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Trait of subsidence under high rate of coal extraction by longwall mining: some inferences

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Abstract. Transformation in surface topography is a common phenomenon caused due to underground mining. With a view to focus outward, underground mining at a depth of 410 m although earlier considered as mothball is indispensable as on date to meet the production target. Subsidence investigation has been carried out over longwal panel no. 1 in Adriyala mine of Singareni Collieries Company Limited (SCCL) located in Godavari Valley Coalfield. The rate of face advance varied between 2.7 and 4.8 m/day. The present study envelops cementing relation of subsidence due to underground mining by longwall method with the active and old dumps, partially covered over the panel. Symmetric subsidence profile has been observed across the panel with higher angle of draw in dip side. Resettlement of dump led to higher vertical displacement and found to be an indispensable investigation for stability viewpoint. The angle of draw has been analyzed to be a controlling parameter with respect to the rate of face advance. The impact of subsidence on surface has been evaluated by constructing walls at maximum possible tensile zones and development of cracks after subsidence has been observed. Hydrogeological study has also been conducted, from seepage viewpoint, to evaluate the extent of damage in the strata for safe underground working. The investigation has been conducted during and after mining, with and without release of canal water, to assess the influence of seepage in ground. The assorted subsidence and hydrogeological investigations can be applied to interpret the extent of damage and for comprehensive understanding of the trait of cracks on the surface, in the strata and their continuity thereof.

Keywords. Subsidence; dump; groundwater; angle of draw; face advance.

1. Introduction

As per global scenario, the depth of underground coal mine workings has reached 1500 m [1]. Based on the exploration carried out in India, 315.149 billion tonnes of geological coal reserves up to 1200 m depth have been established as on March, 2017 [2]. The total coal resource between 600 m and 1200 m depth levels stands at 24,104.26 million tonne [3]. Underground method is suitable for extraction of deeper coal seams [4]. Underground coal mining in India is gradually percolating to a greater depth owing to snowballing demand. Majority of coal is extracted by underground method using advanced technologies except for Australia in developed countries [5]. Various factors need to be considered for selection of mining method such as geological condition (depth, size, type, and quality of deposit), technological development and level of mechanisation [6]. Coal can be extracted at higher rate with improved recovery by longwall mining in respect to conventional Bord & Pillar method. Mechanized longwall mining (longwall powered support) has also been introduced in a limited scale in India. Longwall mining has gained popularity due to the leverage of full extraction mining. Subsidence can cause damage to surface structures and water bodies over the longwall panel [7].

According to Ju and Xu (2015) [8] rock properties and geological structure greatly impact the movement of the overlying strata resulting in surface subsidence. The amount and extent of subsidence depends on the nature of overburden strata. Apart from mining configurations, the geotechnical parameters of the strata play an important role in subsidence limit characteristics [9].

The exhaustive study recapitulates the impact of longwall mining under higher rate of retreat on surface and strata for safety perspective of surface structures and underground workings.

According to Fangtian *et al* (2015) [10] shallow depth coal seams are less than 100-150 m depth. Longwall mining

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was found suitable at Adriyala using double shearer drum for extraction of coal. Subsidence study was conducted over the panel at 410 m, which was nearly half covered by the overburden dump at the surface. In general, subsidence measurement over overburden dump is practically difficult to conduct. However, the site was suitable was made suitable for subsidence investigation over the dump with the support of mine management. Key objective of the study was to investigate the safety of Rachapalli village, stability of the dump and to comprehend the influence of the loose material of old and active dumps on subsidence including groundwater hydrology.

2. Study area

Subsidence study was conducted at Adriyala mine, bounded by northern latitude of 18°41'34" and eastern longitude of 70°35'55" of the SCCL and located in Godavari Valley Coalfield of Karimnagar district in the state of Telangana, India. All the seams at Adriyala colliery are confined to Barakar formation of Lower Gondwana. There are seven seams, namely, IA, I, II, IIIB, IIIA, III and IV in descending order, i.e., from top to bottom out of which only four seams are workable. The lithology of the overburden comprises sandstone, carbonaceous clay and siltstone. The coal measure strata are dominated by sandstone which is followed by carbonaceous clay, above uppermost seam I.

The panel no. 1 (2313 m long and 250 m wide) of seam I was extracted under single-seam mining condition by longwall method with caving using double shearer drum. The dip of the seam was 1 in 5.5 and the depth of working varied between 362 m and 458 m. The width-depth ratio of the panel at shallowest depth of cover was 0.69 m. There are irrigation canal running across the panel and active overburden dump over the panel along with a Rachapalli village at the dip side of the panel (figure 1). Nearly half of the panel was overlain by overburden dump with three benches of 20 m, 40 m and 60 m height. The corresponding stretch of each bench was 36 m, 465 m and 600 m respectively along the M-Line of subsidence monitoring stations.

3. Subsidence behaviour

3.1 *Layout of monitoring stations*

Subsidence monitoring stations were laid in a grid pattern at every 30 m interval, covering all the surface structures. Subsidence monitoring stations of M-Line was located at the longitudinal centre of the panel that followed the direction of the face advance. The monitoring stations up to M48 were located over the dump whereas stations from M52 onwards were on the solid ground. S-Line was located on the intact ground almost at the centre of the panel across the face direction. The monitoring stations along S-Line were fixed at an interval of 10 m to generate precise profiles of subsidence and its parameters.

3.2 *Subsidence investigations*

Subsidence measurements were carried out at different stages of mining to assess the influence of extraction of coal on the surface structures and features. The extraction of panel no. 1 was commenced in October, 2014 and completed in December, 2016. The measurement was last taken in June, 2017 i.e. around six months after the completion of mining, to obtain data inclusive of residual subsidence. The profiles of subsidence measurement in relation to face position along the centre line of longer axis at different period of time i.e. March, 2015, May, 2015, July, 2015, January, 2016, October, 2016 and June, 2017 is represented graphically in figure 2.

The subsidence profile was along the M-Line as shown in plan (figure 1). Surface, strain, slope and subsidence profiles were made across the panel i.e. perpendicular to the M-Line, named as S-Line shown in figure 1. These profiles

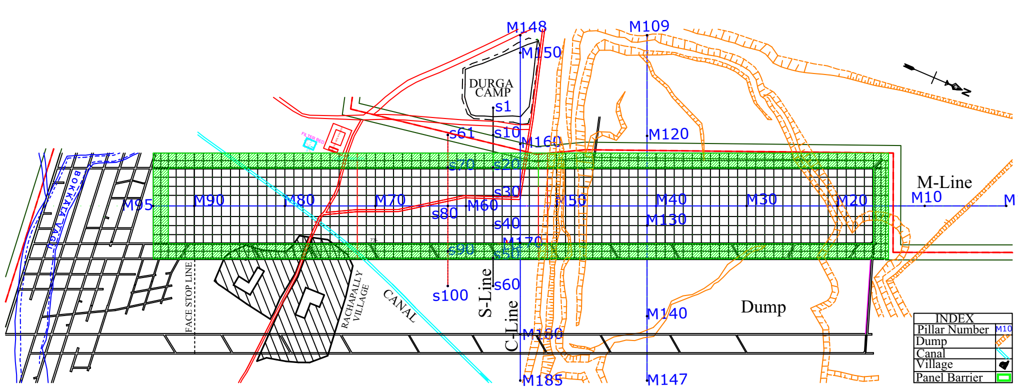

Figure 1. Longwall panel with overlying surface structures.

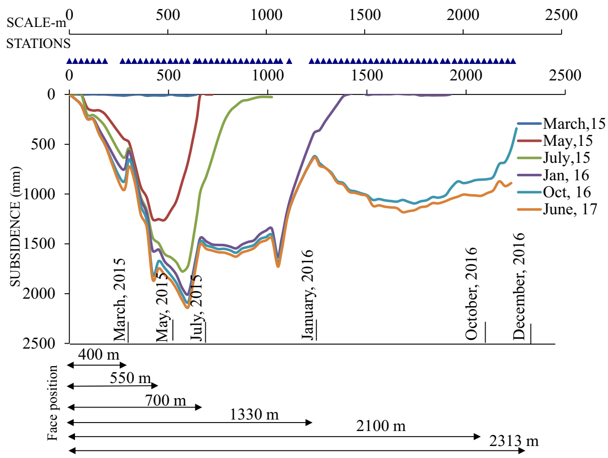

Figure 2. Subsidence profiles with respect to face position at different period of time.

were based on the measurement conducted on the intact ground at the surface after the completion of longwall panel is shown in figure 3. These profiles were developed to perceive the transformation in surface topography across the panel. The outcome of subsidence investigations conducted over longwall panel no. 1 is deciphered in table 1. Subsidence profile along S-Line was inclined slightly on dip side but almost symmetric in nature. Tensile strain above 3 mm/m was observed on the dip side of the panel ranging from 38 m from the goaf edge (towards goaf) to 10 m outside goaf edge. The angle of draw obtained at the rise and dip side of the panel by projecting the line based on subsidence profile found to be around 10° and 13° respectively. It is pragmatically difficult to determine the exact value of angle of draw.

The value of angle of draw was determined by considering 5 mm subsidence limit as this boundary was considered as cut-off value in measurement. Inclination of the seam leads to asymmetry in angle of draw i.e. greater in dip side in comparison to rise side. Dynamic angle of draw was measured in the direction of the face advance and found to be inversely proportional and linearly related to the rate of face advance (figure 4), expressed as:

$$A_d = -10.561F_a + 61.215 \quad \left(R^2 = 0.92\right) \qquad (1)$$

Where, A_d = dynamic angle of draw (degree) and F_a = rate of face advance (m/day).

3.3 *Subsidence behavior over dump and intact ground*

a) *Dump*

The overburden dump, whether active or old, has tendency to shape up into averse and wobbly state due to vertical and lateral movement of the intact ground below it, caused by underground mining. Measurement of

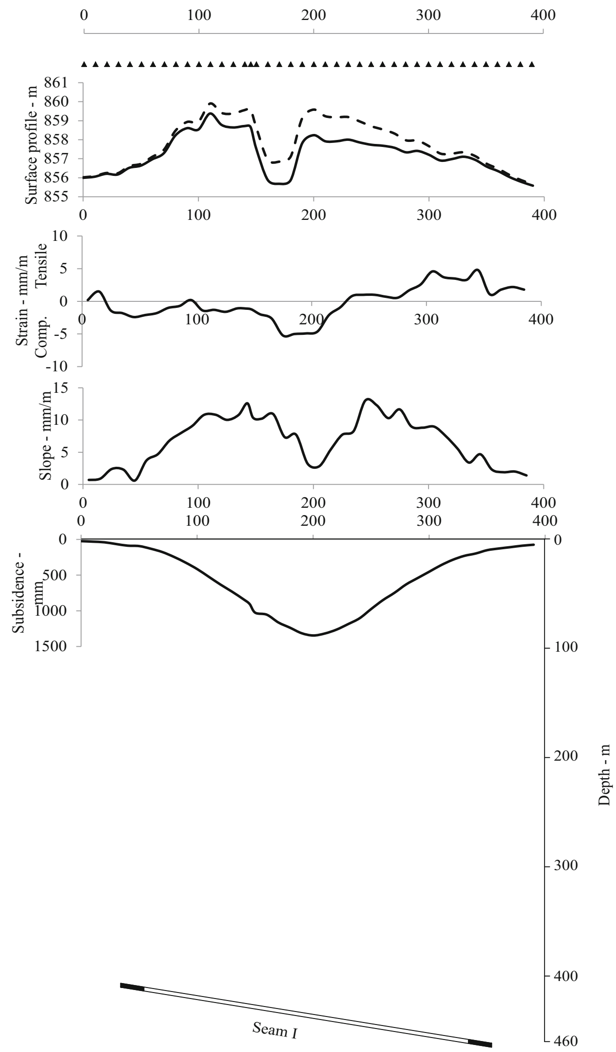

Figure 3. Surface, strain, slope and subsidence profiles across the centre of the panel.

subsidence over active dump is a strategic factor and will backup to assess the stability of dump. The dump notched up to the height of 60 m in two phases. The dump up to 40 m height encompassing two benches was 4-year-old, followed by an additional 20 m active bench above it. The solid waste material comprising mainly sandstone of neighboring opencast mines was dumped over half of the panel. Crushed material of very small size was also dumped and leveled at the top of the dump, which helped in cracking the problem of subsidence measurement without any impediments.

Maximum subsidence measured over the dump was 2132 mm, nearing to 1.58 times higher in comparison to intact ground. Subsidence was observed to be high at the top edge of the dump (both at 60 m and 40 m) indicating more vertical displacement in the vicinity of the dump slope. The notion of age of dump on settlement can be perceived from the subsidence observation over 40 m and 60 m dump

Table 1. Result of subsidence investigation over longwall panel no. 1, Adriyala, SCCL.

Sl. No.	Parameters	Observations over dump	Observations over intact ground
1	Maximum subsidence (mm)	2132	1346
2	Maximum compressive strain (mm/m)	4.77	5.23
3	Maximum tensile strain (mm/m)	1.96	4.78
4	Maximum slope (mm/m)	10.84	13.01

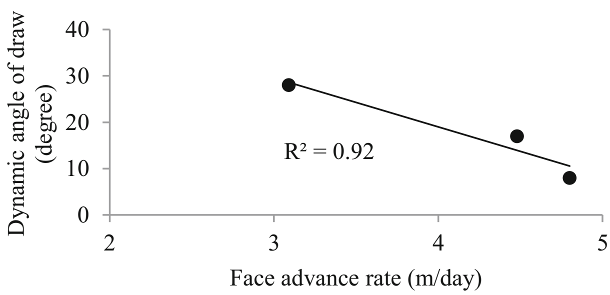

Figure 4. Influence of rate of face advance on dynamic angle of draw.

height. The magnitude of subsidence was found to be less on 40 m bench height in comparison to 60 m high dump because the dump of 40 m bench, being four-year-old, was already settled to a large extent. Hence the magnitude of settlement of dump de-escalated in this stretch.

Practically no ground movement was observed till March, 2015 over the active dump of 600 m stretch and therefore the rate of subsidence was evaluated by taking this as time reference. The position of face was at 550 m in May, 2015, i.e., over the active dump and hence the rate of subsidence (inclusive of dump settlement) was found to be very high (nearing 20 mm/day) after 63 days (figure 5). The actual working days was counted as number of days.

The rate of subsidence reduced with the passage of time. The amount of dump settlement was initially high which later gradually dwindled down. The rate of subsidence over the four-year-old bench of the dump was found to be quite high (nearly 9 mm/day) i.e. half of the active dump and

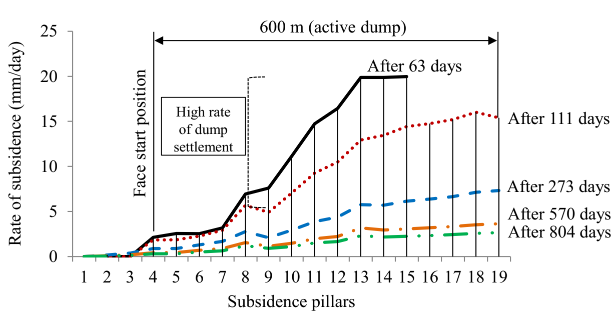

Figure 5. Rate of subsidence over active dump.

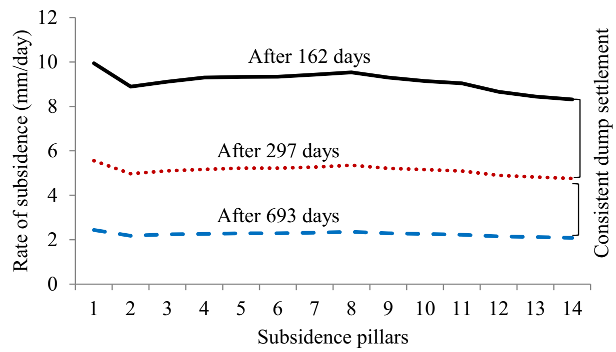

Figure 6. Rate of subsidence over four-year-old dump.

reduced with time as shown in figure 6. Uniform settlement of dump with time all throughout the stretch of 517 m was observed.

b) Intact ground

The magnitude of overall maximum subsidence was found to be 1.58 times higher over the dump in contrast to intact ground due to the influence of unconsolidated dump. The maximum subsidence was found to be 37% times the height of extraction as the ratio of width of the panel to the depth of working was 0.69 i.e. a sub-critical condition. The rate of subsidence was less by manifold in comparison to dump and found to decrease as it approached end of the face, on view in figure 7.

4. Impact of subsidence movements

4.1 *On surface*

During the course of mining, three numbers of experimental wall of 10 m long and 2 m height were constructed near the face position at the dip side of the panel i.e. towards the side of the village, in the region of anticipated high strain that can expound the impact on the walls due to subsidence (figure 8). The aftermath of the subsidence was observed in the form of development of hair line cracks on walls in January, 2016 and same condition prevailed till last measurement (June, 2017) as shown in figure 9. A few superficial cracks with openings on the ground were observed at some locations which covered up later naturally with time (figure 10).

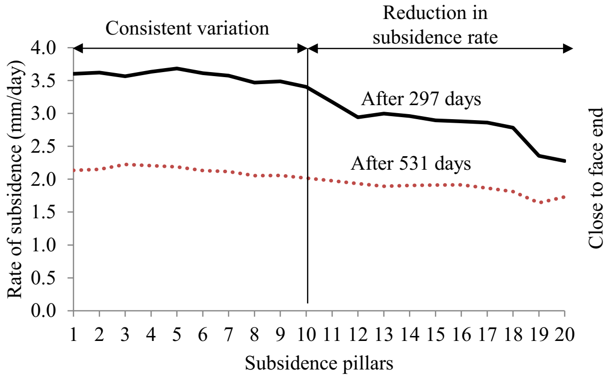

Figure 7. Rate of subsidence over intact ground.

4.2 *In strata*

Subsidence affects the hydraulic properties causing enhancement in permeability and storativity over the longwall panel [11]. According to Holla and Barclay (2000) [12] temporary water loss is anticipated unless affected by geological disturbances for depth more than 150 m.

On the top of subsidence investigation hydrogeological study was conducted to assess the impact on strata over the panel due to longwall mining based on groundwater fluctuations. A piezometric well of 225 m depth was drilled in centre of the panel at 1730 m from the face start line, in the vicinity of canal. The groundwater level was monitored with respect to the face position and even after the completion of mining i.e. from March, 2016 to August, 2018. It

(a) **(b)**

Figure 8. Position of constructed walls at half completed panel.

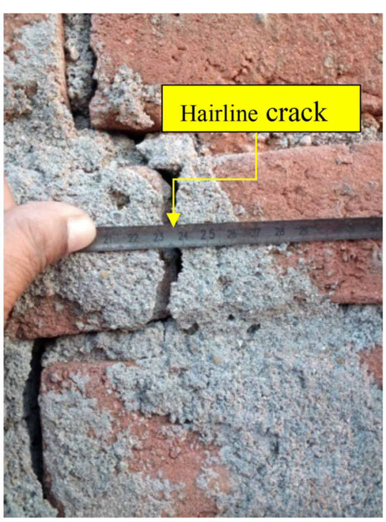

Figure 9. Hairline crack on wall

Figure 10. Development of crack on ground.

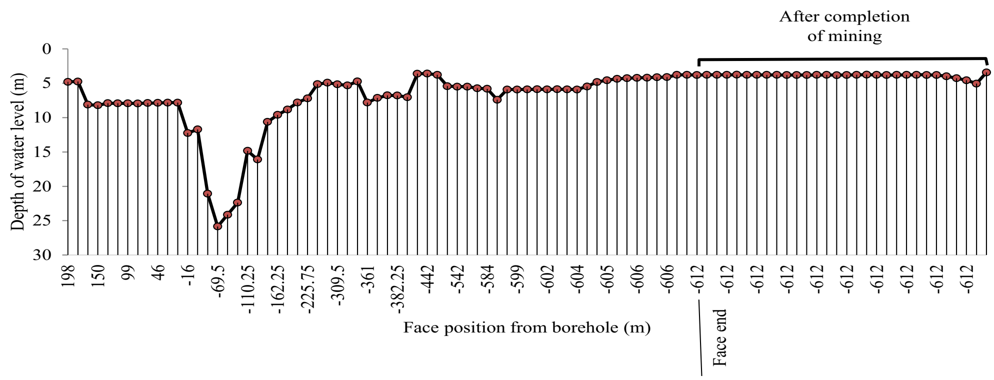

Figure 11. Variation in groundwater level with respect to face position.

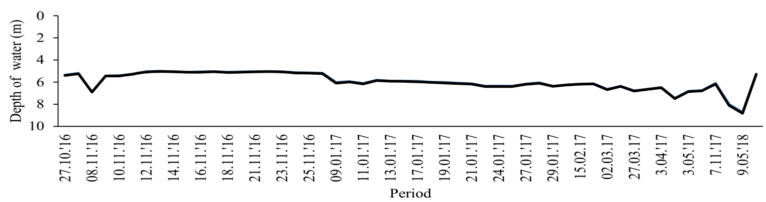

Figure 12. Peizometric measurement during release of water in canal.

Figure 13. Water accumulation over subsided land.

was observed that there was drawdown of water level by around 20 m when the working face was ahead by 70 m from the well and later the groundwater was regained to its original level as the face advanced by around 225 m (figure 11). The figure depicted the groundwater fluctuation during coal extraction. Marginal variation was observed after mining which is likely due to seasonal affect.

Canal water was not permitted to be released till mining operation. Hence, groundwater level was measured after mining with release of water in canal to observe leakage in ground, if any. Piezometric levels were monitored during release of water, i.e., from 27.10.2016 till 09.05.2018 and no variation in level of the groundwater was observed attributing to no leakage/seepage from the canal to the ground (figure 12). The surface cracks developed during mining were covered up naturally with time and was filled with water on the trough portion of the subsided land during rainy season as shown in figure 13.

5. Discussion

5.1 *Subsidence*

The magnitude of subsidence was observed to be higher than anticipated. Stress distribution is large in longwall mining causing massive caving in excavated area [13]. Typical longwall advance rates are 0.3–1.2 m per day and "high-speed" longwall face advance in coal is about 1.5 m per day [14, 15]. According to Kratzsch (1983) [16], rate of subsidence is near enough proportion to the rate of face advance i.e. magnitude of dynamic deformation and its associated disturbance potential is influenced by rate of mining. Rapid face advance is conducive to fragmentation of rock mass and accelerate the development of movement. The rate of face advance also affects the slope of the subsidence [17]. The rate of face advance was high varying between 2.7 and 4.8 m/day attributing to higher stress distribution with massive caving leading to increased subsidence value.

5.2 *Influence of dump*

Higher value of subsidence over the dump in contrast to the intact ground brings to light the wide reason of their resettlement. It can be well brewed from subsidence profile that the amount of resettlement is interrelated by the age of the dump. The cut down in the magnitude of subsidence observed over different benches inferred the influence of age of the dump. The amount of resettlement can be projected in allusion with subsidence measured over solid ground. The risk of slope stability of dump, especially in the vicinity of the edge of the bench, is a matter of concern. The irregular compactness of the dump led to uneven slope and strain profiles.

5.3 *Angle of draw*

The area of subsidence is determined by the magnitude of angle of draw. This information is valuable to assess whether any surface structure falls within the zone of subsidence influence. Angle of draw is experienced to be high in weak overburden [18, 19]. Existence of massive sandstone transfer abutment loads to permanent pillars reducing the angle of draw. As the percentage of shale in the rock mass decreases and the amount of sandstone increases, the angle of draw and the area of potential subsidence decreases [20].

The angle of draw in this coalfield is generally around 25° for panel depillared by Bord & Pillar method. However, the angle of draw was found to be less in this longwall panel. As per the practical experience gained from the field observations, higher is the rate of retreat, the lower angle of draw may be expected. The rate of retreat was pretty high and observed to be a driving factor in cutting down the magnitude of angle of draw. Consequently, this led to higher magnitude of subsidence.

5.4 *Hydrogeology*

There are four zones of movement in the overburden above the panel namely caved, fractured, continuous bending and soil. The combined height of the fractured and caved zones, in general, is 20-30 times the height of extraction [21]. Considering the worst situation, the maximum height of damaged strata may reach around 105 m from the extraction level. The rock characteristic above this height comes under bending zone and as per the depth of water table and impervious layers of shale; aquifer is located in this zone.

Sometimes impermeability is temporarily lost and recovered soon after. When the face was close to the well the strata were subjected to tension that might led to opening up of natural joints or small fissures causing drawdown of groundwater. As the face moved much ahead of the well, the strata returned back to the original position without causing disturbance in its continuity and consequently water level regained to the original level and remained consistent even after the completion of mining. Thus, it may be inferred that groundwater was in the bending zone as this zone is characterized by the continuity of strata without any breakage. Hence, the data are affirmative indication of non-continuity of cracks up to the underground workings. Surface cracks located in soil zone were superficial, well proven by accumulation of water in subsided area.

6. Conclusion

Subsidence investigation was conducted over the longwall panel with a perspective to investigate stability of the dump and to comprehend the influence of mining on surface structures and groundwater. The breakthrough of subsidence behavior on the dump is vital for stability assessment. The maximum subsidence on the solid ground was 55% less with respect to vertical displacement observed over the dump due to its resettlement factor. Thus, subsidence over the dump should be accounted as sum of actual subsidence and resettlement of dump. Higher subsidence in the vicinity of the dump slope indicated its long term instability. Settled old dump quantitatively indicated less subsidence than over active dump. The higher rate of face advance attributed to enhancement in the magnitude of subsidence and reduction in angle of draw. Subsidence profile was inclined slightly on dip side but nearly symmetric in nature. The abutment in angle of draw at higher rate of face advance is a tipping point in evaluating the area of subsidence influence and the magnitude as well. Tensile strain above 3 mm/m was observed on the dip side of the panel. Uneven slope and strain profiles were experienced on dump due to irregular compactness. The intactness of strata during and post-mining was clinched by study of groundwater fluctuation. The outcome of subsidence investigation and hydrogeological study indicated that the surface cracks were skin-deep and there was no possibility of percolation of surface water to the underground working of 410 m depth. The study helped in understanding the influence of old and active dump on subsidence. Rate of mining played a strategic role in affecting the magnitude of subsidence. Regaining of groundwater indicated intactness of the strata.

List of symbols

SCCL Singareni Collieries Company Limited
A_d dynamic angle of draw
F_a rate of face advance

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