

Editorial: Advances in Mathematical, Numerical and Artificial Intelligence Methods in Rock Engineering Applications

Xin Cai ^{1,*} , Shaofeng Wang ¹, Yu Wang ²  and Xueming Du ³

¹ School of Resources and Safety Engineering, Central South University, Changsha 410083, China; sf.wang@csu.edu.cn

² Department of Civil Engineering, School of Civil and Resource Engineering, University of Science and Technology Beijing, Beijing 100083, China; wyzhou@ustb.edu.cn

³ School of Water Conservancy and Transportation, Zhengzhou University, Zhengzhou 450001, China; 2007-dxm@163.com

* Correspondence: xincai@csu.edu.cn

MSC: 65S11; 68U11; 74R11; 74S11; 74F11

1. Introduction

This editorial presents 12 research articles published in the Special Issue entitled “Advances in Mathematical, Numerical and Artificial Intelligence Methods in Rock Engineering” of the MDPI Mathematics journal. The twelve studies collectively advance rock engineering through experimental, numerical, and AI-driven approaches, focusing on structural stability, failure prediction, and system optimization. Common themes include analyzing damage mechanisms (e.g., chemical degradation, dynamic stress effects) via fractal analysis, acoustic emission, and finite element modeling, alongside hybrid frameworks integrating fuzzy logic and machine learning for enhanced predictive accuracy. Distinctive contributions span diverse applications: pore-fracture evolution in coal, thermal efficiency in heat exchangers, and AI innovations such as CNNs for image classification and transfer learning for tunnel design. Methodological uniqueness lies in novel hybrid models (e.g., intuitionistic fuzzy sets, game theory) addressing rockburst propensity and instability, highlighting interdisciplinary synergy in addressing geotechnical challenges.

2. Overview of the Published Papers

Dynamic Evolution of Coal Pore-Fracture Structure and Its Fractal Characteristics under the Action of Salty Solution (by M. Wang, Y. Tian, Z. Zhang, Q. Guo and L. Wu) investigates the influence of salt solution immersion on coal pore structure by analyzing the porosity evolution under varying immersion times and concentrations. The study reveals that prolonged exposure to salt solutions increases coal porosity and deteriorates its structural integrity, providing insights into the damage mechanisms of coal properties under chemical interactions.

Time-Frequency Response of Acoustic Emission and Its Multi-Fractal Analysis for Rocks with Different Brittleness under Uniaxial Compression (by J. Ou, E. Wang and X. Wang) employs acoustic emission (AE) monitoring and multifractal analysis to explore the correlation between rock brittleness and AE time-frequency characteristics during uniaxial compression. The results demonstrate that brittleness is directly proportional to the parameter $\Delta\alpha$ (data uniformity) and inversely proportional to Δf (frequency difference), with abrupt changes in these parameters serving as precursors to rock failure.



Received: 30 March 2025

Accepted: 7 April 2025

Published: 16 May 2025

Citation: Cai, X.; Wang, S.; Wang, Y.; Du, X. Editorial: Advances in Mathematical, Numerical and Artificial Intelligence Methods in Rock Engineering Applications. *Mathematics* **2025**, *13*, 1632. <https://doi.org/10.3390/math13101632>

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Research on Precursor Information of Brittle Rock Failure through Acoustic Emission (by W. Ren, C. Wang, Y. Zhao and D. Xue) proposes a rock failure prediction method using triaxial experiments on granite, integrating the b-value and correlation dimension calculated via the G-P algorithm. The study identifies decreasing trends in both parameters as reliable indicators of impending rock damage, offering a framework for estimating surrounding rock stability.

Numerical Investigation on the Performance of Horizontal Helical-Coil-Type Backfill Heat Exchangers with Different Configurations in Mine Stopes (by B. Zhang, L. Shi, W. Zhang, C. Huan, Y. Zhao and J. Wang) utilizes the COMSOL software platform to simulate 3D unsteady heat transfer in spiral-type horizontal backfill heat exchangers (BFHEs). The results highlight that spiral tube arrangements and optimized pitch-to-diameter ratios enhance thermal efficiency and heat storage capacity, providing guidelines for BFHE design optimization.

Numerical Simulation of Failure Modes in Irregular Columnar Jointed Rock Masses under Dynamic Loading (by Y. Xia, B. Liu, T. Li, D. Zhao, N. Liu, C. Tang and J. Chen) applies the finite element method (FEM) to analyze dynamic failure modes of irregular columnar jointed rock masses (CJRMs) at varying dip angles. The study reveals that increasing dip angles shift failure modes from tension–compression–shear to pure tension, with higher stress wave amplitudes accelerating crack propagation.

Prediction of Rockburst Propensity Based on Intuitionistic Fuzzy Set—Multisource Combined Weights—Improved Attribute Measurement Model (by J. Chen, Y. Zhao, Z. Liu, S. Yang and Z. Zhou) introduces a rockburst prediction model combining intuitionistic fuzzy sets, multisource weighting, and improved attribute measurement. The model outperforms existing methods in accuracy by incorporating parameters such as uniaxial compressive strength, tensile stress, and elastic deformation coefficients.

Evaluation and Application of Surrounding Rock Stability Based on an Improved Fuzzy Comprehensive Evaluation Method (by X. Mao, A. Hu, R. Zhao, F. Wang and M. Wu) develops an improved fuzzy comprehensive evaluation method (IFCEM) integrating analytic hierarchy process (AHP) and coefficient of variation (CV) to assess surrounding rock stability. The results demonstrate enhanced accuracy through game theory-based weight optimization, offering a robust tool for engineering applications.

High Steep Rock Slope Instability Mechanism Induced by the Pillar Deterioration in the Mountain Mining Area (by L. Chen, X. Yu, R. Luo, L. Zeng and H. Cao) establishes a numerical model to investigate slope instability mechanisms caused by pillar deterioration in mountain mining areas. The study emphasizes the critical role of pillars in controlling slope deformation and failure progression, providing practical insights for slope stability management.

A Novel Method for Predicting Rockburst Intensity Based on an Improved Unascertained Measurement and an Improved Game Theory (by Z. Liu, J. Chen, Y. Zhao and S. Yang) proposes a rockburst intensity prediction method combining enhanced unascertained measurement and game theory-based weight integration. The results validate its superior accuracy over traditional models, highlighting its applicability in geotechnical risk assessment.

Investigation of Transfer Learning for Tunnel Support Design (by A. Mitelman and A. Urlainis) explores transfer learning to address data scarcity in tunnel support design. By training artificial neural networks (ANNs) on large datasets and fine-tuning with smaller datasets, the method effectively optimizes support parameters, demonstrating adaptability to unstudied geological conditions.

Rock Thin Section Image Identification Based on Convolutional Neural Networks of Adaptive and Second-Order Pooling Methods (by Z. Zhou, H. Yuan and X. Cai) introduces a convolutional neural network (CNN) model (ASOPCNN) incorporating adaptive and second-order

pooling layers to enhance rock thin section image identification. The results confirm improved feature representation and classification accuracy, establishing ASOPCNN as a reliable tool for geological analysis.

The Application of Machine Learning Techniques in Geotechnical Engineering: A Review and Comparison (by W. Shao, W. Yue, Y. Zhang, T. Zhou, Y. Zhang, Y. Dang, H. Wang, X. Feng and Z. Chao) reviews machine learning algorithms, including SVM, ANN, and random forest (RF), in geotechnical applications. The study highlights RF's efficacy in soil classification, SVM's precision in rock deformation prediction, and the suitability of ANNs for strength and settlement forecasting.

Conflicts of Interest: The authors declare no conflict of interest.

List of Contributions

1. Wang, M.; Tian, Y.; Zhang, Z.; Guo, Q.; Wu, L. Dynamic Evolution of Coal Pore-Fracture Structure and Its Fractal Characteristics under the Action of Salty Solution. *Mathematics* **2024**, *12*, 72. <https://doi.org/10.3390/math12010072>.
2. Ou, J.; Wang, E.; Wang, X. Time-Frequency Response of Acoustic Emission and Its Multi-Fractal Analysis for Rocks with Different Brittleness under Uniaxial Compression. *Mathematics* **2023**, *11*, 4746. <https://doi.org/10.3390/math11234746>.
3. Ren, W.; Wang, C.; Zhao, Y.; Xue, D. Research on Precursor Information of Brittle Rock Failure through Acoustic Emission. *Mathematics* **2023**, *11*, 4210. <https://doi.org/10.3390/math11194210>.
4. Zhang, B.; Shi, L.; Zhang, W.; Huan, C.; Zhao, Y.; Wang, J. Numerical Investigation on the Performance of Horizontal Helical-Coil-Type Backfill Heat Exchangers with Different Configurations in Mine Stopes. *Mathematics* **2023**, *11*, 4173. <https://doi.org/10.3390/math11194173>.
5. Xia, Y.; Liu, B.; Li, T.; Zhao, D.; Liu, N.; Tang, C.; Chen, J. Numerical Simulation of Failure Modes in Irregular Columnar Jointed Rock Masses under Dynamic Loading. *Mathematics* **2023**, *11*, 3790. <https://doi.org/10.3390/math11173790>.
6. Chen, J.; Zhao, Y.; Liu, Z.; Yang, S.; Zhou, Z. Prediction of Rockburst Propensity Based on Intuitionistic Fuzzy Set—Multisource Combined Weights—Improved Attribute Measurement Model. *Mathematics* **2023**, *11*, 3508. <https://doi.org/10.3390/math11163508>.
7. Mao, X.; Hu, A.; Zhao, R.; Wang, F.; Wu, M. Evaluation and Application of Surrounding Rock Stability Based on an Improved Fuzzy Comprehensive Evaluation Method. *Mathematics* **2023**, *11*, 3095. <https://doi.org/10.3390/math11143095>.
8. Chen, L.; Yu, X.; Luo, R.; Zeng, L.; Cao, H. High Steep Rock Slope Instability Mechanism Induced by the Pillar Deterioration in the Mountain Mining Area. *Mathematics* **2023**, *11*, 1889. <https://doi.org/10.3390/math11081889>.
9. Liu, Z.; Chen, J.; Zhao, Y.; Yang, S. A Novel Method for Predicting Rockburst Intensity Based on an Improved Unascertained Measurement and an Improved Game Theory. *Mathematics* **2023**, *11*, 1862. <https://doi.org/10.3390/math11081862>.
10. Mitelman, A.; Urlainis, A. Investigation of Transfer Learning for Tunnel Support Design. *Mathematics* **2023**, *11*, 1623. <https://doi.org/10.3390/math11071623>.
11. Zhou, Z.; Yuan, H.; Cai, X. Rock Thin Section Image Identification Based on Convolutional Neural Networks of Adaptive and Second-Order Pooling Methods. *Mathematics* **2023**, *11*, 1245. <https://doi.org/10.3390/math11051245>.
12. Shao, W.; Yue, W.; Zhang, Y.; Zhou, T.; Zhang, Y.; Dang, Y.; Wang, H.; Feng, X.; Chao, Z. The Application of Machine Learning Techniques in Geotechnical Engineering: A Review and Comparison. *Mathematics* **2023**, *11*, 3976. <https://doi.org/10.3390/math11183976>.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.