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The application of *PFC* to simulate longwall top coal caving

Zhengyang Song, Heinz Konietzky & Martin Herbst
Geotechnical Institute, TU Bergakademie Freiberg, Freiberg, Germany

1 INTRODUCTION

The longwall top coal caving (LTCC) mining method is commonly employed to extract thick coal seams with the thickness larger than 4.5 m. The LTCC was first developed in Soviet Union and France around the 1950s. In recent decades, the quick development of LTCC has significantly boosted the coal output in the China (Wang et al. 2016, Yu et al. 2017), Australia (Alehossein & Poulsen 2010, Vakili & Hebblewhite 2010) and Vietnam (Le et al. 2017). During the extraction procedure in LTCC, the coal seam is divided into two parts: the bottom and the top coal part. The bottom part of the coal seam is directly extracted by the shearer, and the top coal is fractured by the strata pressure and then flows out from the drawing window. The fractured top coal can be regarded as granular rigid bodies and the flow is driven by gravity.

2 MODEL SET-UP

The *PFC3D* (Itasca 2018) model for LTCC is shown at the top of Figure 1. The thickness of the coal layer is 6 m and the gangue layer is 4 m. The coal seam is marked with different colors for better distinguishing the heights. The properties of the particles are given in Table 1. The linear elastic contact model is used to simulate the contact between particles. The support system used in this numerical model is represented by wall elements.

Table 1. Micromechanical parameters of the numerical model.

Coal particles radii	Gangue particles radii	ball-ball friction coefficient	ball-wall friction coefficient	Coal density	Gangue density	Coal particles number
[m]	[m]	[-]	[-]	[kg/m^3]	[kg/m^3]	[-]
0.15-0.2	0.2-0.25	0.5	0.25	1712	1800	50346
Normal stiffness	**Shear stiffness**	**Coal layer porosity**	**Gangue layer porosity**	**Damping ratio**	**Gravity constant**	**Gangue particles number**
[N/m]	[N/m]	[-]	[-]	[-]	[m/s^2]	[-]
5e5	5e5	0.4	0.65	0.2	9.8	18381

The procedure of support advance results in a movement of the fractured top coal and gangue. The boundary between top coal and gangue will further develop due to the influence of support advance. The continuous support advance in this numerical model is implemented based on pre-set multi drawing openings (DO). The middle part of Figure 1 shows the pre-set DO at different positions. The distance between two adjacent columns of DO along the support advance direction is n, the short side of DO is also equal to n. The drawing support (DS) and face-end support (FS) move forward by a distance which is equal to several times of n after drawing. The moving distance in LTCC is called drawing interval. Three possible drawing intervals

(2*n*, 4*n* and 6*n*) in the numerical model are illustrated in Figure 1. In this article, 2*n* (*n* = 1 m) is selected as the drawing interval in the following simulations. The general cyclic procedures at LTCC working face is: DO opens – Drawing – DO closes – DS advances – DO opens. The supports (both FS and DS) move forward when the current round drawing is finished. Figure 1 also shows the implementation of the continuous advance procedures of different DS. At the bottom of Figure 1, the advance procedure of DS #1 is illustrated. The advance speed is 3 m/min, which is close to the advance speed in-situ.

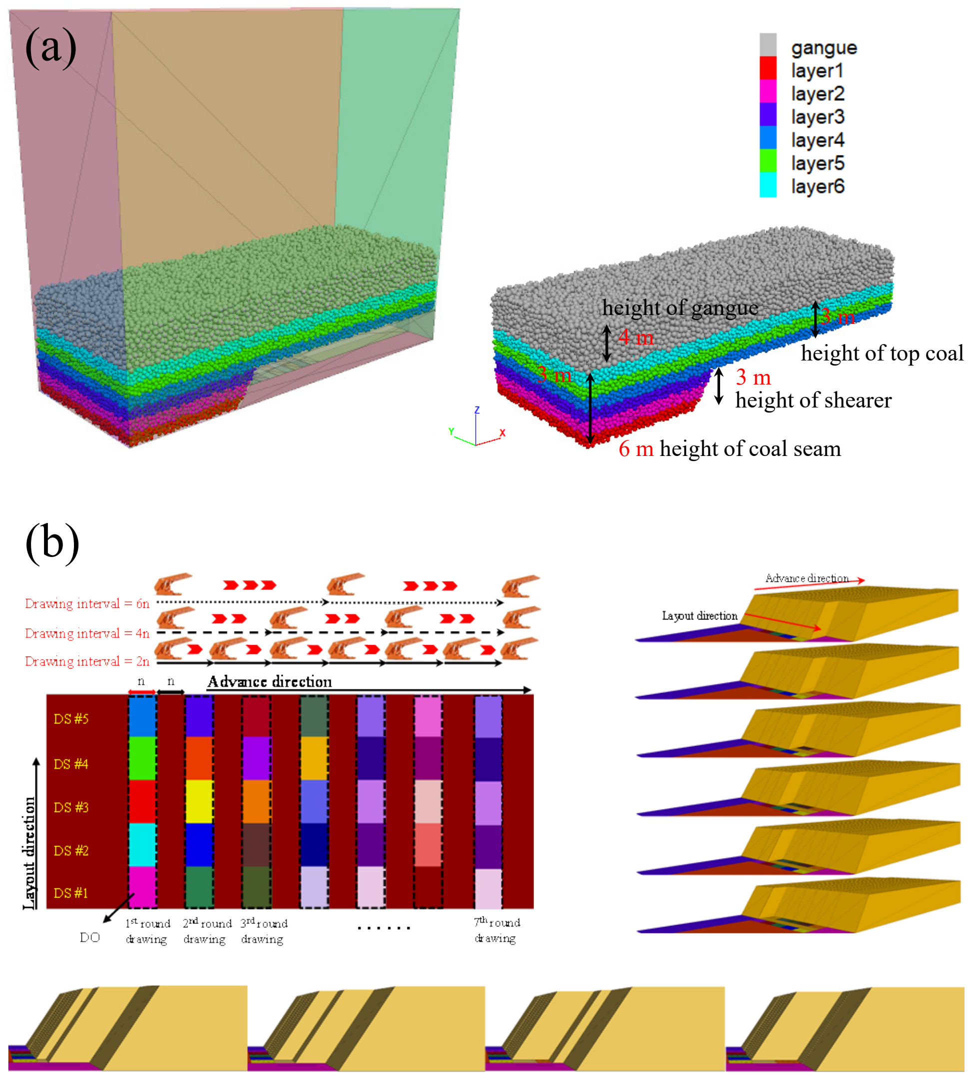

Figure 1. Model of LTCC (a) overview of model (b) illustration of support advance.

3 RESULTS

The drawing body in LTCC is referred to the zone of drawn-out top coal when the first gangue flows out from the DO. This principle is also used in-situ for the miners to control the opening and closure of the DO. The drawing body is similar to the isolated extracted zone (IEZ) in block caving (Melo et al. 2007, Song et al. 2018, 2019). The mass of drawing body is directly related to the top coal recovery ratio. In the numerical model the DO is precisely closed, when the first gangue particle flows out from the DO. Mass and ID of the drawn-out particles are recorded. For each drawing round, all five DS perform the drawing procedure (from DS #1 to DS #5). In our simulation, the support advances four times and five rounds of drawing are conducted in total. Consequently, 25 times (5 drawing rounds × 5 DS = 25) the top coal drawing procedure is conducted. We count the ID of the drawn-out particles and the original positions of the drawn-out particles can be obtained. The drawing bodies with their initial positions (before the initial drawing) connected to the 25 top coal drawing procedures are visualized in Figure 2.

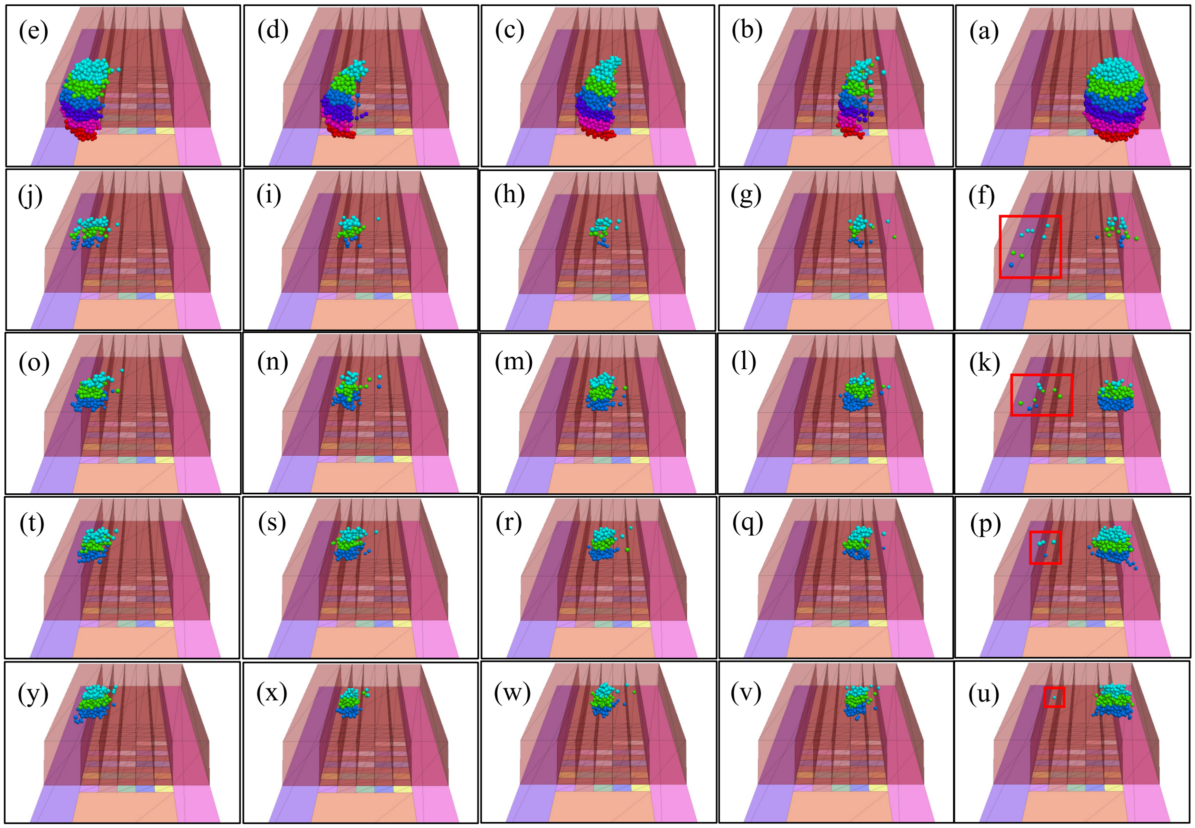

Figure 2. Back view of drawing bodies with original positions (a) R1D1, (b) R1D2, (c) R1D3, (d) R1D4, (e) R1D5, (f) R2D1, (g) R2D2, (h) R2D3, (i) R2D4, (j) R2D5, (k) R3D1, (l) R3D2, (m) R3D3, (n) R3D4, (o) R3D5, (p) R4D1, (q) R4D2, (r) R4D3, (s) R4D4, (t) R4D5, (u) R5D1, (v) R5D2, (w) R5D3, (x) R5D4, (y) R5D5.
Note: R1D1 indicates Round 1 Drawing 1, the red rectangles mark the drawn out particle far away from DO.

4 CONCLUSIONS

This work presents a numerical simulation procedure to model the LTCC process. This numerical model considers the effect of continuous support advance and face-end support. The main conclusions obtained from the numerical simulations are:

- The effects of continuous support advance and face-end support on drawing procedures in LTCC are non-ignorable. The continuous support advance and the face-end support have to be considered in the numerical simulations. Also, the different drawing intervals should be implemented through the pre-set of the drawing openings.
- The shape of drawing body in different drawing rounds are visualized. The shape of drawing body under the condition of sufficient drawing shows an ellipsoidal shape, whereas the drawing body under condition of insufficient drawing shows a top-half ellipsoid.

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