A Knowledge-data Dually Driven Method for Accurate Identification of Key Blocks in Complex Rock Slopes

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Personal Information

Xiaoyu Qi

Geotechnical Engineering

[Research Interests]

Geo-hazards Prevention, Numerical Simulation and Computational Modeling, Machine Learning, Network Science and Applications, Data mining

[Education Background]

- 2020.09 - Present Ph.D. Candidate China University of Geosciences(Beijing)
- 2024.11 - Present Visiting Ph.D. Candidate Politecnico di Milano
- 2016.09 - 2020.06 BSc China University of Geosciences(Beijing)

[Main Achievements]

- Served as the principal investigator of **the Young Elite Scientists Sponsorship Program – PhD Special Program by CAST**, and participated in a General Program funded by the National Natural Science Foundation of China (NSFC).
- Published **6** SCI papers, including **1** in the field of geological hazard prevention (Journal of Rock Mechanics and Geotechnical Engineering), and **2** in the field of artificial intelligence (Future Generation Computer Systems and IEEE Transactions on Intelligent Transportation Systems).

Contents

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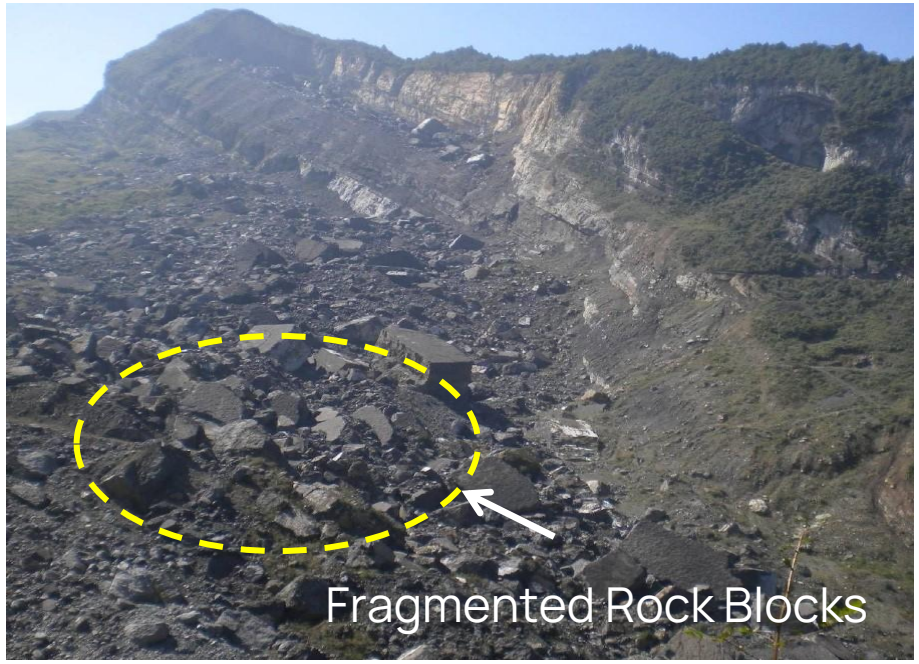
Research Background

1. Research Background - Rock Landslide

- During natural or human-induced events such as rainfall, seismic activity, or engineering excavation, partial sliding along specific structural planes within the rock mass can be induced.

- Partial sliding would cause a chain reaction even overall failure of rock slope.

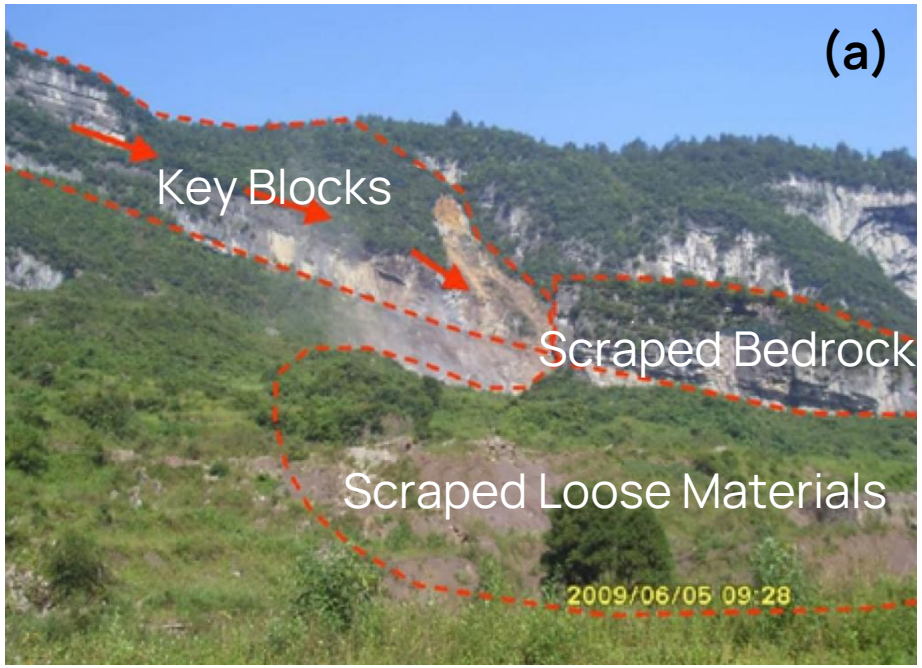


The Large-Scale Landslide at Jiweishan in Wulong, Chongqing (Xu et al., 2009)

1. Research Background - Rock Landslide

- **Example**: In figure (a), after the key blocks become unstable, they scrape the bedrock and loose materials, breaking down into the rock blocks and debris shown in figure (b).

- **Inspiration**: Accurate identification of these key blocks can help prevent rockfalls and landslides, ensure the safety of infrastructure and human life, and contribute to environmental protection.



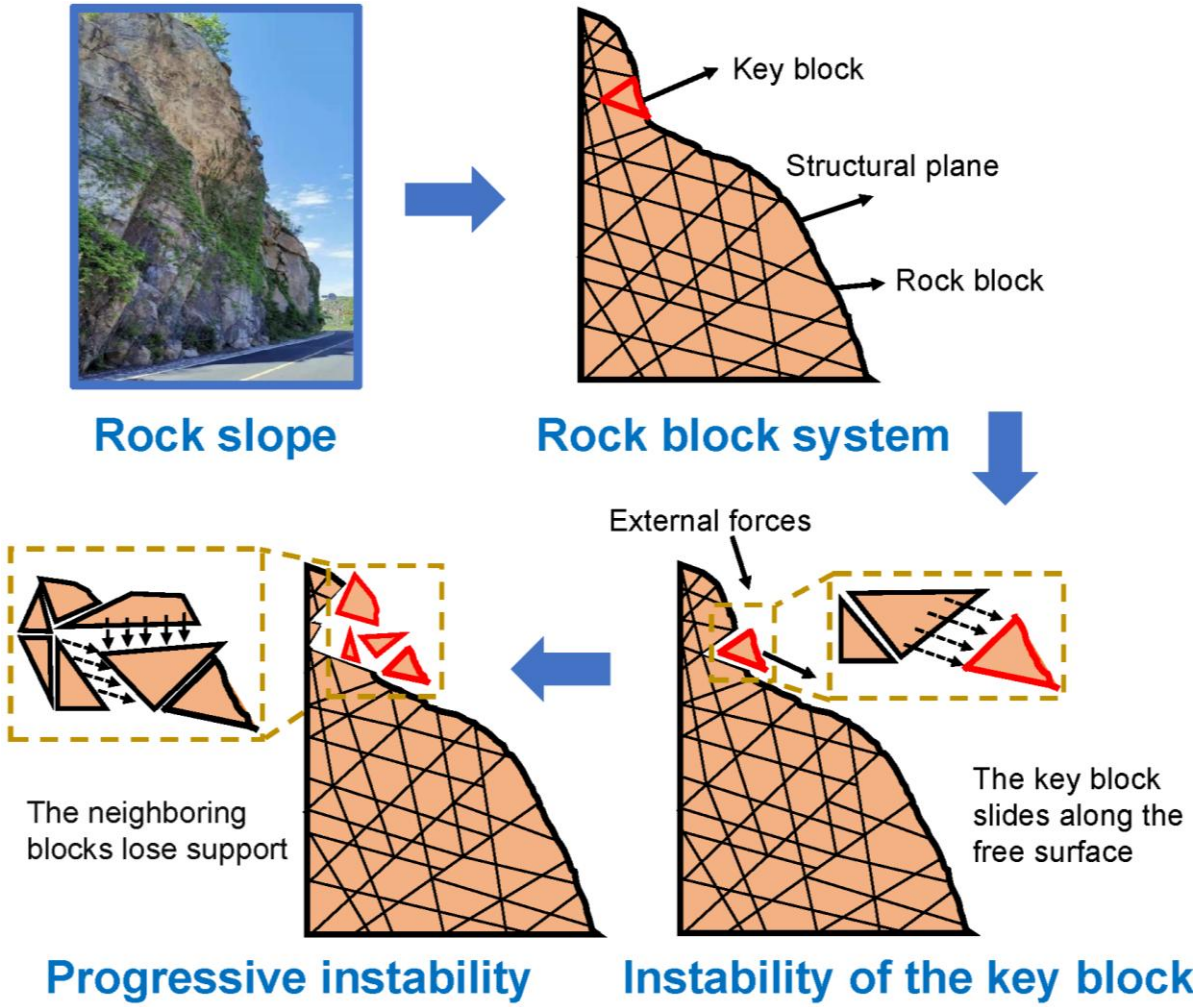
Before the Landslide (Xu et al., 2009)

After the Landslide (Peng et al., 2011)

1. Research Background - Key Block Theory

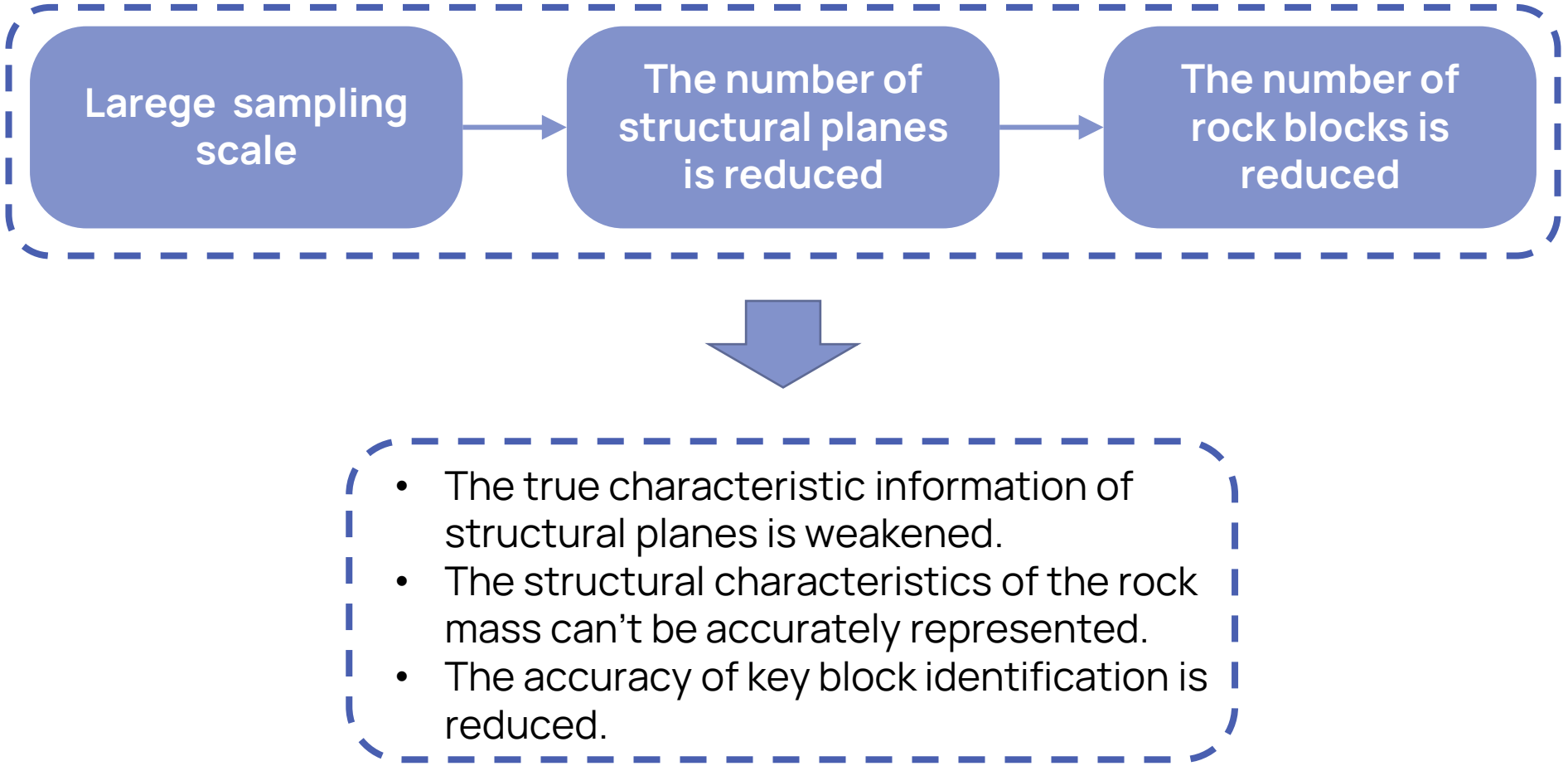
- Shi and Goodman (1989) first proposed the concept of **key blocks**, which refers to the rock blocks that experience significant displacement or even instability first during the deformation and failure process of rock slopes.

- The core concept of key block theory is to identify the key blocks on the excavation surface through geometric and topological analysis methods. Subsequently, the rigid body limit equilibrium method is used to evaluate the stability of the blocks and calculate the required anchoring force.



1. Research Background - Current Challenges

However, at present, identifying key blocks in large and complex rock slopes based on traditional block theory faces the following challenges:



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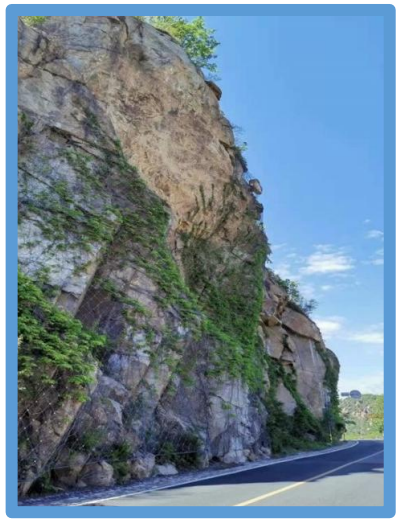
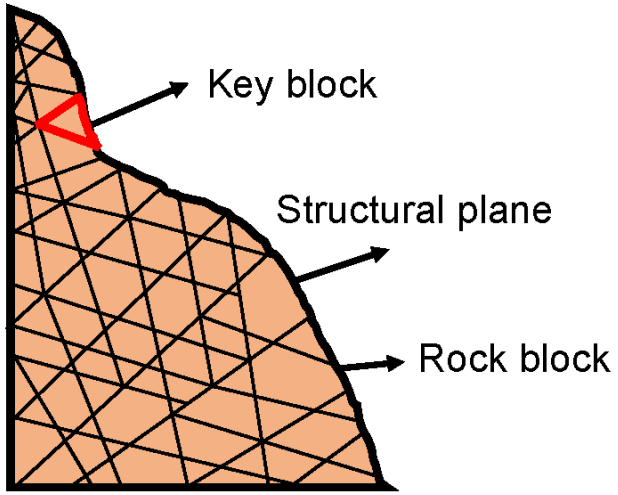
Research Method

2. Research Method - Theoretical basis

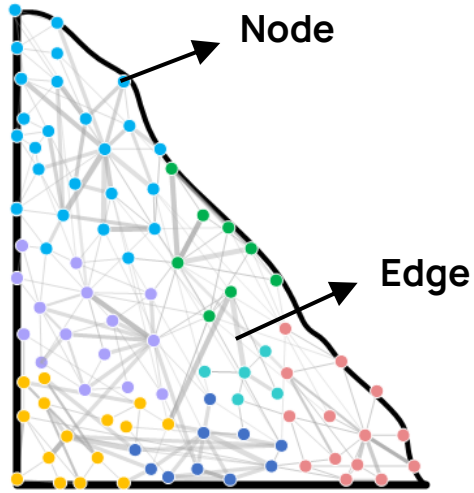
Based on complex system theory, a rock mass can be regarded as a complex system composed of rock blocks and structural planes, allowing for the refined and comprehensive characterization of both structural planes and rock blocks.



Rock Slope



Rock Block System

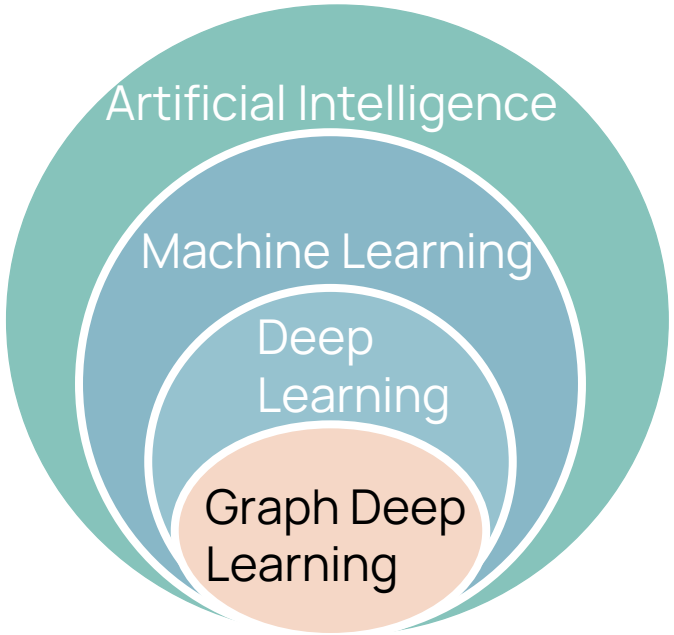


Rock Block Network

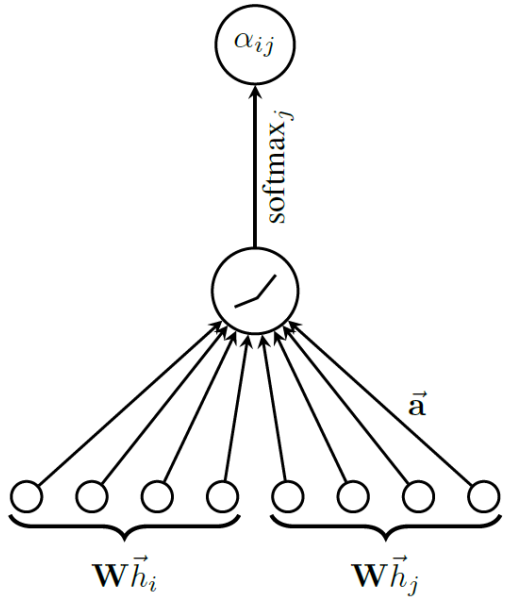
2. Research Method - Theoretical basis

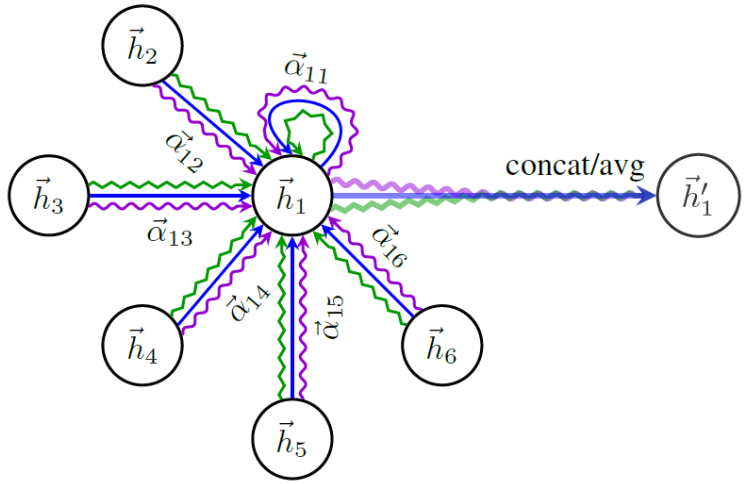
Graph deep learning brings new opportunities for key block identification. Data from irregular domains (i.e., non-Euclidean spaces) in various fields can be directly represented as graphs, such as citation networks.

Key block identification can be seen as a graph-based node classification problem. Graph deep learning methods are useful for handling rock slope graph data, capturing complex nonlinear relationships, and learning the distribution patterns of key blocks for accurate identification.



An Interdisciplinary Branch of Computer Science



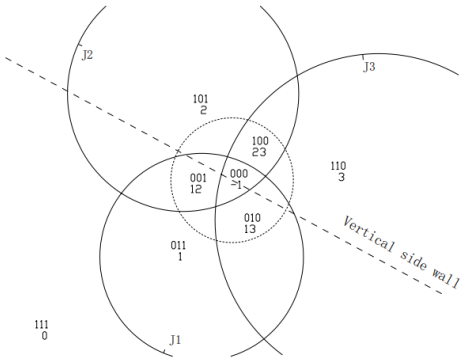


Graph Deep Learning Model (Velickovic et al., 2017)

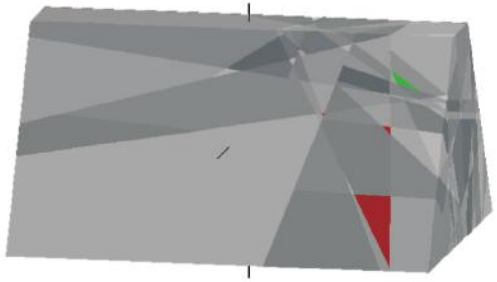
2. Research Method - Essential idea

➢ How to tackle the challenges? By combining scientific knowledge with data-driven models.

Key Block Theory



Stereographic Projection



Key Blocks in Jointed Slopes

Knowledge-data Dually Driven

- Effective support measures
- Prevent slope instability
- Ensure slope safety
- Avoid casualties

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Graph Deep Learning Model

Training

Identification

Prediction

Early warning

Decision-making

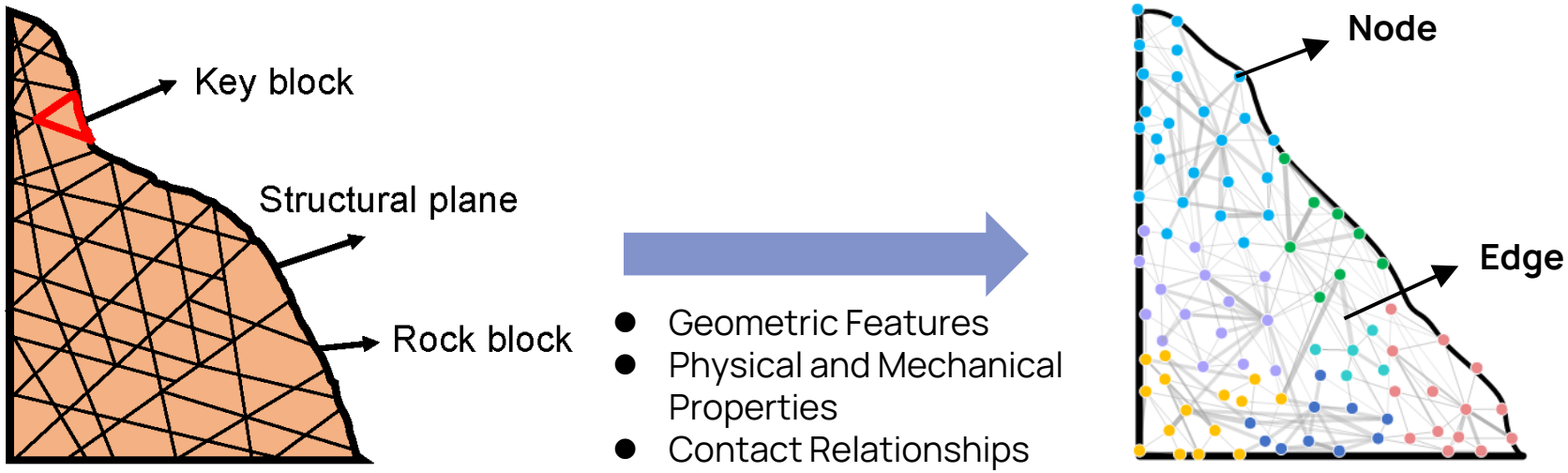
03

Progress and Application

3. Progress and Application - Innovative Work

1) Rock slope graph-structured data construction method.

From the perspective of nonlinear complex systems, we finely and comprehensively characterize the geometric features, physical and mechanical properties of rock blocks, and the contact relationships between rock blocks based on graph structures, representing the rock slope as undirected and attributed graph-structured data.

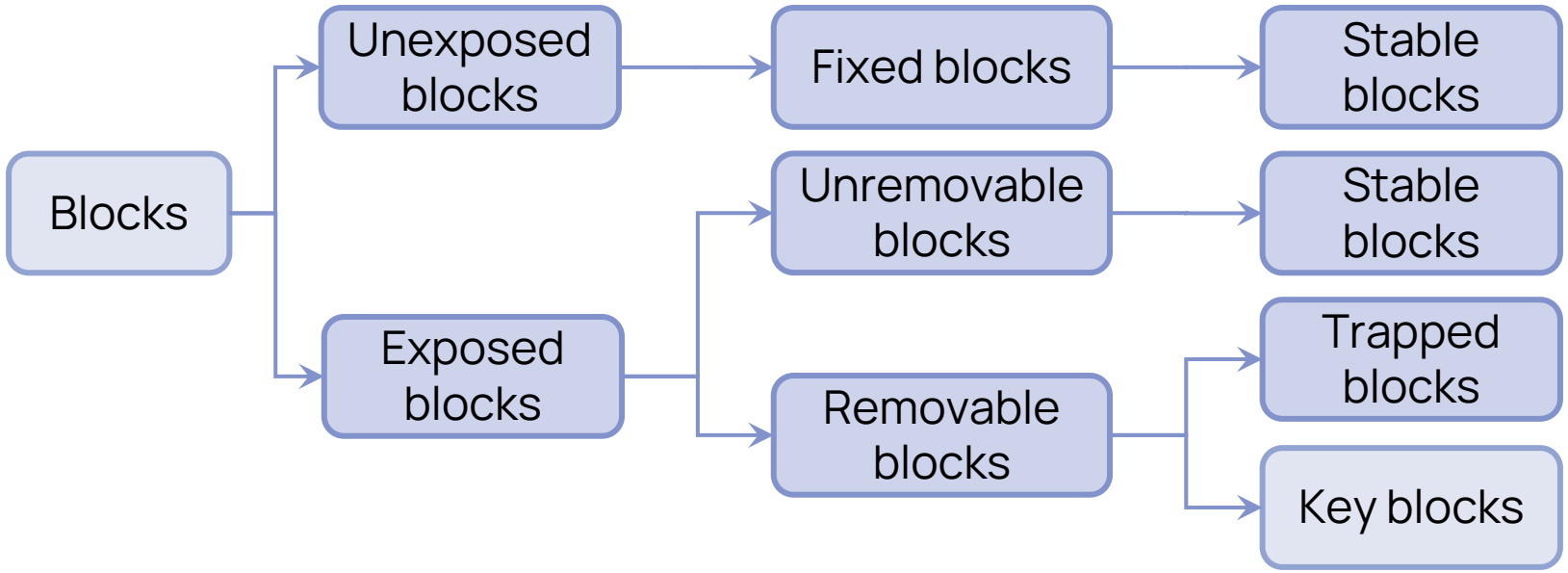


3. Progress and Application - Innovative Work

2) Fusion of key block theory into data-driven model.

Based on key block theory, let the rock blocks have an indicator k, where k=1 for key blocks and k=0 for non-key blocks. The training data incorporating key block theory are labeled. The objective of using deep learning to identify key blocks is to learn a composite function $F(S)$.

$$F(S)=h(g(f(S)))=ks\ (k=1)$$

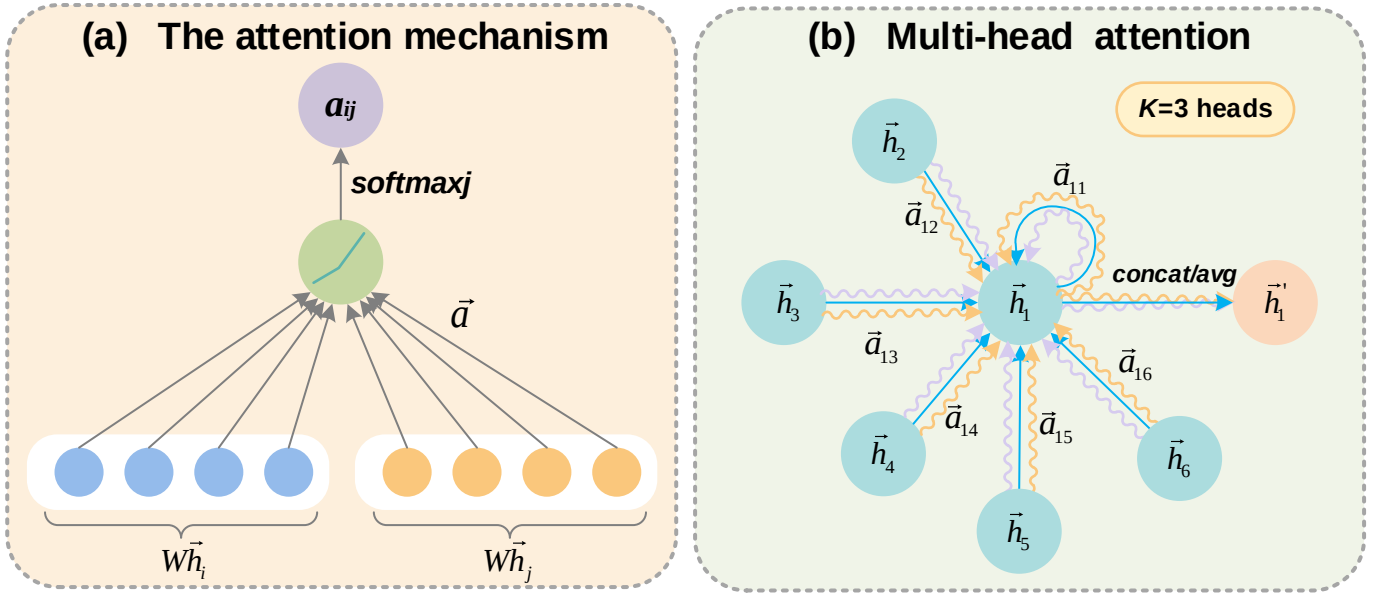


Rock Block Classification Based on Key Block Theory

3. Progress and Application - Innovative Work

3) Utilize graph deep learning for accurate identification of key blocks in rock block system.

We employ the Graph Attention Networks (GAT) inductive learning framework (Velickovic et al., 2017) to learn the internal structural characteristics of rock masses and the distribution patterns of key blocks. The identification results of key blocks are evaluated using classification metrics, including Recall, Precision, F1, AUC, and MCC.

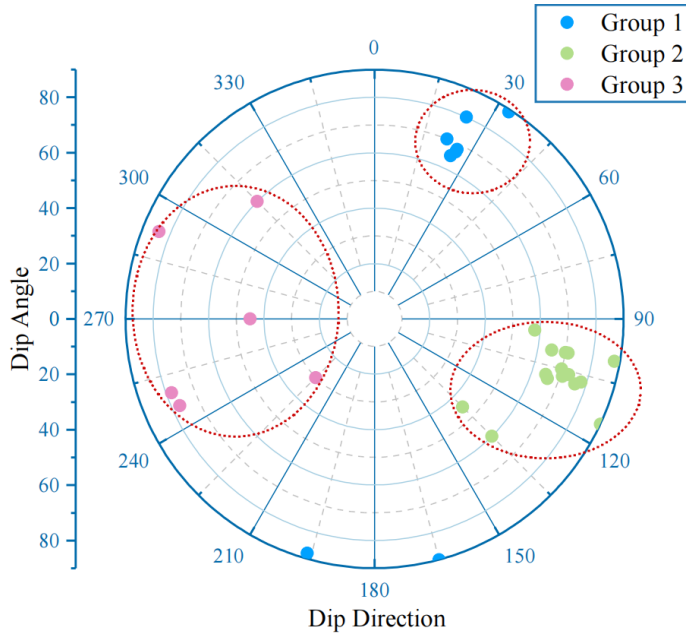


Structure Diagram of the GAT Model

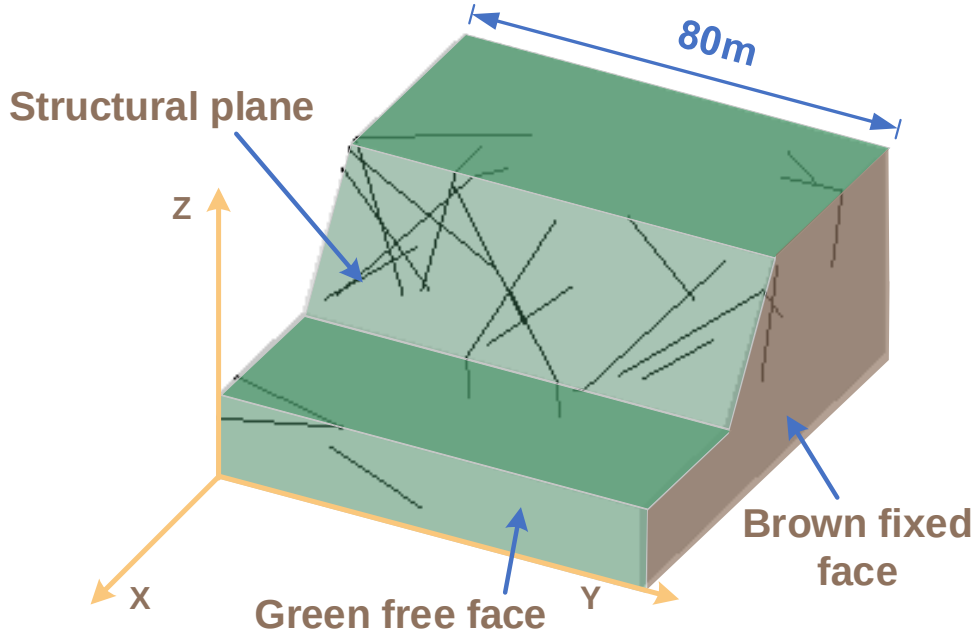
3. Progress and Application - Validation Results

① Validation experiments

Consult relevant literature and based on the obtained geometric, physical, and mechanical parameters, we construct a simplified rock slope model.



Stereographic Projection of the Structural Planes

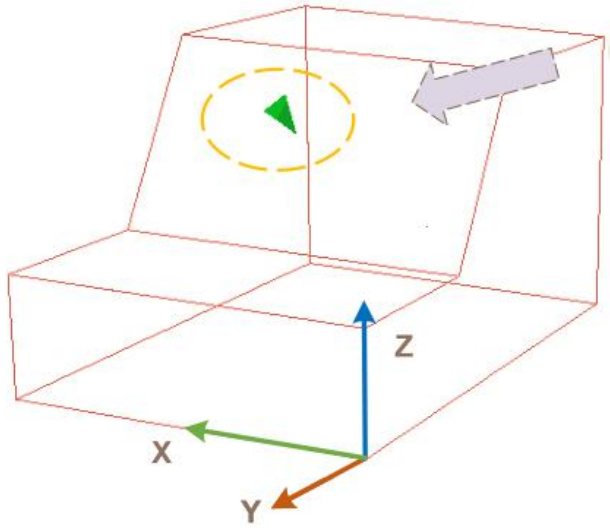


Simplified 3D Rock Slope Model

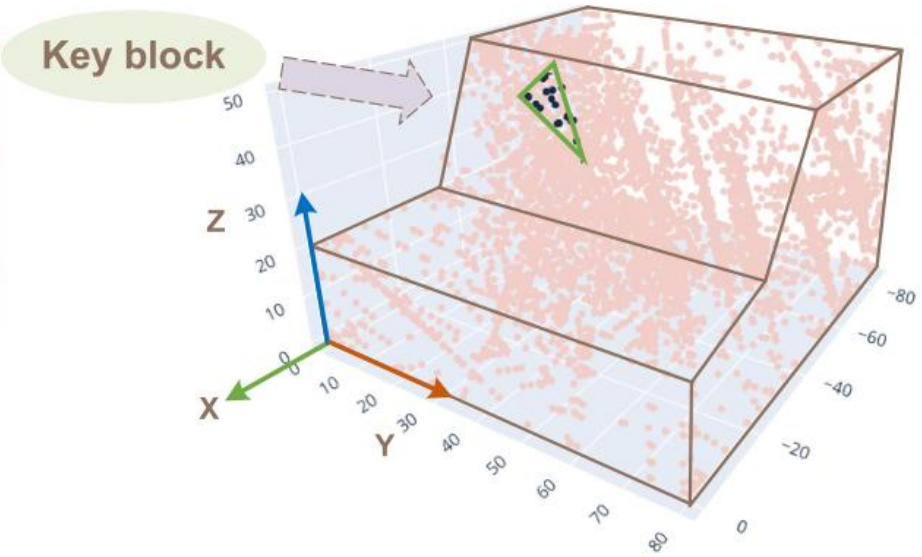
3. Progress and Application - Validation Results

① Validation experiments

The KBTE cloud platform (Software source: Zhang, 2015) was used to input the slope data and structural information. The key block identification results for the jointed slope model were computed and visually analyzed, closely matching the testing outcomes.



Identification Result of KBTE

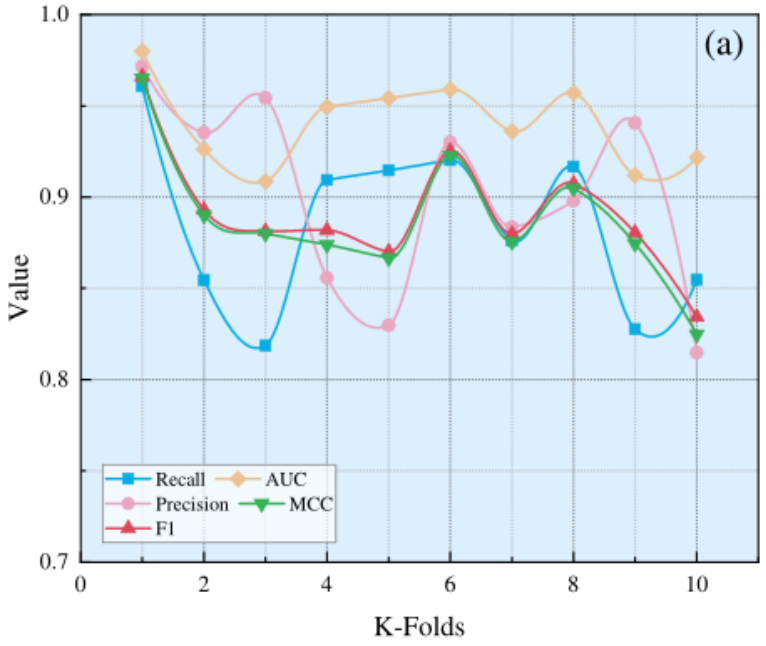


Identification Result of Our Method

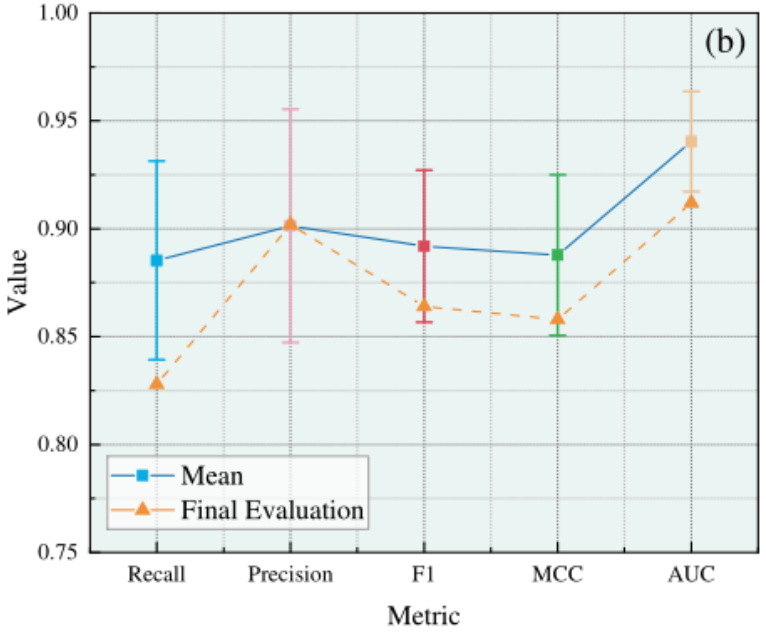
3. Progress and Application - Validation Results

① Validation experiments

A 10-fold cross-validation was performed to reduce partitioning uncertainty, minimize overfitting, and enhance generalization. The results confirm the model's strong generalization ability.



Evaluation results for the ten-fold cross-validation experiment



Ten-Fold cross-validation and test results

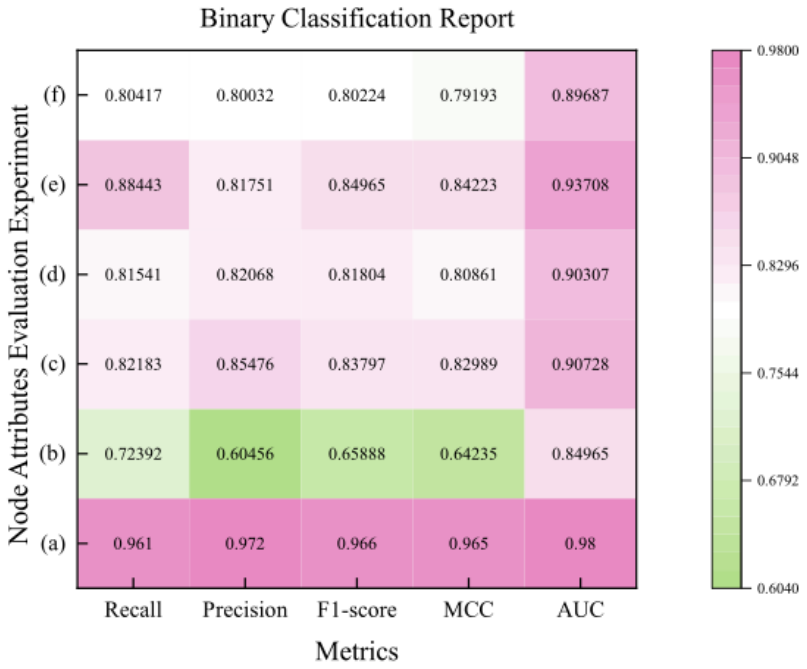
3. Progress and Application - Validation Results

① Validation experiments

Feature analysis was conducted to evaluate the impact of node attributes on classification results. The results indicate that the combination of all node attributes contributes to the comprehensive representation of node features, thereby improving the accuracy of key block identification.

Experiment	Number
Baseline (All Attributes)	a
- Spatial coordinate	b
-Degree (Rigid node degree and virtual node degree)	c
- Vertical distance to the slope surface	d
- Number of faces of corresponding rock block	e
- Intersecting structural planes	f

Evaluation Results of the Node Attributes Evaluation Experiment



Confusion Matrix for the Node Attributes Evaluation Experiment in Binary Classification

3. Progress and Application - Application Results

② Application: A real case

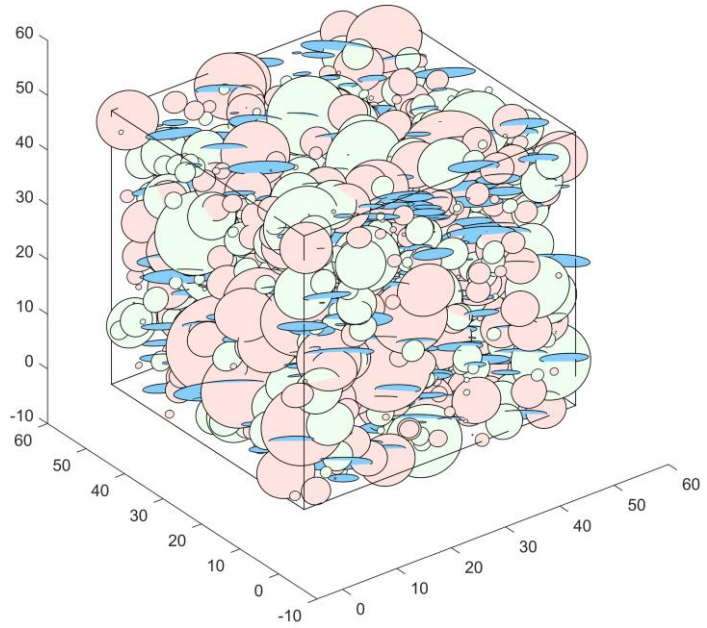
Damage: The extensive exposure of these rock masses due to open-pit mining has led to significant weathering under the influence of atmospheric conditions, rainfall, and biological processes, resulting in weakened mechanical properties of the rock mass.

Field View of Yanqianshan Iron Mine
(Anshan City, Liaoning Province, China)

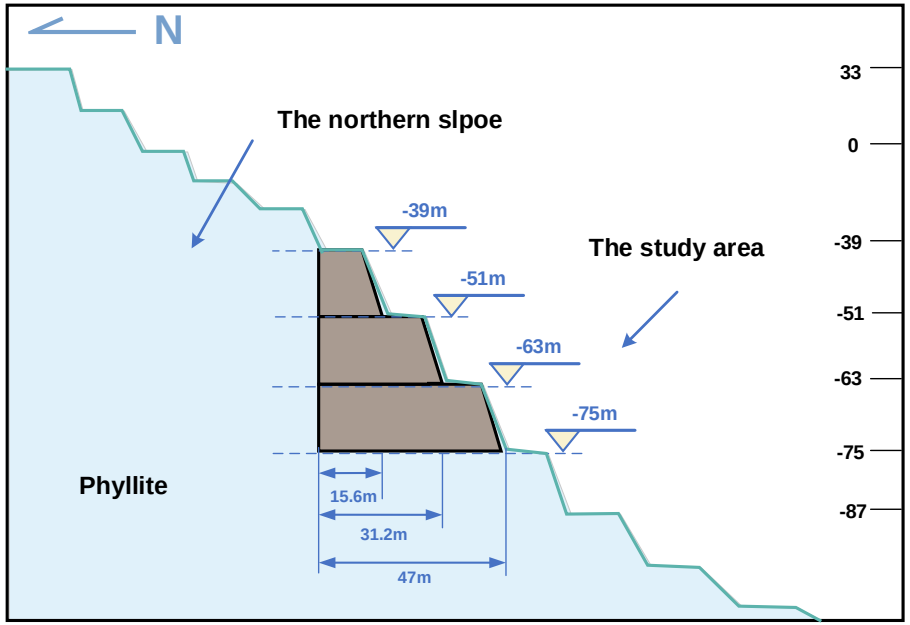
3. Progress and Application - Application Results

② Application: A real case

- According to available information, the north slope, which is characterized by uniform lithology, well-developed joints, and fractured structure, was selected as the study area.
- A three-step slope model and a structural plane network model of Yanqianshan were constructed, and the trained model was used for key block identification.



Structural Plane Network Model

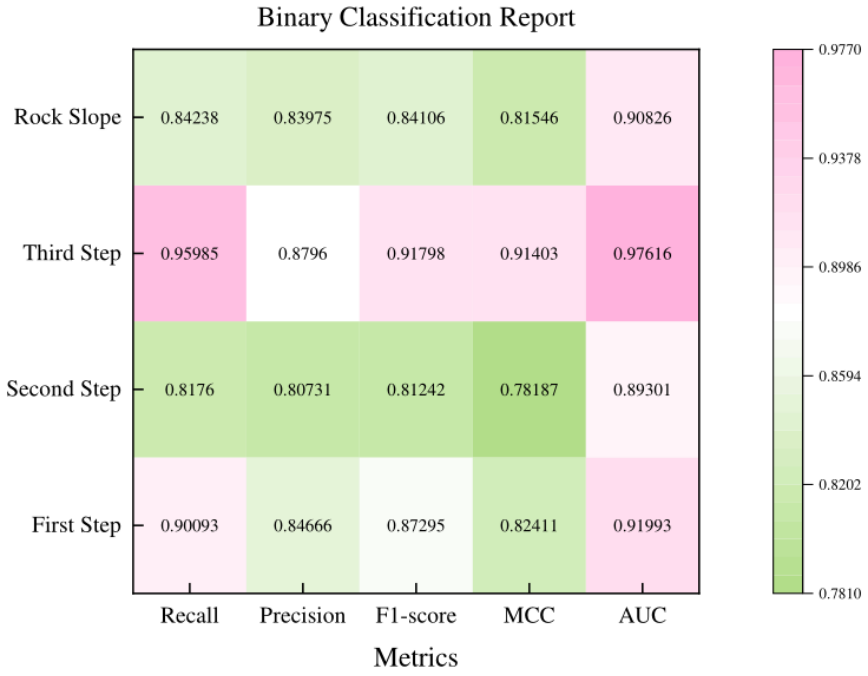


Side View of the Constructed Three-step Slope Model in Yanqianshan Iron Mine

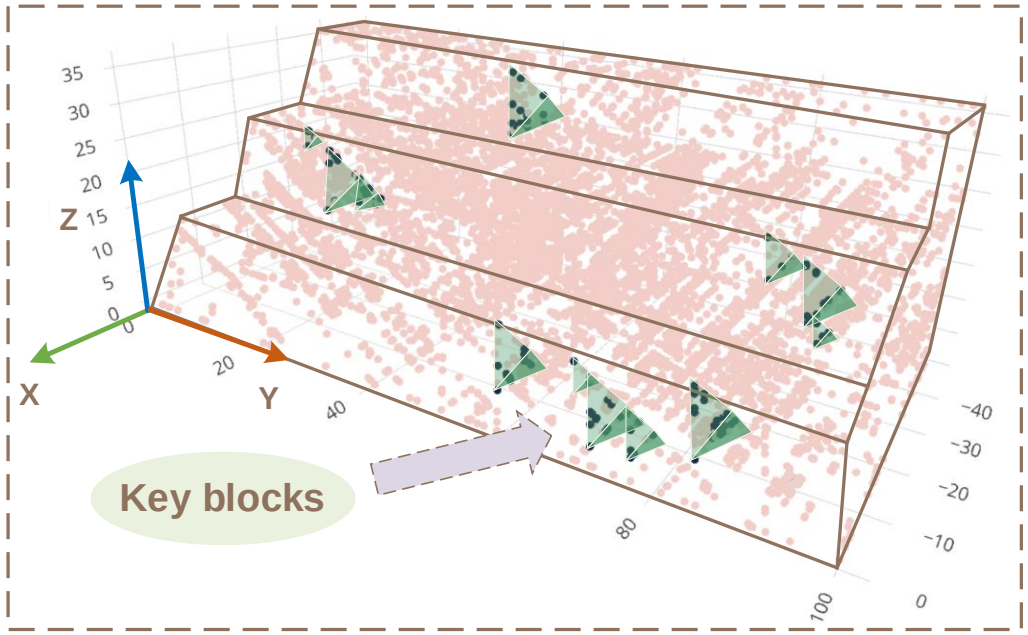
3. Progress and Application - Application Results

② Application: A real case

The distribution of key blocks on the excavation surface of each slope stage was identified. The proposed method demonstrates strong classification performance on imbalanced datasets and can be used for the accurate identification of key blocks in complex rock slopes.



Binary Classification Report of Four Experimental Groups



Key Blocks Identification Result in Yanqianshan Iron Mine

04

Conclusion

4. Conclusion

- The proposed method has advantages in finely representing the structural characteristics of rock masses in complex rock slopes, **improving the accuracy of key block identification**.

- By incorporating **key block theory** into **graph deep learning models**, we can effectively learn and capture the internal structural characteristics of the rock block system and the distribution patterns of key blocks.

- The proposed paradigm excels in accurately identify key blocks from extremely **imbalanced** rock block systems, providing **effective support** for rock slopes and preventing slope instability.

Thanks for your listening!

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