Pak. J. Engg. Appl. Sci. Vol. 25 July, 2019 (*p.* 26–35)

Numerical Analysis of Top Coal Recovery Ratio by using Discrete Element Method

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Abstract

There is a massive quantity of lignite coal reserves at the Thar Coalfield Pakistan which are demarcated through thick coal seams. To extract these thick coal seams, the chosen method for mining is Top Coal Caving. The Longwall Top Coal Caving (LTCC) has been one of the preferred underground mining methods that has been developed and then accepted by its guaranteed results in China's coal mining industry. This paper discusses numerical modeling of top coal caving mining method and studies the coal recovery ratio by using discrete element method. In the modeling consequences, the total top coal recovery ratio was computed to be 83.9% when the top coal thickness was three times the cutting height with the drawing interval of 0.8m respectively. Based on this study, it is proposed that LTCC method can be adopted for the mining of thick coal seam(s) at Thar Coalfield.

Key Words: numerical modeling, Thar Coalfield, top coal caving, top coal recovery ratio, thick coal seams

1. Introduction

Longwall Top Coal Caving (LTCC) is a technique that enhances the efficiency level of production at thick coal seams [1]. The LTCC was developed by combination of longwall and sublevel caving methods. The classification relating to thickness may differ from country to country, but acceptable thickness is not less than 6m as the smallest margin [2]. In thick seams, bottom is mined by longwall, and top coal is exploited by sublevel caving.

This method was developed in China [3] in some years 1982, and it is used for exploitation of thick coal seams. The LTCC is a high product and low-cost method, but have a high dependency on seam condition [4-6]. Capability of top coal and recovery percentage are the most important parameters in LTCC that should be completely explained and investigated [7-8]. Improving the caving ratio of top coal signifies that it can considerably increase the top coal recovery ratio of resources through productive yielding. A wide range of top coal recovery ratio can be used in LTCC method if the compactness of the seam is huge. These indicators – broken immediate roof, the recovery ratio of top coal, and the movement law of fractured top coal affects the compactness of the top coal. The influence of the following parameters (– the compactness of immediate roof, cutting depth of the shearer, and the mining height with top coal recovery ratio through numerical simulation) – has been used by many researchers in their researches [9-14].

The studies that deal with the connection of both the recovery ratio of top coal and its compactness are still scarce. In addition, some intriguing developments can be formed based on the above mentioned researches. This study used the PFC2D software to replicate the surroundings of how thick the top coal is, allowing it to set up the numerical models. Based upon "loose medium flow field theory" [15-20], this study also analyzed the effect of the top coal recovery ratio due to the variations of its thickness. The thickness variable was used in the numerical simulation to provide the basis of the theory to obtain the suitable top coal recovery ratio and reasonable thickness of top coal. Furthermore, the development of chain force, and interface between coal and rock to better understand the drawing process of top coal are also discussed respectively.

2. Drawing interval of top coal caving

The length from one top-coal drawing to another towards the face advancing direction is called the drawing interval. This unit is used to describe its number of cuts. For example, one cut with one mining interval, two cuts with one mining interval, and three cuts with one mining interval with the mathematical values of 0.8m, 1.6m, and 2.4m respectively. The cutting-caving height usual ratios are 1:2 and 1:3. As seen from Fig. 1 (modified after [21]), there is a direct effect on the recovery competence and level of the working face improvement by the caving interval of top-coal. They both avert the event of a gangue in mined-out areas and surge instead to a drawing opening, dodging the influx of sublevel waste on the drawing opening as the cutting face is moving towards the top coal. A capacious caving interval of top-coal would force the sublevel waste to get the drawing opening ahead of time than the waste in the excavated-out zone. This is going to cause the drawing opening to closure. Consequently, the loss of coal behind the conveyor is going to build up as seen in Fig. 1(a). Conversely, a small top coal caving interval would result in drawing the opening of the waste in the excavated-out area earlier. The sublevel waste resulting in the blockage of the excavated-out area by a part of the top coal, as seen in Fig. 1(c). When the waste in the excavated zone and the sublevel waste arrive at the drawing opening simultaneously, the rate of top-coal loss convert into the tiniest as seen in Fig. 1(b). To get to a reasonable top coal caving interval, utilize an analogous material simulation test.

3. Brief introduction of Thar coalfield

The Thar Coalfield is positioned in district Tharparkar, province of Sindh in Pakistan. The coal reserves were exposed by Geological Survey of Pakistan (GSP), and United State Agency for international development in 1991 [22].

After the finding of Thar lignite in Sindh, Pakistan has appeared 7th number in the top-20 list of countries around the globe [23]. The cost-effective coal deposits of Thar Pakistan are circumscribed to Paleocene and Eocene classifications of rock [24]. It is one of the world's largest lignite coal deposits spread over about 9,000 sq. km., contains around 175.5 billion tons, which is enough to complete the fuel requirements of the country for centuries. The cumulative thickness of coal seam at Thar varies from 1.5 to 42m.

Thar coalfield is divided into 12 different blocks as shown in Fig. 2(c), (Fig. 2 is modified after [25-26]). The production of coal can be obtained by open-pit and underground mining methods in the region. The Block-II out of 12-blocks is under development for the open-pit mine while remaining blocks are still under planning. Especially Block-IX is considered in this study for underground method. This is the first time in the history of Pakistan that the mechanized longwall with Top Coal Caving method is going to be adopted at Thar Coal. LTCC is the production efficient and low-cost development method as compared to other longwall methods like single-slice or multi-slice for thick coal seams [27]. Fig. 3 [28] show the highlights of LTCC method and Fig. 4 indicate the general geology of Block-IX, Thar Coalfield.

Therefore, the effective measurement of the properties of coal and its surrounding rock mass with multiple empirical research was determined by laboratory experiments as shown in table 1 [4, 29-32].

4. Numerical simulation

In many circumstances, the assessment of an underground structure is considered as very challenging and costly to execute. However, the modeling with computer provides useful, fast, and real consequences to achieve. Numerical modeling was accomplished by using Particle Flow Code (PFC). PFC is widely used for the modeling of top coal recovery ratio and for analyzing the interaction of circular particles during the drawing. The software is founded on Discrete Element Method (DEM). This research study is considered first time and its applications in thick coal seams were investigated with the help of numerical analysis in two-dimensional at Thar Coalfield.

The general modeling procedure of LTCC is accomplished as in Fig. 5 (after [28, 33-34]).

5. Construction of numerical block model

To be able to comprehend the mechanism of top coal drawing and recovery ratio, the PFC2D was used to mimic the numerical model for the caving process in two-dimensions. The software allowed the modeling of the impact of the dissimilar thickness of top coal, the drawing or mining intervals and the mining practices on the top coal drawing. The PFC model uses the DEM code to simulate the synergy and movement of rounded ball particle [35]. The assumption that separately distinct particle is an inelastic with a very insignificant interaction zone was used in the numerical simulation process. The following are the configuration and specifications for the top coal caving of the panel in the numerical models; a 12m thick coal seam, waste rock thickness of 11m with 100m wide with different cutting to caving heights as shown in Fig. 6.

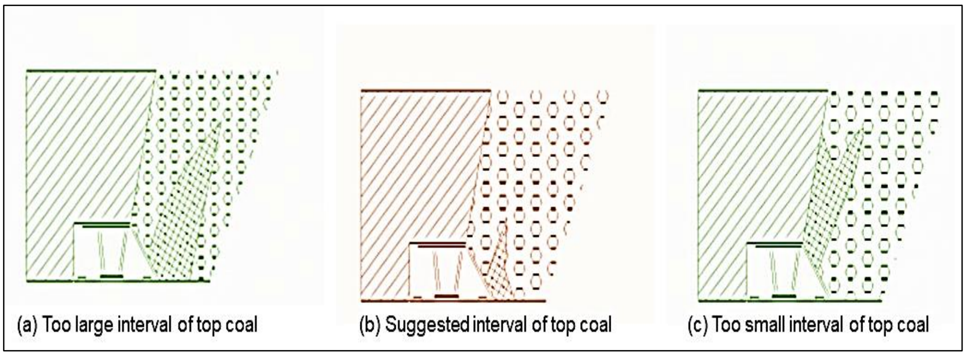


Fig. 1: Correspondence between caving interval and top coal recovery ratio

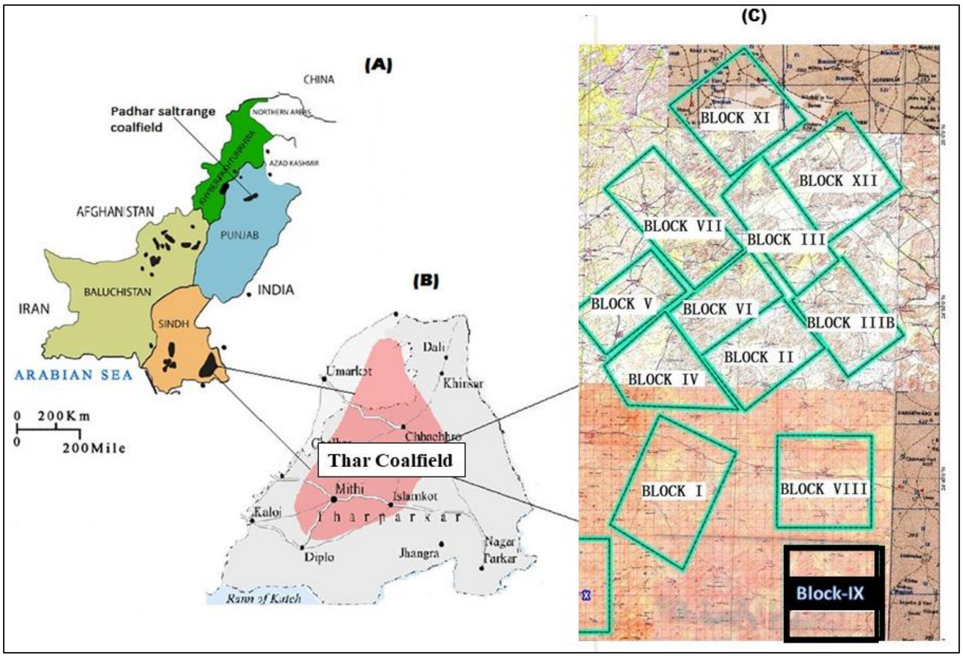


Fig. 2: Location Map of Thar Coalfield

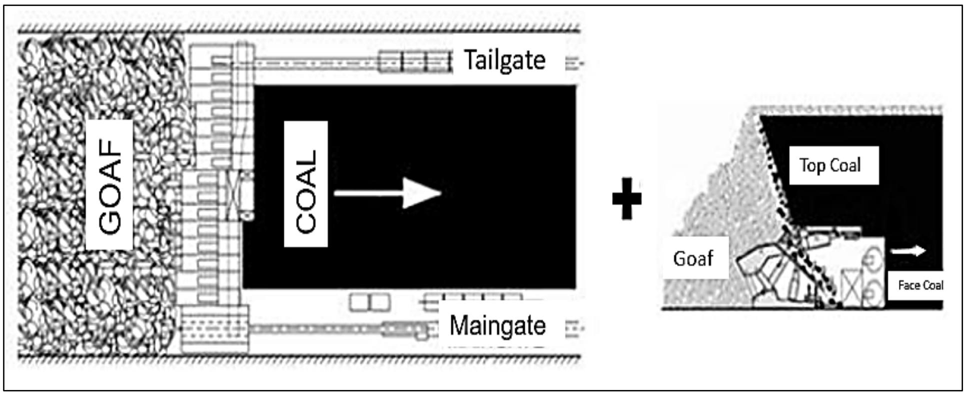


Fig. 3: Highlights of LTCC method

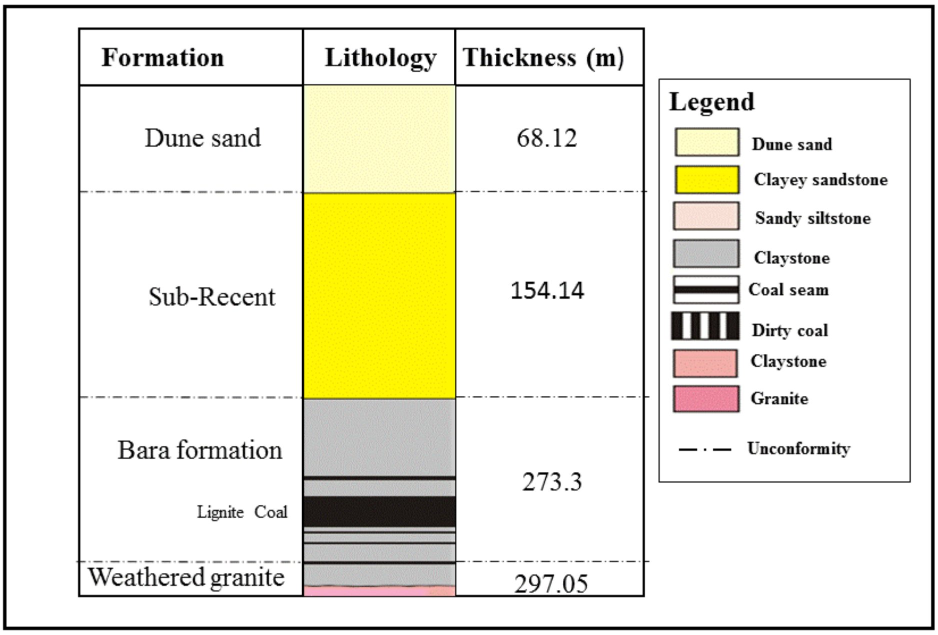


Fig. 4: Generalized stratigraphic column of Block-IX Thar Coalfield

Table 2 shows the input parameters used in the numerical model.

In Fig. 6, red particles are defined as coal. At the top of the model are green particles defined as fractured immediate roof. The PFC Contact Bond Model is used for simulation. Therefore, in the contact bond model, "an elastic spring with continuous normal stiffness (Kn) and shear stiffness (Ks) behaves at the contact points between particles is allowing only forces to be transmitted". The initial velocity of these particles is zero and they experience g-force at 9.81m/s^2. The velocity and the acceleration on the wall is zero as well. Boundary conditions of the model-outer boundaries are the adjacent barrier of the particles and the interior barrier to grip the particles. Though, the acceleration and velocity are considered as zero for the boundaries.

6. Results and discussion

To regulate the numerical modeling, the standard that the drawing growth ends once the waste rock appears out of the model is endorsed. The face advances to 76m when one cut with one drawing interval. The final result is shown in Fig. 7.

To find out the top coal caving ratio during its process of advancing can be calculated by the following formula;

$$Rc = \frac{Nd}{Ni}x100 \qquad (1)$$

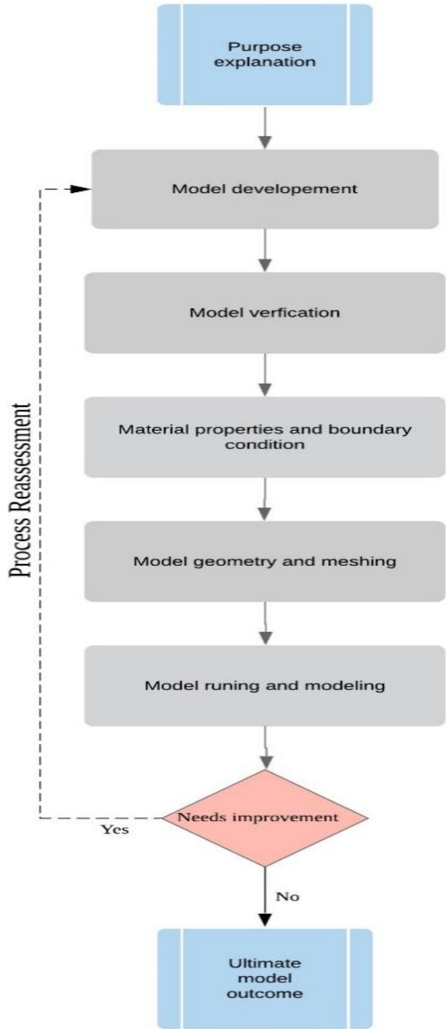
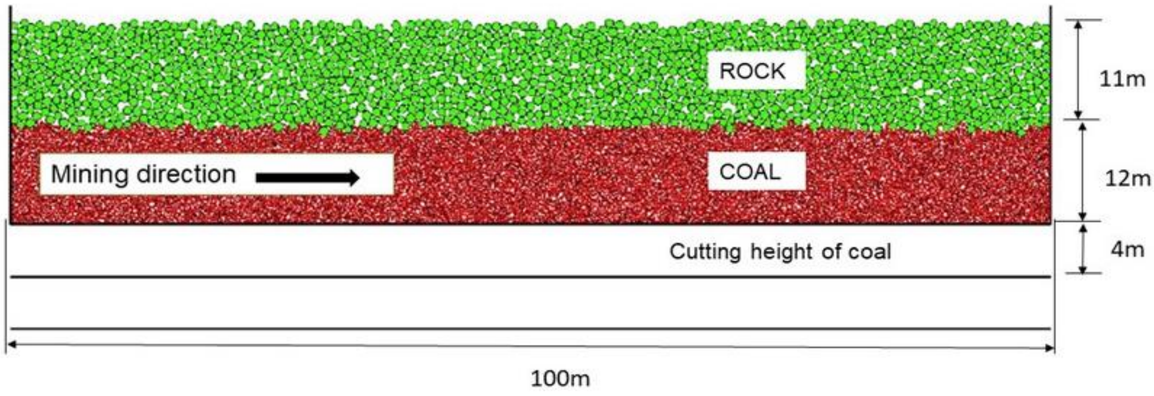
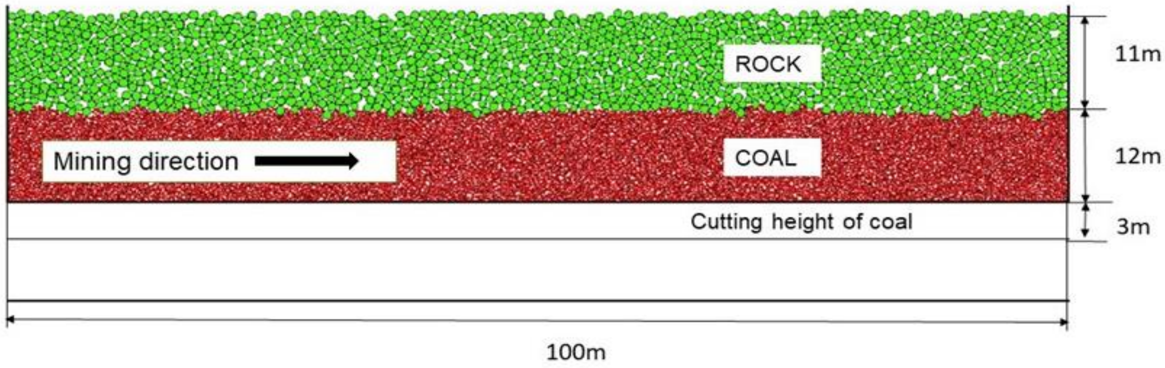


Fig. 5: Flow chart of general modeling procedure



1:2



1:3

Fig. 6: PFC2D numerical models for effective caving process at 1:2 and 1:3

Table 1: Properties of Coal and Rock

Rock type	Unit	Claystone	Siltstone	Coal
Internal friction (φ)	(°)	34.25	45	23.68
Cohesion (c)	(MPa)	0.13	0.13	0.132
Modulus of elasticity (E)	(MPa)	2119	2217	1762
Tensile strength	(MPa)	0.365	0.41	0.217
Poisson's ratio (ϑ)	-	0.25	0.25	0.28
Uniaxial Compressive Strength (UCS)	(MPa)	2.74	2.903	1.88

Table 2: Input Parameters of coal and waste

Solid	Density (kg/m^3)	Coefficient of Friction	[1]Kn (kN/m)	[2]Ks (kN/m)
Coal	1500	0.4	2×10^8	2×10^8
Rock	2300	0.4	4×10^8	4×10^8

[1] Normal stiffness
[2] Shear stiffness

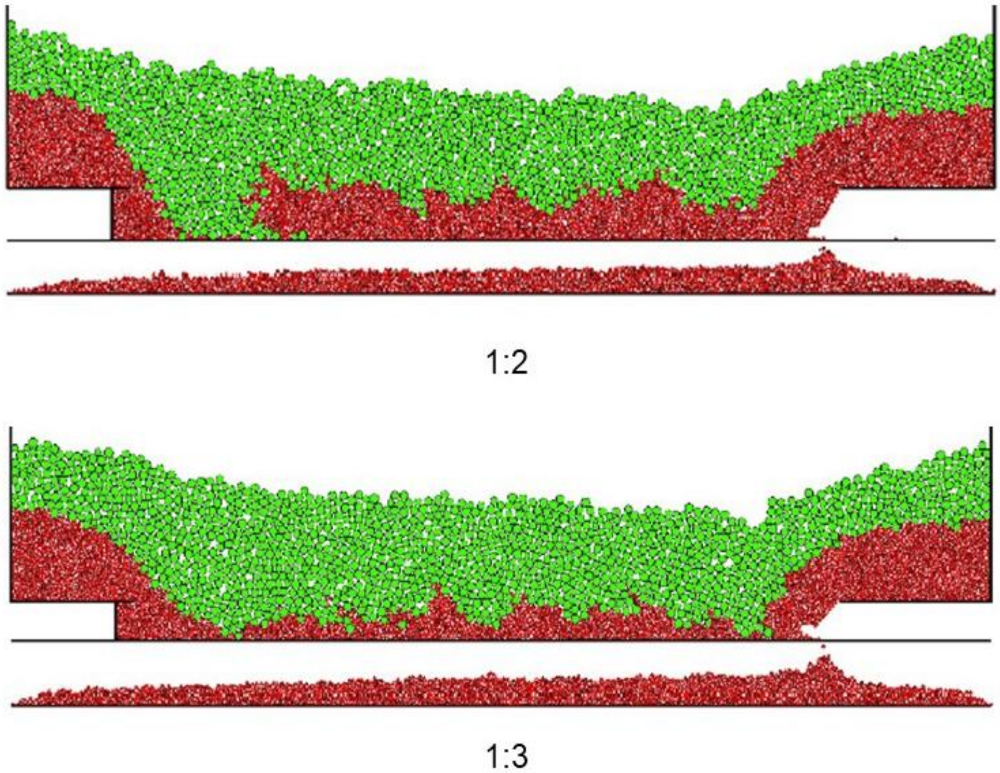


Fig. 7: Numerical analysis at one cut with one drawing interval (0.8m)

Table 3: Dispersal of the coal seam

Seam thickness (m)	Cutting height (m)	Cutting to caving height ratio (%)	Caving height (m)
12	4	1:2	8
12	3	1:3	9

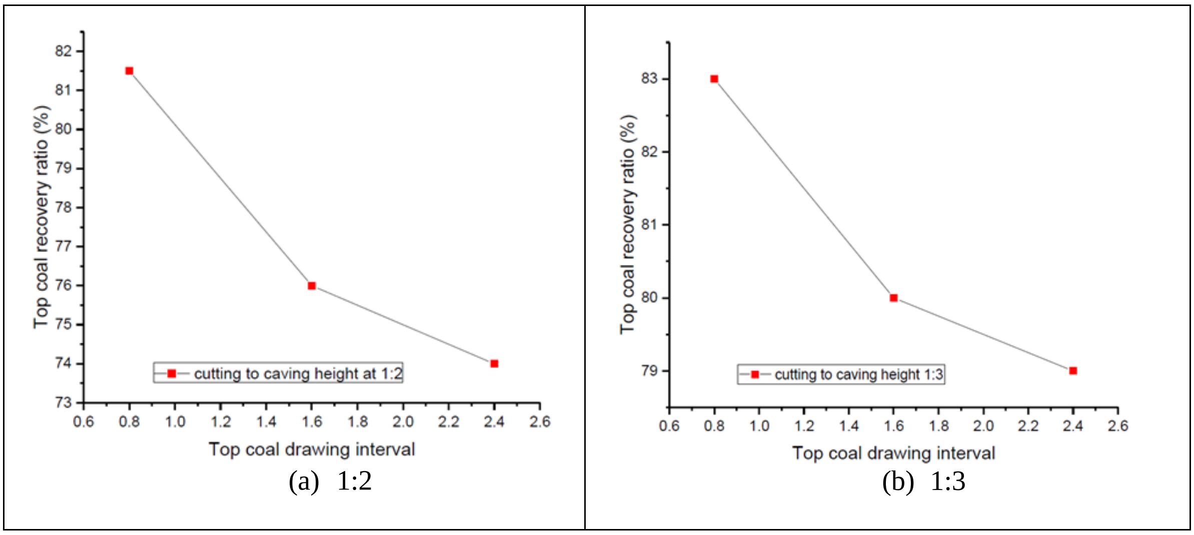


Fig. 8: Analysis of top coal recovery ratio

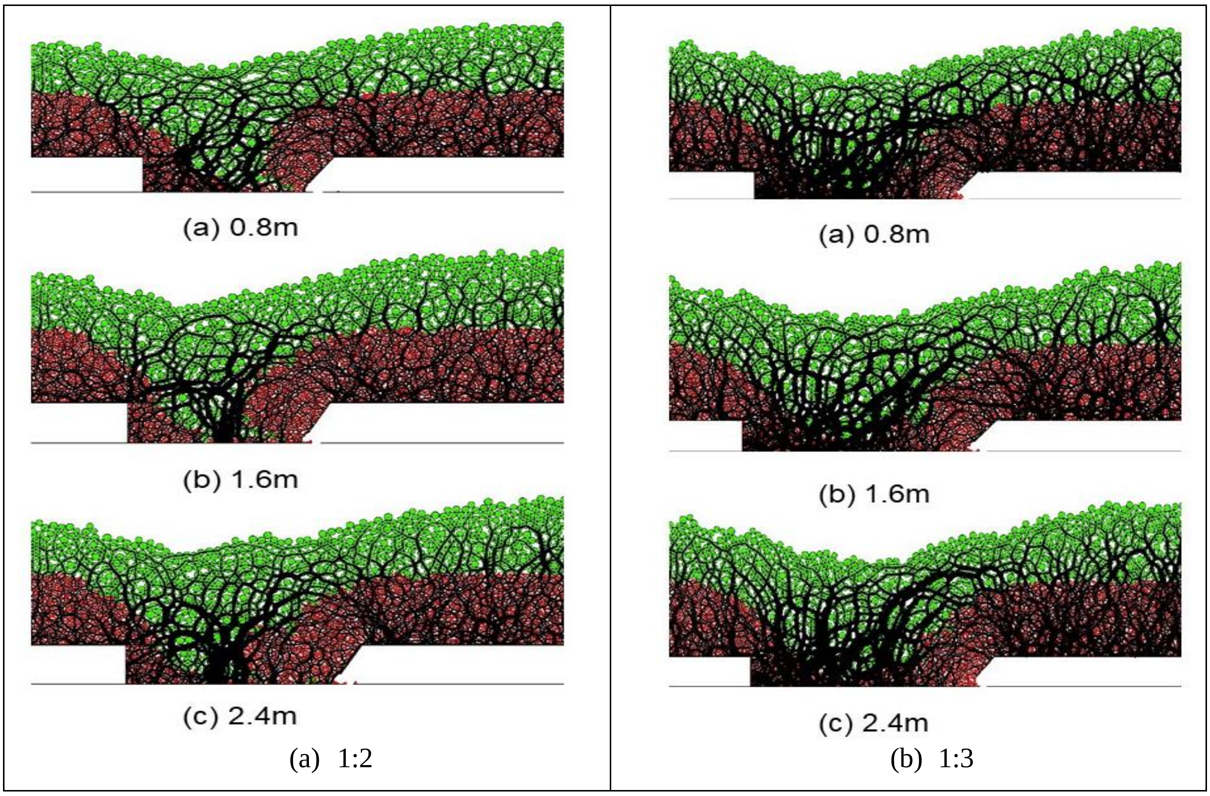


Fig. 9: The developing of chain force during the drawing process

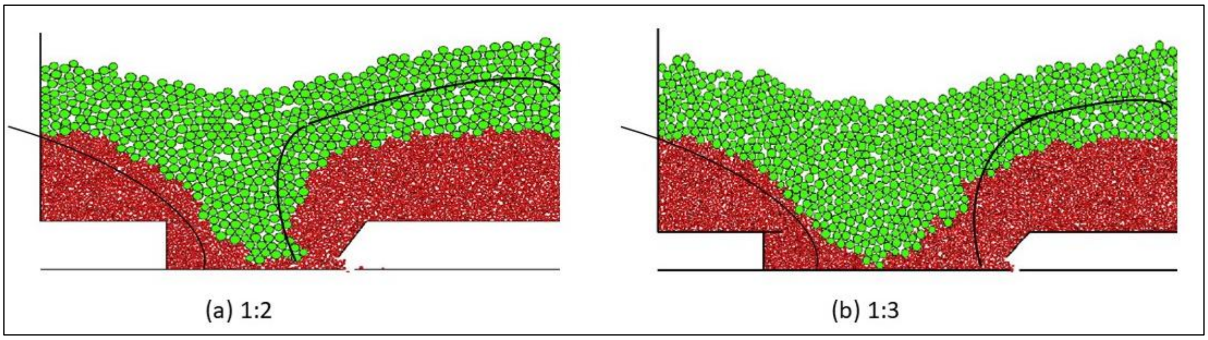


Fig. 10: Interface between coal and rock

Where Rc is the top coal recovery ratio in percentage (%), Nd is the number of drawn-out coal particles, and Ni is the initial number of coal particles.

Fig. 8(a and b) and table 3 show that the top coal recovery ratio can be affected immensely by two variables, the mining interval and cutting-caving height ratio. At different cutting-caving heights (1:2 and 1:3) and drawing intervals (0.8m, 1.6m, and 2.4m), the recovery ratio is higher with a definite cutting-caving height is 1:3 and the drawing interval is 0.8m.

Fig. 9(a and b) show the top coal contact force recorded during the operation. Where the analysis and of the influence caused by different cutting to caving height ratios and different web cuts, on the distribution of coal-rock loose field.

The force chain girth represents the strength of the force among particles in the modeling of the DEM method. A wide chain of force determines the large strength of the force among the particles making it impossible for them to move. Fig. 9(a) shows a cutting-caving height ratio of 1:2. The height of strong force zone moves up but the zone shows a visible arched tendency behind the goaf. Consequently, the waste rock come to the drawing opening quickly and results in a loss of top coal simultaneously. Similarly, the cutting-caving height ratio at 1:3 in Fig. 9(b), the area enclosed through the chain of tight load assumes an elliptical nature that corresponds to the ideal drawn body which is helpful to the extraction of the top coal.

The structure of the drawing coal and effect on top coal caving ratio can be organized by interface between coal and rock. The discrepancies of interface between coal and rock at different cutting to caving height ratios are displayed in Fig. 10(a and b). This can be divided into front and back interfaces. The back interface always remains same and front interface changes onward during the face advancing of coal. Fig. 10(b) show that the structure of interface is best for the drawing of coal in accordance with their external boundary and will increase the recovery ratio of top-coal. The waste behind the face is reached at the drawing opening during the face advancing, as shown in Fig. 10(a). Thus, the consequences of the interface between coal and rock at a cutting-caving height of 1:2 in Fig. 10(a) are not greatly ideal as compared to 1:3 in Fig. 10(b).

7. Suggested cutting-caving height ratio and drawing interval for Block-IX, Thar Coalfield

The effect of a thick and large top-coal on the top-coal recovery ratio is replicated from the deviation of the recovery ratio of top-coal. To be able to boost the recovery ratio of top-coal, the waste-rock should be stopped from the goaf and getting to the drawing opening ahead of time. Using the computations of the varied top-coal thickness conditions, the suggested cutting-caving height ratio is 1:3 instead of 1:2 at one cut with one drawing interval (0.8m) consequently. The top-coal recovery ratio commands its highest point when the top coal thickness is 9m. The past studies have also suggested the response of top coal during the caving process is in good agreement when the thickness of top coal is at 9m [24].

8. Conclusions

At present, the emphasis on longwall top coal caving method growing rapidly for the extraction of thick coal seams and it has become the key method for thick seams. The main research areas are a top-coal mechanism and the enhancement of the recovery ratio of top coal, especially in the field of LTCC. The top-coal thickness may affect caving ratio of top coal.

Due to the variance in top coal thickness, the top-coal recovery ratio is most significant when the thickness of top-coal is around three times as highest as the mining height.

The determined recovery ratio of top-coal in this study is 83.9%. The consequences of numerical simulation propose that 0.8m is the best drawing interval with cutting-caving height ratio of 1:3.

Therefore, based on the numerical modeling, the cutting to caving height 1:3 is suggested instead of 1:2 for the development of LTCC method at THAR COAL Pakistan. A 1:3 ratio means that the conventional longwall face is only 3 m high rather than 4 m high for 1:2, the reduced face height having significant face stability benefits as outlined in the past studies also.

9. Recommendations and future work

The study was conducted with 1:2 and 1:3 for the computation of top coal recovery ratio. Therefore, further study could be recommended with maximum ratios of cutting to caving height to better understand the simulation of top coal recovery ratio. In addition, the results of present study are only based on the numerical simulation in two dimensional analysis. However, the future work could be expanded to this method in three-dimensional analysis.

10. Acknowledgment

The authors want to convey their first and topmost gratitude to School of Mines, China University of Mining and Technology (CUMT) and Department of Mining Engineering, Mehran University of Engineering and Technology (MUET) for their continuous support and dedication to accomplish this task within specified time period.

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