

NUMERICAL APPROACH TO THE TOP COAL CAVING PROCESS UNDER DIFFERENT COAL SEAM THICKNESSES

by

**Bin YU^a, Ru ZHANG^{b,c*}, Ming-Zhong GAO^{b,c}, Guo LI^{b,c},
Ze-Tian ZHANG^{b,c}, and Qian-Ying LIU^{b,c}**

^a Datong Coal Mine Group, Datong, China

^b State Key Laboratory of Hydraulics and Mountain River Engineering,
Sichuan University, Chengdu, China

^c College of Water Resource and Hydropower, Sichuan University, Chengdu, China

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Numerical study of mining-induced stress evolution of coal during the top coal caving process under different coal seam thicknesses is carried out, and the numerical prediction agrees well with the field test data. Main characters on stress distribution and dangerous area are elucidated. For the same coal quality, coal layers under 7 m thick fail earlier than thicker coal layers; correspondingly, the internal fracture networks of thin layers are more easily developed. During the mining of a coal layer less than 7 m thick, stress monitoring of the “dangerous area” in the middle of the top coal should be emphasized, whereas during the mining of coal layers less than 11 m thick, stress monitoring of the “dangerous area” at the bottom of the top coal should be highlighted. The research is to optimize caving technique and extraction process.

Key words: different coal seam thicknesses, mining-induced stress evolution, poppet pressure, delimitation of the risk area

Introduction

A series of studies on coal rock and wall rock deformation failure have been carried out through various methods, *e. g.*, numerical simulation [1-6], theoretical analysis [7-9], *on-site* monitoring [10, 11], and indoor tests [12-14]. However, research on coal rock mining-induced stress evolution for coal seams with various thicknesses during top coal caving has rarely been conducted. In the present study, a working face of Datong Tashan Mine, where the geological occurrence is a 7.25-20.19 m (average 11.17 m) thick coal seam, is used as an example to conduct a numerical study of the stress characteristics and fracture mechanisms of coal seams with three different thicknesses under sequential coal caving.

Calculation model and method

In this paper, coal seams with three different thicknesses are defined: *i. e.*, “relatively thin” (7 m), “medium thick” (11 m), and “super-thick” (19 m). The calculation model is established according to the geological condition of the 8212 working face in Tashan Mine, where the average coal seam slope is 4°, and the uniaxial compressive strength is 20.0 MPa. The calculation model is shown in fig. 1. The excavation’s opposite direction is used as the

* Corresponding author; e-mail: zhangru@scu.edu.cn

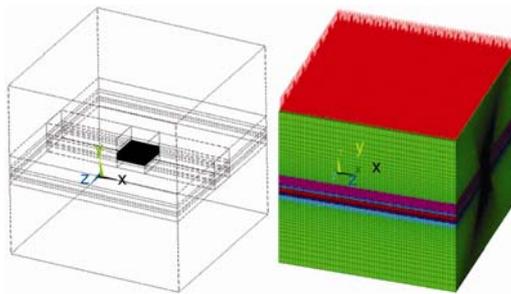


Figure 1. The 3-D finite element model

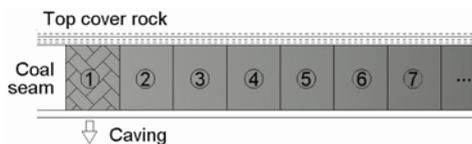


Figure 2. Sequential coal caving process diagram

ed *via* the live or dead state of the unit. Support is implemented *via* a bar unit to simulate top coal caving. During on-site coal caving, top coal caving occurs once every 2 m. Therefore, during the numeric simulation, the top coal is divided into 25 blocks; the sequential caving process is shown in fig. 2. The physico-mechanical parameters of the rock used the in simulation are presented in tab. 1.

Table 1. Mechanical parameters of the rock used in the calculation

Rock type	Natural density [gcm ⁻³]	Deformation modulus E [GPa]	Poisson ratio μ	Uniaxial compressive strength [MPa]
Old bottom – grit stone with gravel	2.53	26.0	0.20	95.0
Direct bottom – kaolin rock	2.60	20.0	0.28	51.0
Coal	1.59	3.5	0.30	20.0
Direct top – mud rock	2.58	5.0	0.28	79.6
Old top – grit stone	2.40	28.4	0.24	90.0
Wall rock	2.50	20.0	0.25	60.0
Support – steel	7.80	206.0	0.26	500

Top coal caving mining can be simplified into three steps: (1) Initial ground stress simulation. The ground stress in Datong Tashan Mine is primarily deadweight stress, and the effect of structural stress is not taken into account. Hence, this paper only uses deadweight stress as the initial ground stress. (2) Excavation and support installation simulation. Based on the initial ground stress, the condition of the original coal rock after 12 m of excavation in the working face is calculated; *i. e.*, the finite element analysis uses the unit live-dead function to simultaneously kill the excavated caving coal unit and activates the support unit. (3) Coal caving process simulation for coal seams with different thicknesses. This study investigates the mining-induced stress distribution rule of top coal during sequential coal caving.

z-axis. The y-axis follows the vertical direction, with upward being the positive direction. The direction of the x-axis is parallel to the coal caving direction. The 3-D model has a range of $300 \times 300 \times 300$ m. The mining covered rock seam area is $50 \times 50 \times 50$ m, which locates in the middle of the model. The bottom rock seam is under displacement constraint from the y-direction; two sides are under Symmetry B. C. constraints from the x- and z-directions. The coal seam burial depth is 470 m. A stress of 8.0 MPa is exerted on the top of the model to simulate the deadweight of the upper cover rock seam. The coal seam thicknesses are 7 m, 11 m, and 19 m, respectively; the mining heights are all 3 m; and the mining caving ratios (mining height vs. top coal thickness) are 1:1.3, 1:2.7, and 1:5.3, respectively. In the model, coal excavation and caving are simulat-

Analysis of the numeric simulation calculation results

The Tashan Mine coal rock’s burial depth is used to calculate that the coal rock’s initial ground stress in the excavation area is $\sigma_0 = 11.8$ MPa under deadweight stress. On this basis, a simulation of 12 m excavation along the working face advancement direction with support installment yields a coal rock stress of $\sigma_w = 18.4$ MPa, which is approximately 1.57 times the initial ground stress σ_0 . This result indicates that excavation has a significant effect on the coal rock stress.

Tashan Mine has a coal seam thicknesses of 7-21 m and is adopting the sequential coal caving method. Figure 3(a) displays the distribution curve of the pressure on the support collected on-site during sequential coal caving. Figure 3(a) shows that during coal caving, the field pressure on the support fluctuates by approximately 30.0 MPa. Figure 3(b) presents the numeric simulation of the distribution curve of the pressure on the support for an 11 m coal seam during sequential coal caving. Figure 3(b) reveals that, during sequential coal caving, the numeric simulation result of the pressure on the support is approximately 30.0 MPa. The numeric simulation result is consistent with the on-site monitored data and provides an excellent reference value.

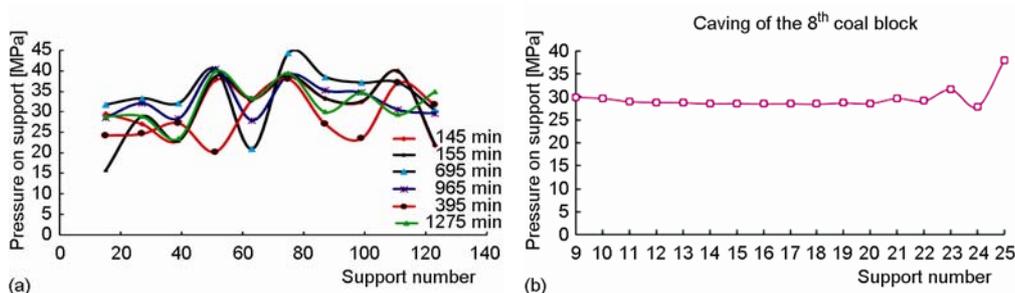


Figure 3. On-site monitored vs. numeric simulated pressure on the support; (a) on-site monitored data, (b) result of the sequential coal caving numeric simulation for the 11 m thick coal seam

Numeric calculation results are used to analyze average top coal stress characteristics and differences for coal seams with three different thicknesses in different areas during sequential coal caving, as described in figs. 4 to 6 and tab. 2.

The sequential coal caving stress variation rule for coal seams with three different thicknesses demonstrates that, during sequential coal caving, the mining-induced top coal stress distribution for coal seams with different thicknesses has significant variance along the direction of height. Based on the stress variation curve, a comparison of the top coal stress status of the 7 m, 11 m, and 19 m coal seams during entire coal caving shows that the top coal stress of the 7 m “relatively thin” coal seam in the direction of height (top, middle, and bottom) is always greater than the stress of the 11 m or 19 m coal seam. The 7 m coal seam has a higher level of top coal stress than the stress of the 11 m or 19 m coal seams

Table 2. Average top coal stress distribution statistics for coal seams with different thicknesses in different areas during sequential coal caving [MPa]

Area	7 m sequential coal caving	11 m sequential coal caving	19 m sequential coal caving
Bottom	20.0	18.6	18.9
Middle	22.4	12.5	9.8
Top	19.6	17.6	17.1

along the direction of height. This result indicates that, during the mining process of the thin coal seam, the stress on the coal rock is higher than that case on the thick coal seam. Under the same coal seam geological condition, the 7 m thick coal rock fails earlier than the thicker coal seams during the mining process and has a more developed internal fracture network. Moreover, the 7 m coal seam has a different stress “risk area” location compared with the other two types of coal seams, which is elaborated as follows: the “risk area” of the 7 m coal seam is located in the middle of the coal seam, whereas the “risk areas” of the 11 m “medium thick” and 19 m “super thick” coal seams are both located at the bottom of the top coal. Therefore, during the mining of coal rock with different thicknesses, the stress at the corresponding “risk areas” should be closely monitored, and proper stress-release measures should be taken simultaneously.

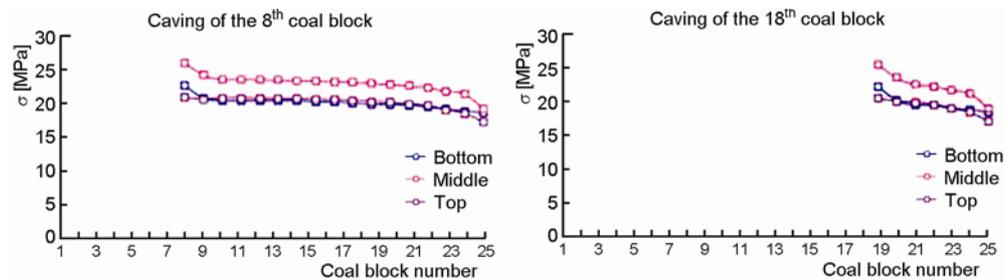


Figure 4. Stress distribution curve in different top coal areas of the 7 m thick coal seam during coal caving

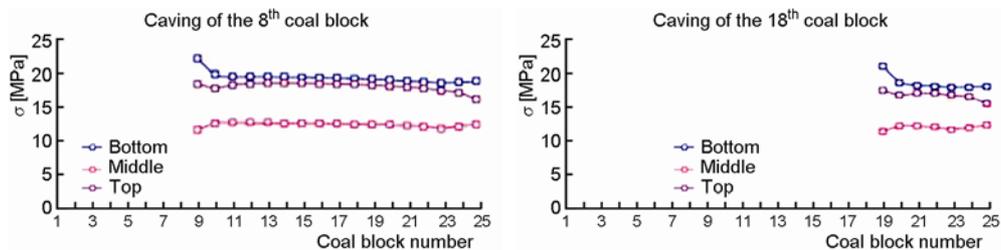


Figure 5. Stress distribution curve in different top coal areas of the 11 m thick coal seam during coal caving

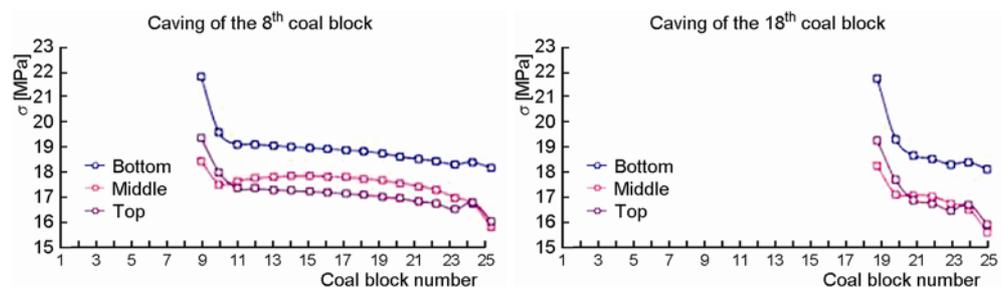


Figure 6. Stress distribution curve in different top coal areas of the 19 m thick coal seam during coal caving

Conclusions

In this paper, geological information of the coal seam in Datong Tashan Mine is used as an example for an ANSYS-based simulation of the mining-induced stress-variation rule and differences for coal seams with three different thicknesses, “relatively thin” (7 m), “medium thick” (11 m), and “super thick” (19 m), during the top coal caving process. This study presents important reference values for studying the top coal rock-failure mechanism, internal fracture evolution and gas migration rule for coal seams with different thicknesses, which also guarantees safe mining of coal seams with different thicknesses in Tashan Mine and has significant theoretical meaning and engineering guidance value to prevent top coal caving-induced gas explosions, as well as for coal caving process and extraction process optimization. Final conclusions are as follows:

- The comparison of the numeric simulated support pressure versus the on-site monitored support pressure reveals that the numeric simulation result is consistent with the on-site monitoring data and therefore has excellent reference value.
- During sequential coal caving, the top coal stress distribution of coal seams with different thicknesses along the direction of height varies significantly. This finding is elaborated as follows: The top-coal stress of the 7 m thick coal seam in the direction of height (top, middle, and bottom) is always greater than the stress of the 11 m or 19 m coal seams. Furthermore, coal seams with three different thicknesses have different top coal stress “risk area” locations; among them, the “risk area” of the 7 m “relatively thin” coal seam is located in the middle of the coal seam, whereas, in the case of the 11 m “medium thick” or 19 m “super thick” coal seam, the “risk area” is located at the bottom of the top coal.
- During mining of the 7 m coal seam, the middle area with the maximum top coal stress increase should be closely monitored for real-time monitoring and alarms. When the coal rock stress in the middle reaches a certain threshold, relevant stress-release measures should be taken immediately. Similarly, during the mining of “medium thick” (11 m) and “super thick” (19 m) coal seams in Tashan Mine, the stress status of the coal-rock bottom area should be closely monitored. Proactive monitoring and alarming can accurately predict stress status in the top coal “risk area”, which can avoid the danger that gas in a certain area exceeds the threshold and explodes out of the mining face, thereby guaranteeing safe mining.

Acknowledgments

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References

- [1] Chen, Z. H., et al., Numerical Simulation of Three Dimensional Deformation and Failure of Top Coal Caving, *Chinese Journal of Rock Mechanics and Engineering*, 21 (2002), 3, pp. 309-313
- [2] Si, R. J., et al., Numerical Simulation of Abutment Pressure Distribution Laws of Working Faces, *Rock and Soil Mechanics*, 28 (2007), 2, pp. 351-354
- [3] Yang, J. X., et al., Analysis on the Rock Failure and Strata Behavior Characteristics under the Condition of Hard and Thick Roof, *Journal of Mining & Safety Engineering*, 30 (2013), 2, pp. 211-217
- [4] Meng, X. Z., et al., Dynamic Analysis of the Initial Caving Process of Roof Coal Seam in Roof Caving Coal Face, *Journal of China Coal Society*, 33 (2008), 8, pp. 841-844

- [5] Zuo, J. P., *et al.*, Analysis and Study on Falling Down Law of Coal and Rock in High Cutting Fully Mechanized Top Coal, *Coal Science and Technology*, 41 (2013), 1, pp. 56-59
- [6] Tang, Z., *et al.*, Numerical Simulation on the Influence of the Pillar on the Lower Coal Seam Mining, *The Chinese Journal of Geological Hazard and Control*, 24 (2013), 2, pp. 83-86
- [7] Wu, L. X., *et al.*, Foundation for Coal Pillar Design and Monitoring, China University of Mining and Technology Press, Xuzhou, China, 2000
- [8] Liu, C., *et al.*, Mechanism and Countermeasures of Layered Floor Heave of Extraction Opening with Large Section, *Journal of China Coal Society*, 39 (2014), 6, pp. 1049-1055
- [9] Wang, J. C., *et al.*, Determining the Support Capacity Based on Roof and Coal Wall Control, *Journal of China Coal Society*, 39 (2014), 8, pp. 1619-1624
- [10] Shao, M. W., *et al.*, Actual Measurement Analysis on Abutment Pressure of Coal Pillars in Working Face with Large Mining Height, *Coal Engineering*, 46 (2014), 4, pp. 74-79
- [11] Wang, C. Q., *et al.*, Field Research on Long-Term Bearing Capacity of Strip Pillar, *Journal of Mining & Safety Engineering*, 30 (2013), 6, pp. 799-804
- [12] Xie, H. P., *et al.*, Mining-Induced Mechanical Behavior in Coal Seams under Different Mining Layouts, *Journal of China Coal Society*, 36 (2011), 7, pp. 1067-1074
- [13] Zuo, J. P., *et al.*, Deformation Failure Mechanism and Analysis of Rock under Different Mining Condition, *Journal of China Coal Society*, 38 (2013), 8, pp. 1319-1324
- [14] Li, W. T., *et al.*, Model Test Study of Surrounding Rock Deformation and Failure Mechanism of Deep Roadway with Thick Top Coal, *Rock and Soil Mechanics*, 34 (2013), 10, pp. 2847-2856