



Enhancing Efficiency of Steel Prop Recovery Processes in Unused Mining Excavation

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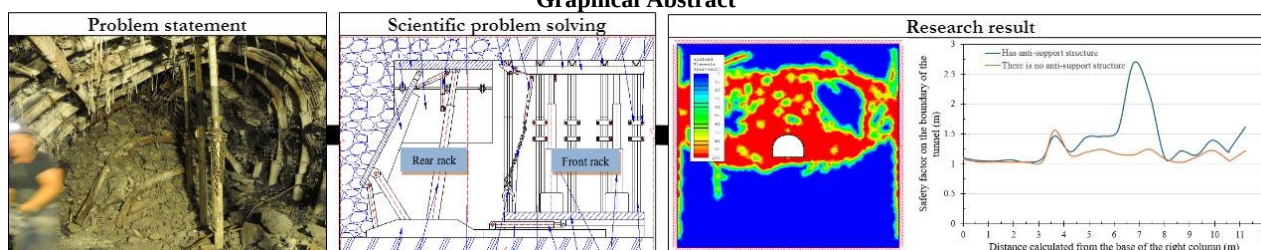
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ABSTRACT

In the field of underground mining, the steel props within the coal face are frequently not fully salvaged, resulting in a low recovery rate. At the present time, approximately 60% of coal mining is conducted through underground methods. Consequently, there is a growing number of mechanical roof supports that utilize steel props. Furthermore, as the raw materials for the manufacture of these props are becoming increasingly scarce, it is of paramount importance to recover steel supports from unused mine shafts and those situated along coal seams. However, the recovery process is beset with numerous challenges due to the complex geological conditions and the arduous and perilous nature of the work, which has resulted in a dearth of attention to prop recovery in these areas during the coal mining process. Phase 2 software from Rock science was employed to ascertain the impact of the dismantling equipment on the mining excavation. Therefore, this paper presents a technical solution to enhance the efficiency of the steel prop recovery process in these shafts by utilizing a combination of hydraulic and mechanical structures to form a cohesive equipment setup for effective recovery.

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Graphical Abstract



1. INTRODUCTION

In the future, the depletion of non-renewable energy and metal resources, along with the environmental degradation caused by resource extraction, underscores the urgent need for research into resource conservation and safety enhancement in coal mining (1, 2). Adopting such measures represents a prudent, sustainable, and logical direction for the coal industry. Presently and looking ahead, the predominant method for coal extraction involves underground mining technologies (3-6). Over time, having extensively used and improved

underground mining methods, the Vietnam Mineral and Coal Group is estimated to require the excavation of approximately 300,000 meters of new mine shafts annually (largely supported by steel props), with the necessity to dismantle an increasing number of old shafts, potentially up to 20,000 meters per year (7-9).

The recovery and reuse of steel props in the construction of new mine shafts are vital to avoid resource wastage and to generate economic benefits for enterprises. However, the dismantling process poses significant risks and demands strenuous effort due to the heavy weight of the roof supports, their elevated position,

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and the complex geological conditions encountered. Especially in areas with high geological instability and significant earth and rock pressure, there is a risk of immediate collapse following the removal of supports, even those prepped for dismantling (10-12). Therefore, in mine shafts with challenging geological features, supports often remain unrecovered, resulting in substantial resource wastage (13-15).

2. METHODOLOGY

The dismantling of supports in underground coal mines in Vietnam is currently performed manually. The prevalent method involves the use of hoists to facilitate the removal of the column bases; single props and rails to temporarily support and hold up the overhead beams, necessitating additional tasks such as positioning and moving single props, installing and relocating reinforced hanging rails, and moving hoists. As a result, the productivity of recovery operations is low. The recovery productivity achieves only about 2.8 meters per shift (for a team of four people), equivalent to recovering four supports per shift at the 5-level +290 Ke Chuoi Coal Mine (Figure 1). The high pressure exerted on the supports during dismantling causes deformation of the supports, thereby reducing the effectiveness of their reuse (16-18).

With the current recovery method, the mine pressure acting on the area of support recovery is depicted as in Figure 2 (19-21):

Zone 1: This area includes rock and coal above the mining excavation that is being dismantled and is in a state of equilibrium with the forces exerted by the steel supports.

Zone 2: This area also comprises rock and coal along the mining excavation direction being dismantled but is in a state of imbalance. The pressure in this zone compresses the area of the mining excavation and may cause deformation of the supports, posing a risk during the dismantling process.



Figure 1. Recovery of iron supports along the 5-level +290 seam at Ke Chuoi Coal Mine

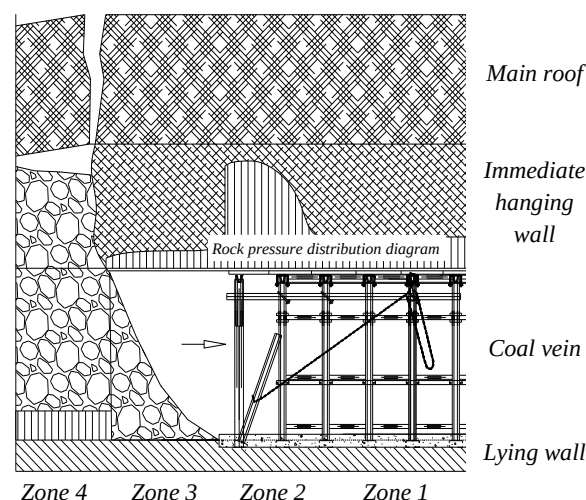


Figure 2. Pressure of rock and earth in the dismantling area

Zone 3: This zone represents the space where supports have been removed, leading to direct rock fall occurrences right after the dismantling of the support structures.

Zone 4: Part of the mining space where rock pressure is established.

Studies of actual mining processes have shown that the pressure in the dismantling area is significant, causing the base of the supports to sink further as the long wall moves. This complicates the dismantling process. Additionally, in Zone 4, the unstable rock materials on the roof are loosely connected and may collapse during the dismantling process, posing risks to both personnel and equipment. Therefore, there is a need for effective recovery solutions to address these issues.

3. RESULTS AND DISCUSSION

The support dismantling equipment is composed of two parts as shown in Figure 3: the front rack and the rear rack, which are connected and controlled by a cylinder 17 (22-24).

The rear rack (whose design is similar to the support trusses used in conventional mining but with the roof beam redesigned to more closely match the profile of the mining excavation) includes a dome-shaped roof 3 connected to the side beams 4 via a hinge 2 and controlled by cylinder 5, hydraulic column 20, and base 21. The dome-shaped design of the roof beam in the rear rack aims to increase its contact with the mining excavation roof, maintaining the original shape of the mining excavation after the supports are removed. Preserving the mining excavation's profile helps maintain the structural integrity of the roof, reducing pressure on the roof beam and minimizing the risk of collapse.

The front rack consists of base 16, hydraulic column 15, roof beam 9, support beam 6, support cylinder 7, and

a mechanism for extracting the props which includes cylinder 8, chain 18, and clamping device 19. This arrangement allows for the effective dismantling of supports, ensuring that the structural elements can be safely and efficiently removed while preserving the stability of the mining excavation during the process.

Working Principle: The operation begins with cylinder 7 controlling support beam 6, pressing it against the upper part 11 of the prop. Following this, clamp 12 of the prop is removed, and clamping device 19 is positioned as shown in Figure 4. At this point, cylinder 8 extends fully (fully extended). Once clamping device 19

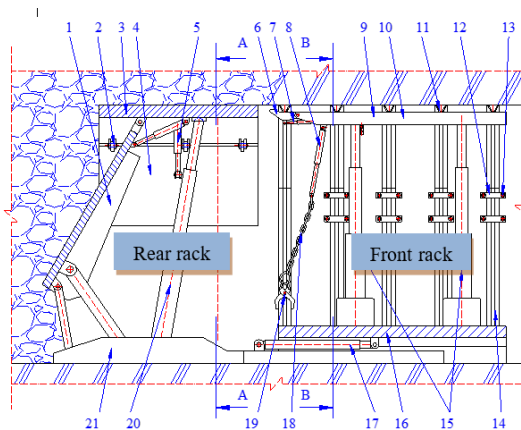


Figure 3. The support dismantling equipment: 1 – Protective Plate; 2 – Hinge; 3 – Dome-shaped Roof Beam; 4 – Dome-shaped Side Beam; 5 – Cylinder; 6 – Support Beam; 7 – Support Cylinder; 8 – Extraction Cylinder; 9 – Roof Beam; 10 – Front Rack; 11 – Upper Part of the Support (Prop); 12 – Clamp; 13 – Bolt; 14 – Base of the Support (Prop); 15 – Hydraulic Column; 16 – Front Base; 17 – Moving Cylinder; 18 – Pull Chain; 19 – Clamping Device; 20 – Support Column; 21 – Rear Support Bas

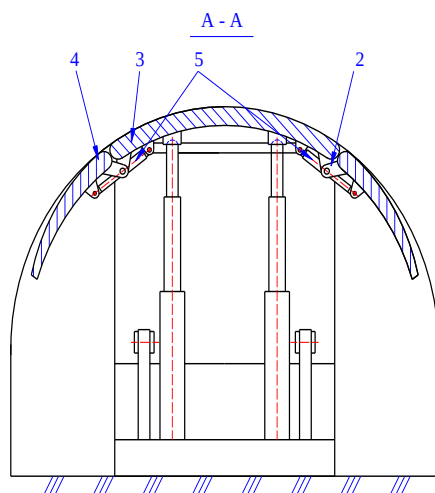


Figure 4. Equipment for dismantling props (view A-A): 2 – Hinge; 3 – Dome-shaped Roof Beam; 4 – Dome-shaped Side Beam; 5 – Cylinder

is correctly positioned, cylinder 8 retracts, creating a pulling force that extracts the base of the prop from the ground. Workers then proceed to remove the base of the prop from the area.

Next, cylinder 7 lowers support beam 6 just enough so that the upper part 11 of the prop does not fall, yet it can still be easily removed. After the prop has been removed and cleared from the work area, the next step involves advancing the rear rack forward: first, the dome-shaped side beam 4 is retracted inward by controlling cylinder 5; next, hydraulic column 20 is used to lower the rear rack, and then cylinder 17 pulls the rear rack forward. Once the rear rack has moved forward, hydraulic column 15 lowers the roof beam 9. Subsequently, cylinder 17 controls the forward movement of the front rack by a step equal to the support step. Finally, hydraulic column 15 presses the roof beam 9 against the props, completing a cycle of operation for the device (Figure 5).

This sequence ensures a systematic and safe dismantling of the props, minimizing physical strain and risk to the workers, while optimizing the efficiency of the dismantling process.

To analyze the pressures in the dismantling area when deploying equipment, a model was set up using the Phase 2 software. The input parameters for the simulation include:

- Mining excavation cross-sectional area before dismantling: 10.9 m²,
- Support force provided by the equipment: 800 kN,
- Length of the front rack: 3.5 m, and the rear rack: 3 m,
- Each rack has two support columns: the front with two standard columns and the rear with two hydraulic columns,
- Diameter of the support columns: Ø160mm,

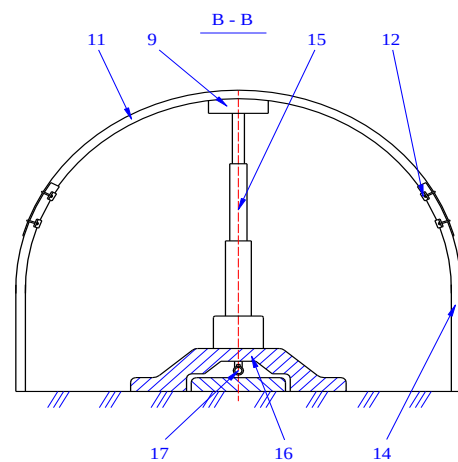


Figure 5. Equipment for dismantling props (view B-B): 9 – Roof Beam; 11 – Upper Part of the Support (Prop); 12 – Clamp; 14 – Base of the Support (Prop); 15 – Hydraulic Column; 16 – Front Base; 17 – Moving Cylinder;

- Operating pressure of the column: 31.5 MPa,
- Geological conditions above the mining excavation as presented in Table 1

Phase 2 software from Rocscience was utilized to determine the effects of the support dismantling equipment in the mining excavation (25-27). The characteristics of the rock mass where the mining excavation is located are shown in Table 1. The mining excavation is supported by SVP-22 steel supports, and the input parameters for this type of support in the numerical model are displayed in Table 2. The mining excavation has a half-moon vault shape with straight walls (Figure 6), with a cross-sectional area of 10.9 m², and the mining excavation is positioned at a depth of 190 meters.

The numerical model has dimensions of 30x30m, with the model boundary fixed in both vertical and horizontal directions (Figure 7).

The mechanical behavior of the rock obeys the Mohr-Coulomb model with plastic deformation. The stress field is generated by the weight of the rock mass above the mining excavation. The model's mesh is divided into triangular elements, totaling nearly 11,000 elements. To simulate the stress relief process around the mining excavation, a stress reduction factor of 40% is used in the model. The simulation process is carried out through the following steps:

TABLE 1. Mechanical Properties of the Rock Mass

Parameter name	Value
Material Model	Mohr-Coulomb, Plastic
Natural Density, Yunsat (kN/m ³)	22
Saturated Weight, Ysat	22,5
Elastic Modulus, E (MPa)	4382
Poisson's Ratio, ν	0,3
Friction Angle, Φ (°)	34,8
Dilation Angle, Ψ (°)	4,8
Cohesion, c (MPa)	0,45
Tensile Strength (MPa)	0,048

TABLE 2. Properties of SVP-22 Supports

Parameter name	Value
Type of Support	SVP-22
Support Step, L (m)	0.7
Cross-Sectional Area, cm ²	22.44
Bending Moment, Ix (cm ⁴)	322.8
Elastic Modulus, E (GPa)	200
Poisson's Ratio, ν	0.2
Tensile/Compression Strength, MPa	400

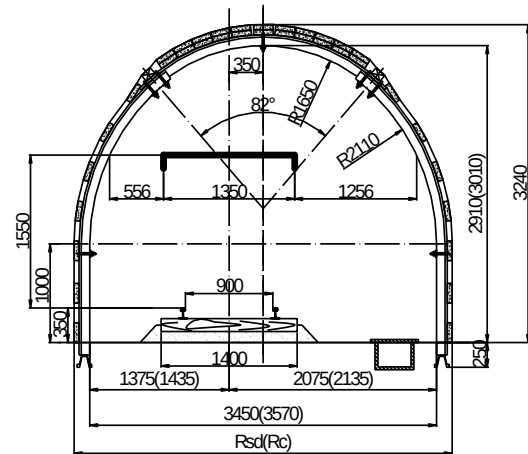


Figure 6. Shape and size of the mining excavation

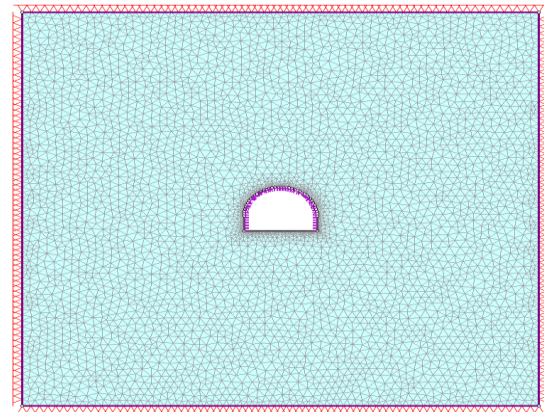


Figure 7. Model setup in Phase 2 software

Step 1: Mesh the model;

Step 2: Excavate the mining excavation, using a 40% loading factor in the model;

Step 3: Support the mining excavation with SVP-22 supports, using a 100% loading factor in the model;

Step 4: Remove the supports (in cases without support equipment); simulate the effect of the support equipment on the edge of the mining excavation roof with a structural reaction force (80% of 800kN) (In cases with support equipment);

Step 5: The support equipment operates with 100% support force (800kN).

3. 1. Simulation and Analysis of Results With the above process, the results of total displacement and stress on the mining excavation boundary obtained from two cases, with and without support equipment, are shown in Figures 8 to 12.

Figure 8 shows the relationship between normal stress and shear stress when SVP-22 steel supports are installed (red '+' signs, where horizontal direction shows shear stress and vertical direction shows normal stress). Under

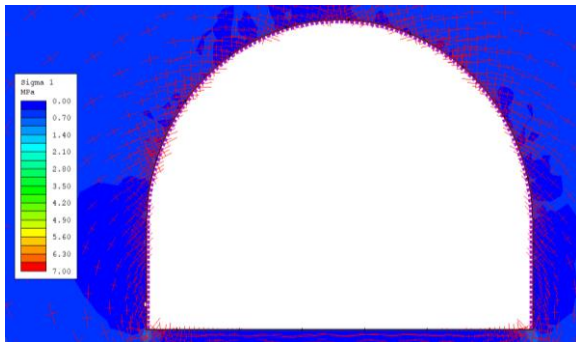


Figure 8. Relationship between normal and shear stress components before removing supports

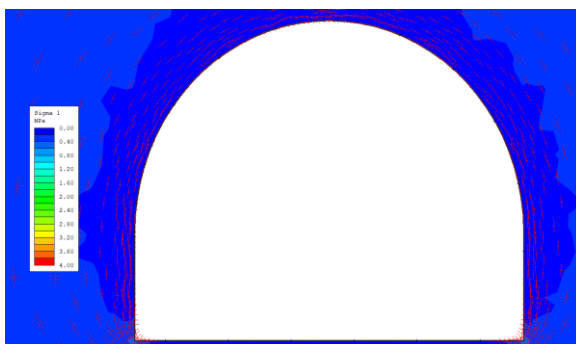


Figure 9. Stress components after removing supports

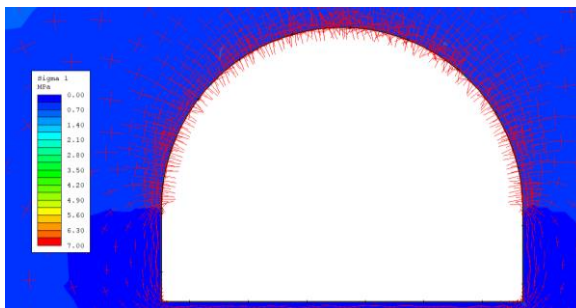


Figure 10. Stress components after removing supports with support recovery equipment

the effect of the structural reaction force of the support, normal stress components appear on the boundary of the mining excavation and in the rock mass around the mining excavation. The magnitude of the normal stress component is influenced by the structural reaction force of the support (compression of the rock). The larger the structural reaction force, the higher the normal stress and the lower the shear stress. Lower shear stress means less likelihood of the rock mass around the mining excavation being pulled apart, stabilizing the rock. In the case of removing supports in the usual way, the structural reaction force on the boundary of the mining excavation is zero (Figure 9). Then, only shear stress components appear on the boundary of the mining excavation, with the normal stress component being zero, and a large

difference between shear and normal stress components. The shear stress component causes tensile forces within the rock mass, the greater the value, the more unstable the rock mass around the mining excavation becomes, and if this value exceeds the tensile strength of the rock, the rock mass around the mining excavation will be destroyed. Additionally, it is observed that the tensile strength of rock is much smaller than its compressive strength (1/10-1/30 depending on the type of rock). Therefore, when designing, attention is usually given to the shear stress component within the rock mass and efforts are made to reduce this component.

Figure 10 shows that, when applying the support structure for removing supports (through pressure on the edge of the mining excavation roof), the normal stress component at the roof does not disappear due to the removal of supports, because there is still support from the support equipment. The shear stress component decreases and the normal stress component increases, with a smaller difference between the two stress components. The rock mass around the mining excavation remains stable due to the reaction force of the support equipment acting on the boundary of the mining excavation.

Continuing with similar analysis results, the damaged area in Figure 11a for the mining excavation using support equipment is much smaller compared to the damaged area in Figure 11b for the mining excavation not using support equipment.

Figure 12, we consider the total displacement on the boundary of the mining excavation, with small total displacement at the base, while the largest displacement is at the sides (Figure 12a). The total displacement at the roof and sides of the mining excavation decreases, and the safety factor on the boundary of the mining excavation increases when there is a support structure for removing supports (Figure 12b).

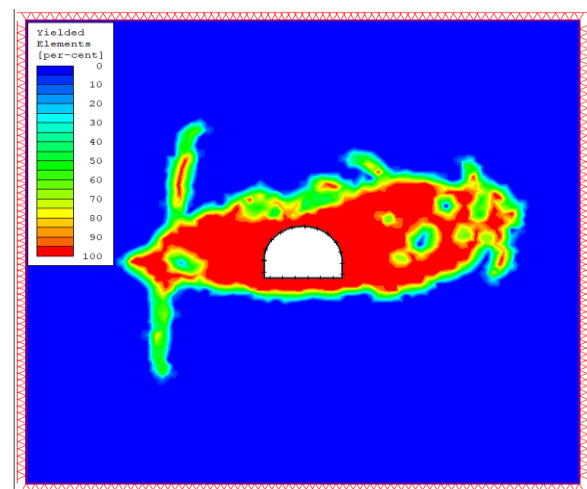


Figure 11-a. Damage area around the mining excavation in the case of using support recovery equipment

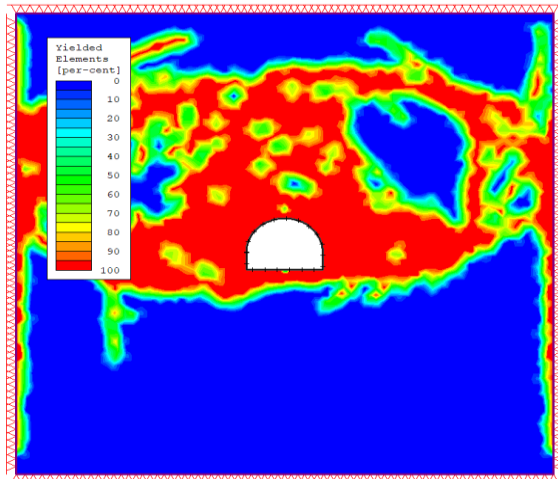


Figure 11-b. Damage area around the mining excavation in the case of not using support recovery equipment

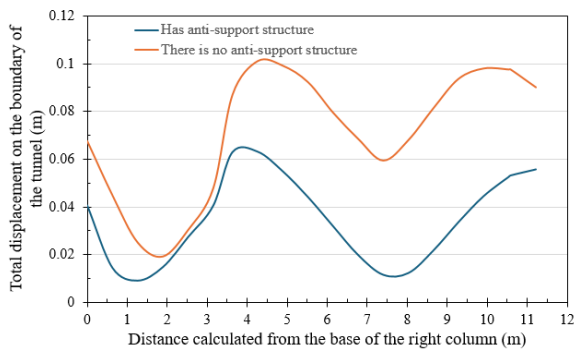


Figure 12-a. Chart of total displacement on the boundary of the mining excavation being recovered

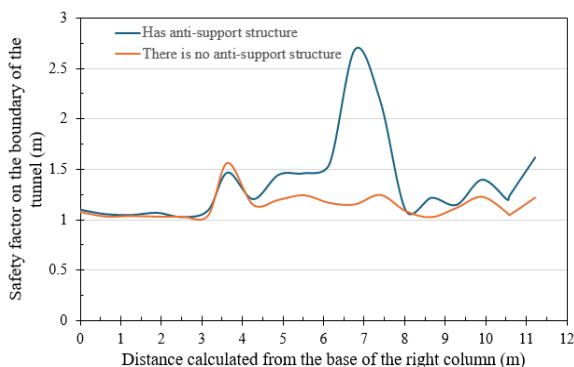


Figure 12-b. Chart of safety factor on the boundary of the mining excavation being recovered

Through the simulation process on the model, it is observed that the load on the mining excavation when there is no support dismantling equipment and no dismantling equipment significantly changes the stability, reduces the size of the damaged area around the mining excavation, increases the safety factor, and

reduces the total displacement on the boundary of the mining excavation.

The steel support recovery equipment used in mining excavations has a simple structure, allowing for flexible movement within the mining excavation space and can autonomously change direction during movement. Additionally, the column removal mechanism is equipped with a vibration unit to facilitate the process of extracting the column's base.

The device is designed in two separate, consecutive sections. Each section includes a base, a roof beam, support columns, and bases of the intermediate and outer racks, linked together by a moving cylinder. These components are coordinated smoothly during the dismantling of supports. The front support rack is designed in two parts that can move simultaneously or independently, alternating to continuously provide support to the portion of the mining excavation that has not been dismantled as the equipment moves. During the dismantling process, both parts simultaneously provide support to enhance safety for both personnel and equipment operating below.

The supporting and lowering mechanism of the steel supports' roof beam is designed such that when lowering the supports, balance is always maintained. Additionally, the beam can rotate along the length of the mining excavation to facilitate the removal of the beam while the worker remains in a safely supported area.

4. CONCLUSION

The proposed technical solution aims to enhance the efficiency of the steel prop recovery process in these shafts by utilizing a combination of hydraulic and mechanical structures to form a cohesive equipment setup for effective recovery. This solution allows for the delineation of the following conclusions:

1. The use of support equipment increases safety during the dismantling and recovery of supports.
2. It reduces the pressure on supports that have not yet been recovered, thereby decreasing the subsidence at the column base, making it easier to extract the columns.
3. It minimizes harmful environmental impacts by more efficiently using resources.
4. It reduces manual labor and injuries among miners, as well as the time required to recover support in unused mining excavations and mining excavations along the seam.

5. ACKNOWLEDGEMENTS

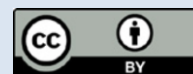
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6. REFERENCES

1. Lebedev A, Cherepovitsyn A. Waste management during the production drilling stage in the oil and gas sector: a feasibility study. *Resources*. 2024;13(2):26. 10.3390/resources13020026
2. Babyr N. Topical themes and new trends in mining industry: Scientometric analysis and research visualization. *International Journal of Engineering, Transactions B: Applications*. 2024;37(2):439-51. 10.5829/ije.2024.37.02b.18
3. Gamez-Montero P, Salazar E, Castilla R, Freire J, Khamashta M, Codina E. Misalignment effects on the load capacity of a hydraulic cylinder. *International Journal of Mechanical Sciences*. 2009;51(2):105-13. 10.1016/j.ijmecsci.2009.01.001
4. Zeng Q, Ma X, Wan L, Zhu Y, Yue Y. Research on the hydraulic support face guard mechanism and coupling characteristic of rib spalling in large mining heights. *Scientific Reports*. 2024;14(1):8110. 10.1038/s41598-024-58542-5
5. Hou T, Kou Z, Wu J, Xu P, Zhang B, Peng Y. Positioning Control Strategy of Hydraulic Support Pushing System in Fully Mechanized Coal Face. *Electronics*. 2023;12(17):3628. 10.3390/electronics12173628
6. Ren H, Wang D, editors. Modeling and control of surrounding rock support of hydraulic support. 2022 IEEE 25th International Conference on Intelligent Transportation Systems (ITSC); 2022: IEEE. 10.1109/ITSC55140.2022.9922098
7. Yang Y, Zhang Y, Zeng Q, Wan L, Zhang Q. Simulation research on impact contact behavior between coal gangue particle and the hydraulic support: Contact response differences induced by the difference in impacted location and impact material. *Materials*. 2022;15(11):3890. 10.3390/ma15113890
8. Kongar-Syuryun C, Kovalski E. Hardening backfill at potash mines: Promising materials regulating stress-strain behavior of rock mass. *Geol Geophys Russ South*. 2023;13:177-87. 10.46698/VNC.2023.34.99.01
9. Tshitema N, Kallon DVV. Product Development of a Rock Reinforcing Bolt for Underground Hard Rock Mining. *Mining*. 2021;1(3):364-90. 10.3390/mining1030023
10. Zuev BY, ISTOMIN RS, Kovshov SV, KITSIS VM. Physical modeling the formation of roof collapse zones in Vorkuta coal mines. *Bulletin of the Mineral Research and Exploration*. 2020;162(162):225-34. 10.19111/bulletinofmre.620478
11. Zhikharev S.Ya. TVD, Rodionov V.A. . Optimization of dust suppression processes during underground mining based on full-scale experimentation and ANSYS Fluent simulation. *Gornyi Zhurnal*. 2023;11:70-5. 10.17580/gzh.2023.11.11
12. Kongar-Syuryun C, Klyuev R, Golik V, Oganessian A, Solovykh D, Khayrutdinov M, et al. Principles of Sustainable Development of Georesources as a Way to Reduce Urban Vulnerability. *Urban Science*. 2024;8(2):44. <https://doi.org/10.3390/urbansci8020044>
13. Borska B, Szurgacz D. Research and Simulation on the Development of a Hydraulic Prop Support System of Powered Roof Support to Increase Work Safety. *Methods and Protocols*. 2024;7(2):33. 10.3390/mps7020033
14. Tien NT, Karasev M. Optimization of geometry design of quasi-rectangular section tunnel by the force criterion. *MIAB Mining Inf Anal Bull*. 2021(6):59-71. 10.25018/0236_1493_2021_6_0_59
15. Gabov V, Zadkov D, Babyr N, Xie F. Nonimpact rock pressure regulation with energy recovery into the hydraulic system of the longwall powered support. *Eurasian Min*. 2021;36:55-9. 10.17580/em.2021.02.12
16. Jasiulek D, Skóra M, Jagoda J, Jura J, Rogala-Rojek J, Hetmańczyk M. Monitoring the Geometry of Powered Roof Supports—Determination of Measurement Accuracy. *Energies*. 2023;16(23):7710. 10.3390/en16237710
17. Kovalski E, Kongar-Syuryun CB, Petrov D. Challenges and prospects for several-stage stoping in potash mining. *Sustain Dev Mt Territ*. 2023;15:349-64. 10.21177/1998-4502-2023-15-2-349-364
18. Szurgacz D. Analysis of the Causes of Damage to the Stabilisation Actuator of the Cap Piece of the Powered Roof Supports and a Proposal to Reduce the Effects. *Machines*. 2023;11(2):194. 10.3390/machines11020194
19. Liao Y, Tao Z, Lian Z. Design, failure analysis, and optimization of a high-flow water valve: A case study. *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering*. 2023;237(4):1331-43. 10.1177/09544089221113687
20. Zhang L, Wang Z, Tan C, Si L, Liu X, Feng S. A fruit fly-optimized Kalman filter algorithm for pushing distance estimation of a hydraulic powered roof support through tuning covariance. *Applied Sciences*. 2016;6(10):299. 10.3390/app6100299
21. Chen X, Paprouski A, Elveny M, Podoprigrora D, Korobov G. A laboratory approach to enhance oil recovery factor in a low permeable reservoir by active carbonated water injection. *Energy Reports*. 2021;7:3149-55. 10.1016/j.egyr.2021.05.043
22. Nguyen KL, Gabov V, Zadkov D. Improving efficiency of cleanup and coal flow formation on conveyor by shearer loader with accessorial blade. *Eurasian Mining*. 2019;1:37-9. 10.17580/em.2019.01.09
23. Linh N, Gabov V, Lykov Y, Urazbakhtin R. Evaluating the efficiency of coal loading process by simulating the process of loading onto the face conveyor with a shearer with an additional share. *International Journal of Engineering, Transactions A: Basics*. 2021;34(7):1804-9. 10.5829/IJE.2021.34.07A.25
24. Gabov VV, Van Xuan N, Zadkov DA, Tho TD. Increasing the content of coarse fractions in the mined coal mass by a combine using paired cuts. *Записки Горного института*. 2022;257:764-70. 10.31897/PMI.2022.66
25. Enkhbold B, Ikeda H, Toriya H, Adachi T. A Comprehensive Numerical Modeling Study for Parameter Optimization and Slope Stability Analysis in the Baganuur Lignite Coal Mine. *Mining*. 2023;3(4):755-72. 10.3390/mining3040041
26. Singh P, Spearing AS, Jessu K, da Silva Ribeiro PCP. Establishing the need to model the actual state of stress along rock bolts. *International Journal of Mining Science and Technology*. 2020;30(3):279-86. 10.1016/j.ijmst.2020.03.002
27. Kuranov A, Bagautdinov I, Kotikov D, Zuev BY. Integrated approach to safety pillar stability in slice mining in the Yakovlevo deposit. *Горный журнал*. 2020(1):115-9. 10.17580/gzh.2020.01.23

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Persian Abstract

چکیده

در زمینه استخراج زیرزمینی، پایه‌های فولادی در سطح زغال سنگ اغلب به طور کامل نجات نمی‌یابند و در نتیجه نرخ بازیابی پایینی به همراه دارد. در حال حاضر، تقریباً ۶۰ درصد استخراج زغال سنگ از طریق روش های زیرزمینی انجام می شود. در نتیجه، تعداد فزاینده‌ای از تکیه‌گاه‌های مکانیکی سقف وجود دارد که از پایه‌های فولادی استفاده می‌کنند. علاوه بر این، از آنجایی که مواد خام برای ساخت این تجهیزات به طور فزاینده‌ای کمیاب می‌شوند، بازیابی تکیه‌گاه‌های فولادی از شفت‌های معدنی استفاده نشده و آن‌هایی که در امتداد درزهای زغال‌سنگ قرار دارند از اهمیت بالایی برخوردار است. با این حال، فرآیند بازیابی به دلیل شرایط پیچیده زمین‌شناسی و ماهیت سخت و خطرناک کار، با چالش‌های متعددی مواجه است، که منجر به عدم توجه به بازیابی پایه در این مناطق در طول فرآیند استخراج زغال‌سنگ شده است. نرم افزار فاز ۲ از Rock science برای تعیین تأثیر تجهیزات برچیدن بر حفاری معدن استفاده شد. بنابراین، این مقاله یک راه حل فنی برای افزایش کارایی فرآیند بازیابی پایه فولادی در این شفت ها با استفاده از ترکیبی از ساختارهای هیدرولیکی و مکانیکی برای تشکیل یک مجموعه تجهیزات منسجم برای بازیابی موثر ارائه می دهد.
