Strata Behaviour During Different Stages of Mechanized Depillaring Operations: An Indian Case Study

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Abstract. Strata control is one of the major challenges in underground coal mining and needs special attention during depillaring operations. Depillaring in underground mining is generally a complex operation, which became a major contributor to accidents as per past experiences. The study of strata behaviour during depillaring is very much important so that proper precautionary measures can be taken to avoid accidents during depillaring. Appropriate planning and installation of quality sensors for continuous monitoring and analysis of strata behaviour improve the safety of the mine as well as productivity. This paper describes behaviour of the strata during different stages of mechanized depillaring operation. A case of an Indian coal mine using continuous miner with split and fender method of pillar extraction has been chosen for study. It was observed that the load-bearing capacity of pillars is high before the splitting and slicing operation and it is gradually decreased by row-to-row extraction. The stress acting on pillars gradually shifts to the adjacent pillars after starting the splitting operation. Various strata monitoring instruments were installed and data were collected & analyzed. Towards the end, the authors highlight the practical behaviour of the strata in different stages of depillaring operations and suggest precautionary measures to improve the overall safety of the mine.

Keywords: Strata Behaviour · Mechanized Depillaring · Split and Fender method

1 Introduction

A developing nation like India is still under growing scrutiny to have rapid economic growth. India is concerned about its energy security since energy is the backbone of every economy [1]. The single most crucial input for the expansion of the Indian industry is coal. It is a critical contributor to the Indian energy scenario [2]. It has the largest domestic reserve base and the majority share of India's energy production, which is one of the four main fuel resources in the country, along with natural gas, uranium, and oil. In India, 70% of coal produced is used for the generation of electricity and the rest for other industries, and public usage [3]. Generally, in India, there are two mining methods for

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the extraction of coal i.e. Opencast mining method, Underground mining method. The depth and quality of the coal seams, as well as the geology and environmental factors, all influence the most cost-effective method of coal extraction [4, 5].

In Opencast mining, the coal is extracted by forming benches and removing overburden material. So there is no need for strata control. In Underground mining, the coal seam is approached by driving an opening into the ground and coal is extracted by different types of extraction methods. There is a problem with strata control while extracting of coal in underground mining. Due to its unique characteristics, underground coal mining requires greater consideration from a safety engineering and management perspective [6]. The geo-mining conditions are making underground coal mining operations more challenging every day [7]. Strata control is a continuing problem for the application of any underground coal mining method but it plays a key role in the success of that particular method.

In India, the bord and pillar mining system is adopted by the majority of coal mines. It includes two stages i.e. development of pillars, and depillaring of pillars [8]. During the development, stage pillars act as natural supports and the strata control problem is minimum. But in depillaring stage, there is a problem with strata control during the extraction of pillars. During the depillaring of pillars, exposure of the area is high and results in the increase of induced stress on the pillars nearby goaf. Monitoring of strata, load on supports, and bed separation gives an idea about rock behaviour and chances of fall or overriding [9]. To meet the demand, the production of coal should be increased by adopting mass exploitation technologies. Mechanized depillaring by using Continuous Miner (CM) machine is very much suitable for mass exploitation. Mechanized depillaring is very much safer, faster and economical method of extraction with a high production rate compared to other methods of extraction. In India, many mines have adopted mechanized depillaring by a continuous miner for extraction of already developed panels by conventional bord and pillar mining methods. In the bord and pillar method of mining the galleries and pillars are developed according to Coal Mine Regulations 2017. Mechanized depillaring by using CM requires more gallery width of about 5.0 m–6.5 m for free movement of machinery. The height of extraction is also high in this method more than 3.5 m. Heightening and widening of pillars leads to a decrease in factor of safety of pillars and causes different problems like floor heaving, side spalling, roof instability, etc. [10] Strata monitoring is very much important during the depillaring stage. Since ancient times, safety has been the priority in underground coal mines, where accidents are frequently caused by roof and side falls. Statistics on individual accidents and fatalities other than disasters due to roof and side falls have been provided, in the Directorate General of Mines Safety (DGMS) standard note 2020. According to data, 10% of fatal accidents out of total fatalities and 30% of below-ground fatalities in 2019 were caused by the fall of roofs and sides [11]. All these accidents and fatality figures have caused concern for the Indian coal mining industry. Depillaring in underground mining is generally a complex operation and strata control is one of the major challenging tasks and became a major contributor to accidents as per the past data [11].

Therefore, there is a need for detailed real monitoring of strata behaviour during depillaring operations in underground mines. Strata control issues in Indian coal mines were studied previously by a few researchers [12–17]. In this paper, strata behaviour during different stages of mechanized depillaring operation has been analyzed for a panel. Towards the end, the authors highlight the behaviour of the strata with the cyclic operation and try to identify the challenges and opportunities to improve the overall safety of the mine.

2 Case Study Description

There are different types of extraction techniques in mechanized depillaring operations like spilt and fender, fishbone or X-mas tree method, modified navid method, etc. The choice of method depends on the Factor of Safety (FoS) of the pillar. The pillars with high FoS (>1.5) will generally be depillared by the split and fender method, and pillars with less FoS (<1.5) will be depillared by the X-mass tree or fishbone method. A bord and pillar panel with already developed pillars adopting split and fender method of extraction by using continuous miner has been chosen for study. The straight line of extraction is followed for the extraction of pillars. The straight line of extraction is preferred rather than other types due to its inherent geological characteristics. The panel has a gradient of 1 in 8 and is situated at a maximum depth of 206 m from the surface with an average thickness of 2.30 m. The lithological formation of the panel consists of an overlying seam (Upper Workable Seam) of 1.15 m thickness which is Non-workable, Underlying coal seam (Bagdona) of 1.78 m thickness which is virgin. Details of mine lithology are represented in Fig. 1. Panel Consists of 60 pillars each of size 24.5 m X 24.5 m (corner to corner), gallery width is 6 m, and Average height of extraction is 2.50 m as shown in Fig. 2. Boundary details of panel: North – Mine boundary, East – CM Panel No. 2, South – CM Panel No. 5, West – Standing on pillar and panel Entry roadway. The immediate roof and floor of the seam are sandstone mostly and sandy shale forms part of the floor occasionally. The predominant rock type 3 m above And 1 m below the seam is also medium to coarse-grained sandstone. Rock instrumentation such as auto warning tell-tale (AWTT), rotary tell-tale, and stress cells were installed in the panel to monitor the strata behavior and record the strata deformation information. The data recorded by the instruments are collected shift-wise manually. The Strata monitoring instrumentation plan of the panel detailing the location of instruments is shown in Fig. 3.

3 Case Study Analysis of Strata Behaviour During Different Stages of Mechanized Depillaring Operation

The panel is comprised of 60 pillars with 24.5 m × 24.5 m (corner to corner), and a 6 m gallery width in fifteen rows. The first five rows of pillars are considered to analyze the strata behaviour in different stages during their extraction by mechanized depillaring operation

3.1 Strata Behaviour After the First Row of Extraction

As presented in Fig. 4, the following observations were made:

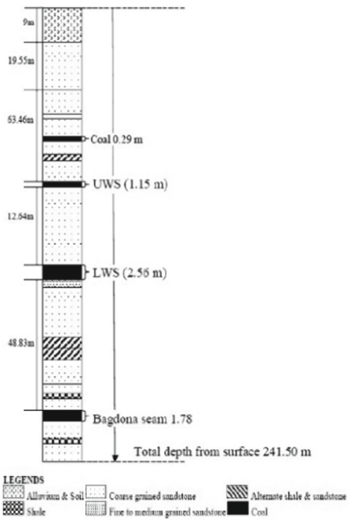

Fig. 1 Mine Lithology

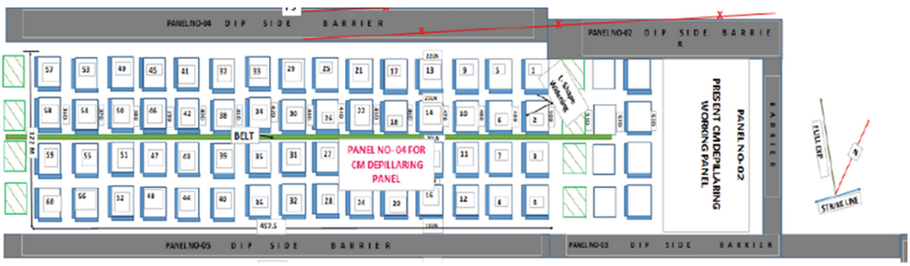

Fig. 2 Continuous Miner Panel Selected for Study

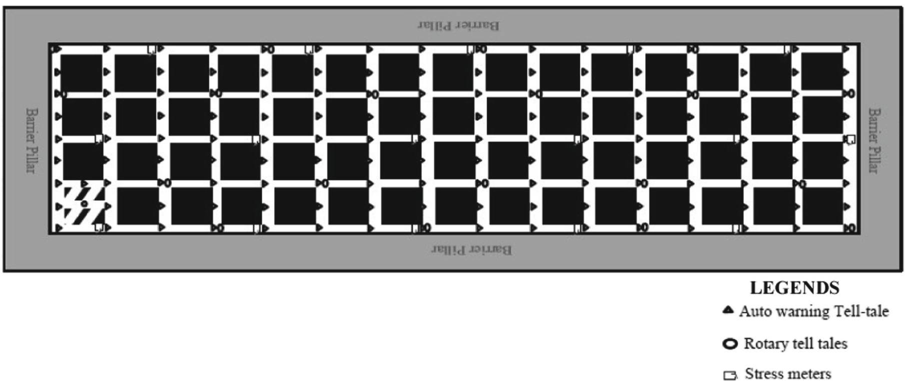

Fig. 3 Strata monitoring instrumentation plan of panel

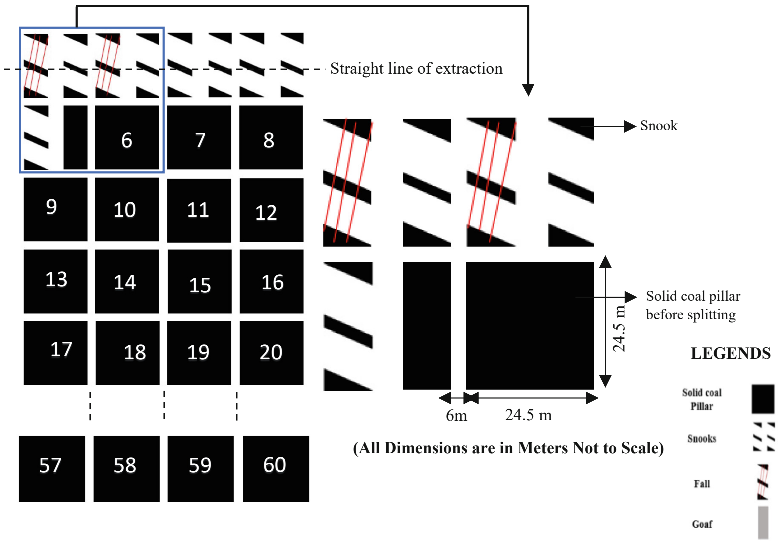

Fig. 4 Status of the panel after the first row of extraction

- Snooks of fender A of Pillars 1 & 2 failed during the extraction of 5th pillar fender-A.
- The load carried by the 5th pillar is shifted to adjacent pillars during this stage, and snooks of the adjacent pillar failed.
- Total exposure during this stage is 4050 m^2, area of fall is 900 m^2 about 2.2 m thickness (approx.).
- It is a local fall and goaf edges are not completely packed.
- AWTT installed at three different locations started blinking from 5 days before to fall, the reading recorded was >5 mm.

3.2 Strata Behaviour During the Second Row of Extraction

As presented in Fig. 5, the following observations were made:

- 5th Pillar snooks failed during the slicing of 6th pillar fender-B.
- The load carried by the 6th pillar is shifted to the adjacent pillar during this stage, and adjacent pillar snooks failed.
- Total exposure during this stage is 4500 m^2, area of fall is 900 m^2 more than 2.5 m thickness (approx.).
- It is a major fall and goaf edges are completely packed.
- AWTT started blinking from the day before to fall, the reading recorded was >5 mm.

3.3 Strata Behaviour During Second Row Last Pillar Extraction

As presented in Fig. 6, the following observations were made:

- 3rd, 4th, 6th pillars snooks and 2nd pillar fender-B snooks failed during the splitting of 8th pillar.

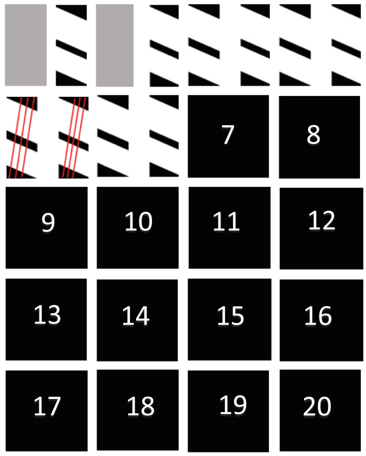

Fig. 5 Status of the panel during the second row of extraction

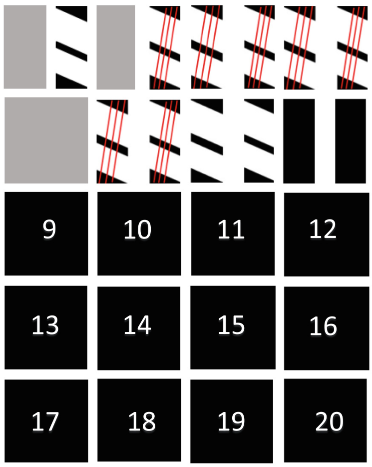

Fig. 6 Status of the panel during the second row of extraction

- The load carried by pillar 8th is shifted to adjacent pillars during this stage, and adjacent snooks left completely failed, except snooks of 1&7 pillars.
- Total exposure during this stage is 4050 m^2, area of fall is 3150 m^2 more than 2.5 m thickness (approx.).
- It is a major fall and goaf edges are completely packed.
- AWTT started blinking near the 7th pillar and goaf trouble before the fall.

3.4 Strata Behaviour During Third-Row Third-Pillar Slicing

As presented in Fig. 7, the following observations were made:

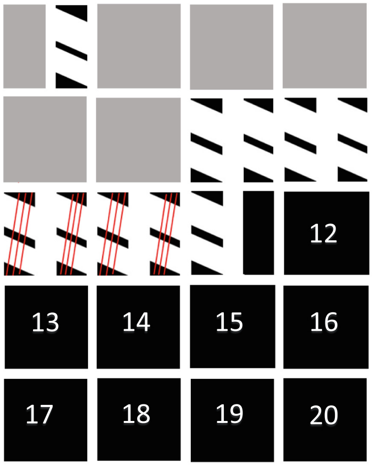

Fig. 7 Status of the panel during the third row of extraction

- 9th & 10th Pillar snooks failed, during the slicing of 11 pillar fender-A.
- The load carried by the 11th pillar is shifted to the adjacent pillar during this stage, and adjacent pillar snooks failed.
- Total exposure during this stage is 4500 m^2, area of fall is 1800 m^2 more than 2.5 m thickness (approx.).
- It is a major fall and goaf edges are completely packed.
- AWTT started blinking from a day before to fall, the reading recorded was >5 mm.

3.5 Strata Behaviour During Third Row Last Pillar Extraction

As presented in Fig. 8, the following observations were made:

- 11th Pillar snooks failed, during the extraction of 12 pillar fender-B.
- The load carried by the 12th pillar is shifted to the adjacent pillar during this stage, and adjacent pillar snooks failed.
- Total exposure during this stage is 4050 m^2, area of fall is 900 m^2 more than 2.5 m thickness (approx.).
- It is a major fall and goaf edges are completely packed.
- AWTT installed at three different locations started blinking from 4h before fall, the reading recorded was >5 mm.

3.6 Strata Behaviour Fourth Row Last Pillar Extraction

As presented in Fig. 9 the following observations were made:

- 13th Pillar snooks and 14th pillar fender A snooks failed, during the extraction of 16th Pillar fender-A.
- The load carried by the 16th pillar is shifted to the adjacent pillar during this stage, and adjacent pillar snooks failed.

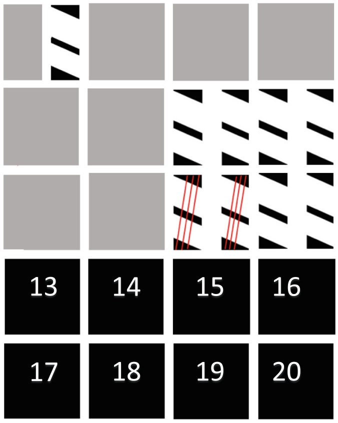

Fig. 8 Status of the panel during the third row of extraction

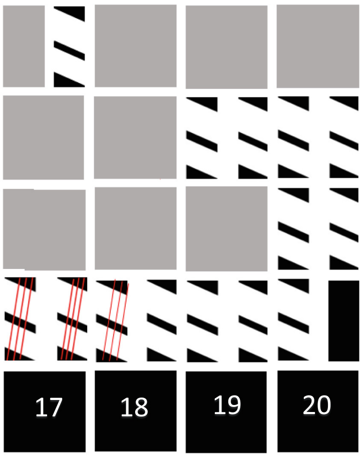

Fig. 9 Status of the panel during the fourth row of extraction

- Total exposure during this stage is 5400 m^2, area of fall is 1350 m^2 more than 2.5 m thickness (approx.).
- It is a major fall and goaf edges are completely packed.
- AWTT installed at three different locations started blinking from 8h before fall, the reading recorded was >5 mm.

3.7 Status of Panel During the Fifth Row of Pillars Extraction

As presented in Fig. 10, the following observations were made:

- 14th Pillar fender B, 15th, 17th, 18th pillars failed during the extraction of the 20th pillar.

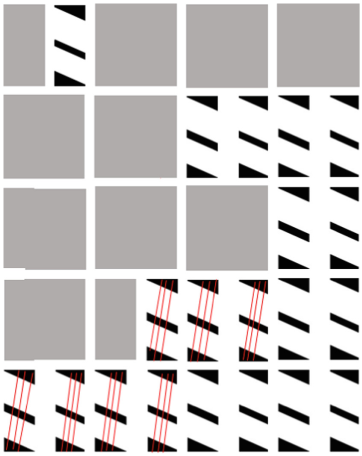

Fig. 10 Status of the panel during the fifth row of extraction

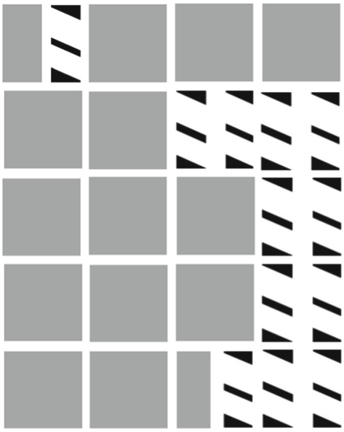

Fig. 11 Status of the panel after the fifth row of extraction

- The load carried by the 20th pillar is shifted to the adjacent pillar during this stage, and adjacent pillar snooks failed.
- Total exposure during this stage is 7650 m^2, area of fall is 3150 m^2 more than 2.5 m thickness (approx.).
- It is a major fall and goaf edges are completely packed.
- AWTT installed at three different locations started blinking from 8h before fall, the reading recorded was >5 mm.
- The final status of the panel after the five rows of pillar extraction is shown in Fig. 11.

4 Analysis of Results

Strata behaviour during different stages of depillaring operation has been analyzed and the following observations were made.

- It was observed that load bearing capacity of pillars is high before splitting and slicing operation and it is gradually decreasing by row-to-row extraction
- After five rows of extraction, the entire snooks of five pillars and fender B snooks of two pillars are stable as shown in Fig. 11.
- The stress acting on pillars gradually shifts to the adjacent pillars after starting the splitting operation
- It also observed that AWTT gives a prior intimation of bed separation, a sign of fall. Observation of readings of AWTT at regular intervals is very much important to take proper safety measures at that place.
- The stability of ribs gradually decreased after the extraction of adjacent row pillars
- Depending upon the depillaring operation's stage, the fall's thickness varied.
- The pillar closest to the goaf is under more stress compared to the pillars at the ends.
- To examine the peak vertical stress, one pillar is targeted; however, as the slicing operation progresses, the peak stress shifts to the adjacent pillar.
- The influence of the goaf is observed up to one pillar ahead of the goaf edge. While pillars distant from the goaf undergo the symmetrical pattern of stress distribution and yield around 2 m from the sides, pillar sides close to the goaf yield about 4 m from the sides. The peak load is consequently slightly transferred towards the core.
- Load bearing capacity of the pillar gradually decreased.
- The Factor of Safety (FoS) of the snooks is very much important, as per the literature review [18] and field experience the snook FoS should be in the range of 1.0–1.3 for safe mine workings.
- If the snook's FOS falls below 1.0, slicing operations must be curtailed.
- In this case, the data were collected shift-wise manually, if the data were collected and analyzed by using real-time monitoring and analysis system, the prediction will be more accurate which ultimately improve production and overall safety of the mine.

5 Conclusion

There is no doubt that strata control study in an underground coal mine is a highly challenging technical task to extract valuable information about the strata behaviour for the safety of the workers and workings. Field experience and knowledge of the geo-mining conditions are essential to evaluate the applicability of various types of equipment for the visualization of rock mass reaction under the varied loading conditions of a dynamic mining face like depillaring. The judicious planning and installation of quality ground movement sensors with continuous remote monitoring along with the careful and timely interpretation of data will ensure the safety of the workers and workings. Future rock instrumentation programmes for strata control during depillaring will be fully automated and wireless with the integrated high-capacity data processing systems playing the ultimate control. It is the need of an hour to develop some automated system for monitoring and prediction of strata failure, which ultimately enhances overall safety as well as production time.

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