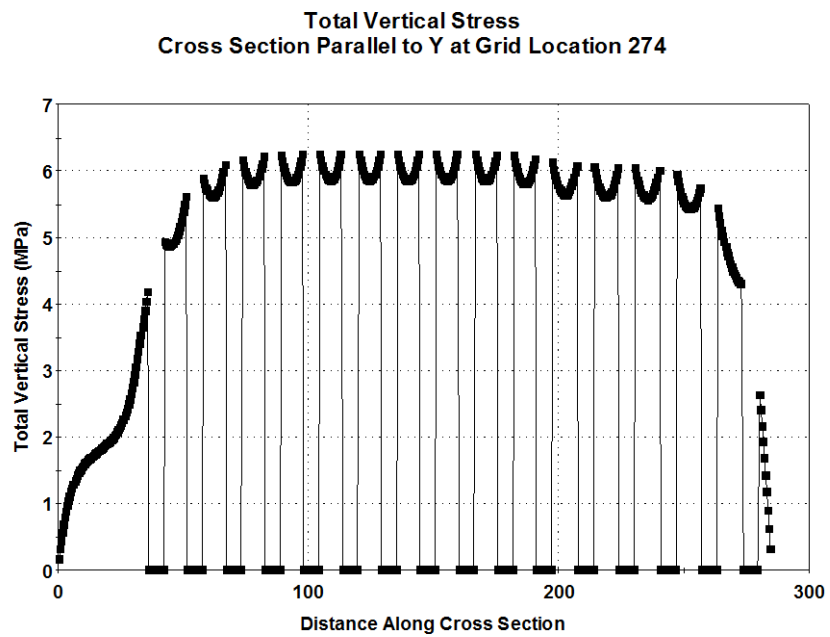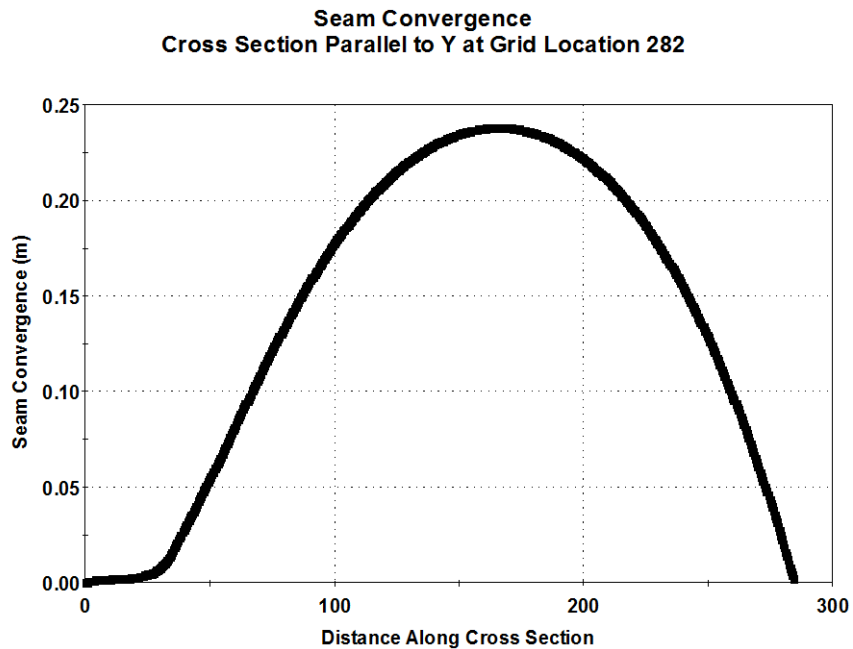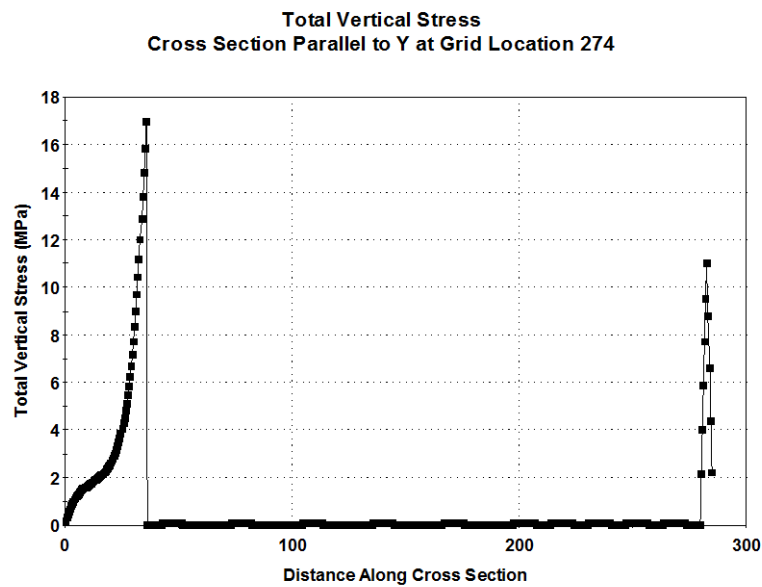
Total Vertical Stress
Cross Section Parallel to X at Grid Location 130

Seam Convergence
Cross Section Parallel to X at Grid Location 124

Block D
Current Scenario:

Total Vertical Stress
Cross Section Parallel to Y at Grid Location 274

Seam Convergence
Cross Section Parallel to Y at Grid Location 282

Post Checkerboard Extraction:

Total Vertical Stress
Cross Section Parallel to Y at Grid Location 274

Seam Convergence
Cross Section Parallel to Y at Grid Location 282

Block E
Current Scenario:

Total Vertical Stress
Cross Section Parallel to Y at Grid Location 224

Seam Convergence
Cross Section Parallel to Y at Grid Location 232

Post Checkerboard Extraction:

Total Vertical Stress
Cross Section Parallel to Y at Grid Location 224

Seam Convergence
Cross Section Parallel to Y at Grid Location 232

Block F
Current Scenario:

Total Vertical Stress
Cross Section Parallel to Y at Grid Location 232

Seam Convergence
Cross Section Parallel to Y at Grid Location 226
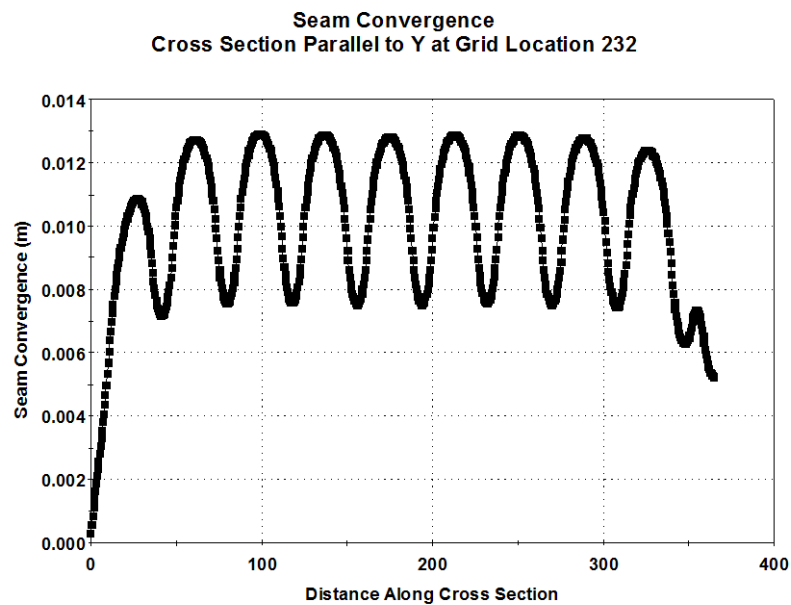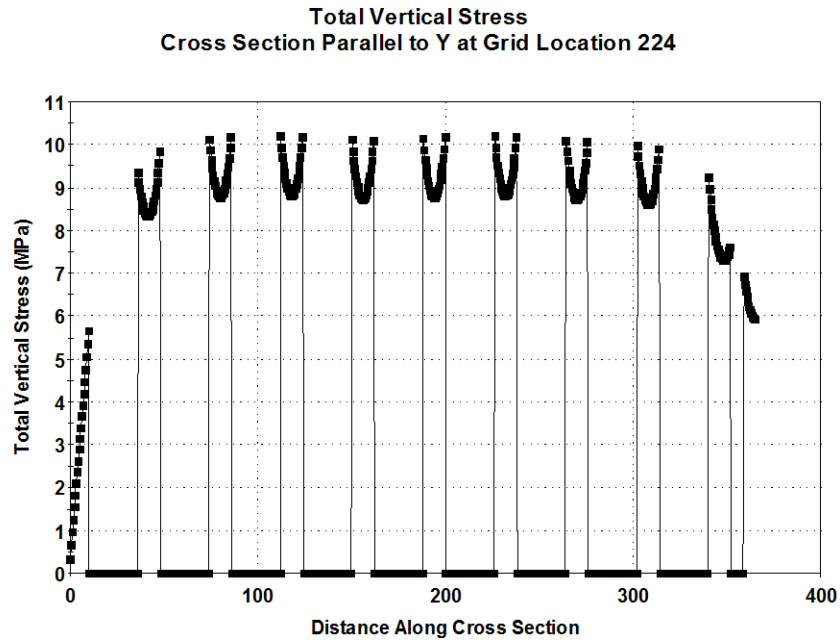
Post Checkerboard Extraction:

Total Vertical Stress
Cross Section Parallel to Y at Grid Location 232
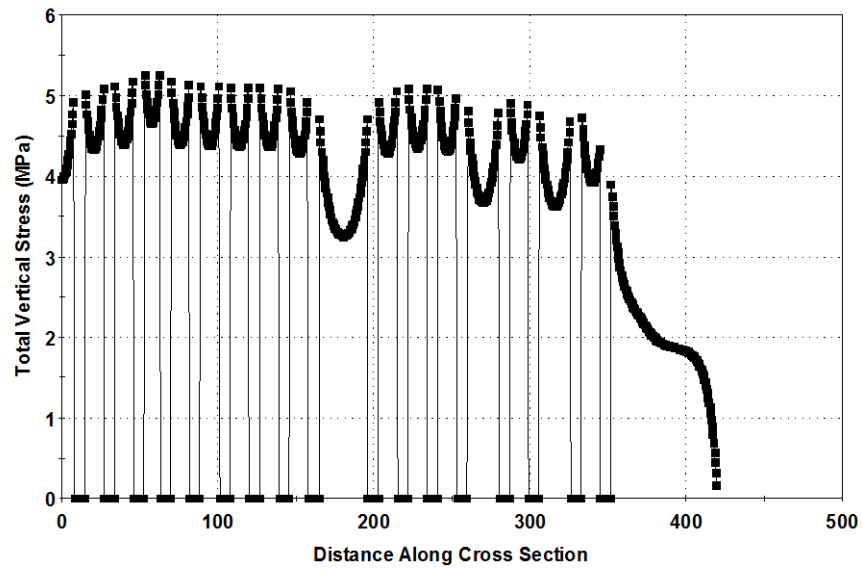
Seam Convergence
Cross Section Parallel to Y at Grid Location 226
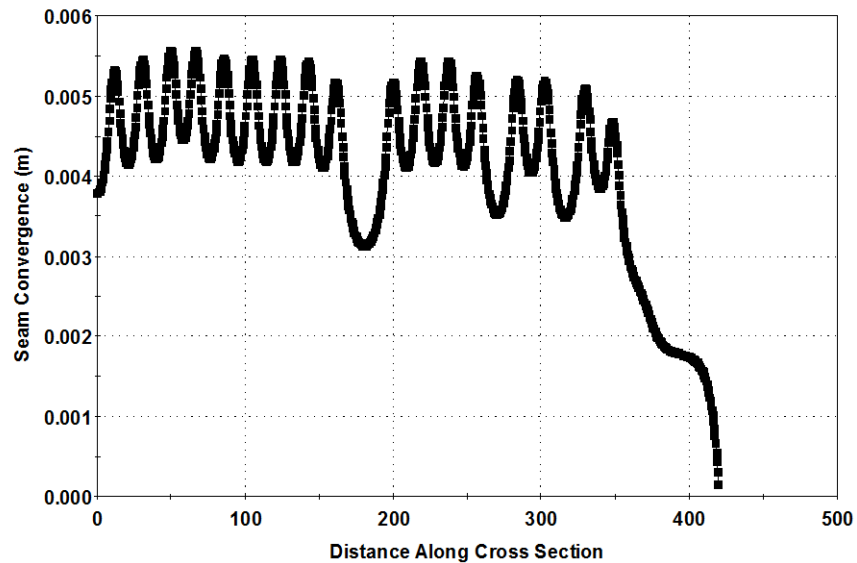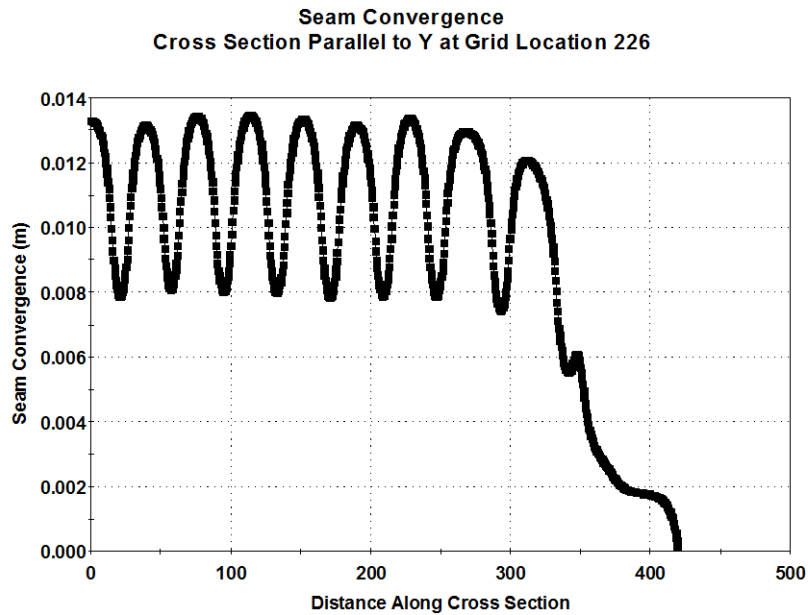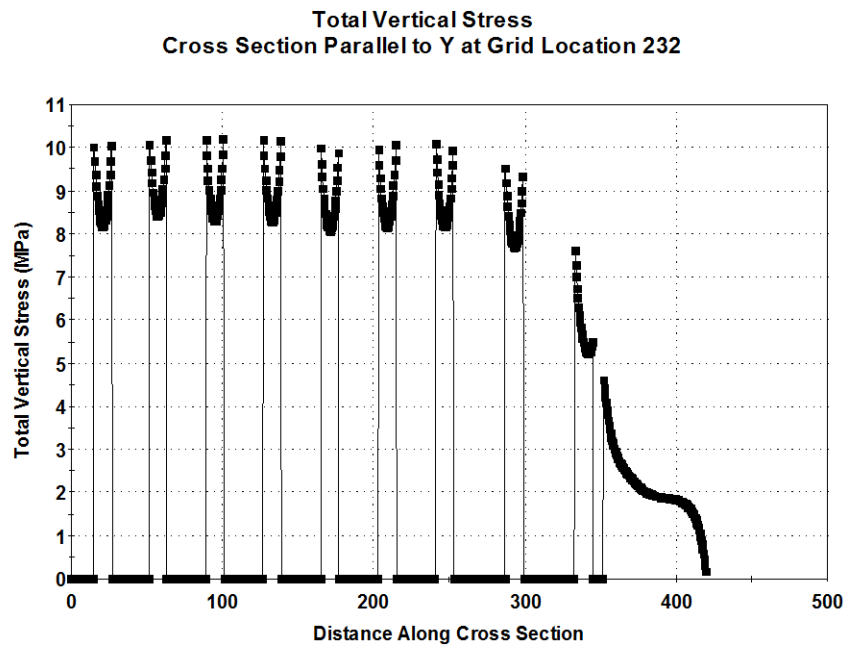
Block G
Current Scenario:

Total Vertical Stress
Cross Section Parallel to Y at Grid Location 172
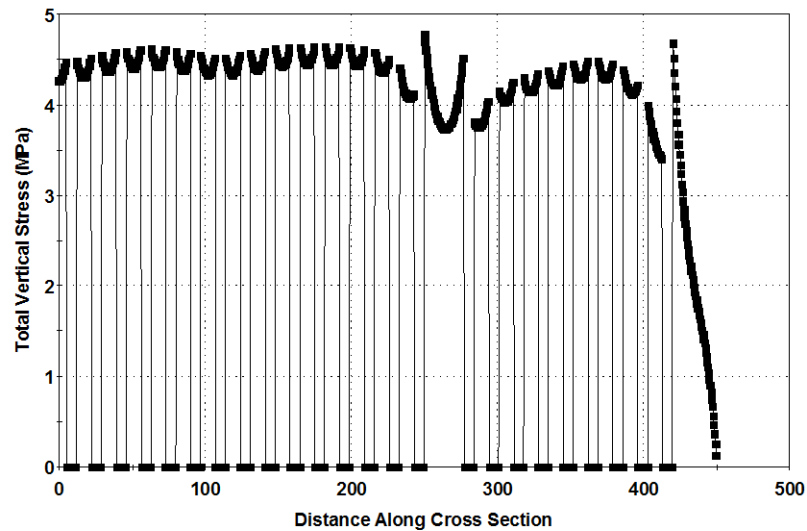
Seam Convergence
Cross Section Parallel to Y at Grid Location 178

Post Checkerboard Extraction:
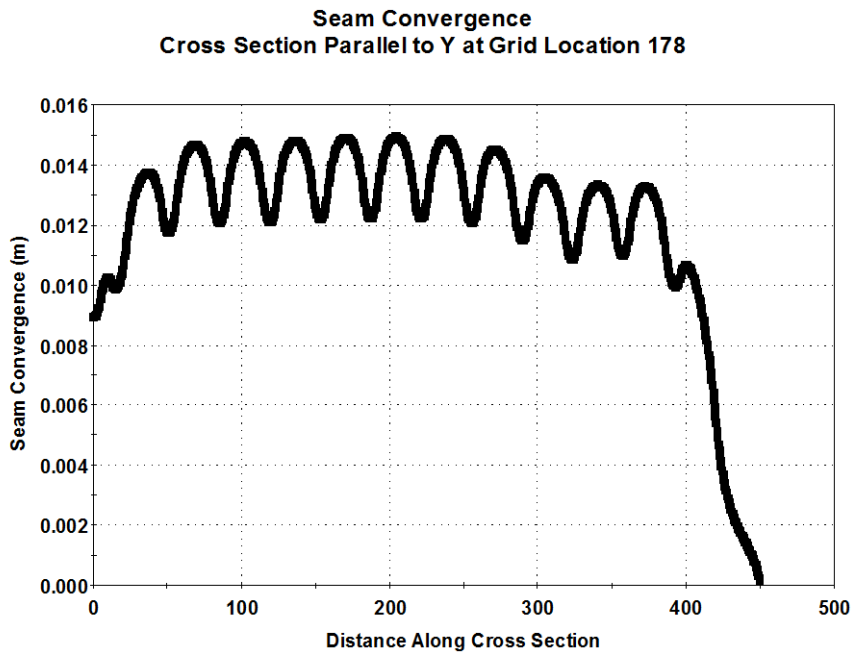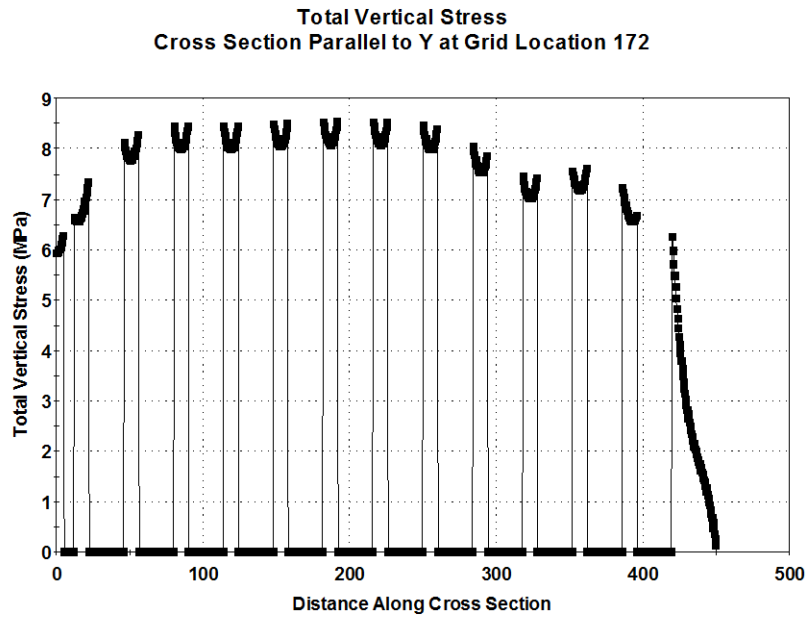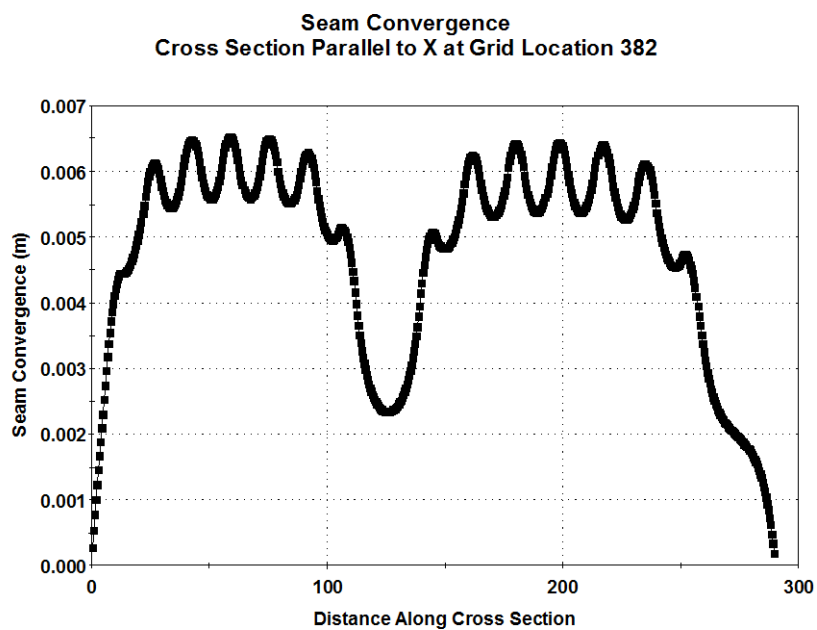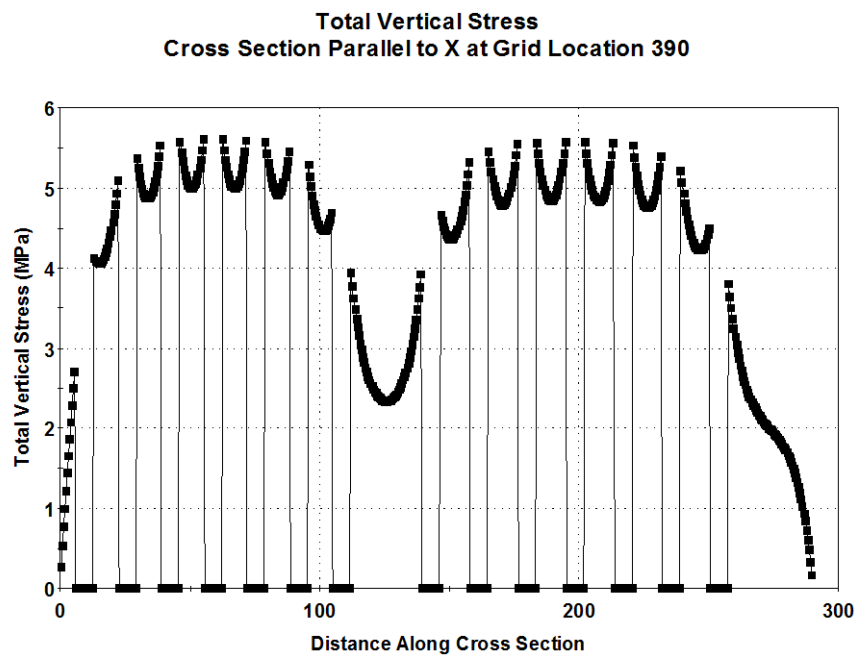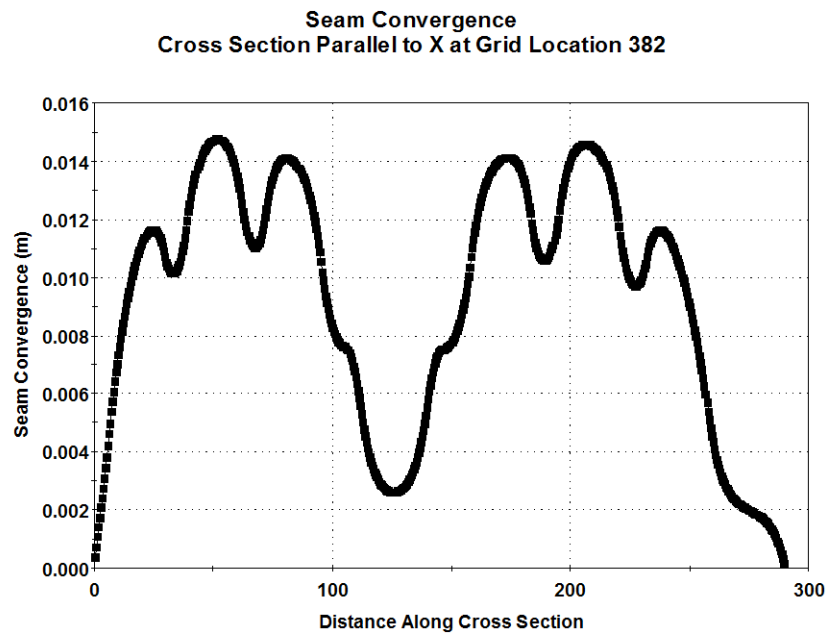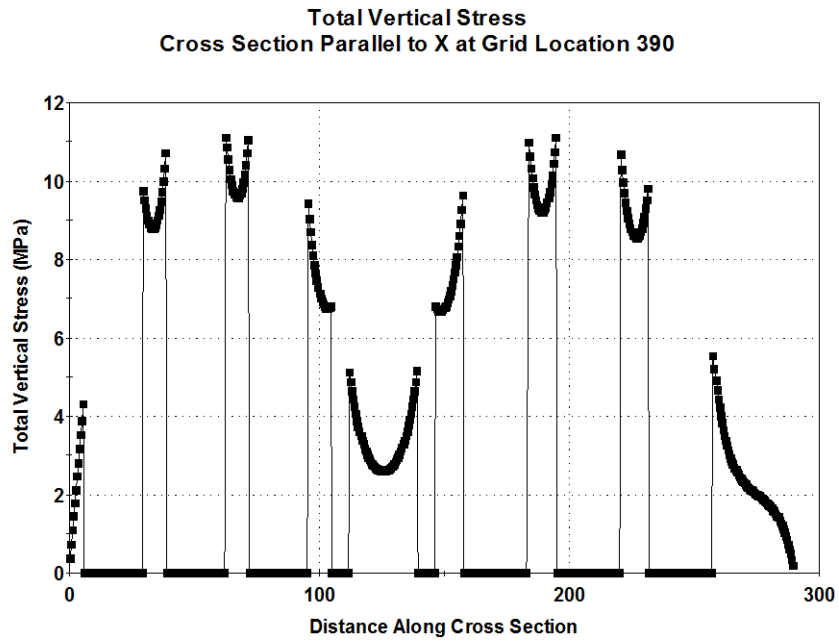
Total Vertical Stress
Cross Section Parallel to Y at Grid Location 172

Seam Convergence
Cross Section Parallel to Y at Grid Location 178

Block H
Current Scenario:

Total Vertical Stress
Cross Section Parallel to X at Grid Location 390

Seam Convergence
Cross Section Parallel to X at Grid Location 382

Post Checkerboard Extraction:

Total Vertical Stress
Cross Section Parallel to X at Grid Location 390

Seam Convergence
Cross Section Parallel to X at Grid Location 382

Block I
Current Scenario:

Total Vertical Stress
Cross Section Parallel to Y at Grid Location 390
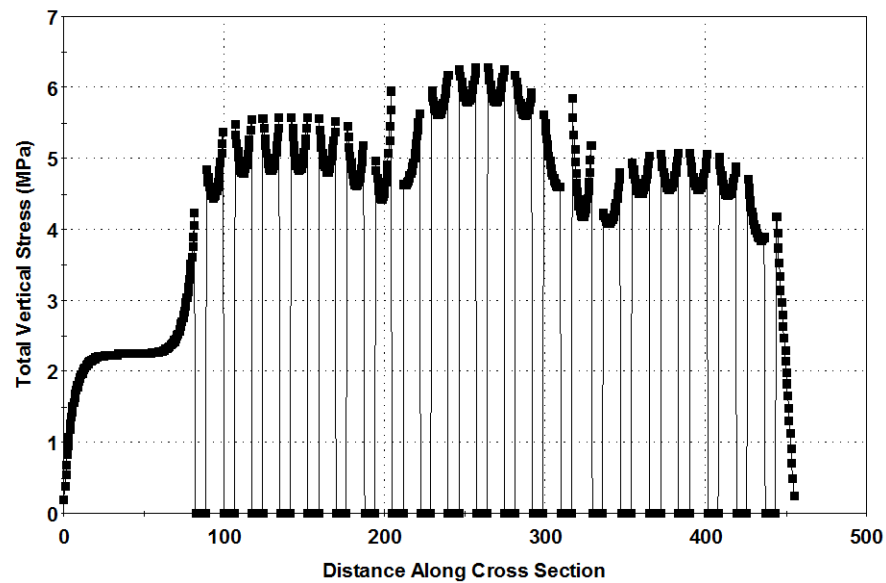
Seam Convergence
Cross Section Parallel to Y at Grid Location 398

Post Checkerboard Extraction:

Total Vertical Stress
Cross Section Parallel to Y at Grid Location 390

Seam Convergence
Cross Section Parallel to Y at Grid Location 398

Block J
Current Scenario:

Total Vertical Stress
Cross Section Parallel to Y at Grid Location 420

Seam Convergence
Cross Section Parallel to Y at Grid Location 428

Post Checkerboard Extraction:

Total Vertical Stress
Cross Section Parallel to Y at Grid Location 420

Seam Convergence
Cross Section Parallel to Y at Grid Location 428

Block K
Current Scenario:

Total Vertical Stress
Cross Section Parallel to Y at Grid Location 528

Seam Convergence
Cross Section Parallel to Y at Grid Location 536

Post Checkerboard Extraction (East Main Panel Only):

Total Vertical Stress
Cross Section Parallel to Y at Grid Location 528

Seam Convergence
Cross Section Parallel to Y at Grid Location 536

Post Checkerboard Extraction (East Main & South Panels):

Total Vertical Stress
Cross Section Parallel to Y at Grid Location 528

Seam Convergence
Cross Section Parallel to Y at Grid Location 534

Block L
Current Scenario:

Total Vertical Stress
Cross Section Parallel to X at Grid Location 664

Seam Convergence
Cross Section Parallel to X at Grid Location 670

Post Checkerboard Extraction:

Total Vertical Stress
Cross Section Parallel to X at Grid Location 664

Seam Convergence
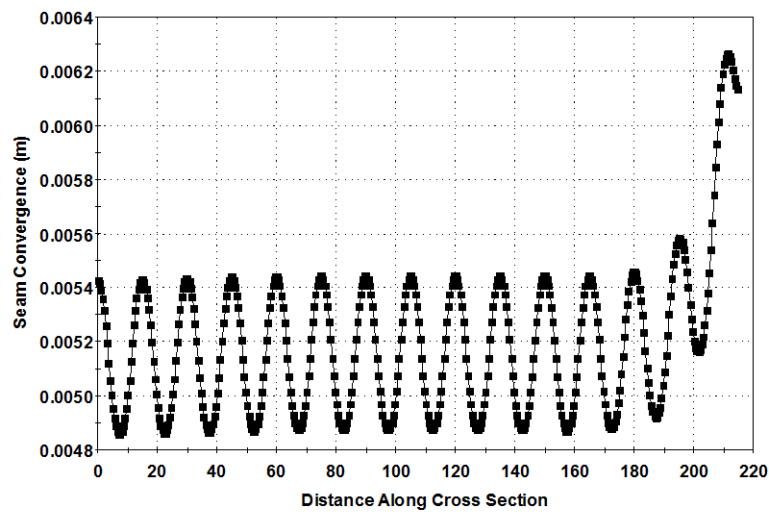**Cross Section Parallel to X at Grid Location 670**

Block M
Current Scenario:

Total Vertical Stress
Cross Section Parallel to Y at Grid Location 342

Seam Convergence
Cross Section Parallel to Y at Grid Location 348

Post Checkerboard Extraction:

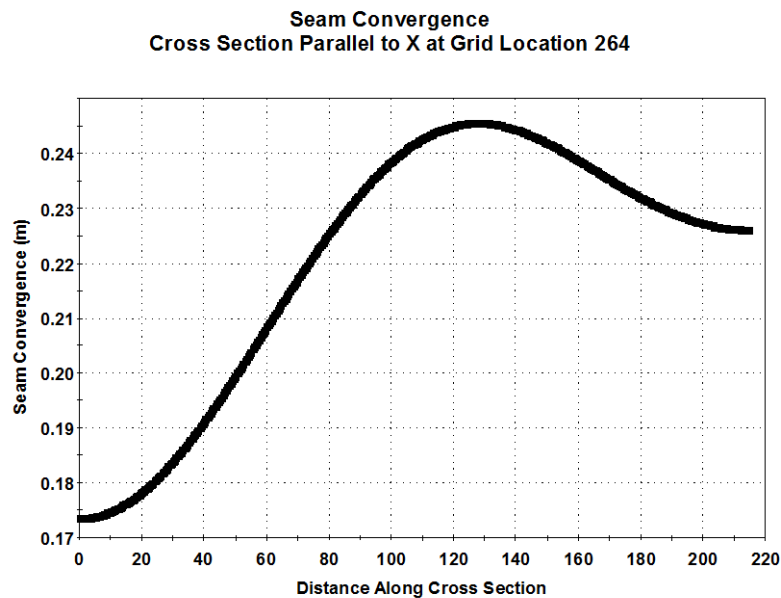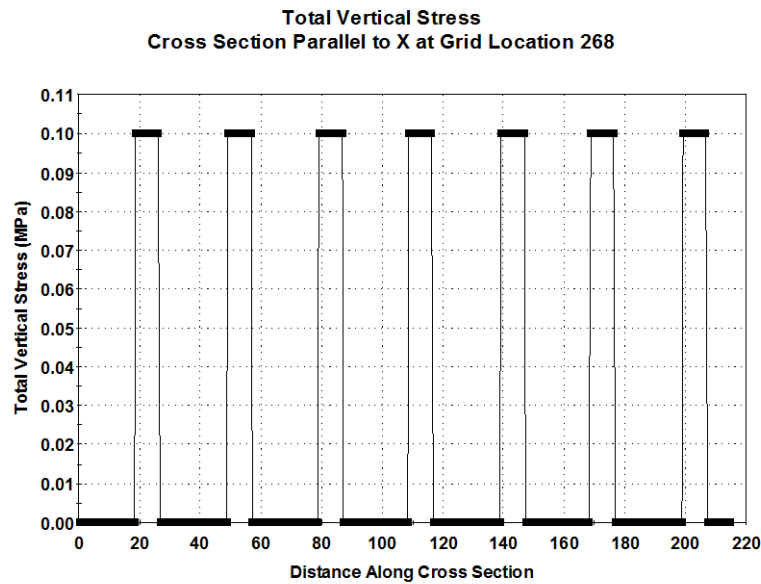**Total Vertical Stress**
Cross Section Parallel to Y at Grid Location 342

Seam Convergence
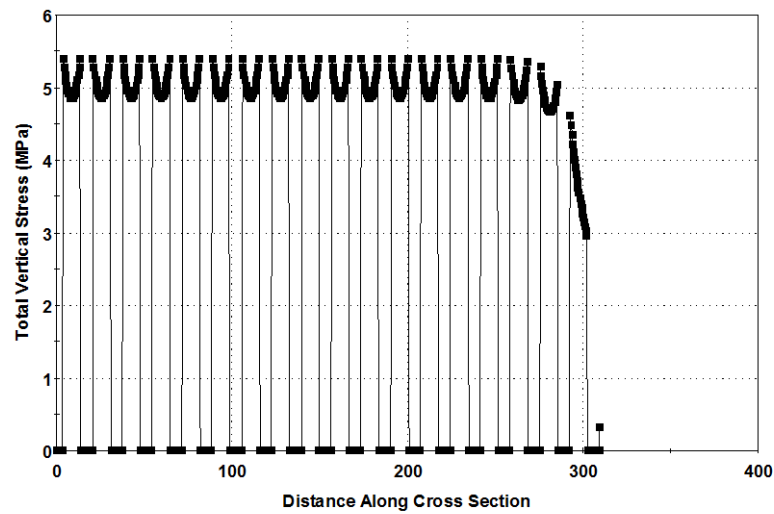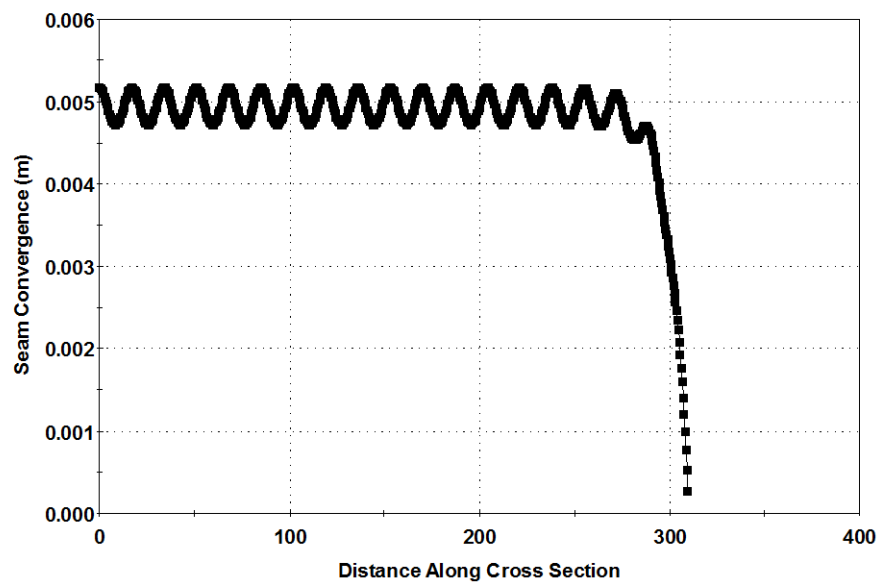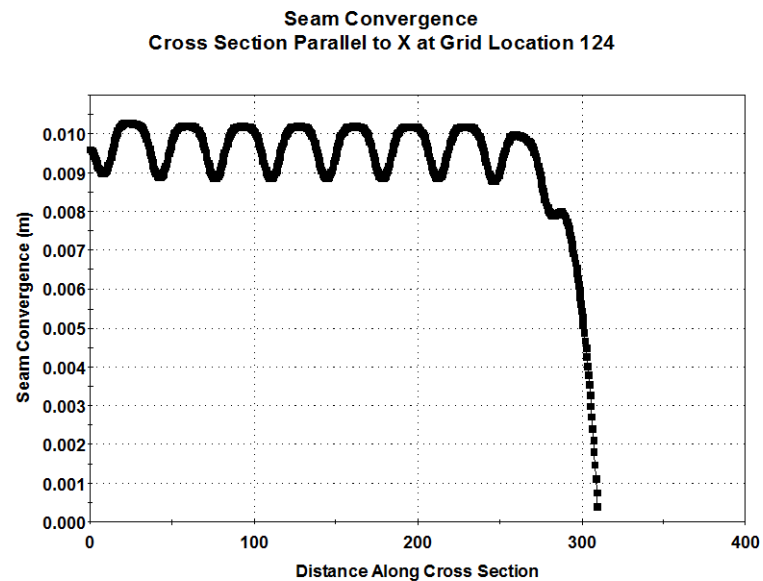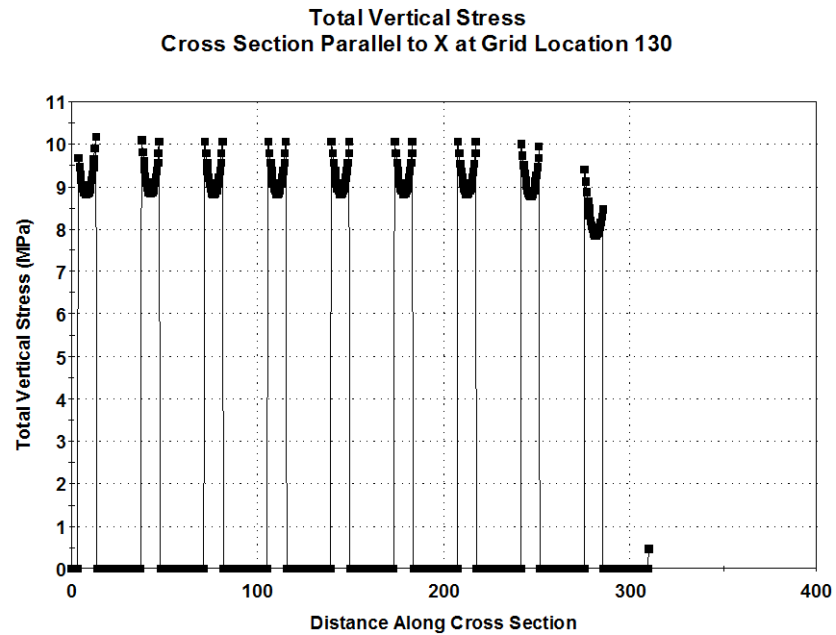**Cross Section Parallel to Y at Grid Location 348**
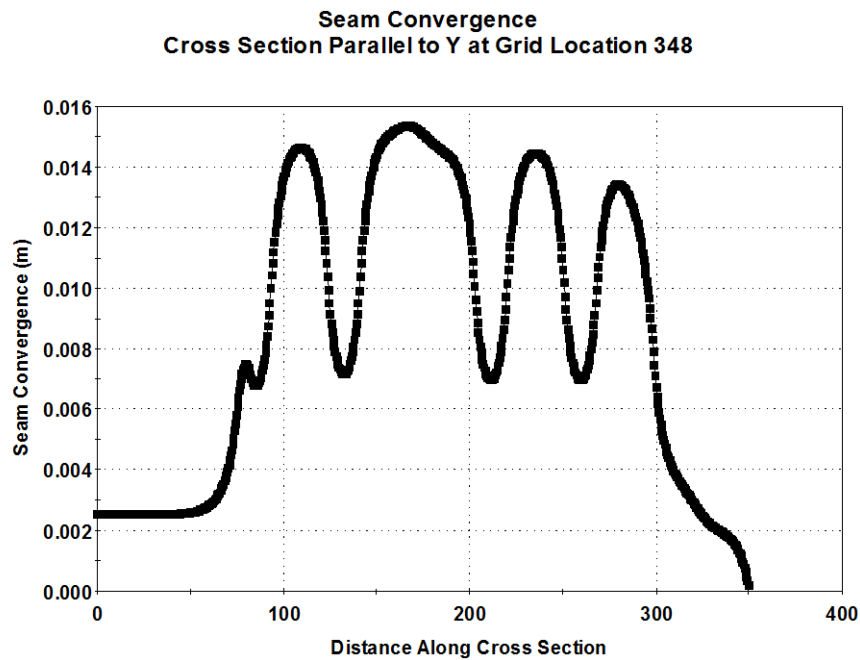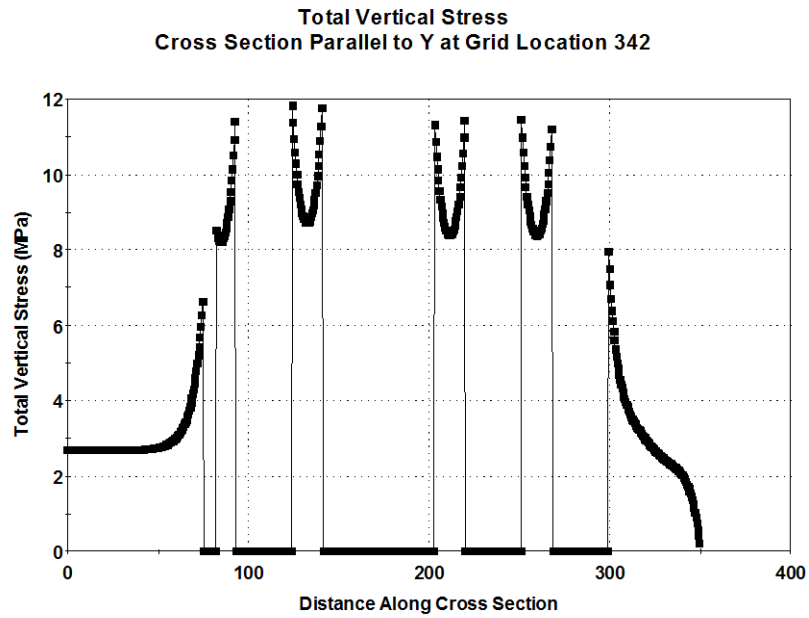
Summary of Modelling Results

Table 3 below represents a summary of the above modelling results.

MODEL NUMBER	BLOCK	CURRENT STATE		POST EXTRACTION		PILLARS
		VERTICAL STRESS	CONVERGENCE	VERTICAL STRESS	CONVERGENCE	
1	A	4.34	3.05	8.7	6.65	Intact
2	B	8.07	7.1	99.99	251.75	Failed
3	C	5.74	5.42	11.29	13.03	Intact
4	D	6.25	6.21	63.04	263.01	Failed
5	E	5.17	5.58	10.59	12.93	Intact
6	F	5.73	5.98	11.42	13.63	Intact
7	G	5.78	7.74	8.84	14.96	Intact
8	H	6.15	6.77	11.64	15.15	Intact
9	I	8.38	11.61	15.04	24.56	Intact
10	J	6.82	7.35	72.55	275.63	Failed
11	K (EM ONLY)	8.14	7.71	14.73	16.35	Intact
11	K (ALL)	8.14	7.71	113.46	284.61	Failed
12	L	8.05	7.01	16.19	16.89	Intact
13	M	7.05	6.7	13.72	15.39	Intact

Table 3. Summary of the Numerical Modelling Results per Block.

The numerical modelling results indicate that in all of the existing workings at Tumelo, there is a significant increase in the vertical stress to which the pillars are exposed once the proposed checkerboard extraction has been conducted, as can be expected.

For the purposes of this investigation, a very basic approach of totally removing every second pillar within the existing workings was applied.
This however will, in most cases, not be the actual scenario in practice due to the fact that in most instances each pillar to be extracted will in fact not be totally removed but will rather have small "snooks" left in the corners of the pillars which will, at least provide some sort of local support for the immediate roof in the enlarged intersection which is created on the extraction of the pillar.

Furthermore the numerical modelling also indicated that a total collapse of the remaining pillars in the panel, left after the proposed checkerboard extraction, could be expected in the following areas (indicated in Figure 7 below):
- East Main Panel – Portion 2
- East Main South 1
- East Main South 1 East 1
- East Main South 1 East 2
- East Main South 2 – Portion 2
- East Main South 2 East 3
- East Main South 2 West 3
- East Main South 4
- East Main South 5
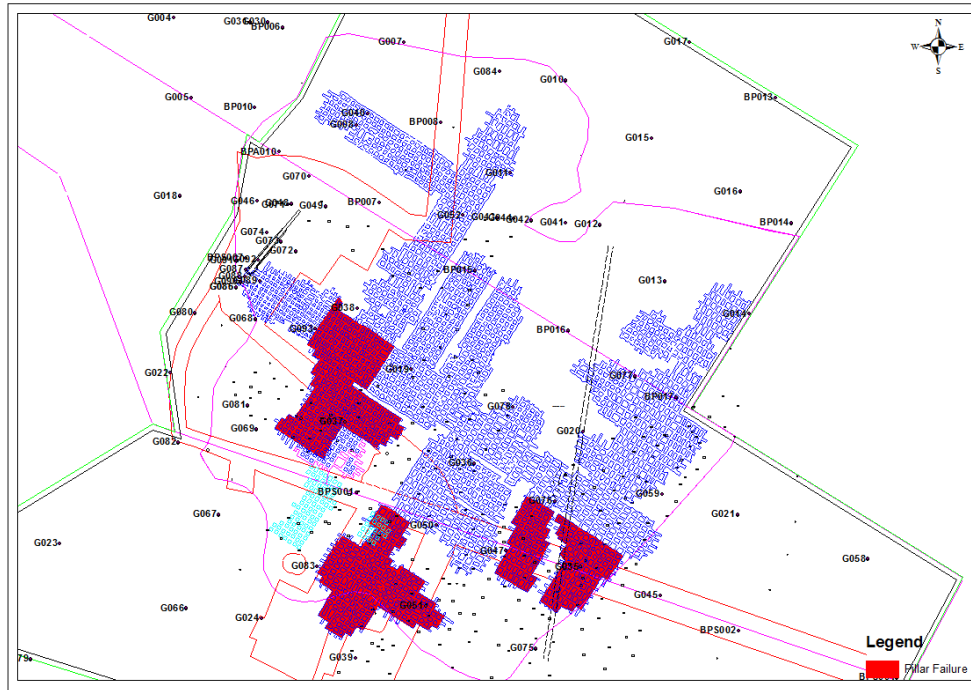
Figure 7. Areas at Tumelo in which Pillar Failure can be expected if Checkerboard Extraction is conducted.

Indicated in Table. 4 below are the vertical stresses which were calculated per panel based on the composition of the immediate roof and overburden.
Also detailed in Table. 4 are the estimated maximum panel spans and the expected maximum deflection of the immediate roof strata before failure.
The vertical stresses which are included in Table 4 were calculated based on the expected maximum deflection of the immediate roof.
From the results of the numerical modelling we can see that the post extraction maximum convergence is significantly lower than that calculated in Table. 4. The difference in these Two (2) values would explain the difference between the maximum vertical stress documented in Table. 4 and that which was estimated based on the numerical modelling results.

For the purposes of this investigation it is assumed that the results of the numerical modelling more accurately represent what can be expected in reality than those included in Table. 4.

Panel	σt (Mpa)	L (m)	Er (Gpa)	t (m)	n (mm)	h (m)	ε	Ec (Gpa)	σ (Mpa)
East Main Portion 1	5	132.80	18	10.69	28.6	2.5	0.011457	5	57.3
East Main Portion 2	5	132.80	18	9.1	33.6	3.4	0.009896	5	49.5
East Main Portion 3	5	150.80	18	12.46	31.7	3.7	0.008564	5	42.8
East Main Portion 4	5	154.80	18	10.62	39.2	4	0.009793	5	49.0
East Main Portion 5	5	114.80	18	9.18	24.9	3.8	0.006559	5	32.8
East Main North 3 Portion 1	5	114.80	18	13.94	16.4	3.9	0.004209	5	21.0
East Main North 3 Portion 2	5	114.80	18	12.07	19.0	4.2	0.004513	5	22.6
East Main North 3 West 3	5	108.80	18	12.07	17.0	3.5	0.004865	5	24.3
East Main North 4	5	105.80	18	12.46	15.6	4	0.003899	5	19.5
East Main North 5	5	117.80	18	12.46	19.3	4	0.004834	5	24.2
East Main North 7	5	108.80	18	8.62	23.8	2.72	0.008765	5	43.8
East Main North 8 Portion 1	5	114.80	18	10.23	22.4	3.1	0.007215	5	36.1
East Main North 8 Portion 2	5	114.80	18	20.37	11.2	3.4	0.003304	5	16.5
East Main North 8 West 2	5	129.30	18	10.52	27.6	2.9	0.009514	5	47.6
East Main North 8 West 3	5	114.80	18	10.52	21.7	3.6	0.006041	5	30.2
East Main South 1	5	105.80	18	14.87	13.1	3.4	0.003844	5	19.2
East Main South 1 East 1	5	111.80	18	14.87	14.6	4.1	0.003559	5	17.8
East Main South 1 East 2	5	102.80	18	14.87	12.3	3.65	0.003380	5	16.9
East Main South 2 Portion 1	5	108.80	18	10.62	19.4	4.4	0.004398	5	22.0
East Main South 2 Portion 2	5	108.80	18	15.08	13.6	4.1	0.003324	5	16.6
East Main South 2 West 3	5	150.80	18	15.08	26.2	3.7	0.007076	5	35.4
East Main South 2 East 1	5	117.80	18	10.62	22.7	4.1	0.005533	5	27.7
East Main South 2 East 2	5	114.80	18	12.08	18.9	4.4	0.004305	5	21.5
East Main South 2 East 3	5	132.80	18	10.51	29.1	3.4	0.008568	5	42.8
East Main South 4	5	108.80	18	9.18	22.4	3.3	0.006784	5	33.9
East Main South 5	5	150.80	18	9.82	40.2	3	0.013401	5	67.0

Table 4. Maximum calculated amounts of beam deflection per panel in the greater overburden before failure as well as estimated associated vertical stresses.

While the stresses expected based on the numerical modelling results, in all of the panels in which pillar failure was not predicted, would most likely result in scaling of the pillars and potential tension fracturing the model does not suggest failure of the pillars in the following panels:

- East Main – Portion 1
- East Main – Portion 3
- East Main – Portion 4
- East Main – Portion 5
- East Main North 3
- East Main North 3 West 3
- East Main North 4
- East Main North 5
- East Main North 7
- East Main South 2 – Portion 1
- East Main South 2 East 1
- East Main South 2 East 2
- East Main North 8
- East Main North 8

b. Roof & Overburden Stability

Based on the available geological information, as indicated in Table 5 below, in a large portion of the mining area at Tumelo, the immediate roof strata would be expected to consist of a competent sandstone layer, in many case, in excess of 5 m thick. In reality however, this has, during the mining of the majority of the Tumelo area, proven not to be the case, and it has been found that the immediate roof tends to be comprised of an interlaminated to interbedded siltstone and sandstone roof which often have micaceous contacts.

In light of these findings, it can be noted from the information included in Table 5 below that for many of the geological boreholes within the area, it has been assumed that the "beam" thickness in the immediate roof is only as thick as the length of the roofbolts installed (1,2 m).

Based on these and a number of other assumptions, also included in Table 5 below, the stability of the immediate roof has been assessed across the maximum span which is expected to be created in each area post the conducting of checkerboard extraction.

The results of this assessment indicate that in the majority of the mining areas at Tumelo, the immediate roof is expected to be stable over the span created during checkerboard extraction, but that in some areas beam failure can be expected and for this reason the importance of breakerlines, proper training and operating procedures, as well as the availability of a "Tooth Extractor" cannot be overemphasized.

Borehole I.D.	Immediate Roof Thickness (m)	Estimated Max Span (m)	Density (kg/m3)	Max Tensile Stress (Pa)	Max Tensile Stress (MPa)	Tensile Strength (Min) (Mpa)	Safety Factor	Tensile Stress Analysis
BP007				OUTSIDE MINING AREA				
BP008				OUTSIDE MINING AREA				
BP016				OUTSIDE MINING AREA				
BP017				LOG NOT AVAILABLE - CLOSE TO G077				
BPA010				OUTSIDE MINING AREA				
BPS001				OUTSIDE MINING AREA				
G008	1.2	23.70	2500	5739770	5.740	5	1.5	Unstable Roof Beam
G010				NO COAL - SILTSTONE				
G011	10.75	25.90	2500	765191	0.765	5	1.5	Stable Roof Beam
G012	9.92	0.00	3000	0	0.000	5	1.5	Stable Roof Beam
G013	1.2	0.00	2500	0	0.000	5	1.5	Stable Roof Beam
G014	1.2	30.70	2500	9631070	9.631	5	1.5	Unstable Roof Beam
G019	1.2	25.30	2500	6540920	6.541	5	1.5	Unstable Roof Beam
G020	1.2	24.80	2500	6284940	6.285	5	1.5	Unstable Roof Beam
G035	2.63	31.70	2500	4685347	4.685	5	1.5	Unstable Roof Beam
G036	10.62	25.40	2500	744941	0.745	5	1.5	Stable Roof Beam
G037	10.59	23.80	2500	655899	0.656	5	1.5	Stable Roof Beam
G038	1.2	25.80	2500	6802009	6.802	5	1.5	Unstable Roof Beam
G040				NO 2 SEAM IN HOLE - STOPPED				
G042	6.92	0.00	3000	0	0.000	5	1.5	Stable Roof Beam
G044	3	0.00	3000	0	0.000	5	1.5	Stable Roof Beam
G046	10.14	0.00	2500	0	0.000	5	1.5	Stable Roof Beam
G047	1.2	26.70	2500	7284845	7.285	5	1.5	Unstable Roof Beam

Borehole I.D.	Immediate Roof Thickness (m)	Estimated Max Span (m)	Density (kg/m3)	Max Tensile Stress (Pa)	Max Tensile Stress (MPa)	Tensile Strength (Min) (Mpa)	Safety Factor	Tensile Stress Analysis
G049	9.36	0.00	2500	0	0.000	5	1.5	Stable Roof Beam
G050	10.95	29.90	2500	1001169	1.001	5	1.5	Stable Roof Beam
G051	10.51	25.70	2500	770624	0.771	5	1.5	Stable Roof Beam
G052	9.24	25.90	2500	890239	0.890	5	1.5	Stable Roof Beam
G059	1.2	30.80	2500	9693915	9.694	5	1.5	Unstable Roof Beam
G068	1.2	20.50	2500	4294430	4.294	5	1.5	Unstable Roof Beam
G069	1.2	0.00	2500	0	0.000	5	1.5	Stable Roof Beam
G070	1.2	0.00	2500	0	0.000	5	1.5	Stable Roof Beam
G073	1.2	20.50	2500	4294430	4.294	5	1.5	Unstable Roof Beam
G074	1.2	20.50	2500	4294430	4.294	5	1.5	Unstable Roof Beam
G075	2.99	31.70	2500	4121225	4.121	5	1.5	Unstable Roof Beam
G076	8.96	30.80	2500	1298292	1.298	5	1.5	Stable Roof Beam
G077	3.18	24.20	2500	2258305	2.258	5	1.5	Stable Roof Beam
G078	8.62	23.70	2500	799040	0.799	5	1.5	Stable Roof Beam
G081	1.2	0.00	2500	0	0.000	5	1.5	Stable Roof Beam
G083	9.93	27.90	2500	961254	0.961	5	1.5	Stable Roof Beam
G084	9.98	0.00	2500	0	0.000	5	1.5	Stable Roof Beam
G086	9.34	20.50	2500	551747	0.552	5	1.5	Stable Roof Beam
G087	9.12	20.50	2500	565057	0.565	5	1.5	Stable Roof Beam
G088	8.91	20.50	2500	578374	0.578	5	1.5	Stable Roof Beam
G089	9.68	20.50	2500	532367	0.532	5	1.5	Stable Roof Beam
G090	9.16	20.50	2500	562589	0.563	5	1.5	Stable Roof Beam
G092	9.82	20.50	2500	524778	0.525	5	1.5	Stable Roof Beam
G093	LOG NOT AVAILABLE - CLOSE TO G038							

Table 5. Tensile stresses generated in as well as the convergence of the immediate roof in the position of each borehole indicating whether or not a stable roof beam can be expected over the typical spans created on extraction of a single pillar.

As can be noted from Table 6 included below it is evident that in the majority of the area under investigation the 2 Seam overburden is expected to consist of a high percentage of sandstone as well as that in all areas considered in this investigation, an individual sandstone unit in excess of at least 5 m thick, exists within the 2 Seam overburden.

Borehole I.D.	Competent Layer Thickness (m)	Depth to Base of Unit (m)	Depth to Floor (H) (m)	% SSN
BP007	OUTSIDE MINING AREA			
BP008	OUTSIDE MINING AREA			
BP016	OUTSIDE MINING AREA			
BP017	LOG NOT AVAILABLE - CLOSE TO G077			
BPA010	OUTSIDE MINING AREA			
BPS001	OUTSIDE MINING AREA			
G008	12.07	20.83	52.75	31.83
G010	NO COAL - SILTSTONE			
G011	10.75	71.37	75.45	36.28
G012	16.6	48	89.89	24.44
G013	5.09	66.44	88.38	29.85
G014	20.37	52.87	86	29.83
G019	12.46	45	78.75	30.85
G020	11.69	36.13	97.45	49.96
G035	9.82	66.6	105.48	50.09
G036	10.62	86.64	90.46	54.65
G037	14.87	36.28	69.92	50.53
G038	13.94	34.72	66.95	46.25
G040	NO 2 SEAM - HOLE STOPPED			
G042	16.47	41.52	80.63	32.49
G044	OUTSIDE MINING AREA			
G046	10.14	34.37	36.82	56.3
G047	14.68	52.51	95.98	58.75
G049	9.36	43.24	46.16	66.98
G050	12.08	58.69	93.49	54.02
G051	10.51	88.3	91.51	55.21
G052	12.07	43.88	79.78	57.11
G059	10.23	78.38	100.29	47.61
G068	10.69	11.69	39.27	60.27
G069	9.6	42.46	45.12	63.12
G070	9.47	43.22	46.02	61.13
G073	9.45	35.66	37.91	59.03
G074	10.2	33.87	36.36	45.73
G075	14.06	65.69	92.05	53.66
G076	9.18	27.89	99.25	47.36

G077	10.52	65.61	95.98	42.91
G078	8.62	84.34	86.81	49.54
G081	2.15	15.16	42.82	46.34
G083	15.08	35.42	67.05	48.23
G084	13.85	37.64	72.24	42.25
G086	9.34	27.94	29.52	52.36
G087	9.12	27.75	29.51	12.43
G088	8.91	28.42	30.17	45
G089	9.68	34.12	36.29	48.09
G090	9.16	28.59	30.21	47.36
G092	9.82	31.47	33.48	40.86
G093	LOG NOT AVAILABLE - CLOSE TO G038			

Table 6. Competent Layer Thickness and Percentage Sandstone per Borehole within the general vicinity of the Panels under investigation.

Theoretical Calculations

Stability of the Immediate Roof

The stability of the beams which exist in the immediate roof can be estimated using the formula for tensile stresses in a fixed beam which calculates the maximum tensile stress (σ_t) to which the material in a fixed beam of unit width will be subjected as:

$$\sigma_t = \frac{\rho g B^2}{2t}$$

Where:
- ρ - Strata Density
- g - Gravitation Acceleration
- B - Span width
- t - Beam Thickness

Using the equation for tensile stresses in a fixed beam detailed above the tensile stress was calculated for each one of the geological units expected to form the immediate roof in the boreholes investigated.

The calculated tensile stresses and maximum convergences have been included in Table 5 above and Table 7 below.

For the purposes of the tensile stress calculations a density of the overburden material of 2500 kg/m$_3$ was assumed and a safety factor of 1,5 applied.

The following formula can be used to calculate the roof sag or convergence of the immediate / individual layer:

$$\eta = \frac{yL^4}{32E_r t^2}$$ After van der Merwe and Madden (2010)

Where: L -   is the span (either between pillars (21,8 m) or the total panel width)
             y -   is the unit weight of the roof material
             E_r -   is Young's Modulus of the overburden (20 GPa)
             t -   is the thickness of the layer under consideration

As can be noted from Table 7 below the theoretical calculations indicate that between 13,33 mm and 70,99 mm of convergence can be expected to occur in the center of the mining panels if there is no resistance (support) provided by the pillars during checkerboard extraction.

In Table 7 below, all of the boreholes indicated in blue are not located directly within the mining area. From the boreholes located within the mining area it can be seen that the maximum amount of roof sag which can be expected to occur over an individual intersection span is estimated at 28,00 mm (G014) due to the large pillar center sizes in that area.

Borehole I.D.		Layer Thickness	Estimated Max Span (m)	Unit Weight (y)	Er (Gpa)	Roof Sag (Convergence) (m)	Roof Sag (Convergence) (mm)
G014	Intersection Span	1.2	30.70	0.024525	43	0.0280	28.00
	Panel Span	20.37	114.80	0.024525	44	0.0225	22.54
G019	Intersection Span	1.2	25.30	0.024525	45	0.0182	18.17
	Panel Span	12.46	134.8	0.024525	46	0.0486	48.60
G020	Intersection Span	1.2	24.80	0.024525	47	0.0167	16.72
	Panel Span	11.69	78.80	0.024525	48	0.0170	16.96
G035	Intersection Span	2.63	31.70	0.024525	49	0.0120	11.95
	Panel Span	9.82	150.80	0.024525	50	0.0710	70.99
G036	Intersection Span	10.62	25.40	0.024525	51	0.0018	1.83
	Panel Span	10.62	111.80	0.024525	52	0.0347	34.69
G037	Intersection Span	10.59	23.80	0.024525	53	0.0015	1.55
	Panel Span	14.87	111.80	0.024525	54	0.0239	23.86
G038	Intersection Span	1.2	25.80	0.024525	55	0.0155	15.46
	Panel Span	13.94	150.8	0.024525	56	0.0447	44.65
G040	HOLE STOPPED BEFORE 2 SEAM						
G042	NO MINING						
G044	NO MINING						

G046	NO MINING						
G047	Intersection Span	1.2	26.70	0.024525	65	0.0140	14.01
	Panel Span	14.68	91.8	0.024525	66	0.0133	13.33
G049	NO MINING						
G050	Intersection Span	10.95	29.90	0.024525	69	0.0018	1.81
	Panel Span	12.08	96.80	0.024525	70	0.0170	16.99
G051	Intersection Span	10.51	25.70	0.024525	71	0.0014	1.36
	Panel Span	10.51	132.80	0.024525	72	0.0357	35.72
G052	Intersection Span	9.24	25.90	0.024525	73	0.0015	1.52
	Panel Span	12.07	132.80	0.024525	74	0.0303	30.27
G059	Intersection Span	1.2	30.80	0.024525	75	0.0162	16.16
	Panel Span	10.23	114.8	0.024525	76	0.0260	25.98
G068	Intersection Span	1.2	20.50	0.024525	77	0.0070	6.97
	Panel Span	10.69	132.80	0.024525	78	0.0324	32.42
G069	NO MINING						
G070	NO MINING						
G073	Intersection Span	1.2	20.50	0.024525	83	0.0065	6.47
	Panel Span	9.45	132.80	0.024525	84	0.0341	34.05
G074	Intersection Span	1.2	20.50	0.024525	85	0.0063	6.32
	Panel Span	10.2	132.80	0.024525	86	0.0308	30.82
G075	Intersection Span	2.99	31.70	0.024525	87	0.0059	5.92
	Panel Span	14.06		0.024525	88	0.0000	0.00
G076	Intersection Span	8.96	30.80	0.024525	89	0.0018	1.82
	Panel Span	9.18	114.80	0.024525	90	0.0245	24.45
G077	Intersection Span	3.18	24.20	0.024525	91	0.0031	3.10
	Panel Span	10.52	150.80	0.024525	92	0.0360	36.02
G078	Intersection Span	8.62	23.70	0.024525	93	0.0011	1.07
	Panel Span	8.62	108.80	0.024525	94	0.0224	22.39
G081	NO MINING						
G083	Intersection Span	9.93	27.90	0.024525	97	0.0012	1.24
	Panel Span	15.08	150.80	0.024525	98	0.0236	23.59
G084	NO MINING						
G086	Intersection Span	9.34	20.50	0.024525	101	0.0007	0.68
	Panel Span	9.34	132.80	0.024525	102	0.0284	28.38

G087	Intersection Span	9.12	20.50	0.024525	103	0.0007	0.69
	Panel Span	9.12	132.80	0.024525	104	0.0285	28.50
G088	Intersection Span	8.91	20.50	0.024525	105	0.0007	0.69
	Panel Span	8.91	132.80	0.024525	106	0.0286	28.62
G089	Intersection Span	9.68	20.50	0.024525	107	0.0006	0.62
	Panel Span	9.68	132.80	0.024525	108	0.0259	25.86
G090	Intersection Span	9.16	20.50	0.024525	109	0.0006	0.65
	Panel Span	9.16	132.80	0.024525	110	0.0268	26.83
G092	Intersection Span	9.82	20.50	0.024525	111	0.0006	0.59
	Panel Span	9.82	132.80	0.024525	112	0.0246	24.58
G093	LOG NOT AVAILABLE - CLOSE TO G038						

Table 7. Estimated maximum roof sag (convergence) which is anticipated will occur in the various geological units in the immediate roof during checkerboard extraction

Stability of the Overburden

The maximum height of overburden which can be supported by the pillars can be calculated from the equation below:

$H_m = 40\sigma_p (1 - e)$

If H_m in the equation above is less than the depth to the mining floor (H) pillar failure can be considered to be distinctly possible.
Under such circumstances the only condition under which the pillars will not fail is if the overburden is able to bridge across the pillars between the barrier pillars on either side of the panel.

A simple way to evaluate the stability of the overburden is to consider the tensile stresses generated in the various beams within the overburden by deflection of the overlying beams.

The maximum compression of a pillar in the center of the panel can be calculated from:

$$dh = \frac{h\,\Delta\sigma_p}{E_c}$$

Where: $\Delta\sigma_p$ -   is the load increase due to mining i.e. $\Delta\sigma_p = \sigma_p - 0.025H$
         E_c – Elastic modulus of coal

From fundamentals the maximum deflection of a beam expressed in terms of tensile stress can be expressed as per the formula below:

$$\sigma_{to} = \frac{16 H_m h \Delta \sigma_p}{L^2} \times \frac{E_r}{E_c}$$

Where: H_m – Maximum height of overburden that pillars can support
            L – Panel width
            E_r – Elastic modulus of the overburden

For the purpose of ensuring a safety factor greater than unity, H_m in the above equation should be substituted with H.
In reality the calculation should be repeated for each of the successive layers within the overburden with t being replaced with the thickness of the layers under question to test each layer for failure.
The values calculated for σ_{to} as well as those assumed for $\Delta\sigma_p$, H_m, E_r and E_c have been included in APPENDIX 1. Table 8 below represents the most important information.

Panel	Hm	H	H/Hm	σto	OSF	PSF
East Main Portion 1	114.1	40.0	0.4	10.4034143	-1.08	0.72
East Main Portion 2	109.3	67.0	0.6	10.6329165	-1.13	-0.04
East Main Portion 3	122.8	68.0	0.6	10.155529	-1.03	0.04
East Main Portion 4	143.0	79.0	0.6	11.9729035	-1.39	0.02
East Main Portion 5	176.6	91.0	0.5	27.9487965	-4.59	0.09
East Main Portion 6	190.0	100.0	0.5	28.7789425	-4.76	0.05
East Main North 3 Portion 1	145.2	70.0	0.5	22.6797355	-3.54	0.17
East Main North 3 Portion 2	135.3	78.0	0.6	20.697736	-3.14	-0.02
East Main North 3 West 3	135.2	65.0	0.5	21.825179	-3.37	0.19
East Main North 4	127.2	79.0	0.6	21.6233177	-3.32	-0.09
East Main North 5	135.4	80.0	0.6	18.9805139	-2.80	-0.04
East Main North 7	159.7	91.0	0.6	22.7191352	-3.54	0.01
East Main North 8 Portion 1	204.6	97.0	0.5	30.9245395	-5.18	0.17
East Main North 8 Portion 2	193.5	92.0	0.5	30.1621496	-5.03	0.17
East Main North 8 West 2	162.3	98.0	0.6	16.63148	-2.33	-0.06
East Main North 8 West 3	159.1	94.0	0.6	22.6945572	-3.54	-0.05
East Main South 1	121.9	63.0	0.5	19.8483721	-2.97	-0.09
East Main South 1 East 1	114.5	75.5	0.7	16.9155495	-2.38	0.12
East Main South 1 East 2	109.5	65.9	0.6	18.5454123	-2.71	-0.13
East Main South 2 Portion 1	117.4	89.1	0.8	18.187618	-2.64	-0.03
East Main South 2 Portion 2	131.2	83.0	0.6	21.472368	-3.29	-0.25
East Main South 2 West 3	160.2	80.0	0.5	14.4059685	-1.88	-0.10
East Main South 2 East 1	134.1	95.0	0.7	17.9647368	-2.59	0.12
East Main South 2 East 2	152.9	97.0	0.6	23.6358174	-3.73	-0.20
East Main South 2 East 3	162.3	92.0	0.6	17.3073002	-2.46	-0.12
East Main South 4	163.0	100.0	0.6	24.9113867	-3.98	-0.01
East Main South 5	215.6	106.0	0.5	18.5915194	-2.72	-0.08

Table 8. Key Information regarding the Overburden and Pillar Stability Factors for the various Panels under Investigation.

It is now possible to define an overburden stability factor, *OSF*, as follows:

$$OSF = \frac{\sigma_{tr} - \sigma_{to}}{\sigma_{tr}}$$

Where: σ_{tr} -   is the tensile strength of the overburden material, taken as 5 MPa

One can then define the pillar stability factor, PSF, as follows:

$$PSF = fs - 1$$

Where: *fs* -   is the safety factor calculated with the full overburden load
Using the loads calculated in the safety factor calculations for each panel, the PSF's were
calculated to be as per the values in Table 9 above.

The pillar / overburden system failure is governed by two factors, namely the *OSF* and *PSF*.

These two factors can be plotted relative to each other into the quadrants shown in Figure 8
below.
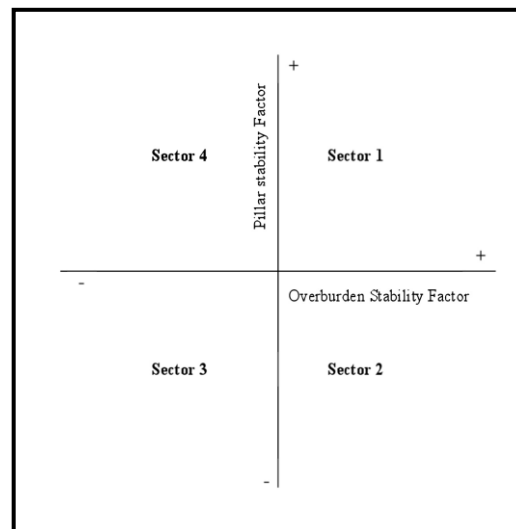
Figure 8. Quadrants (Sectors) into which a system stability can be plotted based on the Pillar
Stability and Overburden Stability Factors.

The quadrants (sectors) have the following meanings (van der Merwe and Madden (2010)):

Sector 1: Stable system. The pillars can support the full overburden and the overburden has not failed in tension.

Sector 2: Possibly the most dangerous situation. The pillars cannot support the overburden, but may appear to be stable because the overburden has not yet failed. A single discontinuity may cause this overburden to fail without warning.

Sector 3: This is a common stooping situation with small snooks which fail as mining progresses.

Sector 4: This sector indicates failure over a long time period, governed by the time related decay of pillar strength. The overburden has failed, resulting in full overburden load on the pillars, but they are (temporarily at least) strong enough to support the overburden.

As can be noted from Figure 9 below, when plotting the PSF against the OSF for each of the panels under investigation all of the panels under investigation either fall into Sector 3 or Sector 4 except for the East Main North 8 East 1 & 2 Panels which fall into Sector 2.
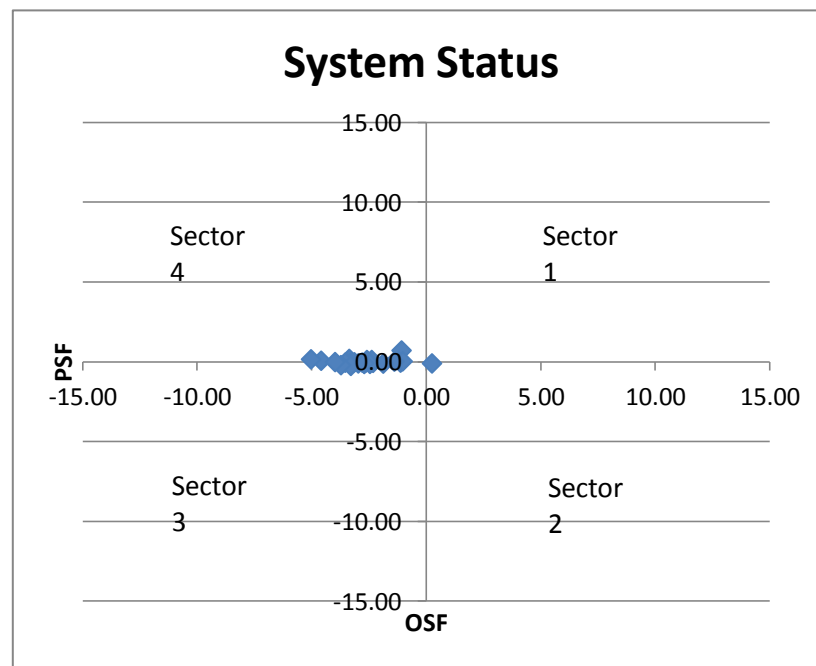
Figure 9. Pillar Stability vs. Overburden Stability Factor plots for the Panels under investigation.

The East Main North 8 East 1 & 2 Panels, if secondary extraction were to be conducted in them, would fall into Sector 2 which has been described as possibly the most dangerous scenario due to the fact that the pillars are unable to support the overburden weight but may appear to be stable due to the fact that the overburden has not yet failed. Failure may however occur at any point without warning and it is therefore suggested that secondary extraction should only be conducted with extreme caution in these panels.

The following panels were noted to fall into Sector 3:
- East Main – Portion 2
- East Main North 3 – Portion 2
- East Main North 4
- East Main North 5
- East Main North 8 West 2
- East Main North 8 West 3
- East Main South 1
- East Main South 1 East 2
- East Main South 2 – Portion 1
- East Main South 2 – Portion 2
- East Main South 2 West 3
- East Main South 2 East 2
- East Main South 2 East 3
- East Main South 4
- East Main South 5

Based on the results of the numerical modelling, pillar failure is expected, and therefore secondary not recommended in all of the panels indicated in "Red" in the list above.
In addition to this there are surface restrictions above the panels indicated in "Orange" in the list above and for this reason secondary extraction has not been recommended in them.
Therefore the only panels in which secondary extraction is deemed feasible and which fall into Sector 3 in Figure 9 above are the following panels:
- East Main North 3 – Portion 2
- East Main North 4
- East Main North 5
- East Main North 8 West 2
- East Main North 8 West 3

The fact that these panels fall into Sector 3 implies that the state of the overburden and the pillars during mining may represent that of a typical "stooping" section. In these areas therefore failure of the pillars in the "Goaf" area as well as subsequent failure of the overburden strata may occur as mining progresses.

The following panels fall into Sector 4:
- East Main – Portion 1
- East Main – Portion 3

- East Main – Portion 4
- East Main – Portion 5
- East Main – Portion 6
- East Main North 3 – Portion 1
- East Main North 3 West 3
- East Main North 7
- East Main North 8 – Portion 1
- East Main North 8 – Portion 2
- East Main South 1 East 1
- East Main South 2 East 1

Based on the results of the numerical modelling, pillar failure is expected, and therefore secondary not recommended in all of the panels indicated in "Red" in the list above.
In addition to this there are surface restrictions above the panels indicated in "Orange" in the list above and for this reason secondary extraction has not been recommended in them.
Therefore the panels in which secondary extraction is deemed feasible and which fall into Sector 4 in Figure 9 above are the following panels:
- East Main – Portion 1
- East Main – Portion 3
- East Main – Portion 4
- East Main – Portion 5
- East Main – Portion 6
- East Main North 3 – Portion 1
- East Main North 3 West 3
- East Main North 7
- East Main North 8 – Portion 1
- East Main North 8 – Portion 2

This implies that failure of the pillars in the above panels can be expected over a long period of time and that failure is governed by the time dependant reduction in the pillar strengths.
For the reasons mentioned above, the area in-bye of the last full line of solid pillars, in all areas in which secondary extraction takes place, should be seen as a "Goaf" area and no personnel should move in-bye of it.

Mode of failure

In situations where pillars are expected to fail, it is important to consider the relative violence with which they are expected to fail.
Violent failure has the potential to result in injury or loss of life as well as severe damage to or loss of equipment.

When considering the relative degree of violence of pillar failure, the most important parameter to consider is the ratio between the system (overburden) stiffness and the pillar stiffness.

As noted by van der Merwe and Madden (2010), while the elastic modulus of intact coal is remarkably consistent at around 4 GPa, the post failure modulus of a coal pillar is a function of its width to height ratio.

Also from van der Merwe and Madden (2010) and based on linear regression of data which was published by van Heerden (1975) the following formula was drawn up for the calculation of the post failure modulus of a coal sample:

$$E_{cp} = \frac{0{,}562\, w_e}{h} - 2{,}293\,\text{GPa}$$

Where: w_e – Effective width of the pillars
          h – Mining height

For the panels under investigation the values for h and w_e have been calculated and are listed in Table 9 below as well as the calculated E_{cp} for each panel.

Panel	h	we	Ecp
East Main Portion 1	2.5	7.5	-0.61
East Main Portion 2	3.4	8.7	-0.86
East Main Portion 3	3.7	10.0	-0.77
East Main Portion 4	4	11.7	-0.65
East Main Portion 5	3.8	13.6	-0.29
East Main Portion 6	3.4	13.6	-0.05
East Main North 3 Portion 1	3.9	11.7	-0.61
East Main North 3 Portion 2	4.2	11.6	-0.74
East Main North 3 West 3	3.5	10.3	-0.64
East Main North 4	4	10.7	-0.79
East Main North 5	4	11.2	-0.72
East Main North 7	2.72	10.3	-0.16
East Main North 8 Portion 1	3.1	13.6	0.18
East Main North 8 Portion 2	3.4	13.7	-0.03
East Main North 8 West 2	2.9	10.8	-0.20
East Main North 8 West 3	3.6	11.7	-0.46
East Main North 8 East 1 & 2	3.3	11.1	-0.40
East Main South 1	3.4	9.4	-0.73
East Main South 1 East 1	4.1	9.9	-0.94
East Main South 1 East 2	3.65	9.1	-0.89
East Main South 2 Portion 1	4.4	10.6	-0.94
East Main South 2 Portion 2	4.1	11.2	-0.75
East Main South 2 West 3	3.7	12.4	-0.41
East Main South 2 East 1	4.1	11.3	-0.74
East Main South 2 East 2	4.4	13.1	-0.61
East Main South 2 East 3	3.4	11.8	-0.35
East Main South 4	3.3	11.6	-0.32
East Main South 5	3	14.0	0.32

Table 9. Values for h and w_e for each one of the panels under investigation as well as the calculated values for the E_{cp} per panel.

For the full destruction of the pillars it is required that the overburden must be able to deflect fully, and for this to occur, in most cases the overburden is required to fail.

According to van der Merwe and Madden (2010) the maximum deflection which can be tolerated by a beam before the induced tensile stress in the beam exceeds the tensile stress of the beam can be calculated.

The maximum deflection which can be tolerated by a beam can be calculated using the following equation:

$$\eta = \frac{\sigma t L^2}{16 E_r t}$$

Where:
σ – Total tensile stress
σ_t – Tensile strength
L – Span / Panel width
t – Thickness of the beam
E_r – Young's Modulus for the Overburden

Using the above formula the values for the maximum deflection of the beams in the overburden per panel under investigation have been calculated and are included in Table 10 below.

These values of deflection of the overburden then also become the amount of compression which is applied to the pillars in the center of the mining panel.
Based on the calculated values of deflection as well as the mining heights (pillar height) in each panel a total strain (Є) as well as the total stress (σ) to which the pillars in the center of the panel may be subjected have been calculated and are also included in Table 10 below.

Panel	σt (Mpa)	L (m)	Er (Gpa)	t (m)	n (mm)	h (m)	ε	Ec (Gpa)	σ (Mpa)
East Main Portion 1	5	132.80	18	10.69	28.6	2.5	0.011457	5	57.3
East Main Portion 2	5	132.80	18	1.2	255.1	3.4	0.075044	5	375.2
East Main Portion 3	5	150.80	18	12.46	31.7	3.7	0.008564	5	42.8
East Main Portion 4	5	154.80	18	10.62	39.2	4	0.009793	5	49.0
East Main Portion 5	5	114.80	18	9.18	24.9	3.8	0.006559	5	32.8
East Main North 3 Portion 1	5	114.80	18	13.94	16.4	3.9	0.004209	5	21.0
East Main North 3 Portion 2	5	114.80	18	12.07	19.0	4.2	0.004513	5	22.6
East Main North 3 West 3	5	108.80	18	12.07	17.0	3.5	0.004865	5	24.3
East Main North 4	5	105.80	18	12.46	15.6	4	0.003899	5	19.5
East Main North 5	5	117.80	18	12.46	19.3	4	0.004834	5	24.2
East Main North 7	5	108.80	18	8.62	23.8	2.72	0.008765	5	43.8
East Main North 8 Portion 1	5	114.80	18	10.23	22.4	3.1	0.007215	5	36.1
East Main North 8 Portion 2	5	114.80	18	20.37	11.2	3.4	0.003304	5	16.5
East Main North 8 West 2	5	129.30	18	10.52	27.6	2.9	0.009514	5	47.6
East Main North 8 West 3	5	114.80	18	10.52	21.7	3.6	0.006041	5	30.2
East Main South 1	5	105.80	18	14.87	13.1	3.4	0.003844	5	19.2
East Main South 1 East 1	5	111.80	18	14.87	14.6	4.1	0.003559	5	17.8
East Main South 1 East 2	5	102.80	18	14.87	12.3	3.65	0.003380	5	16.9
East Main South 2 Portion 1	5	108.80	18	10.62	19.4	4.4	0.004398	5	22.0
East Main South 2 Portion 2	5	108.80	18	15.08	13.6	4.1	0.003324	5	16.6
East Main South 2 West 3	5	150.80	18	15.08	26.2	3.7	0.007076	5	35.4
East Main South 2 East 1	5	117.80	18	10.62	22.7	4.1	0.005533	5	27.7
East Main South 2 East 2	5	114.80	18	12.08	18.9	4.4	0.004305	5	21.5
East Main South 2 East 3	5	132.80	18	10.51	29.1	3.4	0.008568	5	42.8
East Main South 4	5	108.80	18	9.18	22.4	3.3	0.006784	5	33.9
East Main South 5	5	150.80	18	9.82	40.2	3	0.013401	5	67.0

Table 10. Calculated values of deflection of the overburden per panel under investigation as well as the associated possible pillar stress in the pillars in the center of the mining panels.

The deflection of all of the various layers identified in the boreholes within the proposed mining area was calculated.

Such deflections are expected to result in the following pillar stresses in the various panels:

Borehole	Intersection Span	Deflection (mm)	h	ϵ	σ (Mpa)
BP017	LOG NOT AVAILABLE - CLOSE TO G077				
G008	23.70	21.74	3.27	0.00665	21.7416
G011	25.90	2.59	4.08	0.00063	2.58511
G014	30.70	28.00	4.45	0.00629	27.9973
G019	25.30	18.17	4.00	0.00454	18.1692
G020	24.80	16.72	2.87	0.00582	16.7153
G035	31.70	11.95	3.05	0.00392	11.9524
G036	25.40	1.83	3.82	0.00048	1.82584
G037	23.80	1.55	4.08	0.00038	1.54693
G038	25.80	15.46	3.30	0.00468	15.4591
G047	26.70	14.01	3.53	0.00397	14.0093
G050	29.90	1.81	5.21	0.00035	1.81371
G051	25.70	1.36	3.21	0.00042	1.35673
G052	25.90	1.52	4.36	0.00035	1.52438
G059	30.80	16.16	3.07	0.00526	16.1565
G068	20.50	6.97	2.17	0.00321	6.97148
G073	20.50	6.47	2.25	0.00287	6.46751
G074	20.50	6.32	2.11	0.00299	6.31534
G075	31.70	5.92	0.59	0.01004	5.9213
G076	30.80	1.82	3.35	0.00054	1.82344
G077	24.20	3.10	2.92	0.00106	3.10207
G078	23.70	1.07	2.47	0.00043	1.07398
G083	27.90	1.24	3.61	0.00034	1.23873
G086	20.50	0.68	1.58	0.00043	0.68286
G087	20.50	0.69	1.76	0.00039	0.68575
G088	20.50	0.69	1.75	0.00039	0.68854
G089	20.50	0.62	2.17	0.00029	0.62192
G090	20.50	0.65	1.90	0.00034	0.64517
G092	20.50	0.59	0.70	0.00084	0.59097
G093	LOG NOT AVAILABLE - CLOSE TO G038				

Table 11. Expected Pillar Stresses based on the Deflection of the Sandstone Beam in the immediate roof over a Single Intersection Span.

As stated in the report titled "FZN Checkerboard Rock Eng Report Oct-12" compiled by Dr. B. Madden for the Section 2 trial panel at Forzando North; based on the stresses calculated and recorded in Tables 10 and 11 above, it can be said that no signs of pillar slabbing would suggest that the major sandstone layers in the overburden have not yet deflected while sever slabbing would suggest that the major sandstone layers have deflected fully.

In order to guard against such states, a row of pillars could be left from time to time to form a barrier if deemed necessary.

The calculations over intersection spans indicate that only relatively small amounts of roof sag are expected to occur, however this does not take into account planes of weakness i.e. bedding planes within the sandstone layers neither does it take into account the possibility of the presence of discontinuities within the immediate roof strata.

In addition to this a "False" immediate roof in the lower portion of the overlying sandstone layer with a thickness of up to 300 mm is known to occur in certain locations within the Tumelo mine workings. This layer could slab with mining.

In light of the above detailed potential scenarios the possibility of a roof fall cannot be ruled out and in fact based on the tensile stress calculations is quite likely in some areas on the mine.

For this reason it is important that no personnel should go beyond the last line of solid pillars and that the area in which pillars have been either partially or totally extracted should be considered a "Goaf" area.

In addition to this it is suggested that a "Tooth Extractor" should be on hand in the section at all times to recover the continuous miner should a roof fall occur on top of the machine. It is also suggested that a remote control machine be preferred to an "on-board" driver system.

Potential Percentage Extraction and Surface Subsidence

Theoretical extraction percentages by assuming the extraction of every second pillar in each row in a given panel can be calculated.

Based on the proposed checkerboard extraction of every second pillar within each panel the estimated tonnages included in Table 12 below have been calculated over Two (2) rows of pillars within each panel as well as over the entire area of the panels. Note that these tonnages are a very basic theoretical calculation and a more detailed estimate of the total tonnages should be calculated for an accurate economical feasibility analysis.

Panel	ROM Tons per Pillar	Avg. Total Pillars per Row	Avg. Total Pillars Taken Over 2 Rows	Avg. ROM Tons per 2 Rows	Est. Total Splits	Est. Total ROM Tons in Panel
East Main Portion 1	210.94	9	9	1898.4375	17	16 136.72
East Main Portion 2	385.30	7	0	0	12	0.00
East Main Portion 3	555.11	8	8	4440.879251	14	31 086.15
East Main Portion 4	821.34	6	6	4928.04	10	24 640.20
East Main Portion 5	1049.04	6	6	6294.226346	12	37 765.36
East Main North 3 Portion 1	797.88	6	6	4787.305026	15	35 904.79
East Main North 3 Portion 2	844.58	6	6	5067.485557	11	27 871.17
East Main North 3 West 3	556.97	6	6	3341.835	20	33 418.35
East Main North 4	687.71	6	6	4126.256592	17	35 073.18
East Main North 5	749.64	6	6	4497.857937	16	35 982.86
East Main North 7	432.85	6	6	2597.0832	4	5 194.17
East Main North 8 Portion 1	865.04	6	6	5190.255822	15	38 926.92
East Main North 8 Portion 2	953.12	6	6	5718.714886	8	22 874.86
East Main North 8 West 2	507.38	6	6	3044.304	5	7 610.76
East Main North 8 West 3	744.86	4	4	2979.450611	7	10 428.08
East Main North 8 East 1	698.15	5	5	3490.75	1	1745.38
East Main North 8 East 2	698.15	6	6	4188.9	3	6283.35
East Main South 1	454.81	6	0	0	13	0.00
East Main South 1 East 1	601.97	6	0	0	10	0.00
East Main South 1 East 2	453.38	6	0	0	4	0.00
East Main South 2 Portion 1	738.28	6	6	4429.678027	4	8 859.36
East Main South 2 Portion 2	777.59	4	0	0	20	0.00
East Main South 2 West 3	856.32	8	0	0	3	0.00
East Main South 2 East 1	791.49	8	8	6331.918492	9	28 493.63
East Main South 2 East 2	1139.63	6	0	0	8	0.00
East Main South 2 East 3	707.58	6	0	0	8	0.00
East Main South 4	667.14	5	0	0	12	0.00
East Main South 5	878.51	7	0	0	10	0.00
Total						**408 295.29**

Table 12. Estimated ROM Tons per Mining Panel & for Tumelo as a whole.

According to MacCourt et. al. (1986) as referred to by van der Merwe and Madden (2010) the potential surface subsidence above failed bord and pillar workings can be estimated by multiplying the mining height by the areal percentage extraction as per the formula below:

$$h_e = h \text{ x } e\%$$

Where: e – Areal percentage extraction

The potential subsidence based on this method of estimation, for each one of the potential checkerboard panels under investigation has been calculated as per Table 13 below.

Panel	h (m)	b 1 (m)	b 2 (m)	Center 1	Center 2	e %	he
East Main Portion 1	2.5	6.5	20.5	14.0	28.0	85.7	2.14
East Main Portion 2	3.4	6.9	24.9	14.0	36.0	84.3	2.86
East Main Portion 3	3.7	6.9	24.9	16.0	36.0	82.5	3.05
East Main Portion 4	4	6.8	25.3	18.5	37.0	80.0	3.20
East Main Portion 5	3.8	6.8	24.8	24.0	36.0	77.7	2.95
East Main North 3 Portion 1	3.9	6.8	24.8	19.0	36.0	80.0	3.12
East Main North 3 Portion 2	4.2	6.9	24.9	19.0	36.0	80.4	3.38
East Main North 3 West 3	3.5	6.7	23.7	17.0	34.0	81.6	2.86
East Main North 4	4	6.9	23.4	19.0	33.0	81.5	3.26
East Main North 5	4	6.8	25.3	17.5	37.0	80.7	3.23
East Main North 7	2.72	6.7	23.7	17.0	34.0	81.6	2.22
East Main North 8 Portion 1	3.1	6.7	24.7	24.0	36.0	77.5	2.40
East Main North 8 Portion 2	3.4	6.7	24.7	24.0	36.0	77.4	2.63
East Main North 8 West 2	2.9	6.7	24.2	17.5	35.0	81.0	2.35
East Main North 8 West 3	3.6	6.5	24.5	18.5	36.0	79.3	2.85
East Main South 1	3.4	6.8	22.8	16.5	32.0	83.1	2.83
East Main South 1 East 1	4.1	6.8	24.3	16.0	35.0	82.4	3.38
East Main South 1 East 2	3.65	6.9	22.9	16.0	32.0	83.8	3.06
East Main South 2 Portion 1	4.4	6.9	24.9	17.0	36.0	81.7	3.59
East Main South 2 Portion 2	4.1	7.0	25.0	18.5	36.0	81.0	3.32
East Main South 2 West 3	3.7	6.9	24.9	21.0	36.0	79.3	2.93
East Main South 2 East 1	4.1	6.9	25.4	18.0	37.0	80.7	3.31
East Main South 2 East 2	4.4	6.9	24.9	23.0	36.0	78.4	3.45
East Main South 2 East 3	3.4	6.7	24.7	19.0	36.0	79.7	2.71
East Main South 4	3.3	6.7	23.7	20.0	34.0	79.9	2.64
East Main South 5	3	6.7	24.7	25.0	36.0	77.0	2.31

Table 13. Calculated Values of Potential Surface Subsidence Per Panel Under Investigation

According to van der Merwe and Madden (2010) Figure 10 below can be used to adjust the expected maximum amounts of subsidence based on the depth at which mining is taking place.
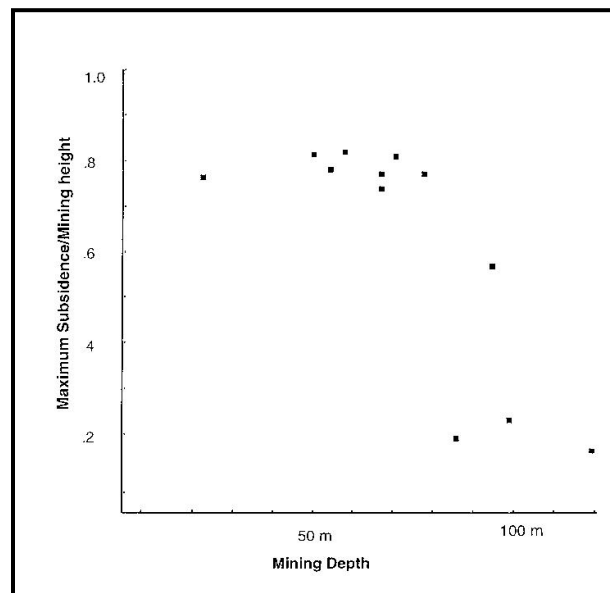
Figure 10. Estimated Factor to be applied to the Maximum Amounts of Expected Subsidence based on Mining Depth.

In the panels under investigation mining is expected to take place at depths ranging from 40 m to 106 m.

Based on the work done by van der Merwe and Madden (2010) the surface subsidence has therefore been assumed to be in the region of 0,8 times the maximum potential surface subsidence calculated in Table 13 above.

The total amounts of potential surface subsidence have then been estimated to be in the region of the values included in Table 14 below.

Panel	Max Sub / Mining Height Factor	he	Est. Max. Total Surface Subsidence	H	Sm / H	Sub. Class
East Main Portion 1	0.8	2.14	1.71	40.0	0.0428	D
East Main Portion 2	0.8	2.86	2.29	67.0	0.0342	D
East Main Portion 3	0.8	3.05	2.44	68.0	0.0359	D
East Main Portion 4	0.8	3.20	2.56	79.0	0.0324	D
East Main Portion 5	0.5	2.95	1.48	91.0	0.0162	C
East Main North 3 Portion 1	0.8	3.12	2.50	70.0	0.0357	D
East Main North 3 Portion 2	0.8	3.38	2.70	78.0	0.0346	D
East Main North 3 West 3	0.8	2.86	2.29	65.0	0.0352	D
East Main North 4	0.8	3.26	2.61	79.0	0.0330	D
East Main North 5	0.8	3.23	2.58	80.0	0.0323	D
East Main North 7	0.5	2.22	1.11	91.0	0.0122	C
East Main North 8 Portion 1	0.5	2.40	1.20	97.0	0.0124	C
East Main North 8 Portion 2	0.5	2.63	1.32	92.0	0.0143	C
East Main North 8 West 2	0.5	2.35	1.17	98.0	0.0120	C
East Main North 8 West 3	0.5	2.85	1.43	94.0	0.0152	C
East Main South 1	0.8	2.83	2.26	63.0	0.0359	D
East Main South 1 East 1	0.8	3.38	2.70	75.5	0.0358	D
East Main South 1 East 2	0.8	3.06	2.45	65.9	0.0371	D
East Main South 2 Portion 1	0.8	3.59	2.88	89.1	0.0323	D
East Main South 2 Portion 2	0.8	3.32	2.66	83.0	0.0320	D
East Main South 2 West 3	0.8	2.93	2.35	80.0	0.0293	D
East Main South 2 East 1	0.5	3.31	1.65	95.0	0.0174	C
East Main South 2 East 2	0.5	3.45	1.73	97.0	0.0178	C
East Main South 2 East 3	0.5	2.71	1.35	92.0	0.0147	C
East Main South 4	0.5	2.64	1.32	100.0	0.0132	C
East Main South 5	0.5	2.31	1.16	106.0	0.0109	C

Table 14. Total amount of the Calculated Potential Subsidence should Pillar Failure Occur.

The estimated total possible amounts of surface subsidence can then be divided by the mining depth (H) to identify which class the subsidence in each panel is likely to fall in.

As can be noted from Table 14 above, all of the proposed extraction panels at Tumelo are expected to fall into either Class C or Class D.

> Class C can be described as: "*Noticeable in flat terrain, smooth, cracks 2 – 10 cm wide, compression ridges 1 to 5 cm high.*"
> Class D can be described as: "*Noticeable in most terrain, visible vertical displacements across cracks, cracks 10 – 50 cm wide, compression ridges 5 to 50 cm high.*"

Class	Sm/H ratio	Description
A	< 0,001	Barely noticeable, smooth, continuous profile, hair-line cracks
B	0,00 – 0,005	Difficult to notice, smooth profile, cracks 1 – 2 cm wide
C	0,005 – 0,02	Noticeable in flat terrain, smooth, cracks 2 – 10 cm wide, compression ridges 1 to 5 cm high
D	0,02 – 0,05	Noticeable in most terrain, visible vertical displacements across cracks, cracks 10 – 50 cm wide, compression ridges 5 to 50 cm high
E	>0,05	Severe profile, almost vertical sides, cracks wider than 50 cm, compression ridges higher than 50 cm high

Table 15. The Various Possible Subsidence Classes as well as the Surface Profile which they can be expected to be Associated with.
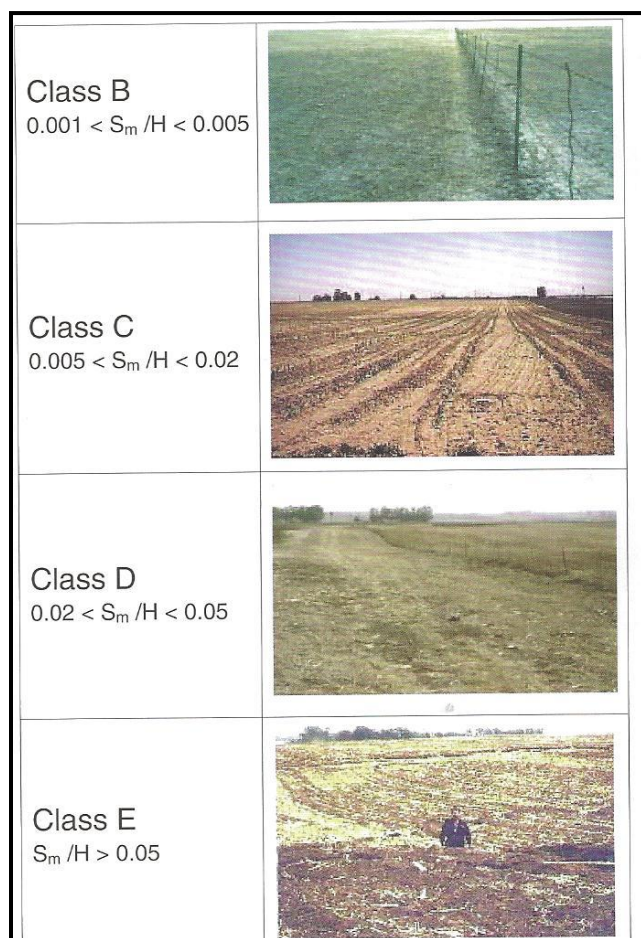
Figure 11. Examples of the Various Possible Subsidence Classes

It is foreseen to be unlikely that such subsidence would occur, especially in the short to medium term due to the bridging effect of the massive sandstone layers in the overburden, however in the long term the massive sandstone beam may fail resulting in the magnitudes of subsidence calculated above.

4. Monitoring

It is suggested that a means of remote monitoring of the convergence on the mining horizon as well as the failure of the overburden at various identified strategic locations i.e. Surface Extensometers be implemented to provide monitoring after the secondary extraction in a panel has been completed as well as to ensure that if overburden failure (which may result in surface subsidence) is propagating towards surface it is detected as soon as practically possible and remedial measures put in place.
Furthermore it is suggested that during the process of secondary mining tell-tales be systematically installed to monitor the movement of the immediate roof in the section and provide underground personnel with a visual means of real-time roof monitoring.
In addition to this convergence monitoring between the mining roof and floor could be conducted by installing monitoring instrumentation in strategic locations before commencing with mining.

5. Risk Assessment

a. Sinkholes

Sinkhole formation has been found by Hill, R. W. (1996), to be possible when mining is conducted at depths of less than 40m.

Canbulat, I. and Ryder, J.A. (2002) proposed a methodology to assess the likelihood of sinkhole formation which takes into account the depth of mining, mining heights, mining dimensions as well as the overburden strata. This methodology was adopted in this investigation and yielded the following results as included in Table 16 below.

Sinkhole Formation						
	h	H	Comp. Layer Thickness	Tensile Stress	Shear Stress	Risk
BP007	OUTSIDE MINING AREA					
BP008	OUTSIDE MINING AREA					
BP016	OUTSIDE MINING AREA					
BP017	LOG NOT AVAILABLE - CLOSE TO G077					
BPA10	OUTSIDE MINING AREA					
BPS001	OUTSIDE MINING AREA					
G008	3.27	52.75	1.20	Roof Failure	Roof Failure	Sinkhole Formation Unlikely
G010	NO COAL IN HOLE					
G011	4.08	75.45	10.75	Roof Failure	Stable Roof	Sinkhole Formation Unlikely
G012 - NO MINING	OUTSIDE MINING AREA					
G013 - NO MINING	OUTSIDE MINING AREA					
G014	4.45	86.00	1.20	Roof Failure	Roof Failure	Sinkhole Formation Unlikely
G019	4.00	78.75	1.20	Roof Failure	Roof Failure	Sinkhole Formation Unlikely
G020	2.87	97.45	1.20	Roof Failure	Roof Failure	Sinkhole Formation Unlikely
G035	3.05	105.48	2.63	Roof Failure	Roof Failure	Sinkhole Formation Unlikely
G036	3.82	90.46	10.62	Roof Failure	Stable Roof	Sinkhole Formation Unlikely
G037	4.08	69.92	10.59	Roof Failure	Stable Roof	Sinkhole Formation Unlikely
G038	3.30	66.95	1.20	Roof Failure	Roof Failure	Sinkhole Formation Unlikely
G040	NO COAL IN HOLE					
G042 - NO MINING	OUTSIDE MINING AREA					
G044 - NO MINING	OUTSIDE MINING AREA					
G046 - NO MINING	OUTSIDE MINING AREA					
G047	3.53	95.98	1.20	Roof Failure	Roof Failure	Sinkhole Formation Unlikely
G049 - NO MINING	OUTSIDE MINING AREA					
G050	5.21	93.49	10.95	Roof Failure	Stable Roof	Sinkhole Formation Unlikely
G051	3.21	91.51	10.51	Roof Failure	Stable Roof	Sinkhole Formation Unlikely
G052	4.36	79.78	9.24	Roof Failure	Stable Roof	Sinkhole Formation Unlikely
G059	3.07	100.29	1.20	Roof Failure	Roof Failure	Sinkhole Formation Unlikely
G068	2.17	39.27	1.20	Roof Failure	Roof Failure	Sinkhole Formation Unlikely
G069 - NO MINING	OUTSIDE MINING AREA					
G070 - NO MINING	OUTSIDE MINING AREA					
G073	2.25	37.91	1.20	Roof Failure	Roof Failure	Sinkhole Formation Unlikely
G074	2.11	35.98	1.20	Roof Failure	Roof Failure	Sinkhole Formation Unlikely
G075	0.59	91.55	2.99	Roof Failure	Roof Failure	Sinkhole Formation Unlikely
G076	3.35	99.25	8.96	Roof Failure	Roof Failure	Sinkhole Formation Unlikely
G077	2.92	95.98	3.18	Roof Failure	Roof Failure	Sinkhole Formation Unlikely
G078	2.47	86.81	8.62	Roof Failure	Stable Roof	Sinkhole Formation Unlikely
G081 - NO MINING	OUTSIDE MINING AREA					
G083	3.61	67.05	9.93	Roof Failure	Stable Roof	Sinkhole Formation Unlikely
G084 - NO MINING	OUTSIDE MINING AREA					
G086	1.58	29.52	9.34	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
G087	1.76	29.51	9.12	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
G088	1.75	30.17	8.91	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
G089	2.17	36.29	9.68	Stable Roof	Stable Roof	Sinkhole Formation Unlikely

G090	1.90	30.49	9.16	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
G092	0.70	21.63	9.82	Stable Roof	Stable Roof	Sinkhole Formation Unlikely
G093	LOG NOT AVAILABLE - CLOSE TO G038					

Table 16. Likelihood of Sinkhole Formation at Each Borehole Position based on the Methodology suggested by Canbulat, I. and Ryder, J.A. (2002).

Based on the methodology proposed by Canbulat, I. and Ryder, J.A. (2002) sinkhole formation is unlikely in all of the proposed checkerboard extraction panels due to the above mentioned factors.

Canbulat, I. and Madden, B.J. (2005) suggested a slightly different method for assessing whether or not sinkhole formation is likely to occur. In this method the material properties (tensile strength) of the competent layers is compared on consecutive charts to the depth and thickness of the most competent layer in the overburden as well as the depth of mining and the percentage of the overburden which is made up of competent strata (sandstone).

Following this methodology, as is illustrated on the charts included in Figures 12 and 13 below, which were plotted based on the information included in Table 17 below, it is unlikely that, even with much weaker than expected strata in the overburden, sinkhole formation will occur in the vicinities of any one of the boreholes in the proposed mining area, even if roof failure on the mining horizon was to occur.
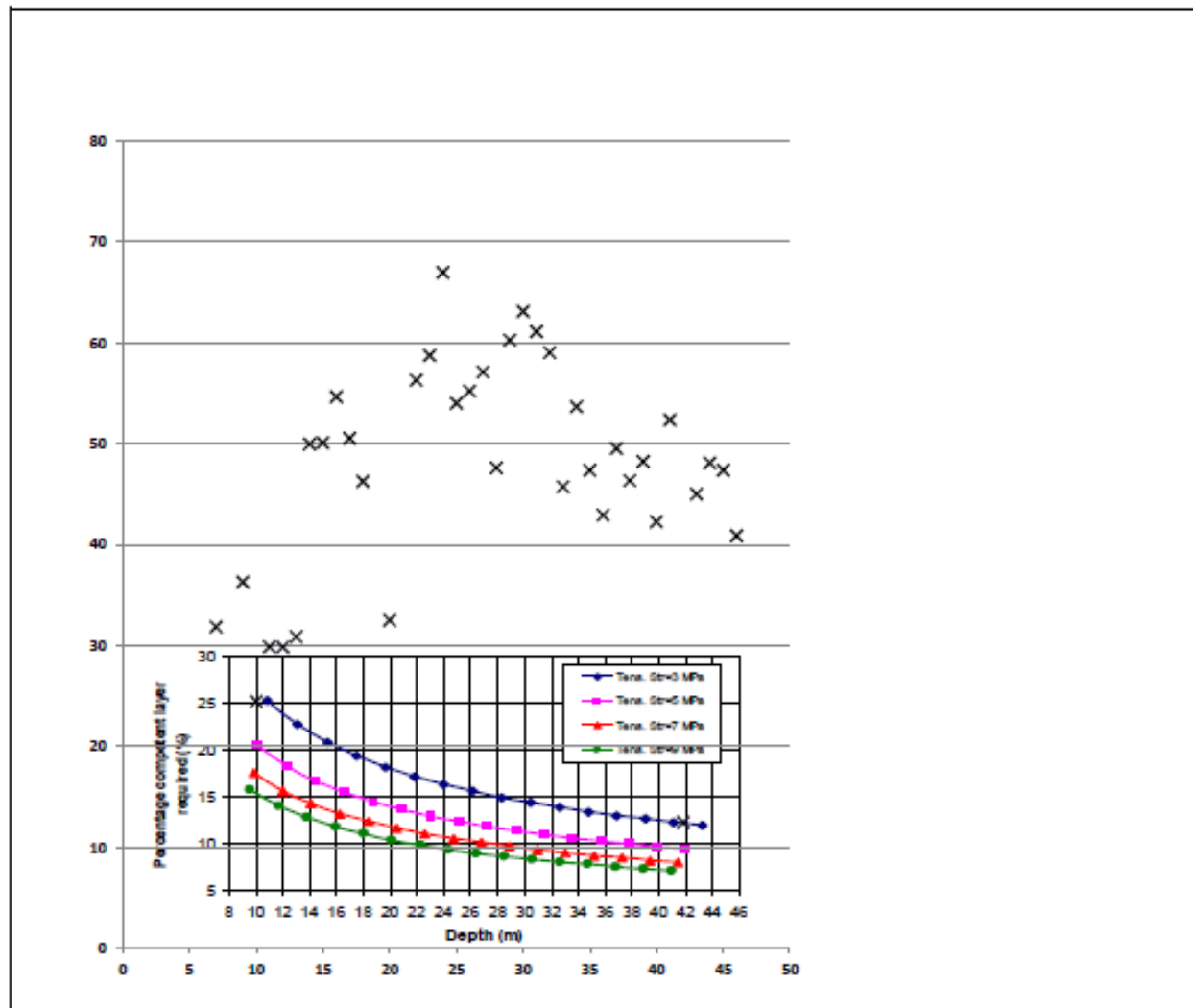
Figure 12. Ratio between the Required Percentage of Competent Layers in the Overburden to the Depth at which Mining is taking Place to Prevent Sinkhole Formation for Material with Varying Tensile Strength Properties, in all of the relevant boreholes in the Tumelo Mining Area.
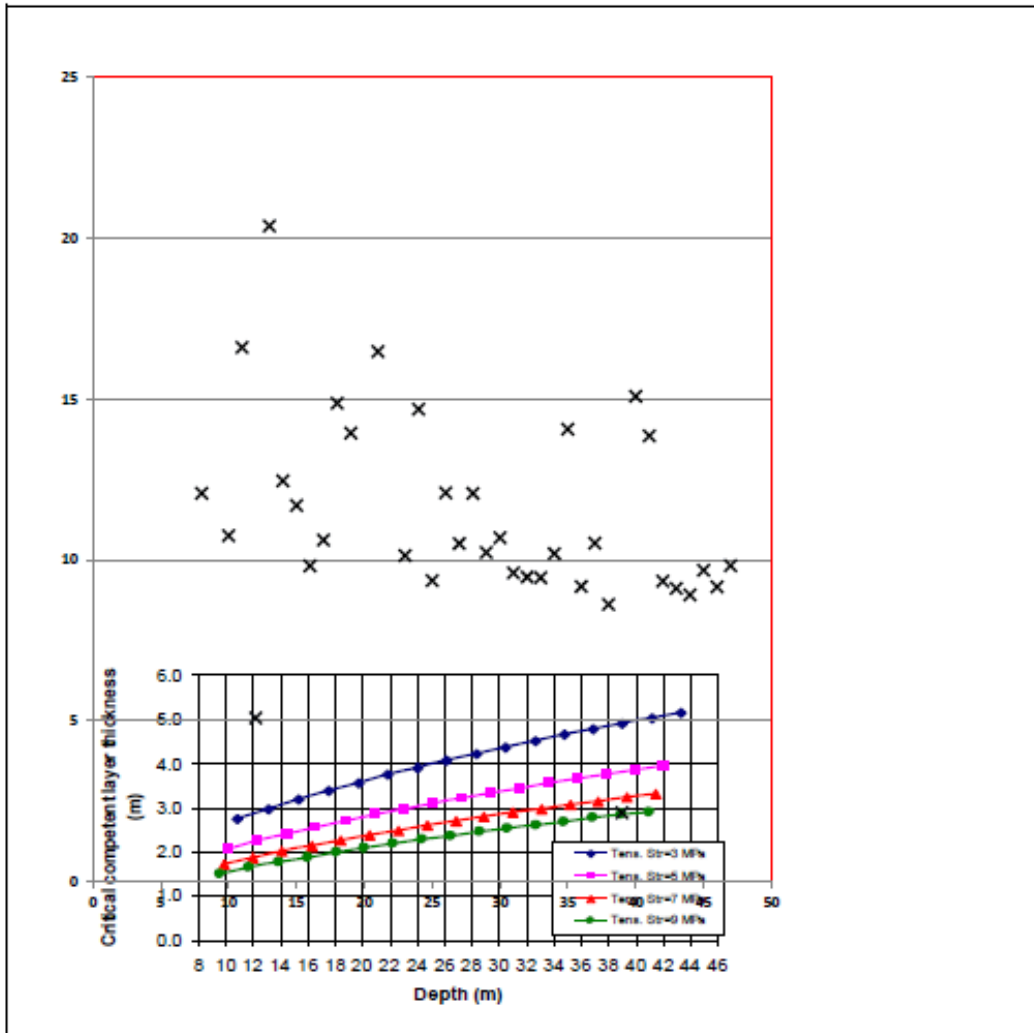
Figure 13. Ratio between the Required Thickness of a Competent Layer in the Overburden to the Depth at which Mining is taking Place to Prevent Sinkhole Formation for Material with Varying Tensile Strength Properties, in all of the relevant boreholes in the Tumelo Mining Area.

Borehole I.D.	Competent Layer Thickness (m)	Depth to Base of Unit (m)	Depth to Floor (H) (m)	% SSN
BP007	OUTSIDE MINING AREA			
BP008	OUTSIDE MINING AREA			
BP016	OUTSIDE MINING AREA			
BP017	LOG NOT AVAILABLE - CLOSE TO G077			
BPA010	OUTSIDE MINING AREA			
BPS001	OUTSIDE MINING AREA			
G008	12.07	20.83	52.75	31.83
G010	NO COAL - SILTSTONE			
G011	10.75	71.37	75.45	36.28
G012	16.6	48	89.89	24.44
G013	5.09	66.44	88.38	29.85
G014	20.37	52.87	86	29.83
G019	12.46	45	78.75	30.85
G020	11.69	36.13	97.45	49.96
G035	9.82	66.6	105.48	50.09
G036	10.62	86.64	90.46	54.65
G037	14.87	36.28	69.92	50.53
G038	13.94	34.72	66.95	46.25
G040	NO 2 SEAM - HOLE STOPPED			
G042	16.47	41.52	80.63	32.49
G044	OUTSIDE MINING AREA			
G046	10.14	34.37	36.82	56.3
G047	14.68	52.51	95.98	58.75
G049	9.36	43.24	46.16	66.98
G050	12.08	58.69	93.49	54.02
G051	10.51	88.3	91.51	55.21
G052	12.07	43.88	79.78	57.11
G059	10.23	78.38	100.29	47.61
G068	10.69	11.69	39.27	60.27
G069	9.6	42.46	45.12	63.12
G070	9.47	43.22	46.02	61.13
G073	9.45	35.66	37.91	59.03
G074	10.2	33.87	36.36	45.73
G075	14.06	65.69	92.05	53.66
G076	9.18	27.89	99.25	47.36
G077	10.52	65.61	95.98	42.91
G078	8.62	84.34	86.81	49.54
G081	2.15	15.16	42.82	46.34

G083	15.08	35.42	67.05	48.23
G084	13.85	37.64	72.24	42.25
G086	9.34	27.94	29.52	52.36
G087	9.12	27.75	29.51	12.43
G088	8.91	28.42	30.17	45
G089	9.68	34.12	36.29	48.09
G090	9.16	28.59	30.21	47.36
G092	9.82	31.47	33.48	40.86
G093	LOG NOT AVAILABLE - CLOSE TO G038			

Table 17. Information regarding Competent Layer Thickness and Percentage per Borehole within the Greater Checkerboard Extraction Area.

Pillar Collapse.
Failure of the pillars left behind after the extraction of pillars by checkerboard methods could occur.
The pillar width to mining height ratio suggests that the pillar failure could be violent.

It is suggested that potential scenarios such as leaving one in every Five (5) rows of pillars intact, in areas where a natural barrier does not exist as a result of a geological intrusion or similar feature, be considered.

Roof Collapse.
Slabbing of the immediate roof could occur after the extraction of a pillar when the span is increased from approximately 7,0 m to in excess of 20 m.

As a result of this identified risk it is suggested that roofbolt beakerlines be installed to prevent failure of the immediate roof from over-running the intersections and occurring in roadways and splits.
Timber "policemen" could also be erected as an indication of roof convergence.

A "Tooth" Extractor should be available at all times within the section for use should a roof collapse burying the continuous miner.

6. <u>Recommended Minimum Procedure to Confirm Suitability of Checkerboard Extraction at Tumelo</u>

A further rock engineering assessment of all potential checkerboard areas should be undertaken and should include but not necessarily be limited to the following:

- A detailed Risk Assessment should be conducted by all relevant and responsible persons to identify all potential risks and document the required remedial and preventative measures,
- Additional vertical geological drilling at regular intervals to confirm expected overburden geology,
- Installation of remote (surface) monitoring instrumentation to allow for monitoring post extraction of the identified areas and provide input into future extraction planning and an early warning of potential subsidence,
- An underground mapping campaign of all the areas to identify the following:
  - The location of enlarged intersections,
  - Odd sized pillars, particularly smaller pillars than designed,
  - Geotechnical mapping of the panels / areas; the panel to be extracted must be mapped and the 'weak' side of all discontinuities noted,
  - Location of rolls in the seam,
  - Assessment of the condition of the initial support installed,
  - Location and extent of falls of ground,
- A sequence of extraction should be drawn up including the following:
  - A plan of the panel with each pillar numbered (pillars should be numbered with the same numbers underground as well),
  - The cutting sequence for each pillar should be determined which should take into account the Geotechnical Mapping, enlarged intersections, pillar sizes, dis-continuities etc.
  - Careful attention should be paid to dis-continuities and their so called "weak" sides and potential wedge formation as such structures may well require additional support,
  - An attempt to extract the pillar beneath the "weak" side of a discontinuity could result in a Fall of Ground on the Continuous Miner and potentially burial of the Continuous Miner as the size and strength of the pillar supporting the roof would be reduced,
  - Pillars should be extracted against the ventilation to prevent personnel being exposed to dust,
  - Position of roofbolt breakerlines: A double row of roofbolts will be required to be installed prior to extraction. The breakerlines should be installed at least two rows ahead of the pillar being extracted. The first row should be installed 0.5 m in-bye of the solid pillar and the second row 1,0 m further in-bye.
- All personnel who will be working in the Checkerboard extraction section should have undergone specific Rockfall hazard identification training,
- It is suggested that a "Tooth Extractor" be available on site for the duration of the period during which secondary extraction is to be conducted.

7. Conclusions and Suggestions

The following conclusions and suggestions are made, based on the investigation which has been conducted into the feasibility of Checkerboard extraction at Tumelo, including all of the available information as well as the results of the theoretical calculations and the numerical modelling:

- Checkerboard extraction in the following panels is deemed to be conceptually viable:
  - East Main – Portion 1
  - East Main – Portion 3
  - East Main – Portion 4
  - East Main – Portion 5
  - East Main – Portion 6
  - East Main North 3 – Portion 1
  - East Main North 3 – Portion 2
  - East Main North 3 West 3
  - East Main North 4
  - East Main North 5
  - East Main North 7
  - East Main North 8 – Portion 1
  - East Main North 8 – Portion 2
  - East Main North 8 West 2
  - East Main North 8 West 3
  - East Main North 8 East 1
  - East Main North 8 East 2
- In the East Main North 8 East 1 & 2 panels however the scenario created during / post extraction would be an extremely dangerous one and it is suggested that if secondary extraction is conducted in these Two (2) panels it is conducted with extreme caution,
- Further investigations should be conducted prior to the execution of secondary extraction in the above panels which should include but not be limited to the following:
  - A detailed Risk Assessment,
  - Additional vertical geological drilling at regular intervals to confirm expected overburden geology,
  - Installation of remote (surface) monitoring instrumentation,
  - An underground mapping campaign of all the areas to identify the following:
  - A sequence of extraction should be drawn up,
  - All personnel who will be working in the Checkerboard extraction section should have undergone specific Rockfall hazard identification training,
  - It is suggested that a "Tooth Extractor" be available on site for the duration of the period during which secondary extraction is to be conducted.
- Sinkhole formation is deemed possible but unlikely,
- In some of the identified panels pillars left behind after extraction could fail as mining progresses and in others pillars could fail with time,
- Localised roof collapses could occur over the large spans created during pillar extraction therefore roofbolt breakerlines, timber "Policeman" and a "Tooth Extractor" are suggested,

- No person should go beyond the last line of solid pillars at any time and the area in-bye of the last line of solid pillars should be treated as a Goaf area,
- Further investigations into the potential of mining additional pillars against the barrier pillar in specific panels and / or leaving intact rows of pillars to form barriers in panels in which pillar failure was noted could be conducted.

Should you have any queries please do not hesitate to contact myself on: Tel (011) 726-5436, Fax (011) 482-5261, Cell No. (082) 854-9321 or E-mail madden@g-ro.co.za

Yours Sincerely

Dr. Bernard Madden

REFERENCES

Canbulat, I. and Madden, B.J. (2005). *Shallow Depth Mining Considerations*. SAIMM, 3rd Southern African Rock Engineering Symposium.

Canbulat, I. and Ryder, J.A. (2002), *Prediction of Surface Subsidence and Sinkholes*, SANIRE Symposium – Re-defining the boundaries. Vereeniging, 6 September 2002.

Hill, R. W. (1996). *Safety and environmental risks associated with shallow bord and pillar workings*. Chamber Of Mines Research Organization, Final Project report CE 9401.

Madden, B.J. (2012). *FZN Checkerboard Rock Eng. Report, Oct-12*. G-Ro Geotechnical Services Consultancy (Pty) Ltd Report for Total Coal South Africa (Pty) Ltd.

Van der Merwe, J.N. (2003). *New pillar strength formula for south african coal*. Journal of the Southern African Institute of Mining and Metallurgy Vol. 103, pp. 281–292.

Van der Merwe, J.N. (2011). *Technical Note on Element Sizes in LaModel*. Consultancy Report for Total Coal South Africa (PTY) LTD.

Van der Merwe, J. N. and Madden, B. J. (2010). *Rock Engineering for Underground Coal Mining, Second Edition*. SAIMM Special Publications Series 8.

Wagner, H., and Madden, B. J. (1984). *15 Years Experience with the Design of Coal Pillars in Shallow South African Colliers: An evaluation of the Performance of the Design Procedures and Recent Improvements*. Design and Performance of Underground Excavations. ISRM/BGS, Cambridge, UK, pp 391 – 399.

APPENDIX 1

Panel	Center 1 (m)	Center 2 (m)	Avg. Bord Width (m)	Weft (m)	Avg. Mining Height (m)	Salamon Strength (Mpa)	H (m)	Load (Mpa)	SF	SF (CM)
East Main Portion 1	14.0	14.0	6.5	7.5	2.5	9.9	40.0	3.5	2.8	3.4
East Main Portion 2	14.0	18.0	6.9	8.7	3.4	8.7	67.0	5.3	1.6	1.9
East Main Portion 3	16.0	18.0	6.9	10.0	3.7	8.7	68.0	4.8	1.8	2.1
East Main Portion 4	18.5	18.5	6.8	11.7	4.0	8.9	79.0	4.9	1.8	2.0
East Main Portion 5	24.0	18.0	6.8	13.6	3.8	9.9	91.0	5.1	1.9	2.2
East Main Portion 6	24.0	18.0	6.8	13.6	3.4	10.6	100.0	5.6	1.9	2.1
East Main North 3 Portion 1	19.0	18.0	6.8	11.7	3.9	9.1	70.0	4.4	2.1	2.3
East Main North 3 Portion 2	19.0	18.0	6.9	11.6	4.2	8.6	78.0	5.0	1.7	2.0
East Main North 3 West 3	17.0	17.0	6.7	10.3	3.5	9.2	65.0	4.4	2.1	2.4
East Main North 4	19.0	16.5	6.9	10.7	4.0	8.6	79.0	5.3	1.6	1.8
East Main North 5	17.5	18.5	6.8	11.2	4	8.7	80	5.2	1.7	1.9
East Main North 7	17	17	6.7	10.3	2.72	10.8	91	6.2	1.7	2.0
East Main North 8 Portion 1	24	18	6.73	13.6	3.1	11.3	97	5.4	2.1	2.3
East Main North 8 Portion 2	24	18	6.7	13.7	3.4	10.7	92	5.1	2.1	2.3
East Main North 8 West 2	17.5	17.5	6.7	10.8	2.9	10.6	98	6.4	1.7	1.9
East Main North 8 West 3	18.5	18	6.5	11.7	3.6	9.6	94	5.7	1.7	1.9
East Main North 8 East 1 & 2	24	15	6.8	11.1	3.3	9.9	97	6.2	1.6	1.8
East Main South 1	16.5	16	6.8	9.4	3.4	9.0	63	4.7	1.9	2.2
East Main South 1 East 1	16	17.5	6.8	9.9	4.1	8.1	75.5	5.4	1.5	1.7
East Main South 1 East 2	16	16	6.9	9.1	3.65	8.4	65.9	5.1	1.7	1.9
East Main South 2 Portion 1	17	18	6.9	10.6	4.4	8.0	89.1	6.1	1.3	1.5
East Main South 2 Portion 2	18.5	18	7	11.2	4.1	8.6	83	5.5	1.6	1.8
East Main South 2 West 3	21	18	6.9	12.4	3.7	9.6	80	4.8	2.0	2.2
East Main South 2 East 1	18	18.5	6.9	11.3	4.1	8.6	95	6.1	1.4	1.6
East Main South 2 East 2	23	18	6.9	13.1	4.4	8.8	97	5.6	1.6	1.8
East Main South 2 East 3	19	18	6.7	11.8	3.4	9.9	92	5.7	1.8	2.0
East Main South 4	20	17	6.7	11.6	3.3	10.1	100	6.2	1.6	1.8
East Main South 5	25	18	6.7	14.0	3	11.7	106	5.8	2.0	2.2

Table 18. Various Panel's Mining Dimensions and Salamon Safety Factor Calculations

Panel	Width/Height (Min)	Areal % Extraction	Strength (vdM) (Mpa)	SF(vdM)	SF(vdM) CM	Load After Extraction	SF After Extraction	SF (CM) After Extraction
East Main Portion 1	3.0	71.3	10.5	3.0	3.6	6.97	1.4	1.7
East Main Portion 2	2.1	68.5	7.3	1.4	1.6	10.64	0.8	1.0
East Main Portion 3	2.5	64.9	8.6	1.8	2.0	9.69	0.9	1.0
East Main Portion 4	2.9	60.0	10.2	2.1	2.3	9.88	0.9	1.0
East Main Portion 5	2.9	55.4	10.3	2.0	2.2	10.20	1.0	1.1
East Main Portion 6	3.3	55.4	11.5	2.1	2.3	11.21	0.9	1.1
East Main North 3 Portion 1	2.9	60.0	10.1	2.3	2.6	8.76	1.0	1.2
East Main North 3 Portion 2	2.6	60.7	9.3	1.9	2.1	9.93	0.9	1.0
East Main North 3 West 3	2.9	63.3	10.3	2.3	2.7	8.85	1.0	1.2
East Main North 4	2.4	62.9	8.4	1.6	1.8	10.66	0.8	0.9
East Main North 5	2.7	61.3	9.4	1.8	2.1	10.34	0.8	1.0
East Main North 7	3.8	63.3	13.3	2.1	2.5	12.39	0.9	1.0
East Main North 8 Portion 1	3.6	54.9	12.7	2.4	2.6	10.76	1.1	1.2
East Main North 8 Portion 2	3.3	54.7	11.6	2.3	2.5	10.17	1.0	1.2
East Main North 8 West 2	3.7	61.9	13.0	2.0	2.3	12.87	0.8	0.9
East Main North 8 West 3	3.2	58.6	11.2	2.0	2.2	11.34	0.8	1.0
East Main North 8 East 1 & 2	2.5	60.8	8.7	1.4	1.6	12.38	0.8	0.9
East Main South 1	2.7	66.2	9.5	2.0	2.4	9.32	1.0	1.1
East Main South 1 East 1	2.2	64.8	7.9	1.5	1.7	10.74	0.8	0.9
East Main South 1 East 2	2.5	67.7	8.7	1.7	2.0	10.19	0.8	1.0
East Main South 2 Portion 1	2.3	63.4	8.0	1.3	1.5	12.16	0.7	0.8
East Main South 2 Portion 2	2.7	62.0	9.4	1.7	2.0	10.92	0.8	0.9
East Main South 2 West 3	3.0	58.6	10.5	2.2	2.4	9.66	1.0	1.1
East Main South 2 East 1	2.7	61.3	9.5	1.5	1.8	12.28	0.7	0.8
East Main South 2 East 2	2.5	56.8	8.8	1.6	1.8	11.24	0.8	0.9
East Main South 2 East 3	3.3	59.4	11.6	2.1	2.3	11.32	0.9	1.0
East Main South 4	3.1	59.7	10.9	1.8	2.0	12.41	0.8	0.9
East Main South 5	3.8	54.0	13.2	2.3	2.5	11.53	1.0	1.1

Table 19. Various Panel's Mining Dimensions, Pillar w/h ratios, % Extraction and Safety Factor Calculations (vdM & Post Extraction)

MODEL 1 - BLOCK A

Original

		Material B	Material C	
	Mining Height	2.5	2.5	
Pillar Centers	Advance	28	14	
	Split	14	14	
	Bord Width	6.5	6.5	
	Weft	11.12068966	7.5	
	Peak Stress	15.56896552	10.5	MPa
	Peak Strain	0.003892241	0.002625	
	Epf	3.956827586	1.922	GPa
		3956.827586	1922	MPa
	Residual Stress	0.1	0.1	MPa
	Poisson's Ratio	0.25	0.25	
	Residual Strain	0.007801678	0.00803603	

19%

		Material B	Material C	
	Mining Height	2.5	2.5	
Pillar Centers	Advance	28	14	
	Split	14	14	
	Bord Width	6.5	6.5	
	Weft	11.12068966	7.5	
	Peak Stress	15.56896552	10.5	MPa
	Peak Stress +19%	18.52706897	12.495	MPa
	Peak Strain	0.004631767	0.00312375	
	Epf	3.956827586	1.922	GPa
		3956.827586	1922	MPa
	Residual Stress	0.1	0.1	MPa
	Poisson's Ratio	0.25	0.25	
	Residual Strain	0.009288798	0.009572761	

MODEL 2 - BLOCK B

Original

Pillar Centers

		Material B	Material C	
	Mining Height	3.4	3.4	
	Advance	28	14	
	Split	18	18	
	Bord Width	6.87	6.87	
	Weft	14.58009299	8.691883899	
	Peak Stress	15.00891926	8.947527543	MPa
	Peak Strain	0.00375223	0.002236882	
	Epf	5.901012263	2.591838751	GPa
		5901.012263	2591.838751	MPa
	Residual Stress	0.1	0.1	MPa
	Poisson's Ratio	0.25	0.25	
	Residual Strain	0.006278732	0.005650492	

19%

Pillar Centers

		Material B	Material C	
	Mining Height	3.4	3.4	
	Advance	28	14	
	Split	18	18	
	Bord Width	6.87	6.87	
	Weft	14.58009299	8.691883899	
	Peak Stress	15.00891926	8.947527543	MPa
	Peak Stress +19%	17.86061392	10.64755778	MPa
	Peak Strain	0.004465153	0.002661889	
	Epf	5.901012263	2.591838751	GPa
		5901.012263	2591.838751	MPa
	Residual Stress	0.1	0.1	MPa
	Poisson's Ratio	0.25	0.25	
	Residual Strain	0.007474911	0.006731416	

MODEL 3 - BLOCK C

Original

Pillar Centers

		Material B	Material C	
	Mining Height	3.7	3.7	
	Advance	36	18	
	Split	16	16	
	Bord Width	6.87	6.87	
	Weft	13.90260847	10.03128332	
	Peak Stress	13.15111612	9.489051786	MPa
	Peak Strain	0.003287779	0.002372263	
	Epf	5.520265959	3.344581224	GPa
		5520.265959	3344.581224	MPa
	Residual Stress	0.1	0.1	MPa
	Poisson's Ratio	0.25	0.25	
	Residual Strain	0.005651998	0.005179506	

19%

Pillar Centers

		Material B	Material C	
	Mining Height	3.7	3.7	
	Advance	36	18	
	Split	16	16	
	Bord Width	6.87	6.87	
	Weft	13.90260847	10.03128332	
	Peak Stress	13.15111612	9.489051786	MPa
	Peak Stress +19%	15.64982818	11.29197163	MPa
	Peak Strain	0.003912457	0.002822993	
	Epf	5.520265959	3.344581224	GPa
		5520.265959	3344.581224	MPa
	Residual Stress	0.1	0.1	MPa
	Poisson's Ratio	0.25	0.25	
	Residual Strain	0.006729319	0.006169293	

MODEL 4 - BLOCK D

		Material B	Material C	
Original				
	Mining Height	3.6	3.6	
Pillar Centers	Advance	16	16	
	Split	17	16	
	Bord Width	6.8	6.8	
	Weft	9.674226804	9.2	
	Peak Stress	9.405498282	8.944444444	MPa
	Peak Strain	0.002351375	0.002236111	
	Epf	3.143915464	2.8774	GPa
		3143.915464	2877.4	MPa
	Residual Stress	0.1	0.1	MPa
	Poisson's Ratio	0.25	0.25	
	Residual Strain	0.005311218	0.005309874	
		Material B	Material C	
19%				
	Mining Height	3.6	3.6	
Pillar Centers	Advance	16	16	
	Split	17	16	
	Bord Width	6.8	6.8	
	Weft	9.674226804	9.2	
	Peak Stress	9.405498282	8.944444444	MPa
	Peak Stress +19%	11.19254296	10.64388889	MPa
	Peak Strain	0.002798136	0.002660972	
	Epf	3.143915464	2.8774	GPa
		3143.915464	2877.4	MPa
	Residual Stress	0.1	0.1	MPa
	Poisson's Ratio	0.25	0.25	
	Residual Strain	0.006326393	0.006325353	

MODEL 5 - BLOCK E

Original

		Material B	Material C		Material D	
Pillar Centers	Mining Height	3.9	3.9		3.9	
	Advance	38	38		19	
	Split	36	18		18	
	Bord Width	6.8	6.8		6.8	
	Weft	30.16688742	16.48301887		11.67863248	
	Peak Stress	27.07284768	14.79245283	MPa	10.48082402	MPa
	Peak Strain	0.006768212	0.003698113		0.002620206	
	Epf	14.66079073	6.970456604	GPa	4.270391453	GPa
		14660.79073	6970.456604	MPa	4270.391453	MPa
	Residual Stress	0.1	0.1	MPa	0.1	MPa
	Poisson's Ratio	0.25	0.25		0.25	
	Residual Strain	0.008608007	0.005805931		0.005051089	

19%

		Material B	Material C		Material D	
Pillar Centers	Mining Height	3.9	3.9		3.9	
	Advance	38	38		19	
	Split	36	18		18	
	Bord Width	6.8	6.8		6.8	
	Weft	30.16688742	16.48301887		11.67863248	
	Peak Stress	27.07284768	14.79245283	MPa	10.48082402	MPa
	Peak Stress +19%	32.21668874	17.60301887	MPa	12.47218058	MPa
	Peak Strain	0.008054172	0.004400755		0.003118045	
	Epf	14.66079073	6.970456604	GPa	4.270391453	GPa
		14660.79073	6970.456604	MPa	4270.391453	MPa
	Residual Stress	0.1	0.1	MPa	0.1	MPa
	Poisson's Ratio	0.25	0.25		0.25	
	Residual Strain	0.010244824	0.006911784		0.006015246	

MODEL 6 - BLOCK F

Original

		Material B	Material C	
Pillar Centers	Mining Height	3.8	3.8	
	Advance	38	19	
	Split	18	18	
	Bord Width	6.7	6.7	
	Weft	16.60516432	11.77881356	
	Peak Stress	15.29423029	10.84890723	MPa
	Peak Strain	0.003823558	0.002712227	
	Epf	7.039102347	4.32669322	GPa
		7039.102347	4326.69322	MPa
	Residual Stress	0.1	0.1	MPa
	Poisson's Ratio	0.25	0.25	
	Residual Strain	0.005982104	0.005196551	

19%

		Material B	Material C	
Pillar Centers	Mining Height	3.8	3.8	
	Advance	38	19	
	Split	18	18	
	Bord Width	6.7	6.7	
	Weft	16.60516432	11.77881356	
	Peak Stress	15.29423029	10.84890723	MPa
	Peak Stress +19%	18.20013405	12.9101996	MPa
	Peak Strain	0.004550034	0.00322755	
	Epf	7.039102347	4.32669322	GPa
		7039.102347	4326.69322	MPa
	Residual Stress	0.1	0.1	MPa
	Poisson's Ratio	0.25	0.25	
	Residual Strain	0.007121403	0.006188287	

MODEL 7 - BLOCK G

Original

		Material B	Material C	
Pillar Centers	Mining Height	3.5	3.5	
	Advance	17	34	
	Split	17	17	
	Bord Width	6.7	6.7	
	Weft	10.3	14.95691489	
	Peak Stress	10.3	14.95691489	MPa
	Peak Strain	0.002575	0.003739229	
	Epf	3.4956	6.11278617	GPa
		3495.6	6112.78617	MPa
	Residual Stress	0.1	0.1	MPa
	Poisson's Ratio	0.25	0.25	
	Residual Strain	0.005492954	0.006169694	

19%

		Material B	Material C	
Pillar Centers	Mining Height	3.5	3.5	
	Advance	17	34	
	Split	17	17	
	Bord Width	6.7	6.7	
	Weft	10.3	14.95691489	
	Peak Stress	10.3	14.95691489	MPa
	Peak Stress +19%	12.257	17.79872872	MPa
	Peak Strain	0.00306425	0.004449682	
	Epf	3.4956	6.11278617	GPa
		3495.6	6112.78617	MPa
	Residual Stress	0.1	0.1	MPa
	Poisson's Ratio	0.25	0.25	
	Residual Strain	0.006542051	0.007345044	

MODEL 8 - BLOCK H

Original

Pillar Centers

	Material B	Material C	
Mining Height	4	4	
Advance	38	19	
Split	16.5	16.5	
Bord Width	6.9	6.9	
Weft	14.67125307	10.70599078	
Peak Stress	12.83734644	9.367741935	MPa
Peak Strain	0.003209337	0.002341935	
Epf	5.952244226	3.72376682	GPa
	5952.244226	3723.76682	MPa
Residual Stress	0.1	0.1	MPa
Poisson's Ratio	0.25	0.25	
Residual Strain	0.00534926	0.004830744	

	Material D	
Mining Height	4	
Advance	17.5	
Split	18.5	
Bord Width	6.8	
Weft	11.17767857	
Peak Stress	9.78046875	MPa
Peak Strain	0.002445117	
Epf	3.988855357	GPa
	3988.855357	MPa
Residual Stress	0.1	MPa
Poisson's Ratio	0.25	
Residual Strain	0.004871996	

19%

Pillar Centers

	Material B	Material C	
Mining Height	4	4	
Advance	38	19	
Split	16.5	16.5	
Bord Width	6.9	6.9	
Weft	14.67125307	10.70599078	
Peak Stress	12.83734644	9.367741935	MPa
Peak Stress +19%	15.27644226	11.1476129	MPa
Peak Strain	0.003819111	0.002786903	
Epf	5.952244226	3.72376682	GPa
	5952.244226	3723.76682	MPa
Residual Stress	0.1	0.1	MPa
Poisson's Ratio	0.25	0.25	
Residual Strain	0.006368811	0.005753688	

	Material C	
Mining Height	4	
Advance	17.5	
Split	18.5	
Bord Width	6.8	
Weft	11.17767857	
Peak Stress	9.78046875	MPa
Peak Stress +19%	11.63875781	MPa
Peak Strain	0.002909689	
Epf	3.988855357	GPa
	3988.855357	MPa
Residual Stress	0.1	MPa
Poisson's Ratio	0.25	
Residual Strain	0.005802439	

MODEL 9 - BLOCK I

Original — Pillar Centers

	Material B	Material C		Material D		Material E	
Mining Height	3.8	3.8		3.6		3.4	
Advance	23.5	47		23.5		17.5	
Split	18	18		17.5		17.5	
Bord Width	6.8	6.8		6.8		6.8	
Weft	13.4078853	17.51906615		13.04306569		10.7	
Peak Stress	12.34936804	16.13598198	MPa	12.68075831	MPa	11.01470588	MPa
Peak Strain	0.003087342	0.004033995		0.00317019		0.002753676	
Epf	5.242231541	7.552715175	GPa	5.03720292	GPa	3.7204	GPa
	5242.231541	7552.715175	MPa	5037.20292	MPa	3720.4	MPa
Residual Stress	0.1	0.1	MPa	0.1	MPa	0.1	MPa
Poisson's Ratio	0.25	0.25		0.25		0.25	
Residual Strain	0.005424013	0.006157203		0.005667758		0.005687422	

19% — Pillar Centers

	Material B	Material C		Material D		Material D	
Mining Height	3.8	3.8		3.6		3.4	
Advance	23.5	47		23.5		17.5	
Split	18	18		17.5		17.5	
Bord Width	6.8	6.8		6.8		6.8	
Weft	13.4078853	17.51906615		13.04306569		10.7	
Peak Stress	12.34936804	16.13598198	MPa	12.68075831	MPa	11.01470588	MPa
Peak Stress +19%	14.69574797	19.20181855	MPa	15.09010239	MPa	13.1075	MPa
Peak Strain	0.003673937	0.004800455		0.003772526		0.003276875	
Epf	5.242231541	7.552715175	GPa	5.03720292	GPa	3.7204	GPa
	5242.231541	7552.715175	MPa	5037.20292	MPa	3720.4	MPa
Residual Stress	0.1	0.1	MPa	0.1	MPa	0.1	MPa
Poisson's Ratio	0.25	0.25		0.25		0.25	
Residual Strain	0.006458199	0.007329587		0.006748404		0.006773139	

MODEL 10 - BLOCK J

Original

		Material B	Material C		Material D	
Pillar Centers	Mining Height	3.9	3.9		3.7	
	Advance	36	18		20	
	Split	18	18		18	
	Bord Width	6.8	6.8		6.8	
	Weft	16.19009901	11.2		12.11803279	
	Peak Stress	14.52957603	10.05128205	MPa	11.46300399	MPa
	Peak Strain	0.003632394	0.002512821		0.002865751	
	Epf	6.805835644	4.0014	GPa	4.517334426	GPa
		6805.835644	4001.4	MPa	4517.334426	MPa
	Residual Stress	0.1	0.1	MPa	0.1	MPa
	Poisson's Ratio	0.25	0.25		0.25	
	Residual Strain	0.005752571	0.004999771		0.005381173	

19%

		Material B	Material C		Material D	
Pillar Centers	Mining Height	3.9	3.9		3.7	
	Advance	36	18		20	
	Split	18	18		18	
	Bord Width	6.8	6.8		6.8	
	Weft	16.19009901	11.2		12.11803279	
	Peak Stress	14.52957603	10.05128205	MPa	11.46300399	MPa
	Peak Stress +19%	17.29019548	11.96102564	MPa	13.64097475	MPa
	Peak Strain	0.004322549	0.002990256		0.003410244	
	Epf	6.805835644	4.0014	GPa	4.517334426	GPa
		6805.835644	4001.4	MPa	4517.334426	MPa
	Residual Stress	0.1	0.1	MPa	0.1	MPa
	Poisson's Ratio	0.25	0.25		0.25	
	Residual Strain	0.006848351	0.005954475		0.006407802	

MODEL 11 - BLOCK K

Original

Pillar Centers

	Material B	Material C		Material D	
Mining Height	3.4	3.1		3.5	
Advance	24	23		17	
Split	17.5	17.5		17	
Bord Width	6.8	6.8		6.8	
Weft	13.19283154	12.88773234		10.2	
Peak Stress	13.580856	14.55066555	MPa	10.2	MPa
Peak Strain	0.003395214	0.003637666		0.00255	
Epf	5.121371326	4.949905576	GPa	3.4394	GPa
	5121.371326	4949.905576	MPa	3439.4	MPa
Residual Stress	0.1	0.1	MPa	0.1	MPa
Poisson's Ratio	0.25	0.25		0.25	
Residual Strain	0.006027489	0.006557048		0.005486559	

19%

Pillar Centers

	Material B	Material C		Material D	
Mining Height	3.4	3.1		3.5	
Advance	24	23		17	
Split	17.5	17.5		17	
Bord Width	6.8	6.8		6.8	
Weft	13.19283154	12.88773234		10.2	
Peak Stress	13.580856	14.55066555	MPa	10.2	MPa
Peak Stress +19%	16.16121864	17.315292	MPa	12.138	MPa
Peak Strain	0.004040305	0.004328823		0.0030345	
Epf	5.121371326	4.949905576	GPa	3.4394	GPa
	5121.371326	4949.905576	MPa	3439.4	MPa
Residual Stress	0.1	0.1	MPa	0.1	MPa
Poisson's Ratio	0.25	0.25		0.25	
Residual Strain	0.007176421	0.007806726		0.006534529	

MODEL 12 - BLOCK L

Original

	Material B	Material C		Material D	Material E	
Pillar Centers						
Mining Height	3	3.1		3.1	3	
Advance	22.5	24		15	17.5	
Split	24	18		24	17.5	
Bord Width	6.8	6.7		6.75	6.74	
Weft	16.41580547	13.67062937		11.16176471	10.76	
Peak Stress	19.15177305	15.43458155	MPa	12.60199241	12.55333333	MPa
Peak Strain	0.004787943	0.003858645		0.003150498	0.003138333	
Epf	6.932682675	5.389893706	GPa	3.979911765	3.75412	GPa
	6932.682675	5389.893706	MPa	3979.911765	3754.12	MPa
Residual Stress	0.1	0.1	MPa	0.1	0.1	MPa
Poisson's Ratio	0.25	0.25		0.25	0.25	
Residual Strain	0.007536053	0.006703707		0.006291772	0.006455578	

19%

	Material B	Material C		Material D	Material E	
Pillar Centers						
Mining Height	3	3.1		3.1	3	
Advance	22.5	24		15	17.5	
Split	24	18		24	17.5	
Bord Width	6.8	6.7		6.75	6.74	
Weft	16.41580547	13.67062937		11.16176471	10.76	
Peak Stress	19.15177305	15.43458155	MPa	12.60199241	12.55333333	MPa
Peak Stress +19%	22.79060993	18.36715204	MPa	14.99637097	14.93846667	MPa
Peak Strain	0.005697652	0.004591788		0.003749093	0.003734617	
Epf	6.932682675	5.389893706	GPa	3.979911765	3.75412	GPa
	6932.682675	5389.893706	MPa	3979.911765	3754.12	MPa
Residual Stress	0.1	0.1	MPa	0.1	0.1	MPa
Poisson's Ratio	0.25	0.25		0.25	0.25	
Residual Strain	0.008970644	0.007980937		0.007491982	0.007687199	

MODEL 13 - BLOCK M

Original

Pillar Centers

		Material B	Material C		Material D	
	Mining Height	3.4	3.4		3.4	
	Advance	31	24		18	
	Split	18	18		18	
	Bord Width	6.8	6.8		6.6	
	Weft	15.31299435	13.56619718		11.4	
	Peak Stress	15.76337654	13.96520298	MPa	11.73529412	MPa
	Peak Strain	0.003940844	0.003491301		0.002933824	
	Epf	6.312902825	5.331202817	GPa	4.1138	GPa
		6312.902825	5331.202817	MPa	4113.8	MPa
	Residual Stress	0.1	0.1	MPa	0.1	MPa
	Poisson's Ratio	0.25	0.25		0.25	
	Residual Strain	0.006422013	0.006092065		0.00576218	

19%

Pillar Centers

		Material B	Material C		Material D	
	Mining Height	3.4	3.4		3.4	
	Advance	31	24		18	
	Split	18	18		18	
	Bord Width	6.8	6.8		6.6	
	Weft	15.31299435	13.56619718		11.4	
	Peak Stress	15.76337654	13.96520298	MPa	11.73529412	MPa
	Peak Stress +19%	18.75841808	16.61859155	MPa	13.965	MPa
	Peak Strain	0.004689605	0.004154648		0.00349125	
	Epf	6.312902825	5.331202817	GPa	4.1138	GPa
		6312.902825	5331.202817	MPa	4113.8	MPa
	Residual Stress	0.1	0.1	MPa	0.1	MPa
	Poisson's Ratio	0.25	0.25		0.25	
	Residual Strain	0.007645205	0.007253122		0.006861613	

Panel	w	h	e	Hm	H	H/Hm	Δσp	dh	σp	L	Er	Ec	σto	σtr	OSF	fs	PSF
East Main Portion 1	7.5	2.5	0.713	114.1	40.0	0.4	8.94	5.59	9.94	132.80	18	4	10.40	5	-1.08	1.72	0.72
East Main Portion 2	8.7	3.4	0.685	109.3	67.0	0.6	7.01	5.95	8.68	132.80	18	4	10.63	5	-1.13	0.96	-0.04
East Main Portion 3	10.0	3.7	0.649	122.8	68.0	0.6	7.06	6.53	8.76	150.80	18	4	10.16	5	-1.03	1.04	0.04
East Main Portion 4	11.7	4	0.600	143.0	79.0	0.6	6.97	6.97	8.94	154.80	18	4	11.97	5	-1.39	1.02	0.02
East Main Portion 5	13.6	3.8	0.554	176.6	91.0	0.5	7.62	7.24	9.90	114.80	18	4	27.95	5	-4.59	1.08	0.08
East Main Portion 6	13.6	3.4	0.554	190.0	100.0	0.5	8.15	6.93	10.65	114.80	18	4	28.78	5	-4.76	1.05	0.05
East Main North 3 Portion 1	11.7	3.9	0.600	145.2	70.0	0.5	7.33	7.15	9.08	114.80	18	4	22.68	5	-3.54	1.17	0.17
East Main North 3 Portion 2	11.6	4.2	0.607	135.3	78.0	0.6	6.67	7.00	8.62	114.80	18	4	20.70	5	-3.14	0.98	-0.02
East Main North 3 West 3	10.3	3.5	0.633	135.2	65.0	0.5	7.58	6.63	9.21	108.80	18	4	21.83	5	-3.37	1.19	0.19
East Main North 4	10.7	4	0.629	127.2	79.0	0.6	6.61	6.61	8.58	105.80	18	4	21.62	5	-3.32	0.92	-0.08
East Main North 5	11.2	4	0.613	135.4	80.0	0.6	6.75	6.75	8.75	117.80	18	4	18.98	5	-2.80	0.96	-0.04
East Main North 7	10.3	2.72	0.633	159.7	91.0	0.6	8.60	5.85	10.87	108.80	18	4	22.72	5	-3.54	1.01	0.01
East Main North 8 Portion 1	13.6	3.1	0.549	204.6	97.0	0.5	8.93	6.92	11.35	114.80	18	4	30.92	5	-5.18	1.17	0.17
East Main North 8 Portion 2	13.7	3.4	0.547	193.5	92.0	0.5	8.39	7.13	10.69	114.80	18	4	30.16	5	-5.03	1.17	0.17
East Main North 8 West 2	10.8	2.9	0.619	162.3	98.0	0.6	8.20	5.95	10.65	129.30	18	4	16.63	5	-2.33	0.94	-0.06
East Main North 8 West 3	11.7	3.6	0.586	159.1	94.0	0.6	7.25	6.53	9.60	114.80	18	4	22.69	5	-3.54	0.95	-0.05
East Main South 1	9.4	3.4	0.662	121.9	63.0	0.5	7.44	6.33	9.02	105.80	18	4	19.85	5	-2.97	0.91	-0.09
East Main South 1 East 1	9.9	4.1	0.648	114.5	75.5	0.7	6.25	6.41	8.14	111.80	18	4	16.92	5	-2.38	1.12	0.12
East Main South 1 East 2	9.1	3.65	0.677	109.5	65.9	0.6	6.81	6.22	8.46	102.80	18	4	18.55	5	-2.71	0.87	-0.13
East Main South 2 Portion 1	10.6	4.4	0.634	117.4	89.1	0.8	5.79	6.37	8.01	108.80	18	4	18.19	5	-2.64	0.97	-0.03
East Main South 2 Portion 2	11.2	4.1	0.620	131.2	83.0	0.6	6.56	6.73	8.64	108.80	18	4	21.47	5	-3.29	0.75	-0.25
East Main South 2 West 3	12.4	3.7	0.586	160.2	80.0	0.5	7.67	7.10	9.67	150.80	18	4	14.41	5	-1.88	0.90	-0.10
East Main South 2 East 1	11.3	4.1	0.613	134.1	95.0	0.7	6.30	6.45	8.67	117.80	18	4	17.96	5	-2.59	1.12	0.12

East Main South 2 East 2	13.1	4.4	0.568	152.9	97.0	0.6	6.43	7.07	8.86	114.80	18	4	23.64	5	3.73	0.80	-0.20
East Main South 2 East 3	11.8	3.4	0.594	162.3	92.0	0.6	7.68	6.53	9.98	132.80	18	4	17.31	5	2.46	0.88	-0.12
East Main South 4	11.6	3.3	0.597	163.0	100.0	0.6	7.61	6.28	10.11	108.80	18	4	24.91	5	3.98	0.99	-0.01
East Main South 5	14.0	3	0.540	215.6	106.0	0.5	9.08	6.81	11.73	150.80	18	4	18.59	5	2.72	0.92	-0.08

Table 20. Calculated values for the Overburden Stability (OSF) and Pillar Stability Factors (PSF) as well as assumptions