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CLASSIFICATION OF METHODS FOR DETECTING VOIDS IN ROCK MASSIF

Purpose. The paper aims to thoroughly analyze and classify methods for detecting voids in rock formations to establish a systematic approach to their use in geotechnical investigations. The main tasks include studying the physical principles of operation of each method, identifying its advantages and disadvantages, and determining the specific conditions and tasks under which it can be most effective. The research also involves exploring various classification approaches, considering the physical properties of rocks, measurement principles, method purposes, field types, information transmission methods, and other criteria. Each approach will be examined to elucidate its unique characteristics and capabilities.

Methodology. The research will involve the examination of various classification approaches, taking into account the physical properties of rocks, measurement principles, method purposes, field types, information transmission methods, and other criteria. Each approach will be studied to elucidate its unique characteristics and capabilities, serving as the basis for further research and development in this field of knowledge.

Results. The obtained research results aim to facilitate understanding and selection of the optimal method for detecting voids in a mining massif, depending on specific tasks, research conditions, and geological circumstances. Such an approach will contribute to a more effective utilization of geophysical methods in geotechnical and hydrogeological investigations, enabling a qualitative assessment of mining reserves and prevention of potential hydrogeological issues.

Scientific novelty. For the first time, through analysis and systematization, a classification of methods for detecting voids in a rock massif has been developed, considering measurement accuracy. This classification enables scientists, engineers, and geologists to better understand the variety of approaches to this task. Additionally, for the first time, a ranking of method classes for detecting voids in a rock massif has been performed, based on comprehensive effectiveness with equal weighting of method determination factors: 1. Seismic, 2. Optical, 3. Acoustic, 4. Gravitational, 5. Electromagnetic and Magnetic, 6. Biofield, 7. Radiofrequency and Microwave.

Practical implementation. The conclusions drawn from the research can have practical applications in conducting a comprehensive assessment of the geophysical condition of a rock massif.

Keywords: Keywords: geophysical condition, detection of voids in rock massif, classification of methods.

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Problem and its connection with scientific and practical tasks. Modern geological and hydrogeological investigations are closely linked to the detection of voids in rock massif. For the effective and precise determination of geological structures, assessment of mineral reserves, and prevention of hydrogeological issues, methods capable of detecting and evaluating the size, shape, and volume of voids are essential. In this context, the development of various geophysical methods becomes a crucial component of contemporary geoengineering.

Research and Publication Analysis. The article is dedicated to the study and classification of methods for detecting voids in rock formations, aiming to provide scientists, engineers, and geologists with a better understanding of the variety of approaches to this task. The growing interest among researchers, engineers, and geologists in studying voids underscores the need for systematizing methods and their utilization in various mining environments. Given the wide range of available techniques, the article examines and categorizes void detection methods, highlighting their advantages and limitations.

Taking into account the diversity of available techniques, this article systematizes void detection methods and classifies them according to their advantages and limitations. By elucidating the essence of each method, the article sheds light on their applicability in different mining environments.

Among the discussed methods are seismic tomography, electrical resistivity, gravitational geophysics, magnetometry, borehole and ground-penetrating radar methods, laser scanning, and biolocation. By analyzing their applications, operating principles, and areas of use, we reveal the uniqueness of each method and its significance in modern geoengineering research. This article serves not only as an in-depth review of the variety of void detection methods but also as an important step towards the rational utilization of these methods in the practice of mining and engineering geology [1-10].

Problem Statement. Classification of methods entails a systematic approach to grouping various techniques or procedures to establish order and structure among them. This approach aims to identify commonalities and define key characteristics for further understanding and organization of these methods. Classification thus serves as a tool for systematizing and structuring knowledge in a specific field.

In the context of void detection in rock formations, method classification allows for organizing and categorizing diverse techniques used for this task. It is based on various criteria such as operating principles, physical properties, purposes, information transmission methods, and others, providing a clear structure for assessing and comparing methods.

Similar to classification in other scientific fields, in geology and mining, it serves as the foundation for further research, practical applications, and the selection of optimal methods in specific conditions. Additionally, it contributes to understanding the essence and peculiarities of different methods, which is crucial for the rational use of resources and the optimization of mining operations.

This approach to classification allows scientists, engineers, and geologists to systematize their knowledge, making it more accessible and useful for developing new methods and improving existing ones. It also facilitates solving specific tasks related to void detection, providing a tool for selecting the optimal approach depending on the context and requirements of a particular problem.

The aim of the research is to conduct a thorough analysis and classification of methods for detecting voids in a mass of rock formations, with the goal of creating a systematic approach to their use in geoenvironmental investigations. The main objectives include studying the physical principles of operation of each method, determining its advantages and disadvantages, as well as identifying specific conditions and tasks under which it can be most effective.

The objective also involves investigating various classification approaches, considering the physical properties of rocks, measurement principles, method purposes, field types, information transmission methods, and other criteria. Each approach will be examined to elucidate its unique characteristics and capabilities.

The results of the research aim to contribute to the understanding and selection of the optimal method for detecting voids in a geological massif, depending on specific tasks, research conditions, and geological factors. Such an approach will lead to a more effective utilization of geophysical methods in geoenvironmental and hydrogeological investigations, facilitating a qualitative assessment of mining reserves and the prevention of potential hydrogeological issues.

Presentation of the Main Material and Results. The classification of methods for detecting voids in a mass of rock formations is a key aspect of modern geoengineering investigations aimed at the efficient utilization of geophysical methods in hydrogeology and mining. This theoretical section of the article focuses on examining the fundamental principles underlying the classification of various methods that enable the measurement of geometric parameters of voids.

Several approaches exist for classification:

Physical Properties of Rocks: One of the primary approaches involves classifying based on the physical properties of rock formations, such as electrical resistivity, gravitational, and acoustic characteristics.

Measurement Principles: Another approach considers methods based on precise measurements, such as resistance measurements, gravitational measurements, and the use of acoustic signals.

Operating Principles: It is important to examine the classification of methods considering their operating principles, as this can determine their effectiveness in different mining environments.

Method Purposes: Considering the purposes of methods, such as exploration or monitoring, helps determine their optimal use in practice.

Field Types: Defining classification based on field types, such as electrical, gravitational, or acoustic fields, reveals possibilities for accurately determining the characteristics of the mountainous environment.

Information Transmission Methods: Classifying methods based on information transmission methods, such as cable or wireless methods, affects their suitability in remote areas.

These aspects of theoretical consideration of approaches to the classification of void detection methods contribute to understanding their functionality and optimal selection for specific tasks in geotechnical investigations.

From various perspectives, classification can be structured as follows:

Classification based on the physical properties of rocks: Electro-physical methods; Electromagnetic and magnetic methods; Radioactive methods; Acoustic methods; Gravitational methods.

Classification based on measurement principles: Resistance measurement methods; Gravitational measurement methods; Acoustic measurement methods.

Classification based on operational principles: Methods based on electronic principles; Methods based on magnetic properties; Methods utilizing acoustic waves.

Classification based on purpose: Methods for exploration; Methods for monitoring and control.

Classification based on field types: Electric methods; Gravitational methods; Acoustic methods.

Classification based on information transmission methods: Cable methods; Wireless methods.

Classification of combined methods: Combination of different methods for comprehensive investigation.

Certainly, there are no perfect methods, but ideal methods for detecting voids in a mass of rock should meet the following requirements:

Accuracy and reliability of measurements: Methods should ensure high precision in measuring the physical properties of rocks to effectively detect voids.

Versatility of application: Methods should be applicable in various geological conditions and for different types of rock formations.

Real-time operation capability: Methods should enable real-time void detection for prompt response to hydrogeological issues.

Adaptability to mining environments: Methods should be adaptable to mining environment conditions, including high pressure, moisture, and temperature variations.

Capability of measurements at different depths: Methods should allow determining void characteristics at various depths for a comprehensive assessment of geological structure.

Minimization of external factors' influence: Methods should be resilient to external factors such as moisture and temperature, which may affect measurements.

Suitability for diverse mining conditions: Methods should be suitable for use in diverse mining conditions, including shafts, tunnels, and open-pit mining.

Effectiveness in detecting various types of voids: Methods should be effective in detecting various types of voids, from microscopic cracks to large caverns.

Cost-effectiveness and availability: Methods should be cost-effective and readily available for widespread use in the mining industry.

Safety of use: Methods should comply with safety standards and pose no risk to operators and the surrounding environment.

Integration capability with other methods: Methods should be compatible and capable of integration with other geophysical and geological methods for a comprehensive analysis of rock formations.

The determination of the location, dimensions, and volume of voids in a rock mass relies on various classes and approaches that utilize the physical properties of rock formations and the interaction of different forms of energy with the geological environment. Measurements are employed for quantifying the parameters obtained through void detection methods in rock formations. The measurement values provide information about the physical properties of rock formations and their structure within the context of each void detection method. Indicators are determined by various instruments and sensors specific to each class of methods, and their measurement provides information about the structure and properties of rock formations. The ranking of classes is based on the overall trend of measurement accuracy (1st rank - maximum accuracy). The characteristics of the classes are presented in Table 1.

Table 1

Characteristics of classes for determining the location, dimensions, and volume of voids in a rock mass

Class Name and Description
1. Optical. Utilizing light devices or laser technologies to determine the dimensions and geometry of voids. This class of methods has high accuracy as it uses light waves for measurements. Optical methods can be effective only in areas where light can penetrate, such as through boreholes or in other open spaces. These methods can provide valuable data and high measurement accuracy under specific conditions, but their effectiveness may be limited to certain conditions, and their accuracy should be assessed considering specific research conditions.
2. Seismic. Using the propagation of seismic waves to determine the depth and shape of voids in rock formations. Seismic wave measurements can provide accurate results regarding the depth and shape of voids.
3. Acoustic. Using sound waves to measure the time of their reflection or propagation in the environment allows determining the dimensions and depth of voids. The use of sound waves can be accurate but depends on various factors, such as the material of the rocks.
4. Electromagnetic and Magnetic. Measuring the properties of rock formations regarding conductivity, dielectric permeability, magnetic, and electromagnetic characteristics to detect voids. The accuracy of this class of methods may vary depending on the properties of rock formations and the working range.
5. Radiofrequency and Microwave. Using radiofrequency and microwave signals to penetrate rock formations and measure their characteristics. The accuracy is moderate as these methods utilize radiofrequency and microwaves.
6. Gravitational. Determining gravitational anomalies to detect masses with reduced density, indicating the presence of voids. Accuracy may depend on the determination of gravitational anomalies and their impact on density.
7. Biofield. Using biofield methods to detect voids in rock formations related to the biological properties of the environment. The accuracy of biofield property measurements may be lower than standard physical methods. This class of methods is mainly used for indicative (preliminary) detection of potential voids.

These classes, in combination with the application of various methods and tools, enable the effective determination of cavity parameters in rock formations. Precision may vary depending on operational conditions and specific characteristics of the geological formations. Table 2 provides the main methods (subclasses) for each class.

Table 2

Subclasses of methods for determining the location, dimensions, and volume of voids in a mining massif

№ and class name	Subclasses (methods)
1. Optical	1.1. Optical tomography 1.2. Fiberoptic sensors 1.3. Optical laser scanning 1.4. Spectroscopy
2. Seismic	2.1. Seismic tomography 2.2. Seismic localization 2.3. Seismic reflectometry 2.4. Seismic impedance tomography
3. Acoustic	3.1. Acoustic impedance tomography 3.2. Acoustic locator 3.3. Acoustic reflectometry 3.4. Acoustic interference
4. Electromagnetic and Magnetic	4.1. Electromagnetic tomography 4.2. Magnetic resonance tomography (MRI) 4.3. Electromagnetic locator 4.4. Electromagnetic induction
5. Radiofrequency and Microwave	5.1. Radiofrequency sounding 5.2. Microwave tomography 5.3. Radiofrequency identification 5.4. Microwave radiometry
6. Gravitational	6.1. Gravitational gravimetry 6.2. Gravitational tomography 6.3. Gravitational inversion 6.4. Gravitational monitoring
7. Biofield	7.1. Biofield tomography 7.2. Biofield monitoring 7.3. Biofield seismicity 7.4. Biofield reflectometry

The selection of a specific class of methods for void detection in a mass of rock formations should be based on several factors. The key factors to consider are listed in Table 3.

Table 3

Key factors of effectiveness for classes of methods in determining the location, dimensions, and volume of cavities in the mountain massif

Factor Name and Description
1. Depth and size of cavities. Different methods may be effective at different depths and for different cavity sizes. It is essential to choose a method that best suits the specific situation. Determining the depth and size of cavities can be one of the most crucial factors, as it defines the required power and sensitivity of the method.
2. Measurement accuracy. Depending on the accuracy requirements, some methods may be more or less suitable. For example, optical methods may have high precision, but they may be limited by lighting conditions. High measurement accuracy is crucial for many studies to ensure reliable results.
3. Rock material. Different rocks have different physical properties. Some methods may be more or less sensitive to specific rock materials. The physical properties of the material can significantly impact the effectiveness of the method, especially its sensitivity and resolution.
4. Investigation conditions. For instance, conditions of high pressure or temperature may limit the selection of methods. Depending on the conditions, it may be necessary to consider which methods are adapted to specific physical conditions.
6. Timeframes. Some methods may require more time for investigations, so it is crucial to consider the urgency of the task. If time is of the essence, the speed of execution can become a key factor.
6. Budget and equipment availability. Some methods may be more costly or require more complex equipment. Considering the budget and available resources is important. Financial constraints and the availability of technical resources can limit the choice of method.
7. Environmental aspects. Some methods may be more environmentally friendly and safer for the surrounding environment, which can also influence the choice. With the growing environmental awareness, environmental aspects may become increasingly important.

Considering these factors allows for selecting the optimal class of methods for a specific situation of void detection in rock formations. Again, each specific task may have its unique characteristics, so the decision to choose a method should be based on the specific requirements and conditions of the particular investigation.

Below (Table 4), the ranking of factors for selecting a particular class of void detection methods in a mass of rock formations is provided. This ranking takes into account the impact of each method on the ecosystem and the environment. The summarized table (Table 4) of results from factor-based ranking of classes of void detection methods in a mass of rock formations is presented below.

The total number of ranks and the resulting rank (considering factors influencing the preference of each method class relative to others, with equal weight for each factor) for each class of methods are listed in Table 5.

Table 4

Factor-based Ranking of Classes of Void Detection Methods in a Mass of Rock Formations

Class Number and Name	Factors of Method Class Efficiency						
	Depth and size of cavities	Measurement accuracy	Rock material	Investi-gation conditions	Time-frames	Budget and equipment availability	Environmental aspects
Optical	2	2	7	6	1	3	1
Seismic	1	1	4	2	2	7	4
Acoustic	3	3	3	4	3	3	6
Electromagnetic and Magnetic	4	4	6	3	4	6	3
Radiofrequency and Microwave	5	5	5	5	5	5	7
Gravitational	6	6	1	1	6	2	5
Biofield	7	7	2	7	7	1	2

(Note: The numbers in each cell represent the ranking of the respective method class for the corresponding factor. Lower numbers indicate better performance within a factor.)

The total (overall) number of rankings and the resulting rank (considering factors influencing the preference of each method class relative to other classes, with equal weight for each factor) for each method class are presented in Table 5.

Table 5

Overall Rank of the factor-based ranking of methods classes for detecting voids in a mass of rock formations

Class №	Method Class Name	Sum of Factors' Ranks	Overall Rank
1.	Optical	22	2
2.	Seismic	21	1
3.	Acoustic	25	3
4.	Electromagnetic and Magnetic	30	5
5.	Radiofrequency and Microwave	37	7
6.	Gravitational	27	4
7.	Biofield	33	6

Conclusions. A study of various classification approaches has been conducted, considering the physical properties of rocks, measurement principles, method purposes, field types, information transmission methods, and other criteria.

For the first time, through analysis and systematization, a classification of methods for detecting voids in a mass of rock formations has been developed, taking into account measurement accuracy. This classification allows scientists, engineers, and geologists to better understand the variety of approaches to this task.

The first-ever ranking of method classes for detecting voids in a mass of rock formations has been performed, based on comprehensive effectiveness with equal weighting of method determination factors: 1. Seismic, 2. Optical, 3. Acoustic, 4. Gravitational, 5. Electromagnetic and Magnetic, 6. Biopole, 7. Radiofrequency and Microwave.

The conclusions drawn from the research findings can have practical applications in conducting a comprehensive assessment of the geophysical condition of the mining rock massif.

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