XVI International Mineral Processing
and Recycling Conference
28-30 May 2025, Belgrade, Serbia

DOI: 10.5937/IMPRC25529P Original research article

THE STUDY ON THE STRESS CHARACTERISTICS OF BACKFILL BARRICADE IN UNDERGROUND METAL MINES BASED ON SIMULATION EXPERIMENTS

Xiaopeng Peng#, 0000-0002-3635-2062,
Lijie Guo, 0000-0003-4355-3038,
Xingshan Jin, 0009-0001-1508-0950,
BGRIMM Technology Group, Beijing, China

ABSTRACT – With the widespread adoption of the backfill mining method in metal mines, the barricade wall, as a crucial structure for stope stability control, has its drainage performance and spatial placement significantly influencing structural stability. This study utilizes a self-developed force simulation device for backfill walls to systematically conduct mechanical tests on non-cemented backfill walls under various installation positions and drainage conditions. The results indicate that non-cemented slurry conforms to the ideal fluid model under undrained conditions, with lateral pressure distribution closely matching the hydrostatic pressure theory. Optimized drainage design can reduce lateral pressure by 70% and accelerate the dissipation process of pore water pressure. For drainage walls, their installation position can significantly regulate lateral pressure; when adjacent to the stope (entry), the peak lateral pressure reaches 73.18 kPa (under 80 kPa loading pressure), which is a 35.43% increase compared to the condition at the end of the entry. This research reveals the load transfer mechanism and pressure evolution 规律 of non-cemented walls, providing theoretical support for mine safety protection design.

Keywords: Metal Mine, Backfill Barricade, Installation Position of Barricade, Drainage Performance of Barricade, Lateral Pressure.

INTRODUCTION

In the process of underground backfill mining, to stop the leak of backfill slurries in stopes, it is necessary to construct a backfill barricade at an appropriate location in the extraction drift, preventing slurries from flowing into the roadway [1,2]. Due to its supporting role, the instability of backfill barricade poses a series of threats to the safety of backfill mining. In 2000, a wall failure at the Bronzewing mine in Western Australia resulted in three fatalities [3,4]. A year later, two backfill wall failures at the Osborne mine caused extensive underground production shutdowns [5]. In 2021, two wall collapse accidents occurred in the Jinchuan mining area of China, leading to a large-scale flow of backfill slurry into the roadways, causing significant economic losses. Thus, it is evident that ensuring the stability of the backfill barricade is crucial for mine safety.

To analyze the stability of the backfill barricade, it is necessary to investigate the forces exerted by the backfill slurry on the wall during the backfilling process [6,7].

corresponding author: pengxiaopeng@bgrimm.com

Comparing to the theoretical study of the forces analysis on the wall, conducting model test research is a more precise approach to accurately understand the forces exerted on the barricade [8,9]. Widisinghe et al. [10] established a backfill loading system based on a cylindrical stope model (310mm in diameter × 465mm in height), using soil pressure gauges to measure the vertical stress at the bottom and the horizontal stress in the roadway, and validated the pressure distribution pattern of the barricade wall through analytical equations. Although this experiment revealed the pressure response characteristics of the barricade under different loads, it did not consider the influence of drainage conditions on the evolution of lateral pressure on the wall. Nujaim et al. [11] conducted a physical model experiment on waste rock backfill barricade based on the principle of qualitative similarity. The results showed that the stability of waste rock barricade depends on factors such as the particle size distribution (PSD) of the waste rock, the degree of compaction, and the frictional resistance between the barricade and the sidewalls. However, the experiment did not consider the impact of the installation position on its lateral pressure. Wang et al. [12] constructed a large-scale in-situ characteristic simulation device (1500×500×1600mm) to systematically monitor the dynamic evolution of parameters such as pore water pressure and effective stress during the curing process of cemented tailings backfill. However, the barricade was not installed during the experiment, which meant the results could not reflect the lateral pressure exerted on the wall.

In light of the aforementioned research background, this study intends to utilize a simulation test apparatus for the stress on backfill barricade. With the permeability of the wall and its installation position as variables, it aims to conduct simulation research on the stress experienced by walls during uncemented backfilling processes, exploring the spatiotemporal evolution patterns of key indicators such as lateral pressure and pore water pressure on the walls. By systematically investigating the stress mechanisms on walls under different working conditions, the study seeks to provide guidance for the design of backfill barricade and offer scientific basis for safe and efficient mine backfilling.

EXPERIMENTAL

Simulation test apparatus

The simulation test apparatus for the stress on backfill barricade is designed to simulate the stress state of barricade during the mine backfilling process, providing theoretical experimental parameters for the design of barricades. This apparatus comprises a pressure control unit, a stope simulation unit, a drift simulation unit, a wall drainage unit, and a data acquisition system. It is capable of adjusting loading pressure, wall position, and wall drainage capacity to simulate various backfilling conditions, as illustrated in Figure 1. The pressure control unit achieves dynamic pressure regulation through hydraulic cylinders and a manual pump. The stope simulation unit and the drift simulation unit mimic the stope and ore extraction drifts, respectively. The wall drainage unit simulates different types of walls. The data acquisition system monitors and records data from various sensors in real-time, ensuring the accuracy and reproducibility of the experimental results. The overall structure of the test apparatus is stable and well-sealed, capable of meeting the research needs for stress analysis under different backfilling conditions, and it exhibits excellent corrosion resistance and mechanical performance.

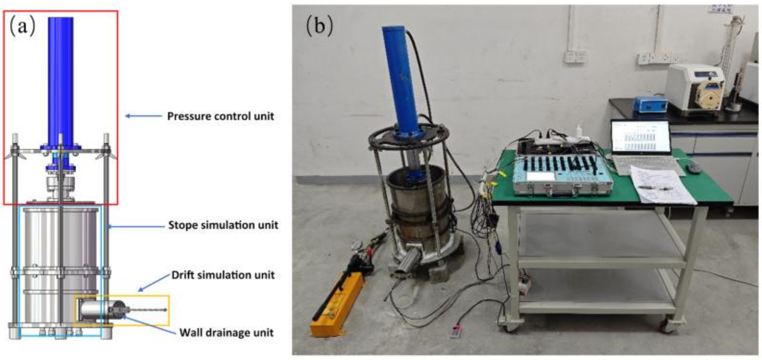

Figure 1 Schematic diagram of the mechanical simulation test device for filled barricade a) Design Schematic; b) Physical Prototype Image

Test Materials and Sensors

The test materials include tailings from a copper mine as the aggregate and tap water for slurry preparation. The tailings were first subjected to particle size analysis using a Mastersize 2000 laser particle size analyzer. The results show that the fine particles, which are below 74 µm, account for 55.45%, while coarse particles, which are above 0.25 mm, make up 3.26%, indicating a gradation characteristic dominated by fine particles with a small number of coarse particles.

For monitoring the pressure on the barricade wall during the test, vibrating wire earth pressure cells were used as sensors. High-precision miniature pore water pressure sensors were employed to monitor the pore water pressure of the slurry. The data collected by the sensors were recorded using a static data acquisition instrument, model DM-YB1820.

Experimental Design

Mix Recipe Design of Backfill Slurry

The volume of the stope simulation unite was calculated to be 36.13 L based on its structural parameters. In accordance with the concentration control requirements of 70%-72% for subsequent backfilling processes at a certain copper mine, the study was conducted using a backfill slurry with a mass concentration of 70%. Through systematic experimental verification, it was found that when the amount of backfill slurry added was 50 kg, it not only meets the filling requirements of the setup's volume but also effectively avoids safety hazards caused by overfilling.

Loading Pressure Design

This study simulated the dynamic changes in wall stress during the backfilling process using the simulation test apparatus. Based on the typical stope parameters of the certain copper mine (size 70 m×20 m×60 m, backfill flow rate 120 m^3/h, assuming continuous backfilling throughout the day) after calculation, the average daily backfill height is about 2 m. Therefore, the maximum loading pressure applied each time was set to be approximately 40 kPa through weight calculation. The experiment simulated the above-mentioned stepwise gradient loading strategy, setting the loading pressure to increase stepwise with equivalent backfill days, exploring the cumulative effect of bottom pressure caused by the rising backfill height in the stope.

Installation Position and Drainage Conditions Design

According to the length of the drift simulation unit, which is 20 cm, the installation position of the barricade wall can be divided into the drift entrance (near the stope end), the middle of the drift (10 cm from the drift entrance), and the end of the drift (20 cm from the drift entrance), which can be illustrated as the following Figure 2.

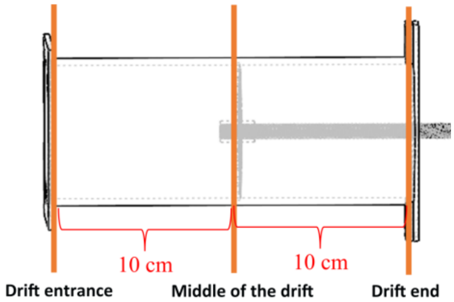

Figure 2 Schematic diagram of barricade l installation location

A detailed classification of the drainage of barricade walls was conducted, aiming to assess the variation patterns of lateral pressure on the walls under different drainage conditions. Based on the efficiency of drainage, this study categorizes the walls into three types: walls without an active drainage (i.e., non-draining), walls with basic horizontal drainage capability (i.e., moderately draining), and walls with high-efficiency drainage capability (i.e., well-draining), as illustrated in Figure 3. Among these, the "moderately draining" walls are equipped with 19 drainage holes each with a diameter of 3 mm, whereas the "well-draining" walls have the number of drainage holes increased to 32, all maintaining a diameter of 3 mm, to achieve superior drainage performance.

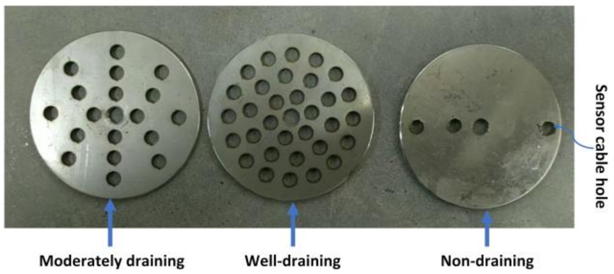

Figure 3 Schematic diagram of barricade walls with varying degrees of drainage filling

RESULTS AND DISCUSSION

Barricade stress under different drainage conditions

In mine backfilling, the drainage performance of barricade walls significantly facilitates the consolidation and hydration hardening processes of the backfill slurry, while also exerting a crucial impact on the stability and safety of the walls. Figure 4 shows the lateral pressure exerted by the backfill slurry on barricade walls under different drainage conditions.

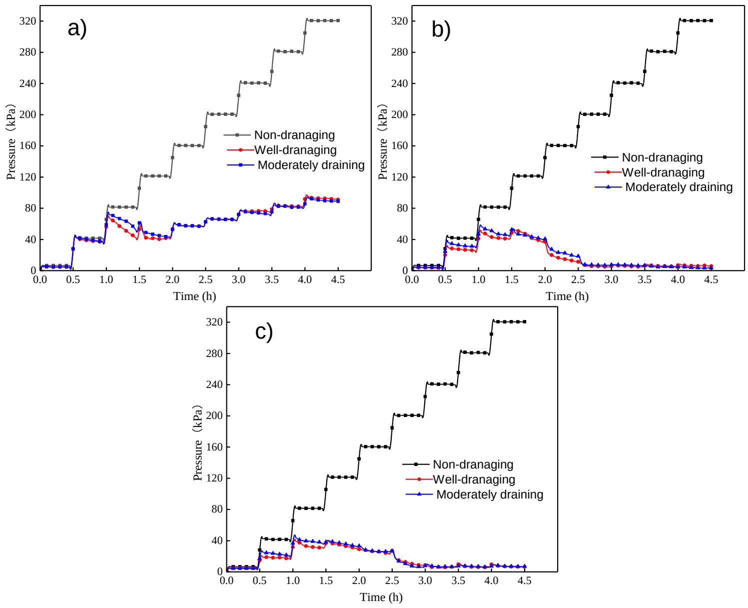

Figure 4 Lateral pressure on barricade walls with different drainage conditions: a) Barricade installed at the drift entrance; b) Barricade installed at middle of the drift; c) Barricade installed at the drift end

As shown in Figure 4, the lateral pressure on the barricade wall is significantly influenced by the drainage conditions. Under non-draining conditions, the lateral pressure increases linearly with the loading pressure, and its value is significantly higher than that under draining conditions. This indicates that the lack of drainage prevents the backfill from dehydrating and solidifying, causing the hydrostatic pressure to be fully transmitted to the wall, resulting in a "full load transfer" state. Under moderate draining conditions, the rate of pressure increase is significantly reduced, with the final pressure reaching 97.65 kPa (a 69.5% reduction compared to non-draining conditions), and the pressure increase on the wall slows down after the loading pressure exceeds 160 kPa. Under well-draining conditions, the final pressure is 96.96 kPa, and after the loading pressure exceeds 160 kPa, the increase is only 36 kPa (a 70% reduction compared to non-draining conditions).

During the rising phase of pressure (before 1.5 h), the lateral pressure under moderate draining conditions is generally higher than that under well-draining conditions, a phenomenon particularly evident in walls installed in the middle and end of the drift. For walls at the drift entrance, the pressure difference between the two drainage conditions is smaller, mainly because walls at the drift entrance directly bear the combined effects of high hydrostatic pressure, dynamic water pressure, and expansion force from the stope side, resulting in similar total stress values monitored by the sensors.

During the pressure decline phase (after 1.5 h), walls with well drainage exhibit more pronounced pressure decay characteristics. Superior drainage performance can quickly dissipate internal pore water pressure, thereby accelerating the overall pressure decline. The pressure change during this phase shows a dual-stage characteristic: an initial linear decline due to the continuous discharge of pore water, followed by a nonlinear change closely related to the alteration in pore water pressure caused by further compaction of the tailings.

Barricade stress under different installed positions

This section will explore the variation patterns of lateral pressure on barricade walls at different installation positions (the drift entrance, the middle of the drift, and the drift end respectively) based on a series of experimental data, as illustrated in Figure 5.

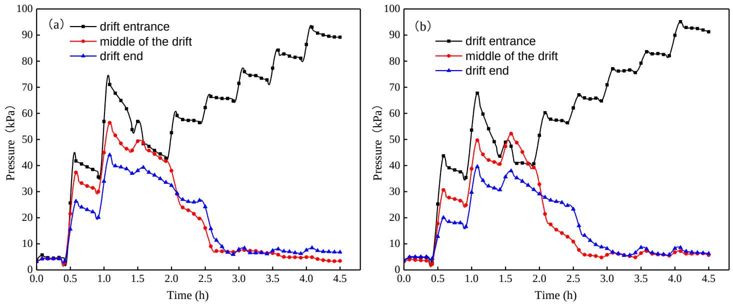

Figure 5 Lateral pressure on barricade walls installed at different locations: a) Barricade walls with moderate drainage conditions; b) Barricade walls with well drainage conditions

As can be seen from Figure 5, when the barricade wall is installed at the drift entrance, its pressure initially increases and then decreases in response to the loading pressure: in the initial stage, the pressure rises synchronously with the loading pressure, decreases due to the dissipation of hydrostatic pressure during drainage, and then resumes a steady increase with the loading pressure. In contrast, the pressure evolution of walls in the middle and at the end of the drift exhibits a three-stage characteristic of "increase-decay-stabilization," eventually reaching an equilibrium state.

Data from Figure 5a show that when the loading pressure reaches 80 kPa, the peak pressure on the wall at the drift entrance reaches 73.18 kPa, while the pressures on walls in the middle and at the end of the drift decrease to 56.85 kPa (a 22.28% reduction) and

47.25 kPa (a 35.43% reduction), respectively. This phenomenon indicates that as the distance between the wall and the stope increases, the lateral pressure exhibits a dual characteristic of numerical decrease and fluctuation attenuation. Mechanistic analysis reveals that the area adjacent to the stope forms a stress arch effect due to tailings settlement, concentrating the load towards the wall, and is significantly influenced by the dynamic changes in pore water pressure induced by mining activities. As the distance increases, the tailings achieve stress redistribution through particle friction and cohesion, reducing the influence range of the arch effect and making the lateral pressure more uniform and stable.

When the external load increases to 240 kPa (3.0 h), walls at different positions show differentiated responses: the pressure on the wall at the drift entrance increases by about 25% (corresponding to 10 kPa) for every 40 kPa increase in load, while the pressures on walls in the middle and at the end of the drift stabilize at around 8 kPa. This indicates that walls farther from the stope have better load buffering performance, suggesting that in engineering practice, walls should be installed as far away from the stope as possible.

CONCLUSION

(1) The mechanical behavior of uncemented backfill slurry under non-draining conditions conforms to the characteristics of an ideal fluid model, and its lateral pressure distribution aligns closely with the predictions of hydrostatic pressure theory, validating the practical engineering applicability of the theoretical model.

(2) The drainage performance of the barricade walls significantly regulates the evolution of lateral pressure and the process of structural stabilization. Optimizing drainage design can reduce lateral pressure by 69.5%-70%, while also accelerating the dissipation of pore water pressure, which plays a crucial role in hastening the self-stabilization of the backfill structure and enhancing the safety margin of the wall.

(3) There is a significant negative correlation between the installation distance of the wall from the stope and the lateral pressure. When the wall is installed at the drift entrance (adjacent to the stope), it is subjected to the combined effects of high hydrostatic pressure, dynamic water pressure, and potential expansion force from the stope side, resulting in a peak lateral pressure of 73.18 kPa (under a loading pressure of 80 kPa), which is 22.28% and 35.43% higher than that of walls in the middle and at the end of the drift, respectively. After the load increases to 240 kPa, the wall at the drift entrance still maintains a load transfer rate of 25%.

(4) As the wall moves away from the stope, the lateral pressure exhibits a dual-decline characteristic of "numerical decrease-fluctuation attenuation": the fluctuation amplitude of the pressure time-history curve for the wall at the end of the drift is attenuated by more than 35% compared to that at the drift entrance. Mechanistic analysis reveals that the stress arch effect induced by tailings settlement near the stope concentrates the load towards the wall, while the far-field region achieves stress redistribution through particle friction energy dissipation and bonding effects, leading to a more balanced and stable pressure distribution.

ACKNOWLEDGEMENT

The authors would like to acknowledge the financial support from the National Science and Technology Major Project (Grant No. 2024ZD1003705).". And *the Youth Innovation Fund Project of BGRIMM Technology Group (04-04-2408).*

REFERENCES

1. Helinski M, FAHEY M, FOURIE A. (2010) Coupled two-dimensional finite element modelling of mine backfilling with cemented tailings. Canadian Geotechnical Journal, 47(11): 1187-200.
2. Li L. (2013) A new concept of backfill design—Application of wick drains in backfilled stopes. International Journal of Mining Science and Technology, 23(5): 763-70.
3. Sheshpari, M. (2015). Failures in backfilled stopes and barricades in underground mines. Electron. J. Geotech. Eng, 20: 191-212.
4. Kuganathan K. Design and construction of shotcrete bulkheads with engineered drainage system for mine backfilling. Proceedings of the international seminar on surface support liners, Australian Centre for Geomechanics, F, 2001 [C].
5. Berndt, C.C., Rankine, K.J., Sivakugan, N. (2007). Materials properties of barricade bricks for mining applications. Geotechnical and Geological Engineering, 25, 449-471.
6. Li L, Aubertin M. (2009) Horizontal pressure on barricades for backfilled stopes. Part II: Submerged conditions [J]. Canadian Geotechnical Journal, 46(1): 47-56.
7. Li L, Aubertin M. (2012) A modified solution to assess the required strength of exposed backfill in mine stopes [J]. Canadian Geotechnical Journal, 49(8): 994-1002.
8. Widisinghe, S.D., Sivakugan, N., Wang, V.Z. (2014). Loads on barricades in hydraulically backfilled underground mine stopes. In Mine Fill 2014: Proceedings of the Eleventh International Symposium on Mining with Backfill. Australian Centre for Geomechanics: 123-133.
9. Thompson, B.D., Bawden, W.F., Grabinsky, M. W., et al. (2010). Monitoring barricade performance in a cemented paste backfill operation. In Paste 2010: Proceedings of the Thirteenth International Seminar on Paste and Thickened Tailings. Australian Centre for Geomechanics: 185-197.
10. Sivakugan, N., Rankine, R.M., Rankine, K.J., et al. (2006). Geotechnical considerations in mine backfilling in Australia. Journal of Cleaner Production, 14(12-13), 1168-1175.
11. Nujaim M, Belem T, Giraud A. (2020) Experimental tests on a small-scale model of a mine stope to study the behavior of waste rock barricades during backfilling. Minerals, 10(11): 941.
12. Wang Y., Na Q, Zhang L. (2022) Monitoring of in-situ properties for cemented tailings backfill that under drainage condition. Construction and Building Materials, 356, 129254.