CHAPTER 4

PARAMETRIC MODELLING STUDY

4.1 General

This chapter discusses the results of the numerical modelling based parametric modelling study to assess the effect of softcover on the strata and support behaviour in the depillaring workings. The primary data of the immediate and the main roof's thickness and strength properties (Table 4.1) have been obtained by averaging the values compiled from different coalfields in India (Singh and Singh, 2009b). A seam thickness of 3 m has been considered for its complete extraction in all the cases. The thickness of the immediate roof layer is 6 m, while the main roof is 18 m thick. Thus, the height of the caving zone is 24 m, which is eight times the height of extraction.

Table 4.1. Rock-mass properties for the parametric modelling study

Strata	Thickness, m	Density, kg/m^3	Young's Modulus, GPa	Tensile strength, MPa	Cohesion, MPa	Friction angle, °	Dilation angle, °
Softcover	37.5 – 262.5	2000	0.072	0.00	0.09	25	2
Parting Strata	13.5 – 209.3	2124	10.86	1.28	2.94	40	5
Main Roof	18	2179	8.57	1.12	2.48	40	5
Immediate roof	6	2164	8.48	1.00	2.26	40	5
Coal	3	1419	2	0.39	1.31	25	2
Floor	50	2387	11.58	1.38	3.19	40	5

The thickness of the parting strata and the softcover has been varied in different proportions keeping the depth of working between 150 – 350 m, considering the most likely condition for the adoption of underground mining below softcover. The thickness of the parting strata has been varied from 13.5 – 209.3 m, marking the total thickness of the hardcover from 37.5 – 233.3 m. The hardcover combines the thickness of strata within the caving zone (immediate and the main roof layers) and the parting strata. The thickness of the softcover has been varied from 37.5 – 262.5 m. Table 4.2 shows the range of different variables in the experimental models.

Table 4.2. Details of experimental depillaring workings at different depths of cover

Depth, m	HC/SC	Hardcover (HC), m	Softcover (SC), m	Parting Strata (PS), m	PS/SC
150	0.33	37.50	112.50	13.50	0.12
	0.50	50.00	100.00	26.00	0.26
	1.00	75.00	75.00	51.00	0.68
	2.00	100.00	50.00	76.00	1.52
	3.00	112.50	37.50	88.50	2.36
250	0.33	62.50	187.50	38.50	0.21
	0.50	83.30	166.70	59.30	0.36
	1.00	125.00	125.00	101.00	0.81
	2.00	166.70	83.30	142.70	1.71
	3.00	187.50	62.50	163.50	2.62
350	0.33	87.50	262.50	63.50	0.24
	0.50	116.70	233.30	92.70	0.40
	1.00	175.00	175.00	151.00	0.86
	1.99	233.30	116.70	209.30	1.79

The progressive mining was simulated in plane strain conditions to observe the failure and caving of strata till the cumulative advance of goaf edge just exceeded the maximum thickness of parting strata for a given depth of cover. The idea is to obtain the response of parting strata of different thicknesses as it undergoes failure under the loading of the softcover with progressive depillaring in a given geo-mining condition.

In all the experimental models, a mobile goaf edge support of 2 × 400 t capacity was deployed at the goaf edge with its setting-yield stiffness characteristics discussed in Chapter 3. The galleries developed in advance were supported by three hydraulic props, 40 t capacity each placed 1 m apart. The filling of caved goaf during the main fall and the periodic caving was also simulated in this process to study the field representative behaviour of the parting strata and the compaction and stress recovery in the goaf.

The model results considered basic parameters like the span of main fall, front abutment stress, load on the goaf edge support, goaf edge convergence, and compaction of the cyclically filled caved goaf material with progressive extraction of the developed pillars. The settlement rate of the parting strata has also been evaluated upon its first failure during the simulated depillaring. All these parameters have been evaluated as a function of the ratio of the thickness of parting strata to softcover thickness for cover depth (CD) of 150 m, 250 m and 350 m.

4.2 Strata and Support Behaviour at 150 m depth

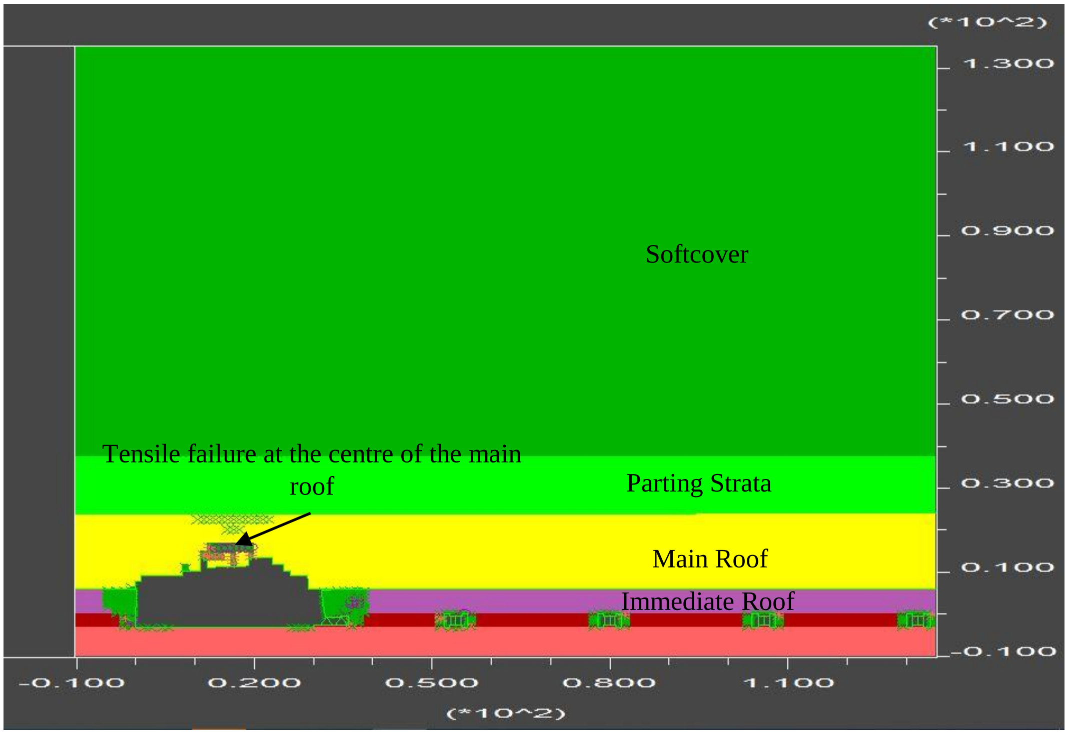
Five experimental models were studied for the thickness of parting strata (PS), varying from 13.5 to 88.5 m and softcover (SC) from 37.5 m to 112.5 m. The thickness of hardcover (HC) varied from 37.5 to 112.5 m, which included the 24 m thick strata within the caving zone and the parting strata. The thickness of parting strata to the thickness of softcover (PS/SC) varied from 0.12 – 2.36, while the ratio of the thickness of hardcover to the thickness of softcover varied from 0.33 – 3.0.

4.2.1 Caving Behaviour

The result shows that for the thinnest PS of 13.5 m overlain by 112.5 m thick SC, the main fall initiated at 36 m of face advance, leaving some tensile failure zones in the overhang of the main roof (Figure 4.1a). As the thickness of PS increased to 26 m, and the SC reduced to 100 m, the extent of tension zones decreased, and the main roof caved after a slightly increased face advance of 38 m (Figure 4.1b). Similar nature of caving of the main roof was observed with PS of 51 m, 76 m, and 88.5 m in combination with the SC of 75 m, 50 m and 37.5 m, respectively (Figure 4.1c – e). The main fall span increased from 36 m to 42 m for an increase in the ratio of PS/SC from 0.12 – 1.52 and remained constant after that (Table 4.3).

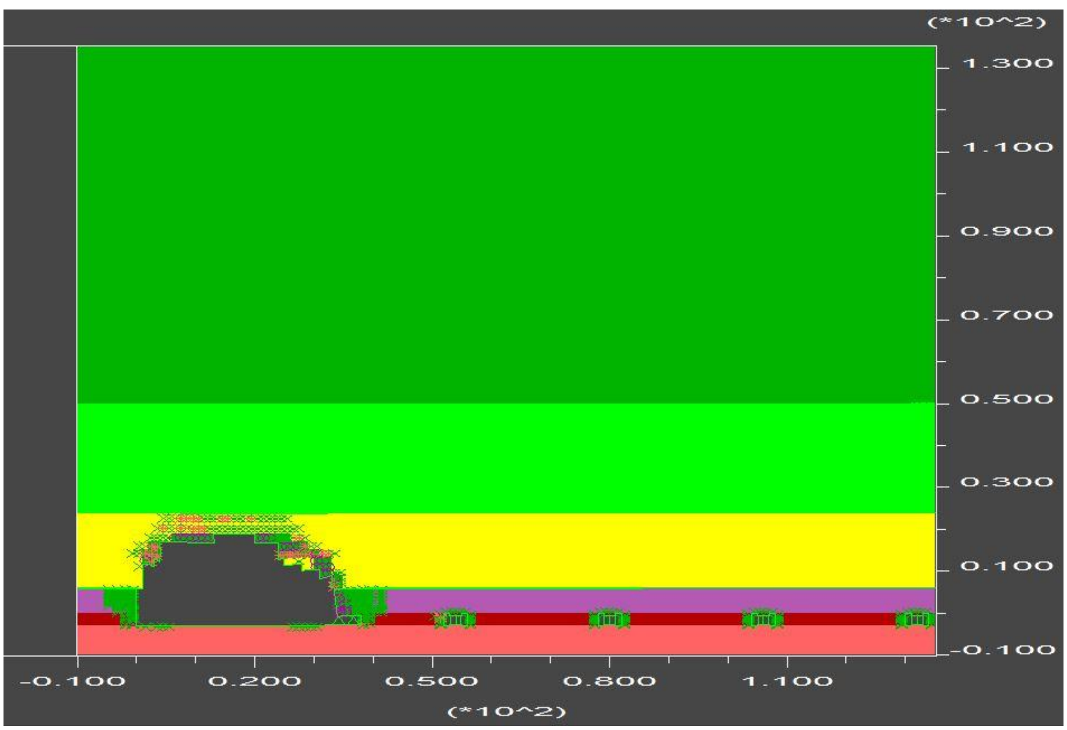
Table 4.3. Model observed main fall span at 150 m cover depth

Parting Strata (PS) thickness, m	Softcover (SC) thickness, m	PS/SC	Main Fall span, m
13.5	112.5	0.12	36
26	100	0.26	38
51	75	0.68	40
76	50	1.52	42
88.5	37.5	2.36	42



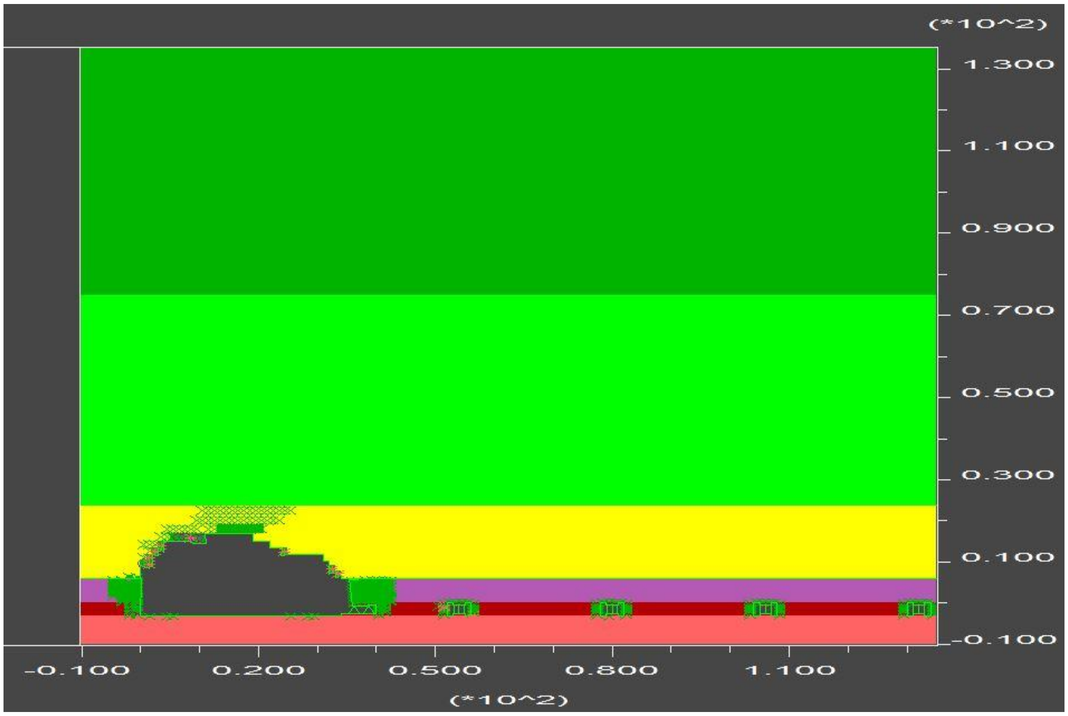
(*10^2)
1.300
1.100
0.900
0.700
0.500
0.300
0.100
-0.100
-0.100
0.200
0.500
0.800
1.100
(*10^2)
Softcover
Tensile failure at the centre of the main roof
Parting Strata
Main Roof
Immediate Roof

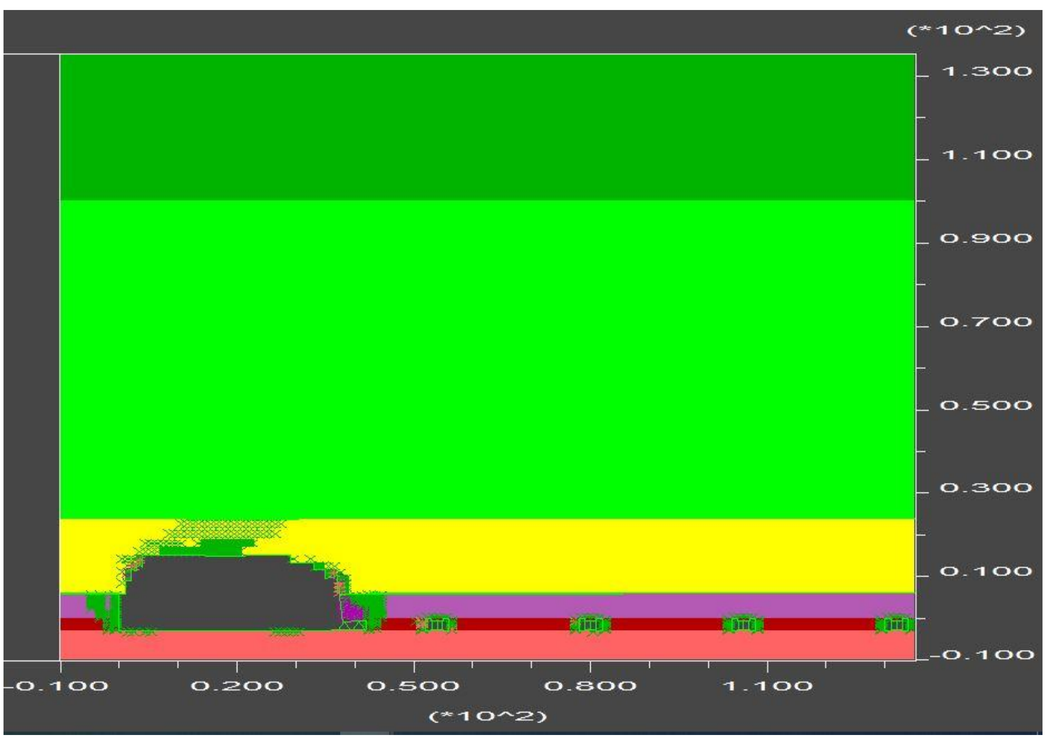
(a)

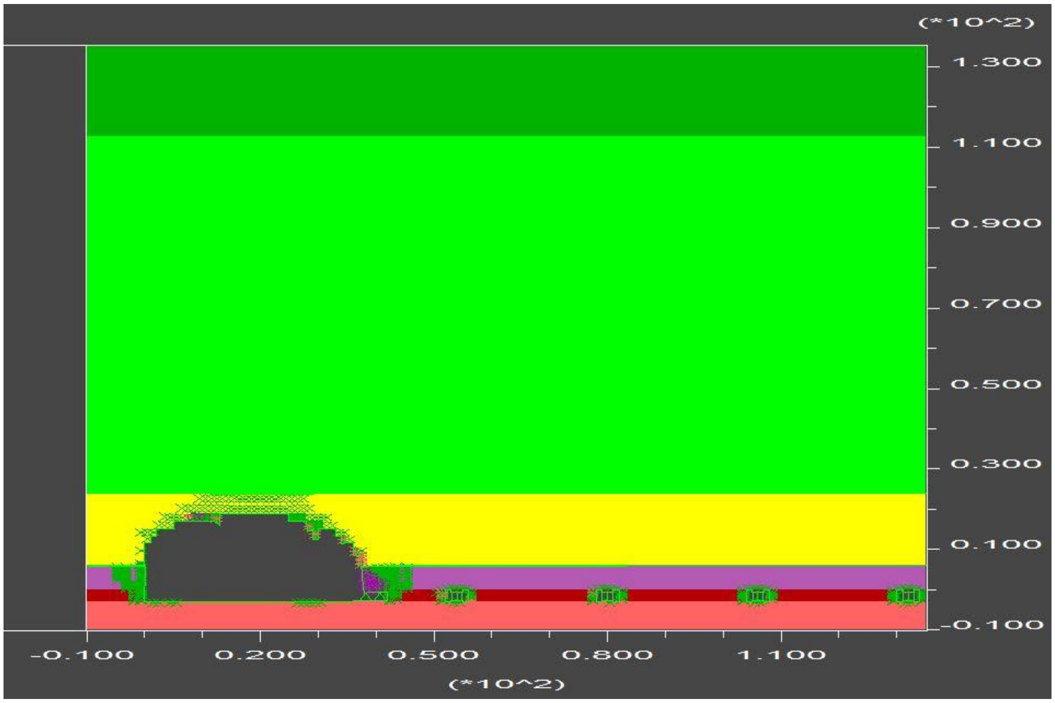


(*10^2)
1.300
1.100
0.900
0.700
0.500
0.300
0.100
-0.100
-0.100
0.200
0.500
0.800
1.100
(*10^2)

(b)


(*10^2)
1.300
1.100
0.900
0.700
0.500
0.300
0.100
-0.100
-0.100
0.200
0.500
0.800
1.100
(*10^2)
(c)


(*10^2)
1.300
1.100
0.900
0.700
0.500
0.300
0.100
-0.100
-0.100
0.200
0.500
0.800
1.100
(*10^2)
(d)



(e)

Fig. 4.1. Model observed main fall for different PS/SC at 150 m cover depth
(a) 36 m face advance, PS/SC= 0.12, PS =13.5 m, SC =112.5 m
(b) 38 m face advance, PS/SC=0.26, PS = 26 m, SC = 100 m
(c) 40 m face advance, PS/SC=0.68, PS = 51 m, SC = 75 m
(d) 42 m face advance, PS/SC=1.52, PS = 76 m, SC = 50 m
(e) 42 m face advance, PS/SC=2.36, PS = 88.5 m, SC = 37.5 m

4.2.2 Front Abutment Stress in the Working

The peak value of the front abutment stress was monitored using a FISH module with progressive extraction of the pillars. The FISH module 'front_abutment' searches for the maximum value of vertical stress at the middle level of the coal face within 30 m ahead of the goaf edge and prints its value and the location concerning the face for every stage of face advance. The abutment stress was normalised, dividing it by the virgin vertical stress to obtain the Front Abutment Stress Ratio (FASR). Figure 4.2 shows the plot of the FASR with the progressive advance of the goaf edge for the maximum and the minimum PS/SC ratios of 0.12 and 2.36 at the cover depth of 150 m. The abutment stress is higher for depillaring working, having the minimum PS/SC ratio of 0.12 compared to that with the higher PS/SC ratio. The peak front abutment stress ratio (FASR) is also higher for the lowest value of PS/SC. In either case, the first peak of the FASR is observed at 21 m of face advance, while the subsequent peaks are observed at 22 – 27 m intervals.

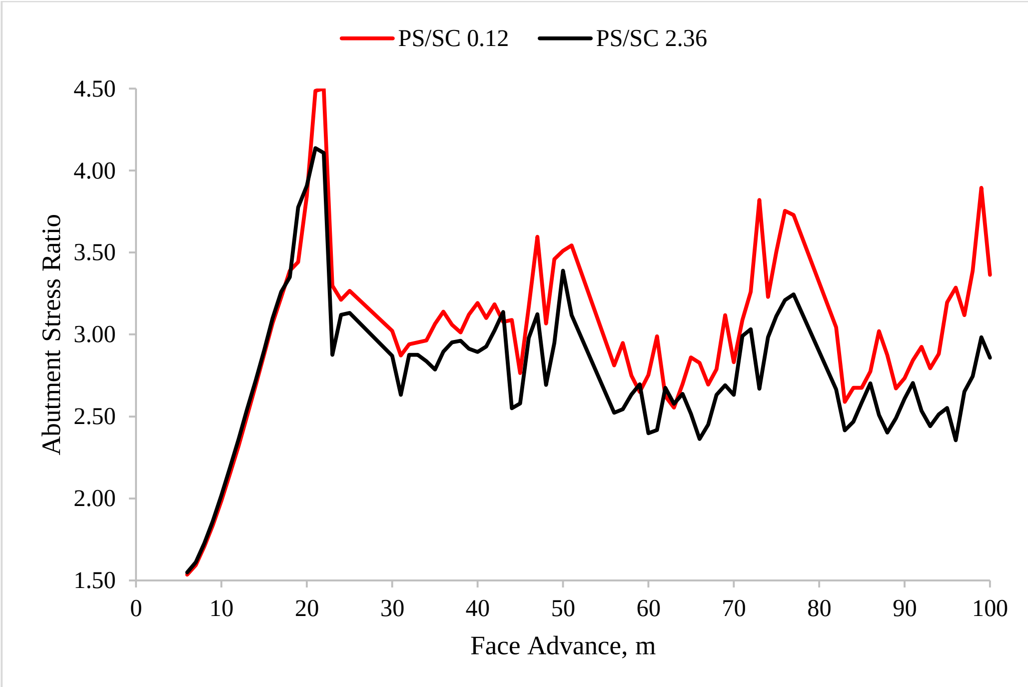


Fig. 4.2. Plot of front abutment stress ratio with progressive face advance at 150 m cover depth

4.2.3 Load on the Goaf Edge Support

Figure 4.3 shows the model observed Load on the goaf edge support of 2 × 400 t capacity during the progressive depillaring under overburden having the lowest and the highest ratios of PS/SC. The overall profile of the support load shows a marginally increased loading while working under the lowest PS/SC ratio. The support achieved the yield load at several stages during the progressive mining in both cases.

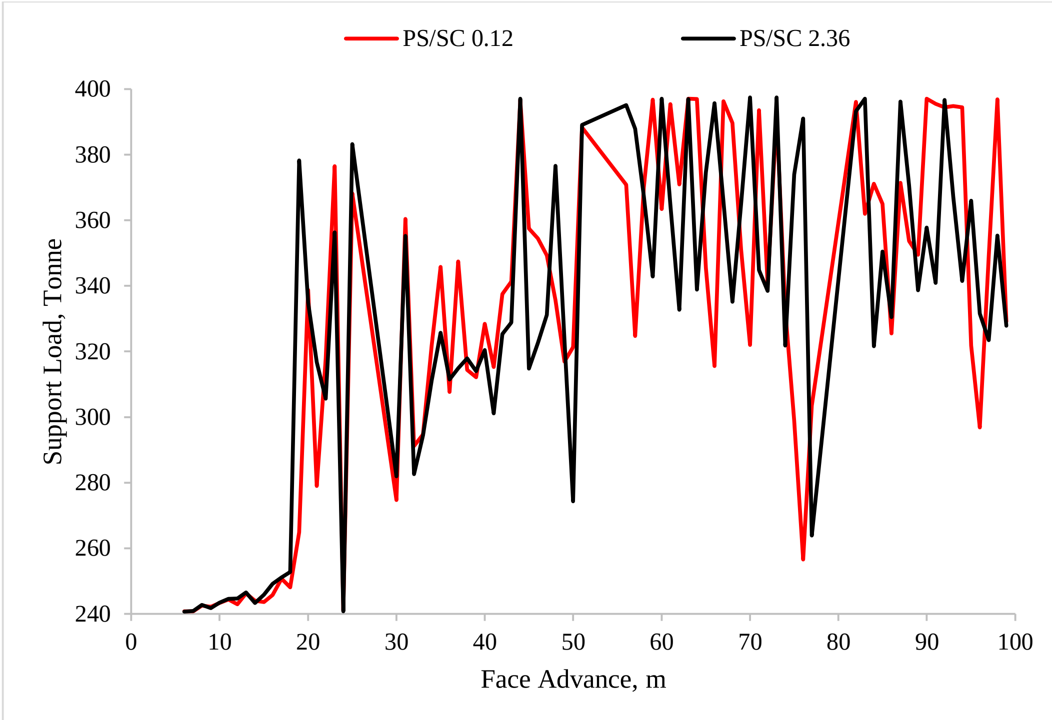


Fig. 4.3. Load on the goaf edge support of 2 × 400 t capacity with progressive face advance at cover depth of 150 m

4.2.4 Convergence at the Goaf Edge

Convergence is the combined function of the vertical deformation of the roof and the floor at a point. In this study, the model stores the face convergence data for 0, 1, 2, 3 and 4 m distance from the face. The convergence slope for 1, 2, 3 and 4 m locations at the face is computed with respect to the convergence at 0 m (i.e. at the face point). The average face convergence slope is obtained by averaging the convergence slope of these four points. Only the post-elastic stage of roof-floor convergence is considered. Thus, if C_0, C_1, C_2, C_3, and C_4 represent the convergence at 0, 1 m, 2 m, 3 m and 4 m locations, as in Equations (4.1 – 4.5).

$$C_0 = epcrf_0 - ecrf_0 \qquad \ldots(4.1)$$

$$C_1 = epcrf_1 - ecrf_1 \qquad \ldots(4.2)$$

$$C_2 = epcrf_2 - ecrf_2 \quad \text{...(4.3)}$$

$$C_3 = epcrf_3 - ecrf_3 \quad \text{...(4.4)}$$

$$C_4 = epcrf_4 - ecrf_4 \quad \text{...(4.5)}$$

Where $ecrf_0$ is the elastic and $epcrf_0$ is the elasto-plastic convergence at the 0 m; $ecrf_1$ is the elastic and $epcrf_1$ is the elasto-plastic convergence at the 1 m; $ecrf_2$ is the elastic and $epcrf_2$ is the elasto-plastic convergence at the 2 m; $ecrf_3$ is the elastic and $epcrf_3$ is the elasto-plastic convergence at the 3 m, and $ecrf_4$ is the elastic and $epcrf_4$ is the elasto-plastic convergence at the 4 m location.

The convergence slope at 1, 2, 3 and 4 m location of the face are obtained by the Equations (4.6 – 4.9).

$$CS_1 = \frac{C_1 - C_0}{1} \quad \text{...(4.6)}$$

$$CS_2 = \frac{C_2 - C_0}{2} \quad \text{...(4.7)}$$

$$CS_3 = \frac{C_3 - C_0}{3} \quad \text{...(4.8)}$$

$$CS_4 = \frac{C_4 - C_0}{4} \quad \text{...(4.9)}$$

The goaf edge convergence slope (GECS) is obtained as the average of convergence slope obtained at these four points as in Equation (4.10), i.e.

$$GECS = \frac{CS_1 + CS_2 + CS_3 + CS_4}{4} \quad \text{...(4.10)}$$

Figure 4.4 shows the convergence slope at the goaf edge with the progressive depillaring under the lowest and the highest PS/SC ratio at the cover depth of 150 m. The plot shows that the GECS observed during progressive depillaring reduces with an increase in the PS/SC ratio. For the lowest PS/SC of 0.12, the goaf edge observed the maximum GECS of 120 mm/m. This maximum convergence was observed while crossing the gallery developed in advance at 52 – 56 m within the mining zone. However, while mining under the highest PS/SC ratio of 2.36, the maximum GECS reduced to 49 mm/m, as observed at 76 m of face advance. This maximum convergence was observed while a rib of 2 m was still left against the advance gallery at 78 – 82 m location. It is mainly attributed due to the poor instability of the rib pillar combined with the loading of the overhang undergoing failure over the goaf edge support (Figure 4.5).

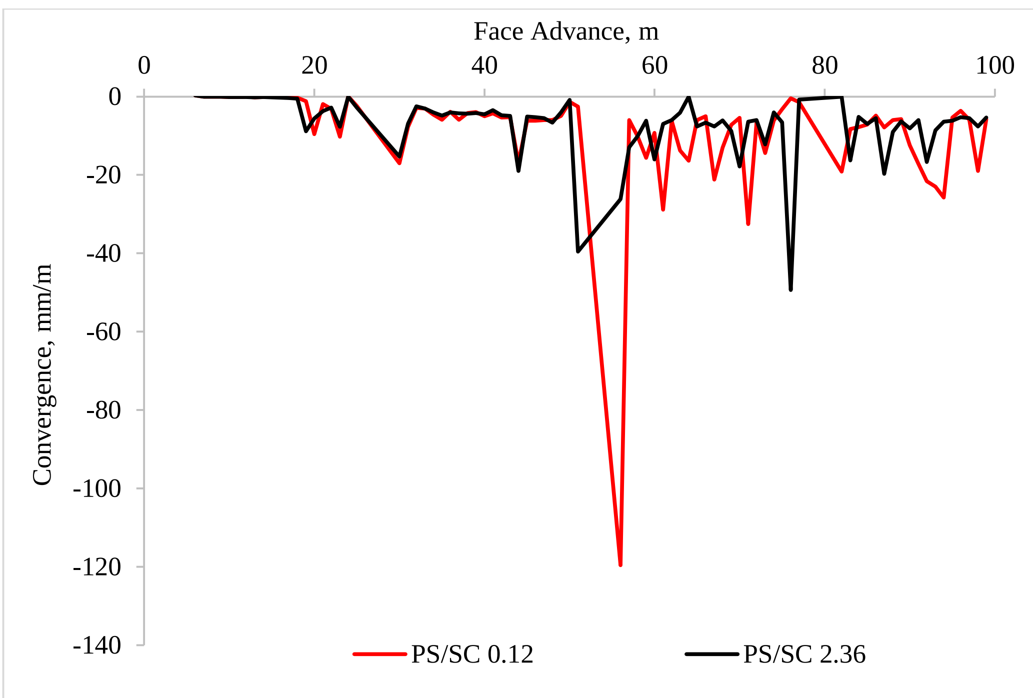


Fig. 4.4. Goaf edge convergence with progressive face advance at cover depth of 150 m

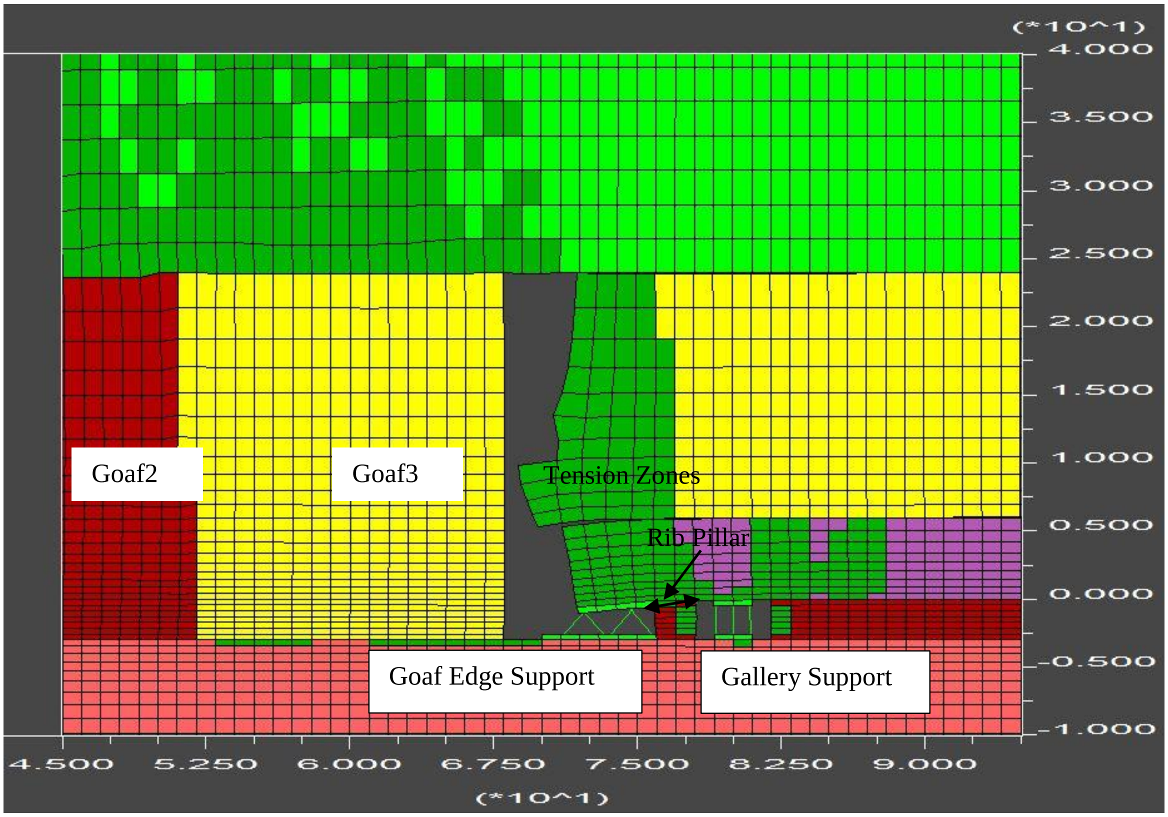


Fig. 4.5. Failure of rib pillar between the advance gallery and the goaf edge

The maximum convergence slope at the goaf edge (GECS) for different PS/SC at 150 m cover depth is given in Table 4.4. The general trend shows that, the maximum convergence at the goaf edge reduces from 120 mm/m to 49 mm/m with increasing thickness of parting strata and simultaneous reduction in thickness of softcover for variation of PS/SC from 0.12 – 2.36.

Table 4.4. Maximum convergence at the goaf edge for varying PS/SC at 150 m depth

Parting Strata (PS) thickness, m	Softcover (SC) thickness, m	PS/SC	Max. Convergence, mm/m
13.5	112.5	0.12	120
26	100	0.26	85
51	75	0.68	62
76	50	1.52	52
88.5	37.5	2.36	49

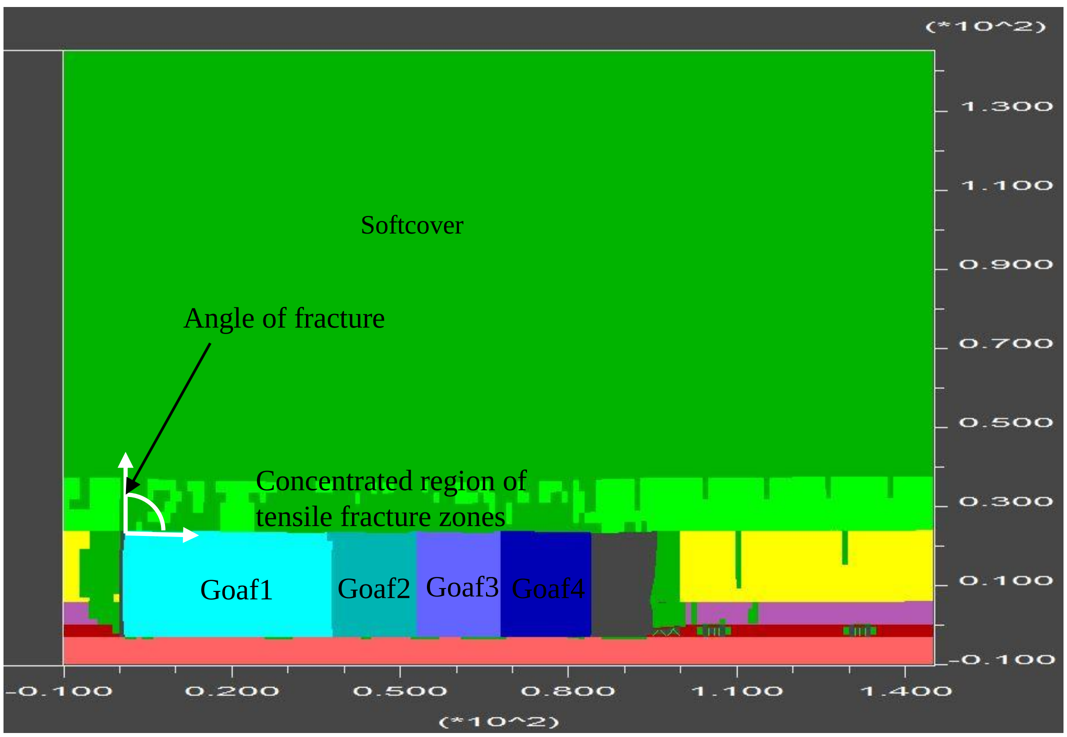
4.2.5 Bending Behaviour of Parting Strata and Stress Recovery in the Caved Goaf

For understanding the bending behaviour of the parting strata and the recovery of goaf stress at the cover depth of 150 m, the results of the parametric model having PS/SC ratio varying from 0.12 – 2.36 were evaluated. The thickness of parting strata varied from 13.5 m to 88.5 m, while the softcover varied from 37.5 – 112.5 m. The progressive depillaring was simulated for a cumulative face advance of 100 m in all the cases. The first filling of the caved goaf was done after 43 – 49 m of goaf exposure, depending on the condition when the majority of the main roof caved during the model observed main fall in a specific strata condition (Figure 4.6a – e). The subsequent fillings were made following the span of periodic caving as stated in Section 3.2.2. Initial properties of the goaf material is incorporated in the model with the considering the caving height is 24 m, mining height is 3 m which corresponds to the bulking factor of 1.125 and bulk density is 1933 kg/m^3. The initial tangent modulus of the goaf material was assigned as 48.13 MPa, while the Poisson's ratio of 0.45 was considered to obtain the bulk and shear moduli following the standard relations.

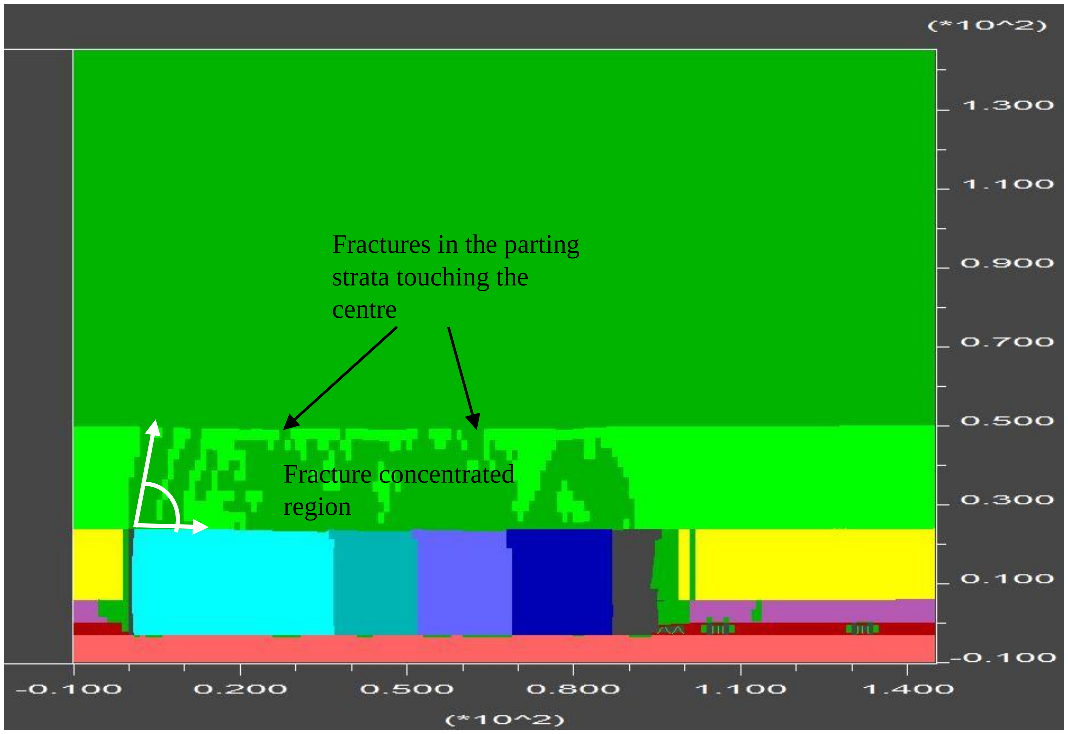
It was observed that in the first case (PS/SC = 0.12), when the parting strata are 13.5 m and the softcover is 112.5 m, almost sub-vertical tensile fractures developed in the parting strata during the settlement of the caved goaf with the progressive mining. It indicates that the thickness of PS was inadequate to develop any arching effect for a controlled load transfer of the softcover in the goaf edge region (Figure 4.6a).

With an increase in the PS/SC ratio to 0.26, only a marginal change in the orientation of the fracture planes that developed in the parting strata upon its settlement was noted (Figure 4.6b). These fractures subsequently merged with each other, indicating that the arching action of the parting strata was still insufficient to offset the load of the softcover towards the central region of the goaf pile.

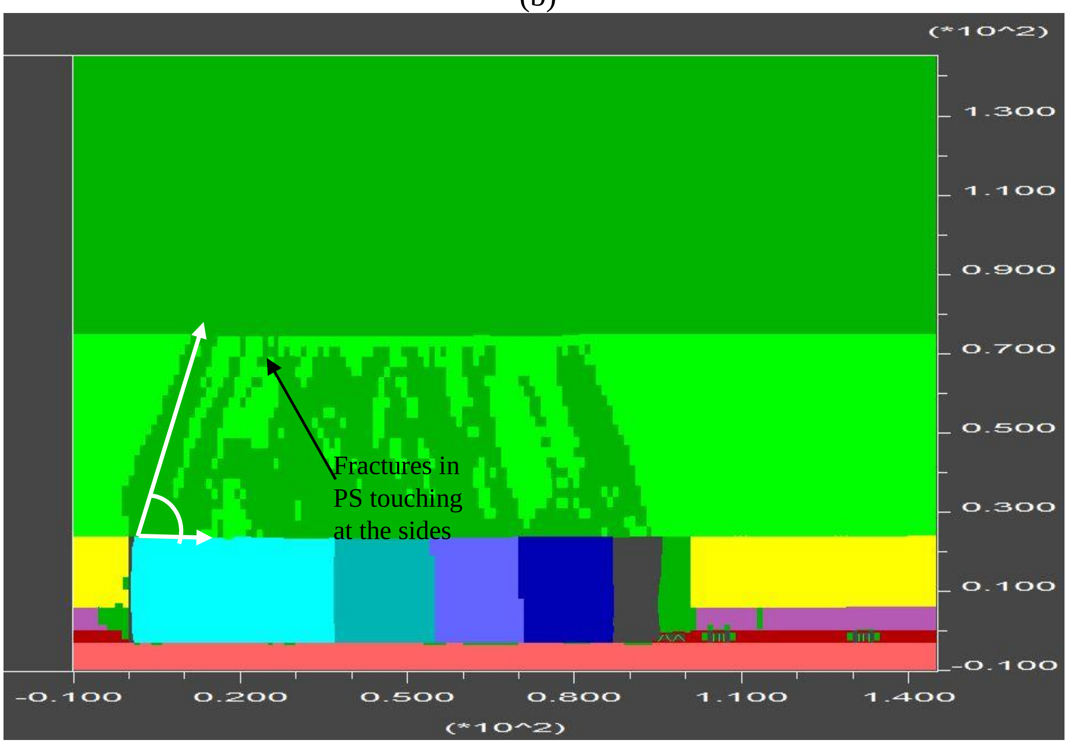
With a further increase in the PS/SC to 0.68, the orientation of tensile fracture planes formed in the PS over the goaf pile indicated a noticeable bending and a reduction in the fracture density (Figure 4.6c). A similar trend continued with the PS/SC ratio of 1.52 and 2.36 as well. When the parting strata is too thick, it does not undergo complete rupture.



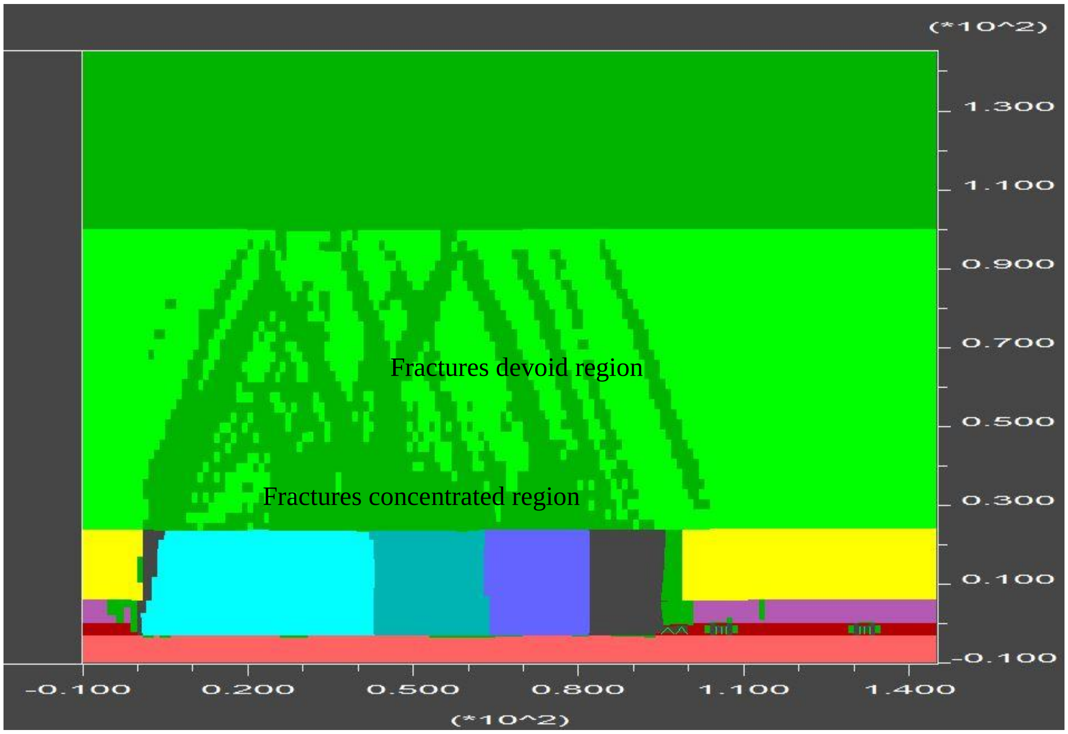
(a)


(*10^2)
1.300
1.100
0.900
0.700
0.500
0.300
0.100
-0.100
Fractures in the parting strata touching the centre
Fracture concentrated region
-0.100
0.200
0.500
0.800
1.100
1.400
(*10^2)

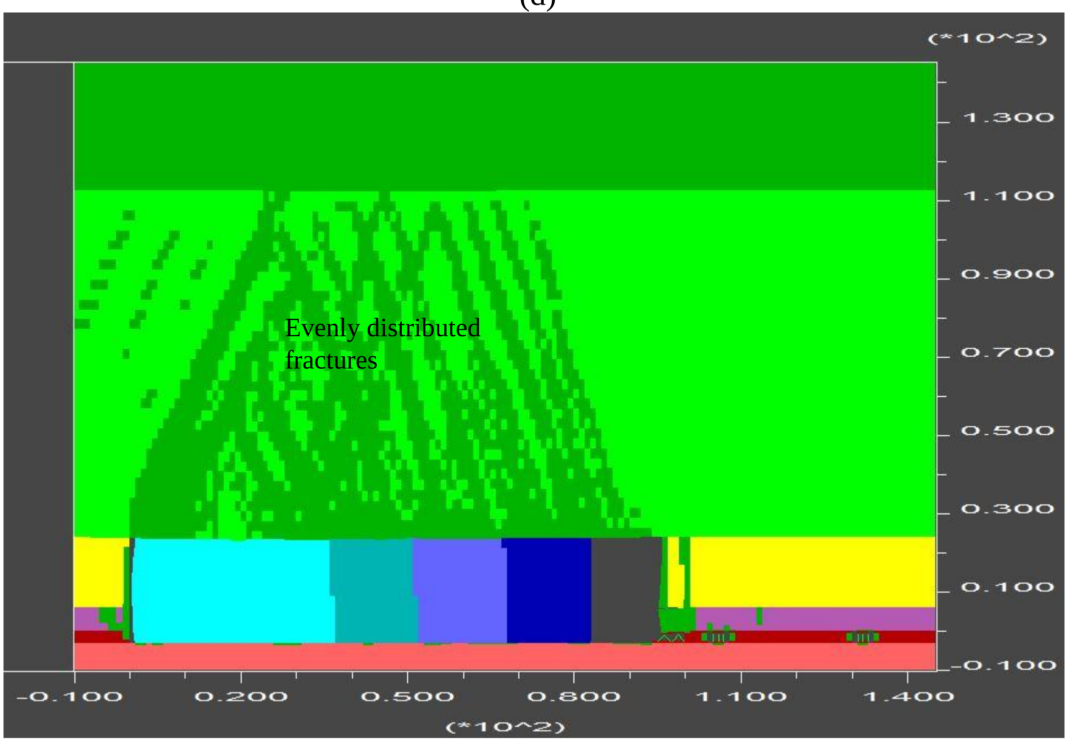
(b)


(*10^2)
1.300
1.100
0.900
0.700
0.500
0.300
0.100
-0.100
Fractures in PS touching at the sides
-0.100
0.200
0.500
0.800
1.100
1.400
(*10^2)

(c)



(d)



(e)

Fig. 4.6. Goaf filling at the cover depth of 150 m, Goaf1 represents the first fill, Goaf 2, 3… represent the subsequent fills (a) PS/SC=0.12, PS = 13.5 m, SC = 112.5 m, (b) PS/SC of 0.26, PS = 26 m, SC = 100 m, (c) PS/SC of 0.68, PS = 51 m, SC = 75 m, (d) PS/SC of 1.52, PS = 76 m, SC = 50 m, (e) PS/SC of 2.36, PS = 88.5 m, SC = 37.5 m

Figure 4.7 shows the trend of the maximum vertical settlement of the parting strata with progressive face advance at a cover depth of 150 m. These settlement values have been arrived at by mapping the cumulative vertical displacement at the middle horizon of the PS over the area exposed in the goaf. The point of maximum displacement behind the goaf edge and its value was recorded for this purpose at every stage of the progressive face advance. The plot shows that for face advance up to a distance of 100 m against the maximum hardcover of 112.5 m, the maximum cumulative settlement of the parting strata is observed for the lowest PS/SC of 0.12, where the thickness of parting strata is 13.5 m while the softcover is 112.5 m. The total hardcover, in this case, was 37.5 m out of which 24 m of the roof caved in the goaf during progressive mining. The minimum cumulative settlement of the parting strata is noted for the highest PS/SC of 2.36, where the thickness of parting strata is 88.5 m while the softcover is 37.5 m. The total hardcover, in this case, was 112.5 m. The cumulative settlement of the parting strata followed a consistently reducing trend with the increase in PS/SC.

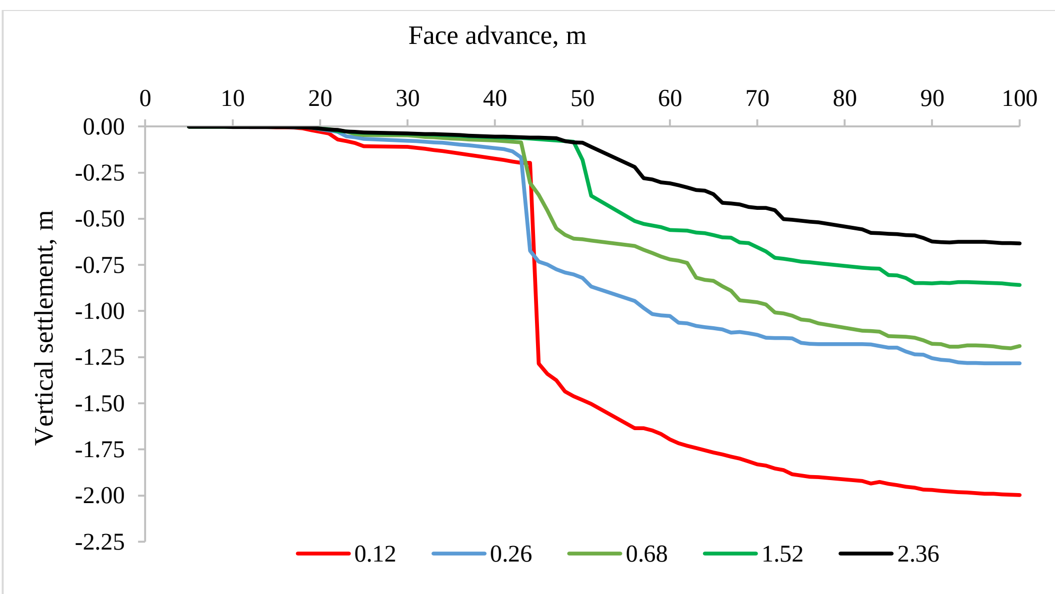


Fig. 4.7. Vertical settlement in parting strata for different PS/SC at 150 m depth

A sudden and considerable surge in the maximum settlement is recorded for PS/SC of 0.12 – 0.26, marking a complete rupture of the parting during progressive depillaring. Such behaviour of the parting indicates an uncontrolled load transfer. For PS/SC of 0.12, the vertical displacement of the parting strata triggered at 44 m but stabilised at 46 m face position. The vertical displacement changed from 0.197 m to 1.341 m during this period. Similarly, for PS/SC ratio of 0.26, the displacement changed from 0.167 m at 43 m face position to 0.732 m at 45 m position. However, for the highest PS/SC ratio of 2.36, the displacement trigger initiated at 51 m and closed at 58 m of face position. The displacement increased from 0.111 m to 0.2875 m in this period. A combined study of the displacement trend and the failure profile observed with progressive face advance shows that as the parting becomes thicker and the SC becomes thinner with increasing PS/SC, the extent of failure in the parting reduces. Thicker parting undergoes a partial rupture only as indicated by a relatively smaller or insignificant surge in the maximum displacement, indicating its controlled settlement with progressive face in such cases.

The vertical stress recovery in the goaf for different PS/SC at 150 m depth shows that the stress recovered in the goaf just after the main fall is 48% of in situ vertical stress for minimum PS/SC of 0.12. The peak stress after the main fall reduces to 20.5% of the peak stress for the maximum PS/SC of 2.36 (Table 4.5).

Table 4.5. Vertical stress recovered after main fall at 150 m cover depth

PS/SC	0.12	0.26	0.68	1.52	2.36
Vertical stress recovery, MPa (% of in situ stress)	-1.50 (48)	-1.26 (40.46)	-0.84 (26)	-0.78 (24.6)	-0.65 (20.5)

The overall trend of stress recovered in the periodically filled goaf piles re-confirms relatively higher stress for the lowest PS/SC (Figure 4.8). The minimum cover pressure distance of 39 m is obtained for PS/SC of 0.12, while the maximum distance of 48 m is observed for PS/SC of 1.52. The goaf could not attain the cover pressure for PS/SC of 2.36.

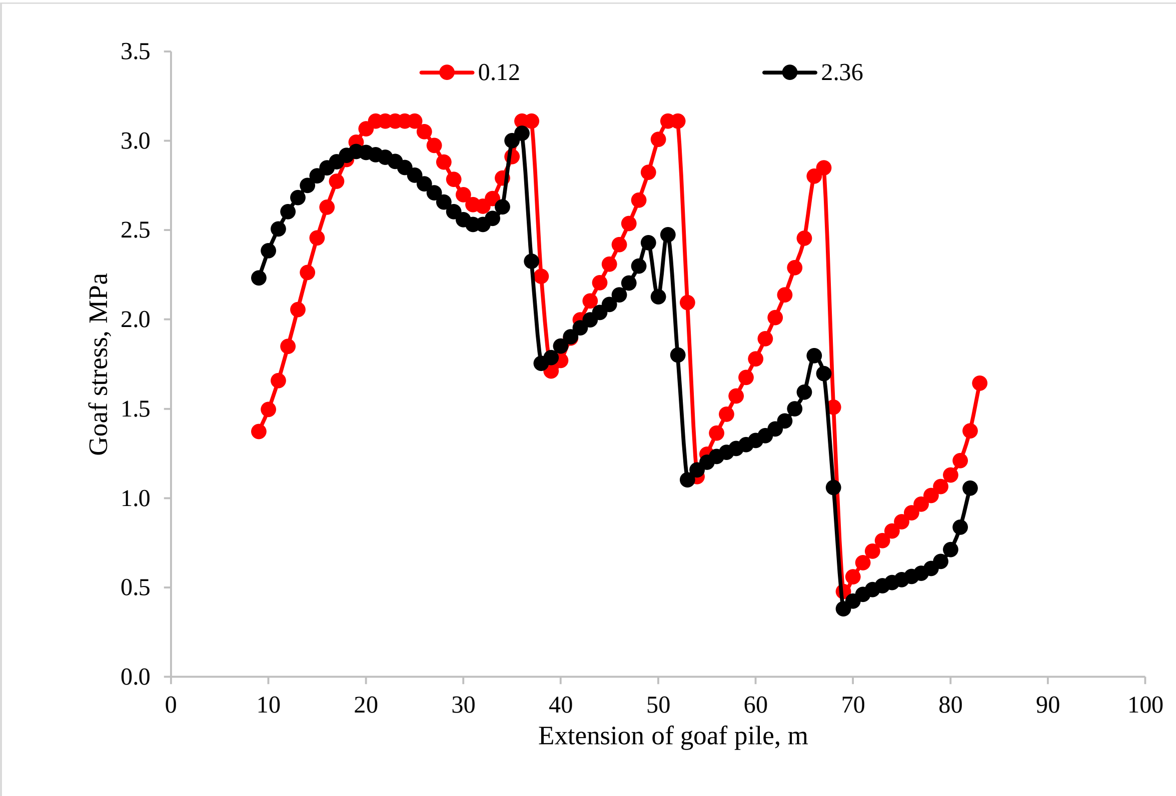


Fig. 4.8. Stress recovery at the cover depth of 150 m, PS/SC= 0.12, 2.36

4.3 Strata and Support Behaviour at 250 m depth

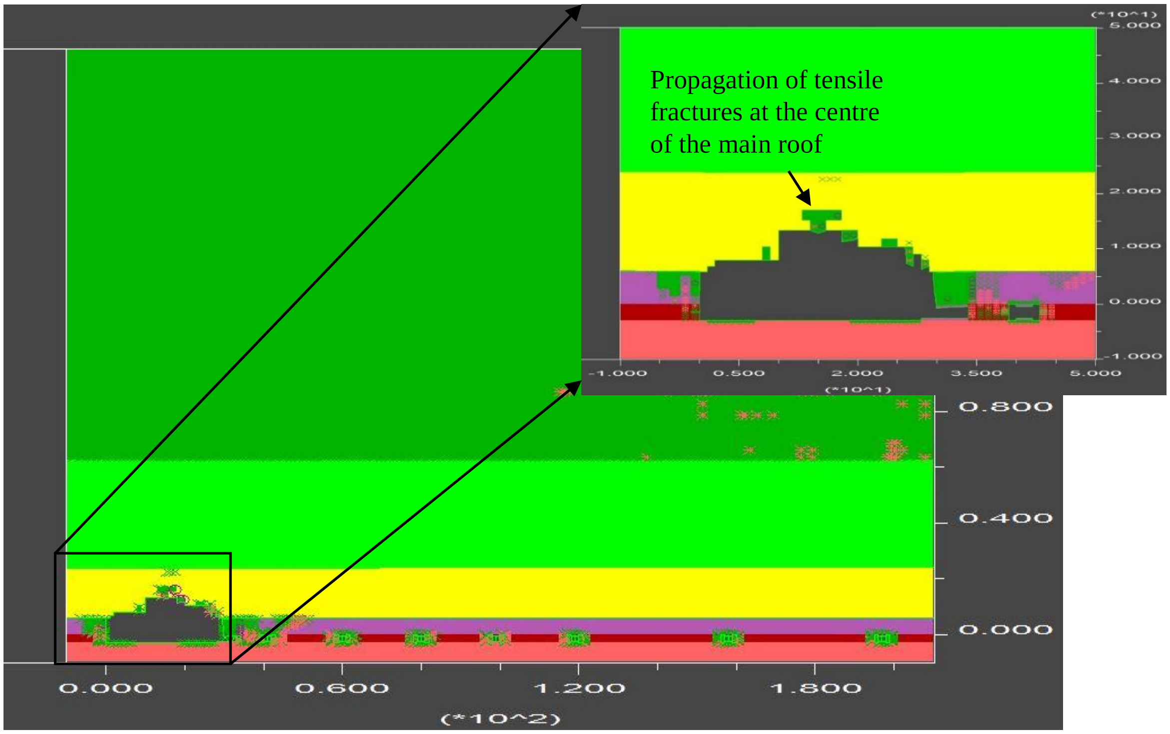
Five experimental models were studied for the thickness of parting strata (PS), varying from 38.5 m to 163.5 m and softcover (SC), varying from 62.5 m to 187.5 m. The thickness of hardcover (HC) varied from 62.5 m to 187.5 m, including the 24 m thick strata within the caving zone and the parting strata. The PS/SC varied from 0.21 – 2.62, while HC/SC varied from 0.33 – 3.0 in this experimental set of studies.

4.3.1 Caving Behaviour

The result shows that for the thinnest PS of 38.5 m overlain by 187.5 m thick SC, the main fall initiated at 34 m of face advance, leaving some tensile failure zones in the overhang of the main roof (Figure 4.9a). As the thickness of PS increased to 59.3 m, and the SC reduced to 166.7 m, the extent of tension zones decreased, and the main roof caved after a slightly increased face advance of 36 m (Figure 4.9b). Similar nature of caving of the main roof was observed with PS of 101 m, 142.7 m, and 163.5 m in combination with the SC of 125 m, 83.3 m and 62.5 m, respectively (Figure 4.9c – e). The main fall span increased from 34 to 38 m for an increase in the ratio of PS/SC from 0.21 – 0.81 and remained constant after that (Table 4.6).

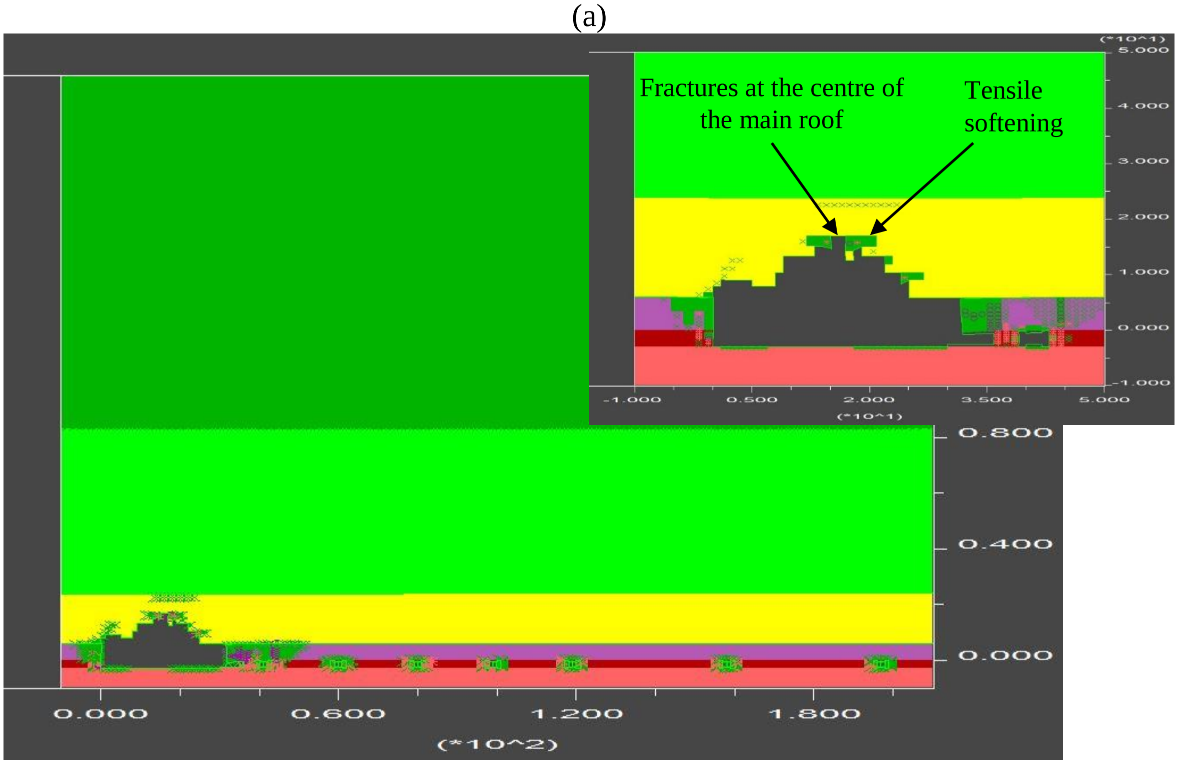
Table 4.6. Model observed main fall span at 250 m cover depth

Parting Strata (PS) thickness, m	Softcover (SC) thickness, m	PS/SC	Main Fall span, m
38.5	187.5	0.21	34
59.3	166.7	0.36	36
101	125	0.81	38
142.7	83.3	1.71	38
163.5	62.5	2.62	38



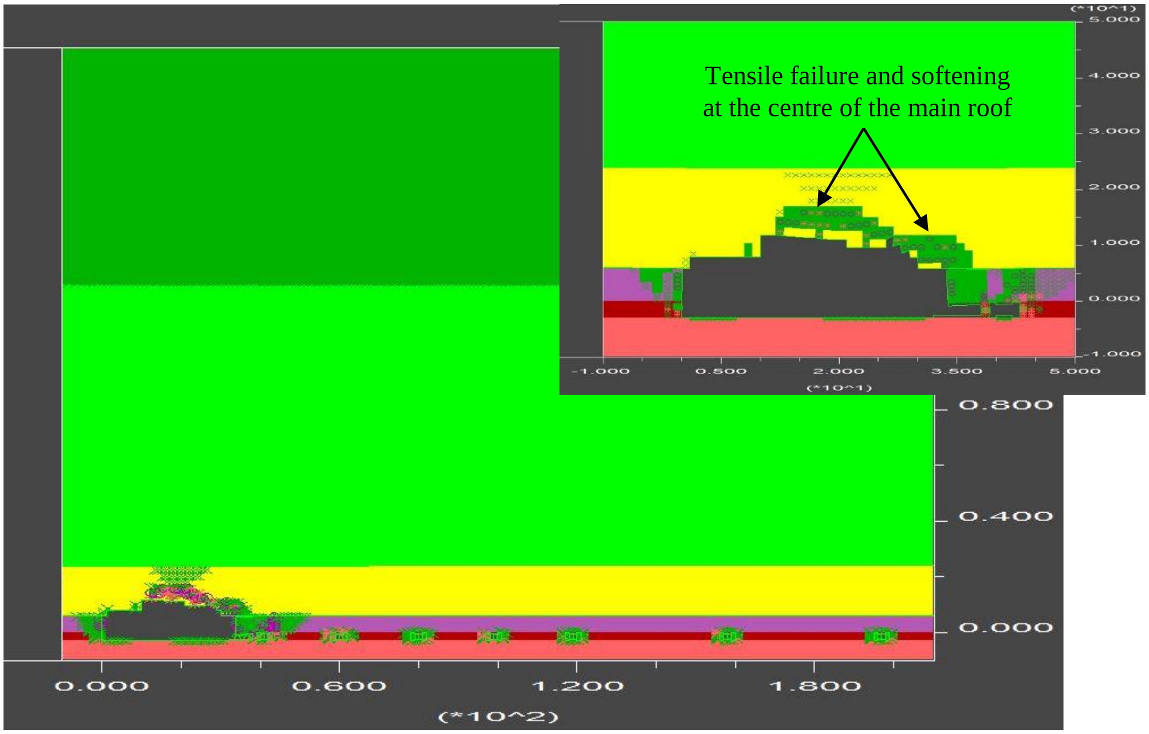
Propagation of tensile fractures at the centre of the main roof
0.800
0.400
0.000
0.000
0.600
1.200
1.800
(*10^2)

(a)

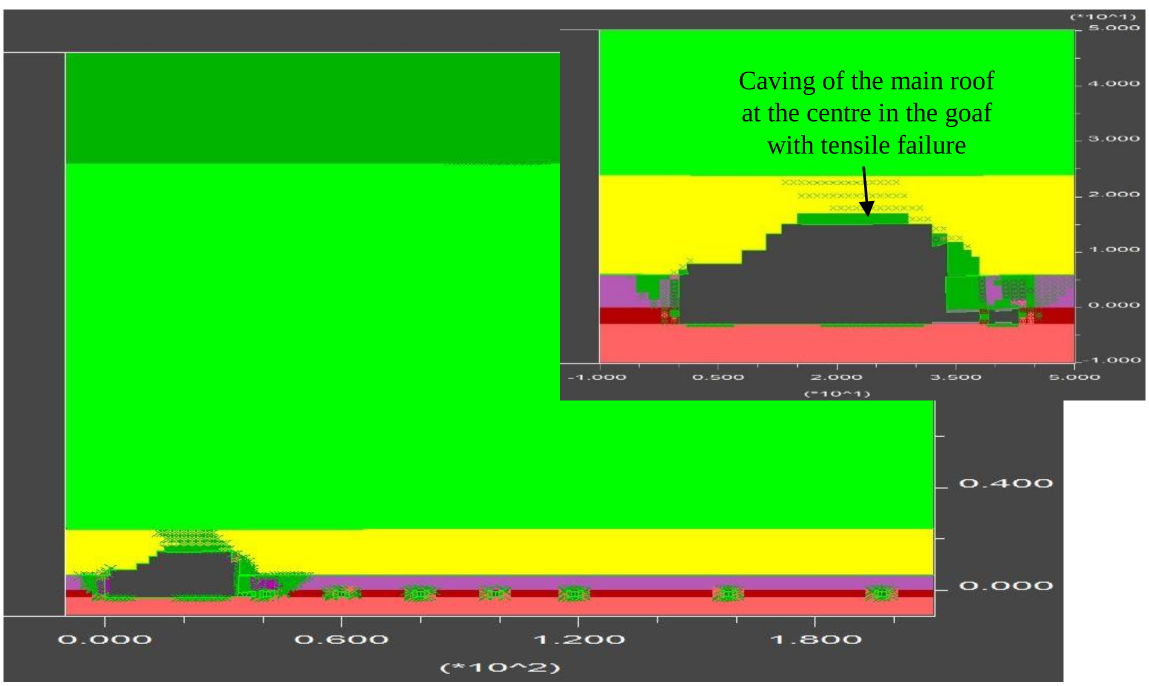


Fractures at the centre of the main roof
Tensile softening
0.800
0.400
0.000
0.000
0.600
1.200
1.800
(*10^2)

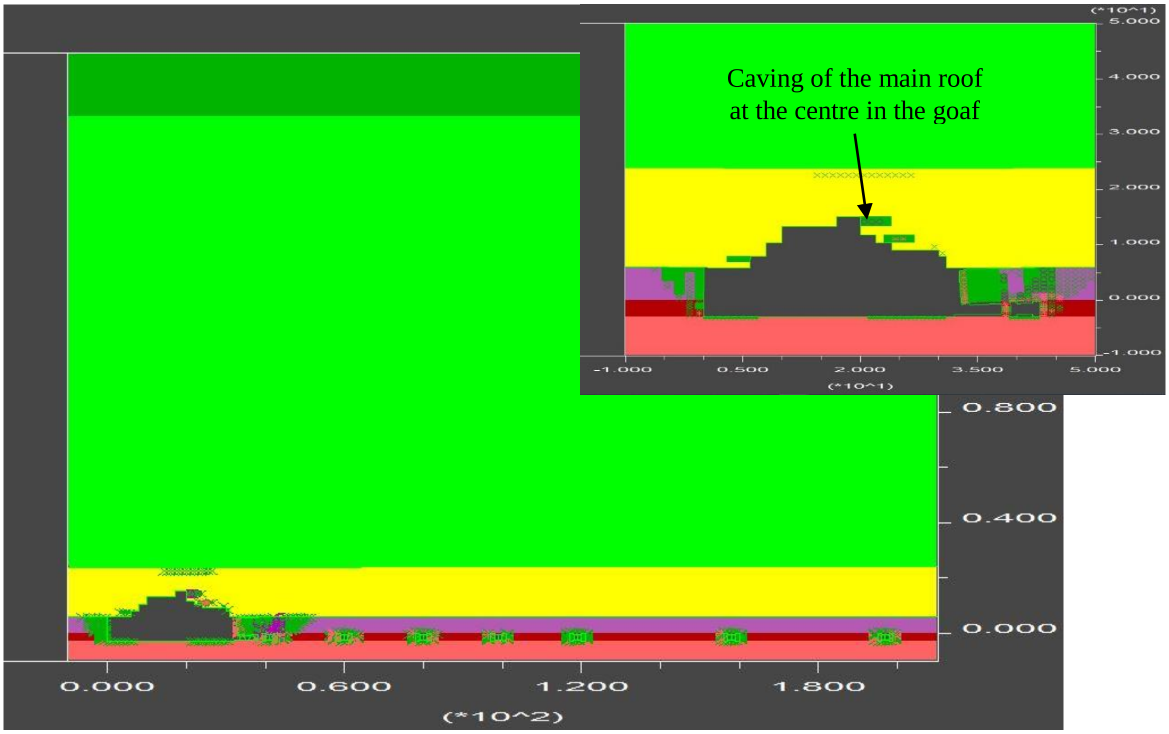
(b)


Tensile failure and softening at the centre of the main roof
0.800
0.400
0.000
0.000
0.600
1.200
1.800
(*10^2)

(c)


Caving of the main roof at the centre in the goaf with tensile failure
0.400
0.000
0.000
0.600
1.200
1.800
(*10^2)

(d)



(e)

Fig. 4.9. Model observed main fall for different PS/SC at cover depth of 250 m
(a) 34 m face advance, PS/SC = 0.21, PS = 38.5 m, SC = 187.5 m

(b) 36 m face advance, PS/SC = 0.36, PS = 59.3 m, SC = 166.7 m

(c) 38 m face advance, PS/SC = 0.81, PS = 101 m, SC = 125 m

(d) 38 m face advance, PS/SC = 1.71, PS = 142.7 m, SC = 83.3 m

(e) 38 m face advance, PS/SC = 2.62, PS = 163.5 m, SC = 62.5 m

4.3.2 Front Abutment Stress in the Working

Figure 4.10 shows the plot of the FASR with the progressive advance of the goaf edge for the maximum and the minimum PS/SC ratios of 0.21 and 2.62 at the cover depth of 250 m. The abutment stress is higher for depillaring working with the minimum PS/SC ratio of 0.21 compared to that with the higher PS/SC ratio. However, the peak FASR is only marginally higher for the lowest PS/SC. In either case, the first peak of the FASR is observed at 14 m of face advance, while the subsequent peaks are observed at 18 – 20 m intervals.

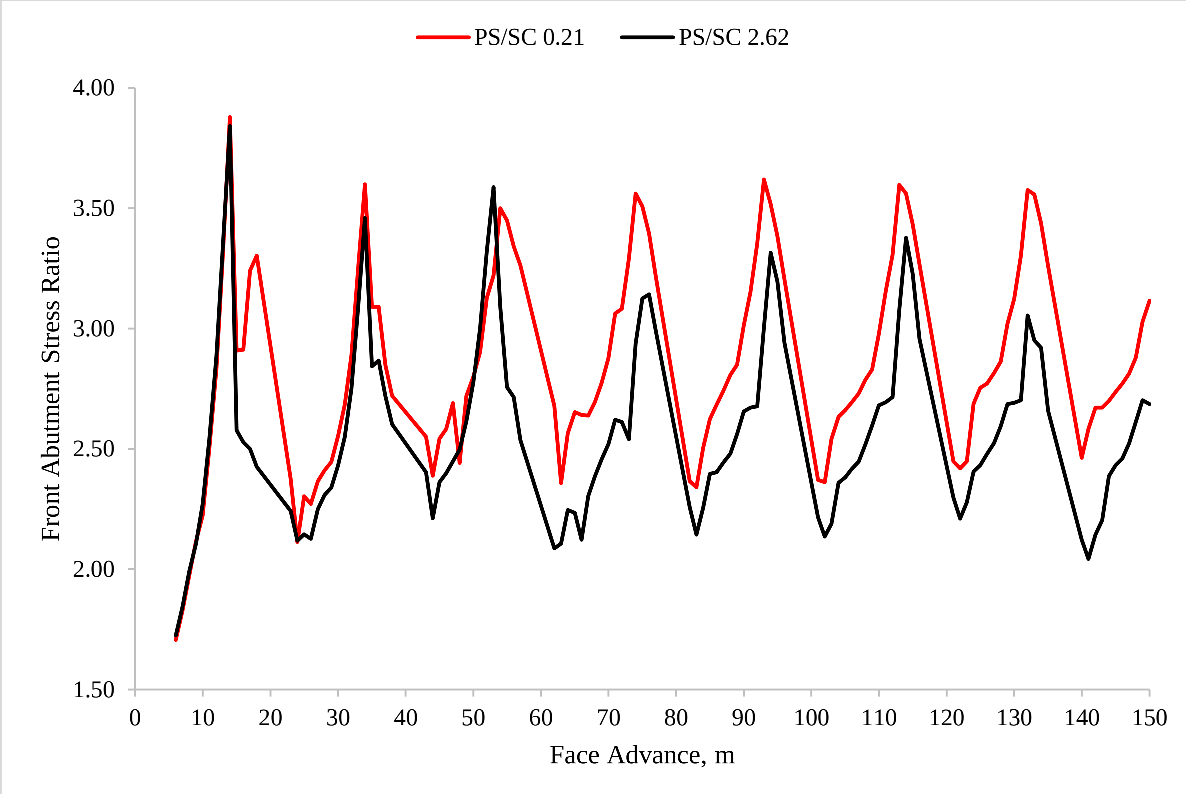


Fig. 4.10. Front abutment stress ratio at 250 m cover depth, PS/SC = 0.21, 2.62

4.3.3 Load on the Goaf Edge Support

Figure 4.11 shows the model observed load on the goaf edge support of 2 × 400 t capacity during the progressive depillaring under overburden having the lowest and the highest ratios of PS/SC. The overall profile of the support load shows a marginally increased loading while working under the lowest PS/SC ratio. The support achieved the yield load at several stages during the progressive mining in both cases.

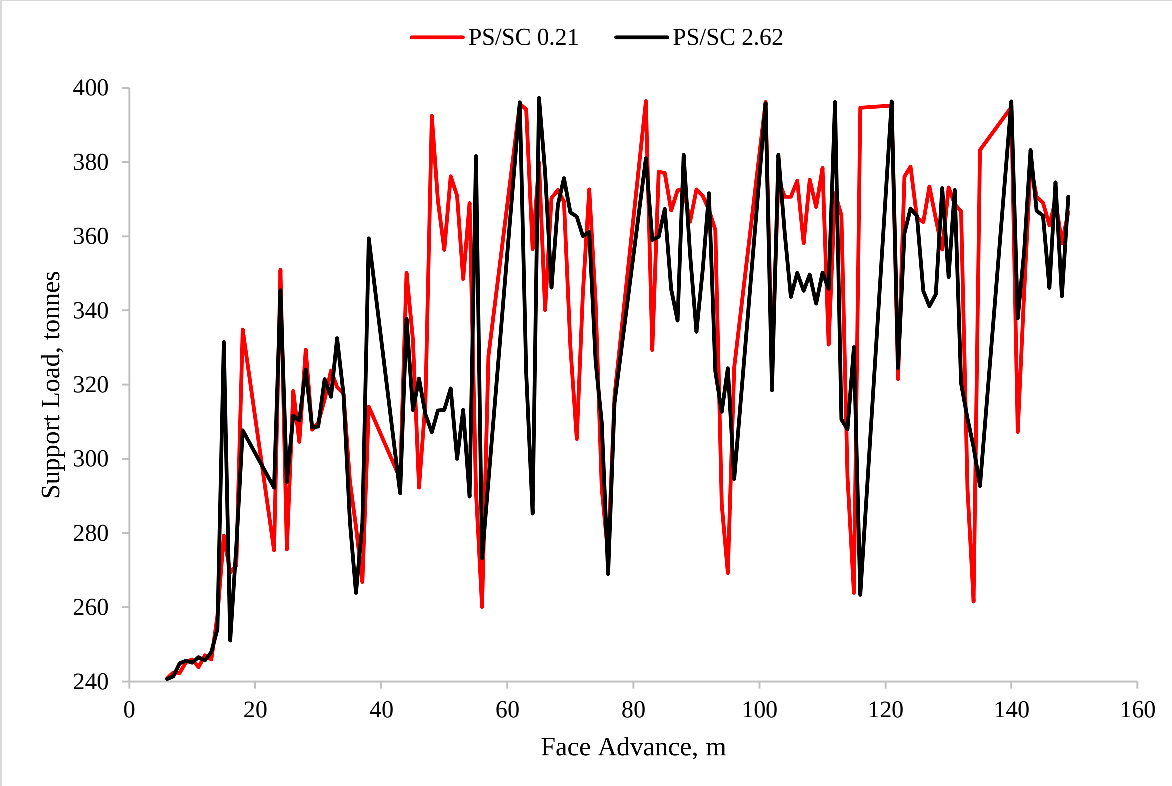


Fig. 4.11. Load on the goaf edge support of 2 × 400 t capacity at the cover depth of 250 m

4.3.4 Convergence at the Goaf Edge

Figure 4.12 shows the convergence slope at the goaf edge with the progressive depillaring under the lowest and the highest PS/SC ratio at the cover depth of 250 m. The plot shows that the GECS observed during progressive depillaring reduces with an increase in the PS/SC ratio. For the lowest PS/SC of 0.21, the goaf edge observed the maximum GECS of 102 mm/m. However, while mining under the highest PS/SC ratio of 2.62, the maximum GECS reduced to 55 mm/m, as observed at 82 m of face advance. These maximum values of goaf edge convergence were observed crossing the advance gallery at 78 – 82 m location.

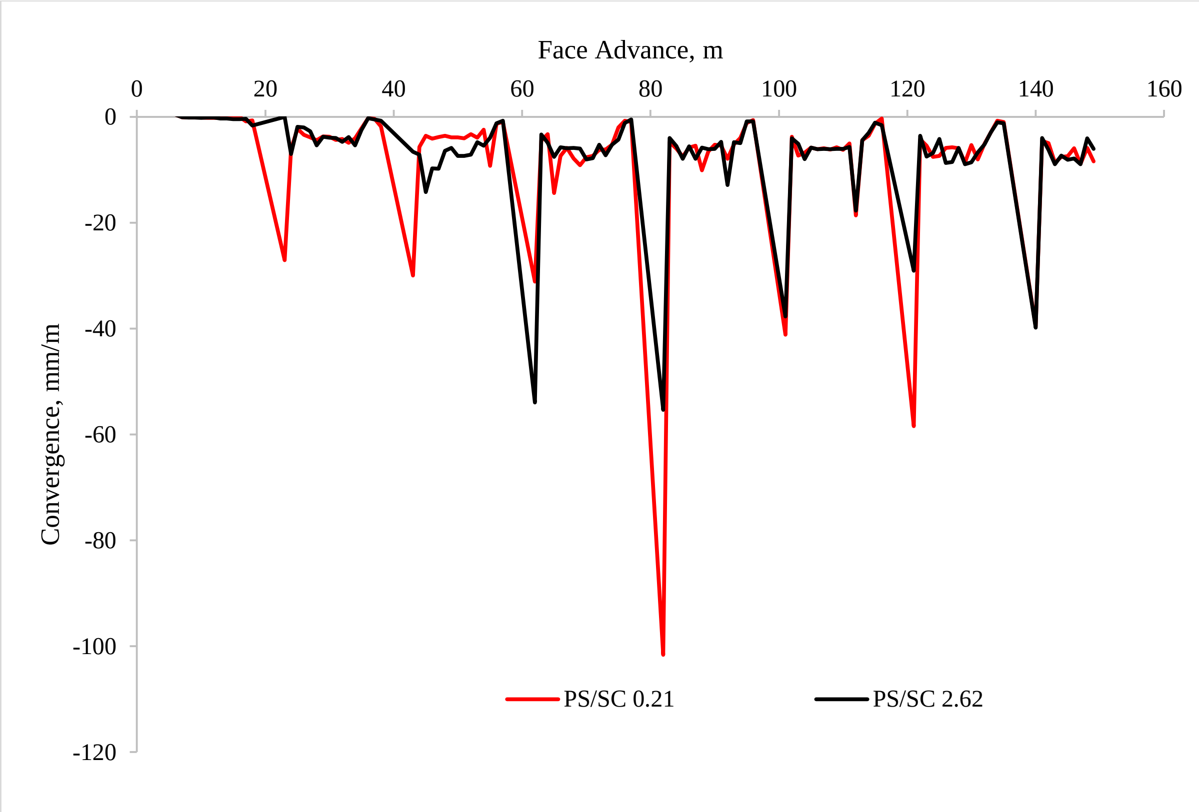


Fig. 4.12. Goaf edge convergence for different PS/SC at the cover depth of 250 m

The maximum convergence slope at the goaf edge (GECS) for different PS/SC at the cover depth of 250 m is given in Table 4.7. The general trend shows that with increasing thickness of parting strata and simultaneous reduction in thickness of softcover, the maximum convergence at the goaf edge reduces, consistent with the observation reported above.

Table 4.7. Maximum convergence at the goaf edge for varying PS/SC at 250 m depth

Parting strata (PS), m	Softcover (SC), m	PS/SC	Maximum convergence, mm
38.5	187.5	0.21	102
59.3	166.7	0.36	91
101	125	0.81	71
142.7	83.3	1.71	62
163.5	62.5	2.62	55

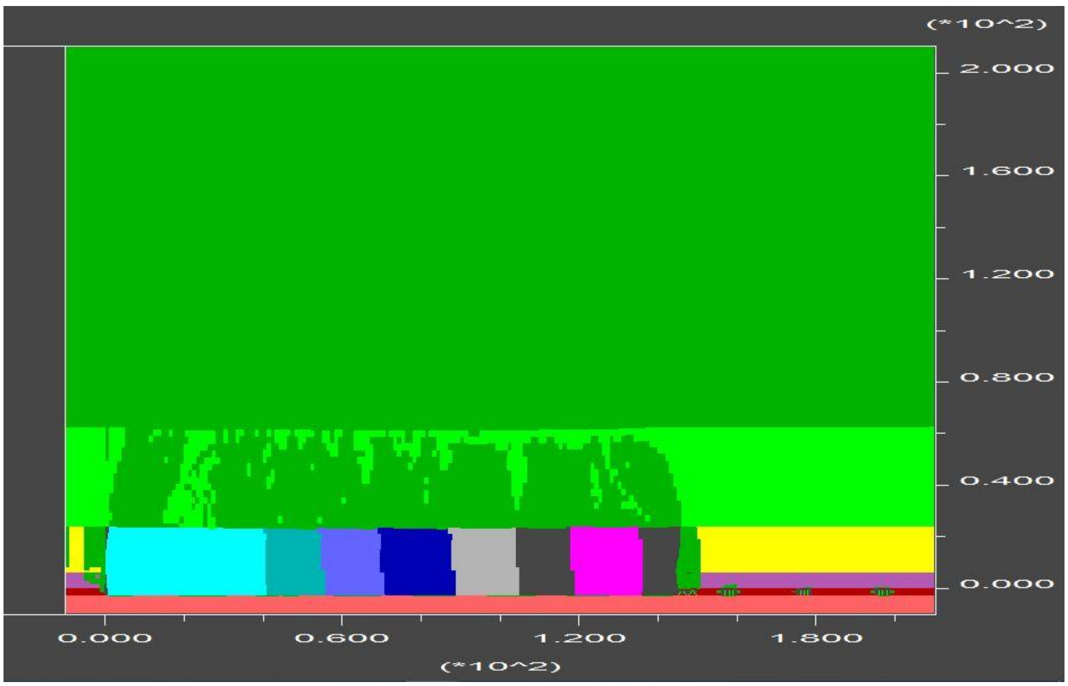
4.3.5 Bending Behaviour of Parting Strata and Stress Recovery in the Caved Goaf

For understanding the bending behaviour of the parting strata and the recovery of goaf stress at the cover depth of 250 m, the results of the parametric model having PS/SC ratio varying from 0.21 – 2.62 were evaluated. The thickness of parting strata varied from 38.5 m to 163.5 m, while the softcover varied from 62.5 – 187.5 m. The progressive depillaring was simulated for a cumulative face advance of 150 m in all the cases. The first filling of the caved goaf was done after 44 – 54 m of goaf exposure, depending on the condition when the majority of the main roof caved during the model observed main fall in a specific strata condition (Figure 4.13a – e). The subsequent fillings were made following the span of periodic caving as stated in Section 3.2.2.

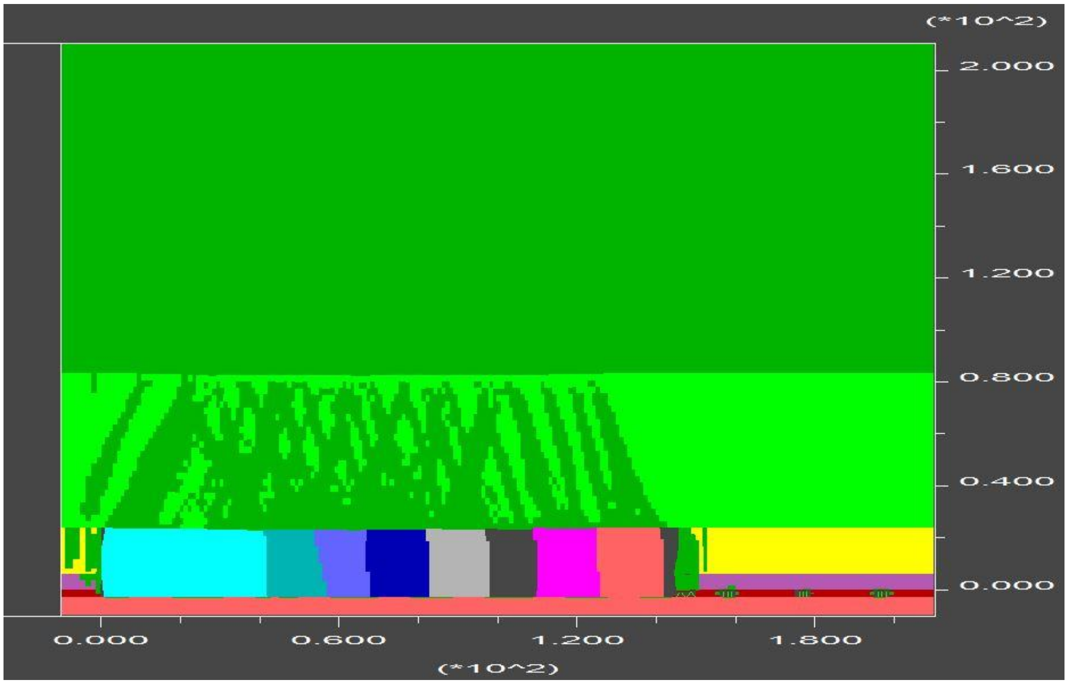
It was observed that in the first case (PS/SC = 0.21), when the parting strata are 38.5 m and the softcover is 187.5 m, almost sub-vertical tensile fractures developed in the parting strata during the settlement of the caved goaf with the progressive mining. It indicated that its thickness was inadequate to develop any arching effect for a controlled load transfer of the softcover in the goaf edge region (Figure 4.13a).

With an increase in the PS/SC ratio to 0.36, a noticeable change in the orientation of the fracture planes that developed in the parting strata upon its settlement was noted (Figure

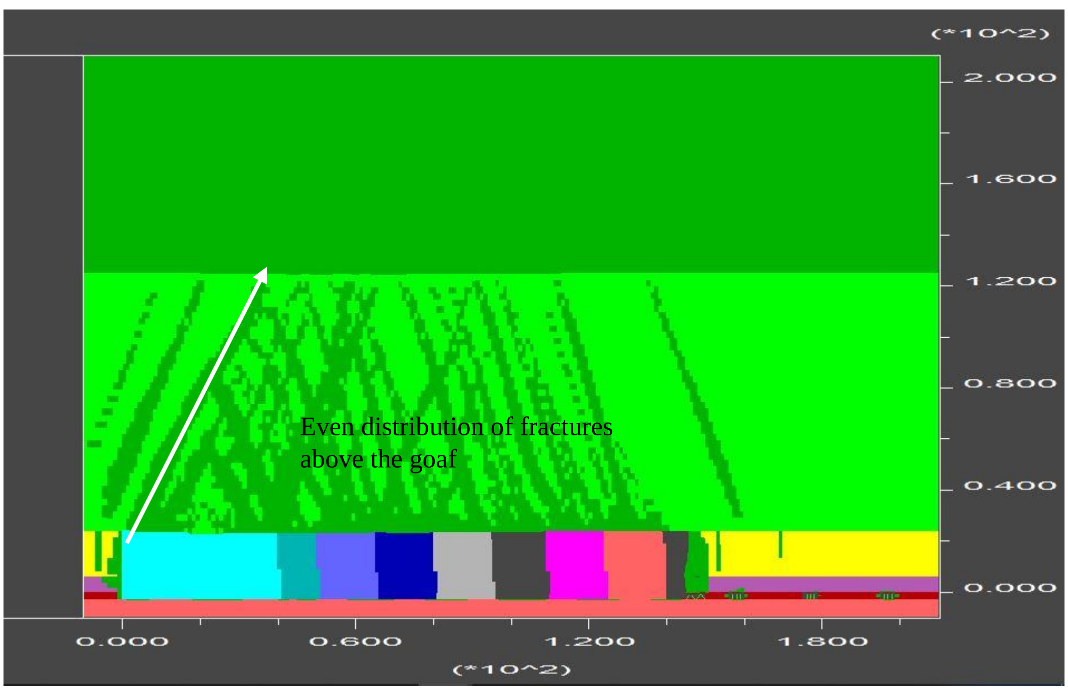
4.13b). These fractures subsequently merged, indicating that the arching action of the parting strata was still insufficient to offset the load of the softcover towards the central region of the goaf pile. With a further increase in the PS/SC to 0.81, the orientation of tensile fracture planes that formed in the PS over the goaf pile became further noticeable, along with a reduction in the fracture density (Figure 4.13c). A similar trend continued with the PS/SC ratio of 1.71 and 2.62 as well.



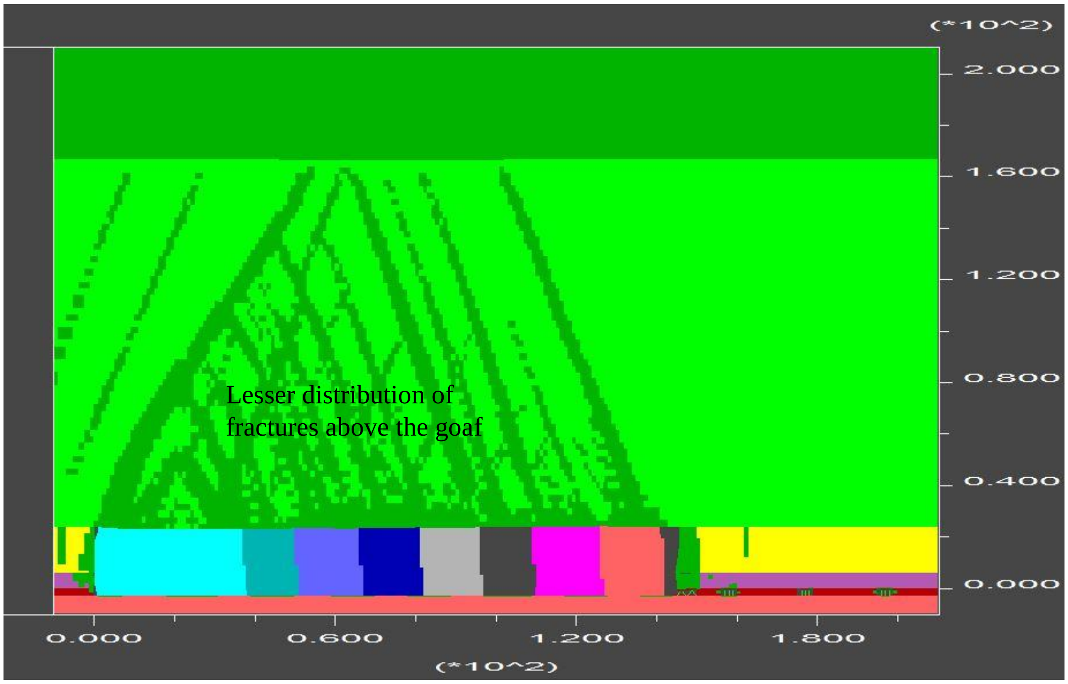
(a)


(*10^2)
2.000
1.600
1.200
0.800
0.400
0.000
0.000
0.600
1.200
1.800
(*10^2)

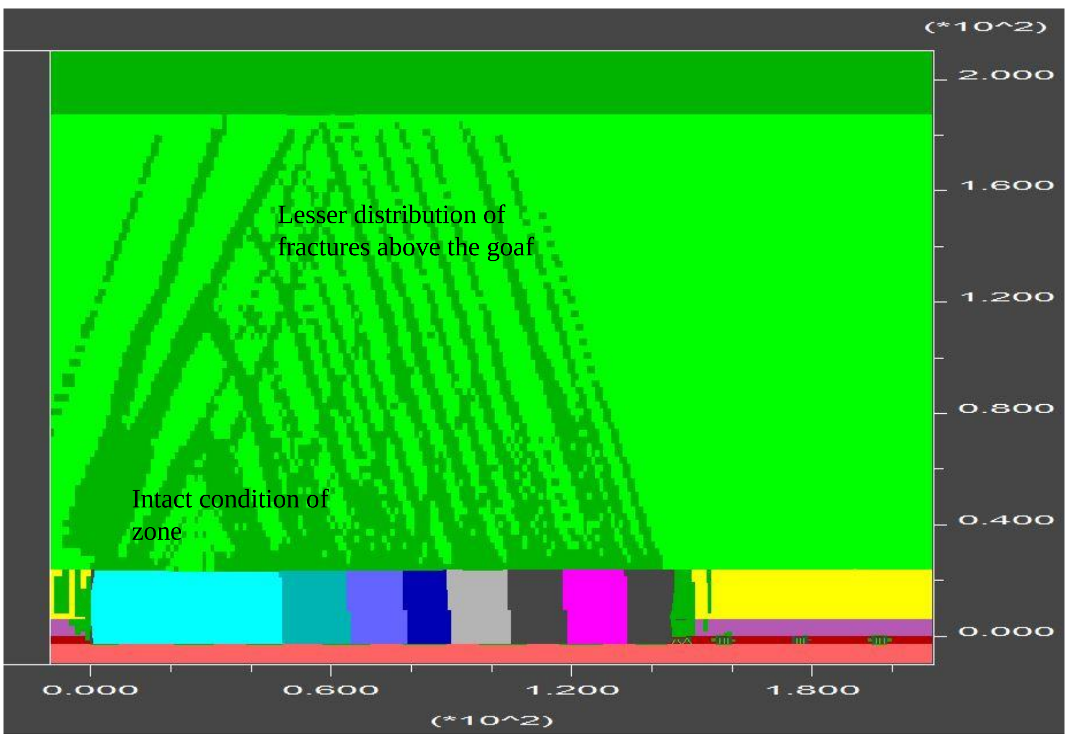
(b)


(*10^2)
2.000
1.600
1.200
0.800
0.400
0.000
Even distribution of fractures
above the goaf
0.000
0.600
1.200
1.800
(*10^2)

(c)



(d)



(e)

Fig. 4.13. Periodic goaf filling at 250 m cover depth; (a) PS/SC = 0.21, PS =38.5 m, SC =187.5 m, (b) PS/SC = 0.36, PS = 59.3 m, SC = 166.7 m, (c) PS/SC = 0.81, PS = 101 m, SC = 125 m, (d) PS/SC = 1.71, PS = 142.7 m, SC = 83.3 m, (e) PS/SC = 2.62, PS = 163.5 m, SC = 62.5 m

Figure 4.14 shows the trend of the maximum vertical settlement of the parting strata with progressive face advance at the cover depth of 250 m. The plot shows that for face advance up to a distance of 150 m against the maximum hardcover of 187.5 m, the maximum cumulative settlement of the parting strata is observed for the lowest PS/SC of 0.21, where the thickness of parting strata is 38.5 m while the softcover is 187.5 m. The total hardcover, in this case, was 62.5 m, out of which 24 m of the roof caved in the goaf during progressive mining. The minimum cumulative settlement of the parting strata is noted for the highest PS/SC of 2.62, where the thickness of parting strata is 163.5 m while the softcover is 62.5 m. The total hardcover, in this case, was 187.5 m. The cumulative settlement of the parting strata followed a consistently reducing trend with the increase in PS/SC. However, the relative difference between the maximum displacement observed for PS/SC of 1.71 and 2.62 is very small.

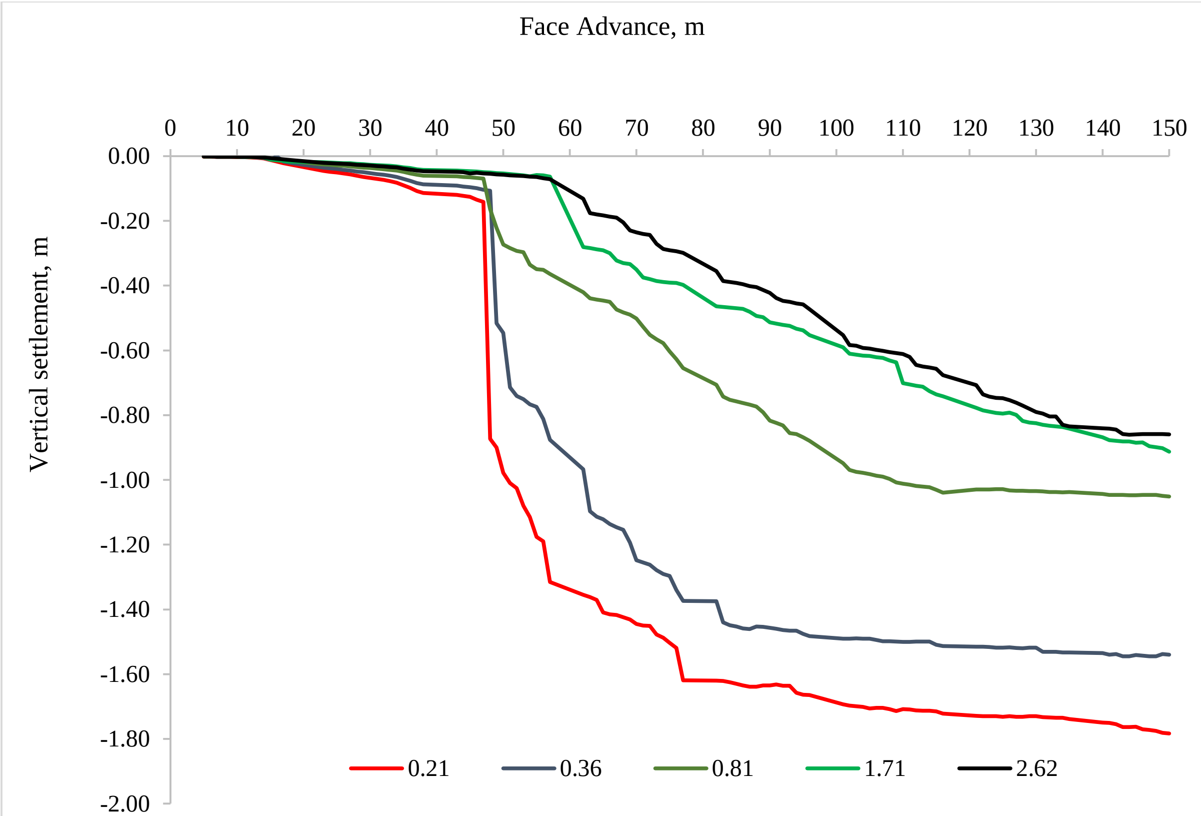


Fig. 4.14. Vertical settlement in parting strata for different PS/SC at 250 m cover depth

A sudden surge in the maximum settlement is recorded for PS/SC of 0.21 – 0.36, marking a complete rupture of the parting during progressive depillaring. For PS/SC of 0.21, the vertical displacement of the parting strata triggered at 47 m but stabilised at 50 m face position. The vertical displacement changed from 0.142 m to 0.978 m during this period. Similarly, for PS/SC ratio of 0.36, the displacement changed from 0.107 m at 48 m face position to 0.740 m at 52 m. Such behaviour of the parting indicates an uncontrolled load transfer.

As the parting becomes thicker and the SC becomes thinner with increasing PS/SC, the parting undergoes a partial rupture only as indicated by a relatively smaller surge in the maximum displacement in such cases. When the thickness of the parting is significantly higher than the softcover, no noticeable surge in its displacement trend is recorded, indicating its controlled settlement with the progressive face advance. However, for the highest PS/SC ratio of 2.62, the displacement trigger initiated at 62 m and ceased at 64 m of face position. The displacement increased from 0.131 m to 0.18 m in this period. The combined study of the displacement trend and the failure profile observed with progressive face advance shows that with increasing PS/SC, the extent of failure in the parting reduces. The partial rupture of relatively thicker parting leads to a smaller or insignificant surge in the maximum displacement, indicating its controlled settlement with the face progress.

The vertical stress recovery in the goaf for different PS/SC at 250 m depth shows that the stress recovered in the goaf just after the main fall is 36% of in situ vertical stress for minimum PS/SC of 0.21. The peak stress after the main fall reduces to 14% of the peak stress for the maximum PS/SC of 2.62 (Table 4.8).

Table 4.8. Vertical stress recovered after main fall at 250 m cover depth

PS/SC	0.21	0.36	0.81	1.71	2.62
Vertical stress recovery, MPa (% of in situ stress)	-1.85 (36)	-1.01 (19.7)	-1.01 (19.5)	-0.76 (14.5)	-0.73 (14)

The overall trend of stress recovered in the periodically filled goaf piles re-confirms relatively higher stress for the lowest PS/SC (Figure 4.15). The minimum cover pressure distance of 42 m is obtained for PS/SC of 0.21, while the maximum distance of 103 m is observed for PS/SC of 2.62.

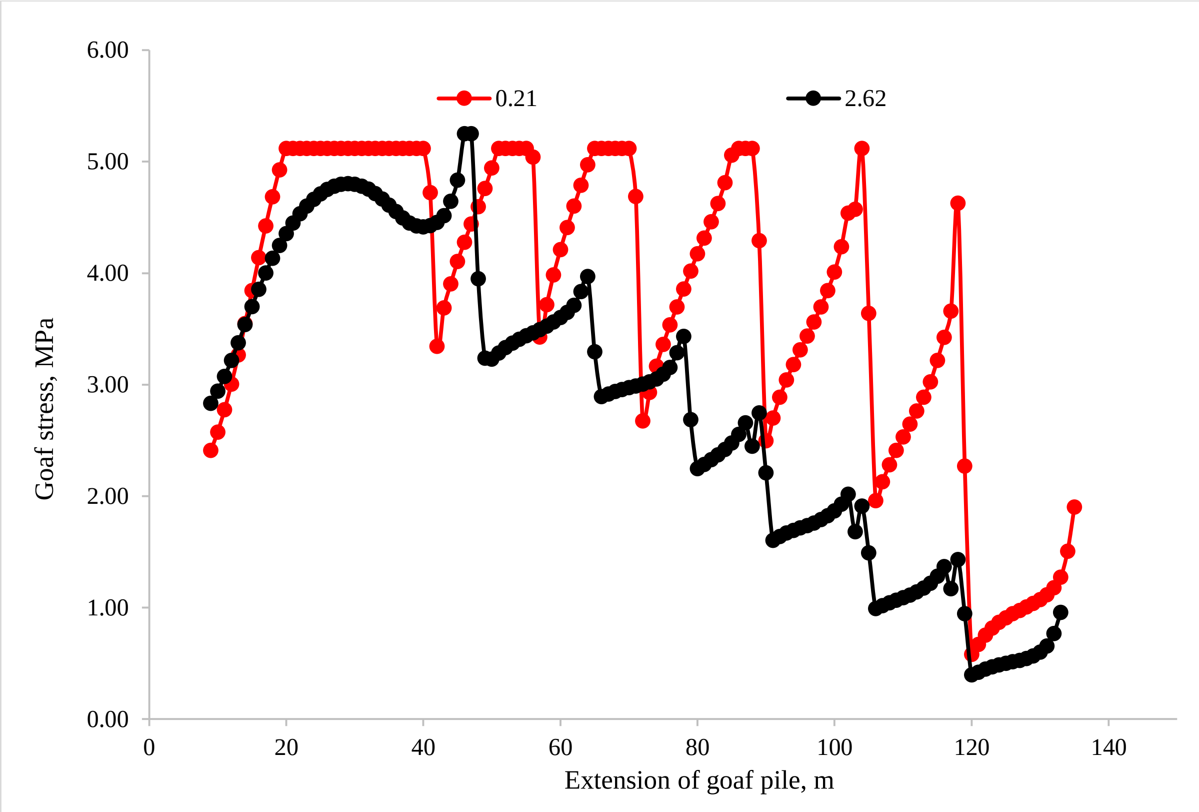


Fig. 4.15. Stress recovery at the cover depth of 250 m, PS/SC = 0.21, 2.62

4.4 Strata and Support Behaviour at 350 m depth

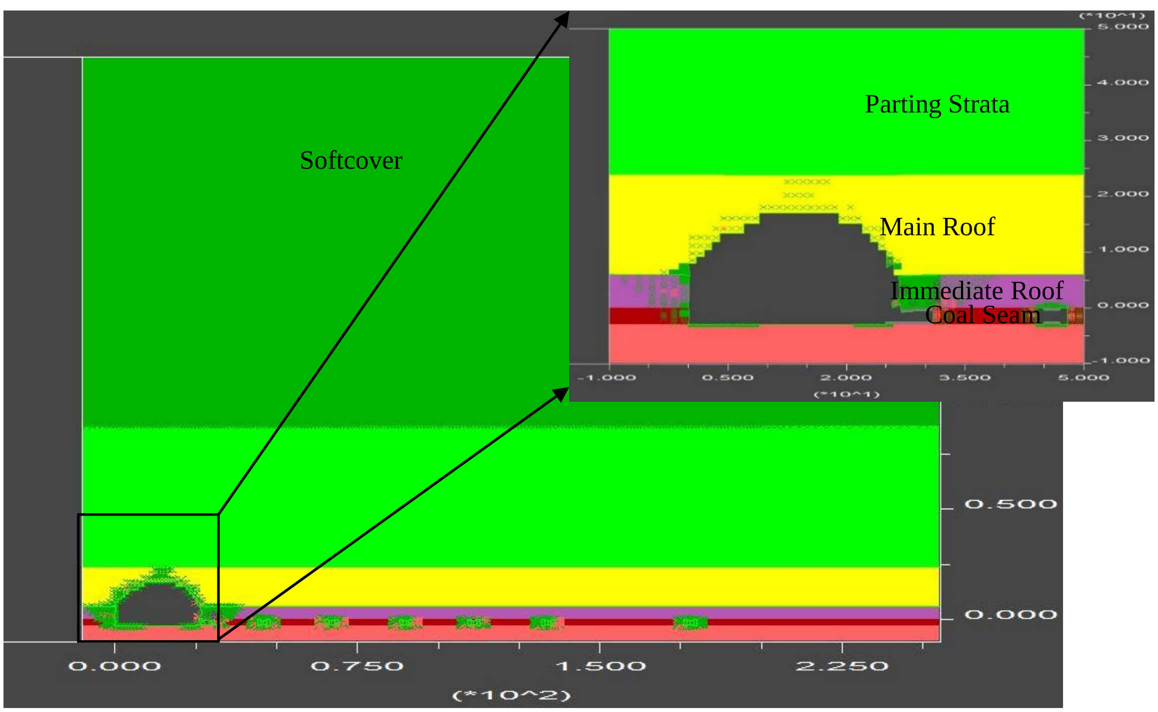
Four experimental models were studied for the thickness of parting strata (PS), varying from 63.5 m to 209.3 m and softcover (SC), varying from 116.7 m to 262.5 m. The thickness of the hardcover (HC) varied from 87.5 m to 233.3 m. The ratio of PS/SC varied from 0.24 – 1.79, while the HC/SC varied from 0.33 – 2.0 in this experimental study set.

4.4.1 Caving Behaviour

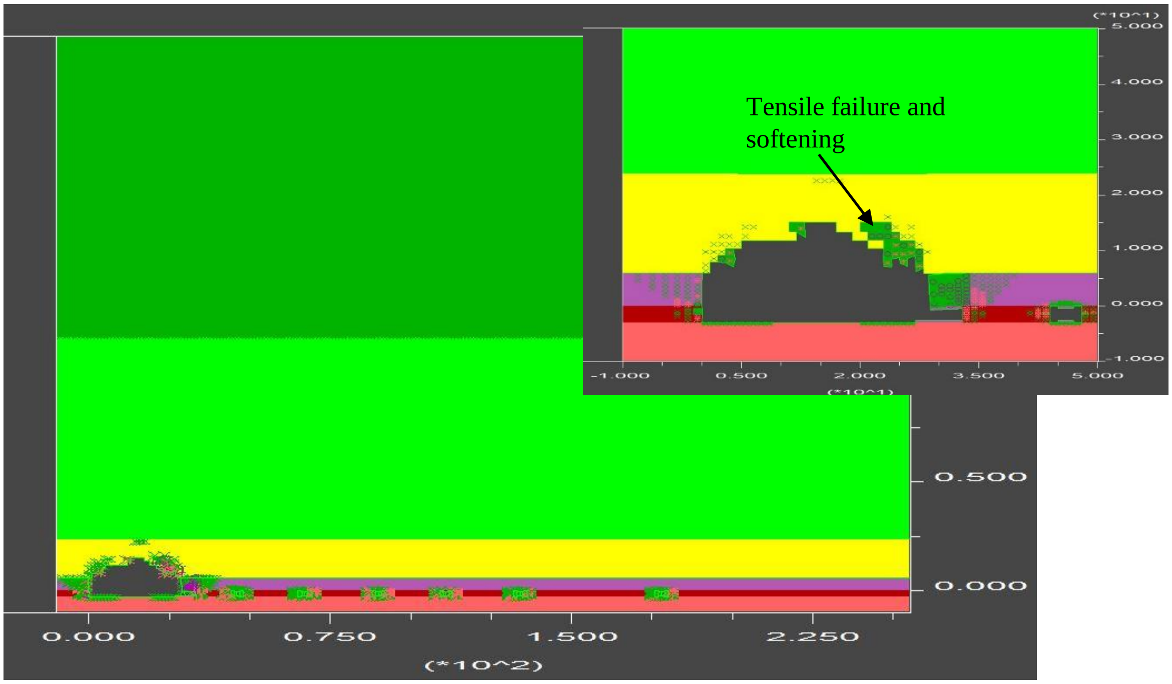
The result shows that for the thinnest PS of 63.5 m overlain by 262.5 m thick SC, the main fall initiated at 31 m of face advance, leaving some tensile failure zones in the overhang of the main roof (Figure 4.16a). As the thickness of PS increased to 92.7 m, and the SC reduced to 233.3 m, the extent of tension zones decreased, and the main roof caved after a slightly increased face advance of 33 m (Figure 4.16b). Similar nature of caving of the main roof was observed with PS of 151 m and 209.3 m in combination with the SC of 175 m and 116.7 m, respectively (Figure 4.16c – d). The main fall span increased from 31 to 36 m for an increase in the ratio of PS/SC from 0.24 – 0.86 and remained constant after that (Table 4.9).

Table 4.9. Model observed main fall span at 350 m cover depth

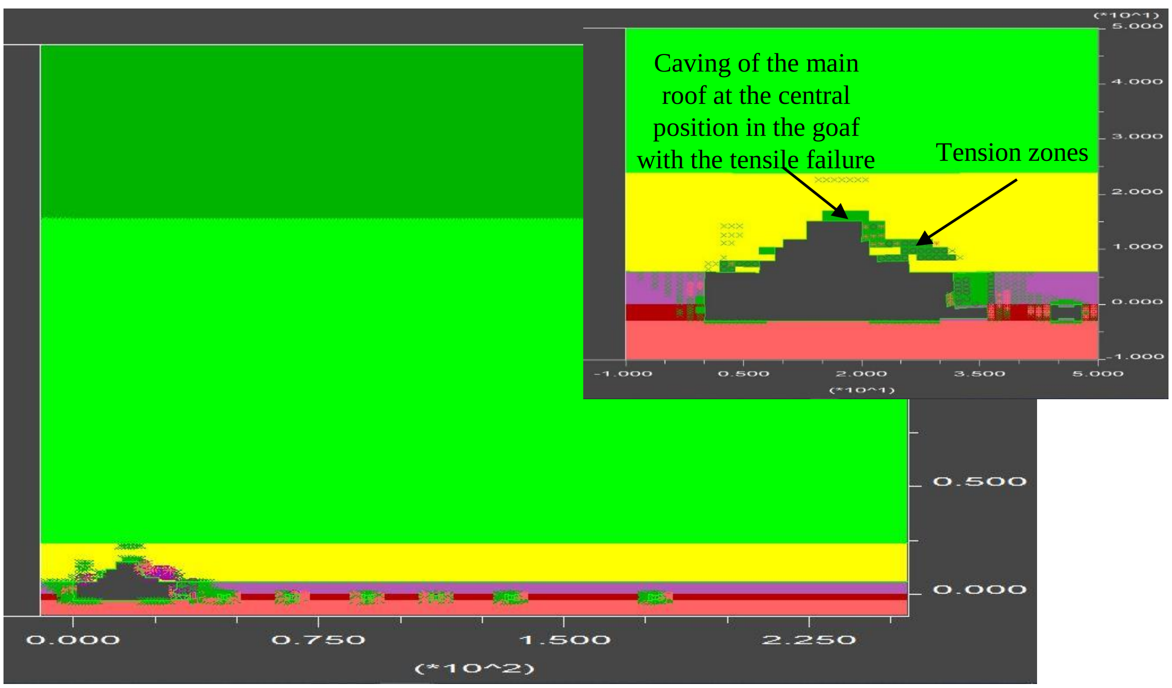
Parting Strata (PS) thickness, m	Softcover (SC) thickness, m	PS/SC	Main Fall span, m
63.5	262.5	0.24	31
92.7	233.3	0.4	33
151	175	0.86	36
209.3	116.7	1.79	36



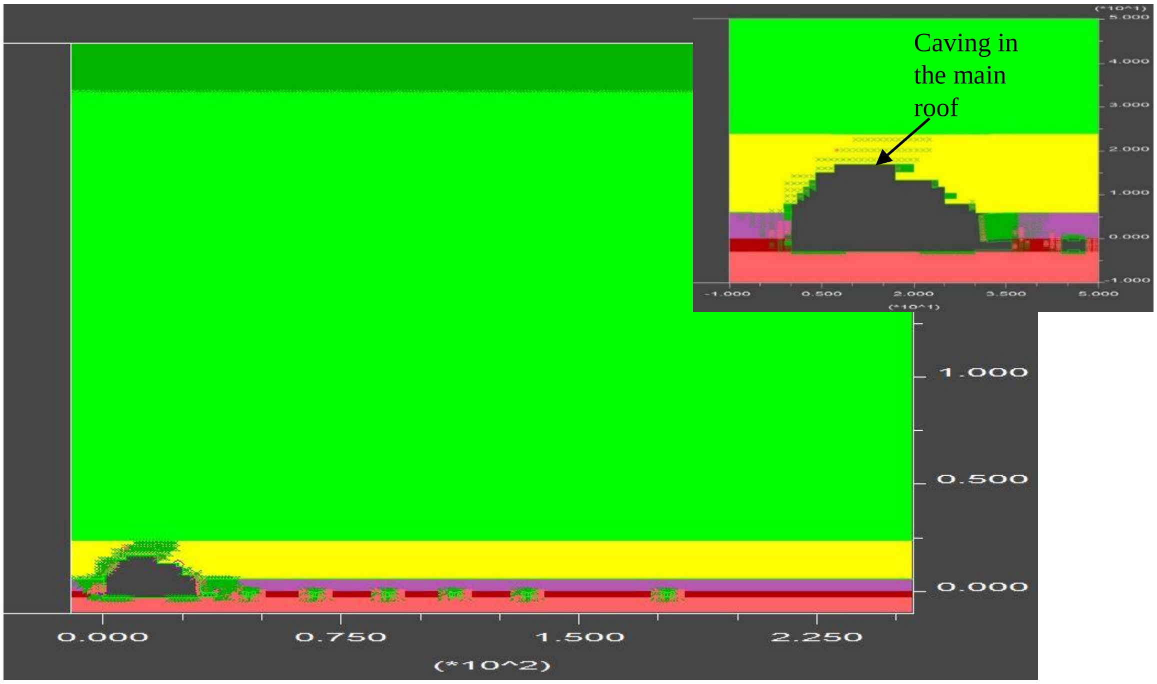
(a)


Tensile failure and softening
0.000
0.750
1.500
2.250
(*10^2)
0.500
0.000

(b)


Caving of the main roof at the central position in the goaf with the tensile failure
Tension zones
0.000
0.750
1.500
2.250
(*10^2)
0.500
0.000

(c)



(d)

Fig. 4.16. Model observed main fall at 350 m cover depth; (a) 31 m face advance, PS/SC = 0.24, PS = 63.5 m, SC = 262.5 m, (b) 33 m face advance, PS/SC = 0.4, PS = 92.7 m, SC = 233.3 m, (c) 36 m face advance, PS/SC = 0.86, PS = 151 m, SC = 175 m, (d) 36 m face advance, PS/SC = 1.79, PS = 209.3 m, SC = 116.7 m

4.4.2 Front Abutment Stress in the Working

Figure 4.17 shows the plot of the FASR with the progressive advance of the goaf edge for the maximum and the minimum PS/SC ratios of 0.24 and 1.79 at the cover depth of 350 m. The abutment stress is relatively higher for the minimum PS/SC ratio of 0.24 compared to that with PS/SC of 1.79. However, the peak FASR is almost similar for the two conditions. In either case, the first peak of the FASR is observed at 15 m of face advance, while the subsequent peaks are observed at 20 – 24 m intervals.

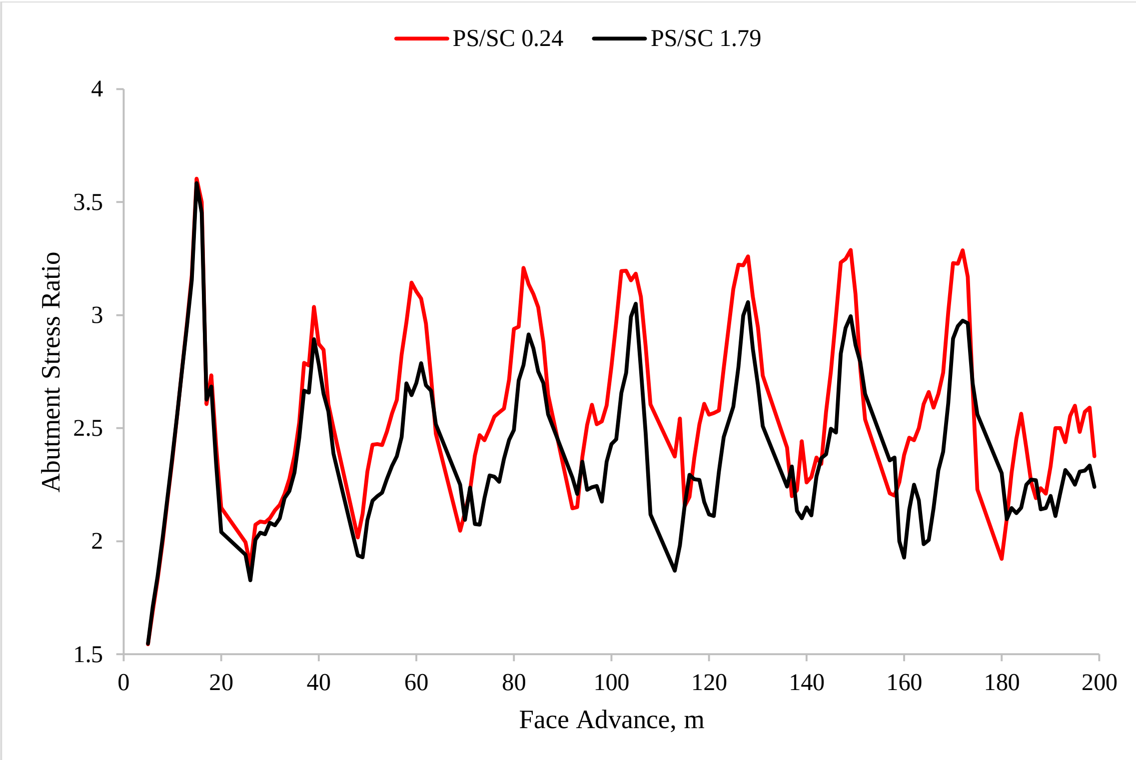


Fig. 4.17. Front abutment stress ratio at 350 m cover depth, PS/SC = 0.24, 1.79

4.4.3 Load on the Goaf Edge Support

Figure 4.18 shows the model observed load on the goaf edge support of 2 × 400 t capacity during the progressive depillaring under overburden having the lowest and the highest ratios of PS/SC. The overall profile of the support load shows higher loading while working under lesser PS/SC. The support achieved near yield load at several stages during progressive mining in both the cases.

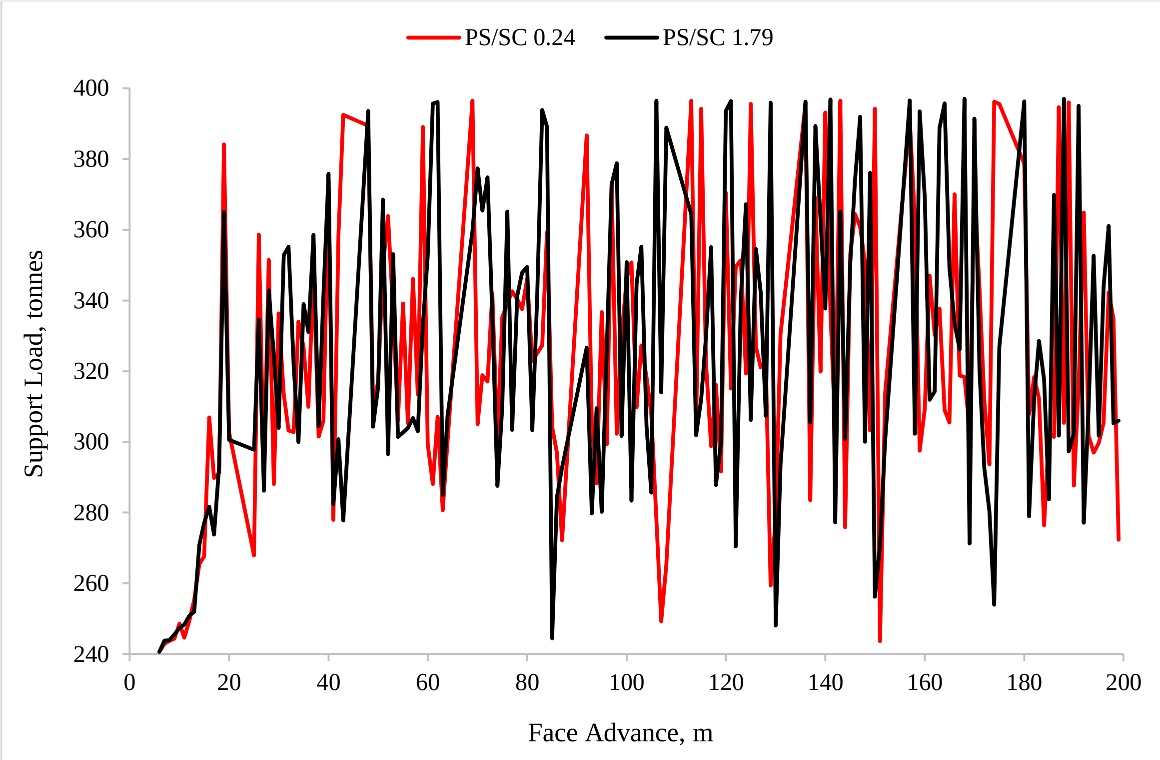


Fig. 4.18. Load on the goaf edge support of 2 × 400 t capacity at the cover depth of 350 m

4.4.4 Convergence at the Goaf Edge

Figure 4.19 shows the convergence slope at the goaf edge with the progressive depillaring under the lowest and the highest PS/SC ratio at the cover depth of 350 m. The plot shows that the GECS observed during progressive depillaring reduces with an increase in the PS/SC ratio. For the lowest PS/SC of 0.24, the goaf edge observed the maximum GECS of 91 mm/m at 136 m face advance. However, while mining under the highest PS/SC ratio of 1.79, the maximum GECS reduced to 54 mm/m, as observed at 48 m of face advance. These maximum goaf edge convergence were observed crossing the advance gallery at 132 – 136 m and 44 – 48 m locations.

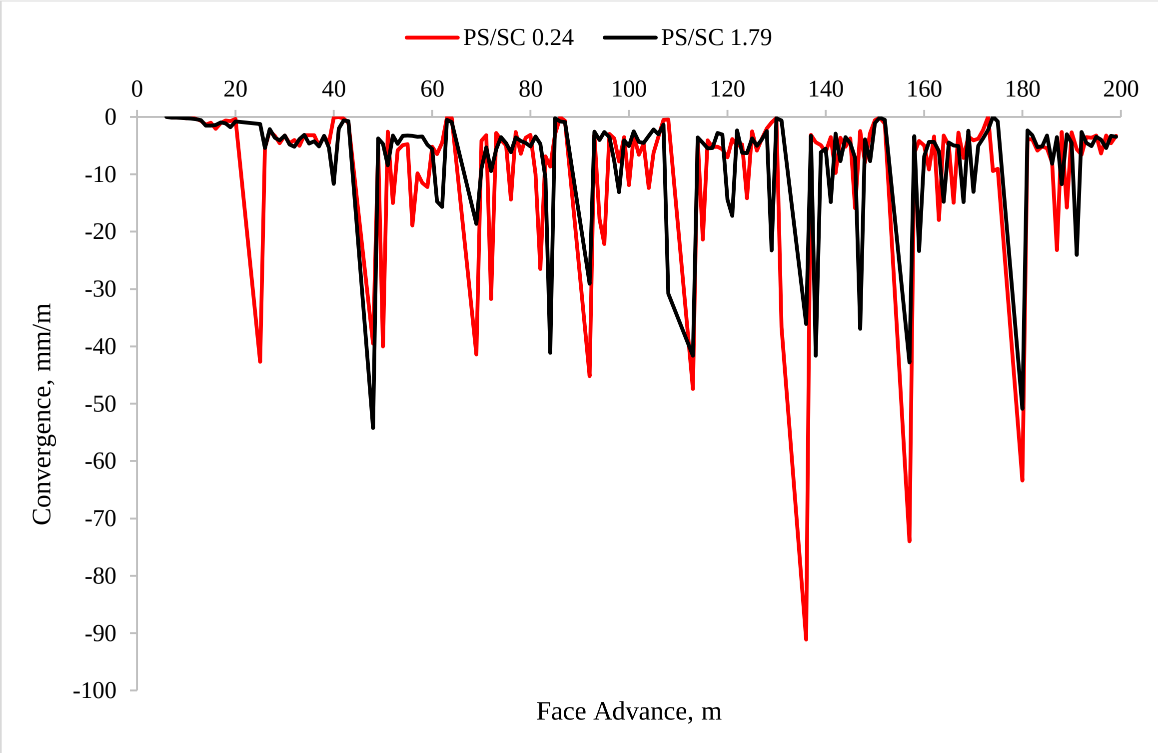


Fig. 4.19. Goaf edge convergence for different PS/SC ratios at the cover depth of 350 m

The maximum convergence slope at the goaf edge (GECS) for different PS/SC at 350 m cover depth is given in Table 4.10. The general trend shows that with increasing thickness of parting strata and simultaneous reduction in thickness of softcover, the maximum convergence at the goaf edge reduces, consistent with the observation reported above.

Table 4.10. Maximum convergence at the goaf edge for varying PS/SC at 350 m depth

Parting Strata Thickness, m	Softcover, m	PS/SC ratio	Max. Conv, mm
63.5	262.5	0.24	91
92.7	233.3	0.4	88
151	175	0.86	67
209.3	116.7	1.79	54

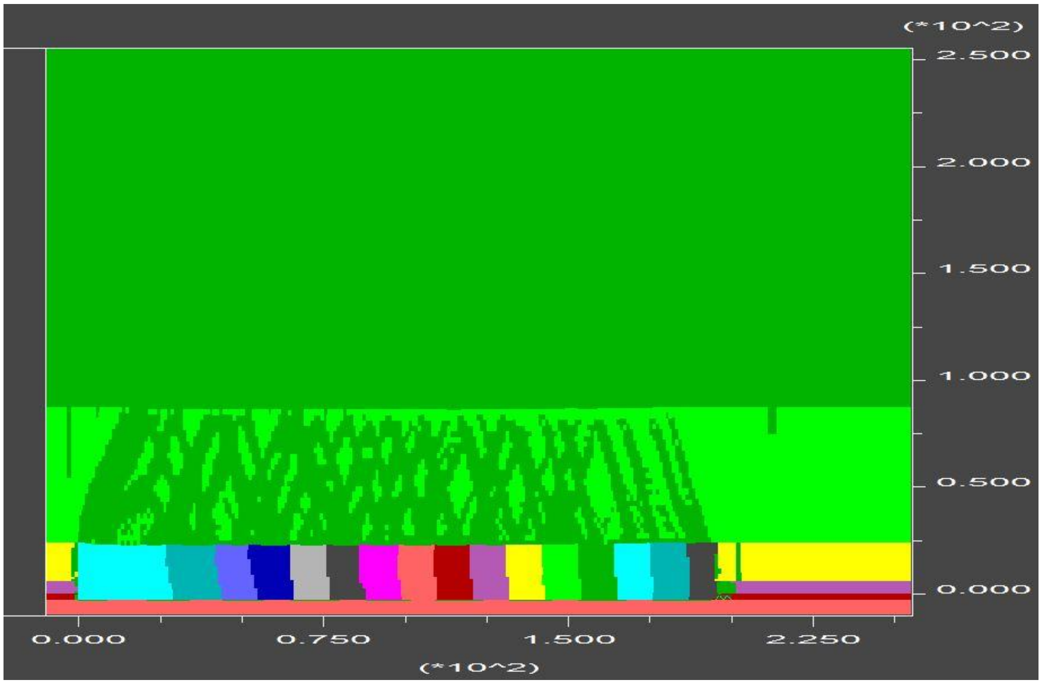
4.4.5 Bending Behaviour of Parting Strata and Stress Recovery in the Caved Goaf

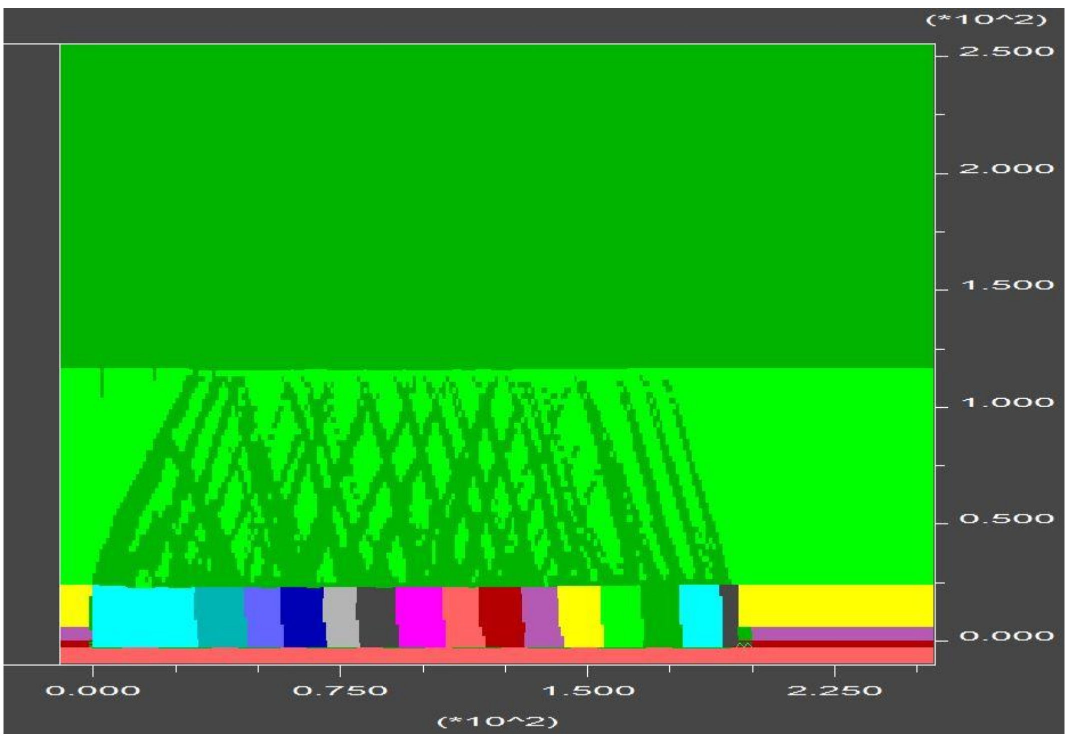
For understanding the bending behaviour of the parting strata and the recovery of goaf stress at the cover depth of 350 m, the results of the parametric model having a PS/SC ratio varying from 0.24 – 1.79 were evaluated. The thickness of parting strata varied from 63.5 m to 209.3 m, while the softcover varied from 116.7 – 262.5 m. The progressive depillaring was simulated for a cumulative face advance of 200 m in all the cases. The first filling of the caved goaf was done after 39 – 49 m of goaf exposure, depending on the condition when the majority of the main roof caved during the model observed main fall in a specific strata condition (Figure 4.20a – d). The subsequent fillings were made following the span of periodic caving as stated in Section 3.2.2.

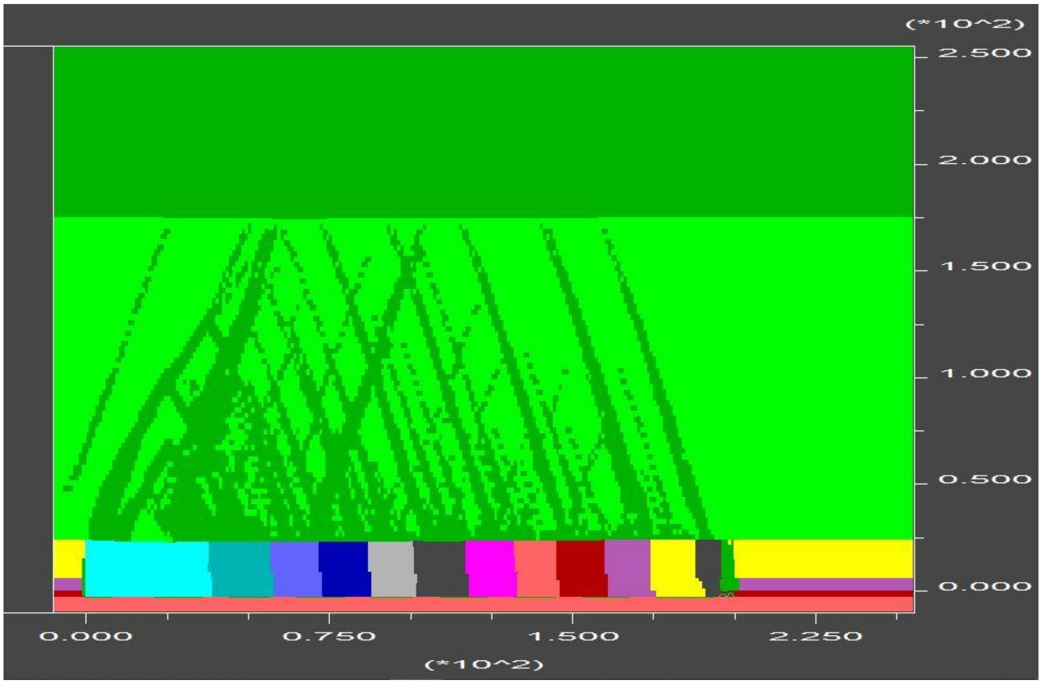
It was observed that in the first case (PS/SC = 0.24) when the parting strata are 63.5 m while the softcover is 262.5 m, sub-vertical tensile fractures developed in the parting strata during the settlement of the caved goaf with the progressive mining indicating that its thickness was inadequate to develop any arching effect for a controlled load transfer of the softcover in the goaf edge region (Figure 4.20a).

With the increase in the PS/SC ratio to 0.4, a noticeable change in the orientation of the fracture planes that developed in the parting strata upon its settlement was noted (Figure 4.20b). These fractures subsequently merged, indicating that the arching action of the parting strata was still insufficient to offset the load of the softcover towards the central region of the goaf pile.

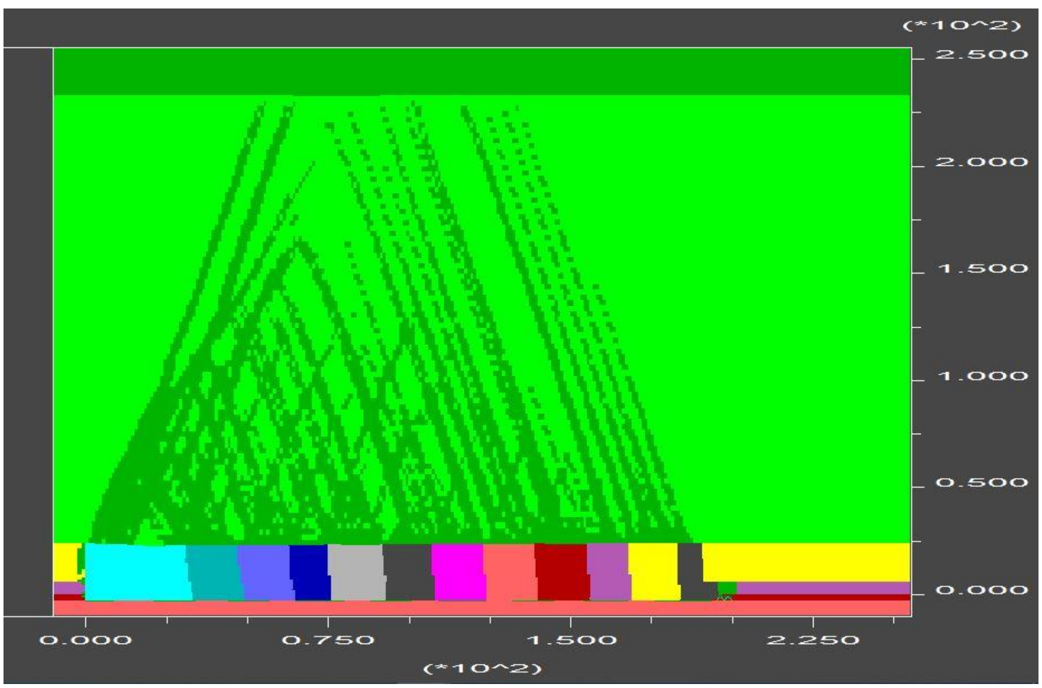
With a further increase in the PS/SC to 0.86, the orientation of tensile fracture planes that formed in the PS over the goaf pile became further noticeable, along with a reduction in the fracture density (Figure 4.20c). A similar trend continued with the PS/SC ratio of 1.79.


(*10^2)
2.500
2.000
1.500
1.000
0.500
0.000
0.000
0.750
1.500
2.250
(*10^2)
(a)


(*10^2)
2.500
2.000
1.500
1.000
0.500
0.000
0.000
0.750
1.500
2.250
(*10^2)
(b)



(c)



(d)

Fig. 4.20. Periodic goaf filling at 350 m cover depth, (a) PS/SC = 0.24, PS = 63.5 m, SC = 262.5 m; (b) PS/SC = 0.4, PS = 92.7 m, SC = 233.3 m; (c) PS/SC = 0.86, PS = 151 m, SC = 175 m; (d) PS/SC = 1.79, PS = 209.3 m, SC = 116.7 m

Figure 4.21 shows the trend of the maximum vertical settlement of the parting strata with progressive face advance at cover depth of 350 m. The plot shows that for face advance up to a distance of 200 m against the maximum hardcover of 233.3 m, the maximum cumulative settlement of the parting strata is observed for the lowest PS/SC of 0.24, where the thickness of parting strata is 63.5 m while the softcover is 262.5 m. The total hardcover, in this case, was 87.5 m, out of which 24 m of the roof caved in the goaf during progressive mining. The minimum cumulative settlement of the parting strata is noted for the highest PS/SC of 1.79, where the thickness of parting strata is 209.3 m while the softcover is 116.7 m. The total hardcover, in this case, was 233.3 m. The cumulative settlement of the parting strata followed a consistently reducing trend with the increase in PS/SC.

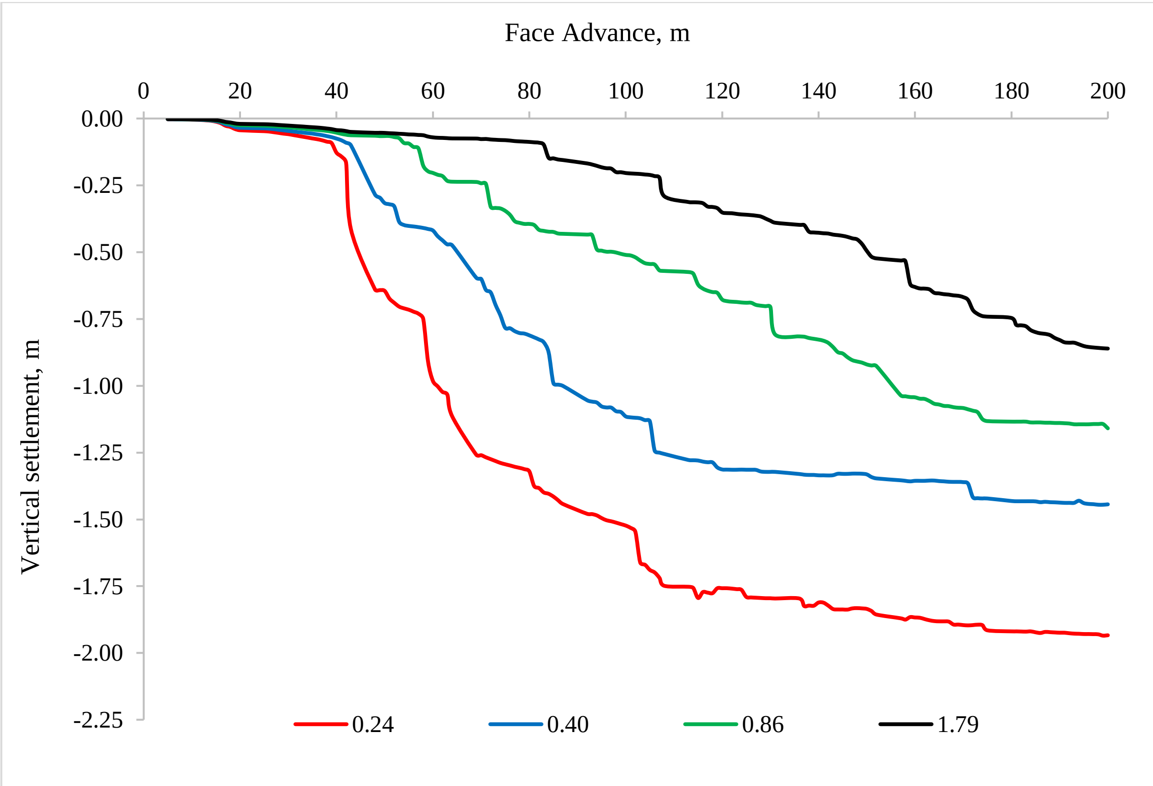


Fig. 4.21. Vertical settlement of parting strata for different PS/SC at 350 m cover depth

A sudden surge in the maximum settlement is recorded for PS/SC of 0.24 – 0.40, marking a complete rupture of the parting during progressive depillaring. For PS/SC of 0.24, the vertical displacement of the parting strata triggered at 39 m but stabilised at 49 m face position. The vertical displacement changed from 0.09 m to 0.642 m during this period. Similarly, for PS/SC ratio of 0.4, the displacement changed from 0.1 m at 43 m face position to 0.40 m at 55 m. However, for the highest PS/SC ratio of 1.79, the displacement trigger initiated at 83 m and ceased at 107 m of face position. The displacement increased from 0.098 m to 0.221 m in this period. The combined study of the displacement trend and the failure profile observed with progressive face advance shows that with increasing PS/SC, the extent of failure in the parting reduces. The partial rupture of relatively thicker parting leads to a smaller or insignificant surge in the maximum displacement, indicating its controlled settlement with progressive face movement.

The vertical stress recovery in the goaf for different PS/SC at 350 m depth shows that the stress recovered in the goaf just after the main fall is 9.36% of in situ vertical stress for minimum PS/SC of 0.24. The peak stress after the main fall increased to 15.8% of the in situ vertical stress for the maximum PS/SC of 1.79 (Table 4.11).

Table 4.11. Vertical stress recovered after main fall at 350 m cover depth

PS/SC	0.24	0.40	0.86	1.79
Vertical stress recovery, MPa (% of in situ stress)	-0.67 (9.36)	-0.73 (10.3)	-0.95 (13.2)	-1.15 (15.8)

The overall trend of stress recovered in the periodically filled goaf piles re-confirms relatively higher stress for the lowest PS/SC (Figure 4.22). The minimum cover pressure distance of 89 m is obtained for PS/SC of 0.24, while the maximum distance of 145 m is observed for PS/SC of 0.86. The goaf did not achieve cover pressure in the case of PS/SC of 1.79.

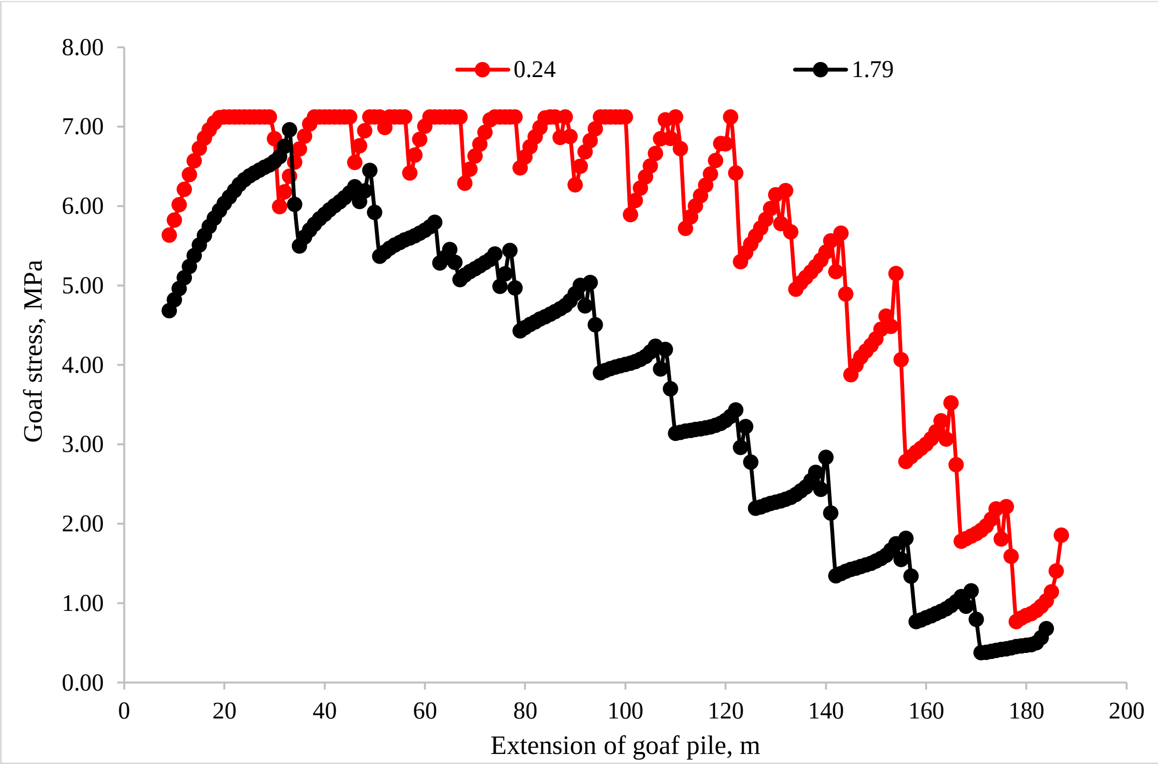


Fig. 4.22. Goaf stress recovery at 350 m cover depth for PS/SC = 0.24, 1.79

4.5 Results

The modelling observations showed that for cover depth of 150 m, the span of main fall varied from 36 to 42 m for change in PS/SC from 0.12 – 2.36. Similarly, the span of the main fall increased from 34 – 38 m for the PS/SC of 0.21 – 2.62 at 250 m and 31 – 36 m for the PS/SC of 0.24 – 1.79 at 350 m cover depth (Table 4.12). For a given cover depth, the span of the main fall followed a non-linear increasing trend with increasing PS/SC, but it reduced with the increase in the cover depth (Figure 4.23). The previous work reported by Kushwaha and Banerjee (2005) and Wang et al. (2019c) support these findings.

Table 4.12. Main fall span at different PS/SC at the cover depth of 150 – 350 m

Cover depth, m	PS/SC	Main Fall span, m
150	0.12	36
	0.26	38
	0.68	40
	1.52	42
	2.36	42
250	0.21	34
	0.36	36
	0.81	38
	1.71	38
	2.62	38
350	0.24	31
	0.40	33
	0.86	36
	1.79	36

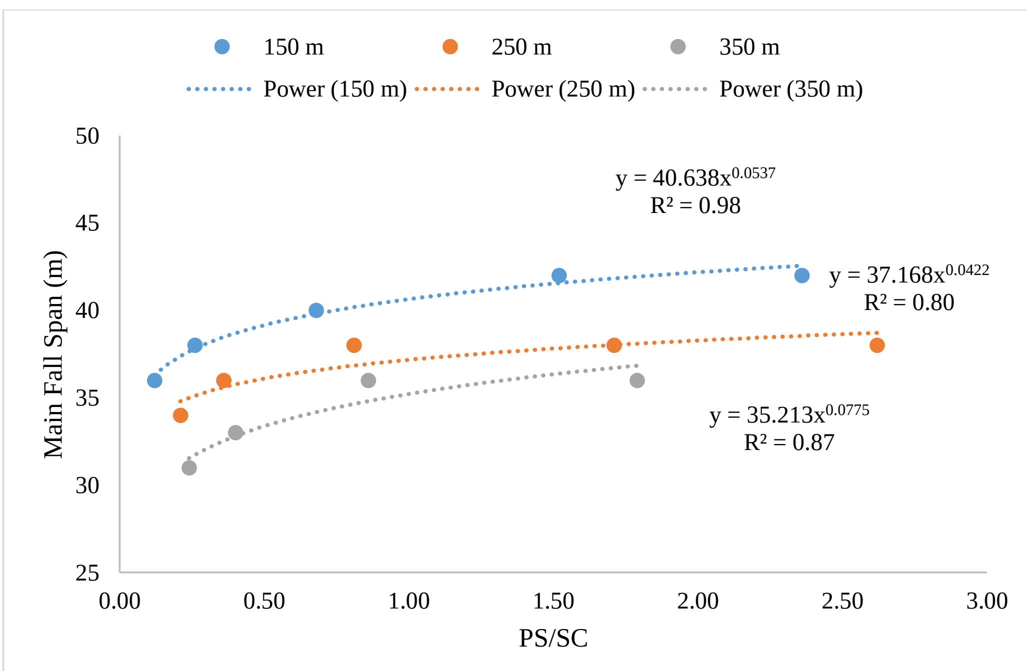


Fig. 4.23. Effect of PS/SC on the main fall span at different cover depth

The influence of the front abutment stress ratio on different PS/SC ratios at all cover depths was determined in terms of the maximum and the average front abutment stress ratio. The maximum front abutment stress ratio is the ratio of the maximum front abutment stress obtained during progressive face advance to the in situ vertical stress for a given condition. In contrast, the average front abutment stress ratio is the average of front abutment stress obtained at each stage of progressive face advance to the in situ vertical stress. These parameters have been used to assess the maximum and average abutment loading intensity at the face while progressive depillaring at different cover depths and PS/SC. The findings show that at a shallow depth of cover, the maximum, as well as the average values of the FASR, reduce with an increase in PS/SC (Figure 4.24-4.25). However, at higher depth, the maximum FASR remains almost the same while the average FASR reduces with an increase in the PS/SC.

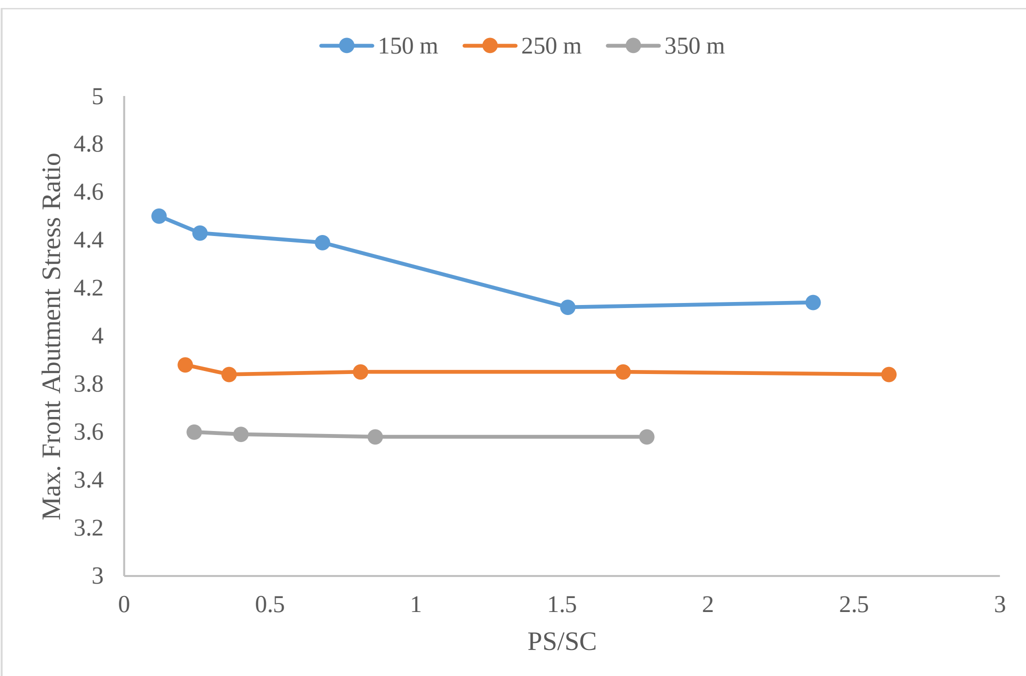


Fig. 4.24. Variation in the maximum FASR with PS/SC at different cover depth

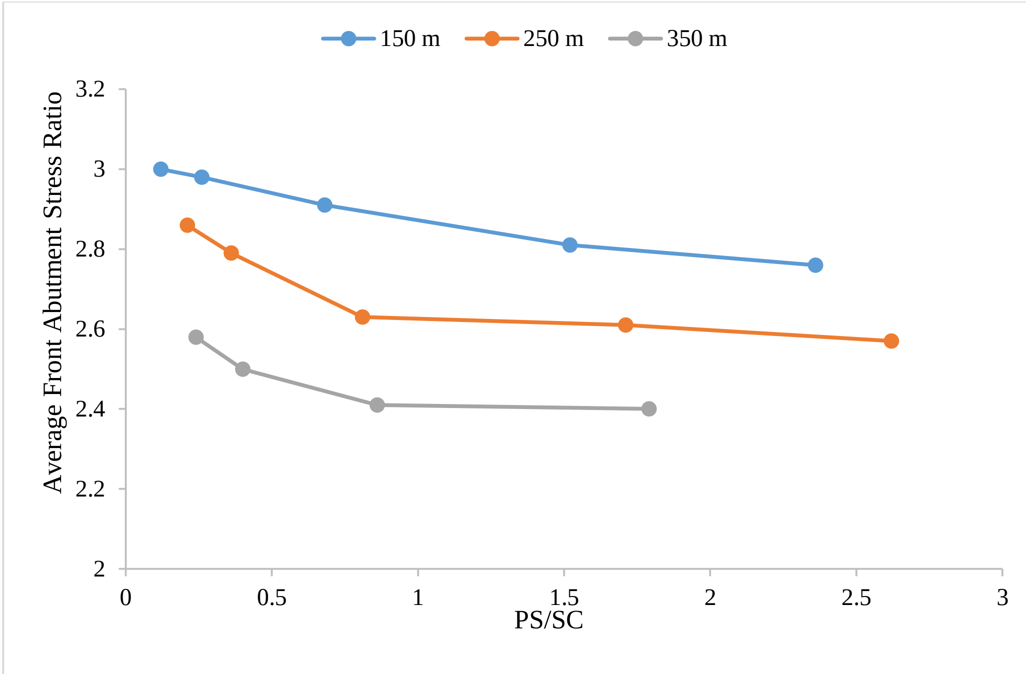


Fig. 4.25. Variation in the average FASR with PS/SC at different cover depth

Although the overall loading pattern of the goaf edge support of 2 × 400 t capacity indicated marginally increased loading while working with lower PS/SC ratio at different cover depths, the in-depth study of the maximum and the average induced load (Table 4.13) could not confirm any such relation indicating almost similar loading of the support in all the conditions.

Figure 4.26 shows the maximum goaf edge convergence slope (MGECS) for different PS/SC at the cover depth of 150 m. These maximum values for the respective conditions have been obtained from their plot of goaf edge convergence slope with progressive face advance as shown in Figure 4.26. It is noted that the MGECS is higher at lower values of the PS/SC, but it reduces with an increase in the ratio of PS/SC following a non-linear relation. The range of MGECS at the cover depth of 150 m is 120 – 49 mm/m for PS/SC varying from 0.12 – 2.36 (Figure 4.26). For cover depth of 250 m, the MGECS reduces from 102 – 55 mm/m for PS/SC of 0.21 – 2.62. Its value reduces from 91 – 54 mm/m for PS/SC of 0.24 – 1.79 at 350 m cover depth. This comparative study also reveals that the MGECS shows a reducing trend with an increase in the cover depth.

Table 4.13. Maximum and average load on the support in different conditions

Cover depth, m	PS/SC	Support Load, tonnes	
		Maximum	Average
150	0.12	397	330
	0.26	397	324
	0.68	397	329
	1.52	397	329
	2.36	397	330
250	0.21	397	328
	0.36	396	335
	0.81	397	333
	1.71	396	333
	2.62	397	331
350	0.24	398	327
	0.40	396	323
	0.86	397	322
	1.79	397	326

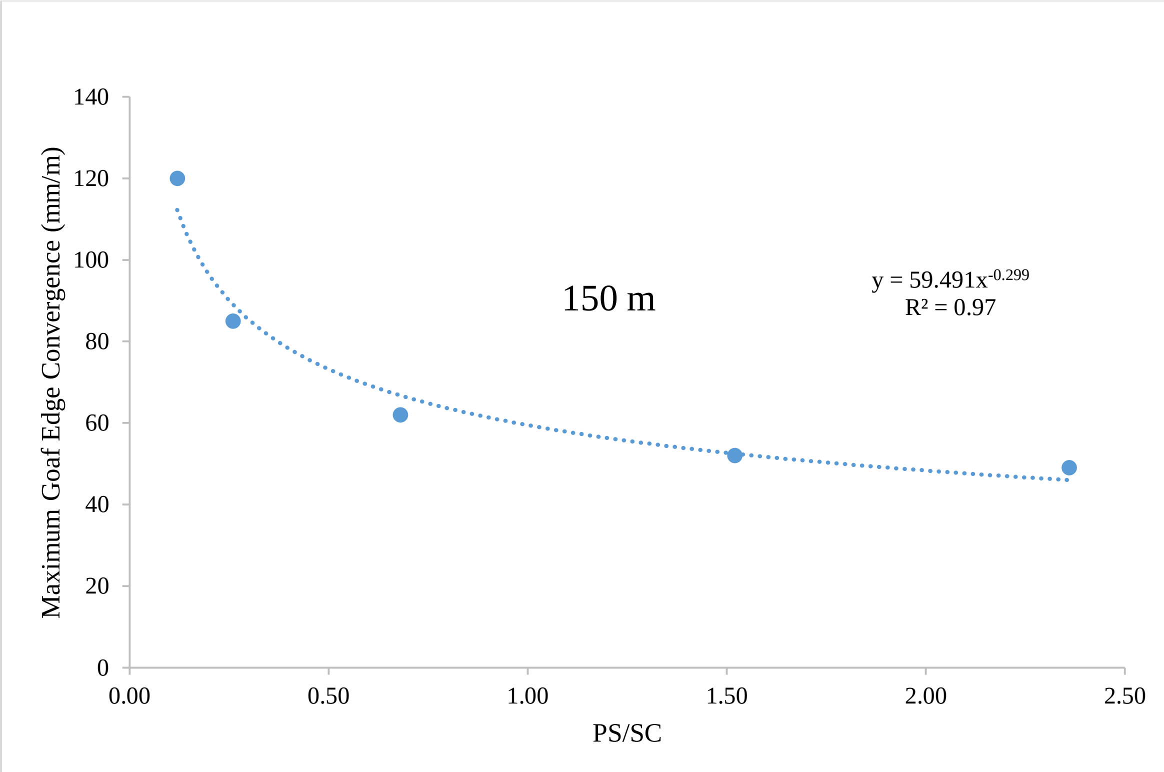


Fig. 4.26. Maximum goaf edge convergence for different PS/SC at 150 m depth

The behaviour of parting strata at the 150 m cover depth showed that almost sub-vertical tensile fractures developed in the parting strata during the settlement of the caved goaf with the progressive mining for PS/SC of 0.12 (Figure 4.6a), indicating that the parting thickness of 13.5 m was inadequate to develop any arching effect for a controlled load transfer of the softcover. With the increase in the PS/SC ratio to 0.26, only a marginal change in the orientation of the fracture planes was noted (Figure 4.6b). These fractures subsequently merged, indicating that the arching action of the parting strata was still insufficient to offset the load of the softcover towards the central region of the goaf pile. With a further increase in the PS/SC to 0.68, the orientation of tensile fracture planes indicated a noticeable bending along with a reduction in the fracture density (Figure 4.6c). A similar trend continued with the PS/SC ratio of 1.52 and 2.36.

For PS/SC of 0.21 at the cover depth of 250 m, when the parting strata are 38.5 m and the softcover is 187.5 m, almost sub-vertical tensile fractures developed in the parting strata during the settlement of the caved goaf with the progressive mining indicating that its thickness was inadequate to develop any arching effect for a controlled load transfer of the softcover in the goaf edge region (Figure 4.13a). With an increase in the PS/SC ratio to 0.36, a noticeable change in the orientation of the fracture planes that developed in the parting strata upon its settlement was noted (Figure 4.13b). These fractures subsequently merged, indicating that the arching action of the parting strata was still insufficient to offset the load of the softcover towards the central region of the goaf pile. With a further increase in the PS/SC to 0.81, the orientation of the tensile fracture planes further tilted towards the goaf, along with a reduction in the fracture density (Figure 4.13c). A similar trend continued with the PS/SC ratio of 1.71 and 2.62.

For PS/SC of 0.24 at 350 m cover depth, sub-vertical tensile fractures developed in the 63.5 m thick parting strata during the settlement of the caved goaf with the progressive mining. It indicated that its thickness was inadequate to develop any arching effect for a controlled load transfer of the 262.5 m thick softcover in the goaf edge region (Figure 4.20a). With an increase in the PS/SC ratio to 0.4, a noticeable change in the orientation of the fracture planes was noted (Figure 4.20b). These fractures subsequently merged, indicating that the arching action of the parting strata was still insufficient to offset the load of the softcover towards the central region of the goaf pile. With a further increase in the PS/SC to 0.86, the orientation of tensile fracture planes further changed along with a reduction in the fracture density (Figure 4.20c). A similar trend continued with the PS/SC ratio of 1.79.

The maximum vertical settlement of the PS reduces with an increase in the PS/SC at a given cover depth. A sudden increase in the settlement is recorded at the failure of the PS under the dead load of the SC. At the cover depth of 150 m, the peak settlement of 1.34 m is observed for PS/SC of 0.12, which reduced to 0.28 m for the PS/SC of 2.36. The failure of the PS initiated at 44 m and completed on 46 m of the face advance for the PS/SC of 0.12. For the PS/SC of 2.36, the failure initiated at 51 m and completed at 58 m. Similarly, at the cover depth of 250 m, the peak settlement of 0.978 m is observed for PS/SC of 0.21, which reduced to 0.18 m for the PS/SC of 2.62. For PS/SC of 0.21, the failure of the PS initiated at 47 m and completed at 50 m of face advance. For the highest PS/SC of 2.62, the failure initiated at 62 m and completed at 64 m. At 350 m cover depth, the peak settlement of 0.642 m is observed for PS/SC of 0.24, which reduced to 0.221 m for the PS/SC of 1.79. For PS/SC of 0.24, the failure of the PS initiated at 39 m and completed on 49 m of face advance. For the highest PS/SC of 1.79, the failure initiated at 83 m and completed at 107 m.

The vertical stress recovery in the goaf just after the main fall was 48% of in situ vertical stress for minimum PS/SC of 0.12 at the cover depth of 150 m. The peak stress reduced to 20.5% for the maximum PS/SC of 2.36. The overall trend of stress recovered in the periodically filled goaf piles confirms relatively higher stress for the lowest PS/SC (Figure 4.8). The minimum cover pressure distance of 39 m is obtained for PS/SC of 0.12, while the maximum distance of 48 m is observed for PS/SC of 1.52. The goaf could not attain the cover pressure for PS/SC of 2.36. As the cover depth increased to 250 m, the stress recovered after the main fall was 36% of in situ vertical stress for minimum PS/SC of 0.21.

The peak stress reduced to 14% of the vertical stress for the maximum PS/SC of 2.62 (Table 4.8). The minimum cover pressure distance of 42 m is obtained for PS/SC of 0.21, while the maximum distance of 103 m is observed for PS/SC of 2.62 in this condition.

At 350 m cover depth, the goaf could develop vertical stress of 9.36% only for the minimum PS/SC of 0.24. However, it increased to 15.8% for the maximum PS/SC of 1.79 (Table 4.11). The overall trend of stress recovered in the periodically filled goaf piles re-confirms relatively higher stress for the lowest PS/SC (Figure 4.22). The minimum cover pressure distance of 89 m is obtained for PS/SC of 0.24, while the maximum distance of 145 m is observed for PS/SC of 0.86. The goaf did not achieve cover pressure in the case of PS/SC of 1.79.

4.6 Summary

A numerical modelling based parametric study was conducted to assess the effect of softcover and parting strata on the strata and support behaviour in a depillaring working. The caving zone of eight times extraction height was considered while changing the HC/SC from 0.33 to 3.0 below the cover depth of 150 – 350 m. The ratio of PS/SC was varied from 0.12 – 2.62 in different models of the depillaring working. A mobile goaf edge support of 2 × 400 t was considered in this study which was set at 60% of its yield load during progressive mining following the straight line pattern of pillar extraction.

The study confirmed that the main fall span reduces with the increase in the thickness of softcover and decrease in the thickness of the parting strata. The caving span also decreased with an increase in the cover depth. When the parting strata are relatively thinner, the dead load of the softcover is transferred to the main roof without any considerable control causing a faster bending of the main roof. Such a situation generally lead to the development and growth of tensile fracture from the bottom portion at the centre of the span of the main roof layer hanging in the goaf. Subsequently, these fractures propagate towards the abutment causing its further multi-dimensional softening. However, when the parting strata are thick, the transfer of dead load to the main roof is relatively gradual, resulting in delayed caving of the main roof. The caving of the main roof extends to the entire goaf area in such conditions.

The depillaring working with a lower PS/SC ratio was subjected to a higher peak front abutment stress as compared to that with higher PS/SC at the same cover depth. A similar trend was also noted for the maximum convergence slope at the goaf edge and the failure and settlement pattern of the parting strata in different conditions. The stress recovered in the goaf just after the main fall is the highest for the lowest PS/SC at the lower depth of cover. The stress recovery reduces with the increase in the PS/SC, which confirms the role of PS in the controlled transfer of load of the SC. A similar trend is observed at moderate cover depth as well. However, for deeper workings where the parting strata become very thick for the similar PS/SC ratio, an opposite trend in the stress recovery is observed, indicating a limited influence of the softcover on the transfer of its dead load to the parting strata in the depillaring workings. The cover pressure distance increases with the increase in PS/SC in all the conditions.