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Analysis of Surface Subsidence and Relative Movements of Underground Rock Strata over an Inclined Longwall Panel

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Abstract

Subsidence monitoring and analysis is an integral part of longwall operation. It provides an assessment of the effect of mining on the surface. In this study, subsidence data is recorded periodically over a longwall panel of 250m of face length and 2333m of gate roadway length for a duration of 12 months. The working seam is inclined at 10 degrees (1 in 5.5) towards tailgate side. Based on the measured data, a profile function is derived indicating vertical ground movement over the major section of the longwall panel. The bed separation of layers in the roof rock is also measured by installing Multi-Point Borehole Extensometer (MPBX) at the centre of the longwall panel and its results are correlated with those of subsidence monitored data. It is found from the analysis of subsidence and MPBX data that there is a good correlation between the bed separation sequence and the subsidence over longwall panel.

Keywords: *Longwall, Multipoint Borehole Extensometer, Profile Function, Subsidence*

1.0 Introduction

The dimension of modern longwall panel, typically consists of a face length of around 150 m to 300 m and gate roadway length of 1000 to 3500 m. Coal seam thickness may vary in between 2 m and 5 m and it has a gentle dip less than 5 degrees. A shearer cuts the coal along the face width and advances towards the length of the panel. Hydraulic shield supports are installed along the face width to protect the ground movement at the face area. The supports also provide safe passage of the men at the face and allow uninterrupted transportation of coal through chain conveyor. A typical vertical section of a coal face and surrounding rock strata and coal seam are shown in Figure 1. In Figure 1, it is shown that coal is being cut by the shearer from the face in each pass. The broken coal is being carried out by an armoured face conveyor which runs all along the full length of face and discharges the coal onto a belt conveyor. The belt conveyor carries the coal from underground to surface.

The immediate roof is supported by hydraulic supports, which temporarily support the roof strata and provide a safe working space for the shearer and Armoured Face Conveyor. After each cut of coal, the

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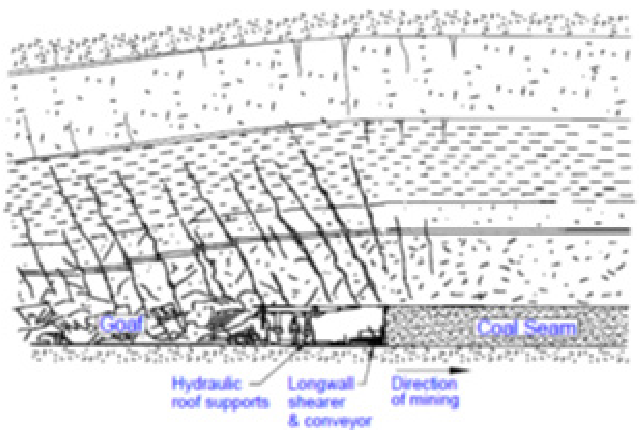

Figure 1. Schematic diagram showing the Longwall Face (Mine Subsidence Engineering Consultants, 2007).

hydraulic supports, the Armoured Face Conveyor and the shearer are advanced.

After extraction of the coal, the immediate roof is allowed to cave into the goaf. The void so formed is called as goaf. The miners engaged at the Longwall face for operating the machinery are safe guarded by the hydraulic roof supports from the danger of roof falls occurring in the goaf. The subsidence on the surface ground occurs due to propagation of fracturing and settlement of the roof rocks resulting in sagging, bending, fracturing and cracking of the rock layers near the surface as shown in Figure 1.

When the panel width of a longwall face is small, depth of the panel is high and the immediate roof strata above the seam are strong and competent, it may be possible that the cracking and fracturing of rock strata will not progress up to the surface. Due to this, negligible subsidence may occur at the surface. In case of wider panels for maximum extraction of coal reserves and other economic reasons, the cracking and fracturing will reach up to subsidence leading to surface subsidence.

The Singareni Collieries Company Limited (SCCL) has envisaged Adriyala shaft project, a deep shaft mine with fully mechanized longwall technology with the target production of 2.5 MTPA. The coal block is situated in Adriyala Project Area of Ramagundam Region of SCCL. Extraction of longwall panel no.1 has been completed and a maximum subsidence of 1.267 m or 19.5% of seam height has occurred on the surface. In anticipation of the possible occurrences of subsidence, mine management has taken a comprehensive plan prior to the extraction of the coal seam. Monitoring of subsidence has been conducted along 80 paths along the major transverse section of the panel and 13 paths along the length of the panel. Subsidence monuments or pillars are installed at every 30 m along a path. The detail monitoring plan is discussed in this paper. The easting, northing and elevation of each pillar are recorded at 30 days interval. In this paper, analysis of vertical ground movement along a major path in transverse section is presented after 690 days of longwall operation. The knowledge gained from the monitoring and analysis of the subsidence data will be used to estimate the possible subsidence of other panels to be mined in the future. Apart from that multipoint borehole extensometers are also installed at the middle of the panel no.1 to monitor the bed separation with respect to face movement.

1.1 Subsidence Mechanism

After extraction of the coal, the immediate roof falls into the goaf and the strata lying above the immediate roof sag to fill the void formed beneath them. The same process continues towards the surface and the affected width increases as we move towards the surface resulting in larger effected area higher than the dimension of the extracted panel. In general, maximum possible subsidence is less than the height of extraction of coal seam.

The angle subtended between the vertical line drawn at panel edge and a line joining zero subsidence is called as angle of draw. It mainly depends on the strength of the roof rocks and the depth of working. In general, the angle of repose lies between 10 and 35 degrees from the vertical.

1.1.1 Inclined Seam Subsidence

After examining worldwide subsidence observations (John Loui Porathur & Chandrani P. Verma, 2017) over inclined seam extractions, the general characteristics of subsidence troughs resulting from inclined seam extractions, as compared to those obtained over level seam extraction panels, can be briefly summarized as follows:

- The point of maximum subsidence shifts towards the dip side and away from the centre of the excavation. This shift is quantified using the maximum subsidence angle (ϕ)
- The draw limit would be farther at the dip side compared to the rise side and the strike side, amounting to different angles of draws viz., dip side (θd), rise side (θr) and strike side (θs) angles of draw (Figure 2).

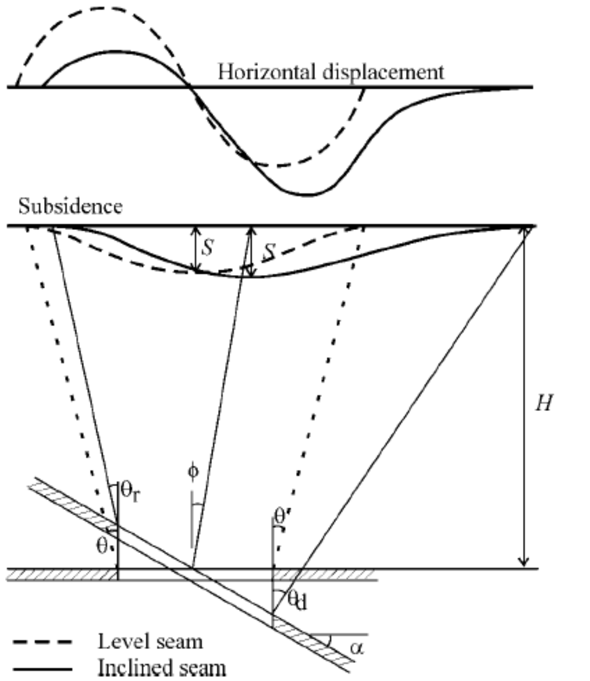

Figure 2. Nature of subsidence troughs caused by level and inclined seam extractions.

Figure 3. Multipoint borehole extensometer.

- The subsidence profile along the strike direction is similar to that obtained for a level seam extraction.
- Horizontal displacement and strains are more on the dip side as compared to the rise side.

1.2 Multipoint Borehole Extensometer (MPBX)

The multi-point rod extensometer (MPBX) is designed to monitor changes in the distance between downhole anchors, each set at a specified depth in the borehole, and a measurement head at the surface. Rods extend upward from the anchors to the head, where measurements are made with a depth micrometer or displacement transducers.

2.0 Case Study

The Adriyala Longwall Project (ALP) is located in Ratnapur Mandal of Peddapalli district, Telangana state. Four punch entries were driven from dip side highwall of RG OCP-II to work as trunk roadways for the long-wall panels. It is situated on dip side i.e., due South-East of GDK-10A/GDK-10 Incline. It is bounded by Northern Latitude of 18039’03” to 180’41’34” and East Longitude of 79034’28” to 79035’55”. The mining block covers an area of 3.4 sq.km.

ALP is having total 8 seams viz. No 1B, No 1A, No 1, No 2, No 3A, No 3B, No 3 and No 4 seams in descending order in the lease hold area of the mine. Out of 8 seams, No 1 seam, No 2 seam, No 3 seam and No 4 seam are found to be persistent with workable thickness. Presently, No 1 seam is being worked and extracted coal with longwall technology. All other seams are virgin and not having any access.

2.1 Surface Subsidence Monitoring

The subsidence over the longwall panel no. 1 at Adriyala Longwall Project was monitored by installing permanent pillars in 30m x 30m grid as per the DGMS Circular No 4 of 1988 as shown in Figure 4. A total of around 1040 no of monitoring pillars were installed within the longwall panel no.1 including the barriers. Further, 100 monitoring pillars were also installed in two rows at 10m interval in the middle of the panel on the original surface.

Overburden material is dumped over a portion of the surface of the longwall panel no.1 and hence installation of pillars are not perfect on that zone. Hence, in this study, ground movement data collected from the pillars on the dump are ignored as shown in Figure 4.

The subsidence monitoring pillars were made up of RCC. The width of the pillar was kept as 20cm to 25 cm whereas the depth was maintained as 50 cm as shown in Figure 5. MS rod of 1.0cm to 1.4cm diameter was fixed in the middle of the pillar. The rod was projected 1cm to 2cm above the base of the pillar and other end of the rod was kept in bend position. A punch mark was made at the center of the rod. The pillars were fixed in the ground leaving a projection of around 5cm above the ground surface.

The subsidence profile along line S, 50, 63 and 75 was measured in the month of December 2017 over longwall panel no 1 and is shown in Figure 6. The Line S, 50, 63 and 75 are at a distance of 1265m, 1535m, 19525m and 2195m respectively. The maximum subsidence is observed along path S, which is located near the middle of the panel. Hence, the subsidence analysis is done along the path 'S'.

The data are collected along the path 'S' (11-58) for the analysis as shown in Figure 4. The subsidence monitoring along the path 'S' was started in the month of January – 2016 and continued up to November-2017. For the analysis purpose and profile function, the data collected in the month of November-2017 is considered to account for the maximum possible subsidence. The selected path 'S' is at about a distance of 1265m from the face dip of the longwall panel 1. The cutting face of the longwall crossed the path 'S' on 22.01.2016 and subsidence monitoring of the path 'S' was also started in the month of January-2016 and continued for 23 months. The subsidence was monitored on monthly basis.

For analysis purpose, the subsidence recorded over the natural surface is considered. The subsidence recorded over the overburden dump material is sum of the actual subsidence due to mining and the compaction of the loose overburden material.

2.2 Multipoint Borehole Extensometer Installed at Longwall Panel No.1

At Adriyala longwall project, during retreat of longwall panel no.1, caving behaviour of the strata in the goaf monitored with deep hole Multi-Point Borehole Extensometer (MPBX) from surface.

One such MPBX is installed at 1700m from installation face location at the centre of the face width with anchors at a depth of 415m, 350m, 290m, 185m, 130m, 70m from surface. The coal seam under extraction is at 427m depth. Due to the caving, the movement of anchors in terms of displacement, with respect to longwall face is monitored daily. The displacements in all anchors is monitored. It was observed that, the displacement trend is continuously increased with respect to movement of longwall face. The displacement starts increasing when longwall face is crossed 50m away from MPBX station (1700m) and continued in increasing trend up to 382m and stabilized later.

At the same location on the surface subsidence was monitored. The subsidence pillar is within 5m from the MPBX location. The subsidence pillar is M-72. Subsidence was monitored monthly once. It was observed that the subsidence started increasing towards the goaf side after 52m retreat and continuously increasing up to 370m away from longwall face. Later it is stabilized. The maximum subsidence noticed at this location is 1088mm.

The trend of displacement in MPBX anchors and subsidence pillar followed the same. It can be concluded that the caving behaviour of strata in the goaf is in relation with the subsidence measured on the surface.

3.0 Profile Function for Subsidence Prediction at ALP

In mining horizontal and inclined coal seams, different methods can be used for prediction of subsidence trough: theoretical and graphical ones, physical and numerical

Table 1. Details of longwall panel no 1 at Adriyala

Seam		1 seam
Seam thickness		6.5m to 7.00m
Extraction height		3.6m
Seam gradient		1 in 5.5
Depth		
a	Minimum	366m
b	Maximum	458m
Panel length		2333m
Panel width		250m
Panel started on		15.10.2014
Panel closed on		29.12.2016

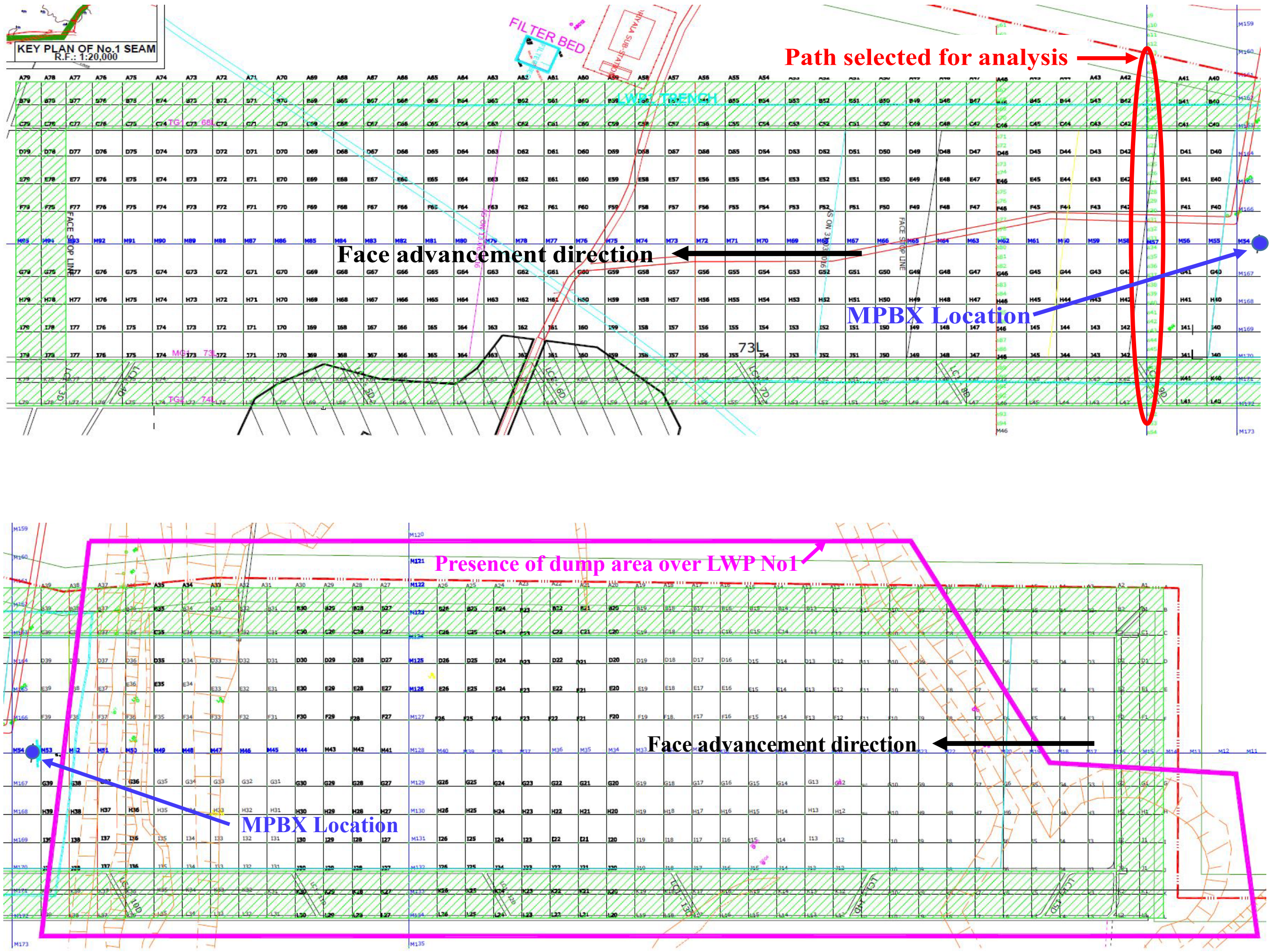

Figure 4. Surface monitoring plan of longwall panel no.1 at Adriyala.

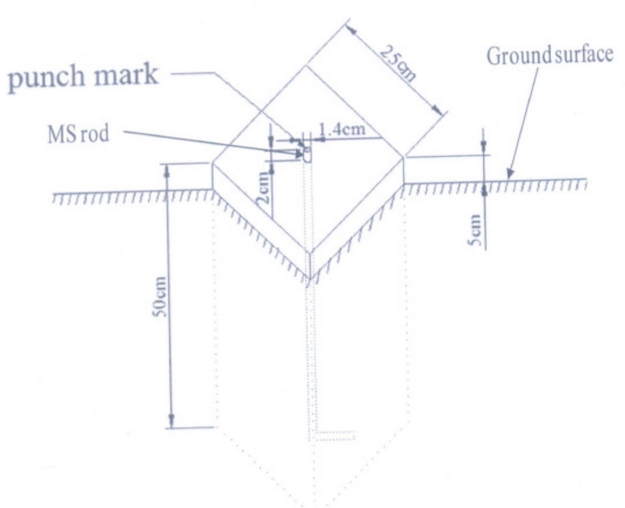

Figure 5. Design of subsidence pillar.

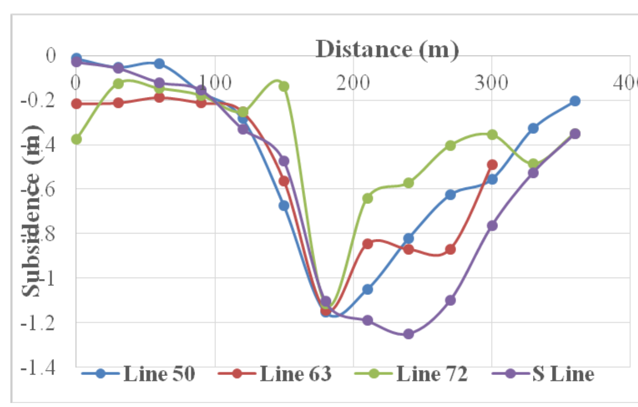

Figure 6. Subsidence profile at different

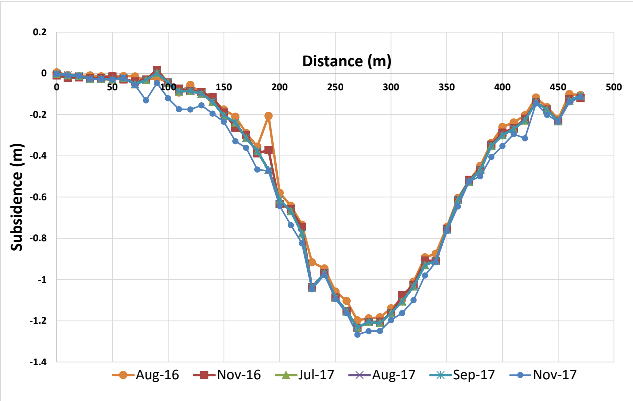

Figure 7. Subsidence profile along the path 'S' of Longwall panel no.1.

modelling, as well as profiling function and influence function. Theoretical investigations are carried out for elastic and elastoplastic models. However, it is hard to predict surface subsidence by elastic deformation theory.

Method of profile function enables satisfactory results to be obtained quickly and simply. In this paper, prediction procedure is developed for inclined seam of longwall panel at Adriyala Longwall Project. It is based on assumption that there are two types of soil movement. The first one takes place in perpendicular to stratification due to bending and fracture of layers. The second type movement occurs in parallel to stratification as a result of shear and slip. The profiling function is a sum of three exponential functions.

3.1 Problem Model

The principle lateral section of the subsidence trough is a vertical cross section that passes along the seam strike through the point of maximum surface subsidence. In this paper, each subsidence profile used is the principle one. It is symmetrical and asymmetrical in section for horizontal and inclined seam respectively as shown in the following figure.

In the proposed model, the asymmetrical trough subsidence is divided into ascending and descending parts as shown in the Figure 9.

The first one extends from the point of the subsidence beginning on the ascending side of the panel up to the place of maximum subsidence. The second part is from the point of the subsidence maximum to the zero value of subsidence in the descending part of the panel. For prediction of surface subsidence in both parts of trough, the specific profiling functions are developed:

$$S(x) = S_{max}\left[c\, e^{-f\left(\frac{-x}{R_1}\right)^{g}} + d\, e^{-p\left(\frac{x}{R_2}\right)^{q}}\right] \dots (1)$$

where S(x) is the subsidence at the point x; x is the distance from the point of maximum subsidence of movement trough (here, the point corresponding to S_{max} is assumed the coordinate origin x = 0; negative and positive values of x are for the ascending and descending sides of seam, respectively); f, g, p and q are the constants obtained experimentally.

The other parameters are calculated as follows:

$$S_{max} = ma\ cos\alpha S_{max} = ma\ cos\alpha \qquad \dots (2)$$

$$R_1 = h\ tan\beta_u + 0.5l\ cos\alpha + (h + 0.5l\ sin\alpha)\ tan\theta \qquad \dots (3)$$

$$R_2 = 0.5l\ cos\alpha - (h + 0.5l\ sin\alpha) tan\theta + (h + l\ sin\alpha)\ tan\beta_l \qquad \dots (4)$$

where m is the seam thickness; α a is the factor of subsidence; α is the angle of seam dip; R_1 and R_2 are the distances from the maximum subsidence point up to the zero-subsidence point on the ascending and descending sides of trough, respectively; h is the depth of mine working on the ascending side of the panel; β_u $\beta_u \beta_u$ and $\beta_l \beta_l \beta_l$ are the angles of caving on the ascending and descending sides of the panel respectively; l is the width of working; θ θ is the angle of trough; c and d are the coefficients:

Table 2. Parameters of mining operations at the ALP mine

Parameter	value
m	3.6 m
α	0.358
h	410 m
l	2390 m
α	10.3^0

Table 3. Parameters of profiling function at the ALP mine

Parameter	Value
β_u	2^0
β_l	13^0
R_1	270
R_2	280
f	6.55

g	1.65
p	7.60
q	2.25

Table 1 presents some parameters of mining operations at the ALP mine, where coal had been mined by longwall. The indices calculated in correspondence with values of surface subsidence obtained from the data of field survey are cited in Table 3.

With allowance for these parameters, the profiling function:

$$S(x) = 1.267\left[c\, e^{-6.55\left(\frac{-x}{270}\right)^{1.65}} + d\, e^{-7.60\left(\frac{x}{280}\right)^{2.25}}\right] \ldots (5)$$

The calculation results showed that predicted values have good correlation with the measurement data as shown in the Figure 12.

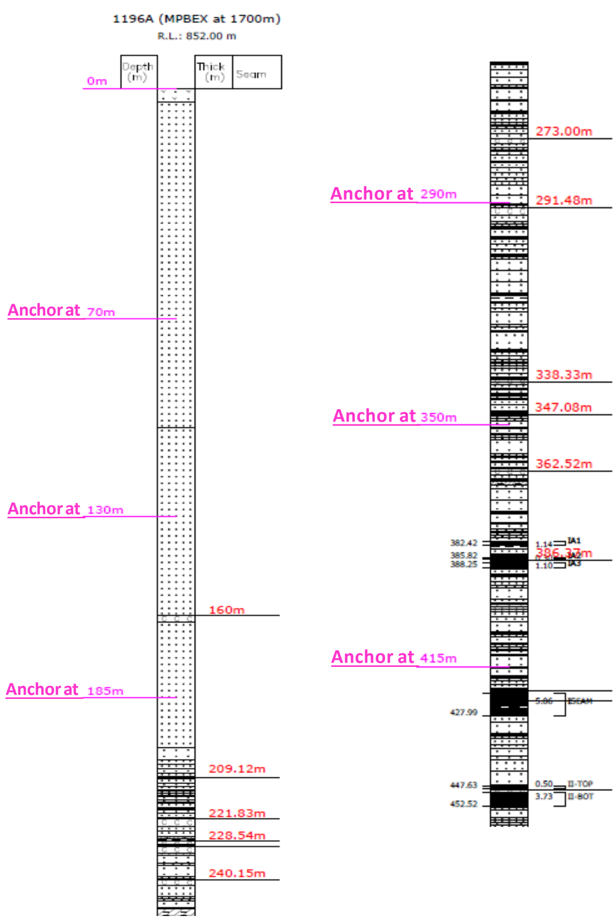

Figure 8. Borehole section showing the anchoring points of MPBX 1700.

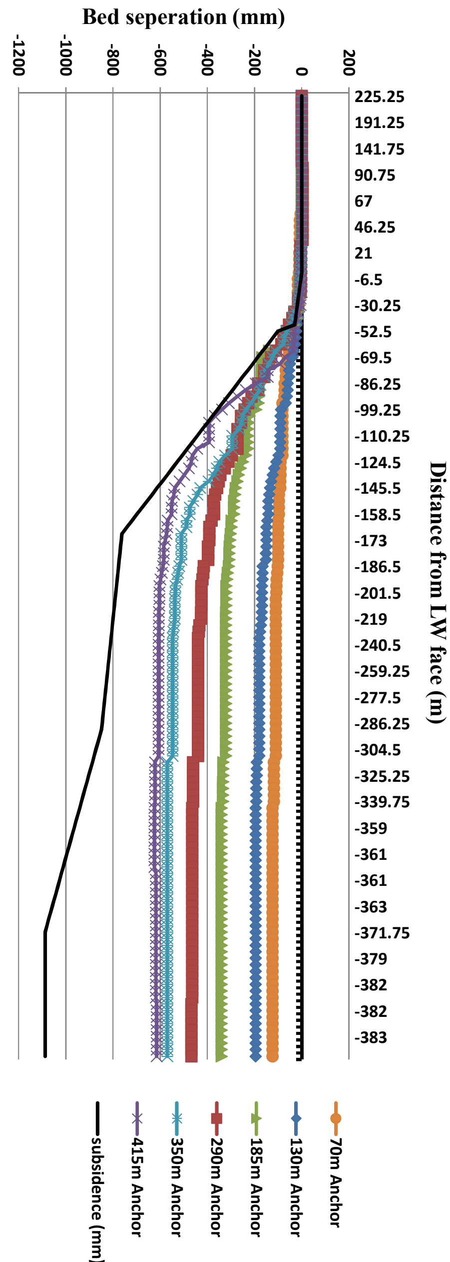

Figure 9. Graph showing the readings of MPBX and subsidence data.

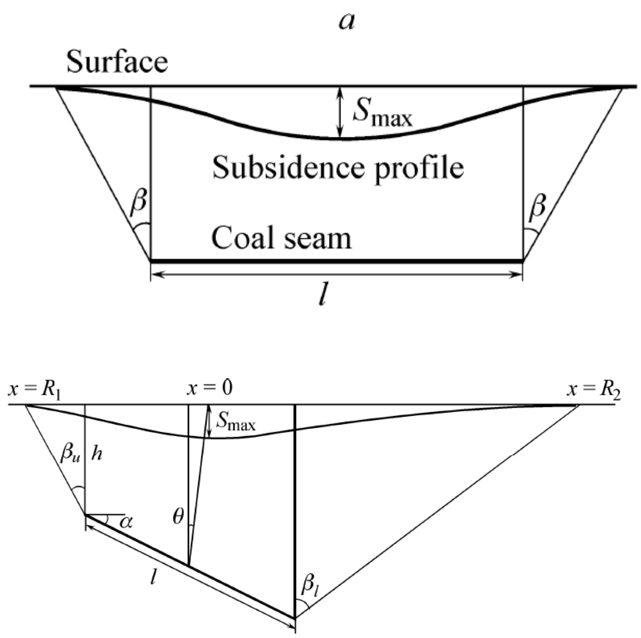

Figure 10. Profile of subsidence in (a) horizontal and (b) inclined seams.

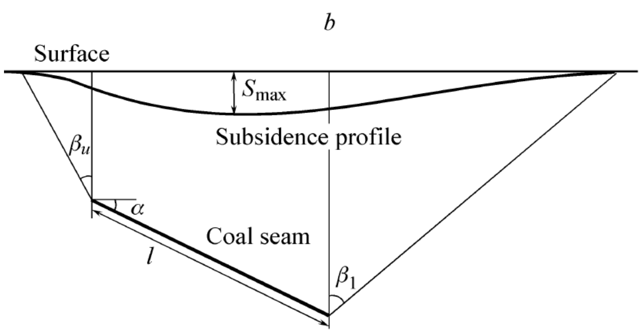

Figure 11. Parameters of new model.

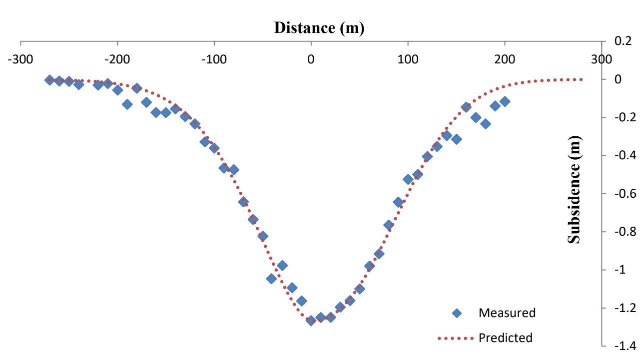

Figure 12. Measured and predicted surface subsidence over longwall panel no.1.

4.0 Results and Discussions

The trend of displacement in MPBX anchors and subsidence monitored on the surface have followed the same pattern, which implies that the caving behaviour of strata in the goaf is in relation with the subsidence measured on the surface. The profile function given by Equation 5 has good correlation with the measured subsidence values.

5.0 Conclusions

It can be concluded from this study that there is a good correlation between the bed separation sequence and the subsidence over longwall panel. The subsidence also lagging behind the longwall face by around 55m. The profile function proposed in this paper could make prediction of subsidence over future longwall panels in the Adriyala Project Area.

6.0 Acknowledgements

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