Proceedings of the World Congress on Mechanical, Chemical, and Material Engineering (MCM 2015)
Barcelona, Spain – July 20 - 21, 2015
Paper No. 354

Application of Longwall Top Coal Caving in Challenging Geological Conditions

Ning Shi
Terra Energy LLC
#29-206, BLK 13, Heping St., Beijing, China 10013
ning.s@terraenergy.mn

Zhizeng Huang
China Coal Research Institute
#5 Qingniangou East St., Beijing, China 10013
huangzhizeng@tdkcsj.com

Abstract **-**Longwall top coal caving (LTCC) techniques has been employed in favourable geological conditions widely in China since the mid-80s and in Australia recently. With the improvement of highly-powered face equipment and the method itself, in the past 15 years, LTCC was introduced to more challenging geological conditions, such as unfavourable roof conditions, complex seam formations, gaseous seam and sponcom prone seam. Different practices were adopted to ensure the safety and productivity of LTCC operations with one or more challenges on various sites in China. In this paper, firstly, the development and application of LTCC techniques in China was introduced and summarized; Secondly, 7 types of challenging conditions including weak roof, strong roof, steeply dipping, ultra-thick seam, marginally thick seam, gaseous, and sponcom prone are define and described; Apart from the 7 conditions, 5 types of safety risks are categorized for the further discussion on operational challenges in LTCC; Thirdly, based on previous experience of LTCC applications, the best practices are recommended in conjunction with those risks or challenging conditions.

Keywords**:** Thick seam, LTCC, Risk, Practice, Challenging Geological Conditions

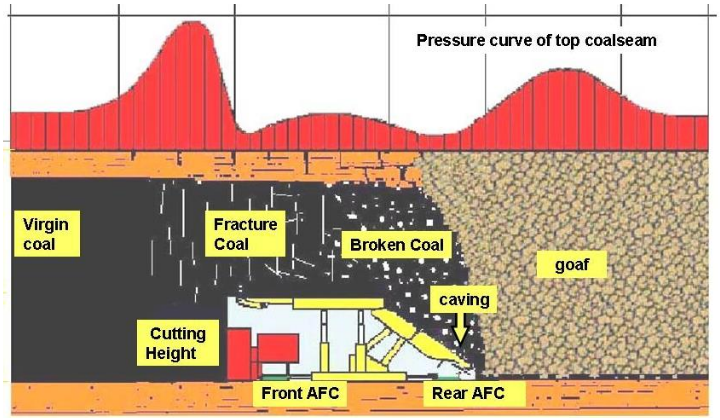
1. Introduction

The coal reserve of thick-seam (>3.5m) accounts for 43% of total minable reserve of China. Similarly, 40~45% of coal production of China is out of the thick-seam reserve. Since 1980's, coal miners in China carried out a series of R&D campaigns on thick seam mining techniques; a few of methods were developed mature in technology and employed in production for thick-seam deposits. These methods include: Multi-Slice Longwall, High Reach Longwall (single slice) and Longwall Top Coal Caving (LTCC). LTCC can mine out a seam varying from 4 to 20m in a single pass, requiring insignificant change to the face equipment. In comparison to the other two methods respectively, especially in complex geological conditions, LTCC has higher productivity and better flexibility and proves to be a safe and efficient techniques (Wang, J., 2013). A schematic LTCC operation can be demonstrated in Fig. 1.

While High Reach Longwall (single slice) is constrained by the seam condition – only viable in such seams as (thickness<7m, medium to high strength and mild undulation), LTCC has predominant advantages to the Multi-Slice Longwall and has been employed widely in China for the thick coal seam.

As of 2012, there are more than 200 of LTCC operations in China, 18 of which produced more than 3Mtpa, LTCC has become a predominant mining method for the thick coal seam in China (Shen, H., Guo, Y., 2012).

The success of LTCC application in early period encourages miners to extend the techniques in more challenging conditions and more aggressive manner. **Error! Reference source not found.** classifies those challenges for LTCC in 7 types and lists the name of typical operations in China.



(Courtesy Image from the Mining Division of Tiandi Science and Technology)
Fig. 1. A schematic diagram of LTCC operation

Table. 1. List of LTCC operations in challenging geological conditions in China

Condition	Count	Name of Operations
Soft and weak roof/ seam/floor	11	Lu'an Wuyang, Lu'an Tunliu, Datong Tongxin, Quandian, Yankuang Nantun, Pingzhuan Gushan, Luling, Xinji No.1, Zhuxian, Xinyao, Shitanjing Wulan
Hard and strong roof/seam	7	Meiyukou, Xinzhouyao, Mahuangliang, Dafosi, Jinyuan Honghui No.1, Taixi Baijigou
Steeply dipping & Ultra-thick	8	Luweihu, Liudaowan, Dahonggou, Jiangou, Wangjiashan, Yaojie, Adaohai, Huating
Mildly dipping & Ultra-thick	6	Pingshuo U/G No.1, Pingshuo U/G No.3, Datong Tashan, Pangpangta, Shenhua Liuta, Buliangou
Soft & Marginally Thick	3	Xishan Chengzhendi, Renlou, Huainan Mines, Pingdingshan No.12, Handan Yunheling
Gaseous	7	Lu'an Tunliu, Tingnan, Dafosi, Laohutai, Baijigou, Gengcun, Qingqiu
Sponcom Prone	8	Dayan No.2, Ciyaopu No.2, Qingshuiying, Daxing, Zhuxianzhuang, Qianqiu, Yimei, Changcun

2. Safety Risks in Challenging Conditions for LTCC

Safety is always the first concern for any mining operations. The safety risks of LTCC would normally be classified in 5 types: roof/wall failure, gas, sponcom, water, and dust (Yu, H., 1995).

Based on the observation in the mines listed in Table 1, 7 types of challenging conditions are defined in Table 2. Each of the classification addresses a specific geological feature and operational challenge – safety risk. Table 2 also correlates the probable hazard to 7 types of challenging conditions. When planning and managing a LTCC operation, all these risks need to be addressed and assessed so that adequate avoiding and responding actions can be established and executed.

2. 1. Roof/Wall Failure

Inadequate control to the roof and cutting wall of the LTCC face may lead to the damage of shield support, gas eruption, rock burst and unexpected roof falling (ahead of shield support). These risks are closely related to seam stratigraphic structure, rock strength, face dimension and design of shield supports. There are mainly two types of roof/wall failure issues with LTCC.

For the structure with strong main roof and weak immediate roof, the collapsed immediate roof may not be able to fill full of the mined void. As the face advances, a cavity comes into being, which is a great threat to a continuous operation. The negative impact include: (a) loss of coal as indicated in Fig. 2, (b) accumulation of gas, (c) ventilation leakage, and (d) air bumping disaster due to the uncontrolled roof falling.

For the structure with weak roof and soft coal, the cutting wall is prone to spalling, which may lead to a large unexpected roof falling ahead of the shield support and thus a great threat to a contentious operation.

Table. 1. Risks in Challenging Conditions for LTCC

Condition	Geological Feature	Safety Risk Category: Risk	Threat or Hazard
Soft and weak roof/seam/floor	Soft coal (UCS<10Mpa) and weak roof/floor rock (UCS<20Mpa)	Roof/wall failure: Wall spalling, unexpected large roof falling; Dust: high dust level	Hurt to operators' body and/or equipment; Loss of operating time; Coal dust explosion
Hard and strong roof/seam	Strong Strength in coal (UCS>25Mpa) and roof rock (UCS>80Mpa)	Roof/wall failure: Poor coal caving and roof falling performance , large area of unfalling roof	Low productivity and recovery; Hurt to operators' body and/or equipment
Steeply dipping & Ultra-thick	Inclination>25deg, Thickness>30m	Roof/wall failure: Unstable shield support and other face equipment, poor caving performance	Hurt to operators' body and/or equipment; Loss of operating time
Mildly dipping & Ultra-thick	Thickness >15m	Roof/wall failure: Wall spalling, unexpected roof falling Coal Dust: high dust level	Hurt to operators' body and/or equipment; Loss of operating time
Soft & Marginally Thick	Seam thickness ~4m, soft coal	Roof/wall failure: Unexpected caving activity, Unexpected roof falling	Low productivity and recovery
Gaseous	Gas content > $6m^3$/t in-situ	Gas: High gas level, gas eruption due to ground movement	Hurt to operators' body and/or equipment; Loss of operating time
Sponcom Prone	High Volatile Matter Coal prone to Sponcom	Sponcom: Sponcom and fire in gob area	Hurt to operators' body and/or equipment; Loss of operating time

2. 3. Gases

Gas control is one of critical challenges for LTCC operations and perhaps the most risky one. The LTCC face gas is mainly sourced from (a) surrounding wall and roof, (b) mined coal, (c) caved coal, and (d) gob. In comparison to the ordinary longwall, because the coal and upper strata are disturbed and broken in a larger extent, there are more sources with higher rate of gas emission for LTCC operation. Specially, insufficient ventilation for rear AFC will result in an accumulation of gases in the caving area.

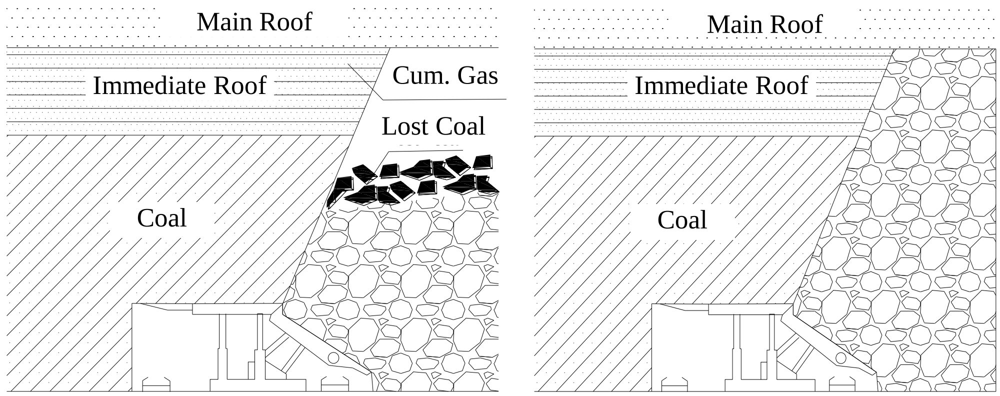
In case there is a cavity formed subsequent to caving operation, the gas will accumulate in the cavity. When the main roof and upper strata fall subsequently, the gas will be squeezed into the face instantaneously and the gas level in working area is very likely exceeding the limit at the moment so that the operation has to be ceased.

In addition, if there are adjacent coal seams either in upper or lower strata, additional gas source should be counted for the purpose gas control.

2. 4. Spontaneous Combustion

The application of the LTCC has also brought with it an increased risk of sponcom in active LTCC gob because of the large caving zones formed and some fragmented coal left in the gob (Xie. J., et al., 2008). Moreover, because the coal above headgate and tailgate zones cannot be caved and would often be left in the gob, there is higher risk of sponcom in these zones.

Once a sponcom occurs in a LTCC operation, the fire will spread quickly if there is no proper control. The sponcom and later fire produce a great amount of hazardous gases and heat and thus threaten miners' and equipment's safety.



(a) Hanging roof and unfilled cavity (b) Falling roof and filled collapse

Fig. 2. Different Roof Falling and Coal Caving Behaviour

2. 5. Dust

Because LTCC involves more equipment operations, more mining procedures and the cutting and caving operations may be conducted simultaneously, there are more and stronger dust sources than the ordinary longwall. As opposed to ordinary longwall, it is more challenging to control the dust at a safe level all the time. Typically, for a LTCC operation, the airborne dust is mainly sourced from (a) coal cutting activity – accounting for about 60%, (b) caving activity – about 25%, (c) support operation – about 10%, and (d) crushing and loading – about 5% (Liang, S., 2010). Needless to say, excessive airborne dust in LTCC face may lead to severe hazard to operators' health and safety and even risk of explosion. According to China "Coal Mine Safety Regulations 2014", the airborne dust concentration in longwall face can't exceed 10mg/m^3, however the shearing and caving operations can result in an instantaneous dust concentration peaking at about 1500mg/m^3 and 250mg/m^3 respectively (Niu, W., et al., 2008).

2. 6. Underground Water

As the mining activities disturb the surrounding rock mass, fracture and channels develop, through which underground water may flow into the mining area and result in great hazard to operators' and equipment's safety. The disturbance to rock mass from LTCC is stronger than the ordinary longwall so that the fracture and channel may develop to a larger extent. In case there is an aquifer above the seam, a connecting channel may lead water to the mining area and result in a severe accident.

An LTCC water leakage accident was reported by State Administration of Coal Mine Safety of China in 2013. The eruption of water and slurry into a LTCC face from the fractured main roof and upper strata resulted in 18 fatality and USD4M value of equipment loss in Zhenxing Coal Mine, Heilongjiang China on March 11, 2013. (Web-1).

3. Best Practice for Challenging Conditions

3. 1. Weak Roof/Seam/Floor

For LTCC operations in soft and weak coal strata, in order to avoid the risk of wall spalling and unexpected roof falling, the following practice was adopted and proves to be effective.

- Optimizing mining operational procedure
  - Advancing the shield support with pressure and roof touching

  - Advancing the shield support immediately following the shearer
- Control the cutting height to a designed limit
- Reducing the cutting depth
- Reinforcing coal wall with grouting, such as polyurethane and urea-formaldehyde resin

3. 2. Hard Roof/Seam

The survey to LTCC operations in hard roof/seam condition indicates that the pre-fragmentation must be conducted before caving activities for the expected caving performance. Fragmentation of coal seam and roof ensures not only the proper control to the roof and ground pressure but also the continuity of synchronized coal shearing and caving operations.

The following practice was adopted to improve the LTCC operation in this condition:

- Pre-blasting of coal and roof
- Coal seam water weakening
- Optimizing the design of shield support for better caving performance

Although all above practice may help the LTCC performance to some degree, the success is heavily relying on the first one. For highly strong (UCS>40Mpa) coal strata, even the pre-blasting techniques is still incapable to deliver satisfying result for safe and productive LTCC operation. More work is needed to improve the pre-blasting techniques in this circumstance.

3. 3. Steeply Dipping and Ultra-Thick Seam

As indicated in Fig. 3**Error! Reference source not found.**, sub-level LTCC method was employed in some of steeply dipping ultra-thick seams. In this method, the LTCC face is arranged perpendicular to the striking and advances along the striking direction horizontally. The sub-level interval is the height of one cutting and one caving. A rational increase in height of the interval (or mining to caving ratio) may improve the LTCC performance substantially. However, the increased height may require additional coal weakening treatment for proper caving performance. Similar to the practice for hard roof/seam, the following practice was adopted for the LTCC in this condition.

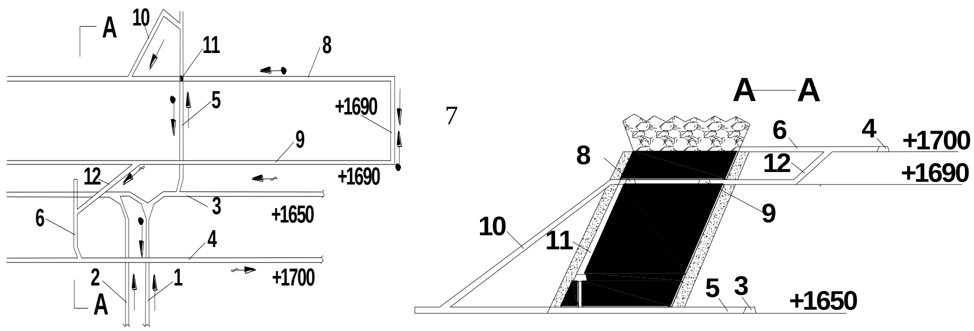
- Pre-blasting to top coal
- Water injection coal weakening

The corner coal outside tailgate has to be either discarded or recovered with a dead end face with manual operation. Although the shortwall stoping method was proposed to compete with the sub-level LTCC method (Uysal, O., Demirci, A., 2006), it is still more cost competitive in China for LTCC because all face equipment can be sourced domestically in China.

3. 4. Mild Dipping and Ultra-Thick Seam

The combination of High Reach and Top Coal Caving is the only solution available for mining ultra-thick seam in one single pass. Besides other risks for the ordinary LTCC operations, roof/wall failure is of special concern for High Reach LTCC. Severe spalling and unexpected roof falling may occur and lead to the cease of operation. It is known that the spalling issue is related to the cutting height, strata structure, support mechanism and support pressure and face advancing rate, however no mature theory was established for predicting its behaviour so far. The practice for improving High Reach LTCC operations includes

- Increasing the initial supporting pressure
- Advancing the support with pressure and roof touching
- Increasing the face advancing rate
- Attaching a designed front canopy to the shield support for more protection to the wall



(a) Plan view of sub-level LTCC (b) Cross-section of sub-level LTCC

Fig. 3. A typical sub-level longwall top coal caving arrangement

1-Main Slope, 2-Auxiliary Slope, 3-Conveyance Drift, 4-Ventilation Drift, 5-Conveyance Gate, 6-Ventilation Gate, 7-Initial Cut, 8-Headgate Road, 9-Tailgate Road, 10-Ventilation Incline (in), 11-Coal Chute, 12-Ventilation Incline (out)

3. 5. Soft and Marginally Thick Seam

Although High Reach Longwall (single slice) can mine the seams up to 7m, if the coal is very weak, it won’t work safely and productively even at a thickness of 4~4.5m. In this condition, LTCC may be a better option than the High Reach Longwall. In this case, because the caving height is relatively small as opposed to most of LTCC, it is challenging to manage the roof and caving operation, especially in the zone above the cutting wall. It is recognized by miners that the key of success in this condition is to manage the wall in good condition. The following practice was adopted for the LTCC in this condition:

- Optimizing the design of the shield support
  - Integrated top frame of the support
  - Longer side guard
- Optimizing mining operational procedure
  - Advancing the support in time
  - Advancing the support with pressure and roof touching
- Controlling the cutting height to a designed limit
- Reinforcing cutting wall with material injection

3. 6. Gas Control

LTCC operation has greater disturbance to the coal strata and surrounding rock mass, thus result in more gas emission into the mining area than the ordinary longwall. The common U pattern ventilation method isn’t sufficient to guaranty the control of gas level all the time, the instantaneous gas eruption may lead to great hazards to miners, loss of time and even explosion. The ventilation practice used in LTCC in China includes:

- Pipe de-gasing when developing the gate roads
- Pipe de-gasing in advance of longwall mining
- Post-mining pumping in gob area
- Plugging pipe at upper corner of gob for de-gasing
- Special de-gasing tunnel above the mining target

More ventilation patterns, such as “E”, “U+L”, “U+I”, “Y”, “Y+L”, “U+u”, were used in LTCC operations for effective ventilation.

3. 7. Sponcom

The unrecovered coal in the fragmented gob area of LTCC operations may result in sponcom occurrence. Inadequate control to sponcom may result in fire and hazardous gases. The practice used for sponcom control in the LTCC includes：

- Injecting mud slurry into the gob or collapsed roof
- Injecting nitrogen gas into the gob
- Injecting flame retardant material into the gob or collapsed roof
- Reinforcing and sealing the wall of both gate roads
- Spaying flame retardant material on the wall surface of gate roads
- Pre-injecting flame retardant material into the caving coal

4. Conclusion

The benefit of LTCC, such as high productivity, flexibility, and low cost, has been well recognized by the coal industry in China. With the improvement of LTCC equipment performance and the operational experience learned, the LTCC techniques has had a much wider utilization in some of challenging conditions that used to be not suitable for LTCC. Some of the achievement of LTCC application is briefed in Table. 2.

Table. 2. Recent achievement of LTCC application

Conditions	**LTCC Application Criteria**
Soft and weak roof/ seam/floor	Ultra-soft coal - UCS<5Mpa
Hard and strong roof/seam	Main Roof - Sandstone UCS>80Mpa, Coal Seam - UCS>40Mpa (Wu, Y., 2010)
Steeply dipping & Ultra-thick	Mining to Caving Ratio - 1:8
Mildly dipping & Ultra-thick	Seam Thickness - >20m
Soft & Marginally Thick	Seam Thickness - <=4m
Gaseous	Seam Gas - <=6m^3/t after treatment

Despite of the success of LTCC in China, miners in other coal mining regions are still concerned with the safety of LTCC, especially in those challenging conditions. As of 2014, only two LTCC operations were implemented in Australia – Austar of Yancoal and North Goonyella of Peabody. While the LTCC techniques is understand, shared and trusted more by the industry, it is anticipated that more LTCC operations will be implemented by the miner outside China.

References

Liang, S., Huang, Y., Sun, Z., Jiang, Z., Ding, K., & Man, J. (2010). Progress And Trend Of Coal Dust Control For Longwall Top Coal Caving Face. *Coal Mine Safety (Chinese),* 429, 116-119.

Niu, W., Jiang, Z., Yu, X., & Tian, D. (2008). Numerical Simulation of Distribution Regularities of Dust Concentration in Fully Mechanized Top Coal Caving Face. *China Mining Magazine (Chinese),* 17, (12).

Shen, H., & Guo, Y. (2012). Current Development and Trend of China Mechanized Coal Mining Equipment. *Journal of Coal Science and Technology (Chinese),* 40(2), 1-3.

Uysal, O., & Demirci, A. (2006). Shortwall Stoping Versus Sub-Level Longwall Caving-Retreat in Eli Coal Fields. *The Journal of the South African Institute Of Mining and Metallurgy,* 206, 425-432.

Wang, J. (2013). Key Technologies For High Reach Longwall Top Coal Caving Of Ultra-Thick Coal Seam. *Journal of Coal Science and Technology (Chinese),* 09, 1-5.

Wu, Y. (2010). Fully Mechanized Longwall Top Coal Caving Technology for Ultra-Thick Seam in Datong Mining Area. *Journal of Coal Science and Technology (Chinese),* 38(11).

Xie, J, Xue, S., & Cheng, W. (2008). Identification of Spontaneous Combustion Prone Zones in Longwall Top Coal Caving Goafs. *Proc. Of Coal Operators' Conference,* 173-177.
Yu, H. (1995). Fundamental Theory of Longwall Top Coal Caving. *Beijing China Coal Industry Press*

Web sites:
Web-1: http://www.chinasafety.gov.cn/newpage/Contents/Channel_5498/2013/1104/223413/content_-2234, consulted 30 Mar. 2015.